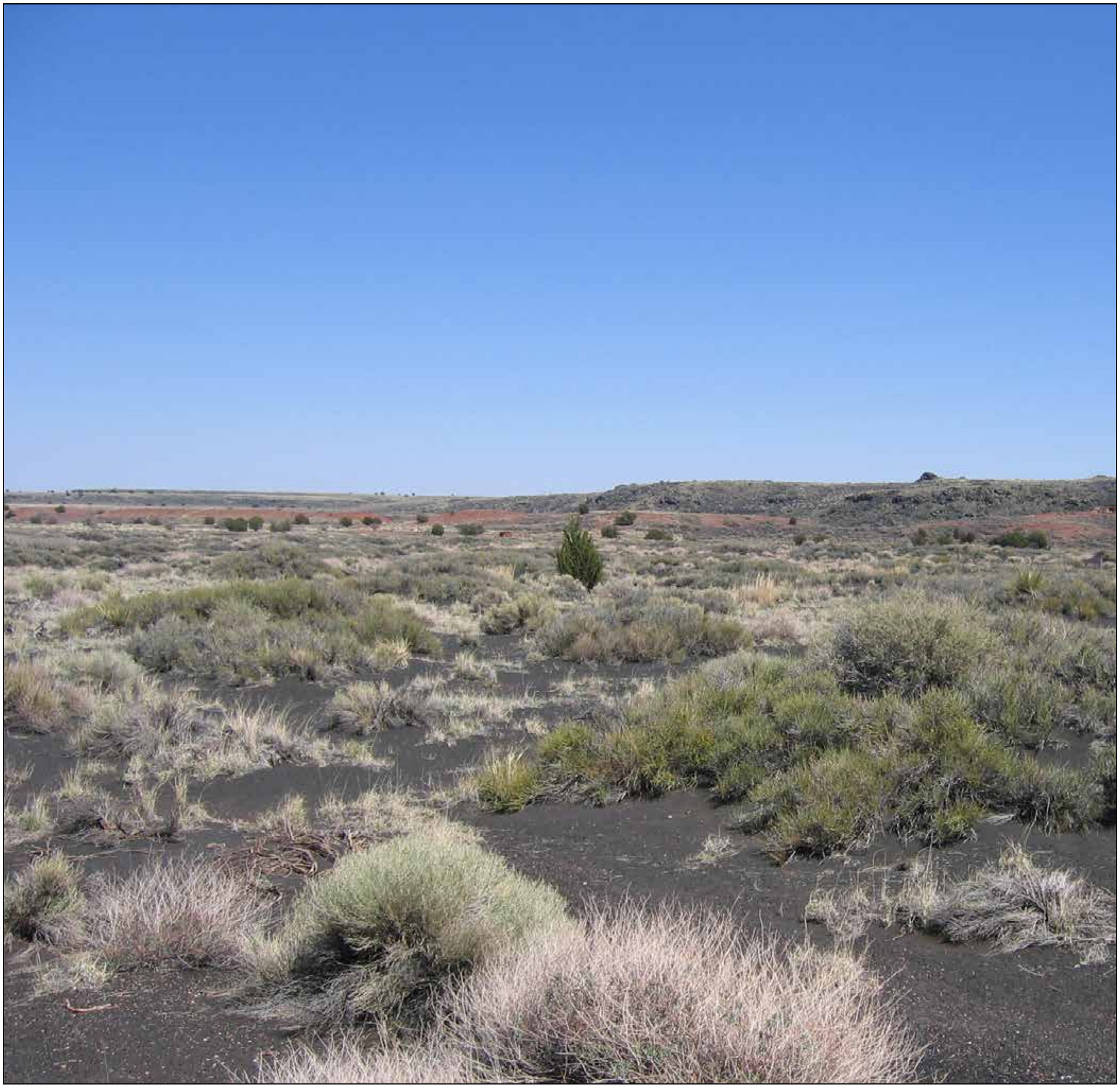
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Wupatki National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/SCPN/NRR—2018/1613



ON THIS PAGE
Black dune in Wupatki NM. Photo Credit: NPS

ON THE COVER
View of the Wupatki NM landscape through geologic feature. Photo Credit: NPS

Wupatki National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/SCPN/NRR—2018/1613

Author Name(s)

Lisa Baril[1], Patricia Valentine-Darby[1], Kimberly Struthers[1], Paul Whitefield,[2] William H. Romme,[3] Kirk Anderson[4]

[1]Utah State University
Department of Environment and Society
Logan, Utah

[2]National Park Service
Flagstaff Area National Monuments
Flagstaff, Arizona

[3]Colorado State University
Natural Resource Ecology Laboratory
Fort Collins, Colorado

[4]Museum of Northern Arizona
Flagstaff, Arizona

Editing & Design

Kimberly Struthers[1]

March 2018

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

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

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

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

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

This report is available in digital format from the Natural Resource Condition Assessment Program website and the Natural Resource Publications Management website.

Please cite this publication as:

Baril, L., P.L. Valentine-Darby, K. Struthers, P. Whitefield, W. Romme, and K. Anderson. 2018. Wupatki National Monument: Natural resource condition assessment. Natural Resource Report NPS/SCPN/NRR—2018/1613. National Park Service, Fort Collins, Colorado.

NPS 322/143923, March 2018

Contents

Contents (continued)

Contents (continued)

Figures

Figures (continued)

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Tables

Tables (continued)

Tables (continued)

Page

Appendices

Page

Executive Summary

The Natural Resource Condition Assessment (NRCA) Program, administered by the National Park Service's (NPS) Water Resources Division, aims to provide documentation about current conditions of important park natural resources through a spatially explicit, multidisciplinary synthesis of existing scientific data and knowledge. The workshop for the Flagstaff Area National Monuments (NM) NRCAs, which includes Wupatki, Walnut Canyon, and Sunset Crater Volcano, was held from May 17 - 19, 2016. This NRCA report is for Wupatki NM.

Wupatki was established as a national monument in 1924 to preserve the thousands of archaeological sites and cultural evidence of past inhabitants of the region, including several large and prominent pueblos located throughout the monument. It also includes one of the largest protected areas of juniper savanna, grassland, and desert shrubland within the southern Colorado Plateau region and provides habitat for native species sensitive to human land-use and habitat fragmentation impacts. The monument's in-tact habitat serves as a critical scientific research area for American pronghorn (*Antilocapra americana*) and regional environmental change.

For Wupatki NM's NRCA, monument staff selected 14 natural resource topics for condition assessments and an evaluation of habitat connectivity between the three Flagstaff Area NMs. Wupatki NM's resources were grouped into five broad categories: landscapes, air and climate, geology and soils, water, and biological integrity, which included wildlife and vegetation resources. Resource conditions ranged from good for the landscape topics (i.e., viewshed, night sky, and soundscape), mammals, and vegetation to moderate concern for air quality, non-native invasive plants, and certain aspects of the water-related resources, such as seeps and springs and the Little Colorado River riparian corridor. Conditions of significant concern included the Sunset Crater tephra layer, aspects of water quantity, and erosion-related measures. The primary threats influencing these conditions are shared across resource categories, most notably climate change and increasing population and associated developments.

Wupatki NM faces many threats due to an ever-increasing human population within and surrounding Flagstaff, Arizona and increasing temperatures and erratic precipitation events due to climate change. The monument's proactive science program will become even more important in influencing resource conditions and identifying necessary adaptations in a rapidly changing environment.

Acknowledgements

Natural resources staff in the Flagstaff Area NM's Science and Resource Management Division participated in the development and reviews of this report's condition assessments. Lisa Leap, Division Chief of Resources; Paul Whitefield, Natural Resource Specialist; Mark Szydlo, Biologist; and Michael Jones, GIS Specialist provided their expertise as chapter and assessment reviewers and as information facilitators assisting with the development of indicators, measures, reference conditions, and maps, as needed. Paul Whitefield contributed significantly to the assessment development process, providing an overview of the regional resource-context and significance to the monument's resources.

Dr. William (Bill) Romme, Professor Emeritus of Fire Ecology and Research Scientist in the Natural Resource Ecology Laboratory, Colorado State University, was selected as the subject matter expert for the monument's vegetation condition assessment. Dr. Kirk Anderson, with the Museum of Northern Arizona, was selected as the subject matter expert for the monument's Sunset Crater tephra layer condition assessment. Both served as report authors.

National Park Service's Southern Colorado Plateau Inventory and Monitoring Program's annual monitoring data for Wupatki NM informed conditions for the springs, seeps, and surface water, Little Colorado River riparian corridor, non-native invasive plants, and birds assessments.

Jeff Albright, National Park Service Natural Resource Condition Assessment Program Lead provided programmatic guidance. Phyllis Pineda Bovin, National Park Service Intermountain Region Natural Resource Condition Assessment Coordinator, and Donna Shorrock, former National Park Service Intermountain Region Natural Resource Condition Assessment Coordinator, assisted with overall project facilitation and served as peer review managers. To all of the reviewers listed in Appendix B and contributors who are listed within each Chapter 4 assessment, we thank you. Your contributions have increased the value and application of Wupatki NM's NRCA report.

Pueblo ruins at the end of a rainbow. Photo Credit: NPS.

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 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; and [5]
- 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

[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.

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*

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 understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs. Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

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

An NRCA is intended to provide useful science-based information products in support of all levels of park planning. Photo Credit: NPS.

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*

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.

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 a 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.

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 at http://www.nature.nps.gov/water/nrca/.

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*

[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.


Wupatki National Monument's Citadel Pueblo. Photo Credit: NPS.

Chapter 2. Introduction and Resource Setting

2.1. Introduction

2.1.1. Enabling Legislation/Executive Orders

Wupatki National Monument (NM) was established on December 9, 1924 to preserve the thousands of archaeological sites and cultural evidence of past inhabitants of the region, including several large and prominent pueblos located throughout the monument. Members of the Sinagua, Cohonina, and Kayenta peoples are believed to have inhabited the region from 8,000 B.C. to A.D. 1225 (NPS 1996). The vast trade network with each other and the Hohokam to the south made the region a "cultural frontier" at the time (NPS 1996). The monument also protects unique geologic features including earthcracks and blowholes, red sandstone of the Moenkopi formation used to construct pueblos, and cinder cones and lava flows of the San Francisco Volcanic Field (Graham 2011).

The monument's unique resources and values are further described in its four significance statements as follows (text excerpted from NPS (2015)):

> ***Archeology-*** Wupatki National Monument protects one of the most densely populated archeological landscapes of the Southwest, where multiple cultural groups coexisted and interacted in the wake of the eruption of Sunset Crater Volcano.
>
> ***Connections from Past to Present-*** Natural and cultural resources within the monument are significant to a number of contemporary American Indian tribes, as evidenced by oral history, archeological study, and continuing traditional practices.
>
> ***Native Grasslands-*** Wupatki National Monument harbors one of the largest protected areas of juniper savanna, grassland, and desert shrubland within the southern Colorado Plateau region. It provides habitat for native species sensitive to human land-use and habitat fragmentation impacts and serves as a critical scientific research area for pronghorn (*Antilocapra americana*) and regional environmental change.
>
> ***Scenery and Setting-*** The clean air and environment of Wupatki National Monument provide exceedingly rare opportunities to experience uninterrupted vistas, stunning

night skies, and natural sounds in a wilderness environment.

Additional fundamental and other important resources and values are identified for the monument in its Foundation Document (NPS 2015a), which further expand on the themes related to its purpose and significance statements.

Wupatki NM Wilderness

Wilderness is defined as "an area of undeveloped federal land retaining its primeval character and influence without permanent improvements or human habitation…" (The Wilderness Act of 1964; Public Law 88-577 [16 U.S.C. 1131-1136]). While few developments exist within Wupatki NM's eligible wilderness boundary, rapid urban development originating from and surrounding the city of Flagstaff, Arizona, threaten the survival of wildlife species and their associated habitats. It is also this juxtaposition of a protected area within an ever-expanding landscape of development that makes the Wupatki NM wilderness a very important resource.

A wilderness eligibility assessment for Wupatki NM was completed in 2013. Eligible wilderness land comprises approximately 96% (13,838 ha/ 34,194 ac) of the monument. The grasslands, remote archeological sites, such as the pueblos and petroglyphs in the Crack-in-Rock area, badlands, natural sounds, and spectacular night skies all contribute to the monument's outstanding wilderness qualities (NPS 2015a).

2.1.2. Geographic Setting

Wupatki NM is located in northern Arizona's Coconino County 66 km (41 mi) north of Flagstaff, Arizona (Figure 2.1.2-1) and encompasses 14,266 ha (35,253 ac). It is located along Arizona Highway 89, which provides access to the park along its western

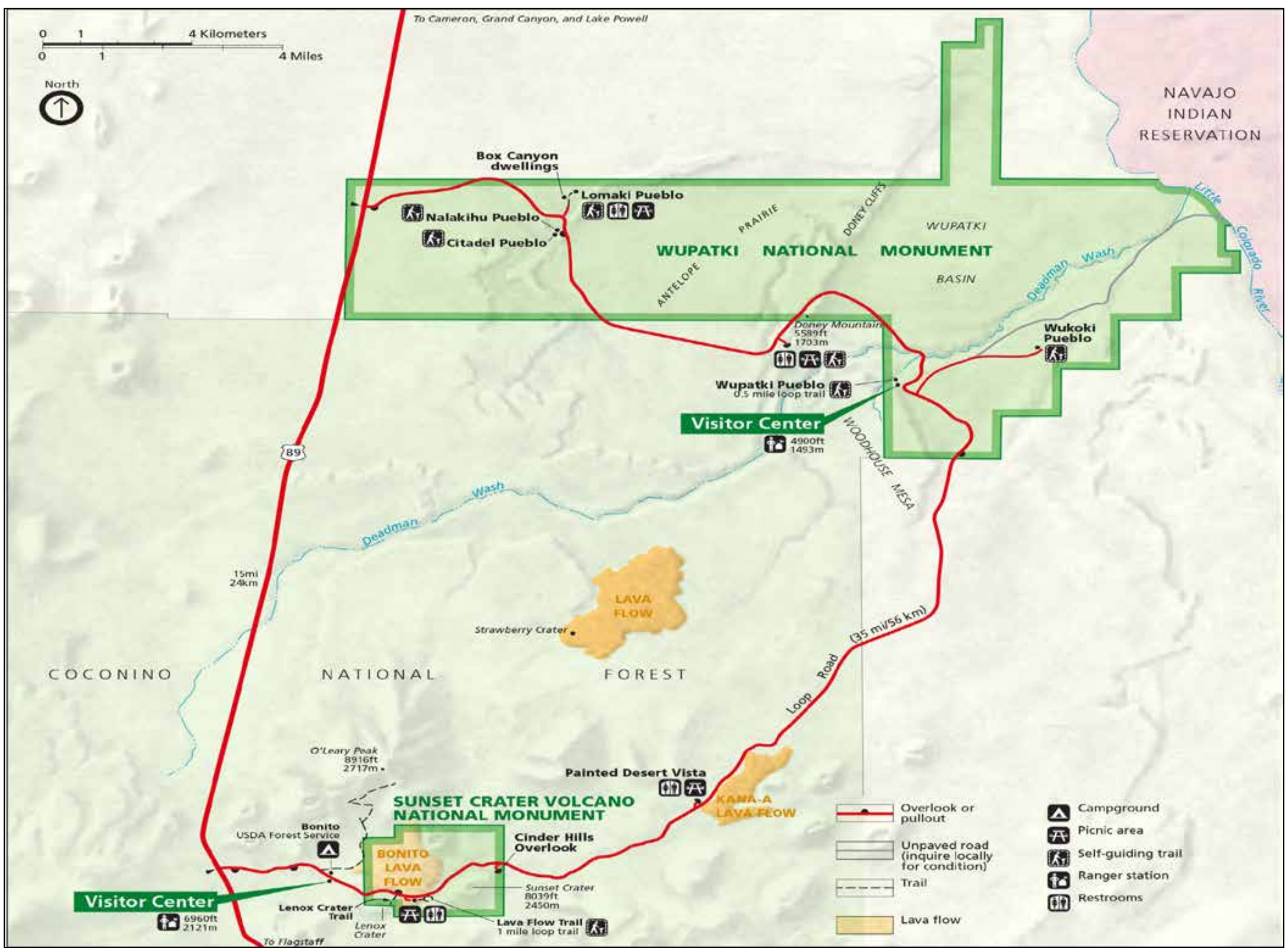


Figure 2.1.2-1. Wupatki NM is located along Arizona Highway 89, approximately 66 km (41 mi) north of Flagstaff, Arizona. Figure Credit: NPS (2015).

boundary and Loop Road, which provides access from Sunset Crater Volcano National Monument, with which it is administered, along with Walnut Canyon NM, collectively referred to as Flagstaff Area National Monuments. The monument is bounded by state trust land to the west, by the Coconino National Forest to the south, private land to the southeast, the Navajo Reservation to the east, and a mix of private and state trust land to the north (NPS 1996).

Population
Arizona is the fourth fastest growing state in the U.S. based on projected percent change in population size from 1995 to 2025 (U.S. Census Bureau 2016a). The population estimate for Coconino County was 139,097 in July 2015, with an increase of 3.5% since April 2010, and the population of Flagstaff was an estimated 70,320 in July 2015, with a 6.4% increase since April 2010 (U.S. Census Bureau 2016b).

Climate
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, with low annual precipitation. Rain comes in July-September from monsoon storms that originate in the Pacific Ocean and the Gulf of Mexico, and in November-March from winter storms that originate in the Pacific Ocean (Sheppard et al. 2002). The Colorado Plateau, where the monument is situated, is an arid region with irregular rainfall, periods of drought, warm to hot growing seasons, and long winters with freezing temperatures (Davey et al. 2006).

The National Weather Service Cooperative Observer (COOP) Network station, 29542, is located in the monument and has collected temperature and precipitation data since 1940 at an elevation of 1,497 m (4,911 ft). The temperature in Wupatki NM varies throughout the year, with the warm season occurring from May-September (1940-2016). The average daily high temperatures range from 27-35ºC (81-95ºF) during these months (Figure 2.1.2-2 top graph; Climate Analyzer 2016). The cold season generally occurs from November to February, with the coldest temperatures occurring in December and January (average daily high temperature of 8ºC (47ºF)) (Figure

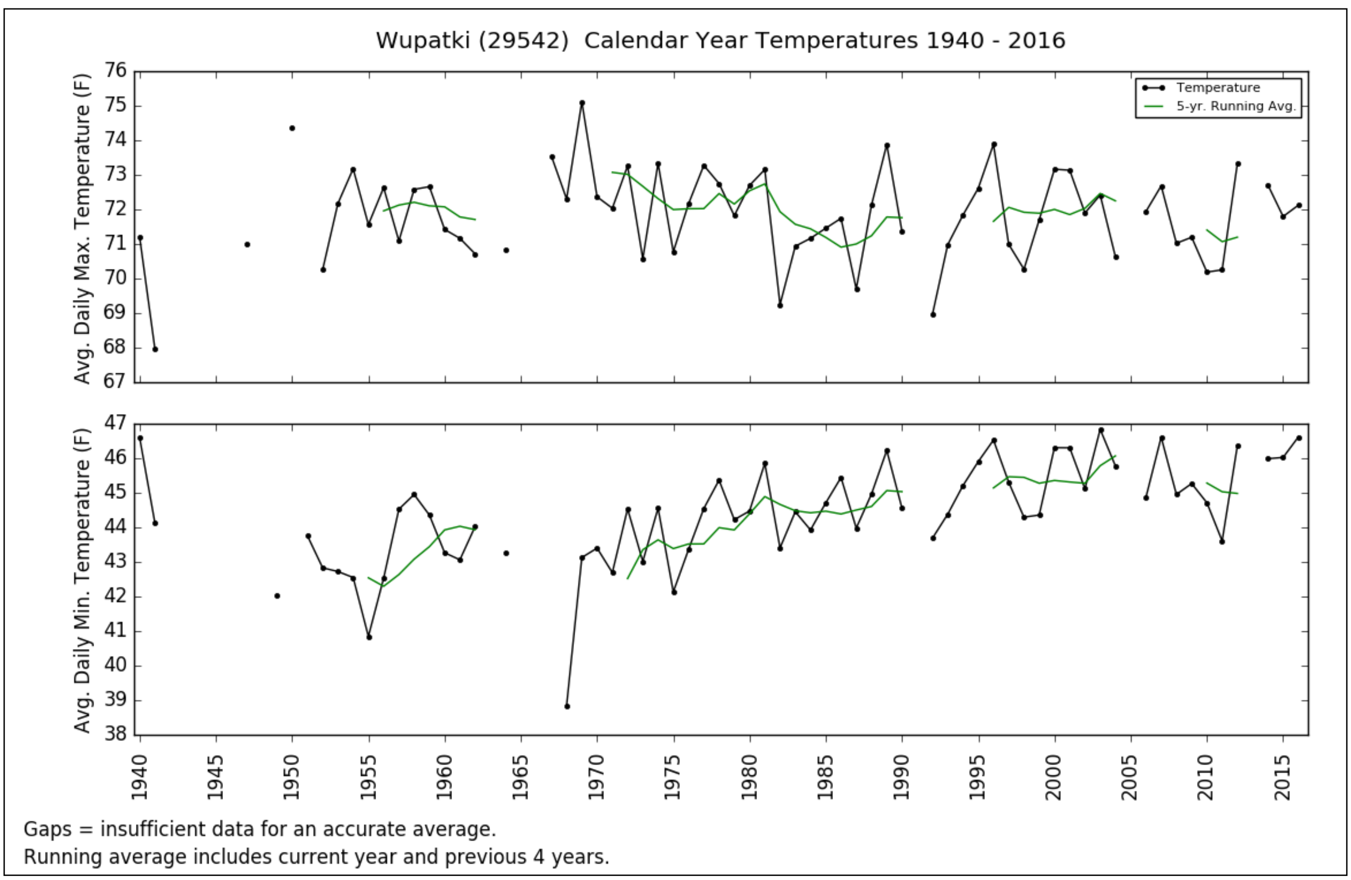


Figure 2.1.2-2. Average daily maximum (top) and minimum (bottom) temperatures (1940-2016). Figure Credit: Climate Analyzer (2016).

2.1.2-2 bottom graph; Climate Analyzer 2016). The average temperature is 14.3°C (57.9°F) (NPS SCPN 2016).

Wupatki NM receives the majority of its precipitation from July through September (1940-2016). The average annual precipitation in the monument from 1940-2016 is 169 mm (6.7 in) (Figure 2.1.2-3), compared to the average precipitation in the Colorado Plateau, which is 254-889 mm/year (10-35 in/year) (NPS SCPN 2016).

2.1.3. Visitation Statistics

Monthly visitation data for Wupatki NM are available from 1979-2016 (NPS Public Use Statistics Office 2017). The visitor use counting procedures from 1993-present include direct visitor center counts multiplied by two different regression formulas for June - September then for October - May (NPS Public Use Statistics Office 1993). The total number of Wupatki NM visitors each year ranged from a low of 161,846 (in 1980) to a high of 267,090 (in 1992). The months with the highest average number of visitors over the recording period were June-August (Figure 2.1.3-1).

2.2. Natural Resources

A brief summary of the natural resources at Wupatki NM is presented in this section. For additional information, please refer to Chapter 4 assessments and cited reports within the summaries below.

2.2.1. Ecological Units, Watersheds, and NPScape Landscape-scale

Ecological Units

Wupatki NM is located in the Colorado Plateau Ecoregion, which includes portions of Arizona,

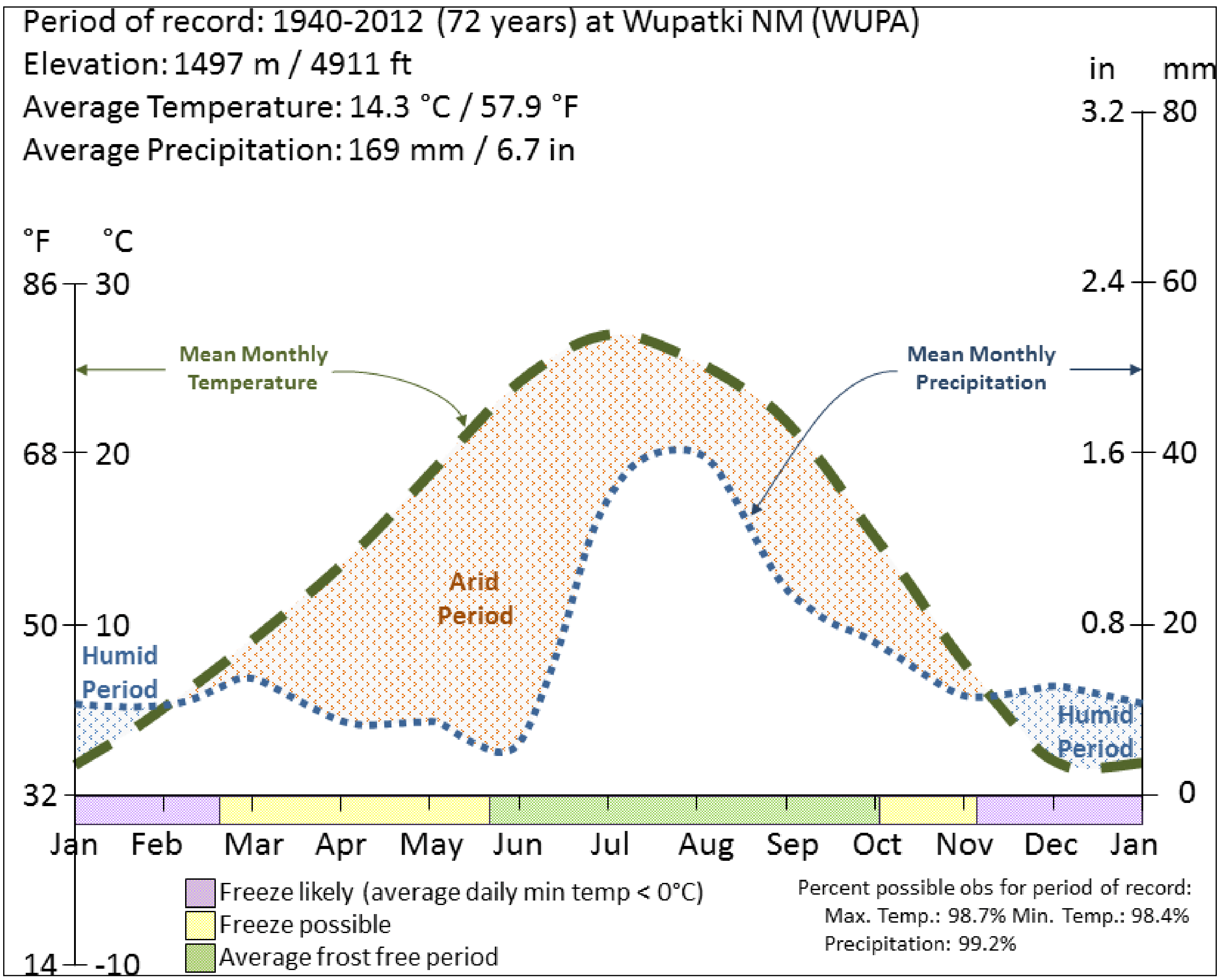


Figure 2.1.2-3. Annual precipitation and temperature at Wupatki NM (1940-2016). Figure Credit: NPS SCPN (2016).

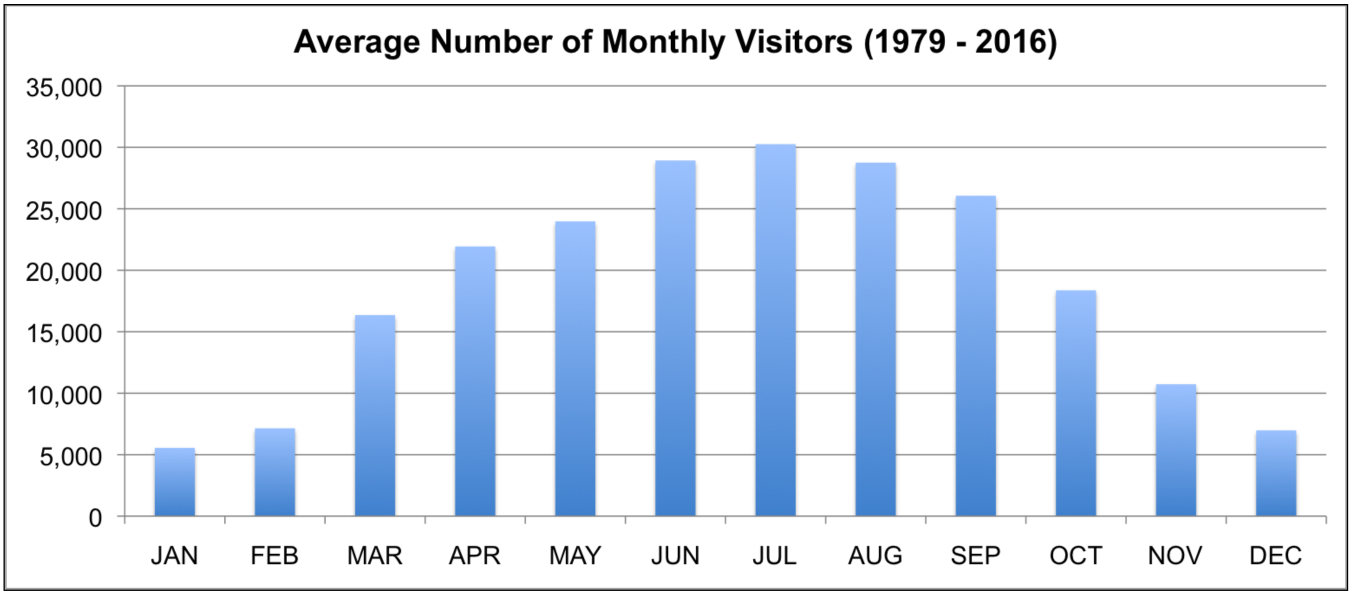


Figure 2.1.3-1. Average number of visitors by month to Wupatki NM from 1979-2016.

Utah, Colorado, and New Mexico (AZGFD no date). The entire area encompasses 9.3 million ha (22.9 million ac) and is characterized by desert scrub and shrublands. Elevations reach as high as 2,804 m (9,200 ft) throughout the ecoregion. The elevation in Wupatki NM ranges between 1,304.5 m (4,280 ft), along the Little Colorado River, to 1,743.5 m (5,720 ft) in the southwest corner of the monument. The monument's landscape is characterized by high plateaus, mesas, plains, breaks, canyons and valleys (NPS 1996).

Watershed Units

The national monument is located in eight watersheds (Figure 2.2.1-1) (U.S. Geological Survey [USGS 2014]). The largest watershed is Jackrabbit Wash, covering 159.5 km^2 (39,424.1 ac), but the monument occupies only 15.4% of this watershed. However, the monument occupies most of the Doney Deadman Wash watershed (76.7%). The watersheds areas are presented in Table 2.2.1-1).

NPScape Landscape-scale

Most of the Wupatki NM's natural resources (e.g., viewshed, night sky, water resources, vegetation, wildlife, etc.) are affected by landscape-scale processes, and this broader perspective can provide more comprehensive information to better understand resource conditions throughout the monument. Studies have shown that natural resources rely upon the larger, surrounding area to support their life cycles (Coggins 1987 as cited in Monahan et al. 2012), and most parks are not large enough to encompass self-contained ecosystems for the resources found within their boundaries. This is especially important to Wupatki's natural resources due to the increasing population and developments that fragment what is currently intact natural areas. Where feasible, landscape-scale indicators and measures were included in the condition assessments to provide an ecologically relevant, landscape-scale context for reporting resource conditions. NPS NPScape metrics were used to report on these resource conditions, providing a framework for conceptualizing human effects (e.g., housing densities, road densities, etc.) on landscapes (NPS 2014a,b). This broader perspective of habitat and resource connectivity for selected wildlife species are presented and discussed in Chapter 5.

Table 2.2.1-1. Watersheds for Wupatki NM.

Watershed	Total in sq. km	Total in acres
Lower Kana-a Wash	54.1	13,365.2
Stone House Wash - Little Colorado River	111.5	27,555.1
Lower Deadman Wash	126.5	31,266.5
Doney Deadman Wash	46.7	11,531.4
Citadel Wash	139.1	34,385.7
White Water Wash - Little Colorado River	80.7	19,951.6
Jackrabbit Wash	159.5	39,424.1
Yellow Spring - Little Colorado River	62.6	15,459.4

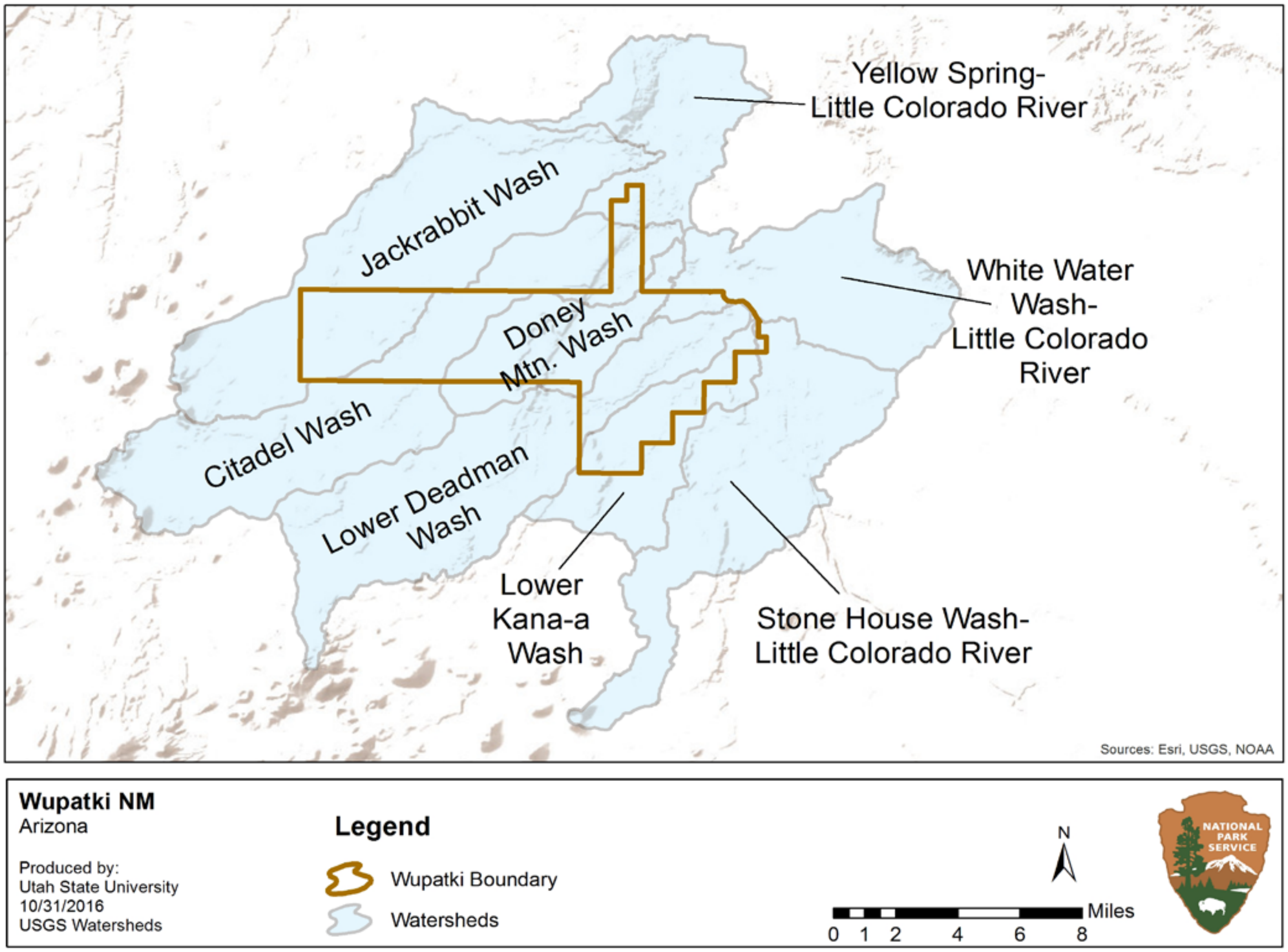


Figure 2.2.1-1. **Wupatki NM is located within eight watersheds.**

2.2.2. Resource Descriptions

Viewshed

Viewsheds are considered an important part of the visitor experience at national parks and features on the visible landscape influence a visitor's enjoyment, appreciation, and understanding of the park (Figure 2.2.2-1). Wupatki NM was established in 1924 to preserve the thousands of archaeological sites and cultural evidence of past inhabitants of the region, including several large and prominent pueblos located throughout the monument that thousands of visitors see during their visit. The red sandstone of the Moenkopi formation, used to construct some of the pueblos, and the surrounding cinder cones and lava flows of the San Francisco Volcanic Field all contribute to the monument's natural and historic scenery. In addition, Wupatki NM is surrounded by state trust land, the Coconino National Forest, and the Navajo Reservation (NPS 1996). As a result, much of the surrounding landscape is currently undeveloped. Wupatki NM's proposed wilderness and proximity to Flagstaff, AZ, a larger urban community, provides access to this undeveloped area where visitors can experience several pristine scenic views throughout the monument. Panoramas were taken from five locations during August 2016 by monument staff and analyses were performed for Wupatki NM's viewshed condition assessment. These data serve as a baseline assessment and are a way to measure the integrity and intactness of the scenic landscape within and surrounding Wupatki NM.

Night Sky

Dark night skies are considered an aesthetic in national parks and offer an experiential quality that is also integral to natural and cultural resources (Moore et al. 2013). Historically, American Indian's observation of the sun, moon and stars was essential for planning festivals and activities such as when to start planting and when to harvest (Aveni 2003). In an estimated 20

Figure 2.2.2-1. A scenic view of cultural and natural resources at the Wupatki Pueblo. Photo Credit: © R. Struthers.

national parks, stargazing events are the most popular ranger- led program (NPS 2010a). But the values of night skies go far beyond visitor experience and scenery. The photic environment affects a broad range of species, is integral to ecosystems, and is a natural physical process (Moore et al. 2013). In 2016, Wupatki NM was designated an International Dark Sky Park by the International Dark Sky Association (IDA), a non-profit organization dedicated to preserving dark night skies around the world (IDA 2016). In addition, the city of Flagstaff, AZ was designated as the world's first International Dark Sky Community due to its progressive outdoor lighting policy enacted in 1958—the world's first outdoor lighting ordinance (IDA 2016).

The NPS Natural Sounds and Night Skies Division (NSNSD) scientists conducted an assessment of Wupatki NM's night sky condition at Wukoki Pueblo on May 12, 2002, June 11, 2004, and March 14, 2012. The results of those surveys were used to evaluate the night sky condition at Wupatki NM to support the IDA application (NPS 2016a).

<u>Soundscape</u>

According to a majority of members of the American public surveyed, opportunities to experience natural quiet and the sounds of nature is an important reason for having national parks (Haas and Wakefield 1998). Baseline acoustical monitoring data for Wupatki NM were collected by park natural resource staff. The National Transportation Systems Center (Volpe Center) analyzed the data and produced the report (NPS 2013a), which was coordinated as part of a technical assistance request with the NPS NSNSD. These data, along with results from a sound model developed by Mennitt et al. (2013), were used to evaluate the soundscape condition at the monument.

<u>Air Quality</u>

Two categories of air quality areas (Class I and II) have been established through the authority of the Clean Air Act of 1970 (42 U.S.C. §7401 et seq. (1970)). Like most National Park Service areas, Wupatki NM is designated as a Class II airshed. No air quality monitoring stations are located within the required distances to derive trends for ozone or atmospheric deposition, however, there is a visibility monitor (IKBA, AZ) nearby. To date, nine plants in the national monument are known to be ozone sensitive species (Bell in review, Kohut 2004).

Geology and Soils

The following description of Wupatki NM's geology was taken directly from NPS (2013b):

> The topography within Wupatki National Monument is shaped by episodes of tectonic-scale geologic deformation in the western United States over the last 65 million years, causing extensive crustal folding, deep faulting, and uplift in north-central Arizona. Rapid uplift associated with the rise of the Colorado Plateau began around 5 million years ago and continues to occur. More recent and localized fracturing, faulting, and uplift is also likely related to volcanism in the surrounding San Francisco Volcanic Field. Among the resulting regional structural features is the Black Point Monocline, along with the more localized Doney Mountain Fault, which essentially divides the national monument in half (Babenroth and Strahler 1945, McCormack 1989, Billingsley et al. 2007a,b). The monocline continues to rise and deform, creating an extensive network of visible fractures and minor offset faults in the surface sedimentary rock formations (Pearce 1998).

These multiple layers of sedimentary, volcanic, and surficial rock features are exposed within the monument. The oldest formation, Coconino Sandstone, covered northern Arizona over 250 million years ago during the Permian period. The younger, Kaibab Formation, a limestone, was also formed during the Permian period and contains a variety of marine fossils. The younger Moenkopi Formation shales and sandstones were deposited by rivers during the Triassic period, 225 to 190 million years ago. These deposits are highly erodable due to their softness. In addition, four lava flows cover areas of the Moenkopi sandstone. Remnants of terrace levels, transported by the Little Colorado River, cap the Moenkopi hills (NPS 1996). The present day soils, distinct in color, grain size, mineral composition, and rate of weathering, are a result of the region's rich and varied geologic past.

> Soils in the basalt areas of Wupatki are on gently sloping to steep slopes and are shallow to moderately deep. Basalt rock outcrops are common on the steep slopes and as cliffs. Cinders blown from nearby volcanic cones and drifted by the wind have formed a thin mulch over much of the area of the monument. Locally, wind action has formed drifts more than one foot thick. Limestone areas have shallow to very shallow soils over bedrock. Areas of sandstone and shale are very complex in slope, generally have thin soils and are influenced by cinders (taken from NPS 1996).

The tephra layer, which formed as a result of the eruption of Sunset Crater Volcano in the late 11th century A.D., had a profound effect on prehistoric settlement and ecosystem productivity throughout Wupatki NM. The Sunset Crater tephra layer was selected as an separate assessment for the monument's NRCA report.

Earthcracks and Blowholes

Some of the monument's geologic fractures and faults have laterally expanded to form unique, open subterranean "earthcrack" fissures (Colton 1938, Lamar 1964, Huntoon 1965, Bridgemon 1975, Cave Research Foundation 1976). The fracture and fissure system is widely interconnected, allowing air currents to move within, driven both by surface/sub-surface temperature differences and atmospheric pressure fluctuations. As a result, air currents "breathe" at unique "blowhole" openings (Schley 1961, Sartor and Lamar 1962, Lamar 1964) that are identified as "traditional cultural properties" by associated Native American tribes (NPS 2013b).

This earthcrack system comprises one of the most fragile ecosystems within the national monument (NPS 2013b), supporting a unique community of cave-adapted species. Two endemic species of blind pseudoscorpions have been described (Muchmore 1981), and recent arthropod inventories (Wynne 2014, Wynne 2015) have resulted in the discovery of as many as five additional endemic taxa (Wynne pers. comm. to Whitefield 2016, two manuscripts in preparation).

Water Resources

In Wupatki NM surface water, which occurs as springs, seeps, ephemeral pools, dry washes, and rivers is a rare but critically important resource for wildlife and plants. To the east of Doney Mountain Fault lies the Wupatki Basin, which is a large, low-lying area characterized by open desert scrub vegetation that occurs primarily on terrace benches (Hansen et al. 2004, Graham 2011).

These terraces are incised by several intermittent, ephemeral stream channels that drain into the Little Colorado River to the east (Graham 2011). In the Doney Cliffs there are numerous arroyos and washes that also drain into the Little Colorado River (Graham 2011). The Little Colorado River and Deadman Wash have historically been important sources of water for humans, wildlife, and plants.

The Little Colorado River (LCR), a major tributary to the Colorado River, flows northwest and drains an area of about 69,930 km^2 (27,000 mi^2) in northeastern Arizona (Arizona Department of Environmental Quality 2007, USGS 2011a). The Little Colorado River follows the eastern boundary of the monument for approximately 2 km (1.2 mi) and is joined by Deadman Wash within the monument's boundary. In the vicinity of the national monument, flow is ephemeral, occurring mainly during the spring due to runoff from the melting of higher-elevation winter snow, and in the summer from sporadic thunderstorms (NPS 2014c).

Additional water sources throughout the monument include three natural springs and one seep: Wupatki Spring, Heiser Spring, Peshlaki Spring (Figure 2.2.2-2), and Spice Seep. Ephemeral pools also develop periodically in natural depressions or in small rock basins formed by erosion of porous sandstone (Graham 2001, Holton 2007). These pools usually contain water for only a short time following heavy rainfall. As with springs and seeps, naturally occurring pools are rare, and many evaporate before they are discovered.

Figure 2.2.2-2. Heiser wash - Peshlaki spring. Photo Credit: NPS.

<u>Vegetation</u>

Vegetation in Wupatki NM is comprised of semi-arid grassland and shrub-steppe, juniper savannas, juniper woodlands, and the densely vegetated riparian corridor along the Little Colorado River. The semi-arid grasslands and shrub-steppe areas are dominated by grasses including blue grama (*Bouteloua gracilis*), galleta (*Pleuraphis jamesii*), western wheatgrass (*Pascopyrum smithii*), needle and thread (*Hesperostipa comata*), three-awn (*Aristida spp.*) and by shrubs including big sagebrush (*Artemisia tridentata*), black sagebrush (*Artemisia nova*), four-wing saltbush (*Atriplex canescens*), rabbitbrush (*Ericameria nauseosa*), broom snakeweed (*Gutierrezia sarothrae*), and joint-fir (*Ephedra spp.*) (LCAS 2010 as cited in Romme and Whitefield 2017). The juniper woodlands are dominated by one-seed juniper (*Juniperus monosperma*) and the juniper savannas support both semi-arid grassland species, younger junipers (<100 years old), and to a lesser extent, shrub species. Early descriptions of the dominant vegetation along the Little Colorado River note that "the river was lined with galleries and groves of Fremont cottonwood (*Populus fremontii*) and narrowleaf willow thickets (*Salix exigua*)" NPS (2014c)."

Wupatki NM protects one of the few native grasslands in the Southwest that is not being actively grazed (Schelz et al. 2013), and while vegetation in Wupatki NM is varied as described above, the landscape is generally sparsely vegetated with between 2% and 15% cover (Hansen et al. 2004). Some areas are even considered naturally barren with <2% cover. These areas include cinder barrens, basalt outcrops, and active river channels near the Little Colorado River (Hansen et al. 2004).

<u>Wildlife</u>

Birds

Inventories of the avifauna at Wupatki NM include surveys by Beatty and Balda (1976) and Beatty (1978), part of the Bateman/Northern Arizona University project; Rosenstock (1999); Yavapai College Elderhostel (2002, 2003, 2004); and Southern Colorado Plateau I&M Network (Holmes and Johnson (2012, 2013, 2016)). A total of 174 species have been recorded at the monument and/or are on the NPSpecies list (NPS

2016b). Forty-seven (27%) are species of conservation concern on one or more government/organization lists. Twenty-two of these species were observed by at least one of the four surveys in the park, and 13 of these were recorded during the most recent SCPN surveys. Prairie falcon (*Falco mexicanus*), golden eagle (*Aquila chrysaetos*), and great horned owl (*Bubo virginianus*) are monitored in the park during the breeding season.

Mammals

There have been a small number of studies of mammals in or in the immediate vicinity of Wupatki NM. A summary of the older studies, taken from NPS (1996) is as follows:

> Bateman's (1976a) survey recorded species present and population densities within each of the plant communities for all three areas [monuments]. Bateman and Schwartz (1978) survey covers density topics for Wupatki and Sunset Crater Volcano. Steven Carothers and Nancy Goldberg's (1976) article covers the biology for both Wupatki and Sunset Crater Volcano National Monuments. A checklist of mammals found at Wupatki and Sunset Crater Volcano is by Vaughan (1976). A study specific to Wupatki is Fisher's (1986) report titled Mircohabitat Selection by Small Mammals on the Basis of Temperature.

The most recently conducted survey of mammals in the national monument was that by Drost (2009) during field work in 2003-2005 and based on his review of museum data and other sources. In addition, Wupatki's NPSpecies (2016b) list of mammals includes eight 'probably present' or 'unconfirmed' species not listed by Drost (2009). A total of 53 species have been documented in the monument, with four representing non-native species (refer to Appendix A for species list). The monument's list of mammal species was compared with lists of federally threatened and endangered species and those of Greatest Conservation Need (SGCN) in the state (Arizona Game and Fish Department [AGFD] 2012). Eight species are on the SGCN list, including two species of particular interest: American pronghorn (*Antilocapra americana*) and Wupatki pocket mouse (*Perognathus amplus cineris*), an endemic subspecies that is known to occur only within habitat at Wupatki NM and adjacent lands within the Little Colorado River Basin. Refer to the separate assessments in Chapter 4 for more details on both species.

Bats

Bats account for 26.4% of the confirmed mammals at the monument and the following bat surveys have been conducted at the monument. During the summer of 1963 park ranger, Terry Gustafson, surveyed several earthcracks as part of a bat inventory project (Gustafson 1964). In September 1975 and January 1976, Cave Research Foundation scientists surveyed for bats in five of the accessible earthcracks (CFR 1976).

Beginning in late 1984 and during the winter of 1985-1986, park volunteer James Bain (1986), conducted a winter roost survey for the Townsend's big-eared bat (*Corynorhinus townsendii*) (Figure 2.2.2-3), listed as a species of conservation concern within Arizona's Heritage Data Management System (AGFD 2013a), in Wupatki NM earthcracks. The most recent bat surveys were conducted during the winters of 2013, 2014 and 2015 (Wynne 2014, 2015). There are a number of known bat hibernacula (winter hibernation sites) at Wupatki NM for Townsend's big-eared bats.

Amphibians and Reptiles

Similar to mammals, there have been a small number of studies of herpetofauna in the monument. A

Figure 2.2.2-3. Townsend's big-eared bats occur in Wupatki NM. Photo Credit: © Robert Shantz.

summary of the older studies, taken from NPS (1996) is as follows:

> Bateman's (1976b) report includes a list of all the herpetofauna for both Wupatki and Sunset Crater Volcano National Monument. There also exists herpetofauna information in the 1980 Natural Resource Survey and Analysis of Wupatki and Sunset Crater Volcano National Monuments. Fowlie's (1965) book Snakes of Arizona has pages that are pertinent of Wupatki. Bergeson (n.d.) produced a checklist of reptiles.

Species listed by Persons and Nowak (2006) were those recorded by their field sampling efforts (in 2001-2003) and others' past, reliable observations or specimens. A total of 27 species have been documented in the monument (noted as present), with an additional five species that may occur (unconfirmed). No non-native species have been observed. The list of species was compared with lists of federally threatened and endangered species and those of Greatest Conservation Need in the State (Arizona Game and Fish Department 2012, species designated as Tier 1A or 1B), but no such species were identified.

2.2.3. Resource Issues Overview

The Southern Colorado Plateau is vulnerable to the impacts of climate change due to its semi-arid climate. The predicted change is that the Southwest will likely continue to become warmer and drier (Garfin et al. 2014, Monahan and Fisichelli 2014). According to Kunkel et al. (2013), the historical climate trends (1895-2011) for the Southwest (including the states of Arizona, California, Colorado, Nevada, New Mexico, and Utah) have seen an average annual temperature increase of 0.9°C (greatest in winter months) and more than double the number of four-day periods of extreme heat. Future climate predictions (Kunkel et al. 2013) for 2070-2099 (based on climate patterns from 1971-1999) estimate temperatures could rise between 2.5°C and 4.7°C.

Monahan and Fisichelli (2014) assessed the Wupatki NM's magnitude and direction of changes in climate for 25 variables, including temperature and precipitation, between 1901-2012 (historical range of variability (HRV)). Results for extreme climate were defined as experiencing either <5th percentile or >95th percentile climates relative to the HRV. The results were as follows:

- Three temperature variables were "extreme warm" (annual mean temperature, maximum temperature of the warmest month, mean temperature of the warmest quarter).
- No temperature variables were "extreme cold."
- Three precipitation variables were "extreme dry" (annual precipitation, precipitation of the driest month, precipitation of the driest quarter).
- No precipitation variables were "extreme wet"

The climate brief can be accessed at (http://science.nature.nps.gov/climatechange/?tab=0&CEtab=3&PanelBrief3=open#PanelBrief).

Monahan and Fisichelli (2014) results for the temperature of each year between 1901-2012, the averaged temperatures over progressive 10-year intervals, and the average temperature of 2003-2012 (the most recent interval) are shown in Figure 2.2.3-2. The blue line shows temperature for each year, the gray line shows temperature averaged over progressive 10-year intervals (10-year moving windows), and the red asterisk shows the average temperature of the most recent 10-year moving window (2003–2012). The most recent percentile is calculated as the percentage of values on the gray line that fall below the red asterisk. The results indicate that recent climate conditions have already begun shifting beyond the HRV, with the 2003-2012 decade representing the warmest decade on record. Garfin et al. (2014) expects more sustained extreme heat and fewer and less extreme cold periods. Overall, it's likely that future climate change will increasingly affect all aspects of park resources and operations (Monahan and Fisichelli 2014).

Prein et al. (2016) report that the western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall. Since 1974 there has been a 25% decrease in precipitation; however, this is a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016).

The timing of precipitation in the Colorado Plateau region has also been affected by climate change (Hereford et al. 2002 as cited by USGS 2011a), as well as changes in the timing of snowmelt (i.e., earlier), a reduction in the relative amount of snowfall to rainfall, and peak streamflow reductions (USGS 2011a). These

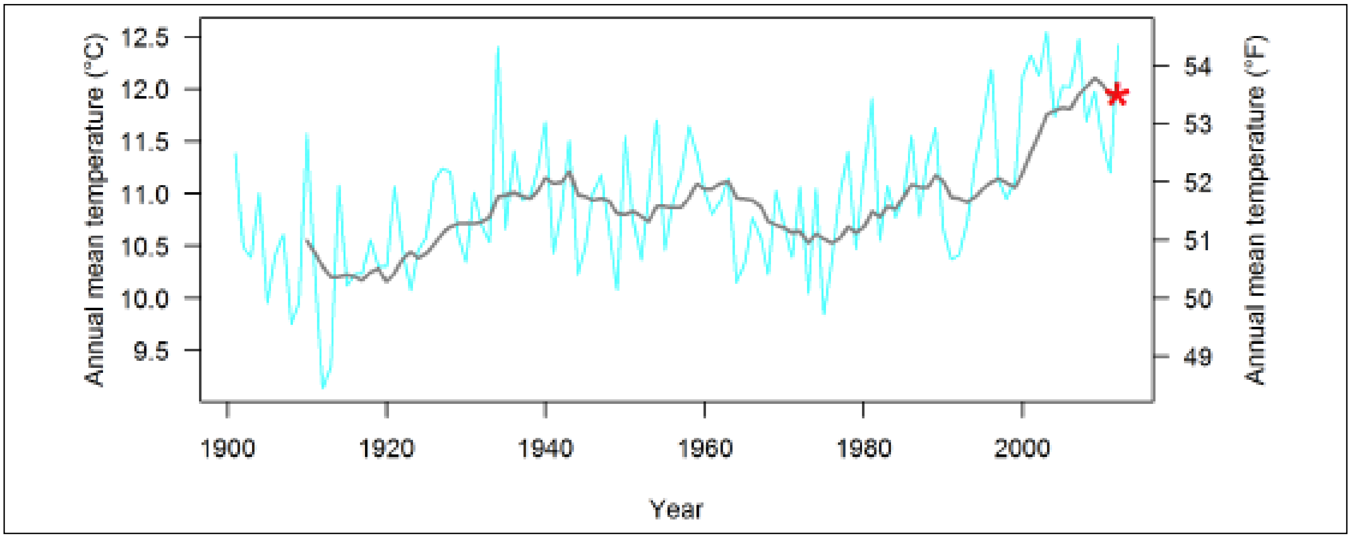


Figure 2.2.3-2. Time series used to characterize the historical range of variability and most recent percentile for annual mean temperature at Wupatki NM (including areas within 30-km [18.6-mi] of the park's boundary). Figure Credit: Monahan and Fisichelli (2014).

climate change factors represent primary threats to the Little Colorado River riparian corridor, including Deadman Wash,- resources that provides freshwater and habitat for a variety of wildlife and vegetation species that occur throughout Wupatki NM.

The redistribution of stream sediments is an important geomorphological process that has been affected by changes in precipitation (e.g., inconsistent flows) and land use patterns (e.g., grazing) (Hereford 1984). Wind is also a significant factor in the rate and amount of erosion (Graham 2011), especially in the upland areas of Wupatki, but how wind has or is redistributing soils in the monument is unknown. Baseline data collection would improve the monument staff's ability to manage its soil resources. The widespread, barren areas of the Sunset Crater tephra blanket covered with loose, unconsolidated cinders, wind-scoured blowouts, and active wind ripples clearly represent severe wind erosion and deteriorating conditions. The lack of any type of protective surface layer (e.g. soil horizons, biological crusts, stone pavements) indicates that the tephra deposits are not likely to become stabilized in the near future.

More moisture in the atmosphere leads to more intense storm events , which may lead to increased erosion and "spikier" stream flow patterns creating more potential for floods during drought periods (USGS 2011a). The changing climate also poses threats to springs and seep ecosystems, including groundwater depletion, pollution, alteration of source area geomorphology, and diversion of runout flows (Springer and Stevens 2008).

Threats to the monument's water quality include mineral, oil, and gas developments. Currently, uranium test pits occur on adjacent Navajo lands east of the Little Colorado River, and the discharge paths of the Leupp or Winslow sewage treatment plants are unknown (NPS 2006a).

Vegetation plays a key role in the stability of soils, but in Wupatki NM vegetation is sparse, particularly along intermittent and ephemeral streams. Erosion of these dry wash systems occurs largely as a result of runoff, but erosion is also affected by land use patterns such as grazing (Hereford 1984). Grazing in Wupatki NM was terminated in 1989 (Schelz et al. 2013). However, once streambeds have become deeply incised, the process may be irreversible (Sankey and Draut 2014). Gullying has occurred along portions of Deadman Wash, but erosion may be partially mitigated by the presence of invasive tamarisk (*Tamarix* spp.) and camelthorn (*Alhagi maurorum*) (P. Whitefield, pers. comm.), although these non-native invasive plants pose inherit threats.

Schelz et al. (2013) identified five primary threats caused by the introduction of non-native plants. These include the loss of native vegetation, lowering of the water table, loss of use by native wildlife, loss of the cultural landscape, and loss of culturally significant plants. However, of all the stressors on native vegetation, climate change has the most potential to influence community composition, vegetation structure, and species richness (Schweiger et al. 2010). Native vegetation has been substantially modified throughout the monument by the expansion of juniper. While the expansion of juniper into grasslands and savannas may benefit species using juniper habitats, it poses a disadvantage to obligate grassland species requiring more open habitat, such as the American pronghorn. Grassland habitat is protected in Wupatki NM, but grasslands across the country have been and continue to be subject to substantial modification. In general, changes in the composition and structure of grassland habitat could lead to changes in the distribution and abundance of many grassland-dependent species.

Population growth and associated developments surrounding the monument have resulted in habitat fragmentation, bisecting grasslands and increasing sources of visibility, light, and sound pollution. Atmospheric dust created from mineral and rock quarries and mineral aerosols from carbon emissions have increased in the interior western U.S. by 500% over the late Holocene average (Neff et al. 2008). This increase is directly related to increased western settlement and livestock grazing during the 19th century (Neff et al. 2008). In addition, effects of climate change and forest fires (natural or prescribed) have also contributed to degraded air quality. Additional land use change threats include barriers, such as roads, that negatively impact wildlife movement patterns. Habitat fragmentation and habitat loss are believed to have contributed to decreases in the pronghorn population over recent decades (Brown and Ockenfels 2007 as cited by NPS and AGFD 2014) and the effect on the ability of pronghorn to cross U.S. 89, a four-lane highway, is currently being assessed (NPS and AGFD 2014). Although Wupatki NM and its partners have made efforts to mitigate habitat fragmentation in the vicinity of the monument and by modifying and removing fences on and off the monument within the pronghorn range, these threats may continue (or potentially, increase) outside of the monument's boundary.

Another significant wildlife threat is that of white-nose syndrome (WNS). WNS affects hibernating bats and is named for the white fungus (*Pseudogymnoascus destructans)* that grows on the muzzle and other parts of the body (USFWS 2017). It was first documented in New York in the winter of 2006-2007, and has since spread across portions of the U.S. and eastern Canada. In the U.S., the occurrence of WNS has been confirmed in eight species of bats. Of these species that have been afflicted with WNS, five are known to occur at Wupatki NM. Efforts are being made at Wupatki NM to monitor for the occurrence of WNS (Wynne 2014, 2015).

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

In addition to NPS staff input based on the park's purpose, significance, and fundamental resources and values, and other potential resources/ecological drivers of interest, 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, I&M NPScape Program for landscape dynamics, Air Resources Division for air quality, and the Natural Sounds and Night Skies Program for the soundscape and night sky sections.

SCPN I&M Program

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 2011a). 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 2011a).

To facilitate this effort, 270 parks with significant natural resources were organized into 32 regional networks. Wupatki NM 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. Wupatki NM's birds, integrated upland ecosystems, and land surface phenology were selected for monitoring by SCPN (NPS SCPN 2014).

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 (SotP) and Resource Stewardship Strategy (RSS) reports rely on credible information found in NRCAs as well as a variety of other sources (Figure 2.3.1-1).

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 Wupatki NM in 2015 and was used to identify some of the primary natural features throughout the monument for the development of its NRCA.

State of the Park

A State of the Park (SotP) 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 SotP reports, and

Figure 2.3.1-1. The relationship of NRCAs to other National Park Service planning reports.

each Chapter 4 assessment includes a SotP condition summary.

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 an 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. An RSS has not yet been started for the monument.

2.3.2. Status of Supporting Science

Available data and reports varied significantly 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. In addition to data from the SCPN I&M and research conducted by other scientists and programs, subject matter expert, Dr. William H. Romme, Professor emeritus of fire ecology and senior research scientist in the Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO provided technical assistance pertaining to the monument's vegetation and fire ecology during a field assessment. Dr. Kirk Anderson, with the Museum of Northern Arizona, was selected as the subject matter expert for the park's Sunset Crater tephra layer condition assessment, which also included a rapid field assessment. Additional Washington level programs, including I&M NPScape, Climate Change Response Program, Natural Sounds and Night Skies, and Air Resources, Divisions provided a wealth of information for the monument's condition assessments.

Flagstaff Area National Monuments' NRCA scoping meeting was held on May 17-19, 2016. Photo Credit: NPS.

Chapter 3. Study Scoping and Design

Wupatki National Monument (NM) Natural Resource Condition Assessment (NRCA) was coordinated by the National Park Service (NPS) Intermountain Region Office, Utah State University, and the Colorado Plateau Cooperative Ecosystem Studies Unit through task agreements, P14AC00749 and P15AC01212.

The NRCA process was a collaborative effort between the Flagstaff Area NMs' (Wupatki, Walnut Canyon, and Sunset Crater Volcano) staff, Southern Colorado Plateau Inventory and Monitoring Network staff, Intermountain Region NRCA Coordinator, and the NRCA team from Utah State University. Dr. Kirk Anderson, with the Museum of Northern Arizona, was selected as the subject matter expert for the monument's Sunset Crater tephra layer condition assessment through the Colorado Plateau Cooperative Ecosystem Studies Unit task agreement P14AC00921. Dr. William (Bill) Romme, Professor Emeritus of Fire Ecology and Research Scientist in the Natural Resource Ecology Laboratory, Colorado State University, was selected as the subject matter expert for the monument's vegetation condition assessment through the Rocky Mountain Cooperative Ecosystem Studies Unit task agreement P15AC00777.

3.1. Preliminary Scoping

Preliminary scoping for Wupatki NM's NRCA project began in March 2015. Paul Whitefield, submitted a draft list of natural resource topics based on the 'key [natural] resources and values identified in the park's Foundation document (NPS 2015a) and General Management Plan (NPS 2002). Paul Whitefield and Michael Jones, Flagstaff Area NMs' GIS Specialist, compiled reports and data sets pertaining to the preliminary list of natural resources, and Donna Shorrock, NPS IMR NRCA Coordinator (former) facilitated the process of uploading the park's information to USU's ftp site. Science writers from USU reviewed these reports and data sets and developed draft indicators, measures, and reference conditions, which served as the primary discussion guide during the on-site NRCA scoping workshop.

The workshop was held over a three day period from May 17-19, 2016 at the Flagstaff Area NMs' headquarters in Flagstaff, Arizona. The initial list of natural resource topics submitted by the park were reviewed, discussed, and refined by scoping workshop attendees (listed in Appendix B). Through discussions, meeting participants reviewed and refined 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 were incorporated into the revised assessment approach. Park staff also identified important concerns, issues/stressors, and data gaps for each natural resource topic. The final list of selected natural resources and their associated indicators and measures are summarized in Tables 3.1-1 - 3.1-5. Data gaps were identified for natural resources not selected for the NRCA and are listed in Table 3.1-6. And finally, threats and stressors were also identified for each natural resource assessed for current condition and are listed in Table 3.1-7.

3.2. Study Design

3.2.1. Indicator Framework, Focal Study Resources and Indicators

Wupatki NM's NRCA utilizes the NPS Inventory & Monitoring (I&M) Program's "NPS Ecological Monitoring Framework" (NPS 2005). This framework was endorsed by the National NRCA Program as an appropriate framework for listing resource components, indicators/measures, and resource conditions. Additionally, Flagstaff Area National Monuments' natural resource files, Southern Colorado Plateau Inventory and Monitoring Network's (SCPN) Vital Signs Plan (Thomas et al. 2006), and the RM-77 NPS Natural Resource Management Guideline (NPS 2004) are all organized similarly to the I&M framework.

Each NRCA report represents a unique assessment of key natural resource topics that are important to each park. For the purposes of Wupatki NM's NRCA, 14 focal resources were selected for assessment. This list of resources does not include every natural resource at the park, but the natural resources and processes that were of greatest significance to park staff at the time of this effort. Staff gave thought to identifying focal resource topics which have been consistently identified in legacy planning documents and literature, possess knowledge bases that are sufficient for establishing baseline condition, are indicative of overall ecologic and biotic integrity, have also been identified by stakeholders as focal resources on adjacent lands, or where resource trend may be increasingly understood as the NPS SCPN progresses with vital signs monitoring (Thomas et al. 2006). Staff were also interested in including some focal resources which may be vulnerable to degradation and possible loss due to climate change.

Reference conditions were identified with the intent of providing a benchmark to which the current condition of each indicator/measure could be compared using existing research and documentation. When a quantifiable reference for a given measure was not feasible, an attempt was made to include a qualitative reference to provide some context for interpreting current resource condition.

3.2.2. Reporting Areas

The primary focus of the reporting area was within the national monument's legislative boundary; however, some of the analyses encompassed areas beyond the park's boundary. Natural resources assessed at the landscape level included viewshed, night sky, soundscape, and habitat connectivity. Data and reports for the night sky and soundscape assessments were provided by the NPS Natural Sounds and Night Skies Division. USU completed both the viewshed and habitat connectivity analyses, augmenting condition reporting using the NPS NPScape Program data sets and Area of Analysis for the viewshed and 30-km boundaries (NPS 2015b).

3.2.3. General Approach and Methods

The general approach to developing the condition assessments included reviewing literature and data and/or speaking to 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 Chapter 4 assessment included six sections briefly described below.

The background and importance section of the NRCA report provided information regarding the relevance of the resource to the national monument using existing project proposals or descriptions previously developed by park staff for various planning documents.

The data and methods section of the assessment described the existing data sets and methodologies used for evaluating the indicators/measures for current condition.

The reference conditions section lists the good, moderate concern, and significant concern definitions used to evaluate the condition of each measure.

The condition and trend section provided a discussion of the condition and trend, if available, for each indicator/measure based on the reference condition(s). Condition icons were presented in a standard format consistent with *State of the Park* reporting

Table 3.1-1. Wupatki NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for landscapes patterns and processes.

Resource	Indicators	Measures
Viewshed	Scenic and Historic Integrity	Conspicuousness of Non-contributing Features
	Scenic and Historic Integrity	Extent of Development
Night Sky	Sky Brightness	All-sky Light Pollution Ratio
	Sky Brightness	Vertical Maximum Illuminance
	Sky Brightness	Horizontal Illuminance
	Sky Brightness	Zenith Sky Brightness
	Sky Quality	Bortle Dark Sky Scale
Soundscape	Sound Level	% Time Above Reference Sound Levels
	Sound Level	% Reduction in Listening Area
	Audibility of Anthropogenic Sounds	% Time Audible
	Geospatial Model	L_{50} Impact

Table 3.1-2. Wupatki NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for air and climate.

Resource	Indicators	Measures
Air Quality	Visibility	Haze Index
	Ozone	Human Health
	Ozone	Vegetation Health
	Wet Deposition	Nitrogen
	Wet Deposition	Sulfur
	Wet Deposition	Mercury
	Wet Deposition	Predicted Methylmercury Concentration

Table 3.1-3. Wupatki NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for geology and soils.

Resource	Indicators	Measures
Sunset Crater Tephra Layer	Soil / Site Stability	Soil Aggregate Stability: Does the tephra form aggregates that are resistant to erosion?
	Soil / Site Stability	Organic Matter (O horizon): Does organic matter protect from erosion?
	Soil / Site Stability	Biological Soil Crusts: Does the BSC protect from erosion?
	Soil / Site Stability	Stone Pavement: Is there a protective layer of stones that help stop erosion?
	Soil / Site Stability	Wind-Scoured Blowouts: How large an area is eroding by wind?
	Soil / Site Stability	Barren Cinder Areas: How large of an area is devoid of vegetation and therefore subject to erosion by wind and water?
	Soil / Site Stability	Subsoil / Bedrock Exposure: How large of an area is present of hardpan or bedrock exposed where cinders cannot accumulate for very long?
	Soil / Site Stability	Wind Ripples: How large of an area are wind ripples exposed to illustrate active wind erosion?
	Soil / Site Stability	Plant Spacing: How much barren area is exposed between plants that is mobile and easily eroded? Is this area expanding or contracting?
	Hydrologic Function	Rainfall Infiltration / Runoff: How rapidly and how deep does precipitation infiltrate into the tephra, and how long is it stored?
	Hydrologic Function	Rills: What is the extent of erosional rill networks?

(NPS 2012a) and serve as visual representations of condition/trend/level of confidence for each measure that was evaluated. Table 3.2.3-1 shows the condition/trend/confidence level scorecard used to describe the condition for each assessment, and Table 3.2.3-2 provides examples of conditions and associated interpretations.

Circle colors convey condition. Red circles signify that a resource is of significant concern; yellow circles signify that a resource is of moderate condition;

Table 3.1.3 continued. Wupatki NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for geology and soils.

Resource	Indicators	Measures
Sunset Crater Tephra Layer	Hydrologic Function	Terracettes / Pedestals: Is wind and water erosion increasing or decreasing their coverage?
	Hydrologic Function	Presence of Hardpan / Bedrock: How deep or shallow is bedrock below barren cinders? (Implications for wind and water erosion)
	Biotic Integrity	Crispleaf Buckwheat Cinder Shrublands: Are these communities improving or declining in health and extent?
	Biotic Integrity	Mormon Tea Cinder Dune Shrubland: Are these communities improving or declining in health and extent?
	Biotic Integrity	Apache Plume Cinder Shrubland: Are these communities improving or declining in health and extent?
	Biotic Integrity	One-Seed Juniper Woodland (Cinder Wooded Herbaceous): Are these communities improving or declining in health and extent?
	Biotic Integrity	Grasslands/Grass-Covered Cinders: Are these communities improving or declining in health and extent?
Geomorphic Stability	Geologic Map Units	No measures
	Soil Survey Map Units	No measures

Table 3.1-4. Wupatki NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for water.

Resource	Indicators	Measures
Springs, Seeps, and Surface Water	Water Quantity & Availability	Presence of Wetted Area or Discharge
	Water Quantity & Availability	Depth to Groundwater
	Water Quality	Core Water Parameters, Inorganic Chemicals, and Uranium
	Biodiversity	Invertebrates, Birds, Mammals, and Herpetofauna

Table 3.1-5. Wupatki NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for biological integrity.

Resource	Indicators	Measures
Little Colorado River Riparian Corridor	Hydrology	Streamflow of LCR & DMW
	Hydrology	Depth to Groundwater in DMW Riparian Area
	Vegetation	Species Occurrence (Presence/Absence) of Native & Non-native Vegetation
	Vegetation	Maintenance of Soil Moisture in/along DMW Confluence Area
	Bird Use of Riparian Area / LCR	Species Occurrence
	Bird Use of Riparian Area / LCR	Vertical Stability of DMW and DMW-LCR confluence area
	Erosion / Deposition	Stream is in Balance with Water & Sediment from the Watershed (DMW)
	Erosion / Deposition	Wind Ripples: How large of an area are wind ripples exposed to illustrate active wind erosion?
Vegetation	Ecological Condition	Are the species present and their distributions consistent with supply and demand of light, water, nutrients, and growing space, and within their natural range of variability?

Table 3.1.5 continued. Wupatki NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for biological integrity.

Resource	Indicators	Measures
Vegetation *continued*	Ecological Condition	Are stand densities within their range of natural variability for their growing conditions?
	Ecological Condition	Are the age class distributions of the trees consistent with the expected range of variability for this site/ ecosystem type?
	Ecological Condition	Do the trees and understory plants appear vigorous and healthy for this site/ ecosystem type?
	Ecological Condition	Are ecological processes (e.g., fire) operating within a natural range of variability?
	Ecological Condition	Are the current levels of insects and/or disease within the normal range for this ecosystem type?
	Biotic Integrity	Species Composition and Landscape-scale Diversity
	Biotic Integrity	Local-scale Species Composition
	Biotic Integrity	Response of Annual Species to Disturbance
	Biotic Integrity	Relative Proportion of Functional Groups
	Biotic Integrity	Relative Proportion of C3 and C4 Species
Non-native and Invasive Plants	Potential to Alter Native Plant Communities	NatureServe Invasive Species Impact Rank
	Potential to Alter Native Plant Communities	AZ-WIPWG Ecological Impact Rank
	Change in Non-native Plants (1977-2011)	% Change in Cover
	Change in Non-native Plants (1977-2011)	% Change in Frequency
	Current Prevalence of Non-native Plants	% Current Cover
	Current Prevalence of Non-native Plants	% Current Frequency

Table 3.1.5 continued. Wupatki NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for biological integrity.

Resource	Indicators	Measures
Non-native and Invasive Plants *continued*	Current Extent of Target Non-native Plants	Area Mapped
	Camelthorn and Tamarisk Control	Treated Area
Earthcracks and Blowholes	Earthcrack Meteorology	Temperature and Humidity
	Earthcrack Species Occurrence	Presence / Absence
	Occurrence of *P. destructans* and/ or White-nose syndrome	Presence / Absence
Birds	Species Occurrence	Temporal Comparison (Changes over Time)
	Species Occurrence	Changes in Most-Common Species in SCPN Surveys
	Species Occurrence	Presence of Species of Conservation Concern
American Pronghorn	Pronghorn Occurrence	Abundance within Wupatki NM & Vicinity
	Habitat Quality	Habitat (Vegetation Communities) for Pronghorn in Wupatki NM
	Habitat Quality	Permeability of Fences & Roads within Wupatki NM & Surrounding Area
Wupatki Pocket Mouse	Occurrence	Site Occupancy by Vegetation/Soil Type
	Occurrence	Presence & Relative Abundance by Vegetation Type

Table 3.1-6. Additional resource data gaps identified during scoping workshop.

Resource	Notes
Mammals	• In general, there is limited information for park • Lots of work on Neotoma for park but it's not of management concern
Herpetofauna	• Limited information for park

Table 3.1-7. Resource condition assessment topic threats and stressors.

Resource	Threats / Stressors / Data Gaps
Viewshed	• Regional development, associated light pollution - effects on most nocturnal species are not well understood
Night Sky	• New visitor activities (e.g., casinos)
	• Increasing dust and smog due to climate change
Soundscape	• Regional development and anthropogenic noises, including military airspace, with air traffic representing the most significant current threat
	• Effects of noise on most species are not well understood
Air Quality	• Increasing dust from various sources (e.g., local industry, USFS Forest-wide Materials Quarry, climate change, etc.)
	• USFS prescribed burns and increasing frequency of wildfires in the southwest
	• The Navajo Generating Station, Cholla Power Plant, and Coronado Generating Station are potential sources for air quality impacts.
	• Lack of vegetation monitoring for potential ozone impact
Sunset Crater Tephra Layer	• Lack of baseline data to evaluate the influence of the Sunset Crater tephra blanket on plant community health and better assess the effects of future climate changes.
	• Erosion of the tephra layer
Geomorphic Stability	• Sparse vegetation and asscoiated erosion
	• Loss of archaeological sites
Springs, Seeps, and Surface Water	• Groundwater depletion, pollution, alteration of source area geomorphology, diversion of runout flows, and climate change
	• Mineral, and oil and gas development may impact water quality (e.g., Uranium test pits on adjacent Navajo lands or discharge path of the Leupp or Winslow sewage treatment plants
	• Unknown whether increased juniper woodlands may increase water stress and reduce spring discharge
	• Limited data for all measures
Little Colorado River Riparian Corridor	• Effects of climate change, including timing of precipitation and snowmelt, and reduced amount of precipitation / surface water
	• Unknown effects of tamarisk beetle on tamarisk mortality
	• Groundwater depletion, pollution, alteration of source area geomorphology
Vegetation	• Detailed fire effects on vegetation and soils
	• Thresholds in juniper density or cover at which herbaceous growth is suppressed sufficiently to inhibit fire spread under a range of fire weather conditions; and similar relationships between herbaceous cover and the depth of volcanic cinders
	• Trends in grassland floristic composition over the past century and surrounding locations of extirpated species
	• Continued monitoring for long term changes in grassland plant composition and cover
	• Likely effects of climate change on vegetation composition and on fire frequency and severity
Non-native and Invasive Plants	• New introductions and spread of invasive plants
	• Climate change effects on spread of non-native invasive species, including precipitation and disturbance events
	• Altered soil chemistry (e.g., increased salinity)
	• Altered stream channel morphology
	• Lack of consistent non-native plant monitoring
Earthcracks and Blowholes	• Introduction of *P. destructans* fungus
	• Resurveys to monitor the continued existence of rare and endemic species and document new species
	• Degradation from recreational activity
	• Unknown impacts from climate change

and green circles denote that a measure is in good condition. A circle without any color, which is often associated with the low confidence symbol-dashed line, signifies that there is insufficient information to make a statement about condition; therefore, condition is unknown.

Arrows inside the circles signify the trend of the indicator/measure. An upward pointing arrow signifies that the measure is improving; double pointing arrows signify that the measure's condition is currently unchanging; a downward pointing arrow indicates that the measure's condition is deteriorating. No arrow denotes an unknown trend.

The level of confidence in the assessment ranges from high-low and is symbolized by the border around the condition circle. Key uncertainties and resource threats are also discussed in the condition and trend section for each resource topic.

The sources of expertise are individuals who were consulted and/or provided a review are listed in this section, along with the writer(s) who drafted the assessment.

Table 3.1-7 continued. Resource condition assessment topic threats and stressors.

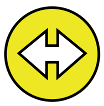
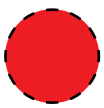
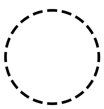
Resource	Threats / Stressors / Data Gaps
Birds	• Threats to habitats from invasive plant species and climate change
	• No surveys of riparian habitat since that of Yavapai College, 2002-2004
	• Expansion of juniper into grasslands and savannas disadvantage obligate grassland species
	• Unknown impacts from climate change
American Pronghorn	• Development, habitat conversion, including juniper increase, and degradation
	• Fragmentation of habitat and barriers to movement
	• Understanding of locations of connectivity/barriers
	• Genetic declines
	• Unknown impacts to vegetation from climate change
	• Surface water decline
	• Re-analysis of existing telemetry data to identify the most utilized habitat areas
Wupatki Pocket Mouse	• Species has limited range and unknown effects from climate change
	• Grazed areas appear to be an issue for the species, and climate change could require a shift to higher elevations
	• Unknown habitat quality and quantity since previous research could not separate effects of vegetation type from land use and elevation.

Table 3.2.3-1. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in good condition.		Condition is Improving.		High
	Resource warrants moderate concern.		Condition is unchanging.		Medium
	Resource warrants significant concern.		Condition is deteriorating.		Low
	An open (uncolored) circle indicates that current condition is unknown or indeterminate; this condition status is typically associated with unknown trend and low confidence.				

The literature cited section lists all of the referenced sources for the assessment. A DVD is included in the final report with copies of all literature cited unless the citation was from a book.

Table 3.2.3-2. Example indicator symbols and descriptions of how to interpret them.

Symbol Example	Description of Symbol
	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.

Chapter 4. Natural Resource Conditions

Chapter 4 delivers current condition reporting for the 14 important natural resources and indicators selected for Wupatki NM's NRCA report. The resource topics are presented following the National Park Service's (NPS) Inventory & Monitoring Program's NPS Ecological Monitoring Framework that is presented in Chapter 3.

View of the narrows within Deadman Wash. Photo Credit: NPS.

4.1. Viewshed

4.1.1. Background and Importance

The conservation of scenery is established in the National Park Service (NPS) Organic Act of 1916 ("… to conserve the scenery and the wildlife therein…"), reaffirmed by the General Authorities Act, as amended, and addressed generally in the NPS 2006b Management Policies sections 1.4.6 and 4.0 (Johnson et al. 2008). Although no management policy currently exists exclusively for scenic or viewshed management and preservation, parks are still required to protect scenic and viewshed quality as one of their most fundamental resources. According to Wondrak-Biel (2005), aesthetic conservation, interchangeably used with scenic preservation, has been practiced in the NPS since the early twentieth century. Aesthetic conservation strove to protect scenic beauty for park visitors to better experience the values of the park. The need for scenic preservation management is as relevant today as ever, particularly with the pervasive development pressures that challenge park stewards to conserve scenery today and for future generations.

Wupatki National Monument (NM) preserves a 14,266 ha (35,253 ac) area that is bounded by state trust land to the west, by the Coconino National Forest to the south, private land to the southeast, the Navajo Reservation to the east, and a mix of private and state trust land to the north (NPS 1996). Much of the surrounding landscape is undeveloped and provides habitat for wildlife and plants unique to this high elevation desert plateau (NPS 2015a). Wupatki NM was established in 1924 to preserve the thousands of archaeological sites and cultural evidence of past inhabitants of the region, including several large and prominent pueblos located throughout the monument (Figure 4.1.1-1). Members of the Sinagua, Cohonina, and Kayenta peoples are believed to have inhabited the region from 8,000 B.C. to A.D. 1225 (NPS 1996). The vast trade network with each other and the Hohokam to the south made the region a "cultural frontier" at the time (NPS 1996). The park also protects unique geologic features including earthcracks and blowholes, red sandstone of the Moenkopi formation used to construct pueblos, and cinder cones and lava flows of the San Francisco Volcanic Field (Graham 2011).

Visitor Experience

Viewsheds are considered an important part of the visitor experience at Wupatki NM, and features on the visible landscape influence a visitor's enjoyment, appreciation, and understanding of the monument. The monument's wilderness setting and proximity to a large urban community "provides an increasingly rare opportunity to glimpse past cultures' experiences," including undeveloped landscapes and dark night

Figure 4.1.1-1. Lomaki Pueblo, constructed of native stone, contributes to the historic viewshed integrity in Wupatki National Monument. Photo Credit: NPS.

skies (NPS 2015a). These views represent much more than just scenery; they represent a way to better understand the connection between self and nature and between past and the present cultures. Visitors to the monument are provided opportunities to immerse themselves in the wilderness where experiences become more remote from anthropogenic sights and sounds, offering an opportunity to literally "visualize" their connection to nature and past cultures.

Inherent in virtually every aspect of this assessment is how features on the visible landscape influence the enjoyment, appreciation, and understanding of the monument by visitors. The indicators we use for condition of the viewshed are based on studies related to perceptions people hold toward various features and attributes of the viewsheds. We also focus on how the cultural integrity of the viewshed enhances the opportunity for visitors to better understand past cultures and their connection to modern Native American cultures in the region.

4.1.2. Data and Methods

The indicator and measures used for assessing the condition of Wupatki NM's viewshed are based on studies related to perceptions people hold toward various features and attributes of scenic landscapes. In general, there is a wealth of research demonstrating that people tend to prefer natural landscapes over human-modified landscapes (Zube et al. 1982, Kaplan and Kaplan 1989, Sheppard 2001, Kearny et al. 2008, Han 2010). Human-altered components of the landscape (e.g., roads, buildings, power lines, and other features) that do not contribute to the natural scene are often perceived as detracting from the scenic character of a viewshed. Despite this generalization for natural landscape preferences, studies have also shown that not all human-made structures or features have the same impact on visitor preferences. Ancient pueblos in Wupatki NM for example, are considered to contribute to, rather than detract from, the monument's viewshed. Visitor preferences can be influenced by a variety of factors including cultural background, familiarity with the landscape, and their environmental values (Kaplan and Kaplan 1989, Virden and Walker 1999, Kaltenborn and Bjerke 2002, Kearney et al. 2008).

While we recognize that visitor perceptions of an altered landscape are highly subjective, and that there is no completely objective way to measure these perceptions, research has shown that there are certain landscape types and characteristics that people tend to prefer over others. Substantial research has demonstrated that human-made features on a landscape are perceived more positively when they are considered in harmony with the landscape (e.g., Kaplan and Kaplan 1989, Gobster 1999, Kearney et al. 2008).

Kearney et al. (2008) showed that survey respondents tended to prefer development that blended with the natural setting through use of colors, smaller scale, and vegetative screening. For example, pueblos constructed during the 12th and 13th centuries, were made of native stone harvested from the Moenkopi formation and Kaibab limestone and basalt, depending upon what was in the vicinity of the monument. These structures blend well with the natural environment and their presence is an integral part of the visitor experience in Wupatki NM. These characteristics, along with distance from non-contributing features, and movement and noise associated with observable features on the landscape, are discussed below.

The indicator, scenic and historic integrity, is defined as the state of naturalness or, conversely, the state of disturbance created by human activities or alteration (U.S. Forest Service (USFS 1995). Integrity focuses on the features of the landscape related to non-contributing human alteration/development. Because of the importance of ancestral pueblo culture to the establishment of the monument, we consider these landscape features to be contributing features. Two measures, conspicuousness of non-contributing features and extent of development, were selected to evaluate the monument's viewshed condition.

<u>Key Observation Points</u>

Five key observation points were selected by park staff (Table 4.1.2-1, Figure 4.1.2-1) and were used to qualitatively evaluate viewshed condition using GigaPan panoramas and to quantitatively evaluate condition using viewshed analysis overlaid with NPScape housing and road densities datasets. These locations were chosen based on viewsheds that are accessible to the public, are located upon a prominent landscape feature, are inclusive of natural and cultural resources, and viewsheds that include scenic views (M. Szydlo, pers. comm.).

Four observation points were located at pueblos: Citadel Pueblo, Wupatki Pueblo, Wukoki Pueblo, and Crack-in-Rock Pueblo. The 545 Road Bend observation point was located at a bend along the main road through the monument.

<u>Conspicuousness of Non-Contributing Features</u>

GigaPan Images

We used a series of panoramic images to portray the viewshed from an observer's perspective. These images were taken from each key observation point using a Canon PowerShot digital camera and the GigaPan Epic 100 system, a robotic camera mount coupled with stitching software (Figure 4.1.2-2).

A series of images were automatically captured and the individual photographs are stitched into a single high-resolution panoramic image using GigaPan Stitch software (http://www.omegabrandess.com/Gigapan). The GigaPan images provided a means of assessing the non-contributing features on the landscape and qualitatively evaluating the viewshed condition based on groups of characteristics of man-made features as follows: (1) distance from a given key observation point, (2) size, (3) color and shape, and (4) movement and noise. A general relationship between these characteristics and their influence on conspicuousness is presented in Table 4.1.2-2.

Table 4.1.2-1. Key observation points used to assess Wupatki NM's viewshed condition.

Site Location	Image Date	Coordinates - Easting, Northing (UTM NAD83 12N)
Citadel Pueblo	8/18/2016	3935899, 457256
545 Road Bend	8/19/2016	3933912, 464513
Wupatki Pueblo	8/19/2016	3930880, 466249
Wukoki Pueblo	8/19/2016	3931967, 470129
Crack-in-Rock Pueblo	8/31/2016	3942828, 468914

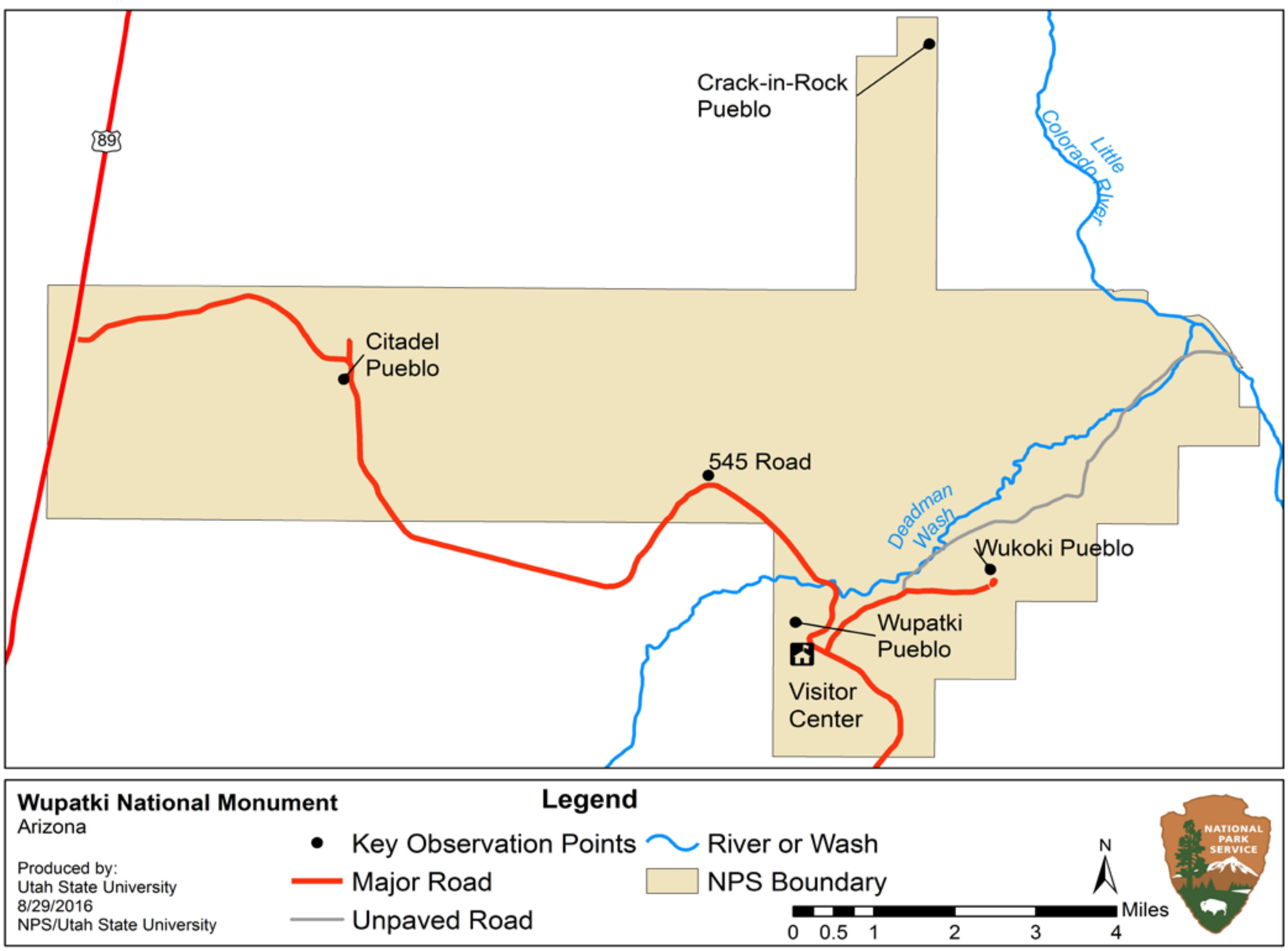


Figure 4.1.2-1. Locations of 2016 viewshed monitoring locations at Wupatki NM.

Distance. The impact that individual human-made features have on perception is substantially influenced by the distance from the observer to the feature(s). Viewshed assessments using distance zones or classes often define three classes: foreground, middle ground, and background (Figure 4.1.2-3). For this assessment, we have used the distance classes that have been recently used by the National Park Service:

- *Foreground* = 0-½ mile from key observation point
- *Middle ground* = ½-3 miles from key observation point
- *Background* = 3-60 miles from key observation point.

Over time, different agencies have adopted minor variations in the specific distances use to define these zones, but the overall logic and intent has been consistent.

The foreground is the zone where visitors should be able to distinguish variation in texture and color, such as the relatively subtle variation among vegetation patches, or some level of distinguishing clusters of tree boughs. Large birds and mammals would likely be visible throughout this distance class, as would small or medium-sized animals at the closer end of this distance class (USFS 1995). Within the middle ground there is often sufficient texture or color to distinguish individual trees or other large plants (USFS 1995). It is also possible to still distinguish larger patches within major plant community types (such as riparian areas), provided there is sufficient difference in color shades at the farther distance. Within the closer portion of this distance class, it still may be possible to see large birds when contrasted against the sky, but other wildlife would be difficult to see without the aid of binoculars or telescopes. The background distance class is where texture tends to disappear and colors flatten. Depending on the actual distance, it is sometimes possible to distinguish between major vegetation types with highly contrasting colors (for example, forest and grassland), but any subtle differences within these broad land cover classes would not be apparent without the use of binoculars or telescopes, and even then may be difficult.

Table 4.1.2-2. Characteristics that influence conspicuousness of human-made features.

Characteristic	Less Conspicuous	More Conspicuous
Distance	Distant from the observation point	Close to the observation point
Size	Small relative to the landscape	Large relative to the landscape
Color and Shape	Colors and shapes that blend into the landscape	Colors and shapes that contrast with the landscape
Movement and Noise	Lacking movement or noise	Exhibits obvious movement or noise

Size

Size is another characteristic that may influence how conspicuous a given feature is on the landscape, and how it is perceived by humans. For example, Kearney et al. (2008) found human preferences were lower for man-made developments that tended to dominate the view, such as large, multi-storied buildings) and were more favorable toward smaller, single family dwellings. In another study, Brush and Palmer (1979) found that farms tended to be viewed more favorably than views of towns or industrial sites, which ranked very low on visual preference. This is consistent with other studies that have reported rural family dwellings, such as farms or ranches, as quaint and contributing to rural character (Schauman 1979, Sheppard 2001, Ryan

Figure 4.1.2-2. The GigaPan system takes a series of images that are stitched together using software to create a single panoramic image.

2006), or as symbolizing good stewardship (Sheppard 2001).

We considered the features on the landscape surrounding Wupatki NM as belonging to one of six size classes (Table 4.1.2-3), which reflect the preference groups reported by studies. Using some categories of perhaps mixed measures, we considered size classes within the context of height, volume, and length.

Color and Shape
Studies have shown that how people perceive a human-made feature in a rural scene depends greatly on how well it seems to fit or blend in with the environment (Kearney et al. 2008, Ryan 2006). For example, Kearney et al. (2008) found preferences for homes that exhibit lower contrast with their surroundings as a result of color, screening vegetation, or other blending factors (see Figure 4.1.2-4). It has been shown that colors lighter in tone or higher in saturation relative to their surroundings have a tendency to attract attention (contrast with their surroundings), whereas darker colors (relative to their surroundings) tend to fade into the background (Ratcliff 1972, O'Connor 2008). This is consistent with the findings of Kearney et al. (2008) who found that darker color was one of the factors contributing to a feature blending in with its environment and therefore preferred. Some research has indicated that color can be used to offset other factors, such as size, that may evoke a more negative perception (O'Connor 2009). Similarly, shapes of features that contrast sharply with their surroundings may also have an influence on how they are perceived.

This has been a dominant focus within visual resource programs of land management agencies (Ribe 2005). The Visual Resource Management Program of the BLM (BLM 2016), for example, places considerable focus on design techniques that minimize visual conflicts with features such as roads and power lines

Table 4.1.2-3. Six size classes used for conspicuousness of human-made features.

Size	Low Volume	Substantial Volume
Low Height	Single family dwelling (home, ranch house)	Small towns, complexes
Substantial Height	Radio and cell phone towers	Wind farms, oil derecks
Substantial Length	Small roads, wooden power lines, fence lines	Utility corridors, highways, railroads

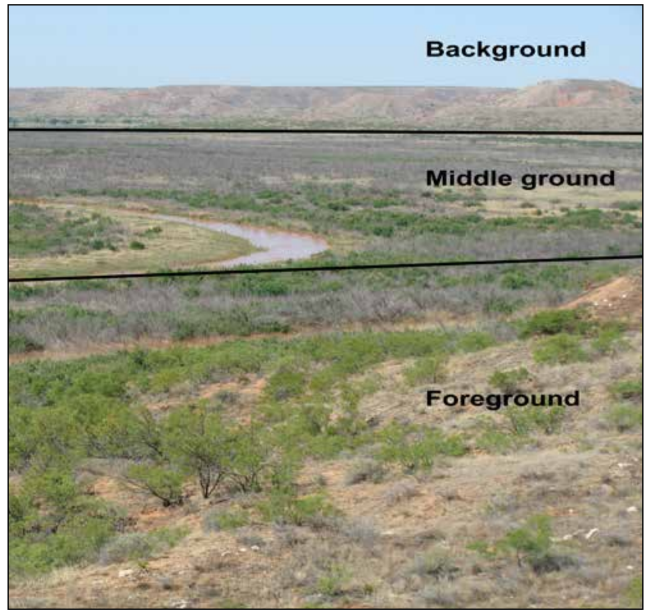


Figure 4.1.2-3. An example of foreground, middle ground, and background distance classes.

by aligning them with the natural contours of the landscape. Based on these characteristics of contrast, we considered the color of a feature in relative harmony with the landscape if it closely matched the surrounding environment, or if the color tended to be darker relative to the environment. We considered the shape of a feature in relative harmony with the landscape if it was not in marked contrast to the environment.

Movement and Noise
Motion and sound can both have an influence on how a landscape is perceived (Hetherington et al. 1993), particularly by attracting attention to a particular area of a viewshed. Movement and noise parameters can be perceived either positively or negatively, depending on the source and context. For example, the motion of running water generally has a very positive influence on perception of the environment (Carles et al. 1999), whereas noise from vehicles on a highway may be perceived negatively. In Carles et al.'s 1999 study, sounds were perceived negatively when they clashed with aspirations for a given site, such as tranquility. We considered the conspicuousness of the impact of movement and noise to be consistent with the amount present (that is, little movement or noise was inconspicuous, obvious movement or noise was conspicuous).

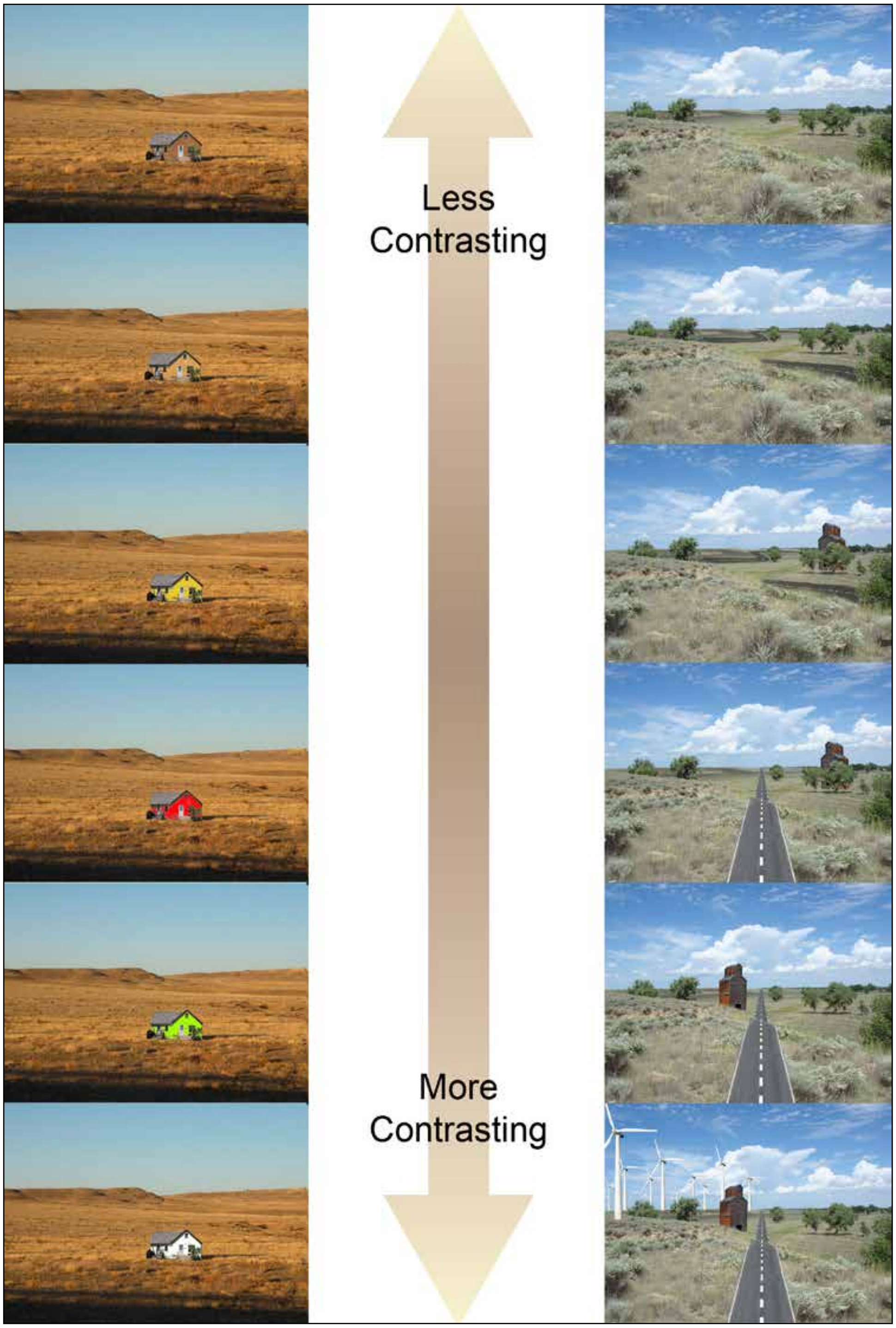


Figure 4.1.2-4. Graphic illustration of how color (left) and shape (right) can influence whether features are in harmony with the environment, or are in contrast.

Hierarchical Relationship among Conspicuousness Measures

The above-described characteristics do not act independently with respect to their influence on the conspicuousness of features; rather, they tend to have a hierarchical effect. For example, the color and shape of a house would not be important to the integrity of the park's viewshed if the house was located too far away from the key observation point. Thus, distance becomes the primary characteristic that affects the potential conspicuousness. Therefore, we considered potential influences on conspicuousness in the context of a hierarchy based on the distance characteristics having the most impact on the integrity of the viewshed, followed by the size characteristic, then both the color and shape, and movement and noise characteristic (Figure 4.1.2-5).

Extent of Development

The extent of development provides a measure of the degree to which the viewshed is altered from its natural (reference) state, particularly the extent to which intrusive or disruptive elements such as structures and roads may diminish the "naturalness" of the view (USFS 1995, Johnson et al. 2008).

We assessed the extent of development using Geographic Information System (GIS) analysis. The analysis provides a spatial and quantitative assessment of the housing and road developments within the monument's Area of Analysis (AOA), which we identified as a 97 km (60 mi) area surrounding the monument.

Viewshed Analysis

Viewshed analyses were conducted to evaluate areas that were visible and non-visible from a given observation point using ArcGIS Spatial Analyst Viewshed tool. USGS' National Elevation Datasets (NED) at 1/3 arc-second resolution (approximately 10 m / 32.8 ft resolution) (USGS 2016a) were used to create the viewshed AOA from each of the five key observation points; these AOAs were subsequently combined to create composite viewsheds based on all five points. Composite viewsheds are a way to show multiple viewsheds as one, providing an overview of the visible/non-visible areas across all observation points used as the input. The analysis assumed that the viewsheds were not hindered by non-topographic features such as vegetation; the observer was at ground level viewing from a height of 1.68 m (5.5 ft), which is the average height of a human; and visibility did not decay due to poor air quality. Additional details are listed in Appendix C. The composite viewshed was overlaid with the housing density and road density output to determine the areas with houses or roads most likely to be visible from the monument.

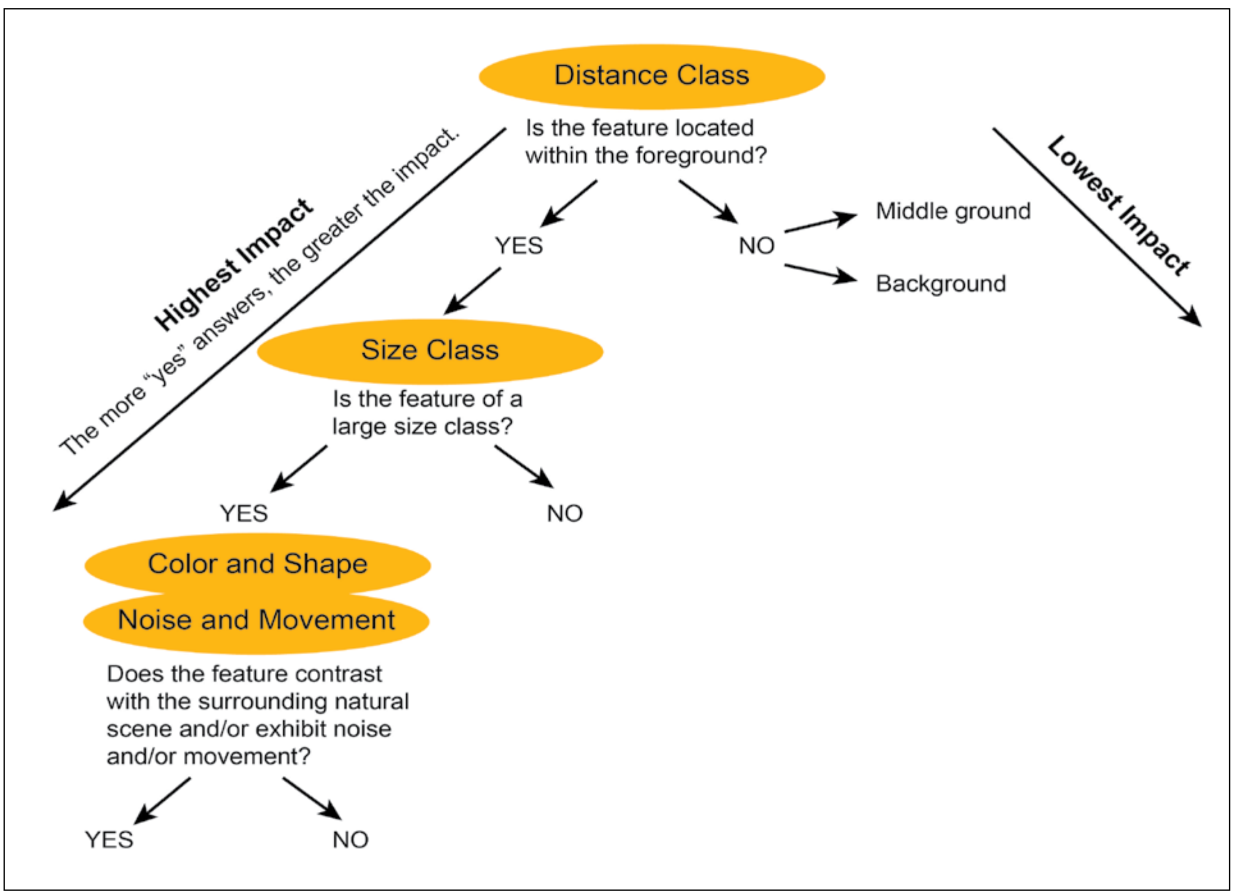


Figure 4.1.2-5. Conceptual framework for hierarchical relationship of characteristics that influence the conspicuousness of features within a viewshed.

NPScape Data
NPScape is a landscape dynamics monitoring program that produces and delivers GIS data, maps, and statistics that are integral to understanding natural resource conservation and conditions within a landscape context (NPS 2016c, Monahan et al. 2012). NPScape data include seven major categories (measures), two of which will be used in the viewshed condition assessment: housing and roads. These metrics were used to evaluate resource conditions from a landscape-scale perspective.

NPScape data are consistent, standardized, and collected in a repeatable fashion over time, and yet are flexible enough to provide analyses at many spatial and temporal scales. Data are further described in the sections that follow.

Housing Density
The NPScape 2010 housing density metrics are derived from Theobald's (2005) Spatially Explicit Regional Growth Model, SERGoM 100 m (328 ft) resolution housing density rasters. SERGoM forecasts changes on a decadal basis using county specific population estimates and variable growth rates that are location-specific. The SERGoM housing densities are grouped into six classes as shown in Table 4.1.2-4. NPScape's housing density standard operating procedure (NPS 2014a) and toolset were used to clip the raster to the monument's AOA then to recalculate the housing densities.

Road Density
ESRI's North America Detailed Streets road features (2014) were used to calculate the road density within the monument's AOA. The Feature Class Code values in the dataset are used to identify road types. According to NPScape's road density standard operating procedure (NPS 2014b), "highways are defined as interstates (FCC: A10-A19) or major roads (FCC: A20-A38, excluding ferry routes). All roads include all road features from the source data regardless of FCC value (excluding ferry routes). New road density rasters, feature classes, and statistics were generated from these data.

4.1.3. Reference Conditions
We used qualitative reference conditions to assess the scenic and historic integrity of Wupatki NM's viewshed, which are as presented in Table 4.1.3-1. Measures are described for resources in good condition, warranting moderate concern or significant concern.

Table 4.1.2-4. Housing density classes.

Grouped Housing Density Class	Housing Density Class (units / km^2)
Urban-Regional Park	Urban-Regional Park
Commercial / Industrial	Commercial / Industrial
Urban	>2,470
	1,235 - 2,470
Suburban	495 - 1,235
	146 - 495
Exurban	50 - 145
	25 - 49
	13 - 24
	7 - 12
Rural	4 - 6
	1.5 - 3
	<1.5
	Private undeveloped

4.1.4. Condition and Trend
Conspicuousness of Non-contributing Features
GigaPan images were collected from the five key observation locations in August 2016. The stitched images are shown in Figures 4.1.4-1, -2, -3, -4, and -5. From the Citadel Pueblo vantage point, the paved road is visible in the foreground and middle ground looking north, east, and west, but this non-contributing feature was generally not conspicuous since the road corridor follows the contours of the landscape and is relatively narrow (Figure 4.1.4-1). When vehicles are present, the road may be more conspicuousness as a result of movement and noise. The only other non-contributing feature was an interpretive sign visible in the eastern viewshed, although the sign is designed to blend well with the landscape in terms of color and size. Furthermore, the sign was installed to provide context for the visitor when viewing the pueblo and surrounding landscape. Overall, the viewshed is good from this vantage point. Native grasslands interspersed with one-seed juniper (*Juniperus monosperma*) dominate the viewshed. Citadel Sink, the largest in the monument, is also visible to the east and south and the San Francisco Peaks are visible in the background of the southeastern viewshed.

From the 545 Road observation location, the road is visible to the east and south, however, as with the

Table 4.1.3-1. Reference conditions used to assess viewshed.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Scenic and Historic Integrity	Conspicuousness of Non-contributing Features	The distance, size, color and shape, and movement and noise of the noncontributing features blend into the landscape.	The distance, size, color and shape, and movement and noise of some of the noncontributing features are conspicuous and detract from the natural and cultural aspects of the landscape.	The distance, size, color and shape, and movement and noise of the noncontributing features dominate the landscape and significantly detract from the natural and cultural aspects of the landscape.
	Extent of Development	Lack of or inconspicuous noncontributing features; road and housing densities are low.	Noncontributing features exist in some areas of the viewshed, with some conspicuousness; road and housing densities are moderate, with minor intrusion on the viewshed.	Noncontributing features intrude prominently on the landscape and are highly conspicuous; road and housing densities are high.

Citadel Pueblo location, the road follows the natural contour of the landscape and is not visible along its entire length (Figure 4.1.4-2). No other non-contributing features were visible at this location. In the foreground and middle ground, vegetation is characterized by native plant communities including Apache plume (*Fallugia paradoxa*) cinder shrubland, black grama (*Bouteloua eriopoda*) Coconino Plateau mixed shrubland, and oneseed juniper shrubland (Hansen et al. 2004). Since only one non-contributing feature was visible from this vantage point and this feature (road corridor) and it blends relatively well with the natural landscape, the viewshed from this vantage point is good.

The Wupatki Pueblo observation location was located immediately adjacent to the Visitor Center Complex Historic District (Figure 4.1.4-3, NPS 2007). The district is a combination of NPS Rustic style architecture constructed by the Civilian Conservation Corps and NPS Modern style architecture constructed as part of the Mission 66 program (NPS 2007). Several historic elements including buildings, walkways, and signs were visible in the panoramic images taken from Wupatki Pueblo and are therefore, considered contributing features. However, not all pathways are considered contributing features. In the eastern and western viewshed, non-contributing features include a walkway and garbage receptacle. These objects occur in the foreground and are highly visible; however, the colors and shapes used to construct these elements blend well with the natural landscape. The gravel and stonework used to construct the paths and steps are made of native stone from the Moenkopi formation and even the color of the handrail is consistent with the native stone's color. One gravel path resembles the color of natural cinder deposits visible in these photos. Wupatki Pueblo is visible in the northern viewshed and contributes to the observation point's historic integrity. Since the size, shape, and color of non-contributing features blend well with the existing landscape, the viewshed from this vantage point is good. As one moves from the south, to the west the viewshed is blocked by cinder hills in the foreground, but the viewshed increases as one pans north.

From the Wukoki Pueblo vantage point a parking area, road, and vault toilet building were the only non-contributing features visible in the panoramas, and these features were visible in the foreground of the southern viewshed, which made them somewhat conspicuous (Figure 4.1.4-4). The parking lot however, is located in a low lying area and is partially obscured by vegetation, which makes this feature less visible. A white truck parked in the lot reveals how the viewshed may be interrupted by these non-contributing features. The valut toilet is less visible than the parking area owing to its color, which blends well with the surrounding landscape, and the fact that this non-contributing is not sky-lined. Wukoki Pueblo, a contributing feature, is visible in the western viewshed, and the San Francisco Peaks are visible to the south. A mesa in the foreground to the north effectively blocks the viewshed beyond this landscape feature, and a mesa in the middle ground to the east also blocks the viewshed in this direction. The viewshed from this location is good.

From the Crack-in-Rock vantage point, few non-contributing features were present (Figure 4.1.4-5). In

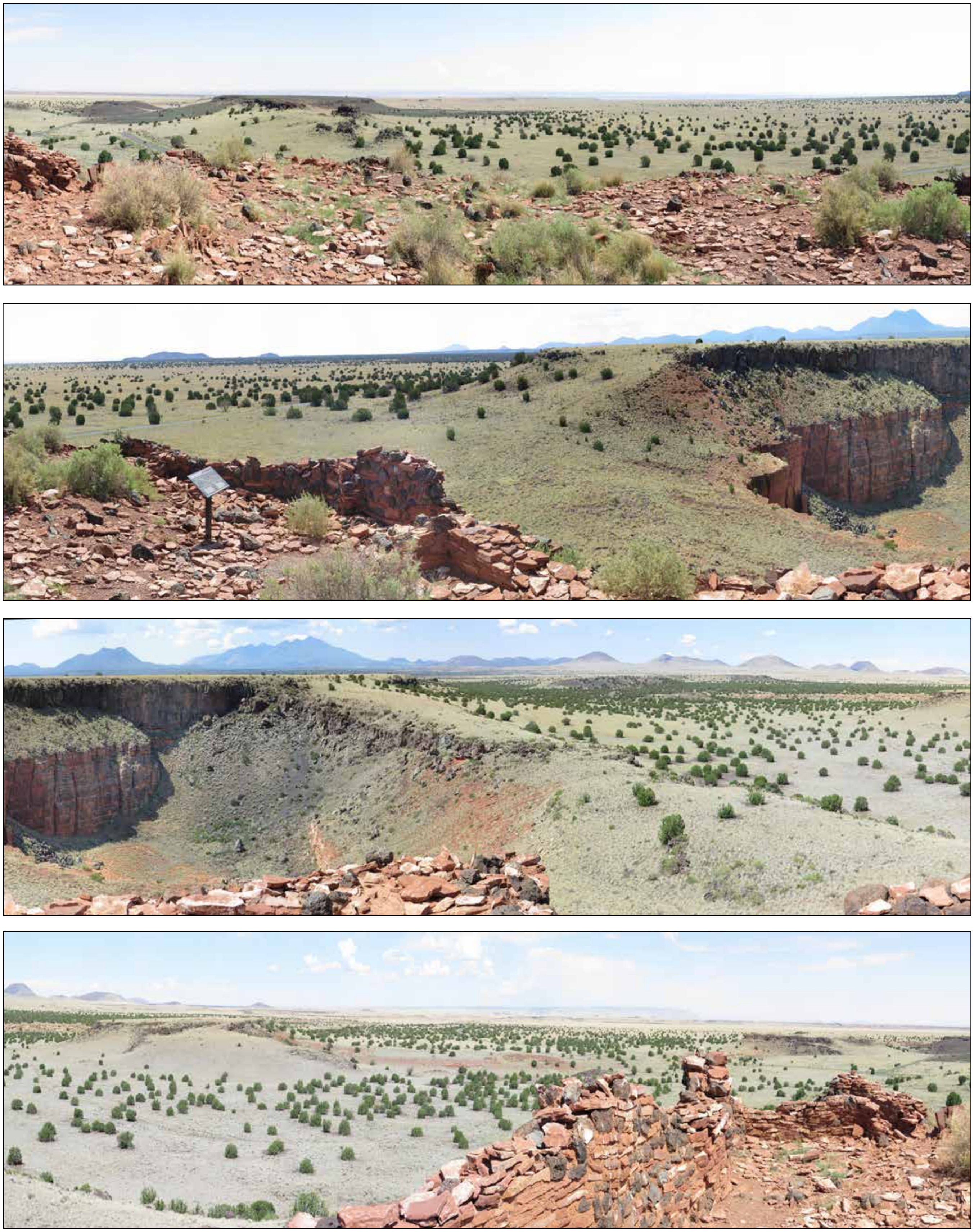


Figure 4.1.4-1. Panoramic views in each direction from the Citadel Pueblo key observation point in Wupatki NM (from top: north to east, east to south, south to west, and west to north).

Figure 4.1.4-2. Panoramic views in each direction from the 545 Road key observation point in Wupatki NM (from top: north to east, east to south, south to west, and west to north).

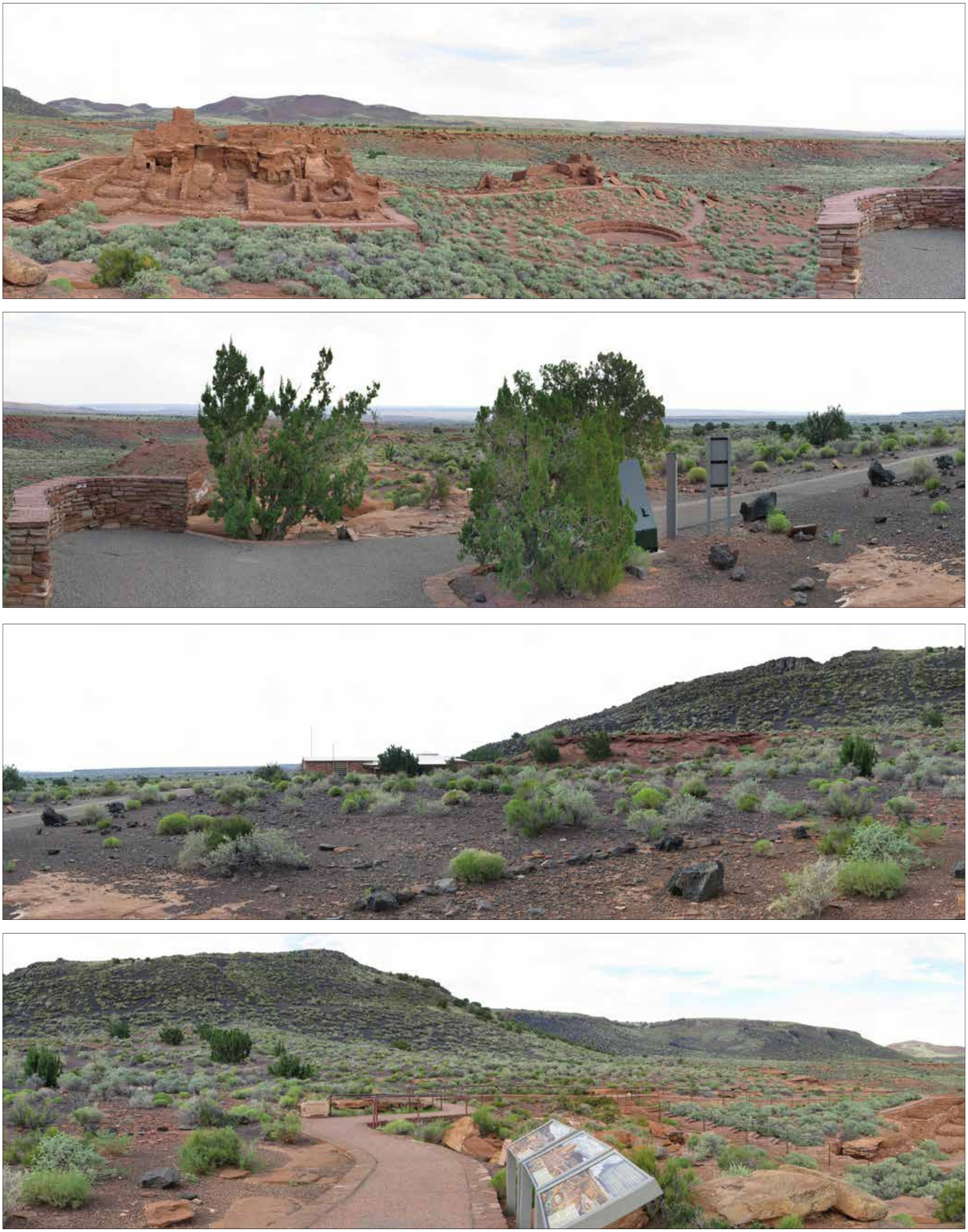


Figure 4.1.4-3. Panoramic views in each direction from the Wupatki Pueblo key observation point in Wupatki NM (from top: north to east, east to south, south to west, and west to north).

fact, only two vehicles parked next to the monument's boundary fence were visible in the northern viewshed, which looks toward the Navajo Reservation that borders the monument. Although the color of these objects (white and blue) can make them more conspicuous they were located in the middle ground and were small relative to the surrounding landscape features. The boundary fence is also a non-contributing feature, but blends in well with the landscape since it is made of wire and wooden or metal posts. The gate is the most conspicuous feature of the fence, but since it is located in the middle ground and it is small, it is not conspicuous. The road along which the vehicles were parked was completely inconspicuous. The road is unpaved and follows the contours of the landscape making it virtually invisible from this vantage point. Non-contributing features were not present in any of the remaining panoramas. The western viewshed was blocked by Crack-in-Rock Pueblo and the southern viewshed was blocked by a hill in the foreground. Looking north to east the viewshed extends over the Painted Desert until the Moenkopi Plateau. From east to south the viewshed was reduced by a hill in the foreground. Overall, the viewshed is good from this location.

The viewshed analyses were consistent with the panoramic images. Figure 4.1.4-6 shows the area and extent that should be visible from each key observation location. The analysis reveals that Citadel Pueblo had the largest viewshed and Wukoki Pueblo exhibited the smallest viewshed. For all five locations, the southern and western viewsheds were the most obscured while views to the north and east were generally good. Overall, few non-contributing features were present at the five observation locations. Native vegetation dominated these viewsheds along with historic pueblos and other historic structures, which contribute to the scenic and historic integrity of these locations. Therefore, we consider the condition for this measure to be good.

Extent of Development

The composite viewshed based on the five key observation locations is shown in blue in Figures 4.1.4-7 and 4.1.4-8. This analysis reveals that areas to the north and east of the monument are most visible, while areas to the south and west are the least visible. Based on data compiled in NPScape (Budde et al. 2009 and Monahan et al. 2012), housing densities surrounding the monument are low (Table 4.1.4-1). The majority (73.3%) of all housing consists of private undeveloped lands and densities less than 1.5 units/km^2 (20.4%). Furthermore, most of this rural development occurs outside of Wupatki NM's viewshed, which lies largely to the north and east of the monument (Figure 4.1.4-7). The viewshed analysis was calculated out to 97 km (60 mi) since this is the area most likely visible to the average observer (USFWS 1995). The white spaces within this boundary indicate no census data; thus, housing densities could not be calculated for these areas. However, these data originate with the U.S. Census Bureau and units with unknown densities were probably not reported, which likely indicates undeveloped areas. Total road density within the 97 km (60 mi) AOA surrounding the monument was 0.78 km/km^2. Figure 4.1.4-8 shows road density by various classes. Road density within the monument's viewshed is less dense than it is elsewhere in the AOA and is representative of a relatively rural landscape since there are few areas with a high density of roads.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Based on this assessment, the viewshed condition at Wupatki NM is good (Table 4.1.4-2). There were few non-contributing features in the monument's viewshed as observed from the five key observation locations, and those that were present blended relatively well with the natural landscape. The composite viewshed shown in blue in Figures 4.1.4-7 and -8 show that views to the south and west are blocked, but this was a result of natural features of the landscape. The housing and road density analyses show that the region surrounding the monument is mostly rural. This assessment represents baseline condition for Wupatki NM's viewshed; therefore, we could not report on trend. Both measures were assigned medium confidence. Factors that influence confidence level include age of the data (<5 yrs unless the data are part of a long-term monitoring effort), repeatability, field data vs. modeled data, and whether data can be extrapolated to other areas in the monument. We assigned medium confidence to the condition ratings because they were largely based on modeled data. Furthermore, the digital elevation model we used to determine visible areas from each vantage point was at 10 m (32.8 ft) resolution. Finer scale data would probably give a better indication of the areas visible. Lastly, we did not account for vegetation height in the viewshed analysis. However, this is probably not much of an issue for Wupatki NM since vegetation is sparse

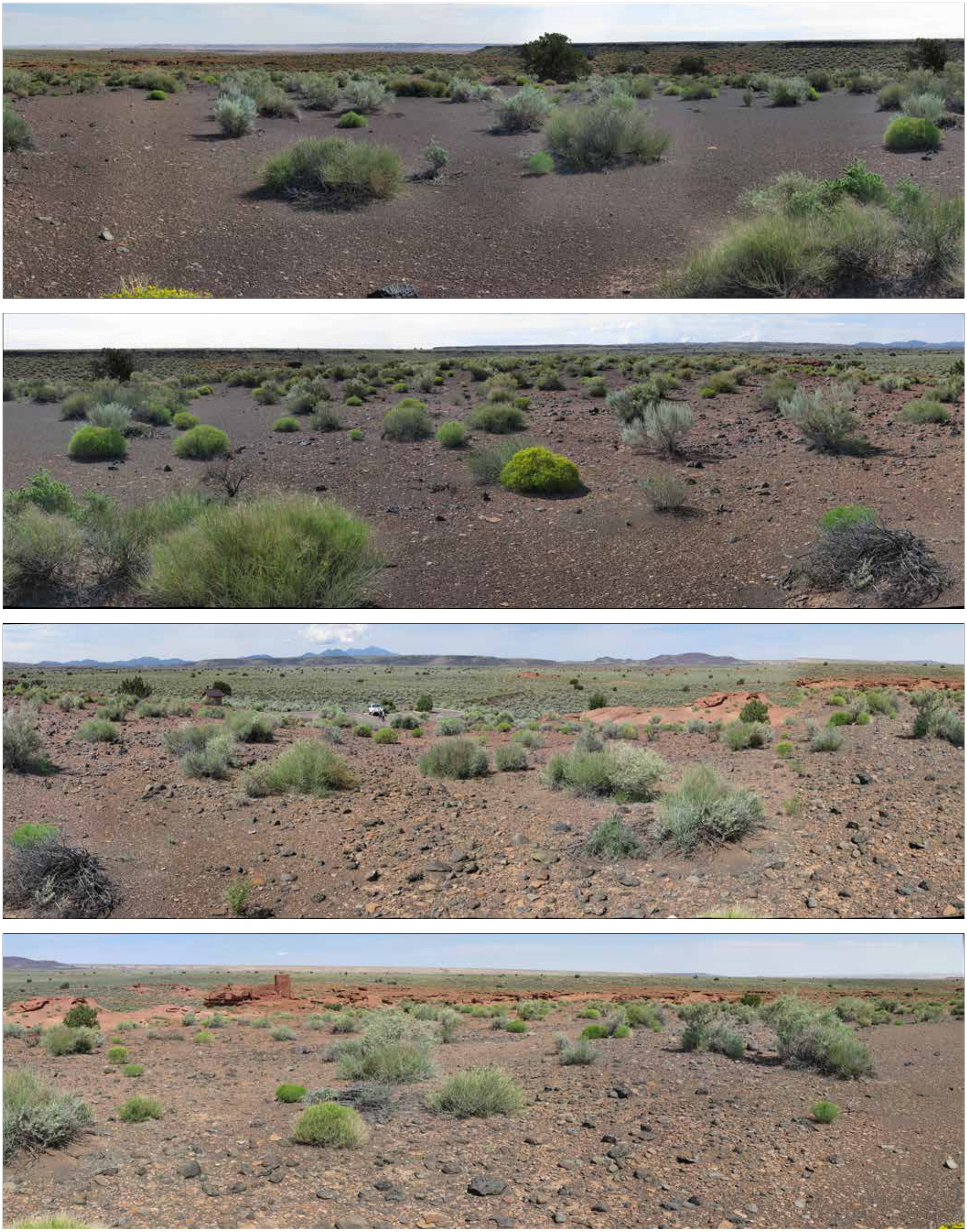


Figure 4.1.4-4. Panoramic views in each direction from the Wukoki Pueblo key observation point in Wupatki NM (from top: north to east, east to south, south to west, and west to north).

Figure 4.1.4-5. Panoramic views in each direction from the Crack-in-Rock Pueblo key observation point in Wupatki NM (from top: north to east, east to south, south to west, and west to north).

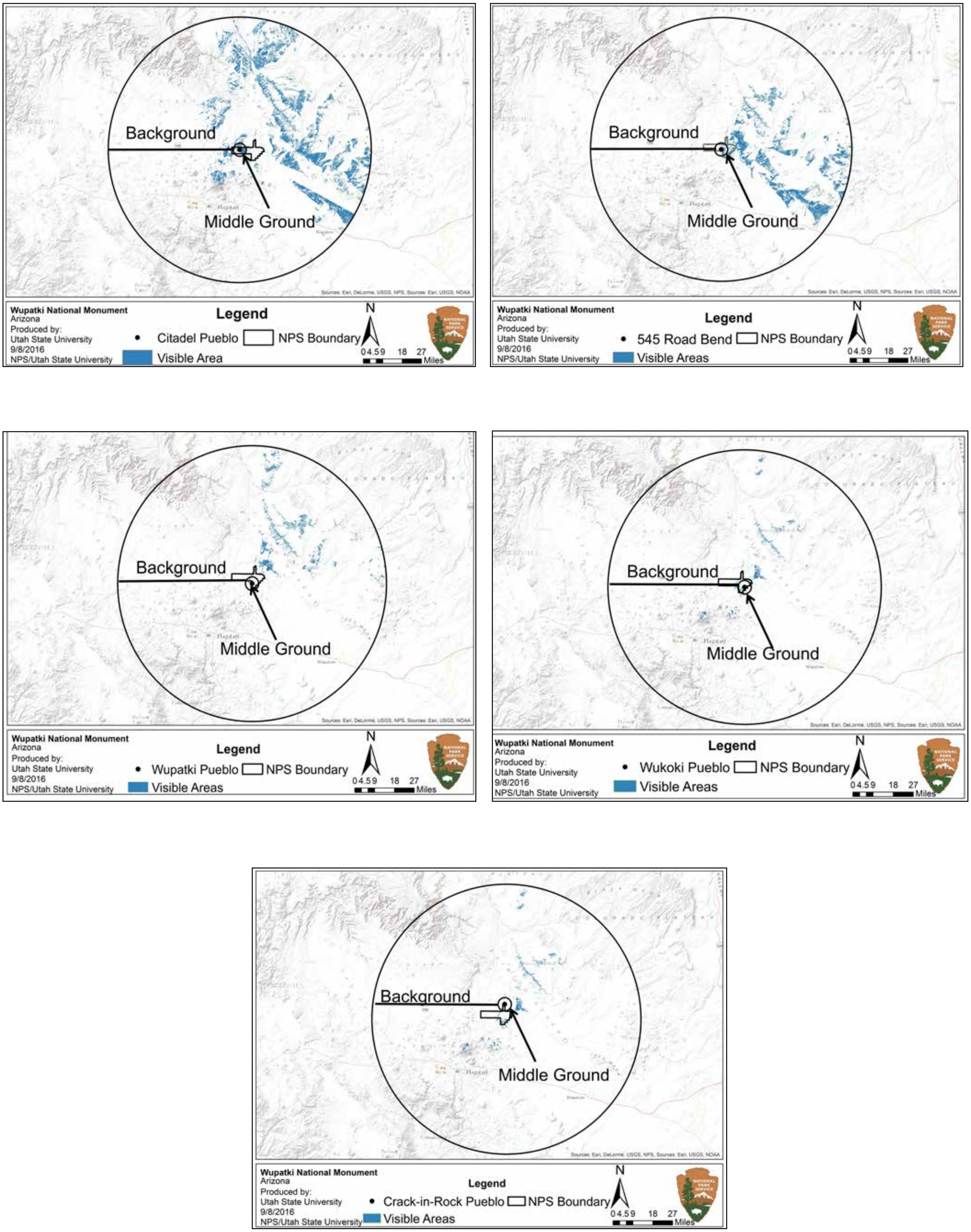


Figure 4.1.4-6. Visible areas from each of the five key observation locations in Wupatki NM.

Table 4.1.4-1. Housing densities within a 97 km (60 mi) buffer around Wupatki NM.

Density Class	Area (km^2)	Percent
Private Undeveloped	14843	73.3
< 1.5 units	4139	20.4
1.5 - 6 units	699	3.5
> 6 units	530	2.6
Commercial/Industrial	45	0.2
Urban-Regional Park	1	< 0.01
Total Area	20256	100

and generally short in stature (Hansen et al. 2004). The GigaPan images support the viewshed analysis. The consistency between the GigaPan images and the corresponding viewshed analysis displayed in Figure 4.1.4-6 is somewhat difficult to see and would be best viewed digitally (e.g., GIS) to determine the visibility of specific geographic features. When zooming in using GIS the landscape features that block the viewshed or allow for a broad viewshed are more obvious and can be easily compared with the GigaPan images. The viewshed analysis should not be used for planning purposes until groundtruthed.

Threats, Issues, and Data Gaps

Potential threats to Wupatki NM's viewshed include development within the AOA, increased visitation to the monument, and atmospheric dust and smog as a result of climate change. According to the housing density analysis however, development within the monument's viewshed is not expected to change substantially over the next 50 to 60 years. Even by 2100, the analysis showed only a slight increase in development. It is important to keep in mind, however, that this prediction based on past development and may not reflect actual future development. Road density is also relatively low, especially within the monument's viewshed. Roads are usually associated with development. Since development is predicted to remain stable, road density is also likely to remain stable.

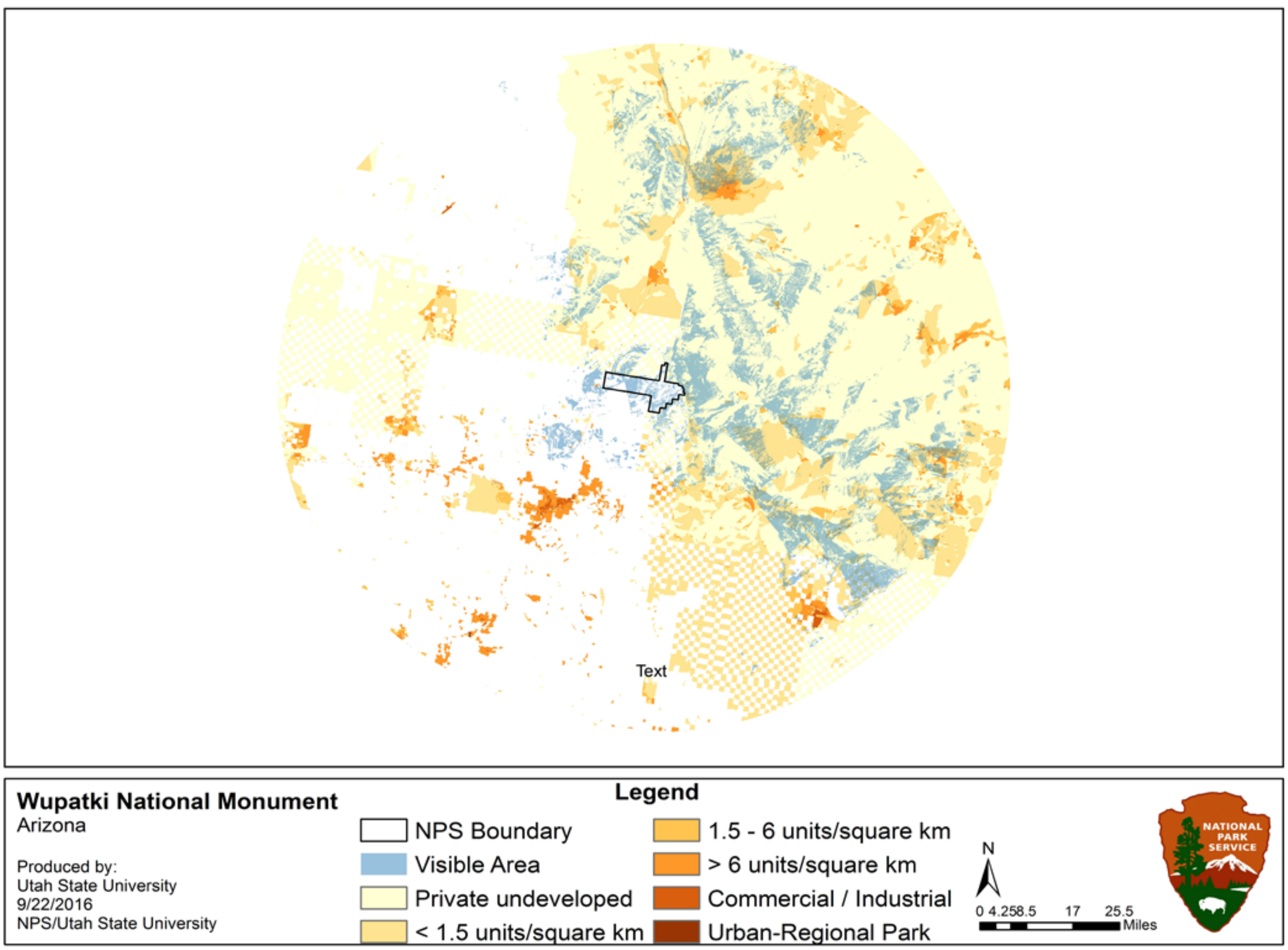


Figure 4.1.4-7. Housing density and visible areas in and around Wupatki NM.

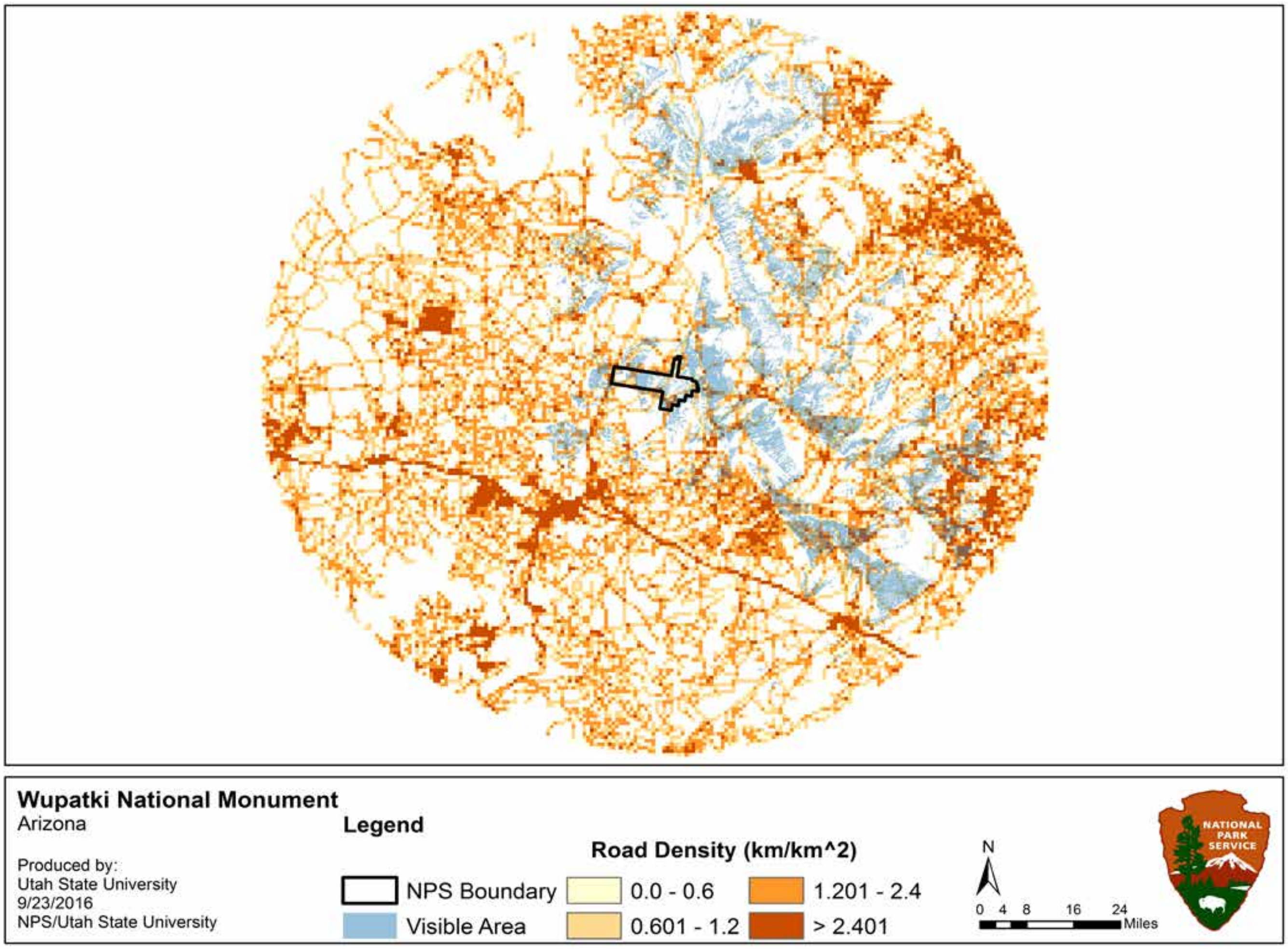


Figure 4.1.4-8. Road density and visible areas in and around Wupatki NM.

Table 4.1.4-2. Summary of viewshed indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Scenic and Historic Integrity	Conspicuousness of Non-contributing Features		Native vegetation dominated the viewshed along with historic pueblos and other historic structures, which contribute to the overall visitor experience in the monument. Therefore, we consider the condition for this measure to be good. There were no data available to determine trend for this measure. Confidence in this condition rating is medium.
	Extent of Development		The housing and road density analyses show that the region surrounding the monument is mostly rural. Therefore, we consider the condition for this measure to be good. There were no data available to determine trend for this measure. Confidence in this condition rating is medium.
Overall Condition			There were few non-contributing features in the monument's viewshed as observed from the five key observation locations, and those that were present blended relatively well with the natural landscape. Housing density indicates the region is mostly rural, and road density is low. There were no data available to determine overall trend. Instead, these data serve as a baseline for which to make future comparisons. Confidence in this condition rating is medium since the majority of data used were based on models.

Increased visitation could impact viewshed to some extent, but backcountry use is limited (NPS 1996) and thus, the majority of visitors are concentrated along road corridors, at pullouts, visitor centers, and interpretive exhibits rather than dispersed across the backcountry. Furthermore, visitation has declined slightly since the early to mid-1990s (NPS 2017). Finally, atmospheric dust and mineral aerosols have increased in the interior western U.S. by 500% over the late Holocene average (Neff et al. 2008). This increase is directly related to increased western settlement and livestock grazing during the 19th century (Neff et al. 2008). Atmospheric dust can impact viewshed quality (refer to the Air Quality assessment for more details). Overall however, there are few potential threats to Wupatki NM's viewshed and its current condition is considered good.

4.1.5. Sources of Expertise

Assessment author is Lisa Baril, wildlife biologist and science writer, Utah State University. No outside experts were consulted for this assessment.

4.2. Night Sky

4.2.1. Background and Importance

Natural dark skies are a valued resource within the NPS, reflected in NPS management policies (NPS 2006b), which highlight the importance of a natural photic environment to ecosystem function, and the importance of the natural lightscape for aesthetics. The NPS Natural Sounds and Night Skies Division (NSNSD) makes a distinction between a lightscape—which is the human perception of the nighttime scene, including both the night sky and the faintly illuminated terrain, and the photic environment—which is the totality of the pattern of light at night at all wavelengths (Moore et al. 2013).

Lightscapes are an aesthetic and experiential quality that is integral to natural and cultural resources. A 2007 visitor survey conducted throughout Utah national parks found that 86% of visitors thought the quality of park night skies was “somewhat important” or “very important” to their visit (NPS 2010a). Additionally, in an estimated 20 national parks, stargazing events are the most popular ranger-led program (NPS 2010a).

The value of night skies goes far beyond visitor experience and scenery (Figure 4.2.1-1). The photic environment affects a broad range of species, is integral to ecosystems, and is a natural physical process (Longcore and Rich 2004). Natural light intensity varies during the day-night (diurnal) cycle, the lunar cycle, and the seasonal cycle. Organisms have evolved to respond to these periodic changes in light levels in ways that control or influence movement, feeding, mating, emergence, seasonal breeding, migration, hibernation, and dormancy. Plants also respond to light levels by flowering, vegetative growth, and their direction of growth (Royal Commission on Environmental Pollution 2009). Given the effects of light on living organisms, it is likely that the introduction of artificial light into the natural light/darkness regime will disturb the normal routines of many plants and animals (Royal Commission on Environmental Pollution 2009), as well as diminish stargazing recreational opportunities offered to national park visitors.

Regular monitoring of the night sky was identified in Wupatki National Monument’s (NM) Foundation Document as fundamental to protecting the wilderness character of the park (NPS 2015a). Approximately 96% of Wupatki NM is eligible for wilderness designation and is managed as such (NPS 2015a). The park also protects more than 5,000 archaeological sites important to American Indian cultural traditions (NPS 2015a). Historically, American Indian’s observation of the sun, moon, and stars was essential for planning festivals and activities such as when to start planting and when to harvest (Aveni 2003). To highlight the area’s nocturnal landscape and night skies, Wupatki

Figure 4.2.1-1. Moon over Lomaki Peublo. Photo Credit: © Stan Honda.

NM regularly hosts interpretive star gazing events and night walks. Protecting the night sky resources at Wupatki NM benefits the natural resources, is important to protecting the wilderness character of the monument, enriches the visitor experience, and has cultural significance.

In 2016, Wupatki NM was designated an International Dark Sky Park by the International Dark Sky Association (IDA), a non-profit organization dedicated to preserving dark night skies around the world (IDA 2016). Wupatki NM was designated along with Sunset Crater Volcano and Walnut Canyon National Monuments since all three monuments are managed jointly by the National Park Service as one unit. Thus the Dark Sky Park designation was applied to all three simultaneously (IDA 2016).

Wupatki NM lies 46.6 km (29 miles) northeast of the city of Flagstaff, Arizona, which in 2001, was designated as the world's first International Dark Sky Community owing to its progressive outdoor lighting policy enacted in 1958— the world's first outdoor lighting ordinance (IDA 2016). The city is also home to Lowell Observatory and the U.S. Naval Observatory Flagstaff Station, both of which research astronomical phenomena.

4.2.2. Data and Methods

The NPS NSNSD goals of measuring night sky brightness are to describe the quality of the lightscape, quantify how much it deviates from natural conditions, and how it changes with time due to changes in natural conditions, as well as artificial lighting in areas within and outside of the national parks (Duriscoe et al. 2007). In this assessment, we characterize the night sky environment in Walnut Canyon NM using four measures that quantify sky brightness and one measure that describes overall sky quality. The quantitative measures are all-sky light pollution ratio, vertical maximum illuminance, horizontal illuminance, and zenith sky brightness. These measures, which are described in detail below, provide information on various aspects of the observed photic environment and proportion of light pollution attributed to anthropogenic sources. We also include the Bortle Dark Sky Scale, which is a measure of sky quality as perceived by a human observer trained to determine the visibility of various celestial bodies and night sky features. Together, these five measures were used to assess the condition of this important park resource (Table 4.2.2-1).

NSNSD scientists conducted an assessment of Wupatki NM's night sky condition at Wukoki Pueblo on May 12, 2002, June 11, 2004, and March 14, 2012 (Figure 4.2.2-1). Data collected during the assessment were used to support the IDA application.

Ground-based measurements were collected approximately one hour after moonset. A CCD camera was used to assess the ALR, zenith sky brightness, maximum vertical illuminance, and horizontal illuminance. The Bortle Dark Sky Scale, which is commonly used by amateur astronomers to assess the night sky for star gazing, was used to evaluate night sky quality. In addition to these field-based data, ALR was also modeled using satellite imagery from October 2015.

<u>All-sky Light Pollution Ratio</u>

The all-sky light pollution ratio (ALR) is the average anthropogenic sky luminance presented as a ratio over natural conditions. It is a useful metric to average the light flux over the entire sky (measuring all that is above the horizon and omitting the terrain). Recent

Table 4.2.2-1. Indicators and measures of the night sky and why they are important to resource condition.

Indicator	Measure	Description
Sky Brightness	All-sky Light Pollution Ratio, Vertical Maximum and Horizontal Illuminances, and Zenith Sky Brightness	The all-sky light pollution ratio describes light due to man-made sources compared to light from a natural dark sky. Vector measures of illuminance (horizontal and vertical) are important in describing the appearance of objects on the landscape and their relative visibility. The zenith is generally considered the darkest part of pristine skies. Understanding the lightscape and sources of light is helpful to managers to maintain dark skies for the benefit of wildlife and people alike.
Sky Quality	Bortle Dark Sky Scale	The Bortle Dark Sky Scale classification system describes the quality of the dark night sky by the celestial bodies and night sky features an observer can see. Observing the stars has been an enjoyable human pastime for centuries.

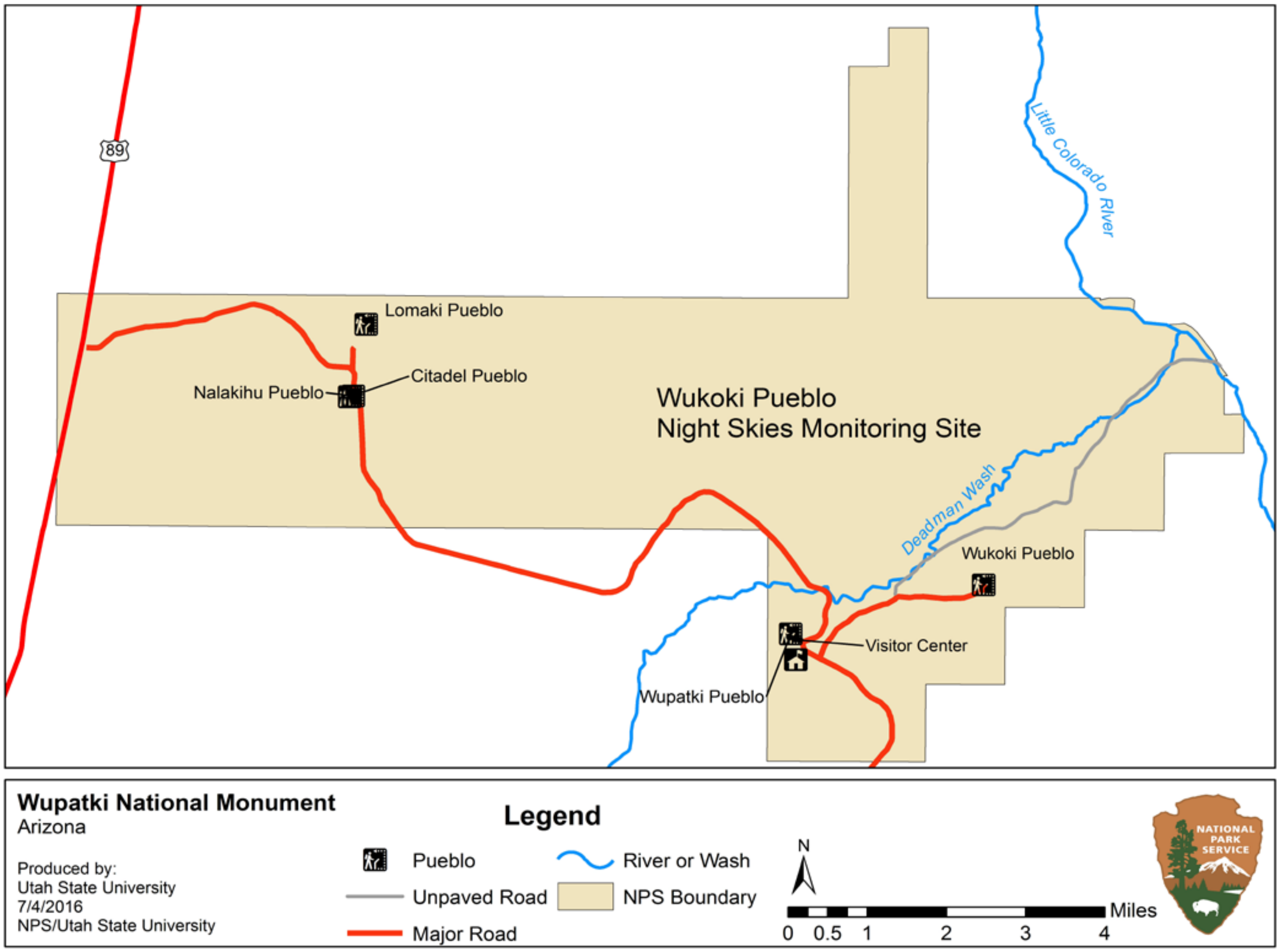


Figure 4.2.2-1. Location of the Wukoki Pueblo night sky monitoring site in Wupatki NM.

advances in modeling the natural components of the night sky allow separation of anthropogenic light from natural features, such as the Milky Way. This metric is a convenient and robust measure. It is most accurately obtained from ground-based measurements with the NPS Night Skies Program's photometric system, however, it can also be modeled with moderate confidence when such measurements are not available.

ALR was modeled for the entire monument, which included 90% of the wilderness eligible area within the monument. Data were modeled for 90% of wilderness areas because the NPS Night Skies Program recommends that the thresholds for lands managed as wilderness be met in more than 90% of the wilderness area (Moore et al. 2013). Modeled ALR data were based on 2015 National Aeronautics and Space Administration (NASA) Day/Night Band data collected by the Visible Infrared Imaging Radiometer Suite instrument located on the Suomi National Polar Orbiting Partnership satellite (NASA 2016). While modeled data provide useful overall measurements, especially when site visits cannot be made, they are less accurate than ground-based measurements.

A natural night sky has an average brightness across the entire sky of 78 nL (nanolamberts, a measure of luminance), and includes features such as the Milky Way, Zodiacal light, airglow, and other starlight. This is figured into the ratio, so that an ALR reading of 0.0 would indicate pristine natural conditions where the anthropogenic component was 0 nL. A ratio of 1.0 would indicate that anthropogenic light was 100% as bright as the natural light from the night sky.

Maximum Vertical and Horizontal Illuminances

The maximum sky brightness is typically found in the core of urban light domes (i.e., the semicircular-shaped light along the horizon caused by the scattering of urban light). The minimum sky brightness is typically found at or near the zenith (i.e., straight overhead). The integrated night sky brightness is calculated from both the entire celestial hemisphere as well as a measure of the integrated brightness masked at the apparent horizon to avoid site-to-site variations introduced by terrain and vegetation blocking. Vector measures of illuminance (horizontal and vertical) are important in describing the appearance of three-dimensional objects on the landscape and their relative visibility.

Vertical illuminance is the integration of all light striking a vertical plane from the point of the observer. In light-polluted areas, maximum sky brightness and maximum vertical illuminance will often measure the same area of sky, typically at the core of urban light domes. Vertical illuminance is an important metric when discussing night sky quality as it is easily noticeable to park visitors (since humans are oriented vertically). Even with dark conditions overhead, high vertical illuminance can hinder or inhibit dark adaptation of the eyes and cast visible shadows on the landscape. This is also an important ecological indicator, as many wildlife species base behavior on visual cues along the horizon. Horizontal illuminance is the amount of light striking a horizontal surface and is an important indicator of sky brightness (Cinzano and Falchi 2014). It is less sensitive in slightly impacted areas. This is because, even though the entire sky is considered, there is a rapid falloff in response to photons near the horizon, owing to Lambert's cosine law. At sites remote from cities, most of the anthropogenic sky glow occurs near the horizon.

For these two measures of illuminance we report the observed (artificial + natural) maximum vertical and horizontal illuminance. We also report the corresponding light pollution ratio (LPR) (i.e., proportion of light attributed to anthropogenic sources) (Duriscoe 2016).The light pollution ratio is useful since it is unit-less, allowing for comparison between measures (Duriscoe 2016). The LPR is also a more intuitive approach to understanding the contribution of artificial light sources for a particular area.

Zenith Sky Brightness

Sky brightness describes the amount of light observed in the night sky. This measure was calculated from the median pixel value of an approximately one degree diameter circle centered on the zenith and was collected using the CCD camera (NPS 2016a). As with maximum vertical and horizontal illuminance, we report the observed zenith sky brightness in addition to its corresponding LPR.

Bortle Dark Sky Scale

The sky quality indicator includes the Bortle Dark Sky Scale, which was proposed by John Bortle (Bortle 2001) based on 50 years of astronomical observations. Bortle's qualitative approach uses a nine-class scale that requires a basic knowledge of the night sky and no special equipment (Bortle 2001, Moore 2001, White et al. 2012, Table 4.2.2-2). The Bortle scale uses both stellar objects and familiar descriptors to distinguish among the different classes. Another advantage of the Bortle scale is that it is suitable for conditions ranging from the darkest skies to the brightest urban areas (Moore 2001, Figure 4.2.2-2).

4.2.3. Reference Conditions

Table 4.2.3-1 summarizes the condition thresholds for measures in good condition, those warranting moderate concern, and those warranting significant concern. The ideal night sky reference condition, regardless of how it's measured, is one devoid of any light pollution. However, results from night sky data collection throughout more than 90 national parks suggest that a pristine night sky is very rare (NPS 2010a).

Of Wupatki NM's 14,266 ha (35,253 acres), 13,838 ha (34,194 acres), or 96%, are eligible for wilderness designation (NPS 2015a). Wupatki NM is considered a non-urban NPS unit, or area with at least 90% of its property located outside an urban area (Moore et al. 2013). For non-urban NPS units and those containing wilderness areas, the thresholds separating reference conditions of good condition, moderate concern, and significant concern are more stringent than those for urban NPS units because these areas are generally more sensitive to the effects of light pollution.

Anthropogenic Light Ratio (ALR)

The threshold for night skies in good condition is an ALR <0.33 and the threshold for warranting moderate concern is ALR 0.33-2.00. An ALR >2.00 would warrant significant concern (Moore et al. 2013).

Maximum Vertical Illuminance

Although no thresholds for maximum vertical illuminance have been set at this time, the NPS Night Skies Division recommends a reference condition of

Table 4.2.2-2. Bortle Dark Sky Scale.

Bortle Scale	Milky Way (MW)	Astronomical Objects	Zodiacal Constellations	Airglow and Clouds	Nighttime Scene
Class 1 Excellent Dark Sky Site	MW shows great detail, and appears 40° wide in some parts; Scorpio-Sagittarius region casts an obvious shadow	Spiral galaxies (M33 and M81) are obvious objects; the Helix nebula is visible with the naked eye	Zodiacal light is striking as a complete band, and can stretch across entire sky	The horizon is completely free of light domes, very low airglow	Jupiter and Venus annoy night vision, ground objects are barely lit, trees and hills are dark
Class 2 Typical Dark Site	MW shows great detail and cast barely visible shadows	The rift in Cygnus star cloud is visible; the Prancing Horse in Sagittarius and Fingers of Ophiuchus dark nebulae are visible, extending to Antares	Zodiacal band and gegenschein are visible	Very few light domes are visible, with none above 5° and fainter than the MW; airglow may be weakly apparent, and clouds still appear as dark voids	Ground is mostly dark, but object projecting into the sky are discernible
Class 3 Rural Sky	MW still appears complex; dark voids and bright patches and a meandering outline are visible	Brightest globular clusters are distinct, pinwheel galaxy visible with averted vision	Zodiacal light is easily seen, but band of gegenschein is difficult to see or absent	Airglow is not visible, and clouds are faintly illuminated except at zenith	Some light domes evident along horizon, ground objects are vaguely apparent
Class 4 Rural-Suburban Transition	MW is evident from horizon to horizon, but fine details are lost	Pinwheel galaxy is a difficult object to see; deep sky objects such as M13 globular cluster, Northern Coalsack dark nebula, and Andromeda galaxy are visible	Zodiacal light is evident, but extends less than 45° after dusk	Clouds are just brighter than the sky, but appear dark at zenith	Light domes are evident in several directions (up to 15° above the horizon), sky is noticeably brighter than terrain
Class 5 Suburban Sky	MW is faintly present, but may have gaps	The oval of Andromeda galaxy is detectable, as is the glow in the Orion nebula, Great rift in Cygnus	Only hints of zodiacal light may be glimpsed	Clouds are noticeably brighter than sky	Light domes are obvious to casual observers, ground objects are easily seen
Class 6 Bright Suburban Sky	MW only apparent overhead, and appears broken as fainter parts are lost to sky glow	Cygnus, Scutum, and Sagittarius star fields just visible	Zodiacal light is not visible; constellations are seen, and not lost against a starry sky	Clouds appear illuminated and reflect light	Sky from horizon to 35° glows with grayish color, ground is well lit
Class 7 Suburban-Urban Transition	MW may be just barely seen near the zenith	Andromeda galaxy (M31) and Beehive cluster (M44) are rarely glimpsed	Zodiacal light is not visible, and brighter constellations are easily seen	Clouds are brilliantly lit	Entire sky background appears washed out, with a grayish or yellowish color
Class 8 City Sky	MW not visible	Pleiades are easily seen, but few other objects are visible	Zodiacal light not visible, constellations are visible but lack key stars	Clouds are brilliantly lit	Entire sky background has uniform washed out glow, with light domes reaching 60° above the horizon
Class 9 Inner City Sky	MW not visible	Only the Pleiades are visible to all but the most experienced observers	Only the brightest constellations are discernible	Clouds are brilliantly lit	Entire sky background has a bright glow, ground is illuminated

Source: White et al. (2012).

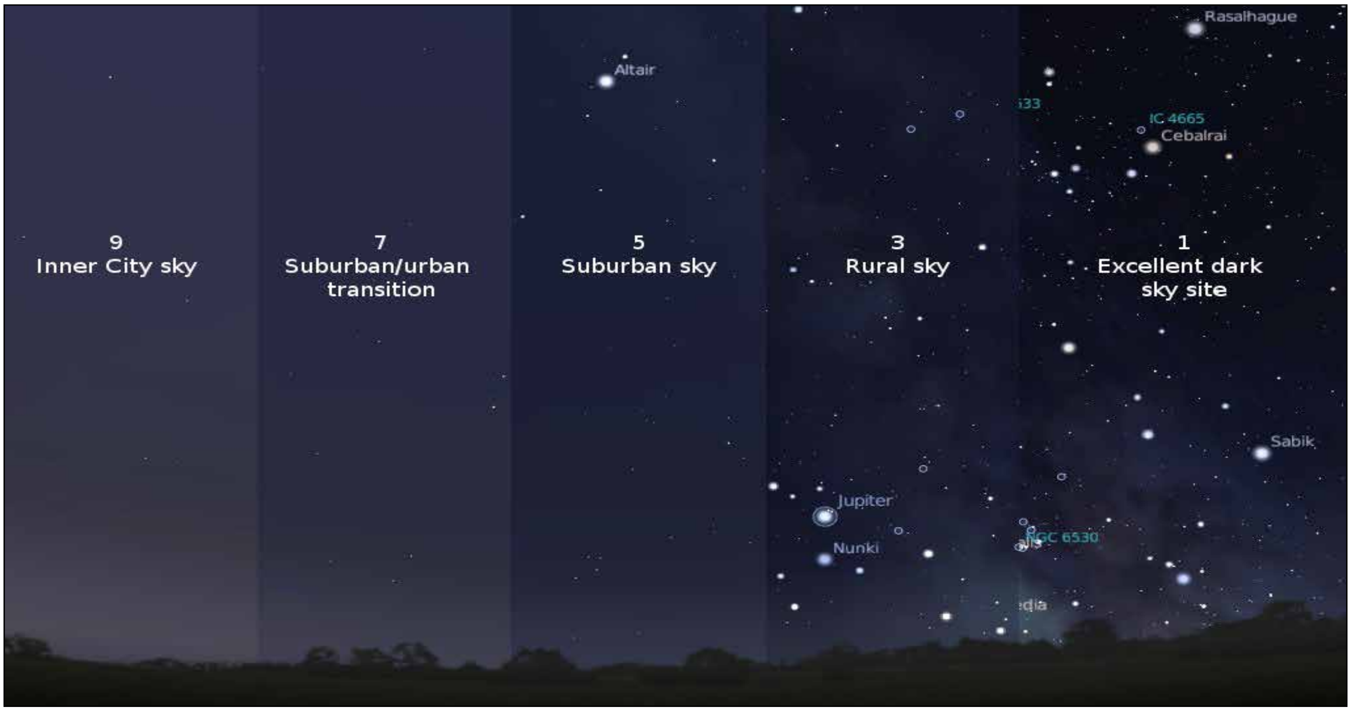


Figure 4.2.2-2. A graphic representation of the Bortle Dark Sky Scale (Bortle 2001). Figure Credit: NPS Natural Sounds and Night Skies Division.

0.4 milli-Lux, since the average vertical illuminance experienced under the natural night sky on a moonless night is 0.4 milli-Lux (derived from Jensen et al. 2006, Garstang 1986, and unpublished NPS Night Skies Program data). Vertical illuminance can also be expressed as a ratio to natural conditions, similar to ALR.

Horizontal Illuminance

As with maximum vertical illuminance, no thresholds for horizontal illuminance have been set at this time. The NPS Night Skies Division recommends a reference condition of 0.8 milli-Lux, since the average horizontal illuminance experienced under the natural night sky on a moonless night is 0.8 milli-Lux (Duriscoe 2016). Horizontal illuminance can also be expressed as a ratio to natural conditions, similar to ALR.

Zenith Sky Brightness

Reference conditions for night sky brightness can vary moderately based on the time of night (time after sunset), time of the month (phase of the moon), time

Table 4.2.3-1. Reference conditions used to assess the night sky.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Sky Brightness	All-sky Light Pollution Ratio (ALR)*	ALR <0.33 (<26 nL average anthropogenic light in sky)	ALR 0.33-2.00 (26-156 nL average anthropogenic light in sky)	ALR >2.00 (>156 nL average anthropogenic light in sky)
	Maximum Vertical Illuminance	Thresholds have not been developed. A recommended reference is 0.4 milli-Lux.	Thresholds have not been developed. A recommended reference is 0.4 milli-Lux.	Thresholds have not been developed. A recommended reference is 0.4 milli-Lux.
	Horizontal Brightness	Thresholds have not been developed. A recommended reference is 0.8 milli-Lux.	Thresholds have not been developed. A recommended reference is 0.8 milli-Lux.	Thresholds have not been developed. A recommended reference is 0.8 milli-Lux.
	Zenith Sky Brightness (msa)*	≥21.60	21.20-21.59	<21.20
Sky Quality	Bortle Dark Sky Scale Class*	1-3	4	5-9

*National Park Service Natural Sounds and Night Skies thresholds for non-urban parks. Non-urban parks are those with at least 90% of their land located outside an urban area (Moore et al. 2013).

of the year (the position of the Milky Way), and the activity of the sun, which can increase "airglow"—a kind of faint aurora. For the minimum night sky brightness measure, the darkest part of a natural night sky is generally found near the zenith. A value of 22.0 magnitudes per square arc second (msa) is considered to represent a pristine sky, though it may vary naturally by more than +0.2 to -0.5 depending on natural conditions (Duriscoe 2013). Lower (brighter) values indicate increased light pollution and a departure from natural conditions. The astronomical magnitude scale is logarithmic, so a change of 2.50 magnitudes corresponds to a difference of l0x (100%); thus a 19.5 msa sky would be 10x brighter than natural conditions. Minimum night sky brightness values of 21.4 to 22.0 msa, are generally considered to represent natural (unpolluted) conditions (Duriscoe et al. 2007).

Bortle Dark Sky Scale

A night sky with a Bortle Dark Sky Scale class 1 is considered in the best possible condition (Bortle 2001); unfortunately, a sky that dark is so rare that few observers have ever witnessed it (Moore 2001). Non-urban park skies with a Bortle class 3 or darker are considered to be in good condition, class 4 warrants moderate concern, and class 5 warrants significant concern. At class 4 and higher, many night-sky features are obscured from view due to artificial lights (either within or outside the park). Skies class 7 and higher have a significantly degraded aesthetic quality that may introduce ecological disruption (Moore et al. 2013).

4.2.4. Condition and Trend

All-sky Light Pollution Ratio

Modeling data by the NPS Night Skies Program shows a median ALR of 0.11 for the entire park (Table 4.2.4-1). This is 11% brighter than average natural conditions. ALR for 90% of the park's eligible wilderness area was 0.13, or 13% brighter than average natural conditions. Modeled median park-wide ALR and ALR for 90% of the wilderness area of the national monument was well below 0.33, the threshold characterizing good condition. Figure 4.2.4-1 shows the modeled ALR for the region surrounding Wupatki NM and the extent of light domes cast by cities located in the region. The light domes from Flagstaff, Arizona located 46.6 km (29 miles) to the south and Phoenix, Arizona located approximately 228.4 km (142 miles) to the south of the monument are faintly visible from Wupatki NM, however, these light domes extend only 10 degrees above the horizon. Other towns including Winslow, Arizona and Tuba City, Arizona are also faintly visible, but do not interfere with the quality of Wupatki's dark night sky.

The modeled ALR results were supported by ground-based measurements, which indicate good condition during all three monitoring dates (Table 4.2.4-1). Figures 4.2.4-2, -3, and -4 show the natural and anthropogenic light sources on the three monitoring dates. These data images are shown in false color with yellow, red, and white corresponding to brighter sky and blue, purple, and black corresponding to darker sky. Since all ALR measurements, modeled and ground-based, were below 0.33, we consider this measure of sky brightness to be in good condition.

Maximum Vertical Illuminance (milli-Lux)

At Wukoki Pueblo maximum vertical illuminance ranged from 0.46 to 0.72 milli-Lux. The LPR ranged between 14% and 23% brighter than average natural conditions. This exceeds the NSNSD recommendation of 0.4 milli-Lux, however, since there are no thresholds for good condition, moderate concern, or significant concern, we did not assign a condition for this measure.

Table 4.2.4-1. Night sky measurements collected at Wukoki Pueblo in Wupatki NM.

Date	All-sky Light Pollution Ratio	Observed Maximum Vertical Illuminance (milli-Lux)	Horizontal Illuminance (milli-Lux)	Zenith Sky Brightness (msa)	Bortle Class
10/2015*	0.11 (0.13)	–	–	–	–
5/12/2002	0.07	0.72	1.11	21.72	3
6/11/2004	0.07	0.46	0.70	22.10	–
3/04/2012	0.10	0.51	0.76	21.92	2

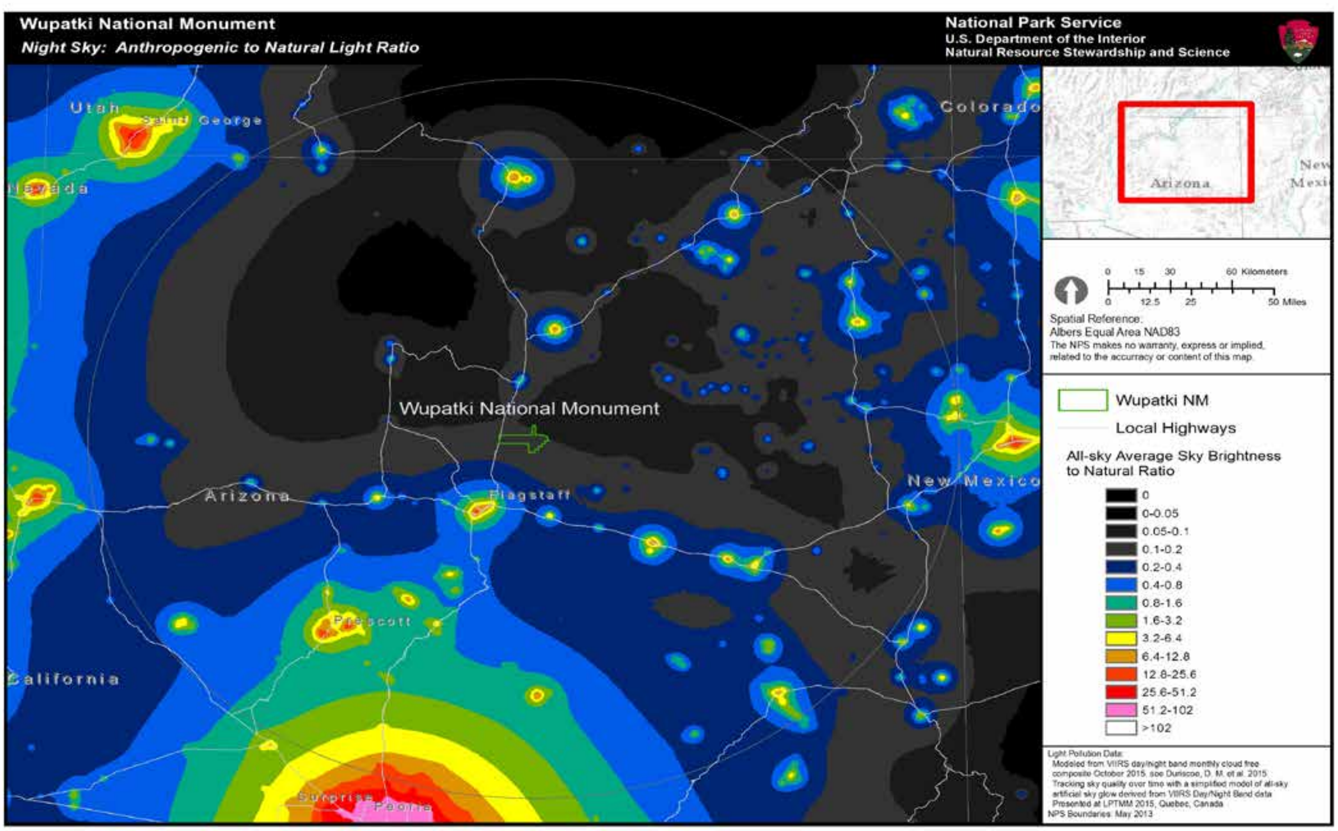
* Modeled median ALR data park-wide and for 90% of the wilderness area. The latter measure is shown in parentheses.

Horizontal Illuminance (milli-Lux)
Horizontal illuminance ranged from 0.70 to 1.11 milli-Lux. The LPR ranged from 2% to 5% brighter than average natural conditions. The NSNSD recommends a threshold of 0.8 milli-Lux, which was exceeded during two of the three monitoring dates. However, since there are no thresholds for good condition, moderate concern, or significant concern, we did not assign a condition for this measure.

Zenith Sky Brightness (msa)
Zenith sky brightness varied from 21.72 to 22.10 msa and all were above the threshold of 21.60 msa, which indicates good condition for this measure. The corresponding ALR measurements for zenith sky brightness were less than 0.10 on all three monitoring dates, which is less than 10% brighter than average natural conditions.

Bortle Dark Sky Scale
NSNSD observers estimated the night sky quality to class 3 on May 12, 2002 and class 2 on March 14, 2012. Bortle Class 2 corresponds with a typical dark site while Class 3 corresponds to a rural sky. The difference in class designation between the two dates does not necessarily reflect an improvement in night sky quality. Rather, the difference is likely due to variability in natural airglow, which can influence the Bortle class designation. Furthermore, the Bortle scale is somewhat subjective depending on the observer. Regardless, the designation for both dates indicates this measure of sky quality is in good condition.

Overall Condition, Trend, Confidence Level, and Key Uncertainties
Overall, we consider the night sky at Wupatki NM be in good condition with an unknown trend and high overall confidence level in the condition rating. For a summary of indicators, measures, and their condition see Table 4.2.4-2. The overall condition rating and confidence level were based on the three measures for which condition thresholds have been developed. These measures were all-sky light pollution ratio, zenith sky brightness, and the Bortle Dark Sky Scale.



Created by NPS Natural Sounds & Night Skies Division and NPS Inventory and Monitoring Program MAS Group on 20160705

Figure 4.2.4-1. Modeled ALR map for Wupatki NM. A 200 km ring around the park illustrates the distance at which anthropogenic light can impact night sky quality within the monument. Figure Credit: NPS Natural Sounds and Night Skies Division.

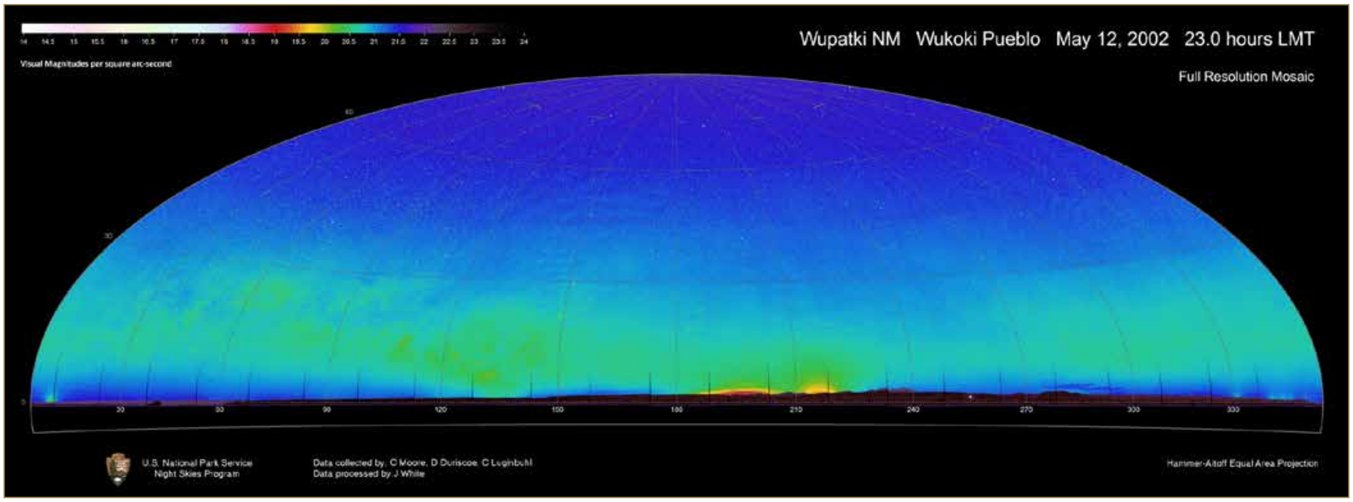


Figure 4.2.4-2. Panoramic all-sky mosaic of all light sources on May 12, 2002 in Wupatki NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.

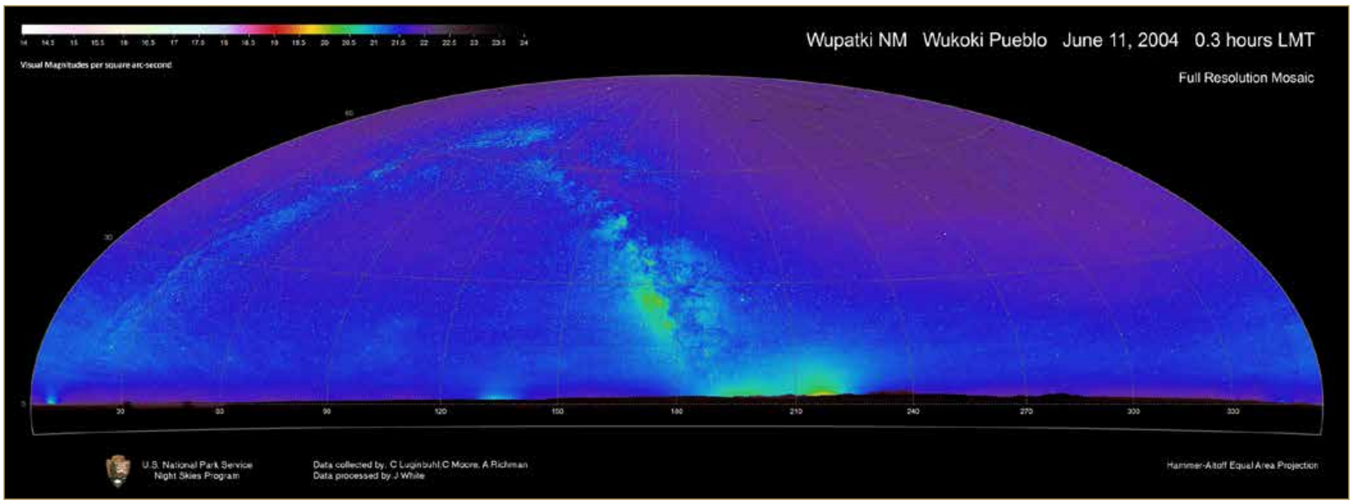


Figure 4.2.4-3. Panoramic all-sky mosaic of all light sources on June 11, 2004 in Wupatki NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.

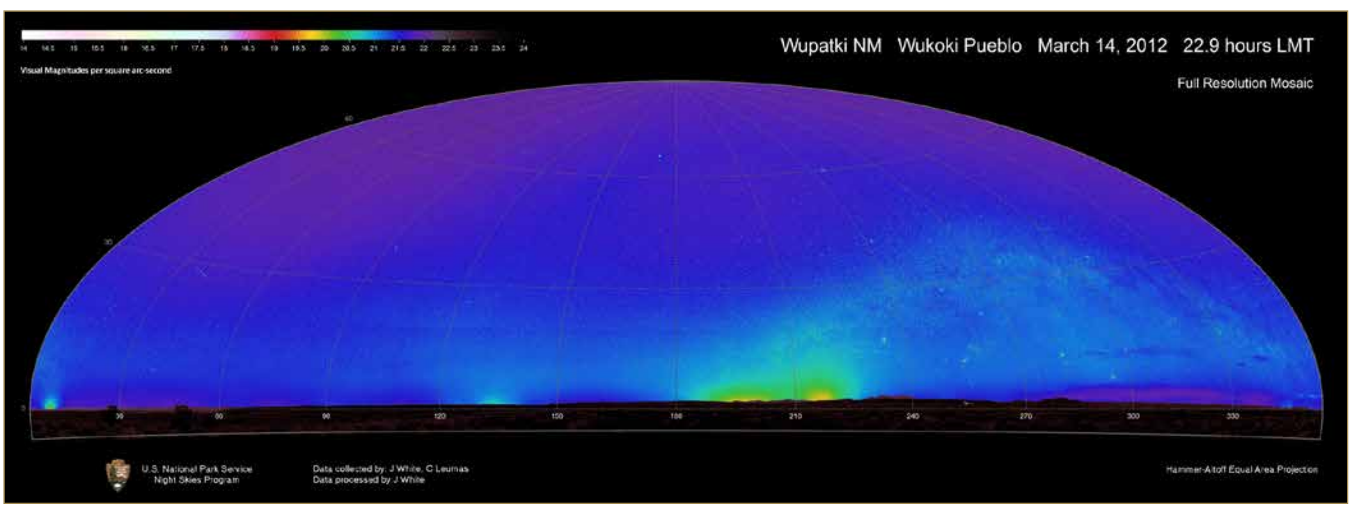


Figure 4.2.4-4. Panoramic all-sky mosaic of all light sources on March 14, 2012 in Wupatki NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.

Table 4.2.4-2. Summary of night sky indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Sky Brightness	All-sky Light Pollution Ratio (ALR)		Ground-based ALR data and modeled ALR data for the national monument indicate this measure is in good condition since all measurements were below 0.33. However, data were collected on only three nights, therefore, we could not determine trend. Confidence in this condition rating is high since it was based on three ground-based measurements and a modeled estimate, which were similar.
	Vertical Maximum Illuminance (milli-Lux)		The condition for this measure is indeterminate since condition class thresholds have not been developed by the NSNSD; however, measurements exceeded the recommended threshold of 0.4 milli-Lux. There were insufficient data to determine trend since measurements were collected on only three nights. Confidence in this condition rating is low due to lack of reference values.
	Horizontal Illuminance (milli-Lux)		The condition for this measure is indeterminate since condition class thresholds have not been developed by the NSNSD; however, two of the monitoring dates exceeded the recommended threshold of 0.8 milli-Lux. There were insufficient data to determine trend since measurements were collected on only three nights. Confidence in this condition rating is low due to lack of reference values.
	Zenith Sky Brightness (SQM)		Zenith sky brightness varied from 21.72 to 22.10 msa, and all three measurements were above the threshold of 21.60 msa, which indicates good condition for this measure. There were insufficient data to determine trend since measurements were collected on only three nights. Confidence in this condition rating is high since it was based on three ground-based measurements.
Sky Quality	Bortle Dark Sky Scale		NSNSD observers estimated the night sky quality to class 3 on May 12, 2002 and class 2 on March 14, 2012. Bortle class 2 corresponds with a typical dark site while class 3 corresponds to a rural sky. Both ratings were within the range for good condition. Trend could not be determined based on these two measurements. Since several factors influence Bortle classification, including observer variability and airglow, confidence in this condition rating is medium.
Overall Condition			Wupatki NM nocturnal landscape is considered to be in good condition. All measures for which thresholds have been developed were at or below the threshold for good condition. Although field data were collected over a 11-year period (2002-2012), there were only three data points. Therefore, trend could not be determined. Confidence in these data is high.

Those measures for which confidence in the condition rating was high were weighted more heavily in the overall condition rating than measures with medium confidence. Factors that influence confidence level include age of the data (<5 yrs unless the data are part of a long-term monitoring effort), repeatability, field data vs. modeled data, and whether data can be extrapolated to other areas in the monument. Two of the three measures were given a high confidence level since the majority of data were collected in the field with field data acquired as recently as 2012. Although there is some uncertainty with the modeled ALR data, the results were consistent with ground-based measurements. The Bortle Dark Sky Scale, which is based on qualitative observations of the night sky, is somewhat subjective and was therefore, assigned medium confidence. Although data spans an 11-year period, data collection occurred on only three nights, which is insufficient to determine trend. However, over time, and in conjunction with other measurements, these data will provide a robust dataset with which to monitor and assess the night sky environment at Wupatki NM.

<u>Regional and Local Context</u>

Wupatki NM preserves a dark night sky rarely found in other regions, an attribute acknowledged by its designation as an International Dark Sky Park in 2016. Criteria for this designation are stringent and require a plan to preserve dark night skies (IDA 2016). To this end, monument staff are committed to long-term monitoring of night skies in addition to continuing outreach and education programs highlighting the monument's nocturnal landscape (NPS 2016a). In 2016, NPS staff purchased three basic Unihedron Sky Quality Meter devices to be shared among the three monuments and has created a data collection form to support long-term sky quality monitoring (NPS 2016a).

Although the city of Flagstaff, Arizona (population 65,870) is located only 46.6 km (29 miles) south of the monument, its light dome is only faintly visible and does not significantly interfere with the monument's dark sky environment (NPS 2016a). The city of Flagstaff, Arizona is a leader in preserving dark night skies and was the first community to receive the Dark Sky designation by the IDA in 2001 (IDA 2016). Lowell Observatory located within the city limits provides numerous educational opportunities for the local community to participate in star gazing events and learn about the importance of dark night skies for aesthetics, wildlife, human health, and as a cultural resource. Although the population of Flagstaff, AZ is expected to grow, city lighting ordinances will limit light pollution in the area, thereby contributing to the preservation of dark night skies in Wupatki NM.

Threats, Issues, and Data Gaps

Although Flagstaff, Arizona and Wupatki NM have implemented plans to preserve dark night skies, light pollution from the city and surrounding area, including Alpine Ranchos (a private development adjacent to the monument), may have unwanted effects on the monument's nocturnal landscape. Arizona is the fourth fastest growing state in the U.S. (NPS 2016a, U.S. Census Bureau 2016a). Continued growth of urban centers such as Phoenix, Arizona (population 1,445,632) may degrade Wupatki NM's dark night sky despite being 228 km (142 mi) away (NPS 2016a).

Effects of Artificial Lighting on Wildlife

Studies show that artificial lighting reduces nocturnal foraging by rodents, modifies patterns of communication among coyotes, stimulates nocturnal activity in birds that are normally diurnal, disorients insects and birds that migrate at night, and alters patterns of pollination by nocturnal moths (Longcore and Rich 2004). Despite these studies, the effects of artificial lighting are not well understood for most species. Wupatki NM protects a prime example of northern Arizona's desert ecosystem that includes important habitat for many nocturnal species (NPS 2015a). Given the good condition of Wupatki NM's night sky environment, the region has the potential to protect species that depend on the nocturnal landscape.

4.2.5. Sources of Expertise

The NPS Natural Sounds and Night Skies Division (NSNSD) scientists help parks manage the night sky in a way that balances the various expectations of park visitors with the protection of park resources. They provide technical assistance to parks in the form of monitoring, data collection and analysis, and in developing baselines for planning and reporting purposes. For more information, see http://nps.gov/nsnsd. Jeremy White, Natural Sounds and Night Skies Division, part of the NPS Natural Resource Stewardship and Science Directorate, provided information pertaining to night sky data collection methodology and interpretation of results. Assessment author is Lisa Baril, science writer, Utah State University.

4.3. Soundscape

4.3.1. Background and Importance

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

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) (Figure 4.3.1-1). Despite this desire for quiet environments, noise continues to intrude upon natural areas and has become a source of concern in national parks (Lynch et al. 2011).

A park's natural soundscape is an inherent component of "the scenery and the natural and historic objects and the wildlife" protected by the Organic Act of 1916. NPS Management Policies (§ 4.9) (2006b) require preservation of parks' natural soundscapes and restoration of degraded soundscapes to natural conditions wherever possible. Additionally, NPS is required to prevent or minimize degradation of natural soundscapes from noise (i.e., any unwanted sound). Although the management policies currently refer to the term soundscape as the aggregate of all natural sounds that occur in a park, differences exist between the physical sound sources and human perceptions of those sound sources. Physical sound resources (e.g., wildlife, waterfalls, wind, rain, and cultural or historical sounds), regardless of their audibility, at a particular location, are referred to as the acoustical environment, while the human perception of that acoustical environment is defined as the soundscape. Clarifying this distinction will allow managers to create objectives for safeguarding both the acoustical environment and the visitor experience.

In addition, sound plays a critical role for wildlife communication. Activities such as courtship, predation, predator avoidance, and effective use of habitat rely on the ability to hear with studies showing that wildlife can be adversely affected by intrusive sounds. While the severity of impacts vary depending on the species and other conditions, documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, separation of mothers and young, and interference with communication (Selye 1956, Clough 1982, USFS 1992, Anderssen et al. 1993, NPS 1994, Dooling

Figure 4.3.1-1. Wupatki NM's wilderness setting provides solitude for park visitors. Photo Credit: NPS.

and Popper 2007, Kaseloo 2006). Researchers have also documented wildlife avoidance behaviors due to increased noise levels (Shannon et al. 2015, McLaughlin and Kunc 2013). An interesting recent publication showed that even plant communities can be adversely affected by noise because key dispersal species avoid certain areas (Francis et al. 2012).

Wupatki National Monument (NM) provides an increasingly rare opportunity for visitors to experience a natural soundscape. The monument's proximity to Flagstaff, Arizona provides a unique opportunity for park staff to engage visitors in appreciating and preserving the monument's natural soundscape through interpretive programs and guided hikes, including an overnight wilderness experience to Crack-in-the-Rock, a remote area of the monument. Furthermore, the monument's pueblos provide visitors opportunities to contemplate previous cultures and experience a soundscape similar to the past. Approximately 96% of Wupatki NM is eligible for wilderness designation, and preservation of the natural soundscape is important to maintaining its wilderness character (NPS 2015).

Sound Characteristics

Humans and wildlife perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air. Sound is measured in terms of frequency (pitch) and amplitude (loudness) (Templeton and Sacre 1997, Harris 1998).

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

The amplitude (or loudness) of a sound, measured in decibels (dB), is logarithmic, which means that every 10 dB increase in sound pressure level (SPL) represents a tenfold increase in sound energy. This also means that small variations in SPL can have significant effects on the acoustical environment. For instance, a 6 dB reduction in background noise level would produce a 4x increase in listening area (Figure 4.3.1-2). Changes in background noise level cause changes in listening opportunity. These lost opportunities will approach a halving of alerting distance and a 75% reduction of listening area for each 6 dB increase in affected band level (Barber et al. 2010).

SPL is commonly summarized in terms of dBA (A-weighted SPL). This metric significantly discounts sounds below 1,000 Hz and above 6,000 Hz to approximate the variation in human hearing sensitivity.

4.3.2. Data and Methods

Baseline acoustical monitoring data for Wupatki NM were collected by park natural resource staff. The National Transportation Systems Center (Volpe Center) analyzed the data and produced the report, which was coordinated as part of a technical assistance request with the NPS Natural Sounds and Night Skies Division (NSNSD). The objectives were to characterize existing sound levels, establish a baseline for future monitoring, and estimate natural ambient sound levels in support of the potential development of an air tour management plan (NPS 2013a); however, the monument was exempted from producing an air tour management plan since fewer than 50 air tours are reported annually (FAA and NPS 2014).

Acoustical monitoring systems were deployed at two locations within the national monument during the months of July and August 2010: Wupatki West and Little Colorado River (Figure 4.3.2-1). Wupatki West

Figure 4.3.1-2. A 6 dB reduction in background noise level would produce a 4x increase in listening area. Figure Credit: © Ted E. Dunn.

was located approximately 3.2 km (2 miles) east of Highway 89. The Little Colorado River site was located near the Wukoki Pueblo, and approximately 4.2 km (2.6 miles) west of the Little Colorado River. Wupatki West was monitored 16 days while the Little Colorado River area was monitored 33 days. The characteristics of both monitoring locations are summarized in Table 4.3.2-1.

The sound level indicator includes two measures, percent time above reference sound levels and percent reduction in listening area.

% Reduction in Listening Area

The percent time above reference sound levels is a measure of the amount of time that the sound level exceeds specified decibel values (NPS 2013a). Research into the effects of noise on wildlife is rapidly developing, and observed responses to noise sources and sound levels have been found across a variety of species. In a literature review of the effects of noise on wildlife, Shannon et al. (2015) found that responses to noise can include "altered vocal behavior to mitigate masking, reduced abundance in noisy habitats, changes in vigilance and foraging behavior, and impacts on individual fitness and the structure of ecological communities." Of the organisms studied, wildlife responses were observed at noise levels as low as 40 dBA, and further, 20% of studies documented impacts below 50 dBA. Human responses to sound levels can serve as a proxy for potential impacts to other vertebrates because humans have more sensitive

Table 4.3.2-1. Location characteristics of acoustical monitoring sites at Wupatki NM.

Location	Dates Deployed	Vegetation	Elevation
Wupatki West	7/6/2010-7/19/2010 and 8/6/2010-8/7/2010	Shrubland	1,690 m (5,544 ft)
Little Colorado River	7/7/2010-8/8/2010	Shrubland	1,367 m (4,486 ft)

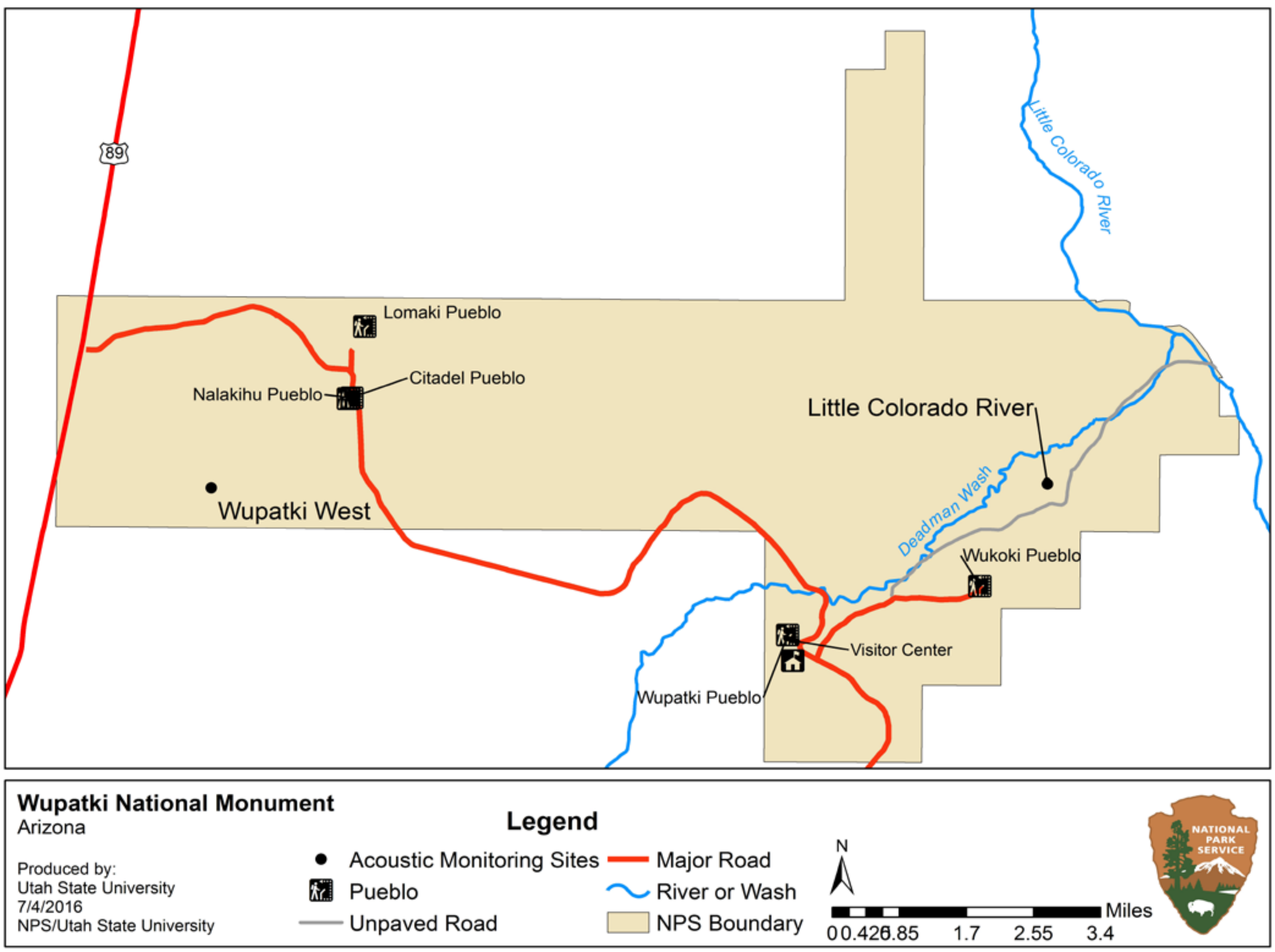


Figure 4.3.2-1. Locations of 2010 acoustical monitoring sites at Wupatki NM.

hearing at low frequencies than most species (Dooling and Popper 2007). Table 4.3.2-2 summarizes sound levels that relate to human health and speech, as documented in the scientific literature.

The first, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dBA can have adverse effects on blood pressure while sleeping (Haralabidis 2008). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third value, 52 dBA, is based on the United States Environmental Protection Agency's (U. S. EPA) speech interference threshold for speaking in a raised voice to an audience at 10 meters (32.8 feet) (USEPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter (3.3 feet). Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations. The NSNSD determined the percent of time sound levels were above these four decibel reference levels for both day (7:00 am to 7:00 pm) and night (7:00 pm to 7:00 am) (NPS 2013a).

<u>% Reduction in Listening Area</u>

A one decibel change is not readily perceivable by the human ear, but any addition to this difference could begin to impact listening ability. To assess the condition of the acoustic environment, it is useful to consider the functional effects that increases in sound level might produce. For instance, the listening area, the area in which a sound can be perceived by an organism, will be reduced when background sound levels increase. Seemingly small increases in sound level can have substantial effects, particularly when quantified in terms of loss of listening area as previously shown in Figure 4.3.1-2 (Barber et al. 2010). Each 3 dB increase in the background sound level will reduce a given listening area by half.

Failure to perceive a sound because other sounds are present is called masking. Masking interferes with wildlife communication, reproductive and territorial advertisement, and acoustic location of prey or predators (Barber et al. 2010). However, the effects of masking are not limited to wildlife. Masking also inhibits human communication and visitor detection of wildlife sounds. In urban settings, masking can prevent people from hearing important sounds like approaching people or vehicles, and interfere with the way visitors experience cultural sounds or interpretive programs.

To determine the effect noise from air tours and other aircraft has on the natural soundscape at the two monitoring stations we calculated percent reduction in listening area from the natural ambient sound level to each of three sound level categories: existing ambient, existing ambient without air tour noise, and existing ambient without all aircraft noise. Air tour noise is distinguished from other aircraft noise because low-level fixed wing/propeller aircraft present unique sound signatures that are indicative of air tour activity. However, it is possible that some portion of these events were categorized erroneously as air tours. These metrics were reported as the level of sound that exceeded fifty percent of the time at a given location, or L_{50} (NPS 2013a).

Natural ambient sound level refers to all naturally occurring sounds and excludes all anthropogenic noise. Existing ambient sound level includes all sounds in a given area, natural and anthropogenic. Existing ambient sound level without air tour noise includes all sounds, natural and anthropogenic, minus noise from air tours. Existing ambient sound level without all aircraft noise includes all sounds, natural and anthropogenic, minus noise from all aircraft, including air tours, commercial jets, military overflights, and any other aircraft. Existing ambient sounds levels were reported for both day (7:00 am to 7:00 pm) and night (7:00 pm to 7:00 am), while existing ambient sound

Table 4.3.2-2. Sound level values related to human health and speech.

Sound Levels (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al. 2008)
45	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund et al. 1999)
52	Speech interference for interpretive programs (USEPA 1974)
60	Speech interruption for normal conversation (USEPA 1974)

Source: NPS (2013).

levels without air tour noise and without all aircraft noise were reported for day only since this is when noise from aircraft is most likely to impact visitor enjoyment (NPS 2013a).

% Time Audible

The audibility of anthropogenic sounds is measured using percent time audible, which is the amount of time that various sound sources are audible to humans with normal hearing. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore, percent time audible is a protective proxy for wildlife. The NSNSD determined the percent time audible of sounds in each of four categories (three anthropogenic and one natural), as follows: fixed-wing aircraft and helicopters, other aircraft sounds, other human sounds, and natural sounds. Data were gathered via in-situ site visits and by audio recordings collected at each site and analyzed later.

L_{50} Impact

The geospatial model indicator estimated sound pressure levels for the continental United States by using actual acoustical measurements combined with a multitude of explanatory variables such as location, climate, landcover, hydrology, wind speed, and proximity to noise sources (e.g., roads, railroads, and airports). The 270-meter (886 feet) resolution model predicts daytime sound levels during midsummer. Each square of color maps generated from this effort represents 270 m^2 (2,960 ft^2), and each pixel on the map represents a median sound level (L_{50}). It should be noted that while the model excels at predicting acoustic conditions over large landscapes, it may not reflect recent localized changes such as new access roads or development.

Model parameters useful for assessing a park's acoustic environment include the understanding of a) natural conditions, b) existing acoustic conditions including both natural and human-caused sounds, and c) the impact of human-caused sound sources in relation to natural conditions. The L_{50} impact condition demonstrates the influence of human activities to the acoustic environment and is calculated by zeroing all anthropogenic factors in the model and recalculating ambient conditions. It is effectively the difference between existing and natural condition.

4.3.3. Reference Conditions

Table 4.3.3-1 summarizes the condition thresholds for measures in good condition, those warranting moderate concern, and those warranting significant concern.

% Time Above Reference Sound Levels

We used decibel levels presented in Table 4.3.2-2 as thresholds to separate the three reference conditions

Table 4.3.3-1. Reference conditions used to assess sound levels.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Sound Level	% Time Above Reference Sound Levels	The majority of sound levels recorded were <45 dBA.	The majority of sound levels recorded were between 45 - 52 dBA.	The majority of sound levels recorded were >52 dBA.
	% Reduction in Listening Area*	Listening area was reduced by ≤ 30% over natural ambient sound levels.	Listening area was reduced by 30-50% over natural ambient sound levels.	Listening area was reduced by >50% over natural ambient sound levels.
Audibility of Anthropogenic Sounds	% Time Audible	Dominant sounds are consistent with the wilderness character of the monument. Natural ambient sounds such as wind, birds singing, thunder claps, etc. dominate, but some sounds related to recreational activities, and/or traffic are also sometimes audible.	Dominant sounds are generally consistent with the park's wilderness character, but noise occurs more frequently and noise from the adjacent highways, etc., begins to infiltrate the area.	A high percentage of the audible sounds heard are from noises such that the natural and/or cultural sense of place is compromised; therefore, the enjoyment of visitors is compromised.
Geospatial Model	L_{50} Impact*	≤ 1.5	1.5 - ≤ 3.0	>3

*National Park Service Natural Sounds and Night Skies thresholds for non-urban parks. Non-urban parks are those with at least 90% of their land located outside an urban area (Turina et al. 2013).

displayed in Table 4.3.3-2 (USEPA 1974, Berglund et al. 1999, and Haralabidis et al. 2008). If sound levels were below the World Health Organization's recommended maximum noise level in bedrooms (45 dBA), then we considered the condition to be good. If sound levels were above that which is expected to cause speech interference for interpretive programs, we considered the condition to warrant significant concern.

<u>% Reduction in Listening Area</u>

Wupatki NM is considered a non-urban park, or park with at least 90% of their land located outside an urban area. Parks outside an urban area are usually quieter and more susceptible to noise intrusions (Turina et al. 2013). Visitors likely have a greater expectation for quiet at non-urban parks and wildlife are likely more adapted to a noise-free environment. Therefore, the thresholds separating reference conditions for non-urban parks are more stringent than for those located in urban areas. A reduction in listening area of 30% would indicate good condition, while a more than 50% reduction in listening area would warrant significant concern (Turina et al. 2013).

<u>% Time Audible</u>

We considered this measure to be in good condition if the dominant sounds at each site were natural. While some anthropogenic noise is expected, it generally does not interfere with the natural soundscape. In contrast, if the dominant sounds are from anthropogenic sources, then we consider this measure to warrant significant concern.

<u>L_{50} Impact (Mennitt et al. 2013)</u>

Reference conditions for this measure were developed by Turina et al. 2013 and are presented in Table 4.3.3-1. We used thresholds for non-urban parks, which are those with at least 90% of their land located outside an urban area (Turina et al. 2013).

4.3.4. Condition and Trend

<u>% Time Above Reference Sound Levels</u>

Figure 4.3.4-1 shows the percent time sound levels were above the reference sound levels at each monitoring location during day (7 a.m. - 7 p.m.) and night (7 p.m. - 7 a.m.) hours. Overall, sound levels were greater at Little Colorado River than at Wupatki West, and sound levels were lower at night than during the day at both sites; however, sound levels were relatively low regardless of location or time of day. Sound levels during the day exceeded 35 dBA only 2.07% of the time at Wupatki West and 14.9% of the time at Little Colorado River, the latter site representing the highest percent time above reference conditions. Sound levels rarely exceeded 45 dBA day or night, which is the World Health Organization's recommendation for maximum noise level in bedrooms; therefore, we considered this measure to be in good condition.

<u>% Reduction in Listening Area</u>

Existing Ambient L_{50} dBA

Table 4.3.4-1 summarizes ambient sound level data. L_{50} represents the level of sound exceeded 50% of the time during the given measurement period. Daytime existing ambient L_{50} values ranged between 24.5 dBA at Wupatki West to 21.2 dBA at Little Colorado River. At night existing ambient sound levels were lower and similar between both sites (20.2 dBA at Wupatki West and 20.0 dBA at Little Colorado River).

Daytime values exceeded the baseline condition (median L_{NAT}) by 6.8 dBA at Wupatki West and 4.3 dBA at Little Colorado River. This resulted in a reduction in listening area of 63% at Little Colorado River and 79% at Wupatki West. The reduction in listening area exceeds 50% in both locations, which warrants significant concern.

Existing Ambient L_{50} w/out Air Tour Noise

Existing ambient sound levels without air tour noise were lower than existing ambient values at both sites, but still greater than natural ambient values (Table 4.3.4-1). At Wupatki West this measure exceeded natural ambient conditions by 5 dBA and by 3.4 dBA at Little Colorado River. This resulted in a listening area reduction of 68% and 54% for Wupatki West and Little Colorado River, respectively. Even though some sound signatures may have been erroneously categorized as air tours, and while these types of overflights are not common at Wupatki NM, they do occur. Three air tour operators had interim operating authority during the monitoring period in 2010, and since 2013, 32 flights have been reported over the monument by only one of the operators (7 in 2013, 14 in 2014, and 11 in 2015 [NPS NSNSD Overflights Branch, pers. comm. 2016]). By eliminating the air tour events, the listening area increased by about 14% at Little Colorado River and Wupatki West over existing ambient conditions; however, the listening area was still reduced by more than 50% over natural ambient sound levels in both locations, which warrants significant concern.

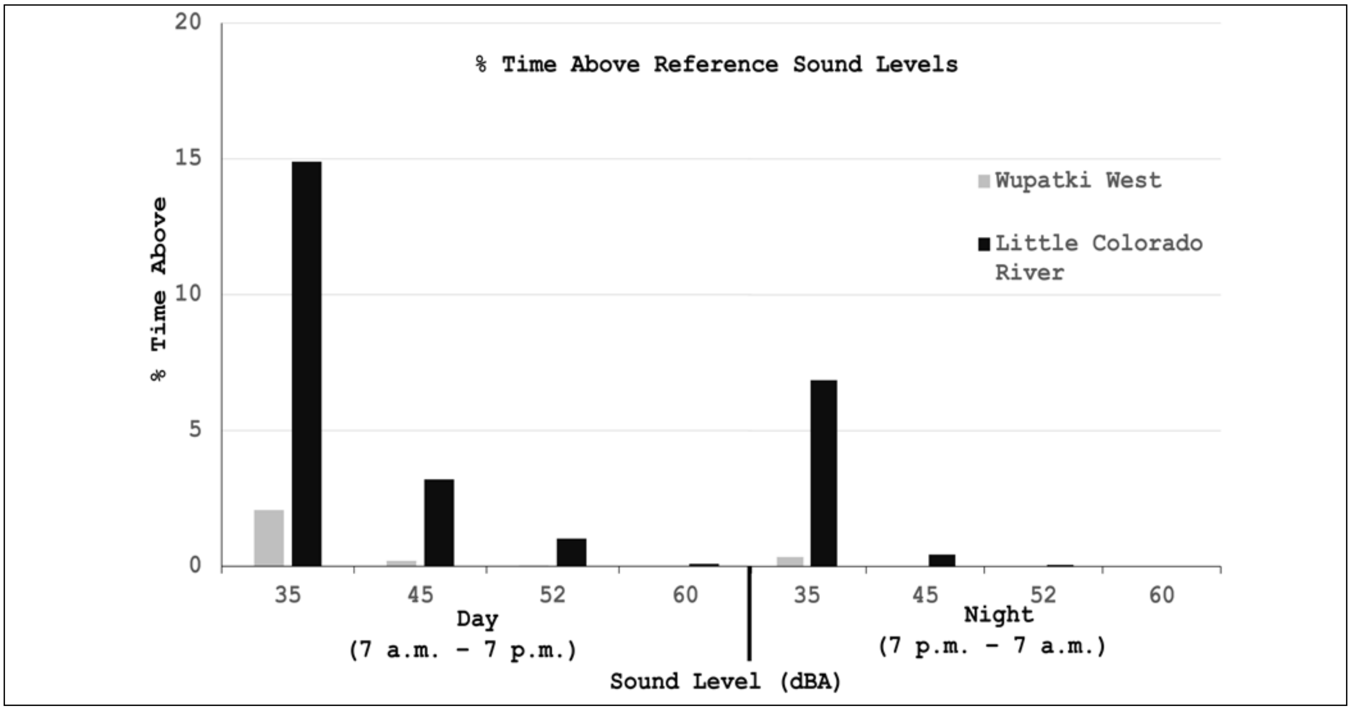


Figure 4.3.4-1. Percent time above reference sound levels in Wupatki NM.

Existing Ambient L_{50} w/out All Aircraft

Compared with the other measures, existing ambient sound levels without all aircraft sound levels exhibited the lowest values. At Wupatki West natural ambient sound level was exceeded by only 1.9 dBA while at Little Colorado River the natural ambient sound level was exceeded by 0.1 dBA. This resulted in a listening area reduction of 35% and 2% for Wupatki West and Little Colorado River, respectively. Eliminating aircraft noise from the data substantially increased the listening area and reduced overall anthropogenic sources of noise; therefore, this measure is in good condition for Little Colorado River but warrants moderate concern for Wupatki West.

% Time Audible

A detailed analysis of audibility at Wupatki West (Figure 4.3.4-2) found that aircraft contributed significant amounts of noise to the acoustical environment (41% including all aircraft sources). Vehicles were responsible for most of the remaining 15% of human sourced noise. At Little Colorado River aircraft noise from all sources was audible 44% of daytime hours while other human noises, mostly vehicles, were audible only 3% of daytime hours (Figure 4.3.4-3). Noise-free or natural sounds accounted for 53% of noise at Little Colorado River and 44% at Wupatki West. Noise from aircraft has the potential to mask natural sounds that provide a sense of place and add to the wilderness character at Wupatki NM. Based on reference conditions we consider the condition to be good at Little Colorado River, but this measure warrants moderate concern at Wupatki West.

L_{50} Impact (Mennitt et al. (2013))

Figure 4.3.4-4 shows the modeled mean impact sound level map for the monument, which was 1.20 decibels (dBA) above natural conditions, ranging from 0 dBA in the least impacted areas to 5.7 dBA in the most impacted areas. The map depicts the area most influenced by human-caused sounds (i.e., lighter areas). The existing and natural acoustic environment

Table 4.3.4-1. Ambient daytime (7:00 am to 7:00 pm) sound levels in Wupatki NM. Percentages indicate reduction in listening area over natural ambient conditions.

Site Location	Natural Ambient L_{50} (dBA)	Existing Ambient L_{50} (dBA)	Existing Ambient w/out Air Tours L_{50} (dBA)	Existing Ambient w/out All Aircraft L_{50} (dBA)
Wupatki West	17.7	24.5 (79%)	22.7 (68%)	19.6 (35%)
Little Colorado River	16.9	21.2 (63%)	20.3 (54%)	17.0 (2%)

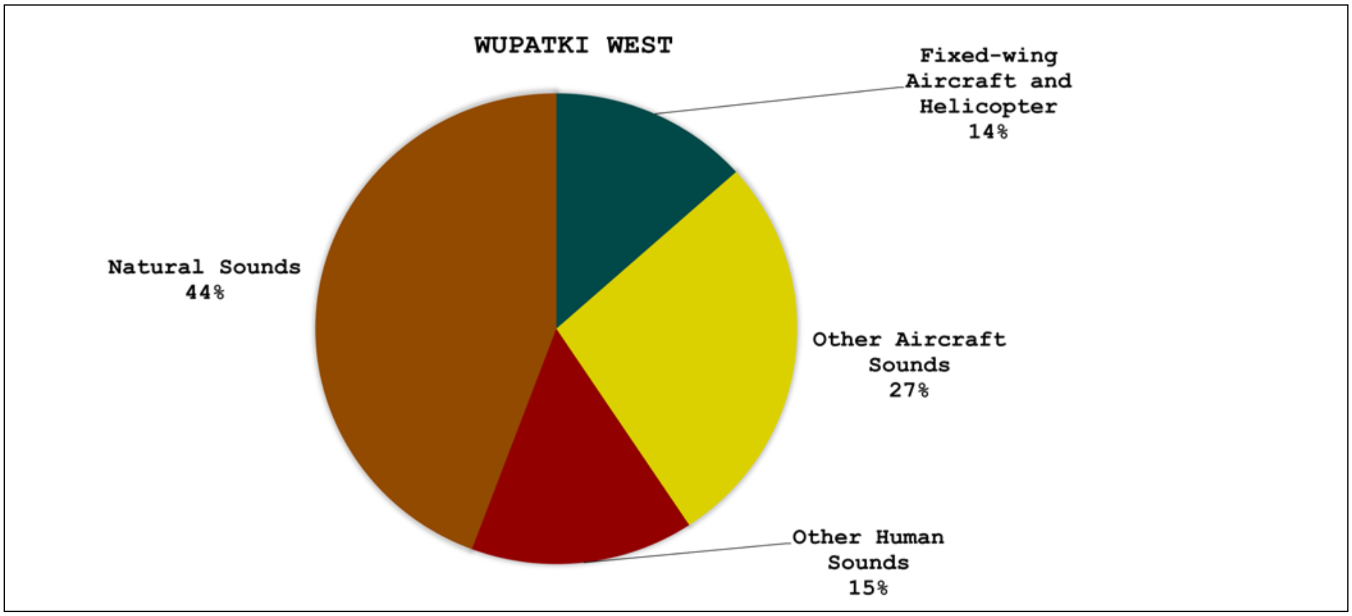


Figure 4.3.4-2. Percent time various sounds were audible at Wupatki West.

condition maps for the monument are included in Appendix D.

Summary statistics of the L_{50} values for the natural, existing, and impact conditions are provided in Table 4.3.4-2. Average values represent the average L_{50} value occurring within the monument boundary, and since this value is a mean, visitors may experience sound levels higher and lower than the average L_{50}. A one decibel change is not readily perceivable by the human ear, but any addition to this difference could begin to impact a visitor's listening ability to hear natural sounds or interpretive programs.

Mennitt et al. (2013) suggest that in a natural environment, the average summertime L_{50}, which is the sound level exceeded half of the time (and is a fair representation of expected conditions) is not expected

to exceed 41 dBA. However, acoustical conditions vary by area and depend on vegetation, landcover, elevation, climate, and other factors (Mennitt et al. 2013). Any one place may be above or below this average depending on these and other variables. Mennit et al. (2013) also state that "an impact of 3 dBA suggests that anthropogenic noise is noticeable at least 50% of the hour or more." The modeled median impact results for the monument was below 1.5, thus the L_{50} Impact was considered to be in good condition according to the reference thresholds developed by Turina et al. (2013).

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Overall, we consider the soundscape at the national monument to range from good condition to warranting moderate concern. This condition rating was based on three indicators with a total of four measures, which are summarized in Table 4.3.4-3. Those measures for which confidence in the condition rating was high were weighted more heavily in the overall condition rating than measures with medium confidence. None of the condition ratings were assigned low confidence.

Factors that influence confidence in the condition rating include age of the data (<5 yrs unless the data are part of a long-term monitoring effort), repeatability, field data vs. modeled data, and whether data can be extrapolated to other areas of the monument. Only one of the four measures, L_{50} impact, was given a medium confidence rating since it was based on modeled data. Although we assigned this measure medium confidence, the model provides a useful map of how sound may change across the monument. The remaining measures were assigned high confidence since they were based on field data despite being six years old. Since data were collected during one season (2010), we could not determine trend. Wupatki NM is a relatively quiet park owing to its limited developed area. The monument's developed area footprint, which includes the visitor center, employee housing, and administrative buildings, is relatively small and limits human-caused noise. Anthropogenic noise was largely attributed to aircraft, both low

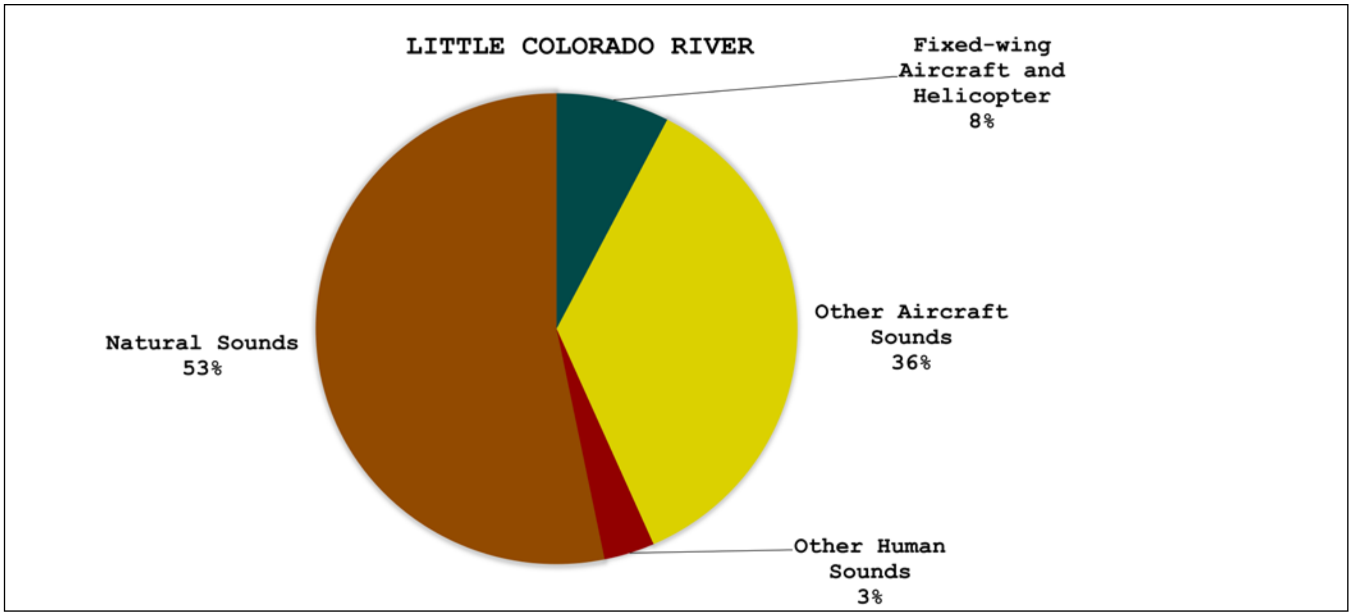


Figure 4.3.4-3. Percent time various sounds were audible at Little Colorado River.

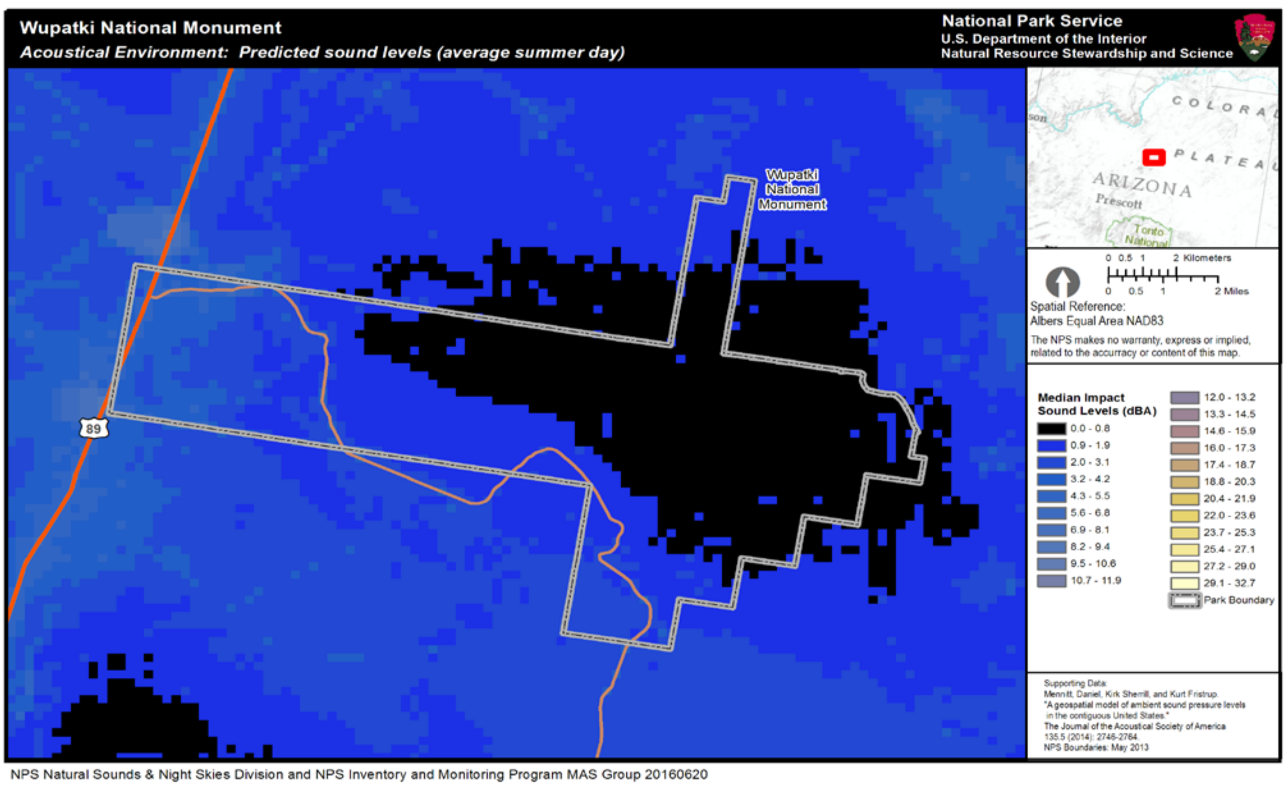


Figure 4.3.4-4. The modeled L_{50} impact sound level at Wupatki NM. Lighter colors represent higher impact areas. Figure Credit: NPS Natural Sounds and Night Skies Division.

level flights and high altitude commercial flights. Without aircraft, anthropogenic noise was low and listening area increased substantially. This suggests that when aircraft are not present, Wupatki West and Little Colorado River are relatively quiet, even when humans are present. This is supported by the percent of time a particular sound was audible. Nearly half of all anthropogenic sound was attributed to aircraft noise, but aircraft noise is typically a discrete occurrence. When present, aircraft noise has the ability to mask other natural sounds that interfere with the visitor experience and wildlife. Despite aircraft

Table 4.3.4-2. Summary of the modeled minimum, maximum, and average L_{50} measurements in Wupatki NM.

Acoustic Environment	Min. (dBA)	Max. (dBA)	Avg. (dBA)
Natural	21.40	23.67	22.31
Existing	20.09	28.37	23.45
Impact	0.00	5.70	1.20

Source: Emma Brown, NPS NSNSD.

noise, the proportion of time decibels were above reference conditions was relatively low, so while noise from aircraft may have been audible, it may not have interfered substantially with the visitor experience. For these reasons, we assigned an overall condition rating of good to moderate concern for Wupatki NM's soundscape.

A key uncertainty is that these results may not fully represent typical aircraft traffic activity and/or other sources of anthropogenic noise within the monument since data were collected during one season. Park staff report that aircraft noise and noise from other sources regularly occurs at night (P. Whitefield, pers. comm.), yet data presented in this assessment focuses largely on daytime aircraft noise. Also, some sound signatures may be misidentified throughout the analysis process. And finally, the information is already six years old (2010) and may no longer reflect current condition. Continued monitoring will provide more information about how and if Wupatki NM's soundscape is changing.

<u>Threats, Issues, and Data Gaps</u>

Air traffic, including air tours, currently represent the most significant threat to Wupatki NM's soundscape. Although air tours are relatively rare (32 reported during 2013-2015), the noise they create in combination with other aircraft, including military overflights and high altitude commercial aircraft, is a regular disruption to the monument's solitude (NPS 1996, FAA-NPS 2014, FAA-NPS 2015, FAA-NPS 2016). Wupatki NM is also in the line-of-sight route for low-level personal aircraft enroute from Flagstaff to Page, AZ and other communities in the Four Corners area, and also on the primary helicopter emergency medical transport route from Tuba City and Kayenta to Flagstaff Medical Center (P. Whitefield, pers. comm.).

Noise from Highway 89, the main Wupatki access road, and the Black Falls Road, a gravel road connecting the main NPS access road with the Navajo Reservation, significantly affect the natural and cultural landscape and will likely increase as the city of Flagstaff continues to spread toward Wupatki NM (NPS 1996). An estimated 70,320 people live in Flagstaff, AZ as of July 1, 2015 (U.S. Census Bureau 2016b). This is a 6.4% increase since April 2010 and the population is expected to increase (U.S. Census Bureau 2016b). Arizona is the fourth fastest growing state in the U.S. based on projected percent change in population size from 1995 to 2025 (U.S. Census Bureau 2016a).

In addition to influencing our experience of the landscape, human-caused noise can influence the behavior and ability of wildlife to function naturally on the landscape as can frequency. 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 (Shannon et al. 2015). In a review of literature addressing the effects of noise on wildlife published between 1990 and 2013, wildlife responses to noise were observed beginning at about 40 dBA, and further, 20% of papers showed impacts to terrestrial wildlife at or below noise levels of 50 dBA (Shannon et al. 2015). Wildlife response to noise was found to be highly variable between taxonomic groups. Furthermore, response to noise varied with behavior type (e.g., singing vs. foraging) (Shannon et al. 2015). One of the most common and readily observed biological responses to human noise is change in vocal communication. Birds use vocal communication primarily to attract mates and defend territories, but anthropogenic noise can influence the timing, frequency, and duration of their calls and songs (Shannon et al. 2015). Similar results have been found for some species of mammal, amphibians, and insects, which also rely on vocal communication for breeding and territorial defense. Other changes include changes in time spent foraging, ability to orient, and territory selection (Shannon et al. 2015).

Several recommendations have been made for human exposure to noise, but no guidelines exist for wildlife and the habitats we share. The majority of research on wildlife has focused on acute noise events, so further research needs to be dedicated to chronic noise exposure (Barber et al. 2010). In addition to wildlife,

Table 4.3.4-3. Summary of soundscape indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Sound Level	% Time Above Reference Sound Levels		Sound levels during day exceeded 35 dBA only 2.07% of the time at Wupatki West and 14.9% of the time at Little Colorado River and rarely exceeded 45 dBA at either site; therefore, we considered this measure to be in good condition. Since data were collected during one season only, we could not determine trend. Confidence in these data is high.
	% Reduction in Listening Area		The reduction in listening area under existing ambient sound levels exceeds 50% over natural ambient sound levels in both locations, which warrants significant concern. By eliminating noise from air tours the listening area increased by about 14% at Little Colorado River and Wupatki West; however, listening area was still reduced by more than 50% over natural ambient conditions in both locations, which still warrants significant concern. Eliminating all aircraft noise substantially increased the listening area and reduced overall anthropogenic sources of noise, and when this occurs in Wupatki NM, sound levels approach natural ambient sound levels at Little Colorado River, but still warrants moderate concern for Wupatki West. Overall, noise from aircraft significantly reduced listening area; therefore, this measure warrants significant concern. Since data were collected during one season only, we could not determine trend. Confidence in these data is high.
Audibility of Anthropo-genic Sounds	% Time Audible		At Wupatki West anthropogenic noise accounted for more than half of all sounds, while at Little Colorado River natural sounds accounted for more than half of all sounds. Based on reference conditions we consider the condition to be good at Little Colorado River, but this measure warrants moderate concern at Wupatki West.
Geospatial Model	L_{50} Impact		The modeled impact results for the monument were below 1.5, thus the L_{50} Impact was considered to be in good condition according to the reference thresholds developed by Turina et al. (2013). Since data were collected during one season only, we could not determine trend. These data were based on a model of sound levels across Wupatki NM's landscape; therefore, confidence in this measure is medium.
Overall Condition			Overall, we consider the soundscape at the national monument to range from good condition to warranting moderate concern. Without aircraft noise sound levels were low but when present, aircraft noise substantially reduced the listening area. Trend in sound levels is unknown and confidence in the data is high.

standards have not yet been developed to assess 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 (Barber et al. 2010).

4.3.5. Sources of Expertise

The NPS Natural Sounds and Night Skies Division (NSNSD) scientists help parks manage sounds in a way that balances the various expectations of park visitors with the protection of park resources. They provide technical assistance to parks in the form of acoustical monitoring, data collection and analysis, and in developing acoustical baselines for planning and reporting purposes. For more information, see http://nps.gov/nsnsd.

Emma Brown, Acoustical Resource Specialist with the NSNSD, provided an NRCA soundscape template used to develop this assessment and the sound model statistics and maps.

Assessment author is Lisa Baril, biologist and science writer, Utah State University.

4.4. Air Quality

4.4.1. Background and Importance

Under the direction of the National Park Service's (NPS) Organic Act, Air Quality Management Policy 4.7.1 (NPS 2006b), and the Clean Air Act (CAA) of 1970 (U.S. Federal Register 1970), the NPS has a responsibility to protect air quality and any air quality related values (e.g., scenic, biological, cultural, and recreational resources) that may be impaired from air pollutants.

One of the main purposes of the CAA is "to preserve, protect, and enhance the air quality in national parks" and other areas of special national or regional natural, recreational, scenic, or historic value. The CAA includes special programs to prevent significant air quality deterioration in clean air areas and to protect visibility in national parks and wilderness areas (NPS-Air Resources Division [ARD] 2012a) (Figure 4.4.1-1).

Two categories of air quality areas have been established through the authority of the CAA: Class I and II. The air quality classes are allowed different levels of permissible air pollution, with Class I receiving the greatest protection and strictest regulation. The CAA gives federal land managers responsibilities and opportunities to participate in decisions being made by regulatory agencies that might affect air quality in the federally protected areas they administer (NPS-ARD 2005).

Class I areas include parks that are larger than 2,428 ha (6,000 acres) or wilderness areas over 2,023 ha (5,000 acres) that were in existence when the CAA was amended in 1977 (NPS-ARD 2016a). Wupatki National Monument (NM) is designated as a Class II airshed. However, it is important to note that even though the CAA gives Class I areas the greatest protection against air quality deterioration, NPS management policies do not distinguish between the levels of protection afforded to any unit of the National Park System (NPS 2006b).

Air Quality Standards

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) to establish National Ambient Air Quality Standards (NAAQS) (40 CFR part 50) to regulate these air pollutants that are considered harmful to human health and the environment (EPA 2016a). The two types of NAAQS are primary and secondary, with the primary standards establishing limits to protect human health, and the secondary standards establishing limits

Figure 4.4.1-1. A view of Wupatki NM on a partly-cloudy day. Photo Credit: © William Romme.

to protect public welfare from air pollution effects, including decreased visibility, and damage to animals, crops, vegetation, and buildings (EPA 2016a).

The NPS' ARD (NPS-ARD) air quality monitoring program uses EPA's NAAQS, natural visibility goals, and ecological thresholds as benchmarks to assess current conditions of visibility, ozone, and atmospheric deposition throughout Park Service areas.

Visibility affects how well (acuity) and how far (visual range) one can see (NPS-ARD 2002), but air pollution can degrade visibility. 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.

Visibility can be subjective and value-based (e.g. a visitor's reaction viewing a scenic vista while observing a variety of forms, textures, colors, and brightness) (Figure 4.4.1-2), or it can be measured objectively by determining the size and composition of particles in the atmosphere that interfere with a person's ability to see landscape features (Malm 1999). The Viewshed assessment of this report addresses the subjective aspects of visibility, whereas this section addresses measurements of particles and gases in the atmosphere affecting visibility.

Ozone is a gaseous constituent of the atmosphere produced by reactions of nitrogen oxides (NO_x) from vehicles, powerplants, industry, and fire, and volatile organic compounds from industry, solvents, and vegetation in the presence of sunlight (Porter and Wondrak-Biel 2011). It is one of the most widespread air pollutants (NPS-ARD 2003), and the major constituent in smog. Ozone can be harmful to human health. Exposure to ozone can irritate the respiratory system and increase the susceptibility of the lungs to infections (NPS-ARD 2017a). It is also phytotoxic, causing foliar damage to plants (NPS-ARD 2003). 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 2004).

Ozone penetrates leaves through stomata (openings) and oxidizes plant tissue, which alters the physiological and biochemical processes (NPS-ARD 2012b). Once the ozone is inside the plant's cellular system, the chemical reactions can cause cell injury or even death (NPS-ARD 2012b), but more often reduce the plant's resistance to insects and diseases, reduce growth, and reduce reproductive capability (NPS-ARD 2012c).

Air pollutants can be deposited to ecosystems through rain and snow (wet deposition) or dust and gases (dry deposition). Nitrogen and sulfur air pollutants are commonly deposited as nitrate, ammonium, and sulfate ions and can have a variety of effects on ecosystem health, including acidification, fertilization or eutrophication, and accumulation of mercury or toxins (NPS-ARD 2010, Fowler et al. 2013). Atmospheric deposition can also change soil pH, which in turn, affects microorganisms, understory plants, and trees (NPS-ARD 2010). Certain ecosystems are more vulnerable to nitrogen or sulfur deposition than others, including high-elevation ecosystems in the western United States, upland areas in the eastern part of the country, areas on granitic bedrock, coastal and estuarine waters, arid ecosystems, and some grasslands (NPS-ARD 2016a). Increases in nitrogen have been found to promote invasions of fast-growing non-native annual grasses (e.g., cheatgrass [*Bromus tectorum*]) and forbs (e.g., Russian thistle [*Salsola tragus*] at the expense of native species (Brooks 2003, Allen et al. 2009, Schwinning et al. 2005). Increased grasses can increase fire risk (Rao et al. 2010), with profound implications for biodiversity in non-fire adapted ecosystems. Nitrogen may also increase water use in plants like big sagebrush (*Artemisia tridentata*) (Inouye 2006).

Figure 4.4.1-2. An expansive, scenic view at Wupatki NM. Photo Credit: © Patty Valentine-Darby.

According to the EPA (2016b), in the United States, roughly two thirds of all sulfur dioxide (SO_2) and one quarter of all NO_x come from electric power generation that relies on burning fossil fuels. Sulfur dioxide and nitrogen oxides are released from power plants and other sources, and ammonia is released by agricultural activities, feedlots, fires, and catalytic converters. In the atmosphere, these transform to sulfate, nitrate, and ammonium, and can be transported long distances across state and national borders, impacting resources (EPA 2016b), including at Wupatki NM.

Mercury and other toxic pollutants (e.g., pesticides, dioxins, PCBs) accumulate in the food chain and can affect both wildlife and human health. Elevated levels of mercury and other airborne toxic pollutants like pesticides in aquatic and terrestrial food webs can act as neurotoxins in biota that accumulate fat and/or muscle-loving contaminants. Sources of atmospheric mercury include by-products of coal-fire combustion, municipal and medical incineration, mining operations, volcanoes, and geothermal vents. High mercury concentrations in birds, mammals, amphibians, and fish can result in reduced foraging efficiency, survival, and reproductive success (NPS-ARD 2016a).

Additional air contaminants of concern include pesticides (e.g., DDT), industrial by-products (PCBs), and emerging chemicals such as flame retardants for fabrics (PBDEs). These pollutants enter the atmosphere from historically contaminated soils, current day industrial practices, and air pollution (Selin 2009).

4.4.2. Data and Methods

The approach we used to assess the condition of air quality within Wupatki NM's airshed was developed by the NPS-ARD for use in Natural Resource Condition Assessments (NPS-ARD 2015a,b). NPS-ARD uses all available data from NPS, EPA, state, and/or tribal monitoring stations to interpolate air quality values, with a specific value assigned to the maximum value within each park. Even though the data are derived from all available monitors, data from the closest stations "outweigh" the rest. Trends are computed from data collected over a 10-year period at on-site or nearby representative monitors. Trends are calculated for sites that have at least six years of annual data and an annual value for the end year of the reporting period.

<u>Haze Index</u>

The haze index indicator is visibility, which is monitored by the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program (NPS-ARD 2010).

NPS-ARD assesses visibility condition status based on the deviation of the estimated current Group 50 visibility conditions from estimated Group 50 natural visibility conditions (i.e., those estimated for a given area in the absence of human-caused visibility impairment; EPA-454/B003-005). Group 50 is defined as the mean of the visibility observations falling within the range of the 40th through the 60th percentiles, as expressed in terms of a Haze Index in deciviews (dv; NPS-ARD 2015a). A factor of the haze index is light extinction, which is used as an indicator to assess the quality of scenic vista and is proportional to the amount of light lost due to scattering or absorption by particles in the air as light travels a distance of one million meters. The haze index for visibility condition is calculated as follows:

Visibility Condition/Haze Index (dv) =
estimated current Group 50 visibility – estimated
Group 50 visibility
(under natural conditions)

The deciview scale scores pristine conditions as a zero and increases as visibility decreases (NPS-ARD 2015a).

For visibility condition assessments, annual average measurements for Group 50 visibility 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 then interpolated across all monitoring locations to estimate 5-year average values for the contiguous U.S. The maximum value within national monument boundaries is reported as the visibility condition from this national analysis.

Visibility trends are computed from the 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 areas designated as Class I, the NPS applies these standard visibility 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.

The level of ozone indicator includes two measures, human health: annual 4th-highest 8-hr concentration and vegetation health: 3-month maximum 12-hr W126). Ozone is monitored across the U.S. through air quality monitoring networks operated by the NPS, EPA, states, and others. Aggregated ozone data are acquired from the EPA Air Quality System (AQS) database. Note that prior to 2012, monitoring data were also obtained from the EPA Clean Air Status and Trends Network (CASTNet) database.

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

The primary NAAQS for ground-level ozone is set by the EPA, and is based on human health effects. The 2008 NAAQS for ozone was a 4th-highest daily maximum 8-hour ozone concentration of 75 parts per billion (ppb). On October 1, 2015, the EPA strengthened the national ozone standard by setting the new level at 70 ppb (EPA 2016a). 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 are 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 the park is the maximum estimated value within park boundaries derived from this national analysis.

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 of the weighted concentrations during daylight hours (8am-8pm). The highest 3-month period that occurs during the ozone season is reported in "parts per million-hours" (ppm-hrs), and is used for vegetation health risk from ozone condition assessments. Annual maximum 3-month 12-hour W126 values are averaged over a 5-year period at all monitoring sites with at least three 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 the park is the maximum value within park boundaries derived from this national analysis.

Indicator, 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, and at the Mercury Deposition Network (MDN) for mercury wet deposition.

Nitrogen and Sulphur

Wet deposition is used as a surrogate for total deposition (wet plus dry), because wet deposition is the only nationally available monitored source of nitrogen and sulfur deposition data. Values for nitrogen (N) from ammonium and nitrate and sulfur (S) from sulfate wet deposition are expressed as amount of N or S in kilograms deposited over a one-hectare area in one year (kg/ha/yr). For nitrogen and sulfur 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. Five-year averages are then interpolated across all monitoring locations to estimate 5-year average values for the contiguous U.S. For individual parks, minimum and maximum values within park boundaries are reported from this national analysis. To maintain the highest level of protection in the park, the maximum value is assigned a condition status. 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.

Mercury

The condition of mercury was assessed using estimated 3-year average mercury wet deposition (ug/m^2/yr) and the predicted surface water methylmercury concentrations at NPS Inventory & Monitoring parks. It is important to consider both mercury deposition inputs and ecosystem susceptibility to mercury methylation when assessing mercury condition, because atmospheric inputs of elemental or inorganic mercury must be methylated before it is biologically available and able to accumulate in food webs (NPS-ARD 2015b). Thus, mercury condition cannot be assessed according to mercury wet deposition alone. Other factors like environmental conditions conducive to mercury methylation (e.g., dissolved organic carbon, wetlands, pH) must also be considered (NPS-ARD 2015a).

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

Conditions of predicted methylmercury concentration in surface water are obtained from a model that predicts surface water methylmercury concentrations for hydrologic units throughout the U.S. based on relevant water quality characteristics (i.e., pH, sulfate, and total organic carbon) and wetland abundance (U.S. Geological Survey [USGS] 2015). The predicted methylmercury concentration at a park is the highest value derived from the hydrologic units that intersect the park.

4.4.3. Reference Conditions

The reference conditions against which current air quality parameters are assessed are identified by NPS-ARD (2015a,b) for NRCAs and listed in Table 4.4.3-1.

Visibility (Haze Index)

A visibility condition estimate of less than 2 dv above estimated natural conditions indicates a "good" condition, estimates ranging from 2-8 dv above natural conditions indicate a "moderate concern" condition, and estimates greater than 8 dv above natural conditions indicate "significant concern." The NPS-ARD chose reference condition ranges to reflect the variation in visibility conditions across the monitoring network.

Level of Ozone

Human Health

The human health ozone condition thresholds are based on the 2015 ozone standard set by the EPA (EPA 2016a) at a level to protect human health: 4th-highest daily maximum 8-hour ozone concentration of 70 ppb. The NPS-ARD rates ozone condition as: "good" if the ozone concentration is less than or equal to 54 ppb, which is in line with the updated Air Quality Index breakpoints; "moderate concern" if the ozone concentration is between 55 and 70 ppb; and of "significant concern" if the concentration is greater than or equal to 71 ppb.

Vegetation Health

The W126 condition thresholds are based on information in EPA's Policy Assessment for the Review of the Ozone NAAQS (EPA 2014). Research has found that for a W126 value of:

- ≤ 7 ppm-hrs, tree seedling biomass loss is ≤ 2 % per year in sensitive species; and
- ≥13 ppm-hrs, tree seedling biomass loss is 4-10 % per year in sensitive species.

Table 4.4.3-1. Reference conditions for air quality parameters.

Indicator and Measure	Very Good	Good	Moderate Concern	Significant Concern
Visibility Haze Index	n/a	< 2	2-8	>8
Ozone Human Health (ppb)	n/a	≤ 54	55-70	≥ 71
Ozone Vegetation Health (ppm-hrs)	n/a	<7	7-13	>13
Nitrogen and Sulfur Wet Deposition (kg/ha/yr)	n/a	< 1	1-3	>3
Mercury Wet Deposition ((µg/m^2/yr)	< 3	≥ 3 and < 6	≥ 6 and < 9	≥ 9 and < 12
Predicted Methylmercury Concentration (ng/L)	< 0.038	≥ 0.038 and .< 0.053	≥ 0.053 and < 0.075	≥ 0.075 and < 0.12

Sources: NPS-ARD (2015a,b), EPA (2016a).

Note: Human health ozone thresholds have been revised since NPS-ARD (2015a).

ARD recommends a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation; this level is considered good; 7-13 ppm-hrs is considered to be of "moderate" concern; and >13 ppm-hrs is considered to be of "significant concern" (NPS-ARD 2015a).

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 (Baron et al. 2011) and in the Pacific Northwest (Sheibley et al. 2014). 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."

Mercury

Ratings for mercury wet deposition and predicted methylmercury concentrations can be evaluated using the mercury condition assessment matrix shown in Table 4.4.3-2 to identify one of three condition categories. Condition adjustments may be made if the presence of park-specific data on mercury in food webs is available and/or data are lacking to determine the wet deposition rating (NPS-ARD 2015a).

4.4.4. Condition and Trend

The values used to determine conditions for all air quality indicators and measures are listed in Table 4.4.4-1.

Haze Index

The estimated 5-year (2011-2015) value (4.3 dv) for the park's visibility condition fell within the moderate concern condition rating, which indicates visibility is degraded from the good reference condition of <2 dv above the natural condition (NPS-ARD 2015a,b). For 2006-2015, the trend in visibility at Wupatki NM improved on the 20% clearest days (Figure 4.4.4-1) and improved on the 20% haziest days (Figure 4.4.4-2) (IMPROVE Monitor ID: IKBA1, AZ [Ike's Backbone]). The CAA visibility goal requires visibility improvement on the 20% haziest days, with no degradation on the 20% clearest days (excerpted from NPS-ARD 2016b). Confidence in this measure is high because there is an on-site or nearby visibility monitor. Visibility impairment primarily results from small particles in the atmosphere that include natural particles from dust and wildfires and anthropogenic sources from organic compounds, NO_x and SO_2. The contributions made by different classes of particles to haze on the clearest days and on the haziest days are shown in Figures 4.4.4-3 and 4.4.4-4, respectively, using data collected at the IMPROVE monitoring location, IKBA1.

The primary visibility-impairing pollutants on both the clearest and haziest days from 2006-2015 were ammonium sulfate and organic carbon, as well as coarse mass on the haziest days (NPS-ARD 2016b). Ammonium sulfate originates mainly from coal-fired

Table 4.4.3-2. Mercury condition assessment matrix.

Predicted Methylmercury Concentration Rating	Mercury Wet Deposition Rating				
	Very Low	Low	Moderate	High	Very High
Very Low	Good	Good	Good	Moderate Concern	Moderate Concern
Low	Good	Good	Moderate Concern	Moderate Concern	Moderate Concern
Moderate	Good	Moderate Concern	Moderate Concern	Moderate Concern	Significant Concern
High	Moderate Concern	Moderate Concern	Moderate Concern	Significant Concern	Significant Concern
Very High	Moderate Concern	Moderate Concern	Significant Concern	Significant Concern	Significant Concern

Source: NPS-ARD (2015a)

Table 4.4.4-1. Condition and trend results for air quality indicators at Wupatki NM.

Data Span	Visibility (dv)	Ozone: Human Health (ppb)	Ozone: Vegetation Health (ppm-hrs)	N (kg/ha/yr)	S (kg/ha/yr)	Mercury (µg/m^2/yr)	Mercury (ng/L)
Condition	Moderate Concern (4.3) 2011-2015	Significant Concern (71.3) (2011-2015)	Significant Concern (17.1) (2011-2015)	Good (0.9) 2011-2015	Good (0.3) 2011-2015	Good (2.8-4.1) 2013-2015	Good (0.03) 2012-2014
Trend: 2006-2015	The trend in visibility at Wupatki NM improved on the 20% clearest days and improved on the 20% haziest days (IMPROVE Monitor ID: IKBA1, AZ) (text excerpted from NPS 2016b).						

Sources: NPS-ARD (2016b,c)

power plants and smelters, and organic carbon originates primarily from combustion of fossil fuels and vegetation.

In 2015, the clearest days occurred during the winter months of January and February (Figure 4.4.4-5), while the haziest days occurred during the months of October and November (Figure 4.4.4-6). Because there are variations between years, one can report the months with the highest sum for the last five years (e.g. for the last five years add up the number of clearest days for each month and then select the months with the highest sum).

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

Ozone data used for this measure were derived from estimated five-year (2011-2015) values of 71.3 parts per billion for the 4th highest 8-hour concentration, which resulted in a condition rating warranting significant concern for human health (NPS-ARD 2016b). No trend information is available because there are not sufficient on-site or nearby ozone monitoring data. Our level of confidence in this measure is medium, because estimates are based on interpolated data from more distant ozone monitors.

Vegetation Health: 3-month Maximum 12-hr W126)

Ozone data used for this measure of the condition assessment were derived from estimated five-year (2011-2015) values of 17.1 parts per million-hours (ppm-hrs) for the W126 Index. Using these numbers, vegetation health risk from ground-level ozone warrants significant concern at Wupatki NM (NPS-ARD 2016b). No trend information is available because there are not sufficient on-site or nearby ozone monitoring data. Our level of confidence in this measure is medium because estimates are based on interpolated data from more distant ozone monitors.

An ozone risk assessment was conducted by Kohut (2004, 2007) for Southern Colorado Plateau Network parks, concluding that plants in the national monument were at moderate risk of foliar ozone injury. The two plant species identified as ozone sensitive at the park during the Kohut (2004) effort are listed in Table 4.4.4-2. Kohut (2004) indicated skunkbush (*Rhus trilobata*) could be used as a bioindicator. Seven additional plant species have also been identified as ozone sensitive at the park and are listed in Table 4.4.4-2 (Bell, in review). Of the nine total ozone-sensitive plant species, seven (77.8%) are bioindicators, which can reveal ozone stress in ecosystems by producing distinct visible and identifiable injuries to plant leaves. Bioindicator status is noted the table.

Nitrogen

Wet N deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 0.9 kg/ha/yr. This resulted in a good condition rating (NPS-ARD 2016b). No trends could be determined given the lack of nearby monitoring stations. Confidence in the assessment is medium because estimates are based on interpolated data from more distant deposition monitors. For further discussion of N deposition, see the section entitled "Additional Information for Nitrogen and Sulfur" below.

Sulfur

Wet S deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 0.3 kg/ha/yr, which resulted in a good condition rating for Wupatki NM (NPS-ARD 2016b). No trends could be determined given the lack of nearby monitoring stations. Confidence in the

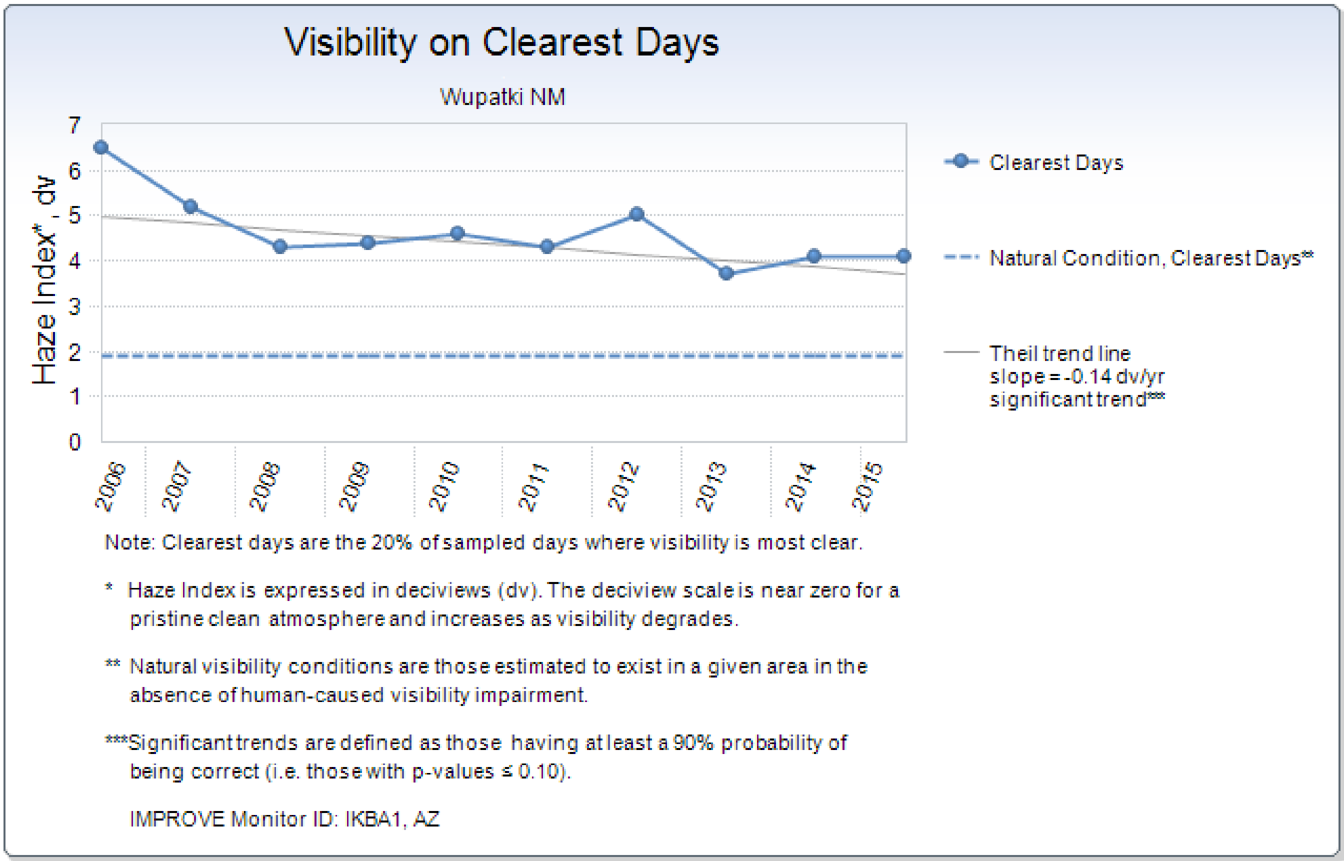


Figure 4.4.4-1. For 2006–2015, the trend in visibility at Wupatki NM improved on the 20% clearest days. Figure Credit: NPS-ARD 2016b.

assessment is medium because estimates are based on interpolated data from more distant deposition monitors. For further discussion of sulfur, see below.

Additional Information on Nitrogen and Sulfur

Sullivan et al. (2011a), studied the risk from acidification from acid pollutant exposure and ecosystem sensitivity for Southern Colorado Plateau Network (SCPN) parks, which included Wupatki NM. Pollutant exposure included the type of deposition (i.e., wet, dry, cloud, fog), the oxidized and reduced forms of the chemical, if applicable, and the total quantity deposited. The ecosystem sensitivity considered the type of terrestrial and aquatic ecosystems present at the parks and their inherent sensitivity to the atmospherically deposited chemicals.

These risk rankings were considered very low for acid pollutant exposure at the park, moderate for ecosystem sensitivity, and moderate for park protection from acidification, for an overall summary risk of low (Sullivan et al. 2011a). The effects of acidification can include changes in water and soil chemistry that impact ecosystem health.

Sullivan et al. (2011b) also developed risk rankings for nutrient N pollutant exposure and ecosystem sensitivity to nutrient N enrichment. These risk rankings were considered very low for pollutant exposure at the park, high for ecosystem sensitivity, and moderate for park protection, with an overall summary risk of very low for the park. Potential effects of nitrogen deposition include the disruption of soil nutrient cycling and impacts to the biodiversity of some plant communities, including arid and semi-arid, grassland, and wetland. These nitrogen sensitive communities cover a relatively large portion of Wupatki NM (Figure 4.4.4-7), but again, the overall summary risk was very low for the park (Sullivan et al. 2011b).

In general, nitrate, sulfate, and ammonium deposition levels have changed over the past 20 years throughout the United States. Regulatory programs mandating a reduction in emissions have proven effective for

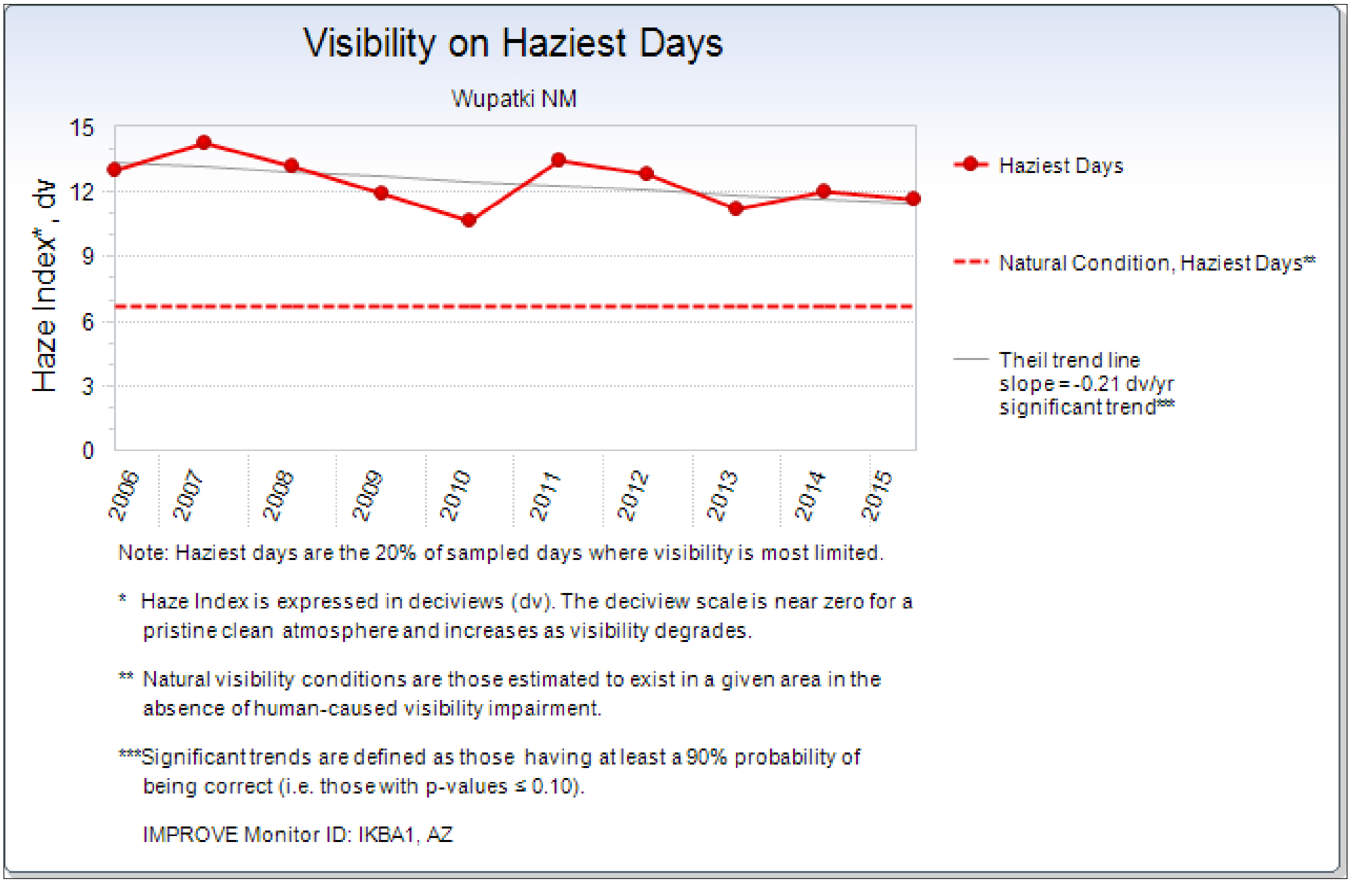


Figure 4.4.4-2. For 2006-2015, the trend in visibility at Wupatki NM improved on the 20% haziest days. Figure Credit: NPS-ARD 2016b.

decreasing both sulfate and nitrate ion deposition, primarily through reductions from electric utilities, vehicles, and industrial boilers, although a rise in ammonium ion deposition has occurred in large part due to the agricultural and livestock industries (NPS-ARD 2012d). A study conducted by Lehmann and Gay (2011) indicated a statistically significant decrease in sulfate concentrations from 1985-2009 in the area surrounding the monument, but a statistically significant increase in nitrate concentrations. According to the Lehmann and Gay (2011) study, for the areas that saw a change in nitrate concentrations across the county, most saw a decrease; increases were seen primarily in Arizona, New Mexico, and a portion of western Texas. It seems reasonable to expect a continued improvement in sulfate deposition levels because of CAA requirements. At this time, however, ammonium levels are not regulated by the EPA, and may therefore continue to rise (NPS-ARD 2010).

Mercury and Predicted Methylmercury

Mercury/toxics deposition is in good condition at Wupatki NM. Because landscape factors influence the uptake of mercury in the ecosystem, the status is based on estimated wet mercury deposition and predicted levels of methylmercury in surface waters. The 2013–2015 wet mercury deposition was low at the park, ranging from 2.8 to 4.1 micrograms per square meter per year (NPS-ARD 2016c), and the predicted methylmercury concentration in park surface waters is very low, estimated to be 0.03 nanogram per liter (USGS 2015). To maintain the greatest level of protection, the higher deposition value and predicted concentration in park surface waters were compared to NPS ARD benchmarks to determine the good condition status.

The level of confidence in the mercury/toxics deposition status is low because wet deposition and methylmercury concentration estimates are based on interpolated or modeled data rather than in-park studies, since there are no park-specific studies examining contaminant levels in taxa from park ecosystems.

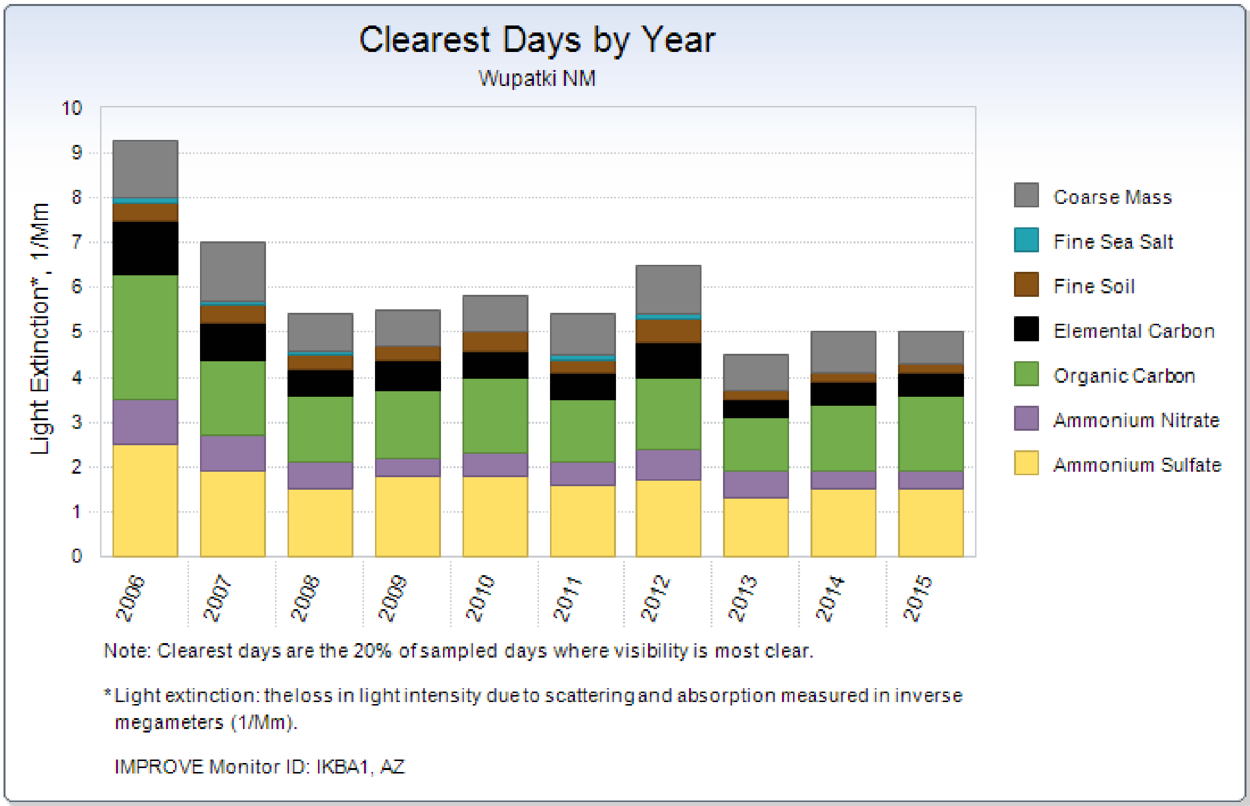


Figure 4.4.4-3. **Visibility data collected at IKBA1, AZ IMPROVE station showing the composition of particle sources contributing to haze during the clearest days by year (2006-2015). Figure Credit: NPS-ARD 2016b.**

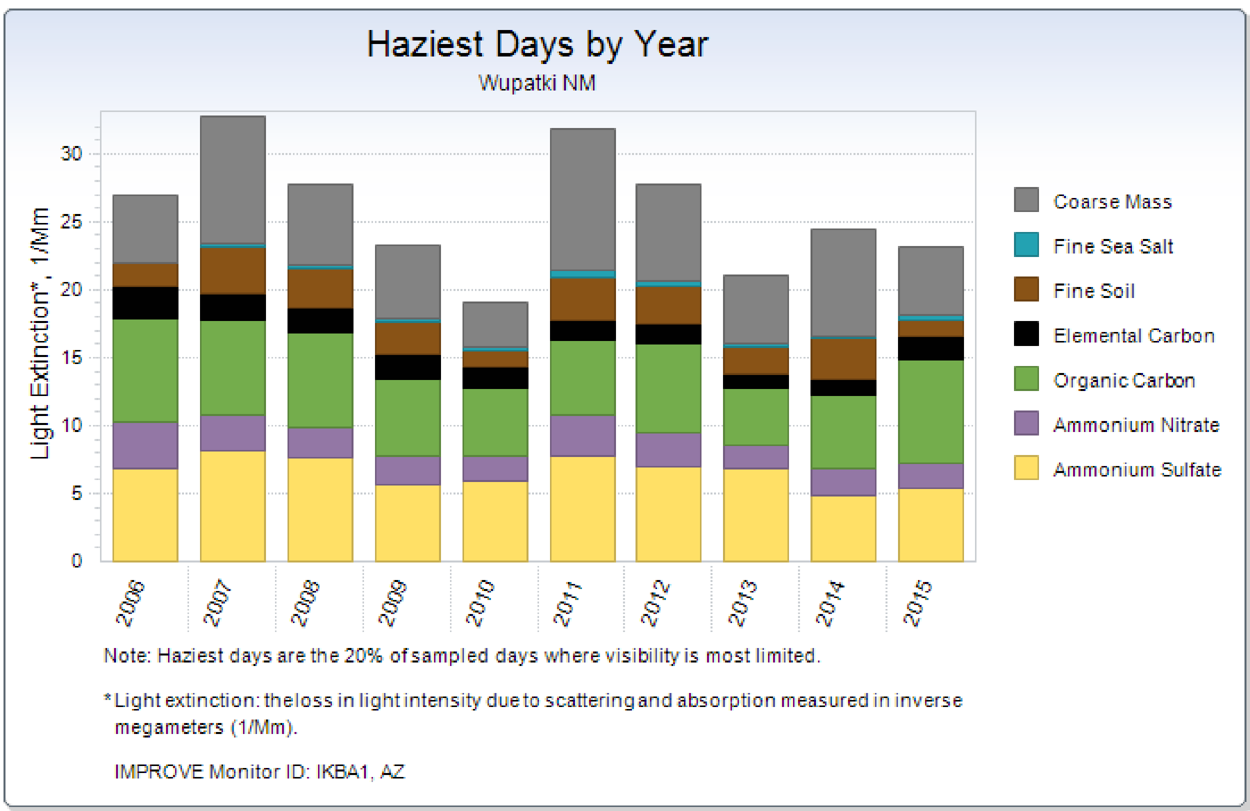


Figure 4.4.4-4. **Visibility data collected at IKBA1, AZ IMPROVE station showing the composition of particle sources contributing to haze during the haziest days by year (2006-2015). Figure Credit: NPS-ARD 2016b.**

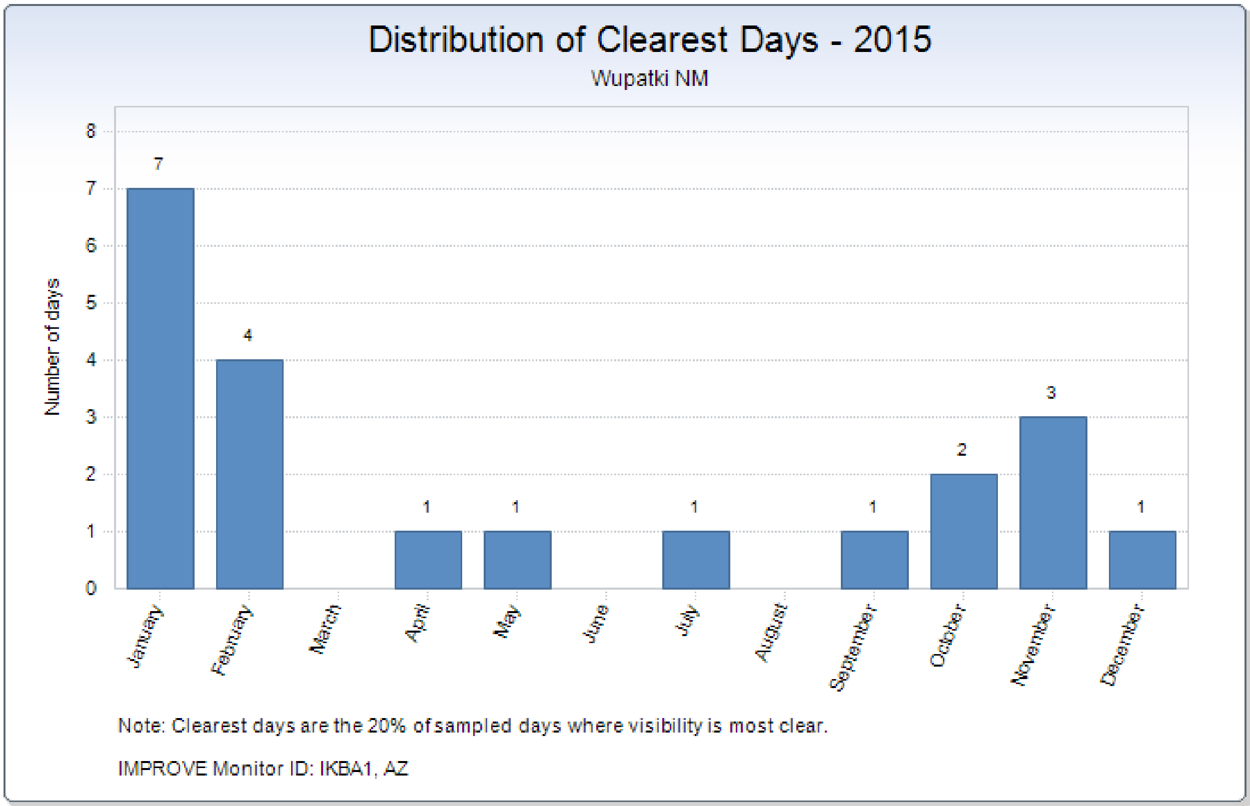


Figure 4.4.4-5. Visibility data collected at IKBA1, AZ IMPROVE station showing the distribution of clearest days by month for 2015. Figure Credit: NPS-ARD 2016b.

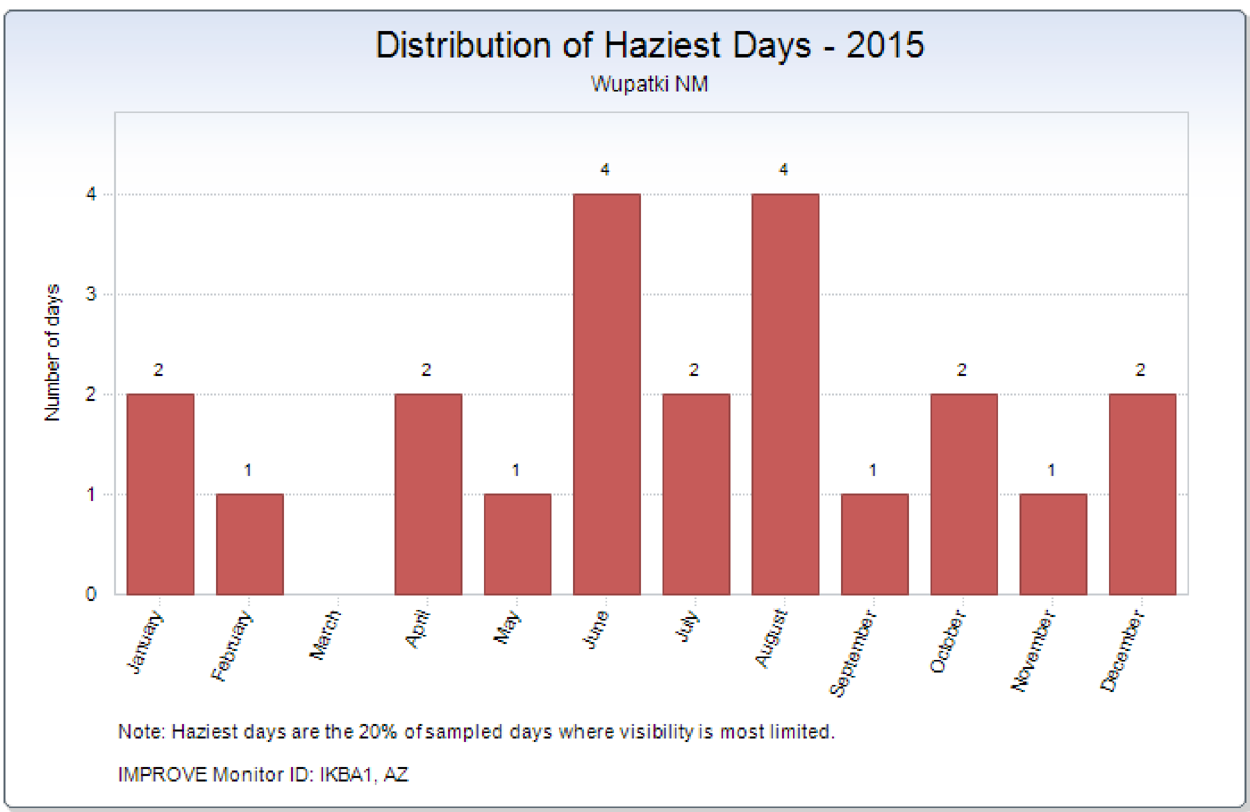


Figure 4.4.4-6. Visibility data collected at IKBA1, AZ IMPROVE station showing the distribution of haziest days by month for 2015. Figure Credit: NPS-ARD 2016b.

Table 4.4.4-2. Ozone sensitive plants found at Wupatki NM.

Scientific Name	Common Name	Bell (in review)	Kohut (2004)	Bioindicator?
Amelanchier utahensis	Utah serviceberry	X	–	No
Artemisia ludoviciana	Prairie sagebrush	X	–	Yes
Liriodendron tulipifera	Tulip poplar	X	–	Yes
Mentzelia albicaulis	White blazingstar	X	–	Yes
Populus fremontii	Fremont's cottonwood	X	–	Yes
Populus tremuloides	Quaking aspen	X	–	Yes
Rhus trilobata	Skunkbush	–	X	Yes
Salix exigua	Coyote willow	X	–	No
Salix scouleriana	Scouler's willow	X	X	Yes

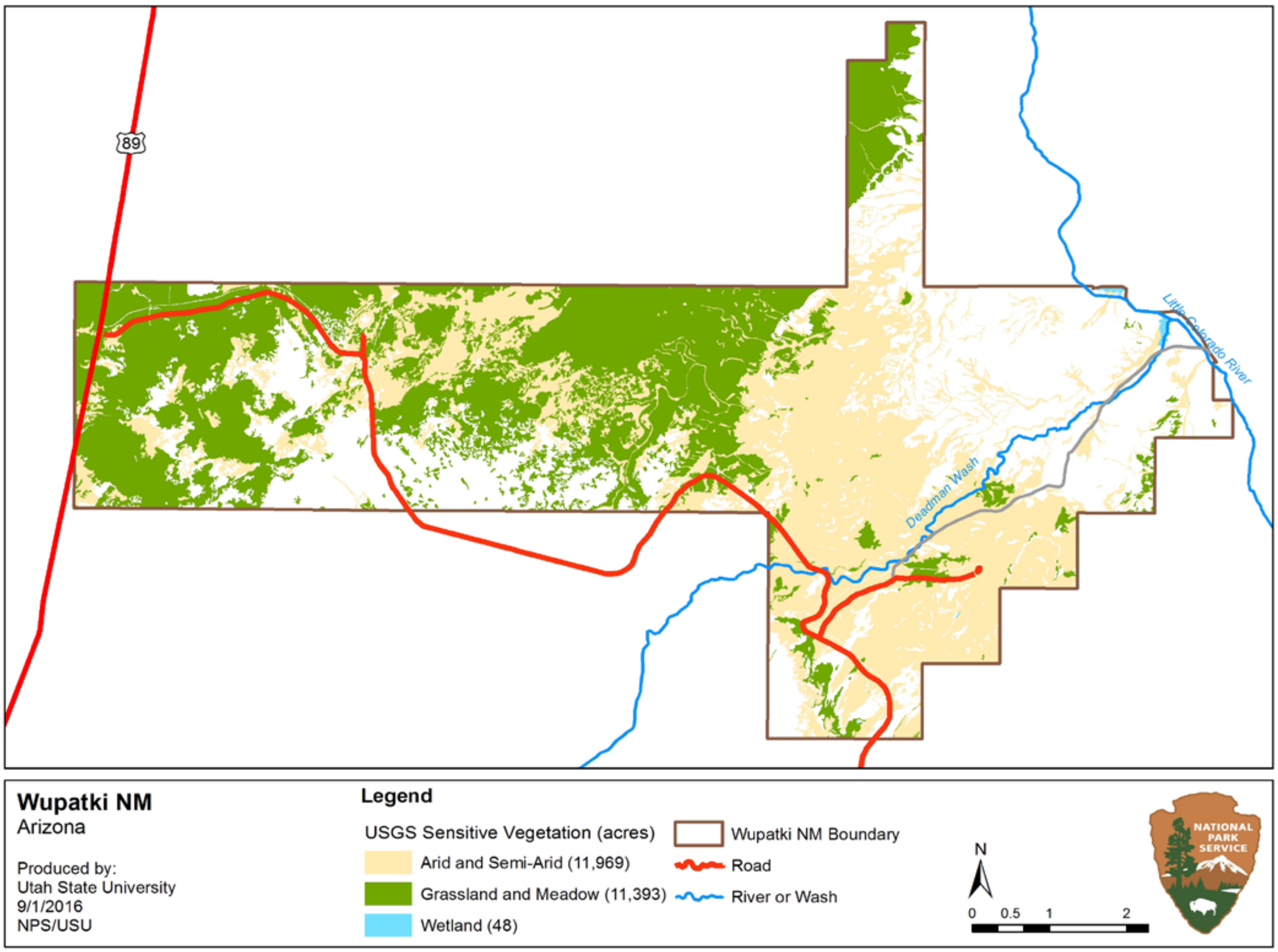


Figure 4.4.4-7. Locations of nitrogen sensitive communities at Wupatki NM using the USGS land cover dataset. Secondary Data Source: E&S Environmental Chemistry, Inc. (2009).

Overall Condition and Trend, Confidence Level, and Key Uncertainties

For assessing the condition of air quality, we used three air quality indicators. Our indicators/measures for this resource were intended to capture different aspects of air quality, and a summary of how they contributed to the overall condition is summarized in Table 4.4.4-3.

We consider the overall condition of air quality at Wupatki NM to be of moderate concern. Among the individual measures, four were considered good, one

Table 4.4.4-3. Summary of air quality indicators, measures, and condition rationale.

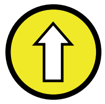
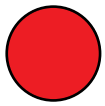
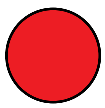
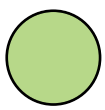
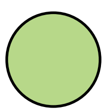
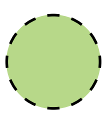
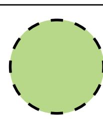
Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Visibility	Haze Index		Visibility warrants moderate concern at Wupatki NM. This is based on NPS ARD benchmarks and the 2011-2015 estimated visibility on mid-range days of 4.3 deciviews (dv) above estimated natural conditions. For 2006-2015, the trend in visibility at the park improved on the 20% clearest days and improved on the 20% haziest days (IMPROVE Monitor ID: IKBA1, AZ). The Clean Air Act visibility goal requires visibility improvement on the 20% haziest days, with no degradation on the 20% clearest days. The level of confidence is high because there is an on-site or nearby visibility monitor.
Level of Ozone	Human Health: Annual 4th-Highest 8-hour Concentration		Human health risk from ground-level ozone warrants significant concern at Wupatki NM. This status is based on NPS ARD benchmarks and the 2011-2015 estimated ozone of 71.3 parts per billion (ppb). No trend information is available because there are not sufficient on-site or nearby ozone monitoring data. The level of confidence is medium because estimates are based on interpolated data from more distant ozone monitors.
	Vegetation Health: 3-month maximum 12hr W126		Vegetation health risk from ground-level ozone warrants significant concern. This status is based on NPS ARD benchmarks and the 2011-2015 estimated W126 metric of 17.1 parts per million-hours (ppm-hrs). The W126 metric relates plant response to ozone exposure. A risk assessment concluded that plants in the park were at moderate risk for ozone damage (Kohut 2007, Kohut 2004). No trend information is available because there are not sufficient on-site or nearby ozone monitoring data. The confidence level is medium because estimates are based on interpolated data from more distant ozone monitors.
Wet Deposition	N in kg/ha/yr		Wet nitrogen deposition warrants moderate concern. This status is based on NPS ARD benchmarks and the 2011-2015 estimated wet nitrogen deposition of 0.9 kilograms per hectare per year (kg/ha/yr). Ecosystems in the park were rated as having high sensitivity to nutrient-enrichment effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011a; Sullivan et al. 2011b). Nitrogen deposition may disrupt soil nutrient cycling and affect biodiversity of some plant communities, including arid and semi-arid, grassland, and wetland. No trend information is available because there are not sufficient on-site or nearby deposition monitoring data. The confidence level is medium because estimates are based on interpolated data from more distant deposition monitors.
	S in kg/ha/yr		Wet sulfur deposition is in good condition. This status is based on NPS ARD benchmarks and the 2011-2015 estimated wet sulfur deposition of 0.3 kilograms per hectare per year (kg/ha/yr). Ecosystems in the park were rated as having moderate sensitivity to acidification effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011a; Sullivan et al. 2011b). Acidification effects can include changes in water and soil chemistry that impact ecosystem health. No trend information is available because there are not sufficient on-site or nearby deposition monitoring data. The level of confidence is medium because estimates are based on interpolated data from more distant deposition monitors.
	Mercury		The 2013–2015 estimated wet mercury deposition was low at the park, ranging from 2.8 to 4.1 micrograms per square meter per year. Low deposition corresponds to a good condition. The level of confidence in the measure is low, because wet deposition estimates are based on interpolated data rather than in-park studies, since there are no park-specific studies examining contaminant levels in taxa from park ecosystems.
	Predicted Methylmercury Concentration		The predicted methylmercury concentration in park surface waters is very low, estimated to be 0.03 nanogram per liter (USGS 2015). A very low concentration corresponds to a good condition. The level of confidence in the measure is low, because methylmercury concentration estimates are based on modeled data.

Table 4.4.4-3 continued. Summary of air quality indicators, measures, and condition rationale .

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Overall Condition			Overall, we consider air quality at the national monument to be of moderate concern. Certain aspects, however, warrant significant concern (i.e., vegetation health risk from ground-level ozone), and others appear to be in good condition (e.g., wet deposition measures). Overall, confidence in the assessment is medium, with confidence in one measure high and that of the other measures either medium (four measures) or low (two measures). The overall trend is unknown, although the trend in visibility is improving.

Note: Condition summary text was primarily excerpted from NPS-ARD (2016b, 2016c, 2016d).

was considered to be of moderate concern, and two were considered to be of significant concern. The only measures that were in good condition were within the wet deposition indicator. We consider the confidence level as high for visibility based on the IMPROVE monitoring station, IKBA1, AZ. The confidence levels for ozone and wet deposition of N and S are medium because estimates are based on interpolated data from more distant monitors. Finally, the confidence level for mercury/toxics deposition is low because wet deposition and methylmercury concentration estimates are based on interpolated or modeled data rather than in-park studies.

The trend in visibility at Wupatki NM improved on the 20% clearest days and improved on the 20% haziest days (IMPROVE Monitor ID: IKBA1, AZ). Trends for the remaining indicators cannot be derived because on-site monitoring does not occur and no monitoring sites are located near enough to be representative of conditions at the park. A key uncertainty of the air quality assessment is knowing the effect(s) of air pollution, especially of nitrogen deposition, on ecosystems at the park.

Threats, Issues, and Data Gaps

Clean air is fundamental to protecting human health, the health of wildlife and plants within parks, and for protecting the aesthetic value of lands managed by the NPS (NPS 2006b). The majority of threats to air quality within Wupatki NM originate from outside the monument and include the effects of climate change, forest fires (natural or prescribed), dust created from mineral and rock quarries, and carbon emissions.

The western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall (Prein et al. 2016). Since 1974 there has been a 25% decrease in precipitation, a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016). 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). In addition to prescribed burns by the U.S. Forest Service (USFS 2016), natural wildfires have increased across the western U.S., and the potential for the number of wildfires to grow is high 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). The Navajo Generating Station ~200 km (124 mi) north, the Cholla Power Plant 100 km (62 mi) east, and the Coronado Generating Station ~200 km (124 mi) east are potential sources for air quality impacts.

4.4.5. Sources of Expertise

The NPS Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. Information and text for the assessment was obtained from the NPS-ARD website and provided by Jim Cheatham, Park Planning and Technical Assistance, ARD. The assessment was written by Patty Valentine-Darby, biologist and science writer at Utah State University, with contributions from Lisa Baril, biologist and science writer at Utah State University.

4.5. Sunset Crater Tephra Layer

4.5.1. Background and Importance

The focus of this assessment is the geomorphic stability of the Sunset Crater tephra layer that covers much of the land surface at Wupatki National Monument (NM) (Figure 4.5.1-1). The tephra layer, a result of the eruption of Sunset Crater Volcano in the late 11th century A.D., had a profound influence on ecosystem productivity. The tephra layer was beneficial to prehistoric farmers and is an important ecological factor in the distribution of modern plant communities, mainly because it acts as a mulch to increase rainwater infiltration, thus decreasing evaporation, surface runoff, and erosion. The decrease in evaporation reduces adverse effects of salinization, and the black cinder cover raises soil temperatures to increase the length of the growing season. Although it remains unclear to what extent the increased soil temperatures influence evaporation rates, numerous studies indicate that the cinder mulch layer conserves valuable soil moisture, with two significant results. First, the cinder mulch increased crop yields for the prehistoric farmers, which in turn lead to population increases, a building boom, and construction of spectacular monumental architecture such as Wupatki Pueblo. Therefore, the establishment of Wupatki is a direct result of the eruption of Sunset Crater Volcano and its effect on soil properties. Secondly, the distribution of modern plant communities is contingent on the geomorphic stability of the tephra deposits, with tephra thickness and mulching effect being of critical significance. The tephra layer is a non-renewable resource. It is diminishing and cannot be replenished without another volcanic eruption. The tephra is being actively transported to the northeast by wind and water erosion. Continued loss of the tephra layer presents a continuing threat to the biologic communities adapted to the tephra-covered landscape. In addition, future climate change scenarios pointing towards a warmer and drier southwest may accelerate loss of the tephra if plant types, densities, and distribution are affected.

Regional Geological Context and the Age of Sunset Crater Volcano

Wupatki NM has two very different landscapes reflecting its geologic and biologic diversity. Antelope Prairie, the western portion of Wupatki NM, is characterized by low basalt-capped mesas, and broad, wind-swept plains (Figure 4.5.1-2). Wupatki Basin, comprising the eastern portion, is an erosional landscape characterized by the dendritic drainage network of Deadman Wash, black sand dunes, and the erosional surfaces of the Little Colorado River. While the geology of Antelope Prairie consists of resistant Kaibab Formation limestone and Cenozoic basalt

Figure 4.5.1-1. Loose, dark, easily eroded tephra from the ~ 1,000 year old eruption of Sunset Crater blankets the ground surface at Wupatki NM. Photo Credit: NPS/P. Whitefield.

flows, Wupatki Basin has easily erodible Moenkopi Formation sandstone and siltstone, alluvial gravels, and eolian surficial deposits (Figure 4.5.1-3). The boundary between these two areas is dramatically demarcated by the northeast trending Doney Cliffs, formed by the Doney Fault and Black Point Monocline. Occurring on the northeast trending lineament is a series of cinder cones known as the Doney Mountains, portions of which are within Wupatki NM (Graham 2011). Vegetative growth differs in the two areas. Higher rainfall and more fertile soils in Antelope Prairie provide for denser vegetative growth than in Wupatki Basin, where the rain shadow of the San Francisco Peaks create drier conditions. Soils are less fertile in Wupatki Basin too, perhaps due in part to differences in parent material. Soils throughout the monument are influenced by long-term, regional deposition of calcium carbonate-rich loess (Rehies 1999, Broadman and Anderson 2013).

The San Francisco Volcanic Field contains over 600 cinder cone volcanoes, many with associated tephra deposits and lava flows. Older flows date between about 8-5 million years ago (mya), with those closer to Wupatki NM ranging from latest Pliocene (~3 mya) through middle and late Pleistocene. Many are younger than about 800,000 years old (Hanson 2008). Pleistocene cinder cone eruptions deposited tephra across the Wupatki NM landscape numerous times. The fate of such tephra is either burial, erosion, or stabilization and soil formation (USDA et al. 2015). Some of the younger dated cinder cones are the approximately 60,000 year old SP Crater to the west, and 50,000 year old Strawberry Crater to the southwest (Houts et al. 2013, Lapo et al. 2013, Rittenour et al. 2015). Nonetheless, sourcing studies by Hooten et al. (2001) of tephra found on or near the ground surface identified Doney Mountain as the only other source of surficial cinders, besides Sunset Crater.

The Sunset Crater eruption produced a > 300 m (1,000 ft) high scoria cone, with a total erupted volume of ~ 0.9 km^3 (0.2 mi3). The cone may have grown to such a height in a relatively short period of time, perhaps less than a year (Elson et al. 2002, 2007, 2011; Ort et al. 2008). Two separate lava flows, the Bonito and the Kaná

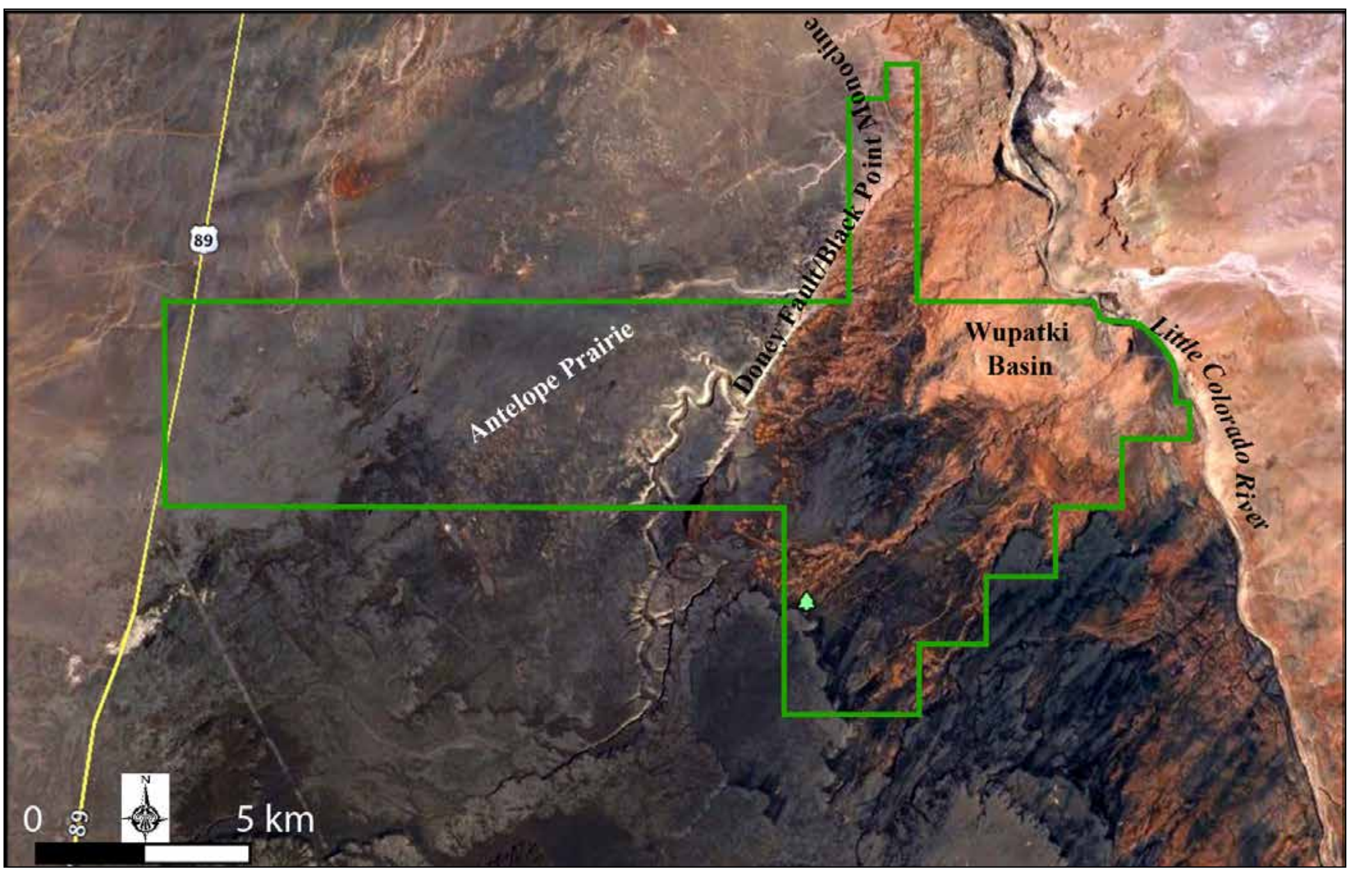


Figure 4.5.1-2. Google Earth aerial image showing physiographic features discussed in the assessment. Darker areas are basalt flows and tephra-covered eolian and alluvial landforms oriented towards the northeast. Lighter tones are Permian and Triassic bedrock formations. Image Credit: © Google Earth.

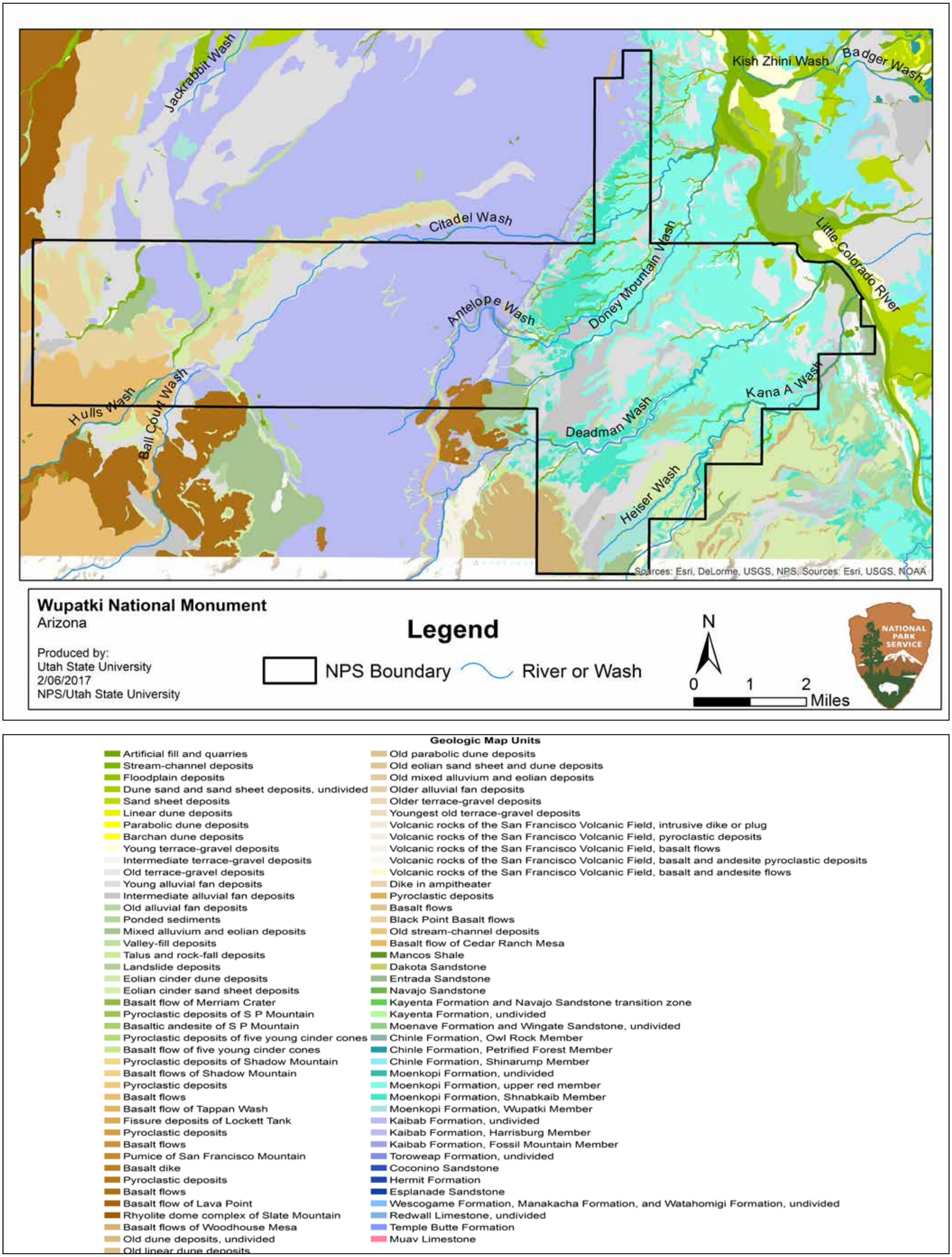


Figure 4.5.1-3. Geologic map of Wupatki NM (Billingsley et al. 2007). Figure Credit: Utah State University.

a flow cover 8 km^2 (3 mi^2). The eruption spread tephra (ash and lapilli size) over an area of about 2,300 km^2 (900 mi^2). In this assessment, we use the terms tephra and cinder interchangeably, while the terms ash and lapilli denote clast size (Table 4.5.1-1). The ash plume was between 8 and 16 km (5 and 10 mi), and the fire fountain between 260 and 660 m (850 and 2,160 ft). The ash plume could have been seen from as far away as present day Palm Springs, Las Vegas, Durango, Colorado, and west central New Mexico and the fire fountain perhaps from southern Utah and the far corners of Arizona. Prehistoric population centers in Chaco Canyon, the Phoenix Basin, and Mesa Verde would have been well aware of the eruption. The last major eruption in Northern Arizona, prior to Sunset Crater and Little Springs Volcano, dammed the Little Colorado River at Grand Falls about 20,000 years ago (Duffield et al. 2006).

Table 4.5.1-1. Definitions of volcanic terms.

Term	Definition
ash	< 2 mm (0.07 in)
lapilli	2-64 mm (0.07-2.5 in)
bomb (or block)	> 64 mm (2.5 in)
tephra	any clastic volcanic material
scoria	vesicular volcanic material
cinder	same as tephra (some definitions have a grain-size component)

Evidence from lava flow properties, stratigraphy of the tephra deposits, and paleomagnetic data indicate that the eruption did not occur over a 200 year period, as was supposed, but most likely did not last more than a year (Ort et al. 2008). Estimates of the age and longevity of the eruption have been debated for decades. The timing, extent, and duration of the eruption is critical to our determination of reference conditions. A brief summary follows.

In 1930, archaeologists from the Museum of Northern Arizona excavated a pit structure buried by a thick layer of black, basaltic tephra, providing the first clues that Sunset Crater erupted during the period when Flagstaff was known to be inhabited by an agrarian society. Subsequent breakthroughs in dendrochronology further refined the eruption to between about AD 1046 and 1071. Continued investigations aimed at dating pre-eruptive and post-eruptive sites using the annual rings of structural beams collected from prehistoric habitations further refined the age to about AD 1061, which Harold Colton adjusted to AD 1066 to account for an unknown length of occupation. Therefore, AD 1066 became the accepted date for the eruption until the discovery of another set of tree rings that illustrated an unusual depression in ring widths.

The University of Arizona's Laboratory of Tree-Ring Research looked at several hundred architectural beams from Wupatki Ruin and noticed that several showed depressed rings at about AD 1064 (Smiley 1958). Surmising that trees damaged by the eruption might respond by stunted growth following the eruption, Smiley determined that the eruption occurred in the year AD 1064, very close to what Colton had determined. Thus the year AD 1064 became entrenched in the literature. However, a re-examination of the trees used by Smiley indicated that most of the examples with depressed rings starting in AD 1064 were from the same tree, and it turned out that only three trees, two Ponderosa pines and one Douglas fir, showed depressed rings. Seeing as how this is a very small data set, and no one knows if these trees had been growing in the ash-fall zone, the AD 1064 date came under suspicion (Elson et al. 2007, 2011). Therefore, in 1999 researchers from Northern Arizona University and Desert Archaeology Inc., began a renewed investigation into the age of the eruption and applied new techniques to this 900 year old problem. Applying dendrochemistry, tree-ring morphology, and paleomagnetic studies, it seems that the age of the eruption is most likely in the AD 1080s. Although the exact date is still in question and research is ongoing, most researchers now lean towards this later date (Elson et al. 2011, Downum 2012).

Archaeological Context – Prehistoric Farming in the Tephra Layer

In order to understand how the tephra layer relates to the distribution of modern vegetation, it is first helpful to review what we know about how the tephra deposits changed the landscape of the prehistoric farmers. We need to consider the tephra blanket within an archaeological context. The eruption of Sunset Crater profoundly affected the Wupatki NM landscape, along with the prehistoric Puebloan people living in the area at the time of the eruption. Approximately 2,000 km^2 (800 mi^2) around the Sunset Crater volcano (what today is Sunset Crater Volcano National Monument) were blanketed with basaltic scoria, lapilli, cinder, and ash, which killed expanses of ponderosa pine forest and pinyon-juniper woodland (Figure 4.5.1-4). People living in this devastated area, volcano refugees, eventually moved to what is now Wupatki NM. Prior to the 11th century eruption there were a few scattered settlements in the Wupatki NM area. After the eruption it became more densely inhabited by large communities that thrived until they migrated out of the area in the late 12th century AD. The monument encompasses 13,330 hectares (ha) (35,400 ac), with more than 3,000 documented archeological sites and cultural features. In 1924 Wupatki NM was established to preserve ancestral Puebloan archeological sites that are of great social, scientific, historic, and educational interest.

At the far range of the deposition, within what is now Wupatki NM, the effect of the eruption was subtle but fundamental to the Puebloan cultural settlement of the area (Figure 4.5.1-4). The thin layer of cinder over the pre-eruptive soil functions to conserve soil moisture, which is the main limiting factor in plant growth in this arid ecosystem. Increased soil moisture increases nutrient availability to plants, which in turn increases ecosystem productivity. Harold Colton, the founder of the Museum of Northern Arizona, coined the phrase “black sand hypothesis” to describe the “prehistoric land rush” that resulted from the newfound ability of the ancient Sinagua and Anasazi farmers to grow corn in this once barren landscape (Colton 1932, 1960, 1965). The positive effect on soil moisture retention and ability to grow corn was verified through corn plot experimentation by Maule (1963), Colton (1965) and more recently by Waring (2006). Anderson (2003, 2006) synthesized our understanding of cinder mulch agriculture related to the eruption of Sunset Crater (Figure 4.5.1-5). In general, seeds do not germinate in soils covered with either less than 2.5 cm (1 in) or greater that 15 cm (6 in) of tephra. Thus, in the absence of the tephra layer, the land that is now Wupatki NM would not support the growth of corn crops. There would have been no settlement, no construction of the large Sinagua Pueblos, and no development of the extensive dry-land agricultural community for which the monument was established. Not only did the tephra layer influence the growth of agricultural plants, but of the natural plant communities as well.

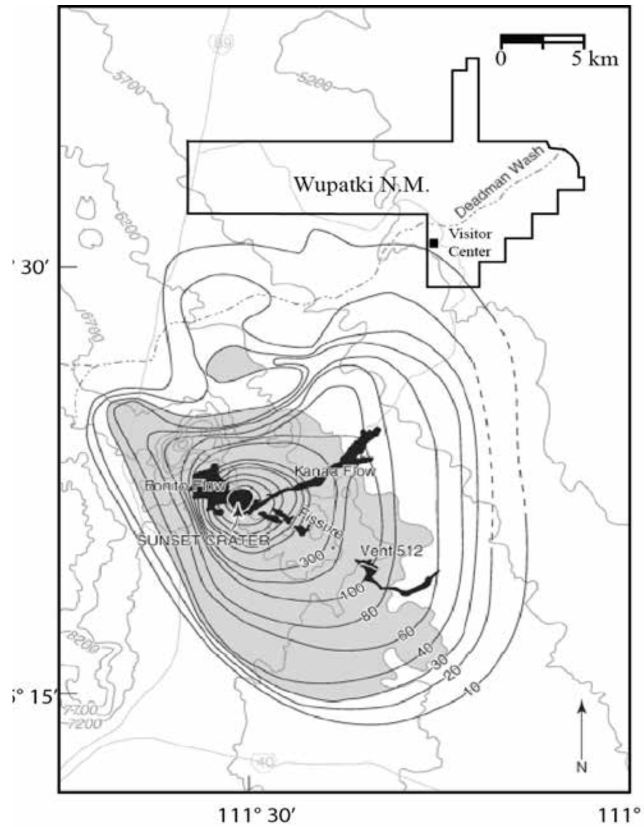


Figure 4.5.1-4. Map of the Sunset Crater lava flows (black), area of abandonment (grey), and tephra thickness in centimeters. Figure Credit: Modified from Ort et al. (2008).

4.5.2. Data and Methods

This assessment relies on data from previous research efforts, and field observations by the author. As far as we know Hooten et al. 2001 is the only previous investigation focused specifically on the tephra layer itself. Three other research efforts that we heavily relied on include the study of plant communities by Hansen et al. (2004), geology by Billingsley et al. (2007a), and soil mapping by the USDA et al. (2015). While these studies supplied valuable information to the assessment, none were tasked with collecting data at the appropriate scale or with the appropriate questions in mind to assess the condition (movement, erosion, stability) of the tephra layer in its various geomorphic settings. Since there has never been a study targeting the stability of the Sunset Crater tephra layer, numerous data gaps exist. To identify conditions and data gaps, field visits were conducted on October 22 and 23rd, 2015 with Paul Whitefield, NPS and Lisa Thomas, NPS; James Harrigan, USDA-NRCS; and William Romme, CSU; on March 31st, 2016 with Paul Whitefield, and the author alone during the summer and fall of 2016. During these visits, it became apparent that surficial characteristics of the geomorphic settings and variability of plant communities could

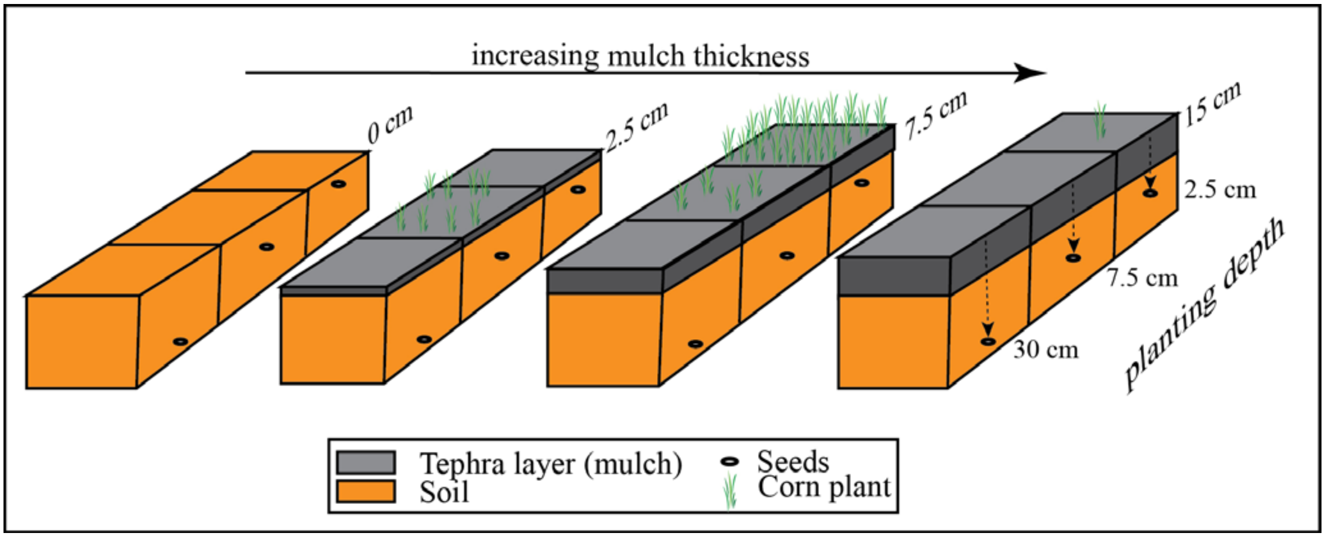


Figure 4.5.1-5. Successful germination of corn occurs where tephra is about 7.5 cm (3.0 in) thick (after Waring 2011). Figure Credit: © Kirk C. Anderson.

be used to inform the assessment. While the scope of this assessment limited collecting quantitative data, qualitative observations have proven useful to this condition assessment.

Soil / Site Stability Indicator

The soil / site stability indicator includes nine measures (soil aggregate stability, organic matter / litter cover, biological soil crusts, stone pavement, wind-scoured blowouts, barren cinder areas, subsoil / bedrock exposure, wind ripples, and plant spacing.

We relied on properties of soil/site stability, hydrologic function, and biologic integrity from Pellant et al. (2005: p.7) to conduct the assessment. Soil stability is the capacity if an area to limit redistribution and loss of soil resources (e.g. nutrients, organic matter) by wind and water. There is very little known about rates of cinder movement (soil/site stability). The Sunset Crater tephra layer is less than 1,000 years old. The youthfulness of this geologic deposit, and the relative ease of transport of the small grain sizes means there has not been enough time or the right conditions to develop resistant surface layers, such as soil horizons or crusts. There may be an O horizon of limited extent and thickness, but there is essentially no A horizon, aggregate stability, stone pavement, or biological soil crusts to hold sediment in place. Qualitatively, large areas of barren cinders with wind ripples indicate active erosion of the tephra layer.

Hydrologic Function Indicator

The hydrologic function indicator refers to the capacity of an area to capture, store, and release precipitation, and to resist the reduction and to recover capacity when a reduction does occur. Measures such as rates of infiltration and runoff, presence and extent of rills, terraces, and hardpans are important properties in which to understand the influence of the tephra layer on water holding capacities and were used as condition measures. How does the infiltration rate and storage capacity vary with different thicknesses, grain sizes, and surface covers?

Biotic Integrity Indicator

Biologic integrity refers to the capacity of a biotic community to support ecological processes within the normal range of variability expected for a site, to resist any reduction and to recover after a reduction does occur. We illustrate the biologic integrity using five vegetation communities as measures of condition.

Modern Vegetation and the Tephra Deposits

This section incorporates the vegetation mapping units from the U.S. Geological Survey (USGS)-National Park Service (NPS) National Vegetation Mapping Program for Wupatki NM to relate geomorphic stability of the re-worked tephra deposits to specific vegetation associations (Hansen et al. 2004). In general, vegetation associations used for our condition assessment include juniper savanna, grassland, and a variety of shrublands. The five geomorphic and vegetation associations discussed below illustrate specific settings where the tephra and vegetation are related. Additionally, these five examples broadly correlate with the eight ecological sites identified in the Soil Survey of Wupatki NM (USDA et al. 2015). Our five settings, termed “ecosites,” do not correlate directly with the eight ecological sites of the USDA et al. (2015).

Elevations range from 1,310 m (4,300 ft) along the Little Colorado River on the eastern boundary, to 1,705 m (5,600 ft) near the southwestern corner. The climate is hot and dry. The mean annual temperature of Wupatki NM is 22°C (71.8 °F), with 43°C (109°F) the all time high. Wupatki NM has about 82 days with the temperature ≥ 32°C (90°F). The mean annual precipitation is 21 cm (8.11 in), with a maximum of about 36 cm (14 in) in 1983 and a minimum of 10 cm (4 in) in 1989. The rain shadow of the San Francisco Peaks causes Antelope Prairie precipitation of 25 – 36 cm (10-14 in) to be slightly higher than the 15 – 25 cm (6-10 in) in Wupatki Basin (USDA et al. 2015). Wupatki NM has about 49 days with precipitation ≥ 0.02 cm (0.01 in) (wrcc@dri.edu). Additionally, even though Wupatki NM is hot it still has about 100 days when the temperature is ≤ 32°F (0°C) (wrcc@dri.edu).

The tephra deposits covering vast areas of Wupatki NM factor into the vegetation inventory report of Hansen et al. (2004), with five associations directly related to (possibly dependent on) the cinder layer. The five vegetation types associated with the cinder terrain are the following: (1) Barren landscape covered by cinders with no vegetation, (2) Crispleaf Buckwheat Cinder Shrubland, (3) Mormon Tea Cinder Dune Shrubland, (4) Apache Plume Cinder Shrubland, and (5) One-seed Juniper Woodland. These five mapped units are intimately associated with the cinders from Sunset Crater, comprising approximately 20% of the mapped vegetation types within Wupatki NM. Some selected geomorphic characteristics of these mapped units are discussed below.

Barren landscapes covered in cinders are intriguing because it is unclear why they are barren and other areas with cinders are associated with certain vegetation types. It may be that the cinders are actively being transported and therefore plants cannot take hold. It may be that the cinders lay directly on bedrock and therefore there is no soil for plants to root into. Or it may be that the cinders are too thick and plants cannot grow up and through the thick cinders. More investigations need to be undertaken in order to understand this setting.

Crispleaf Buckwheat Cinder Shrublands occur on the leeward sides of cliffs descending from high mesas. These geomorphic settings are termed falling dunes. For example, close to the Wupatki NM Visitor Center falling dunes originate atop Woodhouse Mesa and blanket the slopes with thick cinder deposits, commonly with little or no vegetation (Figure 4.5.1-6). Crispleaf Buckwheat (and Apache Plume) occur along the slope and at the more densely populated toes of the slope where moisture concentrates.

The Mormon Tea Cinder Dune Shrubland community is in moderately thick cinder deposits, ranging from about 0.6 to 1.2 m (2 to 4 ft) where cinders accumulate under vegetation, such as ephedra, to form mounded cinder dunes, also termed coppice dunes (Table 4.5.1-2). From an aerial perspective the coppice dunes present a dotted pattern with ephedra at the center of the partially stabilized dunes, surrounded by barren areas (Figures 4.5.1-7, 4.5.1-8, and 4.5.1-9). The coppice dunes occur within a larger pattern of linear dunes and tributary drainages oriented towards the northeast. Extensive wind ripples on the barren areas between ephedra-covered dunes attest to the active transport of the cinders across the landscape.

The Apache Plume Cinder Shrubland is “one of the major shrub map classes at Wupatki NM, and the dominant map class in non-wooded areas covered with volcanic cinders” (Hansen, et al. 2004). Geomorphic characteristics of this map unit include broad cinder-covered areas where Apache Plume has clumps of cinders, not unlike the coppice dunes that are colonized by Mormon Tea.

Table 4.5.1-2. Examples of four geomorphic/ ecosite settings of cinder deposits.

Geomorphic Setting	Ecosite Correlate (Hansen et al. 2004)
Coppice dune fields	Mormon Tea Cinder Dune Shrubland
Deep cinder deposits in depositional areas (Falling dunes, scarps, etc.)	Apache Plume Cinder Shrubland
Playette/grass mound landform	Juniper Cinder Wooded Herbaceous Vegetation and Grasslands
Deep cinder mounds	Juniper Cinder Wooded Herbaceous Vegetation

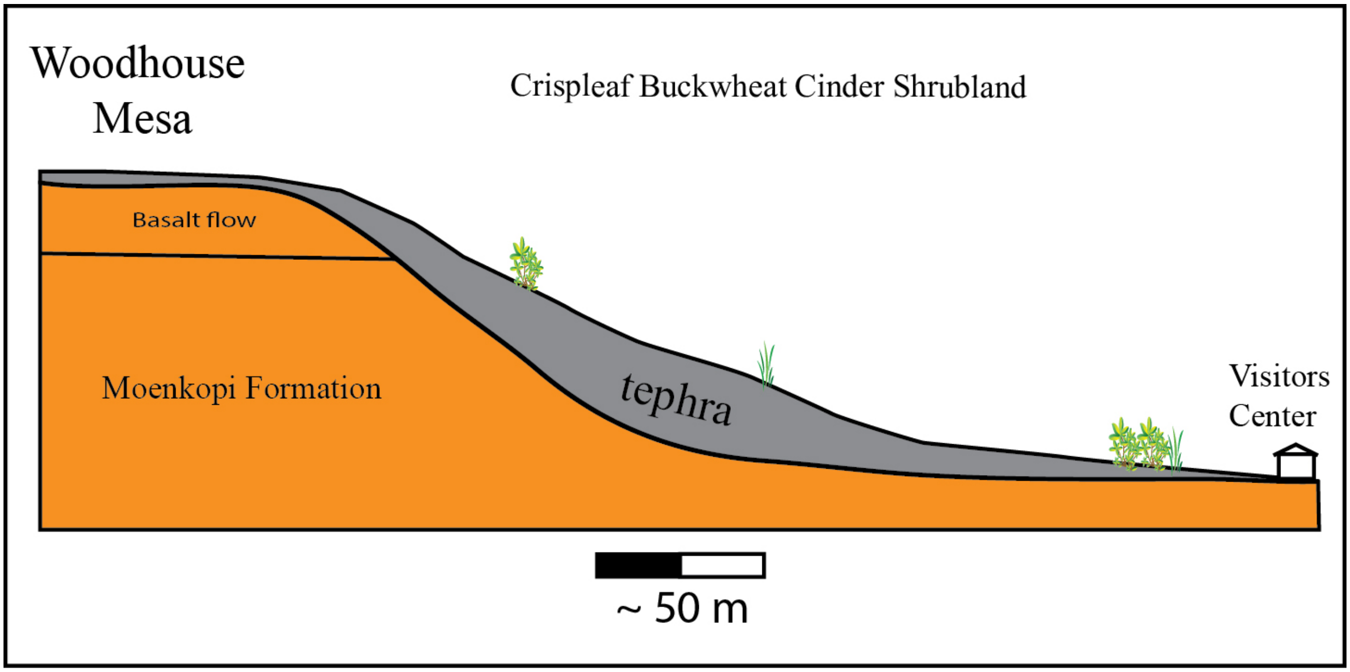


Figure 4.5.1-6. Thick tephra deposits form falling dunes on the leeward side of Woodhouse Mesa where the Crispleaf Buckwheat Cinder Shrublands are found. Figure Credit: © Kirk C. Anderson.

The One-seed Juniper Woodland, dominated by *Juniperus monosperma* occurs in the Cinder Wooded Herbaceous Vegetation area, dominating the southwestern section of the project boundary including Antelope Prairie (Figures 4.5.1-10 and 4.5.1-11). As illustrated in the four examples of the geomorphic setting discussed above, we see a strong correlation between cinder deposits and plant communities.

Another geomorphic setting where the relation between cinder cover and vegetation is apparent are the vast expanses of blowouts in Antelope Prairie. The blowouts become small playas, or playettes, in proximity to mounds and small terraces of cinders covered by grasses. We term these "playette-grass mound" couplets (Figures 4.5.1-12 and 4.5.1-13). Although there have been no studies of erosion in these settings, it appears that the grass mounds are slowly disappearing at the expense of the playettes, as they are expanding.

4.5.3. Reference Conditions

In order to initiate a functional, long-term condition assessment of the tephra layer a useful, identifiable reference condition needs to be determined. As such, there are two reasonable possibilities. One is the immediate aftermath of the ashfall blanket across the landscape. The second is the present day conditions of the different plant community-cinder cover settings. Consideration of the immediate aftermath of the eruption seems reasonable since there was a relatively even aerial distribution of a ≤ 10 cm (≤ 4 in) cinder cover, making comparisons to modern day cinder cover and thickness straightforward. However, this is not an optimum nor a desired reference condition. Over the last 900 years or so, the tephra layer has undergone significant changes to its distribution and thickness, by natural wind and water erosion processes; by prehistoric farming; by cattle grazing; by fires; and by land management. Additionally, it could be argued that because of the relative youthfulness of the deposit, the unconsolidated nature of the loose sediment, and its constantly mobile and ever-changing distribution, the tephra layer has never attained anything resembling a steady state or even a quasi-equilibrium condition with its surrounding physical and biological environment.

Finally, there are no studies that have directly targeted the re-worked cinder layer and its relationship to the landscape, including the various geomorphic settings and biological community associations.

Therefore, it seems to this author that the most useful reference condition is the present day geomorphic and biologic setting. We can consider the present condition as a marker or benchmark from which to move forward to assess changing conditions. This

Figure 4.5.1-7. Google Earth aerial image showing light grey to pale green rounded mounds of coppice dunes colonized by ephedra and other shrubs. Black areas are barren black tephra from Sunset Crater. Note both the drainage (right) and lines of coppice dunes (center) are towards the northeast. Black dots are juniper trees. Image Credit: © Google Earth.

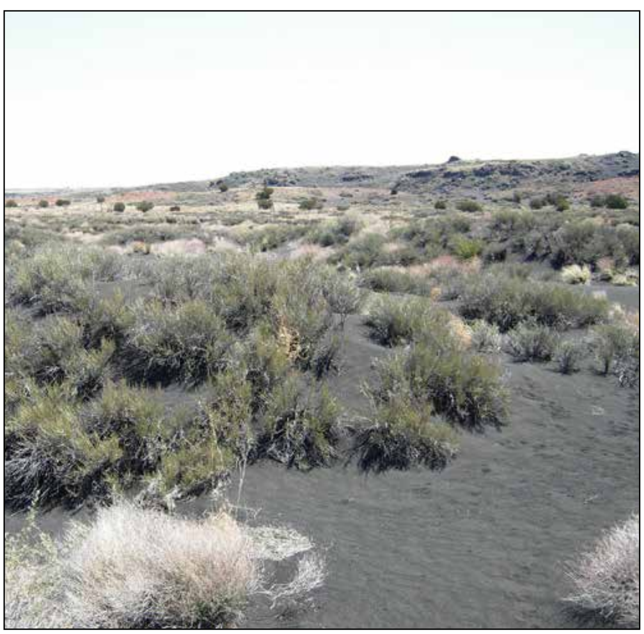


Figure 4.5.1-8. Mormon Tea Cinder Dune Shrubland. Ripple marks (lower right) illustrate mobility of tephra particles. Coppice dune is ~ 2m high by 6 m diameter (6 ft by 18 ft). Photo Credit: NPS/P. Whitefield.

also identifies the most important data gap, that is, the modern distribution, thickness, and stability of the Sunset Crater tephra layer. Besides the author's professional opinion, additional reference condition sources for soil stability included: Bowker et al. (2007), Schoenberger et al. (2012), Soil Conservation Service (2014), and USDA et al. (2015); for hydrologic function they include: USDA et al. (2015), and for the biologic integrity they include: Hansen et al. (2004) and USDA et al. (2015).

4.5.4. Condition and Trend

The eruption of Sunset Crater Volcano in the 11th century AD covered the Wupatki NM landscape with ≤ 10 cm (4 in) of ash and lapilli, which was rapidly reworked into a discontinuous cover of variable thickness. The tephra layer acted as a mulch to increase crop yields for prehistoric agriculturalists, and today the mulching effect increases soil moisture for native plant communities. One hundred years of

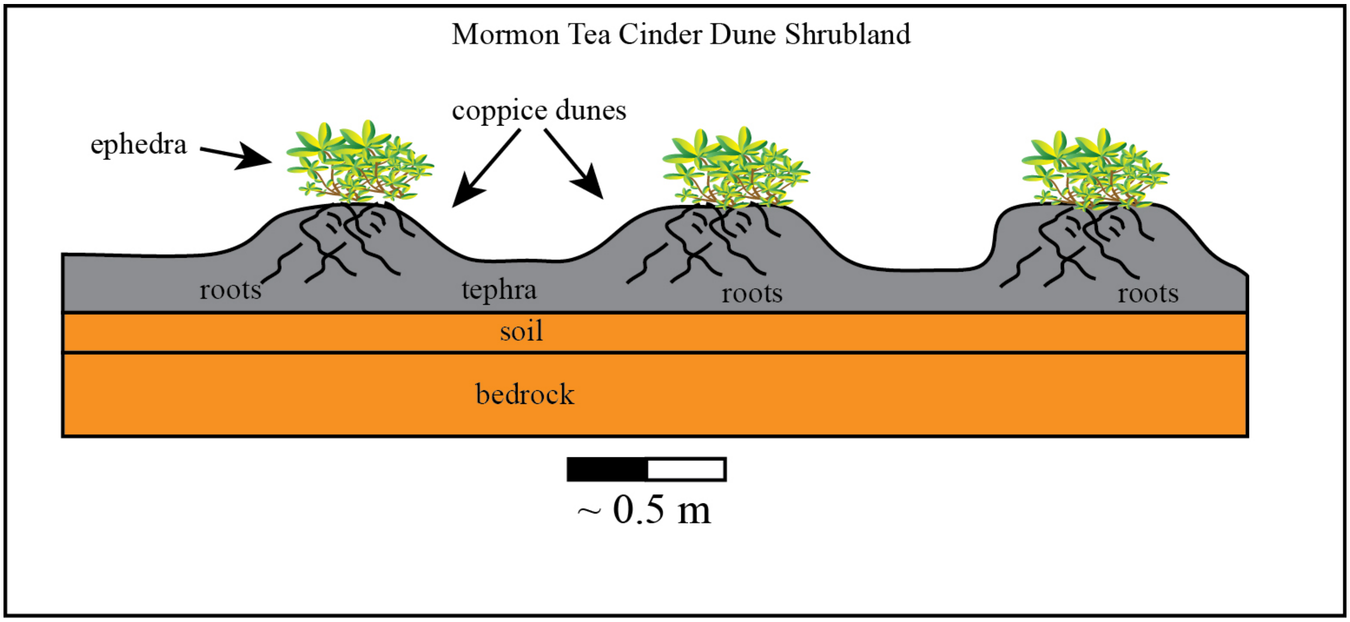


Figure 4.5.1-9. Cross-section of black coppice cinder dune field illustrating the geomorphic setting of the Mormon Tea Cinder Dune Shrubland of Hansen, et al. (2004). Figure Credit: © Kirk C. Anderson.

grazing, from about 1890-1990, caused disturbance of the cinder and soil cover throughout Wupatki NM.

The young, loose, and unconsolidated ash and lapilli is an actively mobile surface sediment that provides a tenuous perch for plant communities. The tephra layer has most likely never achieved anything resembling an equilibrium, or even quasi-equilibrium geomorphic condition. The limited supply of these non-renewable cinders are constantly being transported downwind and downslope, both towards the northeast. The ultimate repository for the cinders is the Little Colorado River, which transports them downstream and away from Wupatki NM. In short, based on field observations, the vast majority of cinders are in unstable geomorphic and ecosite conditions. The vegetation mapping program of Hansen et al. (2004) provides an excellent starting point from which to build a database on geomorphic setting and stability of the cinders, and their importance to plant communities in Wupatki NM. Even though Hansen et al. (2004) and the USDA et al. (2015) provide useful information on plant communities and soil types, respectively, the appropriate scale of investigation and data collection for these projects was not tasked to specifically target the Sunset Crater tephra layer. Therefore, data gaps addressing the appropriate questions at the appropriate scale are numerous and are discussed in the Threats, Issues, and Data Gaps section.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Table 4.5.4-1 summarizes our evaluation of Wupatki NM's Sunset Crater tephra layer assessment. The table includes condition status, trend, if available, confidence level, and condition rationale for each indicator and associated measures.

Figure 4.5.1-10. Juniper Cinder Wooded Herbaceous Vegetation. Cinder mounds are mobile; grass-covered areas are stable. Photo Credit: © Kirk C. Anderson.

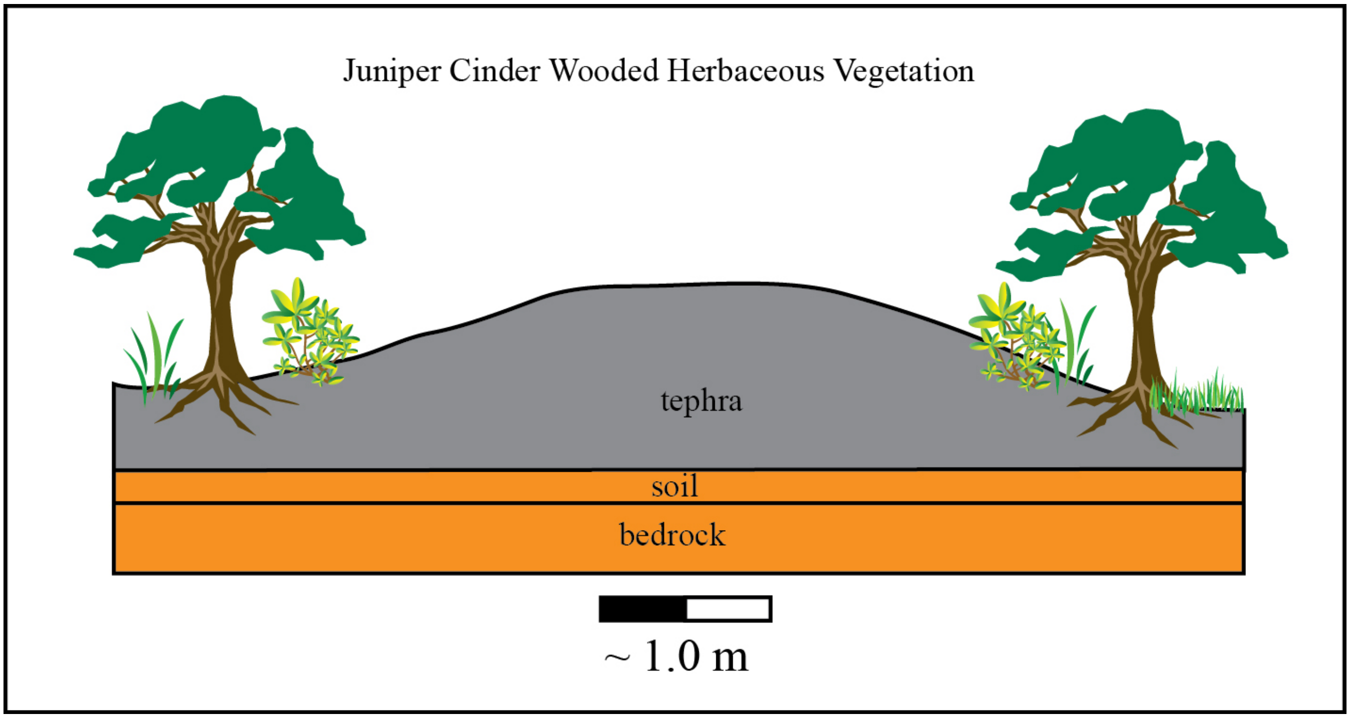


Figure 4.5.1-11. Cross-section of thick cinder areas showing geomorphic setting of the Juniper Cinder Wooded Herbaceous Vegetation areas. Thick cinder deposits may inhibit germination. Figure Credit: © Kirk C. Anderson.

Numerous data gaps exist because the properties of the tephra layer have not been specifically targeted for investigation. Nonetheless, key qualitative indicators such as the widespread, barren areas covered with loose, unconsolidated cinders, wind-scoured blowouts, and active wind ripples clearly represent severe wind erosion and deteriorating conditions. The lack of any type of protective surface layer (e.g. soil horizons, biological crusts, stone pavements) indicates the tephra deposits are not likely to become stabilized in the near future. Based on these observations, there is a high confidence that the condition of the tephra layer is deteriorating, and warrants significant concern. Continued loss of the tephra will adversely affect associated plant communities throughout the monument.

Figure 4.5.1-12. Terracettes and playettes. Grassy mounds are decreasing in size at the expense of the expanding blowout areas and playettes (visible in the background). Photo Credit: © Kirk C. Anderson.

Threats, Issues, and Data Gaps

Baseline data collection would improve the monument's ability to manage this resource, since there has been essentially no targeted work on the influence of the Sunset Crater tephra blanket on plant community health. Data collection might include three spatial scales. Large-scale mapping of aerial extent and thickness of the tephra blanket for the entire Wupatki NM area could be achieved using aerial photography, LiDAR, and multi-spectral remote sensing techniques. Second, meso-scale analysis of the geomorphic/ecosite stability of targeted plant communities would necessitate the identification and location of "sensitive" areas of each ecosite and determining plant types, diversity, distribution, canopy and basal gaps, and overall plant health and vitality. Geomorphic mapping of landform elements within each ecosite

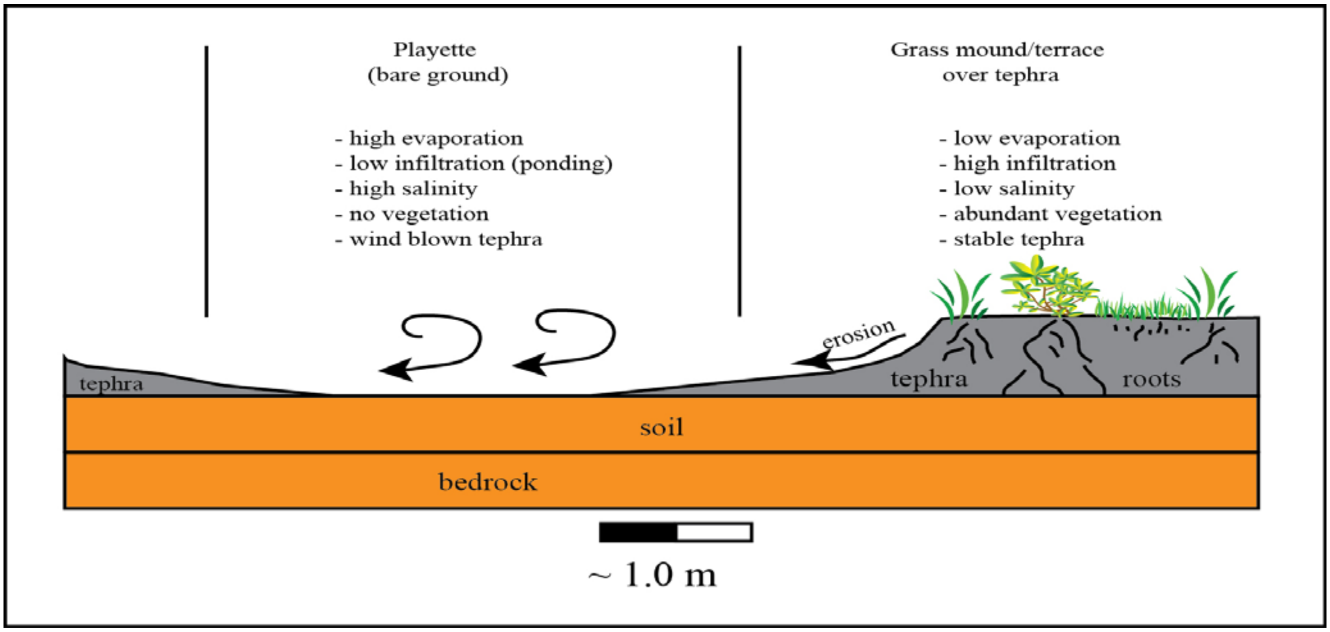


Figure 4.5.1-13. Cross-section of blowout areas illustrating the geomorphic setting of grass-covered mounds and blowouts. Note how the cinder cover influences hydrology and therefore vegetation. Figure Credit: © Kirk C. Anderson.

would identify important geomorphic processes influencing each site.

Third, the micro-scale focuses on properties of the cinders, soils, and substrates. Properties and processes to measure include rate and depth of infiltration, soil moisture and temperature during different seasons, aggregate stability, O horizon properties, and nutrient cycling. Additionally, rates of cinder movement across the landscape should be measured using ground-based LiDAR at selected ecosites.

These three scales are designed to characterize the present reference conditions by collecting qualitative and quantitative data so that future assessments will be able to identify trends of the resource condition.

Erosion of the Tephra Layer/Loss of Plant Communities
Erosion of the tephra is the primary concern because of its ecological importance to plant communities. Threats to the resource are the strong seasonal winds, sparse plant cover, and low amounts of organic matter turnover in this hot and dry climate. Imagine Wupatki NM without the black sand dunes and sand sheets, and the image is one of a windswept, scoured, barren landscape. The tephra layer is a medium for plant growth, helps increase soil moisture, and reduces erosion of overland flow. We know, however, that the cinders are a non-renewable resource, that they have been eroding from the Wupatki NM landscape since they were first deposited, and that they are constantly being removed by wind and water erosion. What we do not know is the rate of erosion today, the variable rates of erosion in the past, or how erosion rates might change in the future. It is also possible that at least some parts of the Wupatki NM landscape have not re-established some type of geomorphic stability in reference to pre-eruption conditions.

Why are the cinders so susceptible to erosion? Erosion of the tephra is due in large part to five factors. First, the small grain size of the ash and lapilli particles makes them easily transported by wind. Second, the basaltic particles are irregular and jagged, have no cohesion for one another, and have a low density, again making them more easily transported. Third, the tephra layer is too young for any significant degree of soil development. In older soil, particles become aggregated by organic matter, microbiota, salt accumulation, and adhesion by clay-sized constituents. None of these processes is significant for the young, loose, poorly consolidated cinders. Fourth, the geology and landform positions are favorable to eolian transport. Mesas, lava flows, alluvial deposits, dunes, the major fault, and the dip of the Black Point Monocline all trend towards the northeast. Essentially all sediment transport vectors favor movement towards the northeast, across the generally broad, flat, barren expanses of exposed

Table 4.5.4-1. Summary of Sunset Crater tephra layer indicators, measures, and condition rationale.

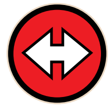
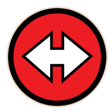
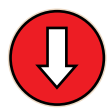
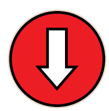
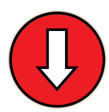
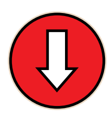
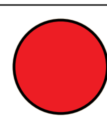
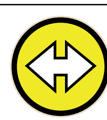
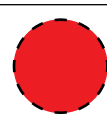
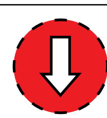
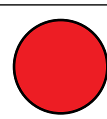
Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Soil / Site Stability	Soil Aggregate Stability: Does the tephra form aggregates that are resistant to erosion?		Youthful, mobile ash and lapilli have no aggregate stability; loose, unconsolidated particles easily eroded (Schoenberger et al. (2012), Soil Survey Staff (2014), USDA et al. (2015), and authors' professional opinion).
	Organic Matter (O horizon): Does organic matter protect from erosion?		Youthful ash and lapilli have no O horizon, except in isolated areas below vegetation (Schoenberger et al. (2012), Soil Survey Staff (2014), USDA et al. (2015), and authors' professional opinion).
	Biological Soil Crusts: Does the BSC protect from erosion?		Youthful, mobile ash and lapilli have no soil crusts (Bowker et al. (2007) and author's professional opinion).
	Stone Pavement: Is there a protective layer of stones that help stop erosion?		Youthful, mobile ash and lapilli have no stone pavement (USDA et al. (2015) and author's professional opinion).
	Wind-Scoured Blowouts: How large an area is eroding by wind?		Youthful, mobile ash and lapilli cover large blowout areas (author's professional opinion).
	Barren Cinder Areas: How large of an area is devoid of vegetation and therefore subject to erosion by wind and water?		Youthful, mobile ash and lapilli accumulate thick layers over large areas (Hansen et al. (2004), USDA et al. (2015), and author's professional opinion).
	Subsoil / Bedrock Exposure: How large of an area is present of hardpan or bedrock exposed where cinders cannot accumulate for very long?		Large areas have bedrock exposure (USDA et al. 2015 and author's professional opinion).
	Wind Ripples: How large of an area are wind ripples exposed to illustrate active wind erosion?		Mobile ash and lapilli form wind ripples in widespread areas (author's professional opinion).
	Plant Spacing: How much barren area is exposed between plants that is mobile and easily eroded? Is this area expanding or contracting?		Data gap -unknown trend (Hansen et al. (2004) and author's professional opinion).
Hydrologic Function	Rainfall Infiltration / Runoff: How rapidly and how deep does precipitation infiltrate into the tephra, and how long is it stored?		Rapid infiltration through loose cinders may store moisture, but shallow bedrock may promote runoff (author's professional opinion, Schoenberger et al. (2012), and USDA et al. (2015)).
	Rills: What is the extent of erosional rill networks?		Data gap -unknown trend (Schoenberger et al. (2012), USDA et al. (2015)).
	Terracettes / Pedestals: Is wind and water erosion increasing or decreasing their coverage?		Data gap –declining trend.
	Presence of Hardpan / Bedrock: How deep or shallow is bedrock below barren cinders? (Implications for wind and water erosion)		Data gap -unknown trend (Schoenberger et al. (2012), USDA et al. (2015)).

Table 4.5.4-1 continued. Summary of Sunset Crater tephra layer indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Biotic Integrity	Crispleaf Buckwheat Cinder Shrublands: Are these communities improving or declining in health and extent?		In relation to tephra properties there is a data gap and unknown trend (Hansen et al. 2004, USDA et al. 2015).
	Mormon Tea Cinder Dune Shrubland: Are these communities improving or declining in health and extent?		Coppice dunes indicate dynamic, unstable landscape. Author's professional opinion (Hansen et al. 2004, USDA et al. 2015).
	Apache Plume Cinder Shrubland: Are these communities improving or declining in health and extent?		In relation to tephra properties there is a data gap and unknown trend (Hansen et al. 2004, USDA et al. 2015).
	One-Seed Juniper Woodland (Cinder Wooded Herbaceous): Are these communities improving or declining in health and extent?		Juniper woodlands can be persistent or dynamic, but in relation to tephra properties there is a data gap (Hansen et al. 2004, USDA et al. 2015).
	Grasslands/Grass-Covered Cinders: Are these communities improving or declining in health and extent?		In relation to tephra properties there is a data gap and unknown trend (Hansen et al. 2004, USDA et al. 2015).
Overall Condition			Overall, the condition of the Sunset Crater tephra layer at the national monument is of significant concern, with a deteriorating trend due to the easily erodible youthful, unconsolidated, ash and lapilli; a hot, dry climate with strong seasonal winds; and generally sparse plant cover. Confidence in the data is high.

bedrock. Finally, strong winds are out of the southwest for much of the year.

Recall that the original thickness of the deposits in Wupatki NM was ≤ 10 cm (4 in), with much of the original deposits being reworked by wind and water shortly after deposition. According to Hooten et al. (2001) it is difficult to find locations of original cinders within Wupatki NM. Constant reworking over the last 900 years produced a very mobile layer of irregularly scattered cinders. Some places are totally devoid of cinder cover, while others have accumulated a meter or more under vegetation and on the lee sides of cliffs. The results of wind redistribution of the tephra are illustrated by Billingsley et al. (2007a) who mapped concentrations of tephra in the form of "eolian cinder dunes" and "eolian cinder sand sheets." These are areas of thick cinders with sparse vegetative cover.

In Wupatki Basin in particular, active cinder movement can be inferred from the northeast oriented linear dunes and alluvial deposits. These landforms represent conveyor belts moving the limited supply of Sunset Crater cinders northeast towards another conveyor belt, the Little Colorado River, which removes them from this geomorphic system. Aerial images starkly illustrate that the black cinders do not make it across the Little Colorado River.

Finally, erosion rates are commonly determined by in-field measurements of sediment yield, which is the weight of captured sediment in a given area (e.g. square meters), for a time interval (e.g. number of years). To date, there have been no studies of sediment yield in Wupatki NM. Sediment yield is strongly influenced by a complex set of factors, including effective precipitation, soil types, vegetative cover, runoff, and land-use. In general, grasslands and grass-covered understory produce less sediment (less erosion) than open shrubland and woodland.

Fate of the Cinders over Time

As discussed above, erosion rates are complexly related to climatic, geomorphic and biologic factors.

In addition, land-use influences erosion of the cinder layer. Below is a brief discussion of periods when erosion of the cinder layer may have been influenced by land-use (Appendix E).

Pre-eruption Landscape

The pre-eruptive ground surface of Wupatki NM consisted of the Kaibab and Moenkopi Formations, basalt flows, and various surficial deposits including eolian, alluvial, and cinders from older volcanic eruptions. Soils that formed in these various deposits vary according to climate, plant and animal activity, slope, parent material, and age. Recent soil mapping by the NRCS identified several soil types that developed in older cinders. These soil types are characterized by volcanic properties with taxonomic classifications such as Vitrandic Torriorthents, Vitrandic Torrispamments, Vitrandic Haplocambids, and Vitrandic Haplocalcids. The vitrandic subgroup identified soils with a layer of cinders at the surface (USDA et al. 2015). The occurrence of these soils, developed in older tephra deposits, merely illustrates one of the ways that cinders may persist on the landscape, namely in the form of stable surfaces with moderate to well-developed soils. In general, soils are relatively stable because they have good aggregation of particles due to the chemical and physical weathering of particles, and to the additions of cementing agents such as calcium carbonate, from loess deposition. While the chemical and physical breakdown of basaltic cinders in this arid landscape is quite slow, the addition of eolian dust accelerates the soil forming processes (McFadden et al. 1986, 1987; Reheis 1999). Aerosolic additions of clay, sand, and silt with different chemical compositions weather at different rates than basalt. The silt and clay-sized fractions alter the texture of the cinder layers, making them hold water longer as well. Finally, aerosolic deposition includes soluble constituents such as halite, gypsum, and calcium carbonate, thus providing abundant materials for increased rates of salt weathering, and for the formation of natric, gypsic, and calcic soil horizons. A common pre-eruptive soil would have been characterized by vesicular A horizon (Av) high in silt, clay, salts, and nutrients (Anderson et al. 2002, Reynolds et al. 2012; Broadman and Anderson 2013).

Eruption and Prehistoric Land-use (AD 1080-1300)

The eruption occurred in the late 11th century AD. Initially the landscape was covered in cinders, adversely affecting vegetation and increasing erosion, as seen following the eruption of Paricutin (Mexico) in 1943 (Elson et al. 2011). It would have been a windswept landscape for several years following the eruption, with cinders blowing around incessantly. Much of the primary ashfall would have blown downwind and washed downstream, thus being removed from Wupatki NM. What remained was an irregular distribution of secondary deposits of varying thickness and aerial extent. Where cinders accumulated in the right area and the right thickness, native vegetation benefited, just as the cultivated plants of the Sinagua.

Wind erosion was a problem for the post-eruptive agriculturalists from the beginning. Ironically, the ash and cinder mulch that conserved soil moisture also proved exceedingly detrimental to the young seedlings. Strong Spring winds blew the sharp-edged, glassy tephra around the landscape, shredding the plants. In response, the farmers constructed thousands of agricultural features amounting to hundreds of kilometers of rock alignments (Colton 1960, Marozas 1983, Brown 1996). As Travis (1990) states "The presence of thousands of rock alignments, aligned in a northwest-southeast manner to protect against the prevailing winds, testifies to the damaging effects of wind." Berlin et al. (1977) identified areas of agricultural mounds made of cinders, and inferred that the tephra needed to be properly managed to improve crop yields which, according to Brown and Rosenberg (1975) will increase by about 14% through the use of wind breaks. Edwards (2007) investigated nutrient cycling in relation to agricultural features and determined that the rock alignments and windbreaks trap organic matter and sediment, thereby adding nutrients to the soil. As another twist to the story, Colton (1960) suggested that loss of the cinder mulch contributed to Sinagua residents migrating out of the area by the by AD 1300.

The Sinagua undoubtedly altered their environment by cutting down trees for firewood and building construction. This may have resulted in the loss of many of the juniper trees in the area, accelerating wind and water erosion. In addition, prehistoric farming activities would break up the surface soil and disturb the stone pavements, further increasing erosion by wind and water. Countering these activities, however, would be the construction of windbreaks, acting to decrease wind erosion.

Post--Sinagua Recovery (AD 1300-1800)
After the Sinagua left the area in about AD 1300, there were about 500 years until people began using the area again. For this period of time there was no harvesting of wood and no need for windbreaks. The landscape was allowed to recover which would include the reestablishment of junipers in areas where they had been cleared. However, the aerial extent, density, and changing vegetation types would have helped to improve geomorphic stability, or hindered it. In addition, although paleoclimate records for this time period are good, it is difficult to know precisely how the numerous droughts influenced vegetation cover and cinder movement (Salzer and Kipfmueller 2005). Droughts may have increased grassland at the expense of juniper expansion. During periods of juniper expansion, however, the open understory would have been more susceptible to erosion. One of the data gaps is whether cinders move more readily in grassland, savanna, or wooded settings, and what the transitional periods from one type of vegetation community to another would have been like regarding geomorphic stability of the cinder deposits.

Livestock Grazing (AD 1800-1989)
In the 1800s, Navajo herded sheep in the area. This was halted in the 1880s by cattle ranchers who took over the land (Kuenert 1989). Cows grazed in what is now Wupatki NM for about 100 years, until it was stopped in 1989 by the NPS. During this time, cattle trampled the soil, pulverized potsherds, and walked across archaeological sites, most likely causing harm rather than good to the architectural elements of houses and fields. Cows trampling the surface soils for 100 years broke up soil crusts, thereby increasing both wind and water erosion.

NPS Management
NPS stopped grazing in 1989 and limited access to back country visitation shortly thereafter. This reduced disturbance caused by both human and cattle traffic. Nonetheless, maintenance infrastructure, including roads, trails, and buildings, impacted the landscape. Future NPS activities of a similar nature could adversely affect the tephra layer.

Future Climate Changes
The southwest U.S.A. has one of the best paleoclimate records in the world, as reconstructed by dendroclimatic methods (Garfin et al. 2013). The climate of the area has been highly variable for much of the Holocene, both spatially and temporally. Climate changes since the eruption of Sunset Crater have been significant enough to cause changes in plant communities, particularly juniper woodlands and grasslands (Ironsides 2006). The influence on the tephra stability and erosion is unknown, though it is probable that grasslands hold the cinders in place more than open juniper woodlands. Future climate changes predicted to be warmer may aid the spread of grasslands, thereby providing for more stable cinder deposits. Predicting rainfall changes is more tenuous, and the influences on the vegetation transitions remains elusive. Transitional states, such as changes in established vegetation communities or geomorphic settings, are times when the landscape may be at an increased threat of erosion. Based on the last 30 years of increasing regional (and global) temperatures, the southwest may be experiencing a transitional phase at this time, when cinder stability (and vegetation communities) becomes increasingly vulnerable to erosion. By designating the previously discussed geomorphic and ecosite settings as the reference conditions we can begin to address data gaps in order to better assess the effects of future climate changes.

4.5.5. Sources of Expertise
Dr. Kirk Anderson is a geomorphologist at the Museum of Northern Arizona in Flagstaff, AZ. He has conducted research and co-authored numerous publications and reports on the eruption of Sunset Crater.

4.6. Geomorphic Stability of Intermittent, Ephemeral Streams

4.6.1. Background and Importance

Wupatki National Monument (NM) protects 14,335 ha (35,422 ac) of grassland prairie and desert habitat in the southwestern corner of the Colorado Plateau geologic province, which includes parts of Arizona, New Mexico, Utah, and Colorado (Figure 4.6.1-1; Graham 2011). The monument is divided roughly in half by the Doney Mountain Fault with distinct geology on either side. To the east of Doney Mountain Fault lies the Wupatki Basin, which is a large, low-lying area characterized by open desert scrub vegetation that occurs primarily on terrace benches (Hansen et al. 2004, Graham 2011). These terraces are incised by several intermittent, ephemeral stream channels that drain into the Little Colorado River to the east (Graham 2011). In the Doney Cliffs there are numerous arroyos and washes that also drain into the Little Colorado River (Graham 2011). On Antelope Prairie, west of Doney Mountain Fault, the monument's landscape is characterized by open one-seed juniper (*Juniperus monosperma*) savanna and grassland vegetation with fertile volcanic soils (Hansen et al. 2004, Graham 2011). Volcanic activity has played a significant role in the monument's present day geology and soils. The most recent volcano erupted approximately 1,000 years ago creating Sunset Crater to the south of the monument. Approximately 5 to 10 cm (2 to 4 in) of ash from the Sunset Crater eruption was blown over the entire monument during this eruption (Graham 2011) (note, volcanic soils are addressed in a separate assessment).

Present day soils and vegetation in the monument are a result of the region's rich and varied geologic past that spans approximately 300 million years (Graham 2011). Multiple layers of sedimentary, volcanic, and surficial rock features are exposed within the monument, and each is distinct in color, grain size, mineral composition, and rate of weathering. Figure 4.6.1-2 summarizes the geologic history of the monument (see Billingsley et al.

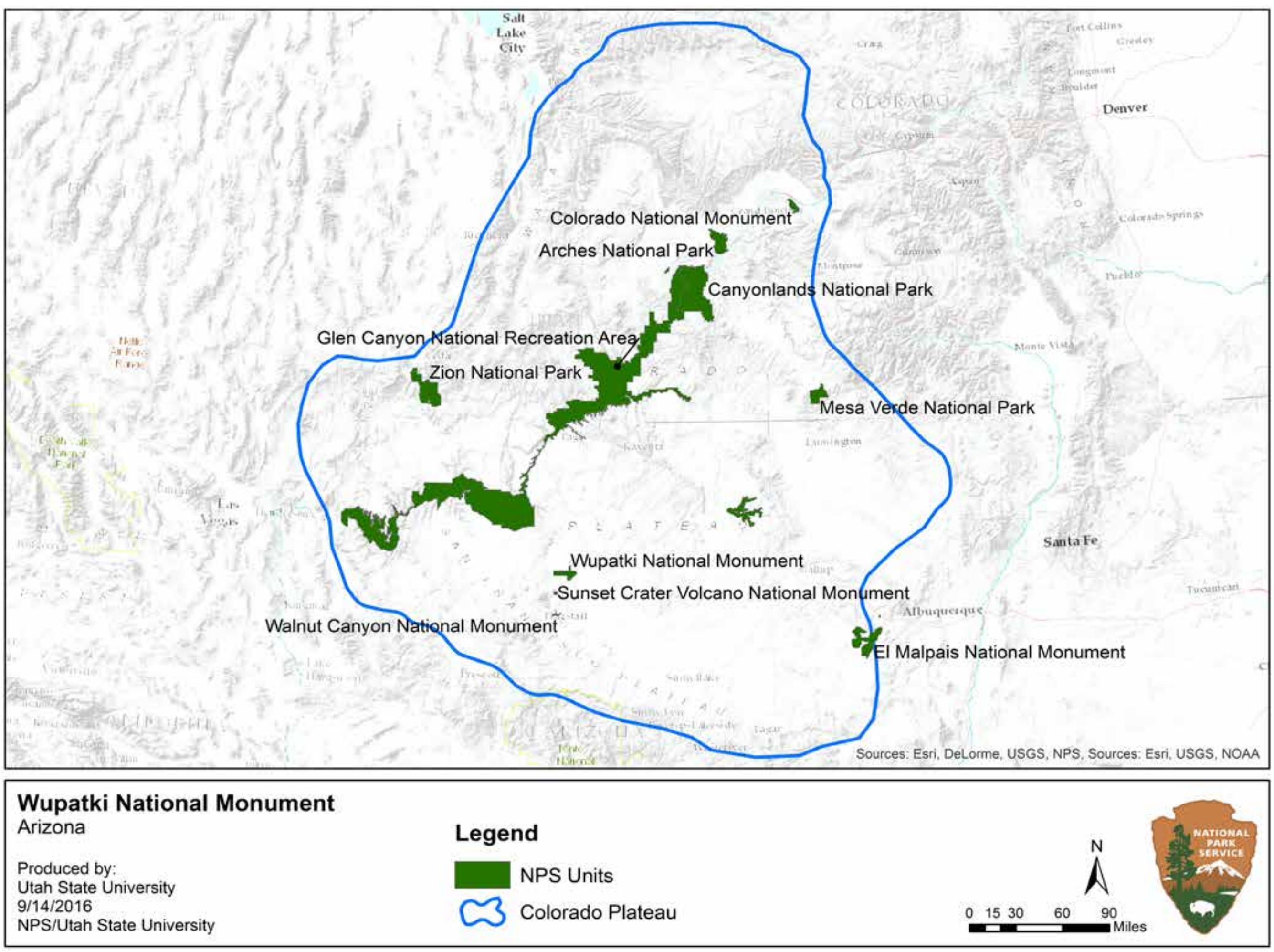


Figure 4.6.1-1. Map of select parks located in the Colorado Plateau geologic province.

2007a and Graham 2011 for a comprehensive geologic history of the monument and surrounding landscape). For the purposes of this assessment, however, we focus on describing the formation of relatively recent terrace, stream channel, and floodplain deposits of the late Miocene to the present day Holocene Epochs (~5 ma - present).

Approximately 5 million years ago, the Colorado River began eroding the Grand Canyon to the north of Wupatki NM (Graham 2011). As the Grand Canyon carved its present day course in the Colorado Plateau, the river's many tributaries, including the Little Colorado River, also incised the plateau transporting silt, sand, gravel, and other materials throughout the drainage system (Graham 2011). Several erosional cycles are responsible for present day alluvial fan, terrace, and floodplain deposits of Wupatki Basin and Antelope Prairie (Blyth 1995).

At least two periods of erosion are responsible for present day fluvial and stream terrace deposits. These erosional cycles beveled the surface to Cretaceous, Triassic, and Permian rocks (Graham 2011). Terrace deposits represent a once contiguous floodplain of the Little Colorado River drainage system, but with the uplift of the Colorado Plateau, the Little Colorado River eroded vertically through these floodplain deposits creating a terraced landscape. Terrace benches are between 1 m (3 ft) to 12 m (40 ft) above stream-channel deposits, depending on age (Graham 2011). Terrace benches above the Little Colorado River are about 43 m (140 ft) above the stream bed (Graham 2011).

Era	Period (age in millions of years)		Formations/Units		Brief Description
CENOZOIC	Quaternary (2.6 to present)	Holocene (0.117 to present)	Artificial fill		Excavated alluvium and bedrock.
			Alluvial fans, floodplain, dune and sheet sand, and terrace-gravel deposits		Unconsolidated deposits of silt, sand, pebbles, cobbles, and some boulders.
		Holocene and Pleistocene (2.6 to present)	Alluvial fan, alluvium, eolian, and older terrace-gravel deposits		Unconsolidated deposits of clay, silt, sand, and pebbles. Partly cemented with calcite and gypsum.
			Landslide, talus, and rockfall deposits		Unsorted rock debris and angular rocks and boulders of red sandstone and siltstone and gray limestone.
			Valley-fill deposits		Silt, sand, and lenses of gravel.
		Pleistocene (2.6 to 0.11)	Basalt flows, pumice, basalt dike, pyroclastic deposits		Volcanic rocks of the San Francisco Volcanic Field. Basalt in various flows, a dike, and pyroclastic deposits and rhyolite airfall pumice associated with San Francisco Mountain.
	Neogene (23 to 2.6)	Pliocene (5.3 to 2.6)			
		Miocene (23 to 5.3)	Old stream-channel deposits		Interbedded siltstone, sandstone, arkosic granite, and conglomerate.
	Paleogene (66 to 23)	Oligocene (34 to 23)	Regional Unconformity (significant break or gap in the stratigraphic record)		
		Eocene (56 to 34)			
		Paleocene (66 to 56)			
MESOZOIC	Cretaceous (146 to 66)				
	Jurassic (200 to 146)				
	Triassic (251 to 200)	Upper (229 to 200)	Chinle Formation	Petrified Forest Member	Slope-forming mudstone, siltstone, and interbedded sandstone. Petrified logs and wood fragments.
				Shinarump Member	Cliff-forming sandstone and conglomeratic sandstone.
		Middle (246 to 229)	Regional Unconformity		
		Lower (251 to 246)	Moenkopi Formation	Holbrook and Moqui Members	Red-brown, slope-forming claystone, siltstone, and sandstone.
				Shnabkaib Member	Yellowish-brown, cliff-forming calcareous siltstone and sandstone.
				Wupatki Member	Red-brown, slope-forming siltstone, sandstone, and crumbly mudstone.
			Regional Unconformity		
PALEOZOIC	Permian (299 to 251)	Cisuralian (Lower) (299 to 271)	Kaibab Formation	Harrisburg Member	Red to brown, slope-forming gypsum, siltstone, sandstone, and limestone.
				Fossil Mountain Member	Light-gray, cliff-forming fossiliferous, cherty, sandy limestone and minor dolomite.
			Toroweap Formation, undivided		White, cliff-forming, cross-bedded sandstone.

Figure 4.6.1-2. Stratigraphic column in Wupatki NM. Figure Source: Graham (2011).

The youngest alluvial fan and terrace deposits occur as a result of continued downcutting of the Little Colorado and its tributaries into the Holocene Epoch (Graham 2011). Downcutting resulted in the main intermittent, ephemeral streams that cross the Wupatki Basin and Antelope Prairie today. These include Kana'a, Heiser, Deadman, Doney Mountain, Antelope, and Citadel Washes (Graham 2011). The rate of erosion and the stability of intermittent, ephemeral streams is dependent upon soil type, grain size, parent material, landform, vegetation, wind, water, and time among other factors.

4.6.2. Data and Methods

This limited assessment is based on the geomorphic stability of intermittent, ephemeral streams in Wupatki Basin and on Antelope Prairie. Antelope, Citadel, Heiser, Deadman, Doney Mountain, and Kana'a Washes are the largest drainage corridors with numerous additional, smaller washes and arroyos that run through the monument (Graham 2011). All drainages in the monument are ephemeral or intermittent (also referred to as dry wash systems) and depend on rainfall and spring snowmelt in the mountains from which they drain (Stumpner 2004). In 2012, the Southern Colorado Plateau Inventory and Monitoring Network conducted a baseline assessment of channel morphology for a small portion of Deadman Wash, and the results of that study are presented in the Little Colorado River/Deadman Wash assessment of this report. For this assessment, we draw on Wupatki NM's geologic resources inventory reports (Billingsley et al. 2007a, Graham 2011) and associated Geographic Information System (GIS) data, and the 2013 U.S. Department of Agriculture's (USDA) soil survey report (USDA et al. 2015) and accompanying GIS data to describe the soils and underlying geology of these intermittent, ephemeral dry wash systems. However, because few or no data exist on the stability of these soils and parent materials, we were unable assess their current condition.

Geologic Map Units

The monument and surrounding area's geology was mapped using black and white 1:24,000-scale aerial photographs from 1958 and 1968 (see Billingsley et al. 2007a for more details). Mapped data were extensively ground-truthed for accuracy. The data derived from this effort was later described in more detail for Wupatki NM (Graham 2011). The geologic map was created for Wupatki NM and the surrounding area through a collaborative effort between the U.S. Geological Survey (USGS), National Park Service (NPS), and Navajo Nation (Billingsley et al. 2007a). Since the primary concern regarding geologic resources in Wupatki NM is erosion of the dry wash systems, we extracted only those geologic map units that pertain to alluvial (stream-deposited), floodplain, stream terrace, valley-fill, or ponded sediment deposits that have been mapped within the monument. We included a description for each of these mapped units along with their erosion potential and geologic significance as described in Billingsley et al. (2007a) and Graham (2011).

Soil Map Units

The soil survey was developed through a partnership between the NPS's Soil Inventory and Monitoring Program and the USDA's Natural Resources Conservation Service. Information on soil profiles, composition, erosion potential, and soil depth were reported in USDA et al. (2015) and each soil type was mapped in the monument. We included only those soils likely to occur in dry wash systems based on their supporting landform as described in USDA et al. (2015). Dry wash systems were likely to occur on landforms described as alluvial fans, valley fill and flood plains, lacustrine deposits, alluvial and fan terraces, and wash bottoms. We included the wind erodibility group index for each soil type (Table 4.6.2-1). Wind erodibility groups are made up of soils that have similar properties affecting their susceptibility to wind erosion in cultivated areas. The soils assigned to group 1 are the most susceptible to wind erosion, and those assigned to group 8 are the least susceptible (USDA et al. 2015). We also included erosion factors Kf and Kw, which describe the erosion potential for a particular soil type for fine soils and for the whole soil profile, respectively. K factors quantify soil detachment based on runoff and raindrop impact and were described for each soil horizon down to the underlying bedrock (USDA et al. 2015). K factors range in scale from 0.02 to 0.69, with high values indicating greater potential for erosion by water (USDA et al. 2015).

4.6.3. Reference Conditions

This is a limited assessment with no measures, therefore no reference conditions.

4.6.4. Condition and Trend

Geologic Map Units

Twelve geologic map units were characterized as alluvial (stream-deposited sediment), floodplain, stream terrace, valley-fill, or ponded sediment deposits. These units correlate relatively well with mapped washes and ephemeral drainages (Figure 4.6.4-1). Table 4.6.4-1 describes the 12 units in order of age from youngest to oldest. Erosion resistance for the three youngest layers was described as low. These were stream-channel deposits (Qs), flood-plain deposits (Qf), and young terrace gravel deposits (Qg1). Only two geologic units were described as highly resistent to erosion. These were ponded sediments (Qps) and old alluvial fan deposits (Qa3). The remaining seven units were described as variable or low in terms of erosion resistance. The Wupatki Basin contained a greater variety of geologic units than upland areas. In the uplands the dominant geologic unit associated with streams was young alluvial fan deposits of Citadel and Ball Court Washes. Antelope Wash west of Doney Mountain Fault consisted primarily of older valley-fill deposits. Young alluvial fan deposits were also common in Wupatki Basin and were co-dominated by intermediate alluvial fan deposits. Not surprisingly, stream-channel deposits were most commonly found along the mapped stream beds in Wupatki Basin but not for the uplands. Alluvial deposits in Wupatki Basin supply a substantial amount of silt and sand to the Little Colorado River drainage northeast of the monument where they develop eolian sand sheet and dune deposits that are then transported back to the Little Colorado River drainage by southwesterly flowing tributaries (Billingsley et al. 2007a).

Soil Survey Map Units

Nine soil units were associated with dry washes and ephemeral streams in Wupatki NM (Figure 4.6.4-2). Soil types differed completely between Wupatki Basin east of Doney Mountain and the western uplands of Antelope Prairie. Five of the nine soil types occurred in Wupatki Basin. These were in order of area:

Table 4.6.2-1. Wind erodibility groups and description.

Wind Erodibility Group (WEG)	Description
1	Very fine sand, fine sand, sand, or coarse sand
2	Loamy very fine sand, loamy fine sand, loamy sand, and loamy coarse sand; very fine sandy loam and silt loam with 5 or less percent clay and 25 or less percent very fine sand; and sapric soil materials (as defined in Soil Taxonomy), except Folists.
3	Very fine sandy loam (but does not meet WEG criterion 2), fine sandy loam, sandy loam, and coarse sandy loam; noncalcareous silt loam that has greater than or equal to 20 to less than 50 percent very fine sand and greater than or equal to 5 to less than 12 percent clay.
4	Clay, silty clay, noncalcareous clay loam that has more than 35 percent clay and noncalcareous silty clay loam that has more than 35 percent clay; all of these do not have sesquic, parasesquic, ferritic, ferruginous, or kaolinitic mineralogy (high iron oxide content).
4L	Calcareous6 loam, calcareous silt loam, calcareous silt, calcareous sandy clay, calcareous sandy clay loam, calcareous clay loam, and calcareous silty clay loam.
5	Noncalcareous loam that has less than 20 percent clay; noncalcareous silt loam with greater than or equal to 5 to less than 20 percent clay (but does not meet WEG criterion 3); noncalcareous sandy clay loam; noncalcareous sandy clay; and hemic soil materials (as defined in Soil Taxonomy).
6	Noncalcareous loam and silt loam that have greater than or equal to 20 percent clay; noncalcareous clay loam and noncalcareous silty clay loam that have less than or equal to 35 percent clay; silt loam that has parasesquic, ferritic, or kaolinitic mineralogy (high iron oxide content).
7	Noncalcareous silt; noncalcareous silty clay, noncalcareous silty clay loam, and noncalcareous clay that have sesquic, parasesquic, ferritic, ferruginous, or kaolinitic mineralogy (high content of iron oxide) and are Oxisols or Ultisols; and fibric soil materials (as defined in Soil Taxonomy).
8	Soils not susceptible to wind erosion due to rock and pararock fragments at the surface and/or wetness; and Folists.

Source: USDA (2016).

Moenkopi-rock outcrop complex, Moenkopi-typic Haplocambids complex, rock outcrop typic Torriorents-Heiser association, Bighawk family gravelly sand, and Ives-riverwash complex. The latter soil type only occurs within Deadman Wash and is bounded by rock outcrop-typic Torriorents-Heiser association soils. On Antelope Prairie soils associated with dry wash systems include Bighawk gravelly sandy loam, Flaco-Pocum complex, Gish very gravelly coarse sand, and Tsosie very gravelly coarse sand. Major washes in the western half of the monument were associated with Flaco-Pocum Complex soils while major washes in Wupatki Basin were associated with Rock Outcrop Typic Torriorthents-Heiser Association and Moenkopi-Rock Outcrop Complex soils. However, Ives-Riverwash Complex soils were most often associated with Deadman Wash and its confluence with the Little Colorado River. None of these soil types were associated with the western portion of Antelope Wash.

The wind erodibility group indicates that Bighawk gravelly sandy loam, Ives-riverwash complex, and the Torriothents component of the rock outcrop soils association have the least potential for wind-driven erosion (Table 4.6.4-2). The latter two soil types occur within dry wash systems of the Wupatki Basin while the former soil type occurs only in the uplands but not within a mapped drainage.

Both K factors for all soil types and horizons indicate high variability for erosion by raindrop impact (Table 4.6.4-2). This makes the interpretation of these values somewhat difficult, however, erosion potential appears to be low to moderate for most soil types. In the soils survey report, each soil horizon is described in depth and the reader should refer to that report for more details (USDA et al. 2015).

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Since we did not include measures in this assessment and field data are limited or non-existent, we could not assess the condition of geomorphic stability of intermittent, ephemeral drainage systems in Wupatki NM. Even though the condition remains unknown, we do describe geologic parent materials and soils along with their described erosion potentials. We found that these geologic units and soil types matched fairly well with mapped ephemeral washes and thus may be used as a starting point for conducting

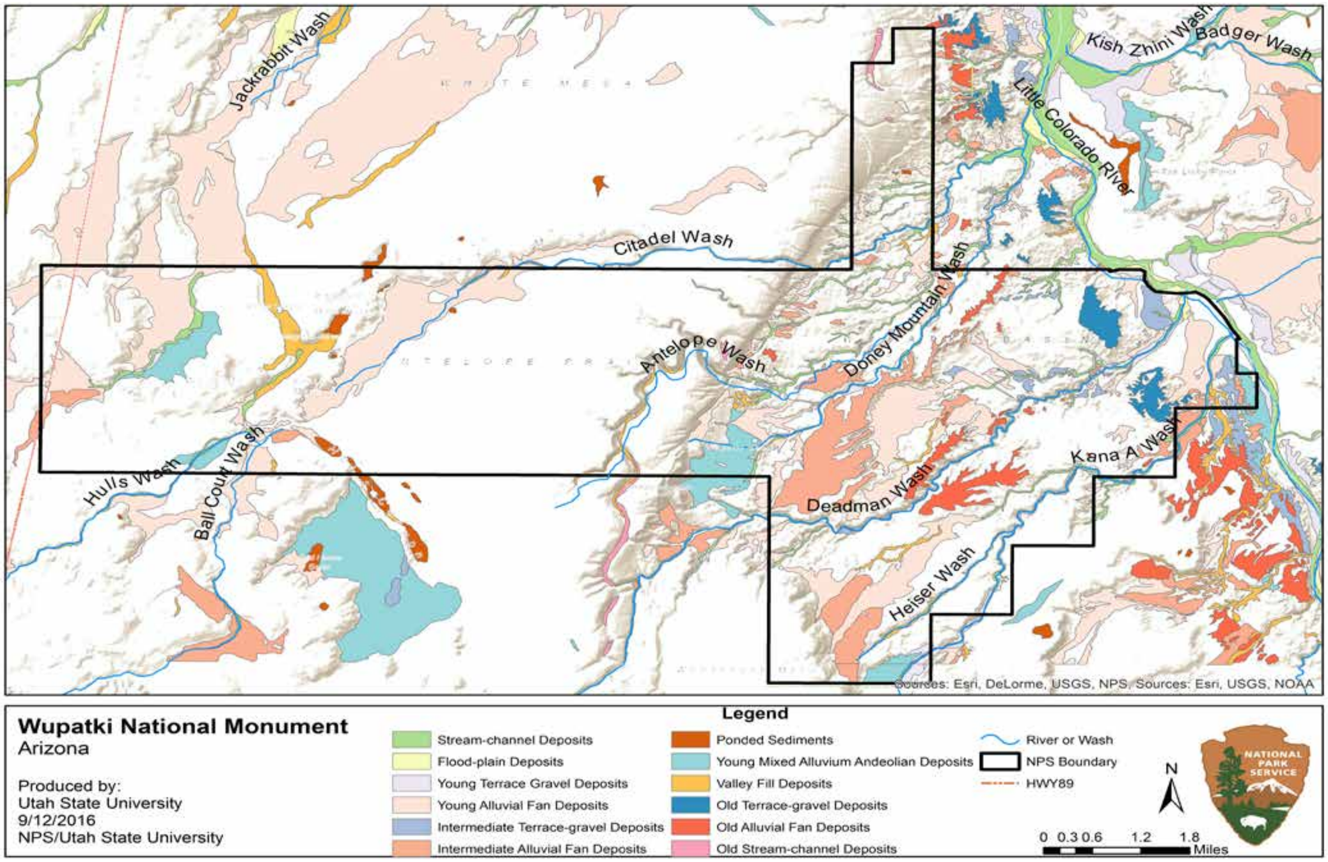


Figure 4.6.4-1. Map of alluvium, floodplain, stream terraces, valley bottom, and ponded sediment deposits in Wupatki NM.

additional field work. However, it should be noted, that the soil survey was developed to guide land use for agriculture, ranching, or construction projects and not for lands managed by the NPS. Therefore, the erosion factors and wind erodibility data do not necessarily apply to the NPS mission. In fact, the mapped soil units and their associated erosion potential do not necessarily correspond well with field data (K. Anderson, pers. comm.). A possible reason for apparent discrepancies is that K factors were based on a combination of field observations and on test data for these and similar soils and may not have been based on field data collected in Wupatki NM (USDA et al. 2015). Furthermore, these erosion factors are indexes used to predict the long-term average soil loss from sheet and rill erosion under crop systems rather than wildlands. A more appropriate approach may be to collect field data using a subset of the 17 rangeland health indicators described in Pellant et al. (2005). There are 11 indicators specifically related to soil and site stability, but other indicators related to hydrologic function and biotic integrity may also be useful. Pellant et al. (2005) provides detailed methods for this type of survey. Baseline ecological site descriptions necessary to complete these surveys have already been developed and are described in USDA et al. (2015).

Threats, Issues, and Data Gaps

Vegetation plays a key role in the stability of soils, but in Wupatki NM vegetation is sparse, particularly along intermittent and ephemeral streams. Erosion of these dry wash systems occurs largely as a result of runoff, but erosion is also affected by land use patterns such as grazing (Hereford 1984). Grazing in Wupatki NM was terminated in 1989 (Schelz et al. 2013). However, once streambeds have become deeply incised, the process may be irreversible (Sankey and Draut 2014). Gullying has occurred along portions of Deadman Wash (Figure 4.6.4-3; also see the Little Colorado Riparian assessment). Erosion may be partially mitigated by the presence of invasive tamarisk (*Tamarix* spp.) and camelthorn (*Alhagi maurorum*) (P. Whitefield, pers. comm.). In fact, tamarisk was initially introduced to western riparian areas to reduce stream bank erosion (GISD 2015; Brehl et al. 2008). Although tamarisk was not purposefully introduced in the monument, its

Table 4.6.4-1. Description of alluvium, floodplain, stream terraces, valley bottom, and ponded sediment deposits mapped in Wupatki NM.

Age	Geology Map Unit*	Features and Description	Erosion Resistance	Geologic Significance
Quaternary (Holocene)	Stream-channel Deposits (Qs)	Poorly sorted, lenses of silt, sand, pebbles, and gravel. Interlayered with young alluvial fan (Qa1), young terrace-gravel (Qg1), and upper part of valley-fill (Qv) deposits; overlaps flood-plain (Qf) and ponded sediment (Qps) deposits. Contacts are approximate with other alluvial deposits. Qs deposits of the Little Colorado River are mapped as shown on 1968 black and white aerial photographs and do not necessarily reflect stream-channel deposits of today due to extensive low-gradient channel changes caused by yearly flooding events. About 2 to 9 m (6 to 30 ft) thick.	Low	Tributaries that provide sediment to the Little Colorado River.
	Flood-plain Deposits (Qf)	Gray, brown, and light-red clay, silt, sand. Includes some lens-shaped gravel deposits. Partly consolidated by gypsum and calcite cement. Intertongue or overlap streamchannel (Qs), valley-fill (Qv), young terrace-gravel (Qg1), and young alluvial fan (Qa1) deposits. Similar to valley alluvial (Qv) deposits in small tributary drainage valleys that form broad, flat, valley floors subject to widespread and frequent overbank flooding along the Little Colorado River and in highland valleys west of Gray Mountain. Subject to temporary ponding and often mixed with ponded sediments (Qps) or young mixed alluvium and eolian deposits in broad drainage floodplains on the Coconino Plateau. Vegetation at higher elevations over 1,524 m (5,000 ft) help trap and accumulate fiine grained sediment on floodplains of Coconino Plateau. About 2 to 9 m (6 to 30 ft) thick.	Low. Subject to lateral and vertical erosion.	Traps sediment being transported to the Little Colorado River.
	Young Terrace Gravel Deposits (Qg1)	Light-brown, pale-red, and gray well-sorted, interbedded mud, silt, sand, pebbles, cobbles, and some boulders; partly consolidated by matrix of mud and sand cemented by calcium carbonate and gypsum. Composed mainly of subangular to well-rounded Paleozoic and Mesozoic sandstone, limestone, and chert clasts of local origin. Includes well-rounded clasts of quartzite, quartz, and assorted metamorphic crystalline rocks reworked from Tertiary conglomerates southeast and south of the monument. In south and southwest part of map area, unit includes well-rounded volcanic clasts derived from the San Francisco Volcanic Field. Locally overlaps Qa1, Qf, and Qv deposits. Contacts with adjacent alluvial and eolian deposits are approximate. Form terraced benches about 1 to 3.6 m (3 to 12 ft) above Qs deposits on Coconino Plateau and 1.5 to 2 m (4 to 6 ft) above the Little Colorado River channel and Qf deposits. Fill erosion channels cut into bedrock, Qa1, and Qf deposits. Thickness is 2 to 6 m (6 to 20 ft).	Low to moderate, depending on amount of consolidation. Subject to sheet wash erosion.	Represents the most recent downcutting by tributaries in the Little Colorado River drainage network.
	Young Alluvial Fan Deposits (Qa1)	West and southwest of the Little Colorado River: Gray-brown silt, sand, pebbles, cobbles, and boulders. Composed mainly of subangular to rounded limestone, chert, and sandstone clasts derived from Permian and Triassic strata of the Coconino Plateau area. Includes medium to small, subrounded to rounded pebbles and cobbles of basalt and andesite and pyroclastic fragments of the San Francisco Volcanic Field. Partly consolidated by gypsum and calcite cement. East and northeast of the Little Colorado River: Gray, light-brown, and light-red mud, silt, sand, as well as cobble and pebble clasts of chert, limestone, and sandstone. Overlapped by Qps, Qf, and Qd deposits. Intertongues with Qg1 and Qae deposits. Thickness is 1 to 6 m (3 to 20 ft).	Variable. Subject to extensive sheet-wash erosion and small arroyo erosion.	Most recent fanshaped deposit resulting from stream erosion and transportation of sediment.

* The Geology Map Unit colors correspond to Figure 4.6.4-1.

Sources: Data extracted from Billingsley et al. (2007a) and Graham (2011).

Table 4.6.4-1 continued. Description of alluvium, floodplain, stream terraces, valley bottom, and ponded sediment deposits mapped in Wupatki NM.

Age	Geology Map Unit*	Features and Description	Erosion Resistance	Geologic Significance
Quaternary (Holocene and Pleistocene)	Intermediate Terrace-gravel Deposits (Qg2)	Southwest of the Little Colorado River: Gray and brown silt, sand, and gravel; unconsolidated. Lithologically similar to Qg1 deposits. Composed mainly of gray and brown siltstone and fine-grained sandstone matrix mixed with subangular to rounded pebbles and boulders of local Permian limestone and Triassic sandstone. Includes wellrounded basalt clasts derived from the San Francisco Volcanic Field. Locally intertongues with Qa1 and Qa2 deposits. Form terrace benches about 4.5 to 9 m (15 to 30 ft) above modern streambeds and about 1.5 to 6 m (5 to 20 ft) above Qg1 deposits. East and northeast of the Little Colorado River: Isolated deposits of gray and red silt, sand, and multi-colored, angular cherty fragments. Terrace benches 3 to 15 m (10 to 50 ft) above the modern Little Colorado River bed. Thickness is 2 to 30 m (6 to 100 ft).	Variable, depending on clast size and vegetation.	Record a history of uplift and erosion in the monument area.
	Intermediate Alluvial Fan Deposits (Qa2)	Lithologically similar to Qa1 deposits; partly cemented by calcite and gypsum, but surfaces are more gravelly and often cut by arroyos as much as 3 m (10 ft) deep southwest of the Little Colorado River area. Northeast of the Little Colorado River, surfaces are sandy and often covered by young sand sheet deposits too thin to show at map scale. Commonly overlapped by Qa1 deposits near the Little Colorado River area and intertongued or overlapped Qv, Qtr, and Qg1 and Qg2 deposits west and southwest of the Little Colorado River. Includes abundant subrounded to subangular basalt clasts in southwest quarter of the map area and abundant subangular chert clasts northeast of the Little Colorado River. Thickness is 2 to 15 m (6 to 50 ft).	Variable, depending on clast size and vegetation.	Unit may help reconstruct the history of sediment erosion and transportation.
	Ponded Sediments (Qps)	Gray to brown clay, silt, sand, and minor lenses of gravel; partly consolidated by calcite and or gypsum cement. Locally includes small chert, limestone, and sandstone fragments or pebbles. Similar to Qf deposits but occupy manmade or natural internal drainage depressions. Internal drainage basins and sinkholes in the western part of Wupatki National Monument and Coconino National Forest formed intermittent shallow freshwater ponds that were likely an important water source for early human inhabitants of this area. Thickness is 1.5 to 12 m (5 to 40 ft).	High. Unit occupies depressions.	Geologically insignificant deposits. Temporary water sources.
	Young Mixed alluvium Andeolian Deposits (Qae)	Gray, light-red, and brown clay, silt, and fine- to coarse-grained sand interbedded with lenses of pebbly gravel. Includes white angular chert fragments locally derived from Permian strata on Coconino Plateau and white, gray, brown, and red chert fragments derived from the Chinle Formation east of the Little Colorado River. Interbedded sequence of thin-bedded, mixed mud, silt, sand, and gravel accumulated from both alluvial and eolian processes. Commonly occupies broad flatland or gently sloping topography downwind (northeast) of local drainage valleys. Thickness is 3 to 40 ft (1 to 12 m).	Variable. Sheet-wash erosion during wet conditions and often covered by dune sand and sand sheet deposits when dry.	Record a combination of alluvial and eolian processes.
	Valley-fill Deposits (Qv)	Gray and light-brown silt, sand, and lenses of gravel; partly consolidated by gypsum and calcite cement west and southwest of the Little Colorado River. Includes minor rounded clasts of limestone and sandstone, subrounded to angular chert, and subrounded to angular basalt southwest of the Little Colorado River. Intertongue with or overlapped by Qa1, Qa2, Qg1, and Qg2 deposits. Commonly reflects low energy and low-gradient shallow drainages. Thickness is 1 to 9 m (3 to 30 ft).	Low, except where cemented by gypsum and calcite.	Unit records the process of how valleys fill with sediments.

* The Geology Map Unit colors correspond to Figure 4.6.4-1.

Sources: Data extracted from Billingsley et al. (2007a) and Graham (2011).

Table 4.6.4-1 continued. Description of alluvium, floodplain, stream terraces, valley bottom, and ponded sediment deposits mapped in Wupatki NM.

Age	Geology Map Unit*	Features and Description	Erosion Resistance	Geologic Significance
Quaternary (Holocene and Pleistocene)	Old Terrace-gravel Deposits (Qg3)	Gray and light-brown silt, sand, pebbles, cobbles, and boulders composed primarily of local Permian and Triassic clasts; partly consolidated by calcite and gypsum cement; unsorted. Lithologically similar to Qg1 and Qg2 deposits, but includes abundant rounded volcanic clasts and some well-rounded quartzite clasts. Basalt clasts as much as 0.3 m (1 ft) in diameter; smaller basalt cobbles form desert pavement surface in southeast quarter of map area. Forms terraces about 3.7 to 12 m (12 to 40 ft) above modern streambeds; about 43 m (140 ft) above the Little Colorado River. Thickness is 0.6 to 6 m (2 to 20 ft).	Low where disturbed; higher where cemented and forming desert pavement.	Record a history of uplift and erosion in the monument area.
	Old Alluvial Fan Deposits (Qa3)	Gray and light-brown, silt, sand and gravel. Lithologically similar to Qa1 and Qa2 deposits, but unit extensively eroded by arroyos; partly consolidated by calcite and gypsum cement. Surface has thin calcrete soil that forms resistant rocky surface east of Doney Mountain Fault and Black Point Monocline. Thickness is 1.5 to 7.6 m (5 to 25 ft).	High. Surface has resistance from calcrete soil formation.	Landscape reconstruction and sediment transportation.
Neogene (Pliocene or Miocene)	Old Stream-channel Deposits (Ts)	Light-red, gray, and brown interbedded siltstone, sandstone, arkosic gravel, and lenticular conglomerate. Unsorted and partly consolidated deposits cover part of an incised meander channel of Antelope Wash west of Doney Mountain. Antelope Wash, an ancestral Deadman Wash drainage, was superimposed onto the Kaibab Formation west of the Doney Mountain Fault and onto the Moenkopi and Chinle Formations east of the Doney Mountain Fault. Pebbles and cobbles are well-rounded quartzite, chert, and minor clasts of granite and metamorphic rocks derived from older gravel deposits southwest of the monument. Includes abundant gray limestone clasts derived from the Kaibab Formation and red sandstone clasts derived from the Moenkopi Formation. Well-rounded quartzite clasts form a lag gravel deposit. The ancestral Deadman Wash (Antelope Wash) is likely Miocene age. Thickness is 0.6 to 3.6 m (1 to 12 ft).	Variable, depending on clast size and composition.	Oldest Little Colorado River terrace-gravel deposit in the area.

* The Geology Map Unit colors correspond to Figure 4.6.4-1.

Sources: Data extracted from Billingsley et al. (2007a) and Graham (2011).

occurrence there may have some beneficial effects in the absence of native riparian plants.

Inconsistent flows in Wupatki NM has likely limited erosion by water, but this also means that stream channels to not gain deposition of materials from upstream (Hereford 1984). The redistribution of stream sediments is an important geomorphological process that has been affected by changes in precipitation and land use patterns (e.g., grazing) (Hereford 1984). Wind is also a significant factor in the rate and amount of erosion (Graham 2011), but how wind has or is redistributing soils in the monument is unknown. Lastly, biological soil crusts (hereafter referred to as BSC) have been shown to reduce erosion (Bowker and Belnap 2013). A study that modeled the presence, biodiversity, and function of BSCs in four national parks, including Wupatki NM, found that soil type was the best predictor of BSC development; however, the authors also found that alluvial soils did not perform well in predicting where BSCs might occur in the monument (Bowker and Belnap 2013). BSCs were predicted to occur on limestone-derived soils, but not on cinder-derived (volcanic) soils as they do in other areas. The authors speculate that the brief monsoonal rains of northern Arizona may prevent BSC development in the monument (Bowker and Belnap 2013). This is supported by the observations of park staff who indicate that BSC cover is rare in Wupatki NM (P. Whitefield, pers. comm.). Soil mineral crusts may be more important for site stability in the Wupatki Basin than BSCs (P. Whitefield, pers. comm.).

Determining the stability of intermittent, ephemeral streams may mitigate the loss of archaeological sites. Wupatki NM was founded in 1924 to preserve the thousands of archeological sites found within the monument, some of which have not been mapped

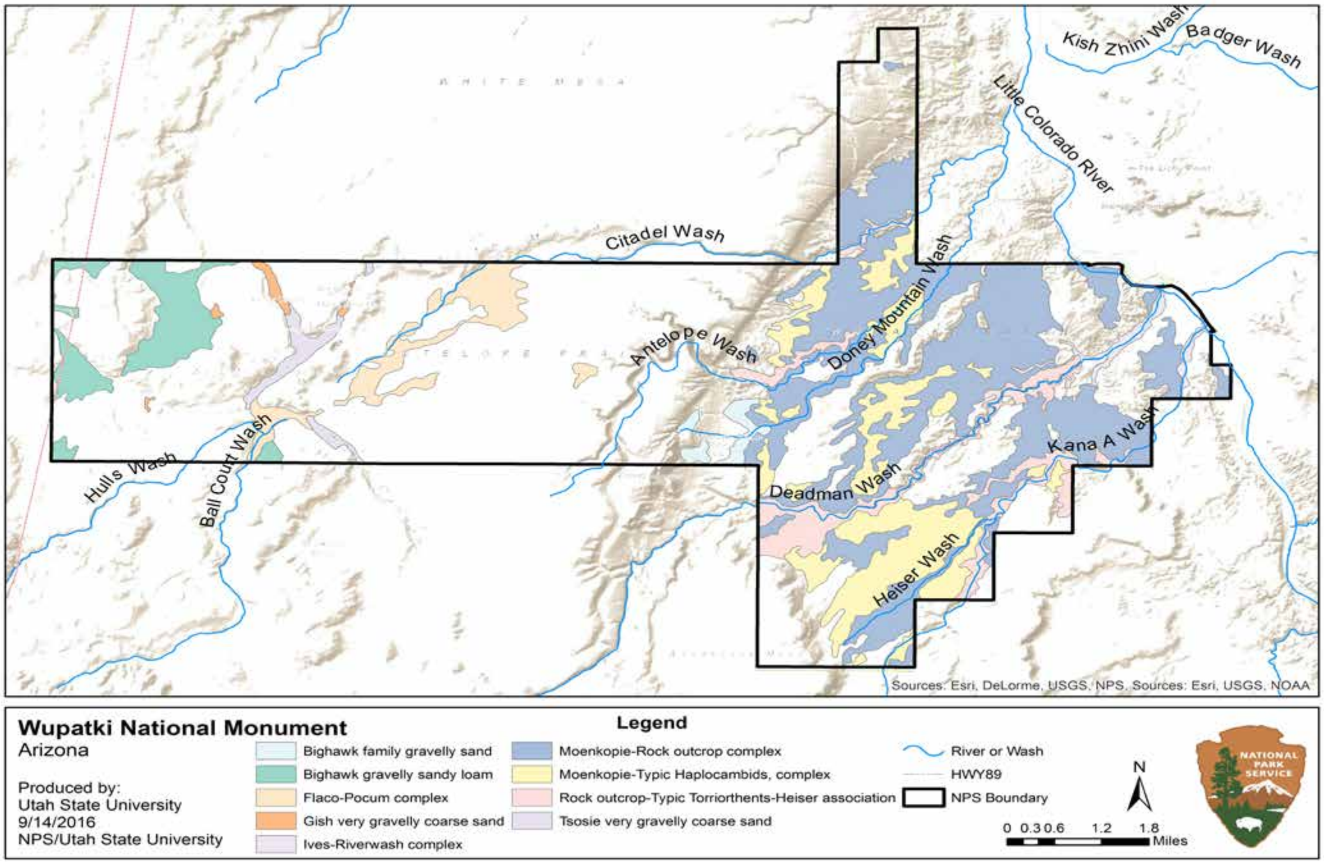


Figure 4.6.4-2. Map of soils occurring on alluvial fans and terraces, valley fills, flood plains, old lake beds, and wash bottom landforms in Wupatki NM.

or surveyed (NPS 2015a). Ancestral Puebloans likely used dry washes and other drainages as seasonal water sources, and evidence of their presence in these areas may be eroded before they have been surveyed (NPS 2015a).

Although erosion is a natural and important geologic process reflective of the region's dynamic landscape, erosion due to anthropogenic climate change and/or past land use patterns may have altered the geomorphology of intermittent, ephemeral streams in Wupatki NM. However, this represents a data gap in park knowledge that may be investigated in the future.

4.6.5. Sources of Expertise

No outside experts were consulted for this assessment. Assessment author is Lisa Baril, biologist and science writer, Utah State University.

Figure 4.6.4-3. Stream erosion along Deadman Wash. Photo Credit: NPS.

Table 4.6.4-2. Description of soils occurring on alluvial fans and terraces, valley fills, flood plains, old lake beds, and wash bottom landforms in Wupatki NM.

Soil Type*	Ecological Site Type	Landform	Parent Material	Wind Erodibility Group	Erosion Factors		
					Depth in cm (in)	Kw	Kf
Bighawk Family Gravelly Sand (2-11% slopes) 101	Volcanic Uplands	Alluvial fans	Tephra over residuum	1	0-5 (0-2) 5-21 (2-9) 21-32 (9-13) 32-74 (13-29) 74-117 (29-46)	0.2 0.10 0.32 0.05 0.17	0.05 0.15 0.32 0.20 0.28
Bighawk Gravelly Sandy Loam (1-5% slopes) 100	Volcanic Uplands	Alluvial fans	Alluvium derived from volcanic rock	5	0-5 (0-2) 5-30 (2-12) 30-47 (12-19) 47-60 (19-24) 60-152 (24-60)	0.10 0.10 0.05 0.10 0.05	0.20 0.24 0.17 0.24 0.24
Flaco-Pocum Complex (1-3% slopes) 105	Loamy Upland	Terraces	Alluvium derived from volcanic rock	1	0-5 (0-2) 5-15 (2-6) 15-36 (6-14) 36-64 (14-25)	0.05 0.28 0.28 0.20	0.05 0.28 0.28 0.32
Gish Very Gravelly Coarse Sand (0-0.4% slopes) 106	Loamy Upland	Relict lakebeds	Lacustrine deposits derived from igneous and sedimentary rock	2	0-2 (0-1) 2-9 (1-4) 9-39 (4-16) 39-76 (16-30) 76-152 (30-60)	0.02 0.10 0.20 0.20 0.28	0.05 0.15 0.20 0.20 0.28
Ives-Riverwash Complex (1-5% slopes) 107	Loamy Wash	Channels	Alluvium derived from sedimentary rock	4L	0-12 (0-5) 12-24 (5-10) 24-61 (10-24) 61-152 (24-60)	0.20 0.20 0.10 0.10	0.20 0.20 0.17 0.10
Moenkopie-Rock Outcrop Complex (1-14% slopes) 113	Sandstone/ Shale Upland	Structural benches	Residuum weathered from mudstone and/ or residuum weathered from sandstone	2	0-5 (0-2) 5-33 (2-13) 33-42 (13-15)	0.10 0.17	0.10 0.24
Moenkopi-Typic Haplocambids Complex (1-6% slopes) 112	Sandstone/ Shale Upland	Structural benches	Residuum weathered from sandstone and shale	1	0-7 (0-3) 7-24 (3-10) 24-42 (10-17) 42-80 (17-32) 80-107 (32-42)	0.10 0.15 0.15 0.17 0.10	0.15 0.24 0.24 0.24 0.20
Rock Outcrop Typic Torriorthents-Heiser Association (3-40% slopes) 116	Sandstone/ Shale Upland	Escarpments	Footslopes and side slopes beneath canyon escarpments	Torriorthents 5 Heiser 1	Torriorthents 0-10 (0-4) 10-31 (4-12) Heiser 0-26 (0-26) 26-97 (10-38) 97-152 (38-60)	 0.15 0.10 0.02 0.02 0.02	 0.28 0.37 0.02 0.02 0.02
Tsosie Very Gravelly Coarse Sand (1-5% slopes) 120	Loamy Upland	Valley fill and flood plains	Cinders derived from volcanic rock over alluvium derived from sedimentary rock	2	0-2 (0-1) 2-18 (1-7) 18-30 (7-12) 30-102 (12-40) 102-152 (40-60)	0.02 0.17 0.28 0.32 0.32	0.02 0.28 0.28 0.32 0.32

* The Soil Type colors correspond to Figure 4.6.4-2.

Source: USDA et al. (2015).

4.7. Seeps, Springs, and Surface Water

4.7.1. Background and Importance

In Wupatki National Monument (NM) surface water, which occurs as springs, seeps, ephemeral pools, dry washes, and rivers is a rare but critically important resource for wildlife and plants at certain times of the year (Figure 4.7.1-1). These water resources have also served as the main water supply for ancestral Puebloans inhabiting the region, and then later, they were used by Navajo sheepherders and Anglo ranchers to water their stock (NPS 2013c, Stumpner 2004).

Springs and seeps are perennial or intermittent pools of water that flow to the ground surface from bedrock or soil (Kreamer and Springer 2008). Only three natural springs and one seep occur within the monument: Wupatki Spring, Heiser Spring, Peshlaki Spring, and Spice Seep (also sometimes referred to as a spring) (NPS 2013c, Springer et al. 2006). These springs and seeps historically flowed from a "perched aquifer within interbedded standstone and shale in the Moenkopi geologic formation" and are "recharged through fractured surface basalts located on upslope U.S. Forest Service lands" (Holton 2007).

After the region was established as a national monument in 1924, Wupatki Spring was developed as the main water supply for the visitor center and employee housing area (NPS 2013c). However, flows at Wupatki Spring ceased in 1959 (NPS 2013c). Heiser Spring, named for a family who ranched the area during 1912-1915, also ceased to flow. During the 1930s, Heiser Spring was developed in support of a Civilian Conservation Corps labor camp and was later developed by the National Park Service (NPS) in support of a maintenance shop and employee housing (NPS 2013c). In the 1980s, most structures were removed from the vicinity of Heiser Spring. From 2008 to 2013, the area surrounding Heiser Spring was restored through the removal of all remaining structures and the area was revegetated with native plants (NPS 2013c, Figure 4.7.1-2). Prior to 2000, however, the water table had fallen so low that flows were no longer observed at or near the surface (Flagstaff Area National Monuments, P. Whitefield, Natural Resources Specialist, comments to earlier draft, 18 January 2017). Peshlaki Spring (a Navajo word meaning "cottonwood") continues to be active and has been a reliable source of water for wildlife and plants for the last 130 years (NPS 2013c). However, surface water there is limited and, at times, inaccessible (Holton 2007). Peshlaki Spring has also been modified to support livestock watering (Springer et al. 2006).

In addition to springs and seeps, ephemeral pools can develop in natural depressions or in small rock basins formed by erosion of porous sandstone (Graham 2001, Holton 2007). These pools usually contain water

Figure 4.7.1-1. Surviving ash tree at Heiser Spring in Wupatki NM. Photo Credit: NPS/Jean Palumbo.

for only a short time following heavy rainfall. As with springs and seeps, naturally occurring pools are rare, and many evaporate before they are discovered. At least two groups of naturally occurring pools persist for several weeks after rainstorms depending on the amount of precipitation (Holton 2007). These are known as Navajo Natural and Coyote Waters.

The Little Colorado River and Deadman Wash have historically been important ephemeral and intermittent sources of water for humans, wildlife, and plants. The Little Colorado River follows the eastern boundary of the monument for approximately 2 km (1.2 mi) and is joined by Deadman Wash within the monument's boundary; however, flows are dependent on the amount of winter snow accumulation in the mountains and late summer precipitation (Holton 2007, NPS 2006a, Stumpner 2004). Numerous other washes occur within the monument, including Kana'a, Antelope, Heiser, Deadman, Doney Mountain, and Citadel (Graham 2011). These washes may contain water during and after periods of heavy rainfall (NPS 2006a).

The Little Colorado River and its confluence with Deadman Wash, which is the focus of a separate assessment, has been impaired by nearly 100 years of grazing (NPS 2012b), the invasion of non-native plants (Brehl et al. 2008), water diversion (NPS 2015a, and minimal groundwater recharge (Stumpner 2004, Springer and Schaller 2012). Thus, there are currently no reliable water resources in Wupatki NM. Springs, seeps, and surface water are considered one of the most impaired natural resources in the monument owing to a long history of use and development (Holton 2007, NPS 2012b).

Figure 4.7.1-2. Heiser Spring pumpshack before restoration. Photo Credit: NPS.

4.7.2. Data and Methods

To assess the condition of springs, seeps, and surface water in Wupatki NM, we used three indicators with between two and eight measures each, for a total of 14 measures. These measures were based on data from several sources, some of which were more than five years old, but represent the most current or only data available on springs, seeps, and surface water in the monument. Figure 4.7.2-1 shows the water resources described in this assessment.

The first indicator, water quantity and availability, included the presence of wetted area or discharge (l/s and depth to groundwater (m) measures.

<u>Presence of Wetted Area or Discharge (L/s)</u>

In 2005, 75 springs and seeps were inventoried in 26 NPS units across the Northern and Southern Colorado Plateau Inventory and Monitoring Networks (I&M), two of which were located in Wupatki NM: Peshlaki Spring and Spice Seep (Springer et al. 2006). Peshlaki Spring is a hillslope spring emerging from the Moenkopi Formation (Springer et al. 2006). Hillslope springs emerge from slopes with 30-60° angles with often indistinct and multiple sources (Springer and Stevens 2008). Peshlaki Spring is a medium to large spring measuring approximately 0.1-1.0 ha (0.2-2 ac) (Springer et al. 2006). Spice Seep is a rheocrene type spring, which means that it emerges into one or more stream channels (Springer and Stevens 2008). Like Peshlaki Spring, Spice Seep also emerges from the Moenkopi Formation (Springer et al. 2006). We used data provided in Springer et al. (2006) to determine discharge for these two water resources. If there was no measurable discharge, we indicate whether the mouth of the spring was wetted or not, which suggests that at least some water flows at the surface.

<u>Depth to Groundwater (m)</u>

We used depth to groundwater as measured at Heiser Spring during June 2010 through June 2015. Like Peshlaki Spring, Heiser is a hillslope spring emerging from the Moenkopi Formation. Depth to groundwater was monitored at Heiser Spring using piezometers inserted into the ground, enabling measurement of

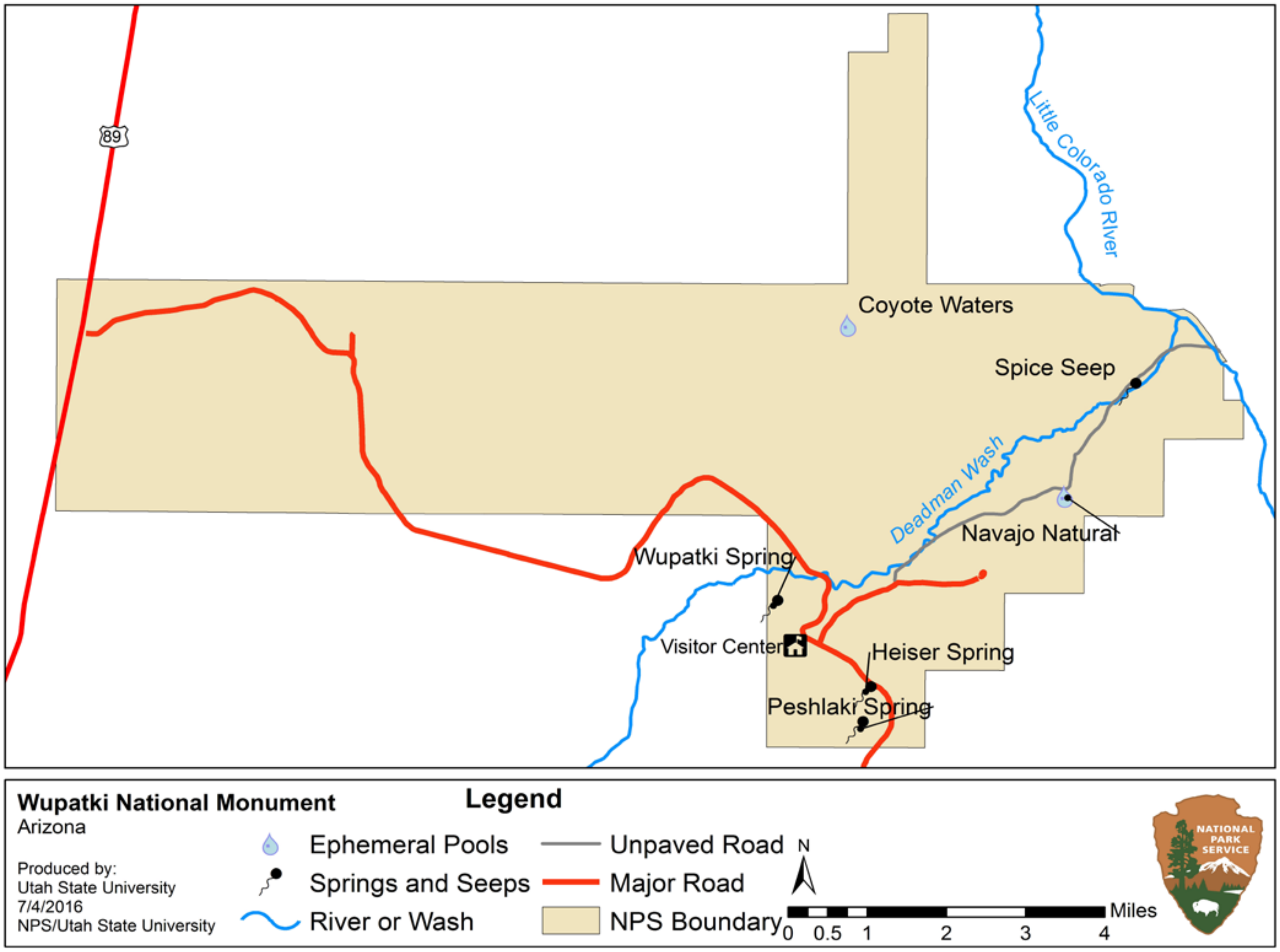


Figure 4.7.2-1. **Map of springs, seeps, and surface water in Wupatki NM.**

water level below the ground surface at the point of insertion. A pressure transducer was suspended inside the piezometer and the water surface elevation above sea level was recorded in hourly intervals beginning in June 2010. Although data for two piezometers were collected, we only report data for one of these (Heiser Spring - WC) since it is representative of depth to groundwater at Heiser Spring. Data were provided by Steve Monroe, Hydrologist, partner of SCPN.

The second indicator, water quality included seven measures: specific conductance, pH, alkalinity dissolved oxygen, temperature, indicator bacteria, and inorganic chemicals and uranium. We draw from several sources to describe water quality measures including Springer et al. (2006), Thomas et al. (2003), and historical data available in STORET (STOrage and RETrieval), the U.S. Environmental Protection Agency's (USEPA) storehouse for water quality data (USEPA 2016c). Each report and data storage system provided different types of data for different water resources within the monument. In some cases, the same data were reported in more than one report or source.

We reported data for a suite of water quality measures for Heiser Spring, Peshlaki Spring, Spice Seep, and the Little Colorado River. Data for these water resources were collected on various dates between 1966 and 2005. For each measurement we report the date of collection, location, and data source. The original intention was to use these data to construct a time series for one or more water resources in the monument, but because of sparse and discontinuous data, this was not possible. Instead, we report these data without inference to change over time. The significance of each water quality measure is described below.

Core Water Quality Parameters

Specific Conductance (µs/cm)

Specific conductance is the ability of water to conduct an electrical current and is dependent on the amount of dissolved solids in the water, such as salts (USGS 2016b).

pH (SU)

The pH of water determines the solubility and availability of compounds and minerals to organisms. The amount of dissolved materials, including heavy metals, rises with increasing acidity. Therefore, pH is a good indicator of change in water chemistry and pollution (USGS 2016b).

Alkalinity (mg/L as $CaCO_3$)

Alkalinity is the ability of water to neutralize acid and is determined by the supporting soil and bedrock of a water feature (USGS 2016b). It is related to pH and is an important indicator of a water body's ability to neutralize acidic pollution from rainfall (USGS 2016b).

Dissolved Oxygen (mg/L)

Oxygen enters a water body from both the atmosphere and groundwater discharge. Temperature is an important factor in controlling the amount of dissolved oxygen in a water body. The colder the water, the more oxygen it can retain. Therefore, dissolved oxygen exhibits both daily and seasonal cycles (USGS 2016b). Photosynthesis affects the dissolved oxygen-temperature relationship, which in turn, affects the rate of photosynthesis. Dissolved oxygen affects the ability of microorganisms and plants to live and grow in water bodies.

Temperature (° C)

All core water quality parameters are influenced by temperature. For example, groundwater with higher temperatures typically has a lower pH, which in turn dissolves more minerals from the surrounding rock than cooler water. This, in turn, influences specific conductivity (USGS 2016b). However, water temperature from springs is usually stable with limited daily and seasonal fluctuations, but variation in temperature depends on rates of discharge and aquifer depth among other variables.

Indicator Bacteria (cols./100 ml)

We report total coliform, fecal coliform, and *Escherichia coli* in colonies (cols.) per 100 ml. Total coliforms are widely spread in nature and are not necessarily associated with the gastrointestinal tract of mammals (USGS 2016b). The measure of total coliform is often used as an indicator for potable water. Fecal coliform are a subgroup of coliform bacteria and indicate fecal contamination by mammals. *E. coli* is a common bacteria found in the gastrointestinal tracts of mammals and can cause illness in humans (USGS 2016b). Coliform bacteria could enter water bodies through past grazing within the monument or through grazing practices upstream of the Little Colorado River (Thomas 2003).

Inorganic Chemicals and Uranium (µg/L)

We describe the chemical constituents of water resources at Heiser Spring and the Little Colorado River as reported in Thomas (2003). We only report measurements for variables that are considered a human health hazard by the USEPA (USEPA 2016d). These are antimony, arsenic, barium, berryllium, cadmium, chromium, copper, lead, uranium, and nitrogen (nitrates and nitrites). Sources of these compounds may be attributed to agricultural practices, mining activities, and waste disposal (USGS 2016b).

The third indicator evaluates the biodiversity of plants, invertebrates, birds, mammals, and herpetofauna.

Plants

We used plant species data presented in Springer et al. (2006). Plant species were inventoried and mapped at Peshlaki Spring and Spice Seep as part of a 2005 effort to assess baseline condition for 75 springs across the Northern and Southern Colorado Plateau I&M Network parks. We report a species list for plants identified at these two springs in Wupatki NM. For each plant species, we determined its wetland status using the U.S. Department of Agriculture's (USDA) PLANTS Database (USDA 2016). Plants were divided into five categories based on wetland status. The categories are: obligate wetland (OBL = almost always occurs in wetlands), facultative wetlands (FACW = usually occurs in wetlands but may occur in non-wetlands), facultative (FAC = occurs in wetlands and non-wetlands), facultative upland (FACU = usually occurs in non-wetlands), and obligate upland (UPL = almost never occurs in wetlands).

Invertebrates

Invertebrates were recorded to taxonomic level for Peshlaki Spring and Spice Seep in 2005 as part of the Northern and Southern Colorado Plateau I&M

Network parks inventory (Springer et al. 2006). As of the writing of this assessment, invertebrates have not been identified to the species level. Therefore, we reported the invertebrate order and the total number of specimens collected at the two sites. We also reported data collected in 1997 for three pools at Navajo Natural and two pools located in Deadman Wash (Graham 2001). Although Graham included impoundments, stock tanks, and borrow pits in his survey, we did not include those data since they are unnatural sources of water in the monument.

Birds

Birds were recorded via camera traps set at Coyote Waters and Navajo Natural ephemeral pools. Cameras were installed from October 2004 through June 2006 (Holton 2007). Cameras were programmed to record activity 24 hours a day and were checked twice per month (see Holton 2007 for more details).

Mammals

We used data collected via camera traps to describe mammal species recorded at Coyote Waters and Navajo Natural ephemeral pools as described above for birds (Holton 2007).

Herpetofauna

We used data provided by the Southern Colorado Plateau I&M Network (SCPN) (Erika Nowak, Herpetologist, USGS Southwest Biological Science Center, Colorado Plateau Research Station, Northern Arizona University). During 2001 to 2003, twelve NPS units were surveyed for reptiles and amphibians (Persons and Nowak 2006). Wupatki NM was surveyed during 2001-2003, using a variety of methods, including pitfall traps, area searches, road-based nocturnal driving surveys, and habitat specific surveys. Random encounters were also recorded. Using the database provided by herpetologist Erika Nowak, we extracted species that were recorded as occurring within washes, riparian areas, floodplains, ex-lake beds, irrigated areas, seeps, springs, pools, and wetlands.

4.7.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.7.3-1. Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the three indicators and 15 measures.

Water Quantity

We considered a spring or seep with measurable discharge or at least the presence of a wetted area at the mouth of a spring to be in good condition. If there was no measurable discharge or wetted area, we considered this to warrant moderate to significant concern. This would indicate that at least some water flows at the ground surface. For depth to groundwater we considered the condition to be good if water flowed at the ground surface for a least a portion of every year data were collected. If this did not occur, then the condition warrants moderate to significant concern.

Water Quality

We compared core water quality data (pH and dissolved oxygen) to reference conditions for Aquatic and Wildlife warm using water quality standards developed by the Arizona Department of Environmental Quality (AZDEQ 2016). Standards were developed separately for surface water occurring above and below 1,524 m (5,000 ft). According to the monument's digital elevation model, all water resources described in this assessment are located below 1,524 m (5,000 ft); therefore, we used water quality standards as described for warm water resources.

For indicator bacteria, inorganic chemicals, and uranium we used maximum allowable thresholds developed by the USEPA (USEPA 2016d). For coliform bacteria, the USEPA's goal is 0 cols/100 ml. If samples test positive, the USEPA requires that the water body be retested. If repeat samples also test positive, then the maximum allowable contaminant level has been violated (USEPA 2016d). Water quality standards were not available for specific conductance, alkalinity, or temperature.

Biodiversity

We did not develop reference conditions for biodiversity in Wupatki NM based on the recommendation of NPS staff. NPS staff recommended reporting species lists that can be used for future comparisons since available data included in this assessment were more than five years old, incomplete, and sparse.

4.7.4. Condition and Trend

Presence of Wetted Area or Discharge (L/s)

There was no discernible discharge at Peshlaki Spring and there was no indication of the presence of a wetted area (Springer et al. 2006). At Spice Seep total discharge was 0.000023 L/s (Springer et al. 2006).

Table 4.7.3-1. Reference conditions used to assess springs, seeps, and surface water.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Water Quantity and Availability	Presence of Wetted Area or Measurable Discharge (L/s)	Yes	No	No
	Depth to Groundwater (m)	Flows occur at the ground surface (0 m) during at least a portion of the year.	Flows do not occur at the ground surface (> 0 m).	Flows do not occur at the ground surface (> 0 m).
Water Quality	Specific Conductance (µ/cm)	AZDEQ standards not established.	AZDEQ standards not established.	AZDEQ standards not established.
	pH (SU)	The pH is between 6.5 and 9 SU.	The pH does not meet AZDEQ water quality standards.	The pH does not meet AZDEQ water quality standards.
	Alkalinity (mg/L as $CaCO_3$)	AZDEQ standards not established.	AZDEQ standards not established.	AZDEQ standards not established.
	Dissolved Oxygen (mg/L)	Dissolved oxygen is ≥ 6.0 mg/L.	Dissolved oxygen is ≤ 6.0 mg/L.	Dissolved oxygen is ≤ 6.0 mg/L.
	Temperature (°C)	Dissolved oxygen is ≤ 6.0 mg/L.	Dissolved oxygen is ≤ 6.0 mg/L.	Dissolved oxygen is ≤ 6.0 mg/L.
	Indicator Bacteria (cols./100 ml)	sample is negative	sample is positive	sample is positive
	Antimony (µg/L)	< 6 µg/L	> 6 µg/L	> 6 µg/L
	Arsenic (µg/L)	< 10 µg/L	> 10 µg/L	> 10 µg/L
	Barium (µg/L)	< 2,000 µg/L	> 2,000 µg/L	> 2,000 µg/L
	Berryllium (µg/L)	< 4 µg/L	> 4 µg/L	> 4 µg/L
	Cadmium (µg/L)	< 5 µg/L	> 5 µg/L	> 5 µg/L
	Chromium (µg/L)	< 100 µg/L	> 100 µg/L	> 100 µg/L
	Copper (µg/L)	< 1,300 (µg/L)	> 1,300 µg/L	> 1,300 µg/L
	Lead (µg/L)	< 15 µg/L	> 15 µg/L	> 15 µg/L
	Uranium (µg/L)	< 30 µg/L	> 30 µg/L	> 30 µg/L
	Nitrogen, nitrite (µg/L)	< 100 µg/L	> 100 µg/L	> 100 µg/L
	Nitrogen, nitrite + nitrate (µg/L)	< 11,000 µg/L	> 11,000 µg/L	> 11,000 µg/L
Biodiversity	Plants	No condition thresholds established.	No condition thresholds established.	No condition thresholds established.
	Invertebrates	No condition thresholds established.	No condition thresholds established.	No condition thresholds established.
	Birds	No condition thresholds established.	No condition thresholds established.	No condition thresholds established.
	Mammals	No condition thresholds established.	No condition thresholds established.	No condition thresholds established.
	Herpetofauna	No condition thresholds established.	No condition thresholds established.	No condition thresholds established.

Although there was measurable discharge and thus, a wetted area, water present at the surface was minimal. These results warrant moderate concern; however, since these data are more than 10 years old, and there is no reliable longer term record of flows from which to gauge natural variability, the current condition is unknown.

Depth to Groundwater (m)

Depth to groundwater from Heiser Spring-WC averaged 1.36 m (4.46 ft) below the ground surface during June 2010 through June 2015 (Figure 4.7.4-1). From June 2010 until April 2013, depth to groundwater was stable and averaged approximately 1.57 m (5.15 ft) below the ground surface. Depth to groundwater then peaked at 1.96 m (6.43 ft) below the ground surface in July 2013. This represents the farthest groundwater was from the ground surface during observations. After this point, during a record year for total precipitation at the long term weather station at the nearby Wupatki Visitor Center, depth to groundwater rapidly improved and neared the surface to 0.68 m (2.23 ft) in November 2013. Although there is some variability after this point, depth to groundwater has remained nearer to the ground surface than prior to July 2013 with an extensive wetted area just below the ground surface as noted on the monthly SCPN hydrology monitoring data sheets. However, no obvious flow is evident at the spring and surface water has not been observed since 2000 (Flagstaff Area National Monuments, P. Whitefield, Natural Resources Specialist, comments to earlier draft, 18 January 2017). This indicates improving conditions for this measure at Heiser Spring; however, flows have never occurred at the surface since measurements began. Therefore, the condition for this measure warrants significant concern.

Specific Conductance (μS/cm)

Specific conductance was reported for Heiser Spring, Peshlaki Spring, Spice Seep, Wupatki Spring, and for the Little Colorado River (Table 4.7.4-1). Dates of data collection range from 1966 at Heiser Spring to 2005 at Peshlaki Spring and Spice Seep. Since these data are more than 10 years old, and no condition thresholds for this measure have been established, the current condition for this measure is unknown.

pH (SU)

The pH of springs ranged from 7.4 at Peshlaki Spring in 2005 to 7.9 at Heiser Spring in 2002 (Table 4.7.4-1). The pH of the Little Colorado River measured 8.7 in 2002. All measurements were with in the range identified as good by AZDEQ; however, since the most recent data available are more than 10 years old, the current condition for this measure is unknown.

Alkalinity (mg/L as $CaCO_3$)

Alkalinity ranged between 156-160 mg/L at Heiser Spring during 1966-2002 (Table 4.7.4-1). Only one sample was collected at Peshlaki Spring (360 mg/L) and it was significantly higher than for Heiser Spring. Wupatki Spring exhibited an alkalinity similar to Peshlaki Spring (336 mg/L). Since these data are more than 10 years old and no condition thresholds for this measure have been established, the current condition for this measure is unknown.

Dissolved Oxygen (mg/L)

Dissolved oxygen was only reported for the Little Colorado River in 2002 (Table 4.7.4-1). This measurement was 8.7 mg/L, which meets the criteria established by AZDEQ. However, since the data is more than 10 years old, the current condition for this measure is unknown.

Temperature (°C)

In general, temperatures in springs were lower in spring than during summer or autumn (Table 4.7.4-1). Only one measurement was reported for the Little Colorado River in September 2002. Although temperatures were collected beginning in January 1966 through September 2002, there were only seven days during which temperature was collected among the four springs and Little Colorado River. Long-term temperature data (2010-2015) has been collected at Heiser Spring in conjunction with depth to groundwater data (Figure 4.7.4-2). Average temperature is roughly consistent but within years temperature varies by approximately 6 °C, with high temperatures usually occurring in September and low temperatures occurring in March. These temperature fluctuations are large for groundwater sources and indicate a shallow aquifer or local recharge. Since these data are more than 10 years old, and no condition thresholds have been established for this measure, the current condition for this measure is unknown.

Indicator Bacteria (cols/100 ml)

At least one sample from Heiser Spring and the Little Colorado River tested positive for total coliform, fecal coliform, and E. coli (Table 4.7.4-2). At Heiser Spring the sample collected in October 2001 contained fecal coliform, but the sample collected in 2002 did not (Thomas 2003). However, since the data are more than 10 years old, we did not assign a current condition for this measure.

Inorganic Chemicals and Uranium (μg/L)

All of the inorganic chemicals and uranium were well below the maximum allowable concentration identified by the USEPA as of October 2001 and May 2002 for Heiser Spring and September 2002 for

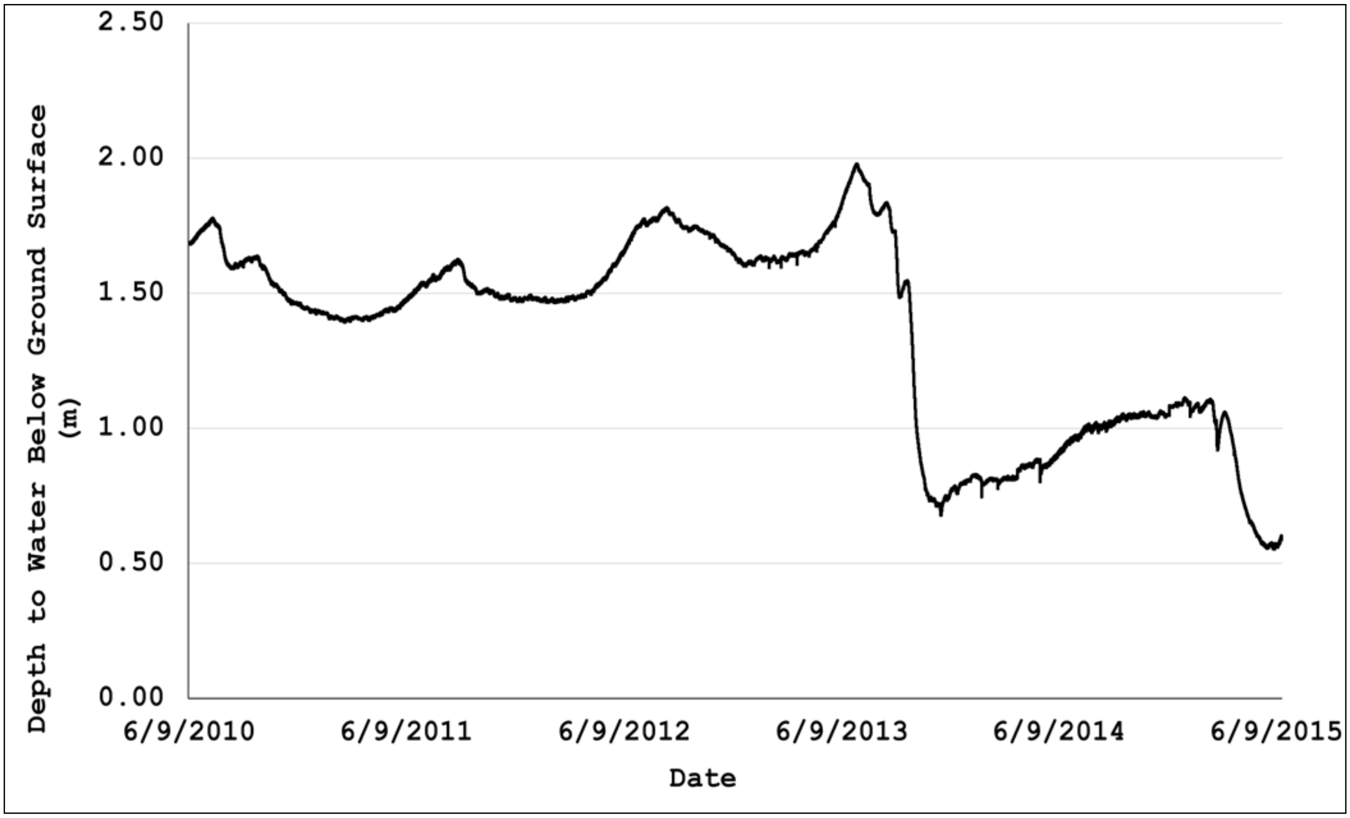


Figure 4.7.4-1. Depth to groundwater (m) at Heiser Spring in Wupatki NM.

Table 4.7.4-1. Water quality data for water resources in Wupatki NM.

Water Resource	Date	Specific Conductance (µS/cm)	pH (SU)	Alkalinity (mg/L as $CaCo_3$)	Dissolved Oxygen (mg/L)	Temperature (°C)	Data Source
Heiser Spring	1/31/1966	875	7.9	159	---	---	EPA (2016c)
	6/25/1979	1000	7.6	160	---	20.5	EPA (2016c)
	10/23/2001	855	7.7	160	---	17.6	Thomas (2003)
	5/3/2002	856	7.9	156	---	13.5	Thomas (2003)
Peshlaki Spring	6/25/1979	2000	---	---	---	20.5	EPA (2016c)
	5/11/2005	1714	7.4	320	---	16.7	Springer et al. (2006)
Spice Seep	5/11/2005	---	6.1	---	---	14.1	Springer et al. (2006)
Wupatki Spring	10/21/1954	1520	---	336	---	17.0	EPA (2016c)
Little Colorado River	9/13/2002	614	8.7	---	8.7	19.3	Thomas (2003)

the Little Colorado River (2016d) (Table 4.7.4-3). However, since these data are more than 10 years old, the current condition for this measure is unknown.

Plants

A total of 31 species and six species that could only be identified to genus were identified at Peshlaki Spring (26) and Spice Seeps (17), combined (Table 4.7.4-4). Red brome (*Bromus rubens*) and tamarisk (*Tamarix spp.*) were the only two non-native species reported by Springer et al. (2006); however, camelthorn occurs at Heiser Spring and Spice Seep (Brehl 2008). Only four of the 31 native species present are normally associated with wetlands as determined by their wetland indicator status (USDA 2016). Three were considered facultative wetland species (usually occurs in wetlands but may occur in non-wetlands) and one was considered facultative (may occur in wetlands and non-wetlands). The remaining 25 species were considered upland plant species (usually occurs in non-wetlands) or facultative upland species (almost never occurs in wetlands). No species was considered an obligate wetland species. These data suggest a relatively dry environment around Peshlaki and Spice Seep, and are indicative of an upland plant community rather than a wetland plant community. The Freemont cottonwood (*Populus fremontii*) at Peshlaki Spring may have even been planted (Springer et al. 2006). Since no reference conditions were developed, we did not assign a current condition for this measure.

Invertebrates

As of this assessment invertebrates collected in May 2005 at springs and seeps had not been identified to species (Flagstaff Area National Monuments, P. Whitefield, pers. comm., Natural Resources Specialist,). Only the order to which the species belonged was recorded along with the number of specimens collected from Peshlaki Spring and Spice Seep (Springer et al. 2006). There were six orders from which specimens were collected and all of them were terrestrial species (Table 4.7.4-5). No aquatic habitat was available for invertebrates. Most species collected from Deadman Wash and Navajo Natural in 1997 were identified to species or genus, many of which are aquatic. Since no reference conditions were developed, we did not assign a current condition for this measure.

Birds

Only two bird species were captured on camera at Coyote Waters and Navajo Natural pools during October 2004 through June 2006 (Table 4.7.4-6). These were common raven (*Corvus corax*) and mourning dove (*Zenaida macroura)*. Common ravens may have visited pools in order to prey on doves rather than for the water itself, whereas doves likely visited pools for access to water (Holton 2007). Since no reference conditions were developed, we did not assign a current condition for this measure.

Mammals

Between Navajo Natural and Coyote Waters, seven mammal species were detected during October 2004 through June 2006 (Table 4.7.4-6). Mule deer (*Odocoileus hemionus*) and pronghorn (*Antilocapra americana*) were only detected at Navajo Natural. Blacktailed jackrabbit (*Lepus californicus*) and a species of antelope squirrel (*Ammospermophilus spp.*) were found only at Coyote Waters. The remaining species occurred at both sites. Since no reference conditions

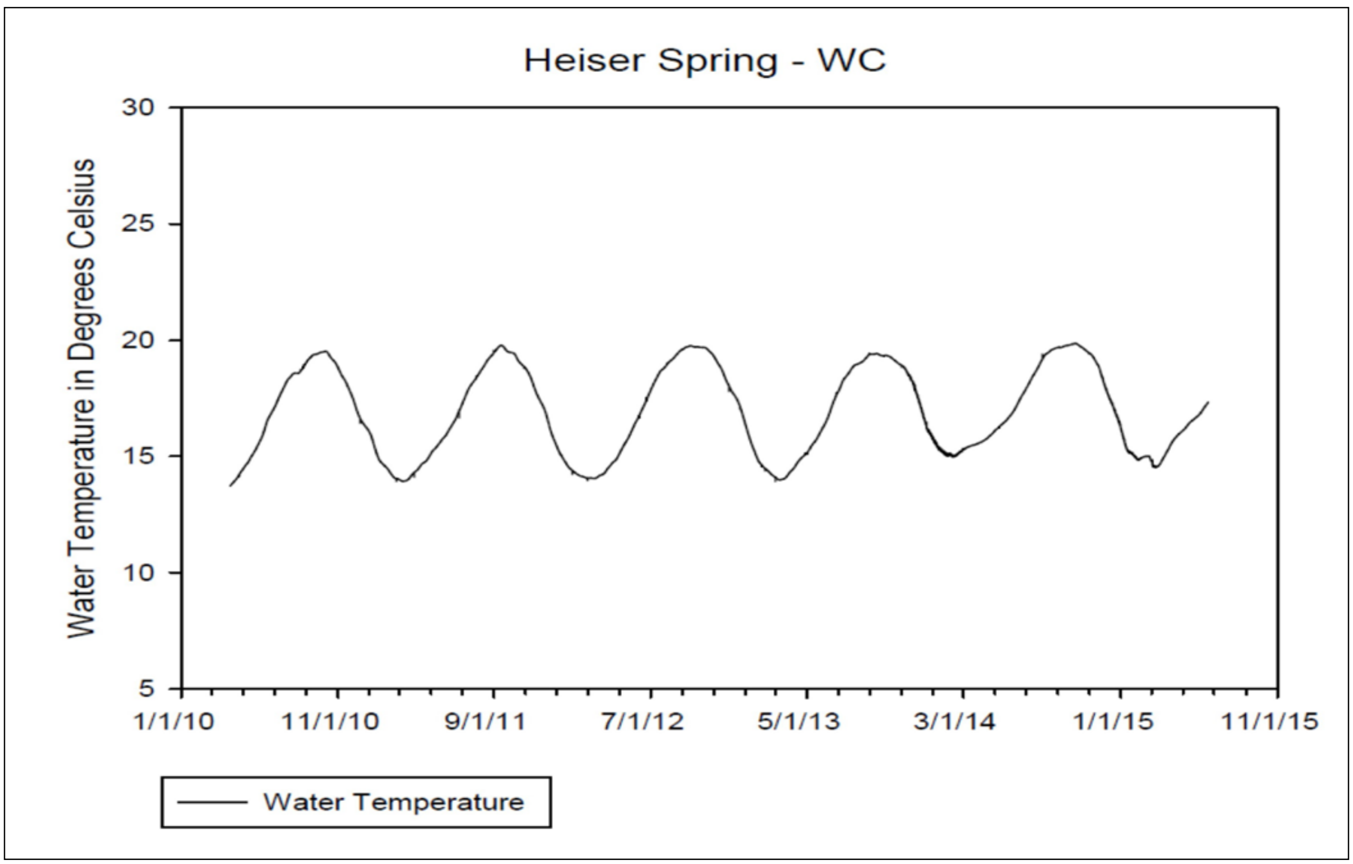


Figure 4.7.4-2. Temperature (°C) at Heiser Spring in Wupatki NM. Figure Credit: © S. Monroe.

Table 4.7.4-2. Indicator bacteria for water resources in Wupatki NM.

Water Resource	Date	Total Coliform (cols./100 ml)	Fecal Coliform (cols./100 ml)	*E. coli* (cols./100 ml)
Heiser Spring	10/23/2001	e1,300	e7	<1
	5/3/2002	>8,000	<1	<1
Little Colorado River	9/13/2002	e70,000k	e5,200k	e10,000k

Source: Thomas (2003).

Table 4.7.4-3. Concentration inorganic chemicals and uranium in water resources in Wupatki NM.

Concentration (µg/L)	Heiser Spring[1]	Little Colorado River[2]
Antimony	<0.05/0.06	54
Arsenic	1.2/1.6	14.3
Barium	11/17	14
Beryllium	<0.06/<0.06	0.09
Cadmium	<0.04/<0.04	0.04
Chromium	1.2/4.7	1.1
Copper	1.0/1.3	14.7
Lead	0.10/<0.08	0.84
Uranium, natural	4.7/4.7	8.3
Nitrogen, nitrite	<0.008/<0.008	0.02
Nitrogen, nitrite + nitrate	1.8/1.7	1

Source: Thomas (2003).

[1] Data collected 10/23/2001 and 05/03/2002.

[2] Data collected 9/13/2002.

were developed, we did not assign a current condition for this measure.

Herpetofauna

In 2001 at least 14 species of reptile and amphibian were recorded by Persons and Nowak (2006) as occurring in washes, riparian areas, floodplains, ex-lake beds, irrigated areas, seeps, springs, pools, and wetlands (Table 4.7.4-6). Many of these, including the western rattlesnake (Crotalus viridis) and desert spiny lizard (Sceloporus magister), are associated with dry desert environments rather than springs, seeps, or surface water. Since no reference conditions were developed, we did not assign a current condition for this measure.

Table 4.7.4-4. Plants documented at springs in Wupatki NM.

Scientific Name	Common Name	Wetland Status
Alhagi maurorum[1,4]	Camelthorn	FAC
Ambrosia acanthicarpa[2]	Flatspine bur ragweed	UPL
Andropogon gerardii[2]	Big bluestem	FACU
Aristida purpurea[2]	Purple threeawn	UPL
Atriplex canescens[2]	Fourwing saltbush	UPL
Atriplex obovata[3]	Mount saltbush	UPL
Atriplex sp.[3]	Saltbush	UPL
Astragalus lentiginosus[3]	Freckled milkvetch	UPL
Bromus rubens[3,4]	Red brome	UPL
Chamaesyce sp.[2]	Sandmat	UPL
Chrysothamnus nauseosus[2,3]	Rabbitbrush	UPL
Ephedra torreyana[2,3]	Torrey's jointfir	UPL
Eriogonum jamesii[2,3]	James' buckwheat	UPL
Fallugia paradoxa[2]	Apache plume	UPL
Forestiera pubescens[3]	Stretchberry	UPL
Gilia [Aliciella] leptomeria[2]	Sand gilia	UPL
Gilia hutchinsifolia[2]	Desert pale gilia	UPL
Gutierrezia sp.[3]	Snakeweed	UPL
Hilaria jamesii[2,3]	Jame's galleta	UPL
Isocoma pluriflora[3]	Southern goldenbush	UPL
Juniperus monosperma[2,3]	One-seed juniper	UPL
Malacothrix sp.[2]	Desert dandelion	UPL
Mentzelia multiflora[2]	Adonis blazingstar	UPL
Oenothera pallida[2]	Pale evening primrose	UPL
Phragmites australis[2]	Common reed	FACW
Poliomintha incana[2]	Frosted mint	UPL
Populus fremontii[2]	Freemont cottonwood	FACW
Puccinellia distans[3]	Weeping alkaligrass	FACW
Rhus aromatica[2]	Skunkbush sumac	FACU
Sporobolus airoides[3]	Alkali sacaton	FAC
Stanleya pinnata[3]	Desert princesplume	UPL
Stephanomeria sp.[2]	Wirelettuce	UPL
Stipa comata[2]	Needle and thread	UPL
Stipa hymenoides[2]	Indian ricegrass	UPL
Tamarix sp.[2,4]	Tamarisk	FAC
Tiquilia nuttallii[2]	Nuttall's crinklemat	UPL
Yucca angustissima[2]	Narrowleaf yucca	UPL
Yucca baileyi[3]	Navajo yucca	UPL

[1] Species found at Heiser Spring and Spice Seep (Brehl et al. 2008).

[2] Species found at Peshlaki Spring in May 2005 (Springer et al. 2006).

[3] Species found at Spice Seep in May 2005 (Springer et al. 2006).

[4] Species in bold are non-native.

Table 4.7.4-5. Invertebrates documented at natural pools and springs in Wupatki NM.

Common Name	Scientific Name
Beavertail fairy shrimp[1]	Thamnocephalus platyurus
Beetle[1]	*Hydrochus* sp.
Common backswimmer[1]	*Neonecta* sp.
Desert fairy shrimp[1]	Streptocephalus dorothae
Giant water scavenger beetle[1]	*Dibolocelus (Hydrophilus)* sp.
Mosquitoe[1,2]	*Culex* sp.
Mosquitoe[1,2]	*Psorophora* sp.
Predaceous diving beetle[2]	*Rhantus* sp.
Triops[1]	*Triops newberryi*
Chironomid[1,2]	Family Chironomidae
Unidentified ant, bee, wasp, or sawfly[3,4]	Order Hymenoptera (7)
Unidentified beetle[3,4]	Order Coleoptera (7)
Unidentified true bug[3]	Order Hemiptera (2)
Unidentified butterfly[3,4]	Order Lepidoptera (5)
Unidentified fly[3,4]	Order Diptera (7)
Unidentified arachnid[3,4]	Class Arachnida (2)

[1] Data collected during August/September at Deadman Wash (Graham 2001).

[2] Data collected during August/September at Navajo Natural (Graham 200).

[3] Data collected during May 2005 at Peshlaki Spring (Springer et al. 2006). Includes number of specimens collected in parentheses.

[4] Data collected during May 2005 at Spice Seep (Springer et al. 2006). Includes number of specimens collected in parentheses.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Table 4.7.4-7 summarizes the condition rating and rationale used for each indicator and measure. The most important measures for assessing the condition of springs, seeps, and surface water in Wupatki NM is the presence of a wetted area or discharge and depth to groundwater. However, since the presence of a wetted area and discharge data were more than 10 years old, we consider the condition for this measure to be unknown. In fact, all measures except for depth to groundwater were considered unknown. Nevertheless, we consider the condition of springs, seeps, and surface water in Wupatki NM to warrant significant concern since the literature reveals a long history of development and disturbance of water resources in Wupatki NM (Brehl 2008, Holton 2007, NPS 2006a, NPS 2013c, Springer and Schaller 2012, and Stumpner 2004).

We assigned a medium or low confidence to all but the depth to groundwater measure. Although data on

Table 4.7.4-6. Vertebrates documented at springs, seeps, and ephemeral pools in Wupatki NM.

Taxa	Common Name	Scientific Name
Birds	Common raven[1]	*Corvus corax*
	Mourning dove[1,2]	*Zenaida macroura*
Mammals	Antelope squirrel[2]	*Ammospermophilus spp.*
	Blacktailed jackrabbit[2]	*Lepus californicus*
	Bobcat[1,2]	*Lynx rufus*
	Coyote[1,2]	*Canis latrans*
	Desert cottontail[1,2]	*Sylvilagus audubonii*
	Mule deer[1]	*Odocoileus hemionus*
	Pronghorn[1]	*Antilocapra americana*
Herpetofauna[3]	Eastern collared lizard	*Crotaphytus collaris*
	Desert spiny lizard	*Sceloporus magister*
	Eastern fence lizard (also known as Plateau lizard)	*Sceloporus tristichus*
	Lesser earless lizard	*Holbrookia maculata*
	Little Striped whiptail	*Aspidoscelis inornata*
	Longnose leopard lizard	*Gambelia wislizenii*
	Ornate tree lizard	*Urosaurus ornatus*
	Plateau striped whiptail	*Aspidoscelis velox*
	Red-spotted toad	*Anaxyrus punctatus*
	Side-blotched lizard	*Uta stansburiana*
	Striped whipsnake	*Coluber taeniatus*
	Western rattlesnake	*Crotalus oreganus*
	Western whiptail (also known as Tiger whiptail)	*Aspidoscelis tigris*
	Woodhouse's toad	*Anaxyrus woodhousii*
	Unidentified *Aspidoscelis*	*Aspidoscelis* sp.

[1] Data collected between October 2004 and June 2006 at Navajo Natural pools (Holton 2007).

[2] Data collected between October 2004 and June 2006 at Coyote Waters pools (Holton 2007)

[3] Data collected during 2001 and provided by the Southern Colorado Plateau Network

Table 4.7.4-7. Summary of springs, seeps, and surface water indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Water Quantity and Availability	Presence of Wetted Area or Discharge		Although there was measurable discharge at Spice Seep and thus, a wetted area, water present at the surface was minimal. There was no measurable discharge at Peshlaki Spring, nor presence of a wetted area. These results warrant significant concern; however, since these data are more than 10 years old, the current condition is unknown. There are no data on trend. Confidence in this condition rating is low.
	Depth to Groundwater (m)		Depth to groundwater has remained nearer to the ground surface during 2014 and 2015 than prior to July 2013. This indicates improving conditions for this measure at Heiser Spring; however, flows have never occurred at the surface since measurements began. Therefore, the condition for this measure warrants significant concern. The trend in depth to groundwater has improved (i.e., groundwater trending closer to the surface). Confidence in the condition rating is high.
Water Quality	Core Water Parameters, Inorganic Chemicals, and Uranium		Although most water quality measures for which condition thresholds have been established were considered good, the data for all measures was more than 10 years old. Since no recent data (i.e., < 5 yrs) exists for water resources in Wupatki NM, the condition for this indicator and all measures is unknown. Since the condition is unknown, the confidence is low.
Biodiversity	Invertebrates, Birds, Mammals, and Herpetofauna		As with water quality, the data for all measures of biodiversity were more than 10 years old. Since no recent (i.e., < 5 yrs) biodiversity data exists for water resources in Wupatki NM, the condition for this indicator and all associated measures is unknown. Since the condition is unknown, the confidence is low.
Overall Condition			The condition for the majority of measures used in this assessment are unknown due to older and few data. In fact, all measures except for depth to groundwater were considered unknown. Nevertheless, we consider the condition of springs, seeps, and surface water in Wupatki NM to warrant significant concern since the literature reveals a long history of development and disturbance of water resources in Wupatki NM. Since there are few data on which to base the overall condition, we gave this condition rating low confidence. Overall trend could not be determined.

depth to groundwater is the most current data used in this assessment, they only apply to Heiser Spring, and do not necessarily reflect conditions at Peshlaki Spring, Wupatki Spring, or Spice Seep. Factors that influence confidence in the condition rating include age of the data (< 5 yrs unless the data are part of a long-term monitoring effort), repeatability, field data vs. modeled data, and whether data can be extrapolated to other areas in the monument. The condition for the majority of measures used in this assessment is unknown because of these factors.

The greatest uncertainty regarding springs, seeps, and surface water in Wupatki NM is that their condition prior to being heavily grazed by livestock with subsequent modification for human use is unknown (NPS 2015a). The inventories presented in this assessment occurred after the development of water resources in the monument. Wupatki NM's water resources have been subjected to more than 100 years of development and disturbance. Furthermore, springs and seeps are influenced by the complex underlying hydrogeology of the region and many factors influence discharge and overall health of these resources (Bills et al. 2007).

Threats, Issues, and Data Gaps

The primary anthropogenic threats to springs and seep ecosystems are groundwater depletion, pollution, alteration of source area geomorphology, and diversion of runout flows (Springer and Stevens 2008). Wupatki NM's water recharge area is at least partially depleted by the public water supply system for the City of Flagstaff, Arizona (NPS 2006a). However, it is unlikely that water withdraw by the city affect spring discharge since water is withdrawn from the C aquifer rather than the perched aquifers that recharge the springs (SCPN, S. Monroe, Hydrologist, comments to earlier draft, 1 November 2016). Mineral, and oil and gas development may also impact water quality in the monument. Uranium test pits occur on adjacent Navajo lands east of the Little Colorado River, and the discharge path of the Leupp or Winslow sewage treatment plants is unknown (NPS 2006a).

Comparison of repeat photos shows that juniper woodlands have increased in and around the monument (Romme and Whitefield 2017), which may increase water stress and reduce spring discharge (P. Whitefield, Natural Resource Management Specialist, pers. comm.), although this has not been tested at the monument. Climate change also affects spring health. Monahan and Fischelli (2014) evaluated which of 240 NPS units have experienced extreme climate changes during the last 10-30 years. The results of this study for Wupatki NM were summarized in Monahan and Fischelli (2014). Extreme climate changes were defined as temperature and precipitation conditions exceeding 95% of the historical range of variability. These results indicate a trend toward warmer, drier conditions within the monument, and are indicative of trends occurring throughout the southwestern U.S. (Prein et al. 2016).In this assessment, most plants found at Peshlaki Spring and Spice Seep are considered upland species. Few species are common plants found in wetlands. Drier conditions may also explain the low species diversity found at Navajo Natural and Coyote Waters. Holton (2007) found that water was absent 72% of 63 site visits during October 2004 to June 2006.

The occurrence of springs and seeps is a result of regional geologic and hydrologic conditions and long-term patterns of precipitation (Bills et al. 2007, Kreamer and Springer 2008). These factors partially determine discharge, water temperature, and water chemistry. Warmer temperatures may increase the rate of evapotranspiration, thereby reducing the amount of water in aquifers (Kreamer and Springer 2008).

A survey of springs located on federal, non-NPS lands in northern Arizona indicate that more than 93% are moderately or severely impaired largely through human use and development (Grand Canyon Wildlands Council 2002). This exploitation has led to diminished discharge or has cut off flows altogether, which has negative consequences for plants and animals that depend on these water resources (Grand Canyon Wildlands Council 2002, Kreamer and Springer 2008, Springer et al. 2006).

4.7.5. Sources of Expertise

Stephen Monroe (Hydrologist, partner of SCPN) provided the data used to assess depth to groundwater, in addition to interpretation of these data and a review of the assessment. Erika Nowak (Herpetologist, Colorado Plateau Research Station) provided data on herpetofauna.

Assessment author is Lisa Baril, biologist and science writer, Utah State University.

4.8. Little Colorado River Riparian Corridor

4.8.1. Background and Importance

Both the Little Colorado River and the Deadman Wash riparian area are a source of water and habitat to plants and animals in the eastern portion of Wupatki National Monument (NM). The Little Colorado River (LCR), a major tributary to the Colorado River, flows northwest and drains an area of about 69,930 km^2 (27,000 mi^2) in northeastern Arizona (Arizona Department of Environmental Quality [ADEQ] 2007, U.S. Geological Survey [USGS] 2011a). The river's headwaters are about 306 km (190 mi) southeast of Wupatki NM, near Springerville, Arizona (National Park Service [NPS] 2014). Approximately two kilometers (1.2 mi) of the LCR run along the eastern boundary of Wupatki NM (Figure 4.8.1-1), and about 30.3 hectares (75 ac) of LCR corridor lie within the national monument boundary (NPS 2014c). Flow along the river's length is "interrupted," with stretches that have perennial, intermittent, or ephemeral flow (ADEQ 2007, USGS 2011a). Perennial flow occurs mainly in headwater streams (ADEQ 2007). In the vicinity of the national monument, flow is ephemeral, occurring mainly during the spring due to runoff from the melting of higher-elevation winter snow, and in the summer from sporadic thunderstorms (NPS 2014c). A brief history of the river, and the degradation it has experienced, is provided in the Reference Condition section.

One of the four largest drainage corridors in the national monument is Deadman Wash. Deadman Wash (DMW) meets the LCR near the park's northeastern boundary (Figure 4.8.1-2). The wash has its origins in the San Francisco Mountains about 64.4 km (40 mi) from the national monument (USGS 1982, Schelz 2012); the wash crosses Coconino National Forest and U.S. Highway 89 before entering the park. Deadman Wash depends on rainfall and spring snowmelt from the mountains (Stumpner 2004), and, within the park, it may have water flowing through it during and after large rainfall events (Thomas et al. 2006).

Although most of DMW has areas of native vegetation that are typical of northern Arizona ephemeral riparian areas (Schelz 2012), riparian areas associated with the wash and the LCR near their confluence include expanses of tamarisk (*Tamarix* spp.), an invasive, non-native tree from Eurasia. This area was completely invaded by tamarisk until eradication efforts were initiated in 2010. The general confluence area, however, also possesses some areas of native vegetation and resources and provides the only extensive closed-canopy woody habitat to various types of wildlife.

Figure 4.8.1-1. The Little Colorado River near the confluence with Deadman Wash in Wupatki NM. Photo Credit: NPS/P. Whitefield.

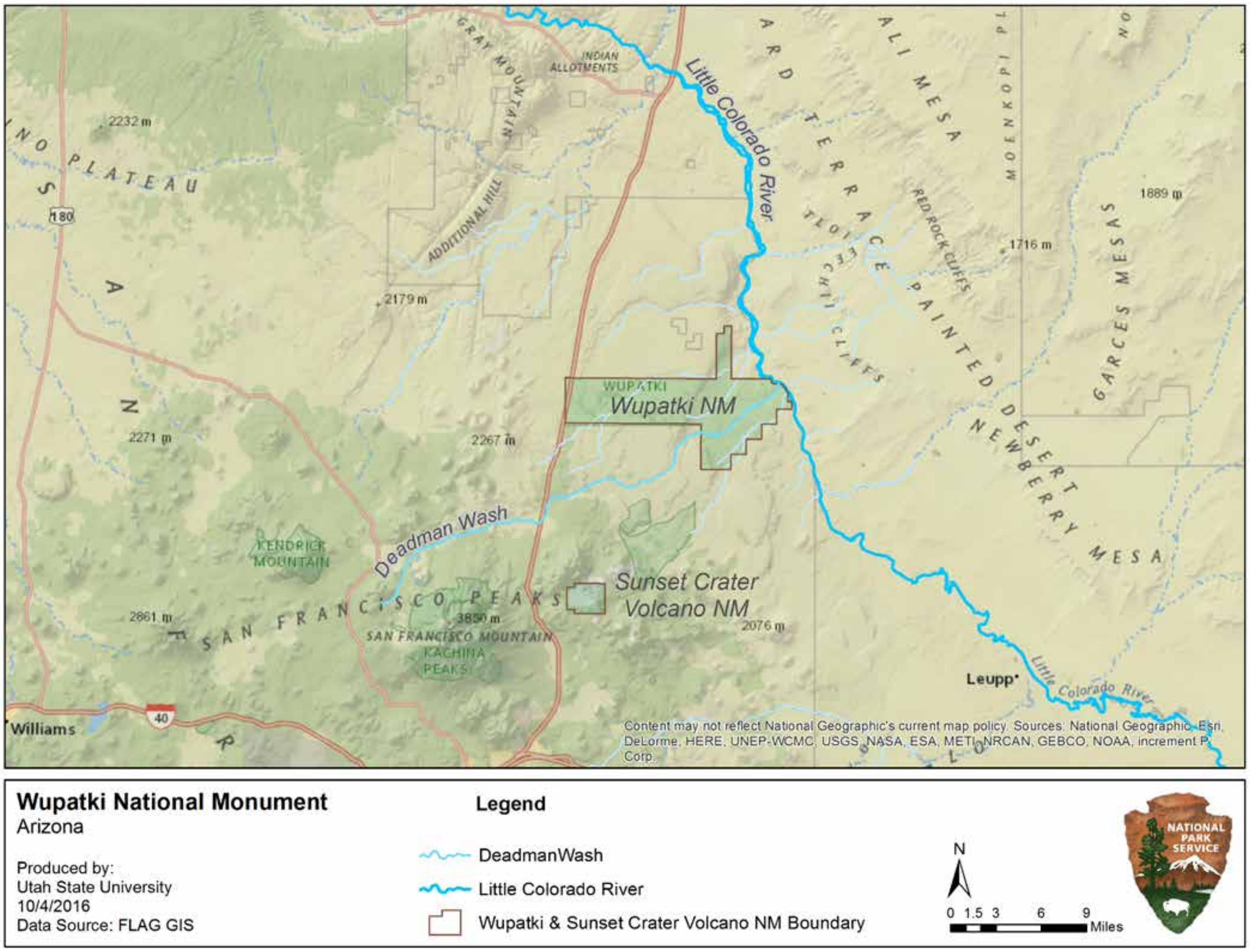


Figure 4.8.1-2. Regional map showing the Little Colorado River and Deadman Wash in relation to Wupatki NM.

For example, bird surveys in and around the tamarisk stands and the LCR have recorded a number of species that do not utilize the other available habitat types within the national monument. Also, the confluence area has been the subject of restoration efforts in recent years to remove dense tamarisk stands and other non-native species and plant and encourage native vegetation (Schelz 2012, NPS 2014c).

The LCR, where it runs along the boundary of Wupatki NM, and the confluence area with DMW, are the focus of this assessment. Also note that there is a separate assessment in this report that focuses on the geomorphic stability of intermittent, ephemeral streams in Wupatki Basin; that assessment describes the soils and underlying geology of several ephemeral dry wash systems in the national monument, including DMW. An additional, separate assessment on the springs, seeps, and streams within the monument addresses water quality in the LCR. Threats to the water quality of the river include those associated with cattle and sheep grazing, sewage lagoons and septic systems, mining activities, and agricultural activities occurring within the river basin upstream of Wupatki NM (Thomas 2003).

More than 81% of streams in the arid and semi-arid Southwest are ephemeral (dry washes) and intermittent (Levick et al. 2008). These streams are often major tributaries to, or the headwaters of, perennial streams. Ephemeral and intermittent streams share functions in common with perennial streams--they are pathways in the watershed for moving water, nutrients, and sediment (Levick et al. 2008). Plant and animal diversity and abundance in the vicinity of streams in arid and semi-arid regions is higher than in surrounding uplands. Properly functioning streams provide many important functions, including, but not limited to: surface and subsurface water storage and exchange; groundwater recharge and discharge;

energy dissipation during high-water flows to reduce erosion; sediment storage, transport, and deposition to maintain and develop floodplains; storage and cycling of nutrients; water supply and filtering; support of vegetation to help stabilize stream banks; and habitat for wildlife, and wildlife movement and migration corridors (Levick et al. 2008).

4.8.2. Data and Methods

For this assessment of the Little Colorado River Riparian Corridor, we used a variety of indicators and measures to examine different aspects of the resource. We used a total of four indicators to examine hydrology, vegetation, physical processes (erosion/deposition), and avian wildlife of the area. In some cases, individual measures apply only to the LCR or DMW, depending on available information/data and the scope of the overall assessment. It should also be noted that this condition assessment is not based on a rapid field assessment, but rather on various reports that were available on the topic and on input from Flagstaff Area National Monuments (NMs) personnel.

The hydrology indicator was assessed using two measures. We initially considered using a third measure focusing on whether degradation or impairment of the DMW riparian area was occurring from the upstream or upland watershed (e.g., from changes in water or sediment being supplied). This is one measure recommended by Dickard et al. (2015) in their protocol for assessing perennial and intermittent streams. We chose not to use this as a measure because no data were available to address it. The Geomorphic Stability of Intermittent, Ephemeral Streams assessment of this overall condition assessment concluded an unknown condition (with no indicators and measures) due to a lack of data. In this assessment, we address issues related to the potential degradation of the riparian area and wash under the erosion/deposition indicator. Discussions of degradation of the LCR from its extensive watershed are beyond the scope of our assessment, other than in a general sense.

<u>Streamflow (Discharge) of LCR & DMW</u>

The purpose of this measure is to examine data on streamflow and assess changes in streamflow over time. Although we include its name in the title, to emphasize its importance, we cannot address discharge for DMW. This is because no data are available, and the Flagstaff Area NMs staff recognize this as an important data gap (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.). The need for streamflow data for DMW is also stated in the park's Foundation Document (i.e., NPS 2015a). Therefore, this measure focuses on streamflow in the LCR along the park's eastern boundary.

Streamflow, or discharge, is the volume of water that passes a given location within a given period of time. It is usually presented in cubic feet per second, which is equal to a volume of water one foot high and one foot wide flowing a distance of one foot in one second. Streamflow data (some raw and some summarized) are available for the LCR from a USGS gaging station (LCR at Grand Falls [0940100]) located about 16 km (10 mi) upstream from the national monument boundary (Thomas 2003). According to Thomas (2003), streamflow at the gaging station is similar to that at the boundary of Wupatki NM. This was confirmed recently by another expert, who indicated this gage would be most appropriate for application to the park, rather than gages farther upstream or downstream (e.g., at Cameron; Stephen Monroe, Hydrologist, Northern Arizona University and Southern Colorado Plateau Network [SCPN] partner, pers. comm.).

Stream discharge data were obtained for the entire period of record for the Grand Falls gaging station. The overall time span for which data are available is 1925 to 2016. However, there are large breaks in the data (Table 4.8.2-1). The data were acquired from two different USGS websites (USGS 2016c and USGS 2016d [specifically, Grand Canyon Monitoring Research Center {GCMRC}]), and data for the earlier period (1925-1995) included summary statistics, while data for the later period (1996-2016) did not.

Although we are interested in the entire period of record (for trends), we are especially interested in the most recent period to assess current condition. Because no summary statistics were available for the most recent period, the reference conditions we used to assess condition were general in nature.

<u>Depth to Groundwater in DMW Riparian Area</u>

Groundwater in the DMW riparian area is of interest because it can relate to the area's ability to support riparian vegetation (see Zaimes et al. 2007, Dickard et al. 2015). For an intermittent stream/river, groundwater is often right below the streambed, even when water is not flowing in the channel (Zaimes et al. 2007). In an ephemeral stream/river, however, the

Table 4.8.2-1. Data from the USGS gage (09401000) at Grand Falls, AZ, from 1925-2016.

Year(s)	Data, No Data, or Incomplete Data
1925	Incomplete data
1926-1949	Data
1950, 1951, 1953	Incomplete data
1952	No Data
1954-1959	Data
1960	Incomplete data
1961-1988	No Data
1989	Incomplete data
1990-1994	Data
1995	Incomplete data
1996-2000	No Data
2001-2010	Data
2011-2012	No Data
2013-2016	Data

distance from the water table to the streambed can be highly variable, both among sites and through time. In some ephemeral streams there is strong connectivity between flow and alluvial groundwater levels (Stephen Monroe, Hydrologist, Northern Arizona University, pers. comm.). Stream channel flow in an ephemeral stream might also result from impervious geological surfaces (e.g., bedrock) near the streambed (Zaimes et al. 2007).

For this measure, we used reports and other sources of information/data that exist for the national monument regarding groundwater. Reports used include Christensen (1982) and Stumpner (2004). There have also been at least two efforts to monitor groundwater within the DMW riparian area, as described by Springer and Schaller (2012) and Grady (2014). In 1963, a perched aquifer was found to exist in the DMW riparian area (Christensen 1982, Stumpner 2004). This perched aquifer was intercepted when a “trench well” 44.2 m- (145 ft-) long was dug to a depth of 3 to 3.7 m (10 to 12 ft) during construction of a portion of the Sunset Crater-Wupatki Loop Road (Christensen 1982).

Although we did not develop reference conditions by which to assess condition for this measure, depth to groundwater is of significance for this resource and is of interest to park personnel. Therefore, we have included available information in the condition assessment.

The riparian vegetation indicator was evaluated using two measures.

Presence/Absence of Native and Non-native Vegetation

To assess the general condition of the vegetation in the DMW riparian area, we chose a measure that examines the types of vegetation present and whether they are native or non-native species. The vegetation in the confluence area of DMW has been described in a number of park reports, and we draw on these resources to describe and assess the vegetation in the riparian area and the LCR in the park. Reports consulted for this measure include: Christensen (1982), Stumpner (2004), Hansen et al. (2004), Brehl et al. (2008), Schelz (2012), NPS (2014), Grady (2012), and Grady (2014). We also present information on plant species that have been planted in the DMW confluence area as part of the riparian restoration effort undertaken by the park and its partners.

Maintenance of Soil Moisture in/along DMW Confluence Area

The purpose of this measure is to examine whether or not soil moisture in the DMW riparian area is available enough to support riparian vegetation. In the approach of Dickard et al. (2015) to determine whether soil moisture is being maintained, they examine whether the plant species present indicate the maintenance of soil moisture. Although we discuss the vegetation present in DMW in this measure, we base the assessment on actual measurements of soil moisture in the DMW confluence area, information that users of the Dickard et al. (2015) protocol may not have in the field. To examine soil moisture in the DMW riparian area, we used the results of a study that collected soil moisture data as part of the restoration activities in the DMW riparian area.

Grady (2014) used two approaches to monitor soil moisture in the DMW riparian area. First, he used Time Domain Reflectometry soil moisture probes at a depth of 45 cm below the soil surface. The probes, installed in August of 2013, were monitored on the installation date and in June, July, and September of 2014. The idea with the use of these probes was to monitor soil moisture before and after planned tamarisk removal.

The second effort to monitor soil moisture was through the use of three transects in areas targeted for the restoration of native vegetation. These areas had already undergone tamarisk removal. Soil water concentration was measured in each plot, and there were five plots per transect. Soil water concentration was measured using a Theta-Probe at two soil depths (0-10 cm [0-3.9 in] and 30-40 cm [11.8-15.7 in] below the soil surface); data were collected in July and September of 2014.

To address the vegetation present in the riparian area, we used various reports for the national monument describing vegetation (i.e., those used for the previous measure). To determine whether or not the species present indicate the maintenance of soil moisture, we generally followed the approach used by Dickard et al. (2015). This was done, however, as supporting information. This approach looks at the indicator status of existing riparian vegetation. Indicator status can be obtained from a listing developed by multiple federal agencies. We obtained the list specifically for Arizona, *The State of Arizona 2016 Wetland Plant List* (Lichvar et al. 2016). The federal and state lists separate plants into categories based on their likelihood of occurring in wetlands or nonwetlands. The categories (from wetter to drier) are obligate, facultative wetland, facultative, facultative upland, and upland. Definitions are provided as needed in the assessment, but we provide two here to provide examples: A facultative wetland plant usually occurs in wetlands, but may occur in non-wetlands. More specifically, "these plants predominately occur with hydric soils, often in geomorphic settings where water saturates the soils or floods the soil surface at least seasonally" (Lichvar et al. 2012). A facultative plant is one that occurs in wetlands and nonwetlands, or, more specifically "these plants can grow in hydric, mesic, or xeric habitats. The occurrence of these plants in different habitats represents responses to a variety of environmental variables other than just hydrology, such as shade tolerance, soil pH, and elevation, and they have a wide tolerance of soil moisture conditions" (Lichvar et al. 2012). The other groups under this categorization are obligate wetland plants (those that almost always occur in wetlands), facultative upland plants (those that usually occur in non-wetlands, but may occur in wetlands), and upland plants (those that almost never occur in wetlands).

The bird use of the riparian area indicator is based on results of bird surveys conducted by the Yavapai College Elderhostel along the LCR in 2002, 2003, and 2004. For this indicator/measure we compiled a comprehensive list of the species recorded during the surveys.

Bird Species Occurrence

The Yavapai College Elderhostel, led by Randy Miller, surveyed for birds along the river in May of 2002 and 2003 and April of 2004. The surveys occurred in areas that were in or near large stands of tamarisk (*Tamarix* spp.; Yavapai College Elderhostel 2002). In general, the sampling locations were in the vicinity of Deadman Wash and Black Falls crossing. Few details of the surveys were provided by Yavapai College Elderhostel (2002), but the "methodology included 8-10 person transects at 100 m (328 ft) intervals which were assigned station point numbers on all sides of tamarisk stands and through the interior of the largest stand" at the confluence of DMW and the LCR. The individuals conducting the surveys recorded species, the numbers of birds by species, gender, and bird activity.

A total of four sites were surveyed, with three located inside of the park (two were located inside of the boundary fence, and the third was outside of the fence but within the park). The fourth site was located outside of the park and about 6.4 km (4 mi) away from the other sites (and in different habitat; Mark Szydlo, Biologist, Flagstaff Area NMs), so it was not included in our assessment.

The erosion/deposition indicator included two measures that are described below.

Vertical stability of DMW, and Confluence Area

This measure is based on one of the indicators/measures from Dickard et al. (2015), which is used to determine whether a channel is changing at a natural versus an accelerated rate. Channels can aggrade or degrade, and naturally occurring channel change usually occurs over hundreds or more years. On the other hand, some accelerated changes (natural or human-related) can occur over a decade or less. Channel lowering reduces the landscape's overall elevation, including the valley bottom, through erosion .

The Dickard et al. (2015) approach uses this measure to address lowering of the channel only; aggradation is addressed in their approach under a separate measure. According to Prichard et al. (1998; an older version of Dickard et al. 2015) "determination of vertical stability in a stream system is most easily documented through repeated measurements of bed elevation through time. Monumented cross sections should be established using a stable reference point as a permanent benchmark. The cross sections are resurveyed at various intervals…"

To address this measure for the DMW riparian area, we examined a channel morphology baseline survey that was conducted in 2012 for the park (Figure 4.8.2-1) by the SCPN. From the figure, note that the four transects were located in the tamarisk removal area (cleared in 2011 and 2012). Only one survey (at one point in time) has been conducted to date. Therefore, we are unable to discuss changes over time in the channel morphology, but we did show the results of the survey. It should be noted that Stumpner (2004) also provided two surface profiles across the DMW channel, with one located in the restoration project area about 200 m (656 ft) upstream of the 2012 SCPN cross section 4. The second of Stumpner's cross sections was farther upstream.

<u>Stream (DMW) is in Balance with the Water & Sediment being Supplied by the Watershed</u>

Although there is little information available on this topic, we included it in the assessment because park personnel are interested in whether the DMW channel has remained relatively stable over the last 70 years, or whether it has aggraded since tamarisk invaded during the 1930s.

Water and sediment are transported out of a watershed by streams (Prichard et al. 1998). If erosion or deposition are extreme, it means that this transport function is not in balance, and, therefore, degradation of the riparian or wetland area could be occurring. To address this measure, we present information that is available on whether aggradation in the riparian area

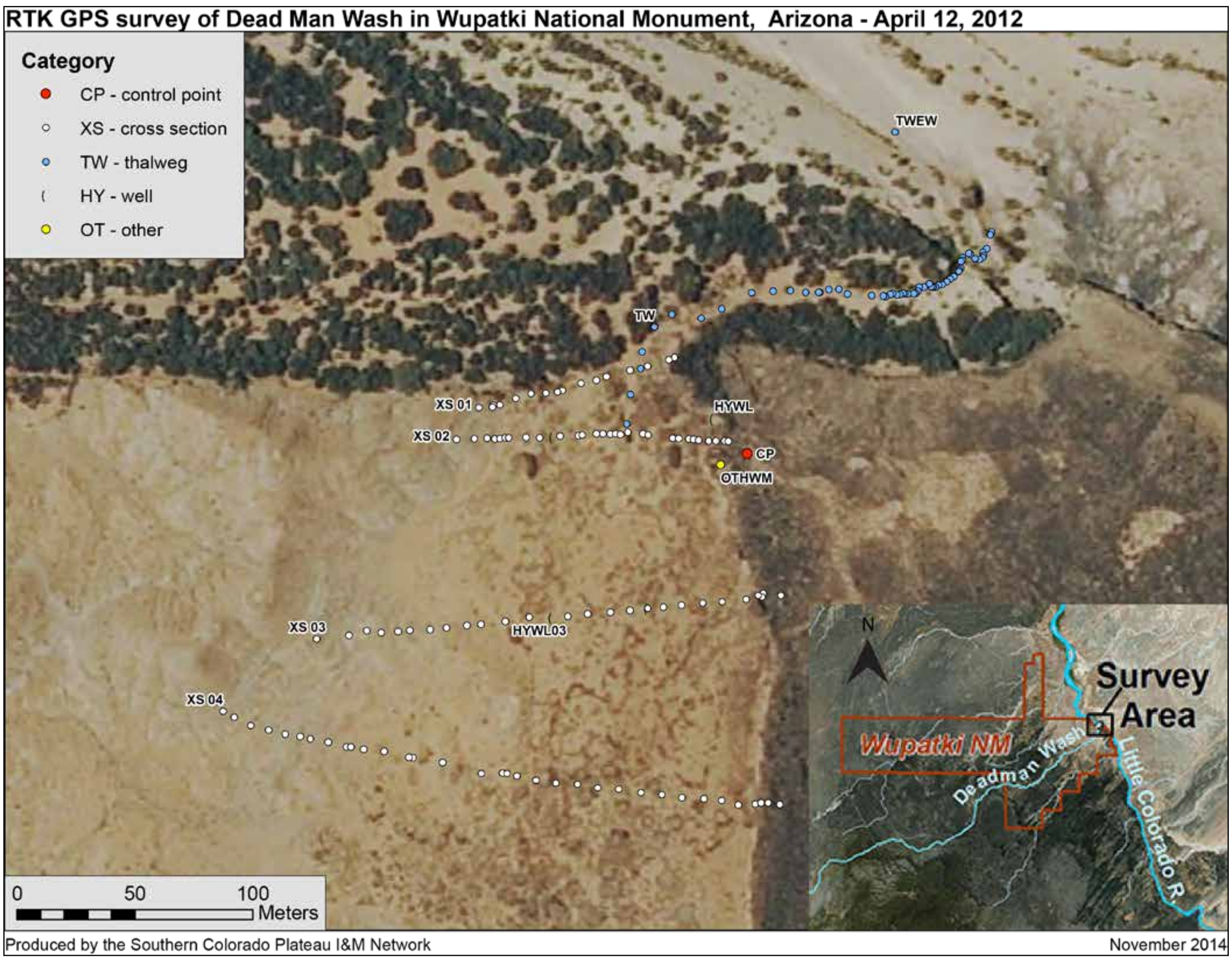


Figure 4.8.2-1. Map showing the location of the four transects (white dots) for the 2012 channel morphology baseline survey for Deadman Wash. Figure Credit: SCPN/Inset added by Utah State University.

of DMW has occurred/is occurring. We focus on DMW because the area drained by and that affects the LCR is extensive, and this large area is outside of our scope for the condition assessment.

4.8.3. Reference Conditions

Table 4.8.3-1 summarizes, for each measure for which reference conditions were developed, resources in good condition, those warranting moderate concern, and those warranting significant concern.

This section of the condition assessment also provides a discussion of conditions (and changes) along the Little Colorado River over the past approximately 100-150 years. This discussion will help "set the stage" for the assessment of current conditions. It should be noted that Deadman Wash was also heavily grazed by livestock, starting around the middle 1800's (Schelz 2012).

<u>Little Colorado River History of Degradation (with Emphasis on the Wupatki NM area)</u>
This description was taken directly from NPS (2014).

> "As with other Southwestern rivers, the entire length of the LCR is highly degraded from its pre-settlement condition. In early historic descriptions and photographs, the river was lined with galleries and groves of Fremont cottonwood (*Populus fremontii*) and narrowleaf willow thickets (*Salix exigua*). Since the 1860's, livestock overgrazing and human water use have favored invasion along most of the entire river by non-native

Table 4.8.3-1. Reference conditions used to assess the Little Colorado River riparian corridor.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Hydrology	Streamflow of LCR & DMW	Streamflow (i.e., discharge) has remained relatively stable over time.	Streamflow (discharge) has changed somewhat over time.	Streamflow (discharge) has changed substantially over time.
	Depth to Groundwater in DMW Riparian Area	No reference conditions were developed.	No reference conditions were developed.	No reference conditions were developed.
Vegetation	Species Occurrence (Presence/Absence) of Native & Non-native Vegetation	Native plant species are predominant along the LCR / DMW riparian area, although a low level of non-native, invasive species may occur. Non-native species occur either in very low numbers or areal coverages, and do not seriously threaten native plant or wildlife species.	Native plant species are predominant along the LCR / DMW riparian area, although non-native, invasive species may occur in substantial numbers/areal coverages.	Non-native plant species are predominant along the LCR / DMW riparian area, and only a low level of native species occur.
	Maintenance of Soil Moisture in/along DMW Confluence Area	Soil moisture in the DMW confluence area is adequate to support riparian species (based on soil moisture monitoring data).	–	Soil moisture in the DMW confluence area is not adequate to support riparian species (based on soil moisture monitoring data).
Bird Use of Riparian/ LCR Area	Bird Species Presence	A number of bird species have been recorded during surveys in the LCR/DMW confluence area, including some that have not been recorded elsewhere in the park.	A small number of bird species have been recorded during surveys in the LCR/DMW confluence area, and/or few or none of the species recorded are unique to the area (i.e., they have been recorded in other areas of the park).	–
Erosion / Deposition	System is Vertically Stable (DMW and DMW-LCR confluence)	System is vertically stable. If channel lowering is occurring, it is doing so at a natural rate.	–	System is not vertically stable. If channel lowering is occurring, it is doing so at an unnatural rate. .
	Stream is in Balance with Water & Sediment from the Watershed	DMW is in balance with water & sediment from the watershed, and no aggradation is occurring.	–	DMW is not in balance with water & sediment from the watershed; aggradation is occurring.

phreatophytic tree species, primarily tamarisk (*Tamarix chinensis*) and Russian olive (*Elaeagnus angustifolia*).

The earliest available aerial photography from 1935-36 for the Wupatki NM reach of the LCR show both the main channel and floodplain terraces were relatively open, with little evidence of trees on stream terraces on either bank (Figure 4.8.3-1). Today the main channel remains scoured and barren, but adjacent floodplain terraces and side drainages support monoculture thickets of tamarisk (Figure 4.8.3-2). Both up- and down-river from Wupatki NM, most LCR river terraces and tributary drywash channels are also extensively infested with non-native camelthorn (*Alhagi maurorum*), a short, heavily-thorned shrub in the legume family, which spreads via extensive and highly persistent subsurface root systems. Narrow patches of native shrub willows are the primary remnants of native riparian vegetation, typically persisting on linear sand levees that parallel the active channel banks. Remnant cottonwood trees also occur in small numbers within 2 mi up- and down-river from Wupatki NM. On the opposite riverbank from Wupatki NM is the expansive Navajo Reservation. Cattle are prevalent and have constant access to the riverbed and both banks up- and down-river from Wupatki NM. Few to no cottonwood seedlings survive to grow above the browse line."

One source of this description is probably Colton (1937), who described changes to the river as observed in 1937. This 1937 account describes observations of the river by early explorers (e.g., in the 1500s) to the region. Thomas et al. (2006) also points to upstream impoundments, irrigation diversions, groundwater withdrawals, and uranium mining as sources of alterations to the LCR riparian corridor.

<u>Tamarisk</u>

Tamarisk species were first introduced in the U.S. in the early 1800s and have been planted as ornamentals, windbreaks, and streambank stabilizers (Kunzmann and Johnson 1989). Tamarisk spread rapidly along streams, ephemeral waterways, and roadsides and other areas in the Southwest since the 1920s (Kunzmann and Johnson 1989). Negative impacts of tamarisk include: high water use due to evapotranspiration, outcompeting and replacing native vegetation, increasing the salt concentration of soils to levels toxic to native vegetation, interference with streamflow, worsened flooding during high flows, and relatively low use by wildlife (Kunzmann and Johnson 1989, University of California Weed Research and Information Center [UCWRIC] 2013).

4.8.4. Condition and Trend

<u>Streamflow of LCR & DMW</u>

Our discussion for this measure focuses on streamflow of the LCR only, because no data are available for DMW. The lack of this information for DMW is an important data gap for the park (NPS 2015a).

Streamflow of the LCR at the Grand Falls gage has been extremely variable over time (Thomas 2003; Figure 4.8.4-1 and 4.8.4-2; Note that a different scale was used for the two figures). Since 1950, discharge has rarely been over 10,000 cfs. Discharge has been less than 2,000 cfs since 2013. These graphs were obtained online from USGS (USGS 2016d) by graphing the entire dataset for each set of years (i.e., 1925-1975 and 1976-2016) using the USGS graphing tool/option. As discussed previously, no summary statistics are available for the period of record to date. [The graphs depict the data available, which for the earlier period were collected at varying intervals per day over the time frame (e.g., two or more times per day). For the later period, data were collected every 15 or 1 minute on each day)]. However, some summary data were available for the period up to 1994, and we also present some of those findings here. It is also worth noting that a detailed hydrological analysis of the stream flow of the LCR will be conducted by the USGS in the near future, but only data prior to 1947 will be analyzed for the Grand Falls gage (David Dean, Research Hydrologist, USGS, pers. comm.). Much of the USGS analysis will be on data from the gage in Cameron (which is not as representative of the river as it flows along the park boundary).

Figure 4.8.4-3 shows annual peak streamflow for 1923-1994. The 1923 entry in the figure was noted as an historic peak (but no additional explanation was provided). Even without the 1923 point in the graph, annual peak streamflow generally decreased over time.

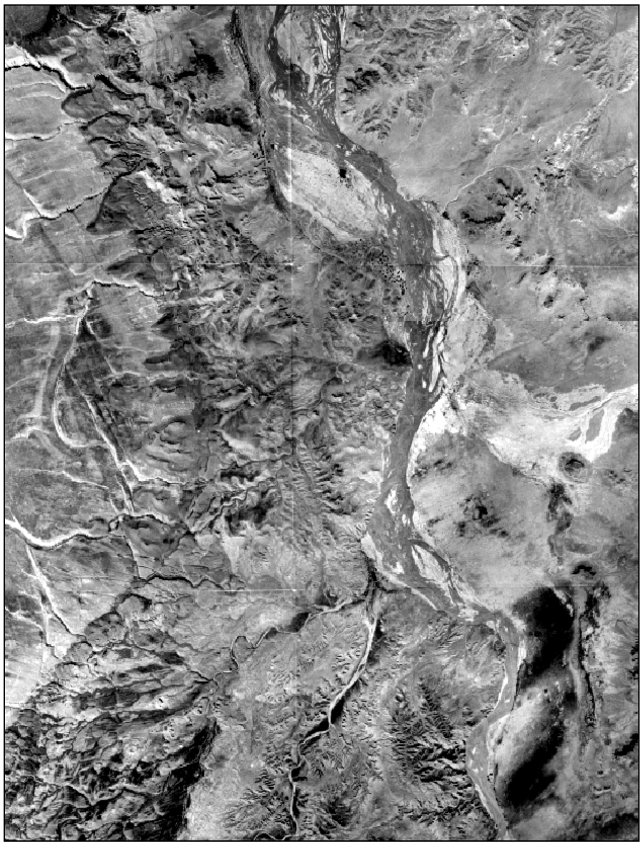


Figure 4.8.3-1. Aerial photography of the LCR near Wupatki NM, 1935/1936. Photo Credit: USDA Soil Conservation Service.

Figure 4.8.3-2. Aerial photography of the LCR near Wupatki NM, 1997. Photo Credit: U.S. Geological Survey.

Also of general interest is how streamflow in the LCR varies throughout the year. Average monthly discharge, based on data from 1925-1995 (and using incomplete data in the calculations, meaning that in some years fewer than 12 months of data were available), was greatest in March and April, followed by August (Figure 4.8.4-4).

Finally, data were available on the average annual discharge of the LCR at the Grand Falls gage for 1926-1994 (Figure 4.8.4-5; no incomplete data were used for the calculations). Unfortunately, no data were available in between 1959 and 1990, and no data were available after 1994.

Based on the information presented here, it appears that there has been a steady decline in peak discharge of the LCR over time, as measured at the Grand Falls gage (Figures 4.8.4-1, 2, and 3). A steady decline in peak discharge over time has also been observed at the downstream gage in Cameron (David Dean, Research Hydrologist, USGS, pers. comm. [and based on a review of data/graphics available at USGS 2016c]). We cannot address whether average monthly or average annual discharges have decreased over time without more quantitative analysis of the data to date. We consider condition to be of moderate concern based on the observed downward trend in peak flows, but we have only moderate confidence in the assessment. A quantitative analysis of the data that are available would allow for a stronger determination of condition, and perhaps even a determination of significant concern for the LCR.

Depth to Groundwater in DMW Riparian Area

Christensen (1982) described a "trench well" that was dug in the DMW confluence area when the main visitor access road was being built in the park in 1963. Christensen (1982) described the trench well as being 3 to 3.7 m (10 to 12 ft) deep and 44.2 m (145 ft) long, with 30,000 to 40,000 gallons of water per working day being pumped from the well for a month. A perched aquifer was described as the source of the water. As described by NPS (2014), "The perched aquifer was believed to recharge via the percolation of captured precipitation on the porous basalt of the Grand

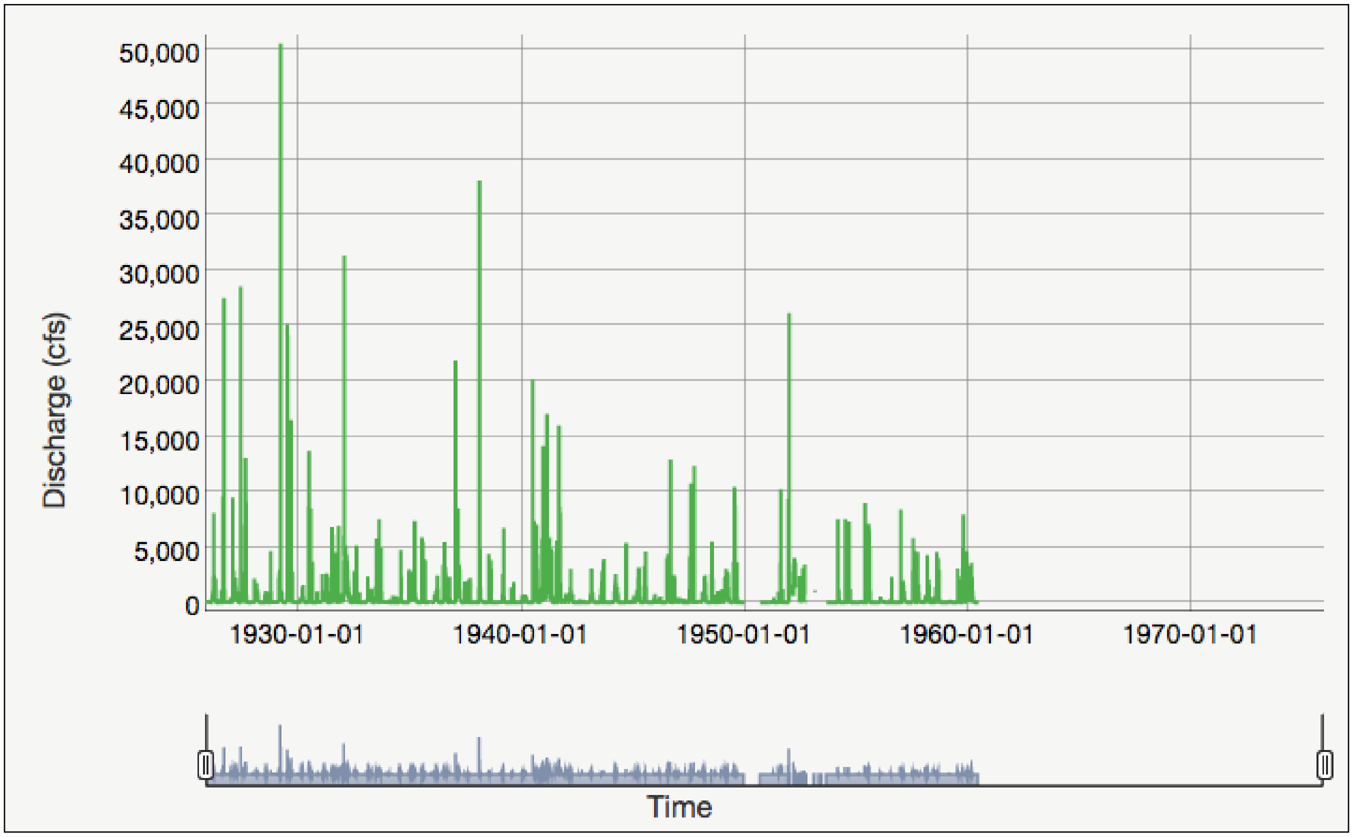


Figure 4.8.4-1. **Discharge data (collected at varying intervals per day) for the LCR at Grand Falls from 1925-1975. Note that no data were available for 1952 and 1961-1975. Figure Credit: GCMRC (USGS 2016d).**

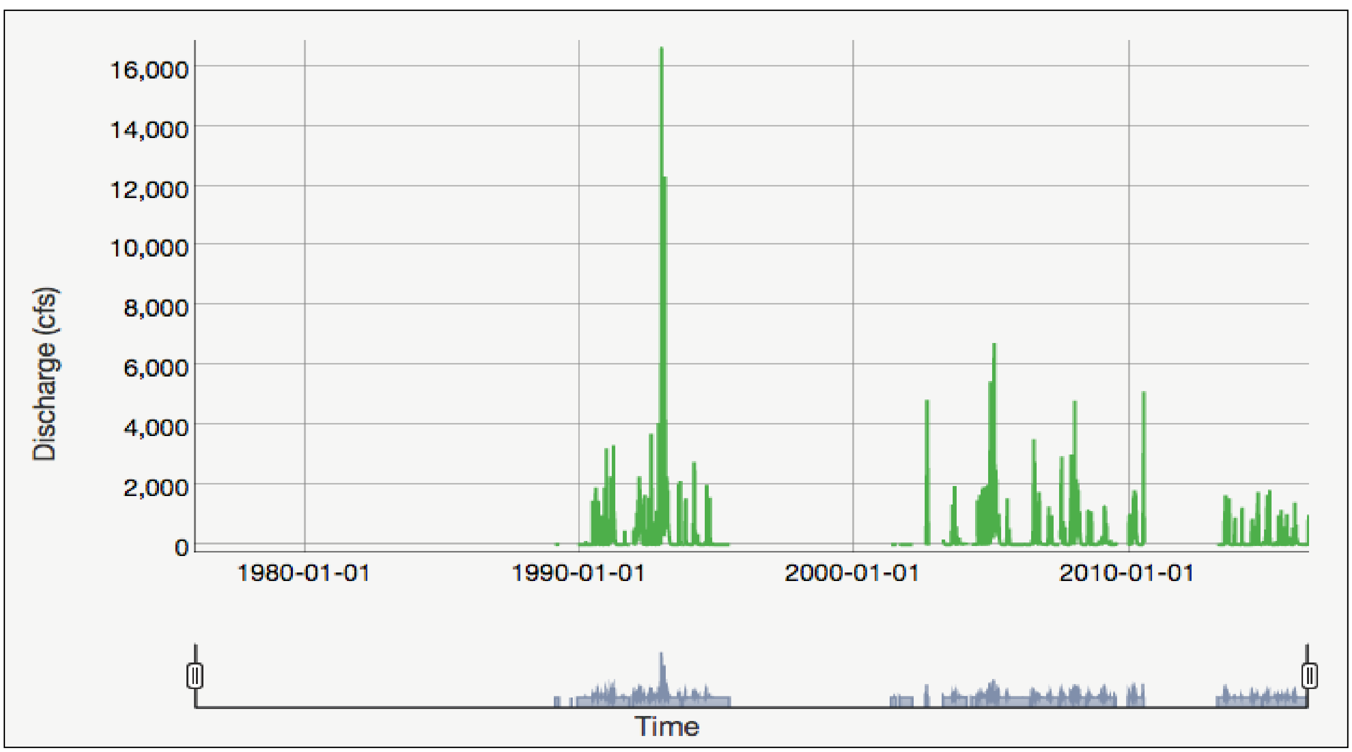


Figure 4.8.4-2. **Discharge data (collected every 15 or 1 minute) for the LCR at Grand Falls from 1976-August 2016. Note that no data were available for 1976-1988, 1996-2000, and 2011-2012. Figure Credit: GCMRC (USGS 2016d).**

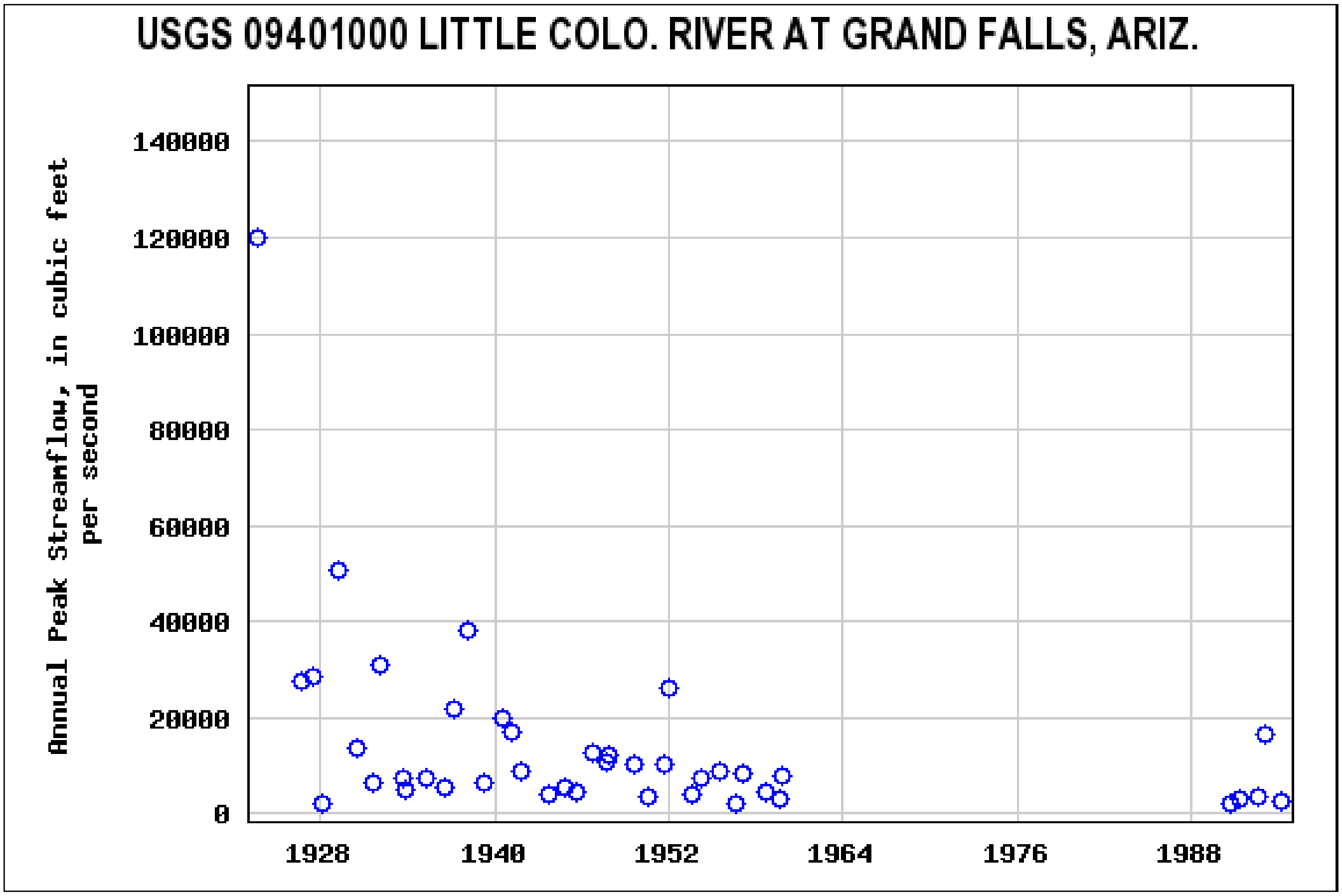


Figure 4.8.4-3. Annual peak streamflow from 1923-1994 at the LCR Grand Falls gage. Figure Credit: USGS (2016c).

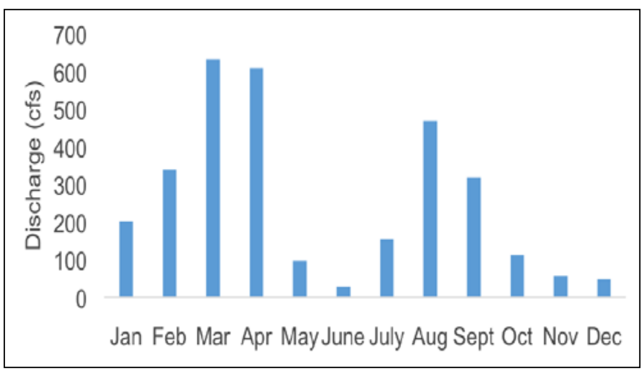


Figure 4.8.4-4. Mean of monthly discharge, 1925-1995, for the LCR at Grand Falls. Data Source: USGS (2016c).

Figure 4.8.4-5. Average annual discharge (cfs), 1926-1994, for the LCR at Grand Falls. Data Source: USGS (2016c).

Falls Flow, which then discharges from flow into the Deadman channel deposits along the southeast side the drainage. It is possible that water flowing in the LCR also percolates laterally through the Grand Falls Flow into the channel deposits. The primary evidence for recharge from lava flow bedrock is the observation that the tamarisk is taller and plants are healthier where the lava flow layer abuts the southeastern side of the wash."

In 2011-2012, wells were installed in DMW to monitor ground water levels beneath the channel (Springer and Schaller 2012). Three shallow groundwater monitoring wells were installed by hand, as well as two more that were drilled with machinery (NPS 2014c). Four of the five wells were located across the channel, while the fifth was located near the site of the 1963 trench well. The maximum depth of the five monitoring wells ranged from 1.5 to 3.35 m (5 to 11 ft).

During all monitoring visits, no water was recorded in any of the wells. The wells were dry even after DMW received "intense monsoonal rains" in September of 2012. Water appeared unable to infiltrate to the depth of the wells, but pockets of standing water and fresh mud were visible in the wash (Springer and Schaller 2012). As of 2014, NPS (2014) indicated the wells remained dry.

Additional wells were installed in the area in 2014 (Grady 2014). These wells, installed to depths of 5.5 m (18 ft), 3.7 m (12 ft), and 2.7 m (9 ft), were measured in May, July, and September of 2014. No water was found in any of the wells during any of the monitoring visits.

NPS (2014) outlined some potential reasons why the perched aquifer may be deeper than it apparently was in the past (1963): tamarisk may have depleted the groundwater over the past several decades; recharge has been reduced during the extended drought period starting in 1996; and the fine surface clay layer is inhibiting water infiltration. Also, drops in groundwater level are often associated with channel incision, such as that observed at the lower end of DMW (Steve Monroe, Hydrologist, Northern Arizona University, pers. comm.).

Although we provided a discussion of studies of groundwater monitoring at Wupatki NM, we did not develop reference conditions for the measure. Condition is unknown. None of the wells revealed groundwater to date, except that groundwater was intercepted in 1963 when the 44.2-m (145-ft) "trench well" was dug to a depth of 3 to 3.7 m (10 to 12 ft; Christensen 1982). The reason(s) that groundwater has not been located in recent years is unknown. Confidence in the measure is low (although some monitoring data exist).

<u>Species Occurrence (Presence/Absence) of Native & Non-native Vegetation</u>

The vegetation near the confluence of DMW and the LCR has been described as being infested with non-native tamarisk (*Tamarix* sp.), which forms a monoculture (e.g., Christensen 1982, Schelz 2012; Figure 4.8.4-6). Christensen (1982) noted that tamarisk predominates in other areas near the river, where it grows in alluvium (not basalt). [The tamarisk species is reported as *T. ramosissima* by Schelz (2012), and as *T. chinensis* by NPS (2014). Literature describes how these two species can hybridize in the U.S., creating some confusion in distinguishing between the two (University of California Weed Research and Information Center [UCWRIC] 2013). This hybrid is reportedly the most common invasive tamarisk in the western U.S. (UCWRIC 2013)]. Tamarisk covers/covered 25-40 acres (Schelz 2012) in the DMW riparian area, and Hansen et al. (2004, as cited by NPS 2014c) mapped 50 acres of tamarisk within the LCR corridor within the park (Figure 4.8.4-7). Areas dominated by tamarisk are shown in dark blue (the Invasive Riparian Shrubland class), and pale blue shows wash areas. [Note that tamarisk removal efforts are described in subsequent paragraphs]. A few small patches of native willows (*Salix exigua*) also occur (NPS 2014c). The vegetation mapping project conducted in the national monument (i.e., Hansen et al. 2004) reported only a few native species of grasses, forbs, and shrubs in the areas dominated by tamarisk and camelthorn (NPS 2014c). However, native plant species are found within the DMW channel upstream of the confluence area; these plants include alkali sacaton grass (*Sporobolus aeriodes*), four-wing saltbush (*Atriplex canescens*), and sand sage (*Artemisia filifolia*) (NPS 2014c).

Some authors have reported that the occurrence of tamarisk indicates that water is present near the ground surface (Christensen 1982), with dense stands needing groundwater within 6.1 m (20 ft) of the surface (e.g., Horton and Campbell 1974 [as cited by Christensen 1982], Stevens 2002 [as cited by Stumpner 2004]).

Tamarisks are invasive, non-native shrubs or trees that are well known in the Southwest. Tamarisk has successfully outcompeted native species along river courses, including the Colorado River (Kunzmann and Johnson 1989) and Little Colorado River. Tamarisk has a high reproductive output and it can survive drought conditions for long periods of time. Stumpner (2004) described tamarisk as consuming the majority of the groundwater where they grow, making it difficult for other native riparian species to survive. Tamarisk reportedly can use up to five acre-feet of water a year when they are growing in dense stands (Horton and Campbell 1974 as cited by Christensen 1982).

Stumpner (2004) noted that the only other species he observed in the area was the non-native species camelthorn (*Alhagi maurorum*) and native willow (*Salix exigua*). At least at the time of Stumpner's (2004) work, the highest densities of camelthorn were "along the base of the basalt ridge on the southeast extent of the study area..." Tamarisk and camelthorn have been present in the national monument since at least 1976 (Brehl et al. 2008). Cinnamon (1989) described control efforts starting in the early 1980s.

DMW Riparian Restoration Efforts

NPS staff have undertaken restoration efforts in the DMW riparian area. These efforts include the eradication and control of tamarisk (by chainsaw stump-cut and herbicide treatment) and camelthorn (herbicide treatment), and the planting of native plant species (Schelz 2012, NPS 2014c). The eradication of tamarisk stands began in 2009 (NPS 2014c) and continued until 2014. In that time, approximately 12 acres of tamarisk were cleared or treated (Figures 4.8.4-8 and 4.8.4-9). The park had plans to leave untreated the remaining ~9.3 acres of tamarisk for some time to provide woody habitat for birds and other wildlife in the area. [The value of tamarisk for breeding riparian birds has been reported in some areas, such as Grand Canyon National Park (Brown and Johnson 1989)]. However, the tamarisk beetle (*Diorhabda elongata*), arrived in the park in 2013, and has killed some tamarisk in the confluence area; the park removes entire trees or dead branches as needed. The decline of tamarisk from beetles is also discussed in the indicator on bird use of the area. NPS has continued to treat tamarisk re-sprouting from stumps and roots with herbicide as needed in the 2009-2014 removal areas.

Other activities that have been undertaken for restoration include the groundwater monitoring described under the hydrology indicator, and the use of an irrigation line above ground to water planted trees to promote root system development (NPS 2014c). A large number (200) of nursery-grown trees of several types have been planted and monitored in the restoration area; these trees include Fremont cottonwood (*Populus fremontii*), narrowleaf [or coyote] willow, Goodding's willow (*Salix gooddingii*), velvet ash (*Fraxinus velutina*), Arizona sycamore (*Platanus wrightii*), and box elder (*Acer negundo*) (Grady 2012; Figure 4.8.4-10). The plants were irrigated, as mentioned above, from 2010-2014.

Because groundwater has not yet been located in the DMW riparian area, future restoration work will focus more on actions to encourage herbaceous and shrub groundcover in the 3.2-ha (8 ac) cleared area in the DMW channel (NPS 2014c). Additional activities

Figure 4.8.4-6. Untreated tamarisk stand (left) in DMW in 2010. Photo Credit: NPS/Charles Schelz.

undertaken include testing the soil and applying amendments to reduce soil salinity, collecting seeds from native grasses and shrubs and conducting a two-year research project on different methods of planting seeds using "dryland" methods in the tamarisk-cleared area. The treatment of camelthorn will continue.

Measure Condition Summary

In summary, the main types of vegetation in the DMW riparian area are the non-natives tamarisk and

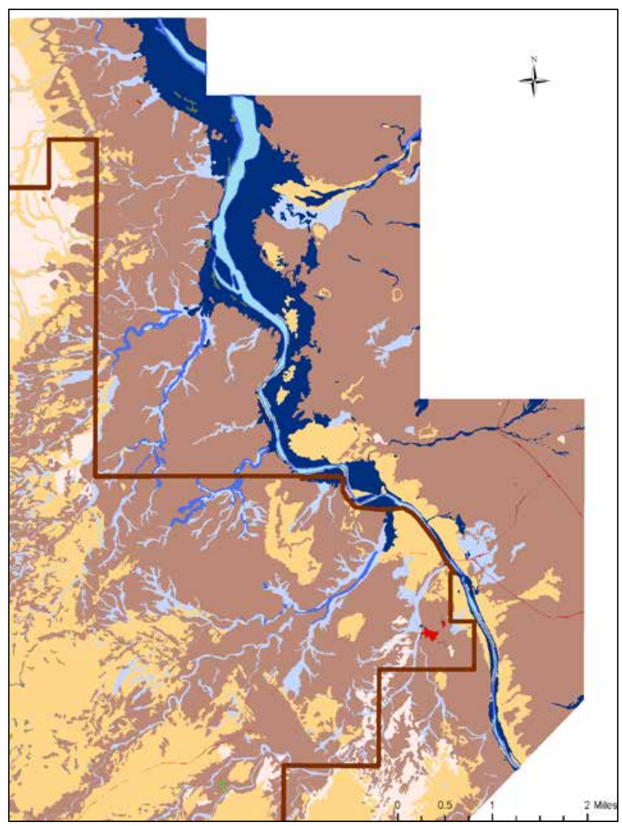


Figure 4.8.4-7. Vegetation map for the northeastern portion of the park, showing tamarisk in dark blue (largely along the LCR) and washes in pale blue.

camelthorn, with small patches of native narrowleaf (or coyote) willow. However, in addition to the small area of native willows present, other native trees/shrubs have been planted as part of the restoration project/study. Vegetation along the LCR within the park and vicinity has been described as highly degraded and disturbed and dominated by non-native species (Schelz 2012, Grady 2014, and NPS 2014c). Based on our reference conditions, the condition under this measure is of significant concern. However, the occurrence of tamarisk is not a recently-developed situation, and substantial management efforts have been taken to reduce the coverage of tamarisk. Some benefits of tamarisk, such as to wildlife, have also been recognized. Our confidence in this measure is high, as there are numerous reports and observations spanning many years that have focused on the vegetation in this area. The trend is improving as park staff have removed some areas of tamarisk and have planted native species as part of the restoration study/project. It should also be noted that in the last few years the tamarisk beetle has affected the growth and survival of at least some of the remaining tamarisk stands. On the other hand, camelthorn has started invading some areas where

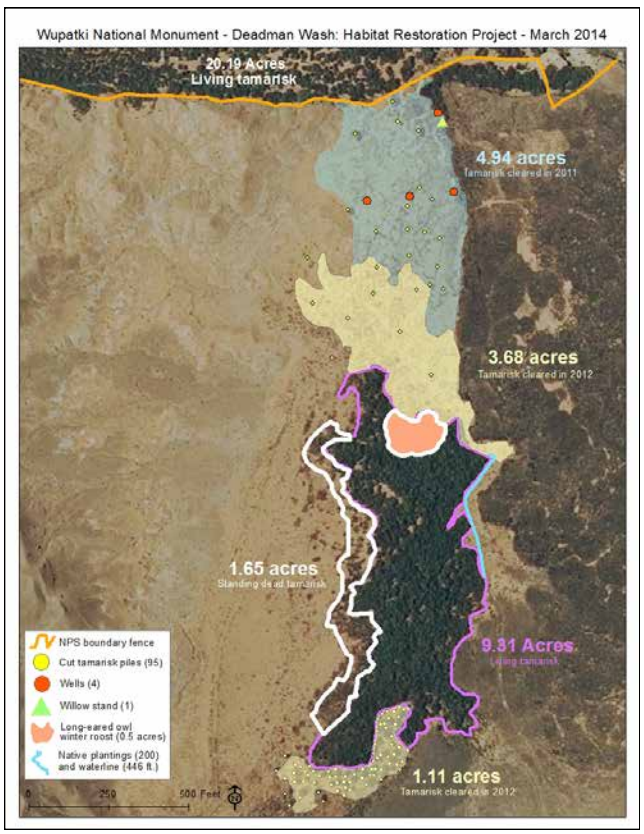


Figure 4.8.4-8. Deadman Wash riparian area showing tamarisk treatment areas (green/yellow shading) and living stands. Figure Credit: NPS.

Figure 4.8.4-9. Dense tamarisk stand (left half of both photos) before (above) and after (below) treatment. Photo Credits: NPS/Charles Schelz.

tamarisk was eliminated, faster than native vegetation is establishing (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.). Most efforts over the last three growing seasons have focused on herbicide control of the camelthorn invasion.

<u>Maintenance of Soil Moisture in/along DMW Confluence Area</u>

From the 2013-2014 soil moisture monitoring, Grady (2014) found that "there is ample soil water available during the growing season to support a diverse array of plants." The monitoring results from both methods used indicated that the soils were saturated at between 30-45 cm (11.8 to 17.7 in) in the majority of the project area. Saturation or near saturation in clayey soils occurs between 25-35% soil water concentration (Grady 2014). The researcher noted that the mechanism of the saturated soils was unclear, and that the soils were saturated even during the hot and dry summer months. [As discussed under the

Figure 4.8.4-10. Trees/shrubs planted along the eastern side of the DMW riparian area (tamarisk is in background of bottom photo). Photo Credits: NPS

hydrology indicator/measures, this effort also included the installation and monitoring of groundwater wells, and all wells remained dry during the monitoring period]. Grady (2014) also found that two of the areas monitored did not stay saturated all year; these areas were the southwestern edge of the study area and the center of the area where tamarisk had already been removed. It was suggested that on the southwestern edge, the reason for lower soil moisture was probably the sandier soils.

In accordance with our reference conditions for this measure, condition is considered good because field monitoring indicated that soil moisture was adequate to support riparian plant species. Saturated soils at 30-45 cm (11.8 to 17.7 in) below the soil surface were found to occur throughout much of the study area. Trend is unknown, as data were collected only over a relatively short time period a few years ago (2013-2014). Our confidence is medium for this measure due to the short period of time in which data were collected. The following discussion of the vegetation is provided as supporting information for this measure.

The presence of native willows (*Salix exigua*) and the non-native tamarisk also suggest that water is available to plants in the DMW riparian area. Although the presence of willow is not extensive in the area, this species is considered a facultative wetland plant (Lichvar et al. 2016), meaning it usually occurs in wetlands. More specifically, facultative wetland plants "predominately occur with hydric soils, often in geomorphic settings where water saturates the soils or floods the soil surface at least seasonally" (Lichvar et al. 2012).

Using tamarisk as an indicator is a bit more complicated. All tamarisk species are facultative phreatophytes (UCWRIC 2013), meaning that they are deep-rooted and obtain water from or just above the water table. A facultative species may occur in wetlands and nonwetlands, or, more specifically "these plants can grow in hydric, mesic, or xeric habitats. The occurrence of these plants in different habitats represents responses to a variety of environmental variables other than just hydrology, such as shade tolerance, soil pH, and elevation, and they have a wide tolerance of soil moisture conditions" (Lichvar et al. 2012). These trees can use surface and groundwater, and, when growing in large numbers around desert springs or riparian corridors can result in reduced surface water availability and underground water tables, potentially reducing flows and drying out wetlands (UCWRIC 2013). Tamarisk species develop deep root systems, greater than 4.6 m (15 ft) deep, and have high evapotranspiration rates (UCWRIC 2013). Tamarisk species "occur mostly on low ground where water collects," and they reach their greatest abundance in riparian habitats where they may form extensive stands (Arizona-Sonora Desert Museum 2016).

Also, as discussed elsewhere, the other species reported in the DMW riparian area is the non-native, camelthorn (*Alhagi maurorum;* Stumpner 2004). This species is also facultative (Lichvar et al. 2016). At least at the time of Stumpner's (2004) report, the highest densities of camelthorn were "along the base of the basalt ridge on the southeast extent of the study area, suggesting a higher water table in this area, since the root system (1.8-2.1-m [6-7 ft]) does not extend as deep as that of tamarisk."

Bird Species Presence

A total of 68 species were recorded along the Little Colorado River during surveys in 2002, 2003, and 2004 (Yavapai College Elderhostel 2002, 2003, 2004; Table 4.8.4-1). Of these, 24 (35%) were observed only during these surveys (designated with a "1" in the table), and not in other surveys that have been conducted in the park. The remaining 44 species have been recorded during other surveys in the park (e.g., the triennial monitoring surveys conducted by SCPN in grasslands; see the separate Birds assessment). The 24 species include six that were recorded only in the one site that is outside of the boundary fence but within the park boundaries (noted in the table). All 68 species, and all bird species that have been recorded in the park, are shown in an appendix of the Birds assessment. No federally threatened or endangered species are known to occur in the national monument. See the birds condition assessment for species that are otherwise listed as species of conservation concern (a general term) by various governmental and non-governmental organizations. Only one non-native bird species (house sparrow [*Passer domesticus*]) was recorded during the surveys.

Of the 24 species unique to the LCR confluence area surveys, some are associated primarily or largely with wetland habitats or habitats near streams, rivers, lakes, and ponds (Cornell Lab of Ornithology 2015). These species include cinnamon teal (*Anas cyanoptera*), greater yellowlegs (*Tringa melanoleuca*), long-billed dowitcher (*Limnodromus scolopaceus*), red-winged blackbird (*Agelaius phoeniceus*), spotted sandpiper (*Actitis macularius*), and yellow warbler (*Setophaga petechia*). Four of these species are within their breeding ranges while in the park, but two are not (greater yellowlegs and long-billed dowitcher; Cornell Lab of Ornithology 2015).

As discussed elsewhere in this assessment, national monument staff had planned to leave, for the time being, the remaining tamarisk stand in the DMW confluence area, at least partially because of the bird habitat it provided. However, as also noted, the tamarisk beetle has been affecting tamarisk trees in the last few years in the DMW riparian area. In Table 4.8.4-1, we noted the species that may possibly use tamarisk habitat for nesting, and which may, therefore, lose some areas of potential nesting habitat in the DMW area. We found 32 species listed in the table that fall into this category (designated with a "2"). Of these, 16 have been recorded, to date, only in the DMW/LCR confluence area.

Using our reference conditions for this measure, we consider condition of bird species use of the LCR/DMW confluence area to be good. A substantial number of birds have been recorded along the river and confluence area during surveys, including a number of species that were not observed during bird surveys in other areas of the park (e.g., grasslands). It is apparent that the LCR and DMW confluence area provides some unique habitat compared to that within the park overall. However, no surveys have been conducted in the area since the 2002-2004 surveys. For this reason, we have low confidence in this measure to represent current conditions. Trend is unknown, but changes have occurred since the early 2000s that might affect bird use of the area (e.g., the restoration efforts in the area and effects of the tamarisk beetle). Effects of the tamarisk beetle on woody habitat for nesting birds does represent an area of concern. It would be of interest to conduct bird surveys again in these sites, approximately 12-14 years after the Yavapai College Elderhostel surveys. Establishing repeatable point count monitoring along the LCR riparian corridor is a data gap acknowledged by the park's natural resource program (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.).

Vertical Stability of DMW and DMW-LCR Confluence Area

The 2012 channel morphology baseline survey results are presented in Figure 4.8.4-11. The figures show the elevations along the four cross section transects, with cross section transect #1 (XS01) being closest to the confluence with the LCR (see Figure 4.8.2-1 for transect locations). The length of the cross section transects decreased substantially from the upstream to the downstream sections (i.e., from transect XS04 to XS01) from approximately 250 m to 90 m (820 ft to 295 ft). The scale on each transect graphic is the same; measured elevations ranged from: 1,305.7 m to 1,312.4 m along XS04; 1,305.7 m to 1,310.6 m along XS03; 1,305.8 m to 1,309.3 m along XS02; and 1,305.6 m to 1,308.3 along XS01.

The profile of the thalweg (the lowest points measured along the channel) is presented in Figure 4.8.4-12.

Table 4.8.4-1. Bird species recorded during breeding seasons in 2002, 2003, and 2004 in three sites along the Little Colorado River.

Common Name	Scientific Name	Common Name	Scientific Name
Abert's towhee [1, 2]	*Melozone aberti*	House sparrow	*Passer domesticus*
American kestrel	*Falco sparverius*	Indigo bunting [1, 2]	*Passerina cyanea*
Anna's hummingbird [1, 2]	*Calypte anna*	Lark sparrow [2]	*Chondestes grammacus*
Ash-throated flycatcher [2]	*Myiarchus cinerascens*	Lesser goldfinch [2, 3]	*Carduelis psaltria*
Bendire's thrasher [3]	*Toxostoma bendirei*	Lesser nighthawk [1]	*Chordeiles acutipennis*
Black-chinned hummingbird [1, 2]	*Archilochus alexandri*	Loggerhead shrike [3]	*Lanius ludovicianus*
Black-headed grosbeak [1, 2]	*Pheucticus melanocephalus*	Long-billed dowitcher [1, 3]	*Limnodromus scolopaceus*
Black-tailed gnatcatcher [1, 2]	*Polioptila melanura*	MacGillivray's warbler [1, 2]	*Oporornis tolmiei*
Black-throated gray warbler [2]	*Setophaga nigrescens*	Mourning dove [2]	*Zenaida macroura*
Black-throated sparrow	*Amphispiza bilineata*	Northern flicker [1]	*Colaptes auratus*
Blue grosbeak [1, 2]	*Passerina caerulea*	Northern mockingbird [2]	*Mimus polyglottos*
Brewer's blackbird [2, 3]	*Euphagus cyanocephalus*	Northern rough-winged swallow	*Stelgidopteryx serripennis*
Brewer's sparrow	*Spizella breweri*	Peregrine falcon [1, 3]	*Falco peregrinus*
Broad-tailed hummingbird [2]	*Selasphorus platycercus*	Plumbeous vireo [1, 2]	*Vireo plumbeus*
Brown-headed cowbird	*Molothrus ater*	Prairie falcon	*Falco mexicanus*
Bullock's oriole [2]	*Icterus bullockii*	Red-tailed hawk	*Buteo jamaicensis*
Bushtit [2]	*Psaltriparus minimus*	Red-winged blackbird [1, 2]	*Agelaius phoeniceus*
Canyon towhee [1]	*Melozone fusca*	Rock wren	*Salpinctes obsoletus*
Cassin's kingbird [2]	*Tyrannus vociferans*	Rufous-crowned sparrow	*Aimophila ruficeps*
Chipping sparrow	*Spizella passerina*	Say's phoebe	*Sayornis saya*
Cinnamon teal [1, 3]	*Anas cyanoptera*	Spotted sandpiper [1, 3]	*Actitis macularius*
Cliff swallow	*Petrochelidon pyrrhonota*	Spotted towhee [2]	*Pipilo maculatus*
Common raven	*Corvus corax*	Summer tanager [1, 2]	*Piranga rubra*
Cordilleran flycatcher [1, 2, 3]	*Empidonax occidentalis*	Turkey vulture	*Cathartes aura*
Dusky flycatcher [1, 2]	*Empidonax oberholseri*	Violet-green swallow	*Tachycineta thalassina*
Eastern meadowlark [3]	*Sturnella magna*	Western kingbird [2]	*Tyrannus verticalis*
Golden eagle [4]	*Aquila chrysaetos*	Western meadowlark	*Sturnella neglecta*
Gray flycatcher	*Empidonax wrightii*	Western tanager [2, 3]	*Piranga ludoviciana*
Greater roadrunner	*Geococcyx californianus*	White-crowned sparrow	*Zonotrichia leucophrys*
Greater yellowlegs [1, 3]	*Tringa melanoleuca*	White-faced ibis	*Plegadis chihi*
Great-tailed grackle [1, 2]	*Quiscalus mexicanus*	White-throated sparrow	*Zonotrichia albicollis*
Green-tailed towhee	*Pipilo chlorurus*	White-throated swift	*Aeronautes saxatalis*
Hooded oriole [1, 2]	*Icterus cucullatus*	Wilson's warbler [2]	*Wilsonia pusilla*
Horned lark	*Eremophila alpestris*	Yellow warbler [1, 2]	*Setophaga petechia*
House finch	*Carpodacus mexicanus*	Yellow-rumped warbler [2]	*Setophaga coronata*

Sources: Yavapai College Elderhostel (2002, 2003, 2004)

[1] Species recorded only by the Yavapai College Elderhostel (2002, 2003, 2004) along the LCR (and not elsewhere in the park).

[2] Species that may possibly nest in tamarisk (based on professional knowledge of writer & biologist Lisa Baril, and Cornell Lab of Ornithology [2015]).

[3] Recorded in Site 3 only (i.e., and not in Sites 1 or 2) of the Yavapai College Elderhostel survey. Site 3 was located outside of the boundary fence but within the park.

[4] National Monument staff conduct nesting surveys for this species.

The profile begins just downstream of transect XS02. Figure 4.8.2-1 shows the path (location) of the thalweg from this point to the LCR. Based on a review of the survey data from the transects, the channel appears braided upstream of transect XS02, as there was not one clearly defined path of lowest elevations (Steve Monroe, Hydrologist, Northern Arizona University and SCPN partner, pers. comm.).

The cross section transects have been surveyed only once to date, so we are unable to determine, based on the survey, whether any unnatural (accelerated) channel lowering is occurring in the area covered by the four transects. However, downstream from transect XS01, there is an area of incision in the DMW channel near the confluence with the LCR (Figure 4.8.4-13, top photo).

During the winter of 2005-2006 NPS staff discovered the main LCR channel had eroded along Wupatki NM's bank about 7.6 m (25 ft) laterally into the mouth of DMW. Along with the lateral bank erosion, the LCR thalweg also likely shifted westward immediately adjacent to the upstream end of the Wupatki/DMW mouth. The river bank eroded completely under the Wupatki boundary fence where it traversed the DMW confluence (see Figure 4.8.4-13, bottom photo). The entire section of fence across the DMW channel was rebuilt in 2006 along a different alignment farther upstream than in its original alignment, where it would be more effective to inspect and maintain. The eroded LCR bank held mostly steady in this location after 2006 (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.).

In 2011, tamarisk eradication began in the lower DMW channel, immediately upstream from where the fence had been realigned across the DMW channel in 2006. During 2011 nearly five acres of tamarisk were cut, piled, and burned (see Figure 4.10.4-8). During the winter of 2011-2012, NPS staff, Whitefield and Schelz, first noted a channel incision migrating headward from the 2006 LCR bank erosion zone towards the section of exposed DMW channel where tamarisk were removed in 2011. The location of this newly forming gully is shown in blue dots in Figure 4.8.2-1. Although this stretch of channel incision is currently short, park staff have concerns that the erosion may expand farther up into DMW (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.). According to Paul Whitefield (Natural Resource Specialist, Flagstaff Area NMs), the area of incision in the DMW channel that is reflected in the thalweg has only formed since 2010.

The pre-2009 thalweg was actually opposite in the DMW channel from the one shown on the map and drained over a much longer distance to the river, well downstream of the area shown in the map figure. It still exists and still conveys a large volume of run-off to the river, perhaps more water than the thalweg shown in the SCPN survey figure. Further survey and investigation of outflow is needed for the older channel to the river.

Based on all of the information presented here, we consider current condition to be of significant concern because of the erosion occurring at the DMW-LCR confluence. However, confidence in the measure is low, and trend is unknown at this time. We do not consider the confidence to be low because of uncertainty that erosion is occurring, but rather because of uncertainties regarding the thalweg and outflow of DMW (described above).

<u>Stream is in Balance with Water & Sediment being Supplied by the Watershed (DMW)</u>

This measure focuses on whether degradation of the DMW confluence area is occurring due to aggradation. NPS (2014) suggested that the thicket of tamarisk growing along the wash has probably slowed flows and caused sediment to accumulate in the channel, which may have raised the elevation by as much as 3 m (10 ft) since around the 1920s. However, there are no data or published reports that provide information on this possibility. Based on coordination with the park (Paul Whitefield, Natural Resources Specialist, Flagstaff Area NMs, pers. comm.), this measure/question is an important data gap. We conclude that condition and trend are unknown. As noted earlier, Wupatki NM's Foundation Document (NPS 2015a) also pointed out the need for channel morphology monitoring of DMW. Additionally, a study of recent deposition history of DMW would be very helpful.

<u>Overall Condition and Trend, Confidence Level, and Key Uncertainties</u>

For assessing the condition of the LCR riparian corridor, we used four indicators with a total of seven measures, which are summarized in Table 4.8.4-2. Overall, based on the measures used, we consider condition of the LCR riparian corridor to be of

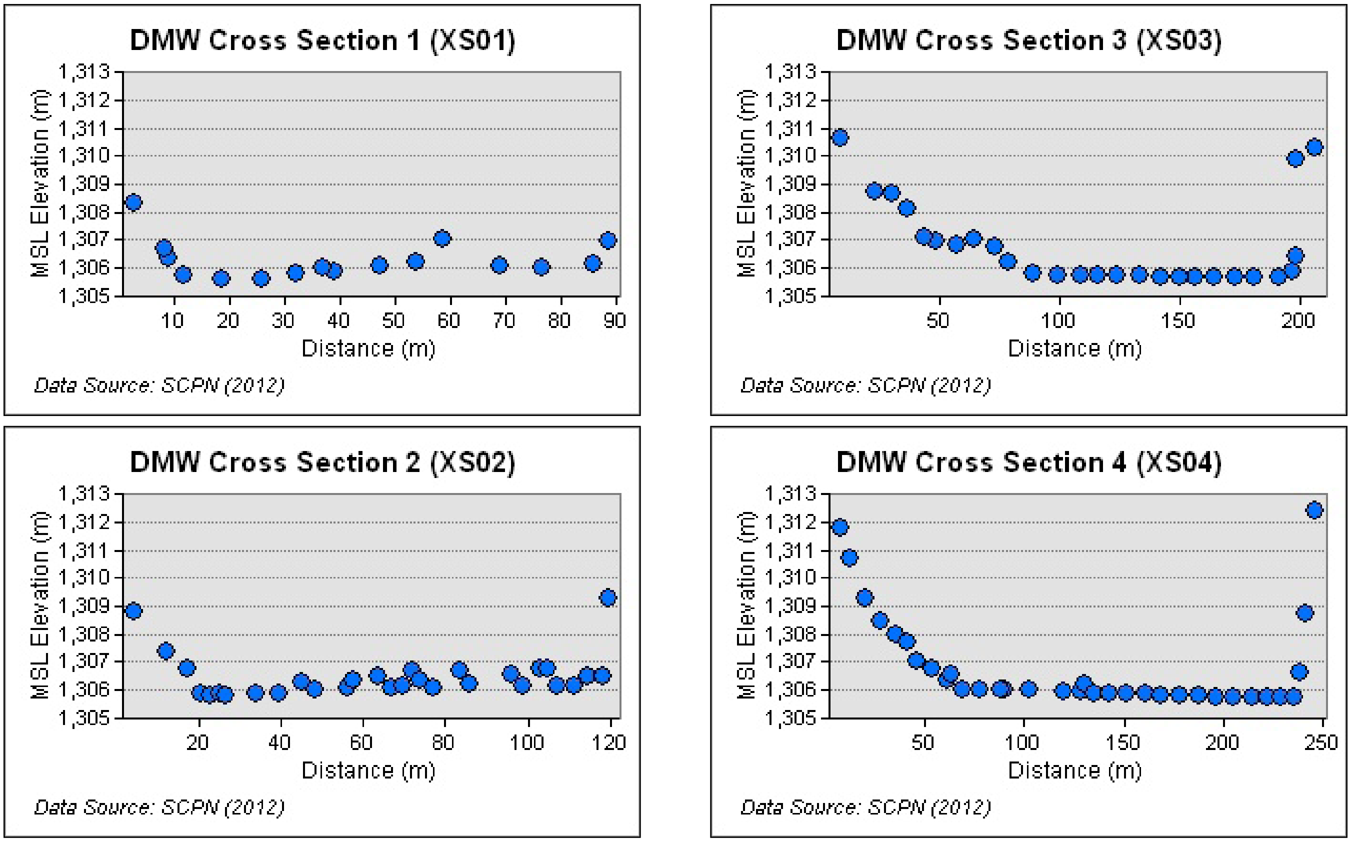


Figure 4.8.4-11. Results of the 2012 channel morphology survey, showing the elevation along each of the four cross section transects.

moderate concern to significant concern. Condition among the various measures is mixed, with the condition of at least two (i.e., two and one-half) of the seven measures unknown. Two of the measures are considered in good condition, although confidence is low for one of them. The remaining measures are of moderate concern to significant concern. Although the overall condition is somewhat subjective, especially given more than a third of the measures are of unknown condition, we chose to go with a rating of moderate concern to significant concern to highlight that concerns exist. Confidence in the assessment is medium, and the overall trend is unknown (but probably mixed). It should also be recognized that a substantial amount of effort to date has been made to restore the DMW riparian area. Various research and monitoring efforts have been conducted, as well as significant efforts to control invasive non-native species such as tamarisk.

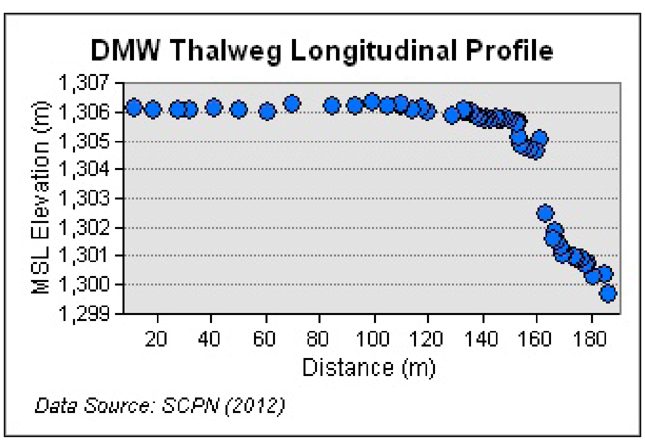


Figure 4.8.4-12. Longitudinal profile of the DMW thalweg from the 2012 channel morphology survey.

There are a number of uncertainties associated with the assessment and the condition of the LCR riparian corridor. This is reflected in the fact that the condition of more than two (i.e., two and one-half) of the measures is unknown. These main areas of uncertainty are with: the streamflow of DMW (data are entirely lacking); the depth to groundwater in the riparian area (efforts in this decade have been unable to locate the water table down to at least 5.5 m [18 ft]); and aspects of erosion/deposition in DMW and the confluence area. Additional uncertainties are with the bird use of the LCR and DMW riparian area, as the surveys conducted there are now more than a decade

Figure 4.8.4-13. Photos (from 2017 [top] 2011 [middle] and 2005 [bottom]) showing erosion in the DMW channel at the confluence with the LCR. Top photo looking toward the confluence, and bottom photo a side view of the confluence. Photo Credits: NPS.

old, and some changes have occurred to tamarisk in the area (from removal efforts and due to tamarisk beetles). Also, a quantitative analysis of the LCR streamflow data over the past 20 years (as well as the entire, up-to-date dataset) would have been useful for the assessment. Also, other than the streamflow data presented (discharge data over the period of record, and peak annual streamflow up to 1994), few data were available on the LCR itself within/along the monument boundary. Regarding the depth to groundwater in the DMW riparian area, questions remain as to why the perched aquifer observed in 1963 has not been observed. Some possible factors are the 30-day continuous pumping that occurred when the trench was dug, the consumption of water by tamarisk over decades, groundwater lowering due to channel incision, and effects of climate change.

Threats, Issues, and Data Gaps

A potential threat to the Little Colorado River riparian corridor is that of climate change. Streams in semiarid regions are especially sensitive to changes in precipitation and runoff (USGS 2011a). Changes in climate variables were studied by Monahan and Fisichelli (2014), and they found that, during the most recent 30-year period, three variables for precipitation were considered "extreme dry" (i.e., annual precipitation, precipitation of the driest month, and precipitation of the driest quarter) at Wupatki NM. They also found that annual mean temperature, maximum temperature of the warmest month, and mean temperature of the warmest quarter have been within the 95th percentile of the historical range of conditions at Wupatki NM since 1901 (i.e., considered "extreme" values/conditions). Other studies have reported changes in the timing of precipitation in the Colorado Plateau region (Hereford et al. 2002 as cited by USGS 2011a), as well as changes in the timing of snowmelt (i.e., earlier), a reduction in the relative amount of snowfall to rainfall, and peak streamflow reductions (USGS 2011a). Also, more moisture in the atmosphere leads to more intense storm events (USGS 2011a), which may lead to "spikier" stream flow patterns. As USGS (2011a) puts it, "these conditions set the stage for floods in a time of drought". These variables of climate change could lead to further changes in the streamflow and channel morphology of the Little Colorado River, an already heavily impacted system, and of Deadman Wash.

Table 4.8.4-2. Summary of LCR riparian corridor indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Hydrology	Streamflow of LCR & DMW		It appears that peak discharge of the LCR, as measured at the Grand Falls gage, has generally decreased over time. It is difficult to determine whether average monthly or annual discharges have decreased over time without more quantitative analyses of the data. We consider condition to be of moderate concern based on the observed decrease in peak flows, but we have moderate confidence in the assessment. A quantitative analysis of the data would allow for a stronger determination of condition (and may even lead to a rating of significant concern). Discharge of DMW is a data gap for the park, so we used an unknown condition for one-half of the condition icon.
	Depth to Groundwater in DMW Riparian Area		Condition for this measure is unknown. Two recent efforts have been made to locate groundwater in the DMW riparian area, but none of the installed wells have revealed groundwater to date (as of 2014). The reason(s) for this is unknown. Confidence in the measure is low.
Vegetation	Species Occurrence (Presence/ Absence) of Native & Non-native Vegetation		Plant species occurrence is of significant concern for both the DMW riparian area and LCR. The main types of vegetation in the DMW riparian area are the non-natives tamarisk and camelthorn, with small patches of native narrowleaf (or coyote) willow. However, native trees/shrubs have been planted as part of the restoration project/study. Also, the occurrence of tamarisk is not a recently-developed situation, and substantial management efforts have been taken to reduce the occurrence of tamarisk and camelthorn. The trend is improving as park staff have removed some areas of tamarisk and camelthorn and have planted native species. Also, the arrival of the tamarisk beetle in the last few years has affected the growth and survival of at least some of the remaining tamarisk. Our confidence in the measure is high.
	Maintenance of Soil Moisture in/along DMW Confluence Area		Condition is considered good for this measure. Field monitoring indicated that soil moisture was adequate to support riparian plant species; saturated soils at 30-45 cm (11.8 to 17.7 in) below the soil surface were found throughout much of the DMW riparian area sampled. Trend is unknown, as data were collected over a relatively short time period a few years ago. Confidence in the measure is medium.
Bird Use of Riparian Area/LCR	Species Occurrence		Condition is good for this measure, although some concern exists for species that may nest or roost in tamarisk. A substantial number of birds have been recorded along the river and confluence area during 2002-2004 surveys during the breeding season (68 species), including a number of species that were not observed during bird surveys elsewhere in the park (24 species). Habitat along the LCR and DMW confluence area provides some unique habitat compared to that within the park overall. Confidence is low, however, as no surveys have been conducted in the area since those in 2002-2004. Trend is unknown.
Erosion / Deposition	Vertical Stability of DMW and DMW-LCR confluence area		Current condition is of significant concern due to erosion occurring at the DMW-LCR confluence. Farther up DMW, surveys have been conducted only once to date in a 2012 baseline channel morphology survey. Trends are unknown and confidence is low. The area of erosion dates back at least to 2005. The park is concerned it may expand farther up into DMW.
	Stream is in Balance with Water & Sediment from the Watershed (DMW)		Condition under this measure is unknown due to a lack of information. However, park personnel have suggested the possibility that DMW upstream of the confluence with the LCR has aggraded since the early 1900s. The thicket of tamarisk growing along the wash probably slowed flows and may have caused sediment to accumulate in the channel, which may have raised the elevation. However, there are no data or published reports that provide information on this possibility.

Table 4.8.4-2 continued. Summary of LCR riparian corridor indicators, measures, and condition rationale .

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Overall Condition			Condition using these indicators is mixed. Two and one-half of the measures are of unknown condition. Two measures are considered in good condition (although confidence is low for one), and the other two and one-half measures are of moderate concern to significant concern. This overall condition rating is somewhat subjective, but we chose to go with a rating of moderate concern to significant concern to highlight that concerns exist. Overall confidence is medium and overall trend is unknown.

While waiting for results from the two-year research project on different methods of planting seeds using "dryland" methods, the Resources Management Division, Flagstaff Area National Monuments, has put most restoration on hold. The following criteria have been identified as current data gaps:

- a better understanding of the effects of tamarisk beetle on tamarisk mortality, and
- a longer range restoration plan for the area (including public involvement under NEPA, tribal consultation, and Wilderness Act compliance) can be developed.

For the near-term, the national monument staff is deferring control on the remaining seven acres of tamarisk, conducting limited treatments of tamarisk re-sprouts in the control area, and attempting to keep camelthorn from rapidly invading the tamarisk cleared area using herbicide treatments (Paul Whitefield, Natural Resources Specialist, pers. comm.).

4.8.5. Sources of Expertise

This assessment is based primarily on park and other reports on DMW and the LCR. Stephen Monroe, a hydrologist with Northern Arizona University and partner of SCPN, provided assistance in interpreting and presenting the results of the 2012 channel morphology survey. He also reviewed and commented on a draft of the assessment. The assessment was authored by Patty Valentine-Darby, biologist and science writer, Utah State University. Kim Struthers, Utah State University, used ArcGIS 3-D Analyst to create the channel morphology graphs, using X-Y coordinates and mean sea level elevations recorded during the SCPN (2012) survey.

4.9. Vegetation

4.9.1. Background and Importance

The western half of Wupatki National Monument (NM) is covered by a mosaic of semiarid grasslands, juniper woodlands, and juniper savannas (Figure 4.9.1-1). Woodlands similar to those at Wupatki NM are widespread in the Southwest, but large, intact grasslands in good condition are relatively rare (Schussman and Gori 2004). The grasslands are of particular wildlife conservation value because they support a unique suite of species not found in other vegetation types, including the American pronghorn (*Antilocapra americana*), Gunnison's prairie dog (*Cynomys gunnisoni*), and burrowing owls (*Athene cunicularia*).

The total extent of grassland within Wupatki NM has decreased during the past century, as juniper trees have expanded from nearby woodlands into the grasslands and savannas. Consequently, the grasslands, along with wildlife species that depend upon this habitat, are highlighted in both the General Management Plan (NPS 2002) and the Foundation Document for Wupatki NM (NPS 2015a). Well functioning grasslands are also crucial to preserving and protecting the cultural resources for which Wupatki NM was established under the Antiquities Act. Tree roots growing into archaeological sites can cause direct structural damage, and woody fuels above ground can increase fire intensity. Packrats (*Neotoma*) at Wupatki NM rely largely on junipers for forage and construct their middens within archeological sites, directly damaging them and further increasing fire damage to sites if the middens burn (Hough 2004). Wupatki NM's juniper savannas and woodlands are of lesser conservation significance and concern, in and of themselves, but the grasslands, savannas, and woodlands are inextricably linked by a set of dynamic interactions that have been taking place for many centuries. Those interactions were dramatically altered by land use changes beginning in the late 1800s, and vegetation dynamics have changed again over the past 25 years. The long-term ecological history of the Wupatki NM area is summarized in detail in Romme and Whitefield (2017), with just the highlights of that history presented in the main body of this assessment.

<u>Grassland Vegetation Structure And Composition</u>

The prominent grasslands on limestone, igneous, and alluvial substrates in the western portion of Wupatki NM (west of the Doney Cliffs) were previously classified as Great Basin grasslands (Brown 1994), but more recently have been distinguished as Colorado Plateau semi-desert grasslands and shrub-steppe (Fletcher and Robbie 2004). This vegetation type extends northward from the Mogollon Rim into southern

Figure 4.9.1-1. Archaeological site and vegetation mosaic in the western portion of Wupatki NM. Photo Credit: © W.H. Romme.

Utah and southwestern Colorado, and eastward from the San Francisco Peaks into northern and western New Mexico. The area is characterized by two peaks in annual precipitation (summer and winter) and by relatively flat topography developed from sedimentary and igneous substrates. The vegetation is notable for having a greater proportion of C3 (cool season) plant species than is seen in the desert grasslands of southern Arizona, New Mexico, and northern Mexico (Fletcher and Robbie 2004, LCAS 2010, TNC 2005). Characteristic species of Colorado Plateau semi-desert grasslands and shrub-steppe throughout its range include blue grama (*Bouteloua gracilis*), galleta (*Pleuraphis jamesii*), western wheatgrass (*Pascopyrum smithii*), needle and thread (*Hesperostipa comata*), three-awn (*Aristida spp.*), big sagebrush (*Artemisia tridentata*), black sagebrush (*Artemisia nova*), four-wing saltbush (*Atriplex canescens*), rabbitbrush (*Ericameria nauseosa*), broom snakeweed (*Gutierrezia sarothrae*), and joint-fir (*Ephedra spp.*) (LCAS 2010).

Zooming in on Wupatki NM itself (Figure 4.9.1-2), the soils and dominant vegetation of the monument's semiarid grasslands have been characterized recently by the USDA Natural Resource Conservation Service (USDA 2015). Wupatki NM lies within the major land resource area MLRA35, which is the Colorado Plateaus Province of the Intermontane Plateaus. The monument can be divided into two fairly distinct zones: the drier, lower-elevation eastern portion, and the wetter, higher-elevation western portion. The semiarid grasslands that are the focus of this report are in the western portion of the monument, west of the Doney Cliffs, and are classified as MLRA 35.1, with 254-356 mm (10-14 in) of average annual precipitation and elevations ranging from 1,554.5-1,829 m (5,100-6,000 ft). Average daily temperature at the monument headquarters, located just a bit to the east of the Doney Cliffs and at slightly lower elevation, is 14° C (58° F) (USDA 2015, p. 268). The MLRA 35.1 area is further subdivided into four more-or-less distinctive "ecological sites," each of which represents "the product of all the environmental factors responsible for its development" (USDA 2015, page 163) including soils, topography, climate, vegetation, and history. The ecological sites include R035XA102AZ Cinder Hills 10-14" p.z., R035XA108AZ Volcanic Upland 10-14" p.z., R035XA113AZ Loamy Upland 10-14" p.z., and R035XA119AZ Shallow Loamy 10-14" p.z. Although each has some distinctive features, and some fine-scale local variation can be found within each, all four ecological sites generally share several common characteristics: Soils are mostly moderately deep to very deep, and are well drained to excessively drained. Surface layers are composed of a variable mix of gravelly coarse sand, loamy sand, and sandy loam, and usually contain volcanic ash and cinders. Vegetation is

Figure 4.9.1-2. Grassland vegetation at Wupatki NM. Photo Credit: © W.H. Romme.

dominated by C3 and C4 grasses, with variable cover of forbs and shrubs.

Woodland And Savanna Vegetation Structure And Composition

Persistent Juniper Woodlands

The extensive persistent juniper woodlands are dominated by one-seed juniper (*Juniperus monosperma*) trees of all sizes including very large and old individuals in some places (Figure 4.9.1-3). The spaces between juniper trees are either bare of vegetation or are covered with native grasses and forbs of similar composition as the nearby grasslands.

The oldest woodlands, with the largest juniper trees, are generally found on rocky sites with shallow soils, e.g., on the tops and edges of lava flows and limestone mesas, or in places having deep deposits of volcanic cinders from the Sunset Crater eruption. Woodlands also are most common in the southwestern portion of the monument and on the Coconino National Forest which lies just to the south of Wupatki NM and gradually extends up to higher elevations.

Dynamic Juniper Savannas

Dynamic juniper savannas are found generally on deeper soils and relatively level topography, between the woodlands and the treeless grasslands (Figure 4.9.1-4). Savannas have a primarily grassland character and are dominated by perennial grasses and forbs of the same composition as the treeless grasslands, but juniper trees of varying abundance are also conspicuous. Most of the trees are relatively young (<100 years old) and small (<2 m [6.6 ft] tall). Scattered shrubs, e.g., rabbitbrush (*Ericameria* (*Chrysothamnus*) *nauseosa*) and four-wing saltbush (*Atriplex canescens*) may also be present, but usually are not abundant.

The juniper woodlands, savannas, and grasslands comprise a dynamic ecosystem. Much of the western portion of Wupatki NM can potentially support any of these three vegetation types; what is present at any given time on any particular piece of ground is largely dependent on the previous history of fire, drought, and grazing on that site. This interaction, which is critical to understanding the condition and trend of Wupatki NM vegetation, is developed in detail in section 4.9.3 below on reference conditions.

4.9.2. Data and Methods

Two approaches were used in evaluating the ecological condition of Wupatki NM's grasslands, savannas, and woodlands. First, we modified the approach developed by Edmonds et al. (2011) and used in the NRCA reports for Capulin Volcano, El Malpais, and El Morro National Monuments. That approach evaluates six measures of ecological condition.

Figure 4.9.1-3. Persistent juniper woodlands at Wupatki NM. Photo Credit: © W.H. Romme.

Are the species present and their distributions consistent with supply and demand of light, water, nutrients, and growing space, and within their natural range of variability?

Are stand densities within their range of natural variability for their growing conditions?

Are the age class distributions of the trees consistent with the expected range of variability for this site/ecosystem type?

Do the trees and understory plants appear vigorous and healthy for this site/ ecosystem type?

Are ecological processes (e.g., fire) operating within a natural range of variability?

Are the current levels of insects and/or disease within the normal range for this ecosystem type?

We drew upon two sources in evaluating these measures of ecological condition. First, we conducted a field trip on October 22-23, 2015, in which we examined the vegetation at several representative sites in western Wupatki NM and in the adjacent Coconino National Forest. Secondly, we compiled and reviewed the relevant literature on Wupatki NM per se and on Southwestern semiarid grasslands in general; this literature was in the form of published articles in scholarly journals, theses, and unpublished reports maintained by the National Park Service. Of particular utility were unpublished theses by Hassler (2006), Ironside (2006), and Parker (2009).

Species Composition and Landscape-scale Diversity, Local-scale Species Composition, Response of Annual Species to Disturbance, Relative Proportion of Functional Groups Relative Proportion of C3 and C4 Species

Secondly, we evaluated biotic integrity using the "attributes of rangeland health" outlined by Pellant et al. (2005). This system also was used in the NRCA for El Malpais National Monument, and we have copied three of the tables from that report to provide definitions and criteria for this assessment. Refer to Appendix F for definitions, full criteria for evaluation, and other details of the Pellant system.

4.9.3. Reference Conditions

Defining the Reference Period

The reference period for our assessment was the several centuries extending from the deposition of volcanic cinders onto the Wupatki landscape by the eruption of Sunset Crater, between 1050 and 1150 A.D., until the onset of excessive livestock grazing in the late 1800s. Climate and human impacts varied, and

Figure 4.9.1-4. Juniper savanna at Wupatki NM. Photo Credit: © W.H. Romme.

vegetation processes were dynamic during this time period. However, the rate and magnitude of vegetation change increased suddenly and dramatically after ca. 1880. Herbaceous cover was reduced and juniper expansion into former grasslands and savannas was accelerated.

Similar changes occurred at about the same time in grasslands throughout the Southwest, although the precise timing of the onset of excessive grazing varied somewhat from place to place (LCAS 2010). As a result, we have no reference areas that escaped the impacts of overgrazing, from which we could directly characterize historical grassland composition, structure, and ecological processes. Instead, we can only estimate those characteristics based on the ecology of the species known to have been present during the reference period (e.g., documented in very old packrat middens and soil layers), and on the responses that we have observed recently in grasslands, savannas, and woodlands wherever grazing has been stopped or reduced in intensity. The problem is exacerbated by the fact that grasslands are highly heterogeneous ecosystems, despite their common appearance of uniformity, such that the response of one area to recent changes in grazing practices or climate may or may not be typical of other grassland areas (Fletcher and Robbie 2004). Thus, our picture of the "natural" or historical condition of Wupatki NM's grasslands, woodlands, and savannas will always be somewhat imprecise.

Vegetation Dynamics

Current conditions in Wupatki NM can be understood only in the context of the ecosystem's inherent vegetation dynamics. In this section we add to our previous description of the three major vegetation types in the western portion of Wupatki NM with a focus on their dynamic properties and interactions. The three vegetation types do not differ much in their species composition. Indeed, a similar suite of grasses, forbs, and shrubs is found in all three types. Rather, they are distinguished on the basis of (1) the presence/absence, distribution, and size of juniper trees and their influence on adjacent herbaceous growth, (2) the abundance of fine fuels, mostly grasses, and whether these fine fuels are arranged in a continuous manner or are separated by patches of bare ground, and (3) the ease with which a fire could sweep through an area under either moderate or severe fire weather conditions (i.e., conditions of fuel moisture, temperature, and wind). Hassler (2006) and Parker (2009) used a similar classification, and we draw on some of their details in our descriptions below.

Persistent Juniper Woodland

Persistent juniper woodland is characterized by large one-seed juniper trees, many of which are surrounded by patches of bare ground extending up to 10 m (32.8 ft) from the base of a large juniper crown (Figure 4.9.1-3). Note in that figure the extensive areas around the trees that lack herbaceous vegetation. This lack of herbaceous vegetation is thought to be the result of competition for water and nutrients between the roots of the trees and the roots of the grasses and forbs, with the tree roots winning the contest. Large one-seed juniper trees can have taproots up to 3.7 m (12 ft) long and lateral roots extending outward to distances two-and-a-half to three times the height of the crown (Emerson 1932, Johnsen 1962). Most of the lateral root mass is located at depths of six inches to three feet, while the grass roots are concentrated in the upper six inches of soil (Johnsen 1962), so any water or nutrients that move below that surface soil layer will likely be snapped up by the juniper.

Note that bare ground also is seen in excessively drained areas of deep volcanic cinder accumulations and where bedrock is exposed at the surface—it is not only junipers that create this condition. Nevertheless, the trees are responsible for many bare soil patches in places otherwise suitable for grasses and forbs.

The bare spaces surrounding large junipers are important because surface fires cannot travel across these fuel-deficient patches. Fire apparently is the major agent that kills one-seed juniper; if they escape burning, the trees can live for centuries and reach considerable size. We saw only one large juniper tree with evidence of past fire (Figure 4.9.3-1), and the fire that charred the base of this tree probably did not spread beyond this spot, since none of the other trees nearby had any evidence of fire. It is possible that fires might jump from tree crown to tree crown under exceptionally dry and windy conditions, but apparently this has never been observed in Wupatki NM's persistent juniper woodlands. We call these woodlands "persistent" because, once established, the trees appear to remain on a site indefinitely.

Hassler (2006) classified juniper woodlands as having more than 30 trees per hectare. However, we observed that tree density (stems/hectare) and total tree cover are not always exceptionally high in stands of persistent juniper woodland. Therefore, we focus on the size of the trees and the presence of bare ground around them rather than the density of trees per se. In fact, some stands consist of somewhat discrete clumps of large old junipers, with the characteristic belt of bare ground surrounding the clump, but with relatively well-developed grassland vegetation within any large gaps that exist between the tree clumps. Parker (2009) also distinguished between "open woodlands" and "closed woodlands."

Persistent juniper woodlands could be regarded as a variant of the persistent piñon-juniper woodlands identified by Romme et al. (2009) as a common woodland type throughout the Southwest. However, there are three important differences between these two kinds of vegetation. First, some persistent piñon-juniper woodlands in the region have been observed to burn in recent decades, and many have evidence of having burned in the past, even though fire intervals tend to be very long in that vegetation type. In contrast, as noted above, we saw no evidence of tree-killing fire in the persistent juniper woodlands of Wupatki NM; this was noted by Hassler (2006) and by Parker (2009) also. Some early reports from Arizona describe abundant fire scars on junipers (e.g., Leopold 1924), but Johnsen (1962) suggests that most such fire scars were formed by lightning strikes that injured a single tree but did not produce a fire spreading beyond that tree. An atlas of wildland fire events in the Flagstaff Area National Monuments (Brehl et al. 2006) also documents multiple lightning ignitions in almost every year since 1957, but few spreading fires.

Figure 4.9.3-1. Large old juniper that was charred at the base by a localized fire that did not spread beyond this point. Photo Credit: © W.H. Romme.

A second important difference is that persistent piñon-juniper woodlands commonly support a greater diversity of herbaceous plants than do the persistent juniper woodlands at Wupatki NM. See, for example, the long list of understory herbs in piñon-juniper woodlands of Mesa Verde (Floyd and Colyer 2003), and compare it with the short list of characteristic species in Wupatki NM's vegetation association named "*Juniperus monosperma Cinder Wooded Herbaceous Vegetation*" (Hansen et al. 2004, and more on this below). Forbs in particular are poorly represented in Wupatki NM's persistent juniper woodlands.

A third important difference is that old persistent piñon-juniper woodlands typically contain large quantities of coarse dead wood—old tree boles and branches that died and fell long ago but remain in place because of slow decomposition rates and absence of fire. In contrast, we saw very little large coarse wood in Wupatki NM's persistent juniper woodlands, and this was noted by Parker (2009) as well.

The paucity of fallen tree boles even in Wupatki NM's oldest woodland stands would suggest that none of these stands are all that old—perhaps several centuries at most (Jacobs et al. 2008). Some of the first junipers to have become established in this area may still be with us. The grassland-like herbaceous flora of these woodlands also suggests that these areas were once grassland, and that they have been transformed into woodlands within the past few centuries. We deal more with this idea in the section below on mechanisms of vegetation change in Wupatki NM.

Dynamic Juniper Savanna

Dynamic juniper savanna is primarily a grassland, but it also contains small to medium-sized junipers scattered through a stand. Parker (2009) described savannas as consisting mostly of trees up to ca. 2 m (6.6 ft) tall but with occasional larger trees and with <30% tree canopy cover; Hassler (2006) defined savannas as having 1-30 trees per hectare. We focused on two other important distinctions between persistent juniper woodland and dynamic juniper savanna. First, the fine herbaceous fuels in the dynamic juniper savanna are sufficiently abundant and continuous to readily carry a spreading fire over a large area. Secondly, many or most of the trees in the dynamic juniper savanna are relatively small and can be killed by spreading fires; the trees have not yet developed a protective bare area around their bases, as is seen in the older and larger trees of the persistent juniper woodlands.

These features are illustrated in Figure 4.9.1-4: note the well-developed grassland component of the vegetation which provides more-or-less continuous fine fuels which can carry spreading fires over large areas, the small size of the trees, and the lack of bare ground around their bases; these trees are vulnerable to injury or death in the fires that can sweep through this vegetation-type.

We call this a dynamic juniper savanna because the relative abundance of trees vs. grasses can oscillate back and forth over time. During long periods without fire or severe drought, the trees increase in density and size; but then a fire or drought knocks back the trees, shifting dominance again to the grasses. We know from observations of recent fires that trees in the savannas can be killed by fire. However, the proportion killed can vary greatly, depending on things like fuel moisture, wind speed, and tree size. Small trees (less than about four feet, or a meter, in height) apparently are most easily killed (Jameson 1962, Dwyer and Pieper 1967), but trees typically become more fire-resistant as they grow larger. This general pattern has been apparent in recent savanna fires in Wupatki NM (Figure 4.9.3-2). Larger trees are probably also more resistant to drought, because of their extensive root systems and their ability to allow a portion of the crown to die, thereby reducing total transpiration and permitting the remainder of the crown to survive.

If a dynamic juniper savanna goes long enough without fire or drought, at least some of the trees can become pretty much invulnerable to fire; they become large and old enough to develop the ring of bare ground around their bases that we see in persistent juniper woodlands. This process can transform a dynamic juniper savanna into a persistent juniper woodland (Figure 4.9.3-3). In fact, as we hinted previously, much of the persistent juniper woodland in Wupatki NM may have originated as dynamic juniper savanna that escaped fire and drought long enough for the trees to become almost immune to fire. Apparently the process can go in only one direction however: from savanna to persistent woodland, not the reverse (so long as the climate remains suitable for trees).

At what point can we say that the transformation is complete, i.e., when does a dynamic juniper savanna reach the point of no return, where fire or drought can no longer readily kill the trees and return dominance to the grasses, when the stand should henceforth be regarded as a persistent juniper woodland? There is no simple tipping point. As the trees get bigger, they can still be killed, but a more intense fire or more severe drought is now required. Fire can benefit from a little extra fine fuel around the base of a larger tree: it has been observed that tumbleweeds accumulating under moderate-sized juniper trees can burn hot enough to ignite the tree crown and kill at least a portion of it (Figure 4.9.3-4).

Tumbleweeds, of course, are a relatively recent introduction to the Wupatki NM landscape, arriving in the late 1800s; they would not have inhibited the transformation of savannas into persistent woodlands prior to the 20th century, but they could be an important part of the story in the 21st century.

Grassland

Grassland vegetation at Wupatki NM has a similar species composition as the two juniper types, except that grassland lacks trees altogether and typically has a greater diversity of herbaceous species. In a few places it may be possible that trees are physically unable to grow in the grassland areas—perhaps because those grassland sites are too dry for trees or because the soil lacks some essential nutrient—but in most of the grassland it appears that trees simply have not gotten there yet. Climate modeling conducted by Ironside

Figure 4.9.3-2. Thirteen years after the Antelope/State Fire of 2002: small trees were killed but large trees were only partially damaged. Photo Credit: © W.H. Romme.

(2006) suggests that junipers could potentially grow in almost all of the western portion of Wupatki NM under 20th century climate conditions. In places where we see dead trees recently killed by fire or drought, the grasslands we see today represent former dynamic juniper savanna in which fire has removed all of the trees (Figure 4.9.3-5).

A State-and-Transition Perspective

Romme and Whitefield (2017) developed a state-and-transition model of the interactions among the three major vegetation types at Wupatki NM; here we provide just the key elements of that model. Grassland and dynamic juniper savanna can oscillate back and forth on a single piece of ground in response to fire or drought or lack thereof. We include severe drought in this model, even though, to date, we have not seen much drought-caused juniper mortality in Wupatki NM savannas. Many trees have had parts of their crowns die in the last couple of decades (Parker 2009, Paul Whitefield, personal observations) but relatively few trees have died entirely. Nevertheless, one-seed junipers in New Mexico died during the severe droughts of the 1950s (Julio Betancourt, personal communication) and early 2000s (Ginter and Marquetti 2016), and projections of future climate suggest that we may see more juniper mortality in coming decades.

In addition to changes in tree size, herbaceous cover, and likelihood of fire, there appears to be a small loss of herbaceous diversity as a savanna transitions into persistent juniper woodland. Many of the dominant grassland and savanna species persist in the juniper woodland, e.g., *Bouteloua eriopoda*, *Hesperostipa comata*, and *Pleuraphis jamesii*, but several of the grasses and forbs listed for Wupatki NM's grasslands are not listed for the juniper woodlands (Hansen et al. 2004; also see Romme and Whitefield (2017) for more details).

Vegetation Trends Through Time

This dynamic interaction among grasslands, savannas, and woodlands has been ongoing from the time when one-seed juniper first arrived in the Wupatki NM area (probably ca. 500 A.D—Cinnamon 1988a) through the present day. The juniper component was reduced by deposition of volcanic cinders from the eruption of Sunset Crater between 1050 and 1150 A.D. (Elson and Ort 2003, Elson et al. 2011), and by wood utilization by the Sinagua culture that thrived in the area from about 1100 to 1250 A.D. After the Sinagua people left the area, juniper gradually increased in abundance, and persistent juniper woodlands slowly expanded their coverage of the landscape. Periodic fires and droughts probably killed most young junipers moving into the savannas and grasslands, but some trees always escaped fire and drought long enough to grow large and develop a fire-resistant ring of bare ground around their crowns. Thus, a gradual expansion of junipers and of persistent juniper woodlands can be viewed as a "natural" process in this ecosystem. However, Euro-American settlers dramatically accelerated the process in the late 19th century.

Figure 4.9.3-3. Junipers that have developed a ring of bare ground around their bases;this area is in transition from savanna to persistent woodland. Photo Credit: © W.H. Romme.

Figure 4.9.3-4. Large juniper tree that was partially killed by a fire that ignited tumbleweeds under the left (upwind) side of the crown. Photo Credit: © W.H. Romme.

Figure 4.9.3-5. Thirteen years after the 2002 Antelope/State Fire: the former savanna in the foreground has been converted to grassland. Photo Credit: © W.H. Romme.

Pellant et al. (2005) developed a system for evaluating the condition of rangelands or grasslands, and Table 4.9.3-1 describes general criteria that would indicate "good," "moderate concern," or "significant concern" for each measure evaluated. Note that our assessment applies only to the treeless grasslands within the monument, not to savannas or persistent woodlands. Lastly, we focused strictly on Biotic Integrity indicators, and do not evaluate the Soil/Site Stability or the Hydrologic Function indicators, which are assessed in separate assessment developed by Dr. Anderson, for the purposes of Wupatki NM's NRCA report.

Table 4.9.3-1. Reference conditions used to assess biotic integrity.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Biotic Integrity	Species Composition and Landscape-scale Diversity	Landscape-scale diversity reflects spatial pattern of soils and disturbance.	Moderate lack of spatial landscape heterogeneity that does not fully reflect the spatial pattern of soils and disturbance.	Significant lack of spatial landscape heterogeneity that does not reflect the expected diversity for the soil types and sites.
	Local-scale Species Composition	Species composition reflects expected native species compliment consistent with the site characteristics. Species composition need not reflect expected climax communities if their current state reflects typical types of natural disturbance (e.g., fire).	Species composition moderately deviates from the expected native species compliment either from exotics or native species in such a way that does reflect typical types of natural disturbance (e.g., fire).	Species composition deviates substantially from the native species compliment that would typically occur at such sites. Such a deviation could also be either from exotics or native species.
	Response of Annual Species to Disturbance	Proportion of perennial species is approximately what would be expected given the site and time since disturbance.	Proportion of perennial species is moderately lower than what might be expected given the site and time since disturbance.	Substantially higher proportion of annual species than expected in sites not recently disturbed.
	Relative Proportion of Functional Groups	Proportions of functional groups (e.g., grasses, forbs, and shrubs) are consistent with what might be expected given the site characteristics.	Proportions of functional groups exhibit moderate departure from what might be expected given the site and disturbance history.	Proportions of functional groups differ substantially from what might be expected based on site characteristics (e.g., lack of forbs, excessive tree density, etc.).
	Relative Proportion of C3 and C4 Species	A mix and natural variability of C3 (cool season) and C4 (warm season) species for the site (to maximize resilience).	Higher than expected proportion of C4 species given the ecological site and disturbance history.	Sites dominated by C4 species traditionally dominated by C3 species.

Source: Pellant et al. (2005).

4.9.4. Condition and Trend

Legacies of Late 19th and Early 20th Century Land Use

The juniper population in the western portion of Wupatki NM began to grow rapidly and to expand into nearby savannas and grassland areas around 1880 (Hassler 2006—see Romme and Whitefield (2017) for details of his methodology). Junipers dating back as far as 700 years are found in woodland areas, but the oldest juniper trees in today's savanna areas are <200 years old and most became established between the late 1800s and early 1900s. This was a unique period in the ecological history of the region. Intensive grazing by large numbers of cattle removed the grass cover, which reduced the potential fuel for fires. Without fires, and with favorable climate conditions for juniper seed dispersal, germination, and establishment, the previous constraints on juniper expansion were no longer in effect.

That large post-1880 cohort of junipers is recognizable today. While driving and walking through the present-day woodland/savanna ecotone during our October 2015 visit, we noticed a great many trees that all looked to be about the same size, shape, and age (e.g., those pictured in Figure 4.9.3-4). We estimated the diameters of these trees as generally about 5-10 cm, (2-4 in), which would make them 70 – 140 years old (Hassler 2006), and thus part of that big juniper pulse from the turn of the 20th century.

As all of these new juniper trees became established and continued to grow larger in grassland and savanna areas, tree cover increased substantially. Parker (2009) compared aerial photos taken in 1936 and in 1997 of Wupatki NM (west of the Doney Cliffs) plus a comparably-sized portion of the Coconino National Forest along the southern border of the monument. In 1936, 27% of this area was open grassland, with no trees, but by 1997 only 10% of the area was still treeless. Over that same time period, the woodland area increased from 40% in 1936 to 52% in 1997. The increase in juniper cover was attributed to growth of individual tree canopies as established trees grew larger, along with infill as young trees established between the older ones. The total area of savanna increased only a little (from 33% to 38%), but locations of savanna on the landscape shifted as previous grasslands transitioned to savanna and previous savannas transitioned to woodland (see Romme and Whitefield (2017) for maps and additional details of this analysis).

Changes in Ecological Processes after 1989

The 1990s ushered in three important changes in ecological conditions and ecological processes at Wupatki NM: (1) Livestock grazing was terminated within the monument in 1989, and livestock management has also changed to more sustainable practices on surrounding lands in recent years, including juniper-grasslands on the Coconino National Forest adjacent to the southern boundary of Wupatki NM. (2) With the end of grazing, the herbaceous vegetation in the monument increased in cover and biomass, which in turn led to re-establishment of continuous fine fuels and the reappearance of extensive grassland fires. (3) A severe drought from ca. 1996 - 2004, exacerbated by unusually high temperatures, killed or injured numerous juniper trees.

Six moderately large fires occurred in Wupatki NM between 1995 and 2016 (Table 4.9.4-1). Notably, these fires burned only in grassland and savanna areas; the fires did not spread into persistent juniper woodlands. The total area burned between 1995 and 2016 is 1,601 ha (3,957 ac) or 29.4% of the grassland and juniper vegetation in the western portion of Wupatki NM (NPS records). This includes re-burning of areas burned earlier, and represents a fire rotation of about 75 years (Table 4.9.4-1). Fire rotation is the time required for the cumulative area burned to equal the size of the study area; it is not the time during which the entire study area burns, because some areas burn more than once while other areas do not burn at all during a rotation (Baker 2009). Fire rotation also equals the average interval between successive fires at a single point on the ground (e.g., a single square meter).

Little formal monitoring or research was conducted after these fires, but from the limited quantitative data collected, plus photographs and field observations, we can draw two general conclusions about the fires' effects on savanna and grassland vegetation.

First, the herbaceous component of the vegetation largely recovered within two years after each fire (Figure 4.9.4-1). The only herbaceous species thought to be especially sensitive to burning is black grama (*Bouteloua eriopoda*), because it spreads via aboveground stolons which are vulnerable to fire injury; close monitoring of black grama's response to future fires would help inform managers about the potential seriousness of fire-caused injury to this important grasslands species. Secondly, numerous shrubs and a moderate proportion of the junipers that had been expanding into the grasslands were killed by each fire (Figures 4.9.4-2 and 4.9.4-3).

Notably, the value for cumulative area burned in the equation in Table 4.9.4-1 includes all of the vegetation types in western Wupatki NM, including persistent woodland areas. Because the woodlands did not burn at all from 1995-2016, it might be appropriate to remove their area from the calculation. The result would be to reduce the calculated rotation by approximately half, resulting in a fire rotation, and an average fire return interval at any small point on the ground, closer to 35-40 years. An average fire return interval of 35-40 years, at the spatial scale of a square meter (about the area of an individual young juniper), might be sufficient to kill most of the trees expanding into savannas and grasslands before they could grow large enough to become fire-resistant (Hassler 2006). However, with an average fire return interval of 40 years at any point on the ground, many points would escape fire for >40 years, and in these places junipers probably could grow large enough to become effectively fire-resistant.

Nevertheless, the ca. 35-40 year fire rotation that we have seen in Wupatki NM's savannas and grasslands during the last two decades is approaching the 10-30 year historical fire rotation estimated for this grassland type (Great Basin grasslands, Schussman and Gori 2004). This suggests that, with just a moderate increase in the frequency and extent of fire in the monument, the process of juniper expansion into Wupatki NM's grasslands could potentially be halted or even reversed.

Figure 4.9.4-1. Three weeks after the 2013 White Fire: the fire stopped at the road on the left; the burned grassland on the right is showing rapid recovery via sprouting from undamaged roots and rhizomes. Photo Credit: NPS.

Table 4.9.4-1. Fire history in Wupatki NM following cessation of livestock grazing in 1989.

Year	Hectares (acres) Burned	Cause
1995	309.6 (765)	lightning
2000	57.9 (143)	lightning
2002 (two fires)	585.2 (1,446) (total)	lightning / cigarette
2013	572.2 (1,414)	lightning
2016	76.5 (189)	lightning
1995-2016	1,601.3 (3,957)	--

Source: NPS records.

Fire rotation:

= 22 years / 29.4% of landscape burned

= 75 year rotation for landscape as a whole

= 75 year average fire return interval at a point on the ground

As noted above, the severe drought that lasted from the mid-1990s through the mid-2000s also injured some large junipers and killed some small trees (Figure 4.9.4-4). Overall, as a result of the cessation of grazing, and the return of fire and drought, the dramatic 20th century expansion of juniper into Wupatki NM's savannas and grasslands appears to have slowed, or even stopped, after about 1990.

Assessing the Indicators from Edmonds et al. (2011)

Drawing upon the natural ecological dynamics and historical background discussed above, we can now evaluate the current condition of Wupatki NM's vegetation by examining the six measures of condition from Edmonds et al. (2011).

Are the species present and their distributions consistent with supply and demand of light, water, nutrients, and growing space, and within their natural range of variability?

The species present and their distributions are probably consistent with supply and demand of light, water, nutrients, and growing space, and within their natural range of variability, even though our understanding of reference conditions is limited, as explained previously. Eight of the characteristic plant species of Colorado Plateau semi-desert grasslands and shrub-steppe as listed above (from LCAS 2010) are well represented at Wupatki NM, based on our observations and recent floristic surveys (Hansen et al. 2004, DeCoster and Swan 2009). Three of the

Figure 4.9.4-2. Three weeks after the 2013 White Fire: small junipers were scorched, and many subsequently died. Photo Credit: NPS.

characteristic species apparently are not present at Wupatki NM—western wheatgrass, big sagebrush, and black sagebrush—but these absences do not appear to represent any kind of degradation. Rather, they reflect the fact that the composition of semiarid grasslands in the Southwest varies greatly from place to place, and that exceptions to generalized descriptions (e.g., those in LCAS 2010) are widespread and normal. For example, the "missing" big sagebrush is found primarily in regions of winter-dominated precipitation to the north of Wupatki NM; its absence in Wupatki NM likely reflects the relatively greater importance of summer rain in Wupatki NM's precipitation regime. Another seeming anomaly to general descriptions of Colorado Plateau semi-desert grasslands and shrub-steppe, again reflecting normal geographic variation in climate, soils, and native biota, is the abundance at Wupatki NM of black grama, a species more typical of desert grasslands south of the Mogollon Rim.

Although we do not know of any plant species that was present during the reference period but has subsequently disappeared, we cannot rule out the possibility that plant species composition (i.e., not just the list of species present but the relative abundance of each species), and things like total herbaceous biomass and soil organic matter, are still recovering from effects of previous grazing, perhaps especially from the intensive overgrazing of the late-1800s to mid-1900s (Fleischner 1994). The most likely compositional legacy of previous livestock grazing, if there is such a legacy, probably would be a disproportionate abundance of grazing-tolerant plant species and a corresponding paucity of grazing-sensitive species.

Figure 4.9.4-3. A small juniper, probably less than 20 years old, that was killed by the 2013 White Fire, photographed two years after the fire. Photo Credit: © W.H. Romme.

Livestock grazing in the monument was terminated only in 1989—less than 30 years ago. Studies elsewhere have demonstrated or suggested lag times of up to 50 years for grasslands to recover after livestock are removed, as well as complex and highly variable patterns of recovery, both spatially (e.g., in relation to local soil conditions) and temporally (especially in association with drought); see Romme and Whitefield (2017) for details.

We do know that composition of the grassland vegetation has been relatively stable for the last 40 years. Plots established in 1977 and 1978 were located and re-sampled in 2011 (Schelz et al. 2013). Some changes were documented, but no consistent differences were

Figure 4.9.4-4. Junipers that were killed or injured by the drought of 2000-2004 on the Coconino National Forest just south of Wupatki NM. Photo Credit: © W.H. Romme.

seen in species composition or trend between grazed and ungrazed plots. (Ungrazed plots were fenced exclosures in 1977-78 and all Wupatki NM plots in 2011; grazed plots were outside of exclosures in 1977-78 and on adjacent national forest lands where grazing has continued but at a much reduced level since ca. 2000.) There was an overall increase in biotic cover and a small decrease in species richness from 1977-78 to 2011, but this may reflect only the generally drier climatic conditions since the late 1980s (Schelz et al. 2013), including a period of extreme drought from 2000 through 2002 (Breshears et al. 2005).

Considering that most of the period since livestock were excluded has been unusually dry, a series of wet years or a sustained wet period may be required for plant cover, soil development, and vegetation productivity to fully respond to the removal of grazing, and for additional species to establish from nearly habitats where those species were able to persist through the period of overgrazing. Unfortunately, we do not know exactly where those putative refuge habitats might be located.

A particularly noteworthy feature of Wupatki NM's grasslands is the relatively minor influence of non-native species. Cheatgrass (*Anisantha* (*Bromus*) *tectorum*) has been seen on some shallow limestone-derived soils, but has been conspicuous only in years of wet conditions in late winter-early spring. Similarly, tumbleweed is found in places where vegetative cover has been disturbed, but its abundance varies greatly from year to year. When walking through the grasslands, what one notices are the native species, with only an occasional non-native. The plots that were sampled by Schelz et al. (2013) also were populated almost entirely by native plants, both in 1977-78 and in 2011.

Despite the possibility of lingering legacies of past land use, the current grassland vegetation in Wupatki NM shows the kinds of patterns in species distribution and abundance that we would expect in this kind of environment. Species presence and local abundance vary individualistically with underlying variation in aspect, substrate, soil depth, micro-climate, and time since fire. Overall, the grassland plant community appears intact, dominated by a moderately diverse mix of native species, few non-natives, and generally what we would expect of structure and composition within the environmental context of the Wupatki NM area.

Species composition in persistent woodland and savanna portions of Wupatki NM also appears to be just what would be expected in these kinds of ecosystems in this part of the Southwest.

<u>Are stand densities within their range of natural variability for their growing conditions?</u>

This measure applies only to the persistent juniper woodlands and savannas, and the answer is complex. The huge cohort of trees in areas where juniper expanded rapidly in the late 1800s and early 1900s is not entirely "natural," in the sense that such a rapid expansion event probably would not have occurred during the historical period when fires were recurring regularly enough to kill most of the expanding junipers before they became large enough to resist fire mortality. However, given the environmental conditions at Wupatki NM in the late 1800s and early 1900s, notably the removal of fire as a major mortality agent, juniper's population response to the conditions of the time was entirely "natural." Since 1989 and the return of fire and drought, the expansion of juniper has slowed or even stopped—consistent with its "natural" response to these new environmental conditions. So our answer to this question is: yes within persistent woodlands, but past land use promoted development of more extensive persistent woodlands than would have occurred naturally.

<u>Are the age class distributions of the trees consistent with the expected range of variability for this site/ecosystem type?</u>

The same issues are at play with this question as with the 'stand densities within their range of natural variability for their growing conditions' measure. The answer is: yes within older persistent woodlands, but past land use promoted development of an unnaturally large cohort of trees 70-130 years old.

<u>Do the trees and understory plants appear vigorous and healthy for this site/ ecosystem type?</u>

The trees and understory plants do appear vigorous and healthy for this ecosystem type. Many of the junipers at Wupatki NM have been killed or injured by recent fires and droughts, both of which are natural ecological processes. However, we have observed no evidence of "unnatural" or excessive mortality or injury in either the woody plants or the grasses and forbs at Wupatki NM.

Are ecological processes (e.g., fire) operating within a natural range of variability?

Processes like productivity and nutrient cycling probably are operating much as they did during the reference period, naturally varying over time and space in response to fine-scale environmental heterogeneity, fluctuating climate conditions, and impacts of fire and grazing by native vertebrates and insects. So the answer here is yes.

But the process of special concern in this assessment is fire. Historically, fire had a powerful influence on the structure and dynamics of most vegetation types in the monument, perhaps especially with respect to the "tension zone" between grassland and woodland vegetation. Although fire is returning as a natural disturbance process within Wupatki NM, these events only occur with pinpoint ignitions in the western half of the monument. It is likely that fires were more frequent and more extensive prior to Euro-American settlement, when fires could have spread over a much larger area of the grassland ecosystem north and east of the San Francisco Mountains. So the short answer to the question whether fire is operating within a natural range of variability, is yes, but just barely so, and only recently.

Are the current levels of insects and/or disease within the normal range for this ecosystem type?

The plants in Wupatki NM's grasslands, savannas, and woodlands appear generally healthy and vigorous (aside from the normal effects of fire and drought), with only localized and low levels of insect herbivory or disease.

Assessing the Measures from Pellant et al. (2005)

This system was developed to evaluate the health of a rangeland (or grassland), and is based on examining key attributes of an ecosystem that are essential for normal functioning and sustainability. Each of these attributes is given a rating of "good," "moderate" or "significant concern" for a picture of the overall condition of the ecosystem. We assess these attributes and measures for the grasslands at Wupatki NM that remain free of trees, i.e., we are not considering the persistent woodlands or savannas in this section because the system was designed specifically for grasslands.

There are two indicators of ecological condition. The first is Soil/Site Stability. We did not assess this indicator because it is evaluated in Dr. Kirk Anderson's volcanic soils assessment in this report. We also did not evaluate biological soil crusts, because soils and climate in this area are not suitable for these kinds of soil communities (Bowker and Belnap 2013).

Species Composition and Landscape-scale Diversity, Local-scale Species Composition
Response of Annual Species to Disturbance
Relative Proportion of Functional Groups
Relative Proportion of C3 and C4 Species

The second indicator is Biotic Integrity, with five measures. We assign a rating of good condition to four of the five measures of biotic integrity at Wupatki NM. The only measure receiving a moderate concern condition rating is the "local-scale species composition" measure, and this rating reflects only the concern that grassland species composition may have not yet fully recovered from the excessive livestock grazing of the late 19th century through early 20th century. In fact, this is only speculation, because we have no empirical data with which to compare pre-grazing species composition with current composition; it is highlighted here only to be kept in mind and tested with future surveys of grassland species composition.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Table 4.9.4-2 summarizes our evaluation of Wupatki NM's grasslands. The total extent of semiarid grassland in Wupatki NM decreased substantially during the past century, as juniper trees expanded and converted former grasslands into savannas and woodlands. That process of woodland expansion into grasslands has slowed in the past 25 years, and may stop altogether in the near future, as periodic fires are again burning through the grasslands and savannas, and a changing climate is becoming less conducive to juniper establishment and survival.

The treeless grasslands that remain within the monument are in generally good condition, dominated by native species that are to be expected in this area, and with stable soils. The one concern about grassland species composition is that some grazing intolerant species may have been eliminated by the excessive grazing that occurred in the last century. However, this is speculation; we have no empirical information with which to either support or refute the idea. Most of the wildlife species typical of this kind of grassland habitat are also present, although Gunnison's prairie dog was

Table 4.9.4-2. Summary of vegetation indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Ecological Condition	Are the species present and their distributions consistent with supply and demand of light, water, nutrients, and growing space, and within their natural range of variability?		Of the species that would be expected in this area, none are conspicuously missing, hence condition rated as good. Nevertheless, it is possible, though unproven, that historical overgrazing extirpated some herbaceous species that had been present before 1880, hence medium confidence.
	Are stand densities within their range of natural variability for their growing conditions?		A good condition is true within persistent woodlands, but past land use promoted development of more extensive persistent woodlands than would have occurred naturally.
	Are the age class distributions of the trees consistent with the expected range of variability for this site/ecosystem type?		A good condition is true within older persistent woodlands, but past land use promoted development of an unnaturally large cohort of trees 70-130 years old.
	Do the trees and understory plants appear vigorous and healthy for this site/ ecosystem type?		Observations during the field visit plus conversations with local botanists and ecologists identified no issues of plant health or vigor, except for normal drought and fire damage in a small number of trees and shrubs.
	Are ecological processes (e.g., fire) operating within a natural range of variability?		Fire returned to Wupatki's grasslands and savannas after 1989, killing small trees and shrubs, and stimulating herbaceous plants, much as it did historically. However, fires probably are still smaller and less frequent than historically.
	Are the current levels of insects and/or disease within the normal range for this ecosystem type?		Observations during the field visit plus conversations with local botanists and ecologists identified no concerns about insect or disease effects. (Junipers in particular tend to be quite resistant to insect and disease.)
Biotic Integrity	Species Composition and Landscape-scale Diversity		The condition is good. Landscape-scale diversity reflects spatial pattern of soils and disturbance.
	Local-scale Species Composition		Local species composition appears to vary as expected with local variation in soils and past disturbance, notably fire.
	Response of Annual Species to Disturbance		Proportion of perennial species is approximately what would be expected given the site and time since disturbance.
	Relative Proportion of Functional Groups		Proportions of functional groups (e.g., grasses, forbs, and shrubs) are consistent with what might be expected given the site characteristics.
	Relative Proportion of C3 and C4 Species		C3 and C4 species are both well represented at Wupatki. However, chronic heavy grazing tends to reduce C3 plants disproportionately; hence the C3 component may have been greater before 1880, but we lack evidence to support or refute this idea.

Table 4.9.4-2 continued. ***Summary of vegetation indicators, measures, and condition rationale.***

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Overall Condition			Overall we consider the vegetation at Wupatki to be in good condition, but two aspects warrant moderate concern: possible (but undocumented) legacies of past overgrazing on grassland species composition, and extensive expansion of juniper woodlands into grasslands during the past century. Trend in vegetation is improving, since grasslands appear to have recovered after cessation of grazing, and juniper expansion has slowed or even stopped with the return of fire and drought. Confidence in the data is high.

locally extirpated ca. 2004, and the population sizes and long-term persistence of some larger species (e.g., pronghorn) may be compromised by the small total extent of the grassland habitat within the monument and by incompatible land use activities in some of the surrounding landscape.

Persistent juniper woodlands are in good shape, with expected structure and composition, and exhibiting only limited injury and mortality from recent drought. The older woodlands are largely fire-resistant, due to lack of herbaceous fuels in the spaces between tree crowns, and have not been affected by recent fires in the monument. The only potential threat that we see to Wupatki NM's persistent juniper woodlands is future climate change. We note, however, that a very large increase in temperatures and moisture stress would be required to kill the very resilient juniper trees over extensive areas, and climate change of that magnitude is not expected within the next several decades.

Savanna vegetation covers about as much area today as it did a century ago, but the specific locations of savanna have changed as older savannas were converted to persistent woodland and new savannas were created by trees expanding into former grasslands. Today's savannas are in good condition, with stable soils and a scattering of small trees and shrubs within a diverse and healthy herbaceous component. Some trees and shrubs have been killed by recent fires—a natural and important ecological dynamic in this system—and native grasses and forbs have either tolerated or been stimulated by the fires. Establishment of non-native plants in burned areas, a serious problem in many other areas, has been minimal at Wupatki NM.

The Wupatki NM landscape looks different in some respects today than it would have looked in the pre-1880 reference period: notably, juniper woodlands have expanded and grassland areas have shrunk. This change in the vegetation mosaic, a legacy of late 19th and early 20th century land use, probably cannot be undone without intensive management intervention such as mechanical juniper removal; such treatments could have undesirable impacts to cultural resources and be contrary to wilderness management policy. Nevertheless, the vegetation today retains all or nearly all of the native species that were present historically, with relatively few non-natives, and today's woodlands, savannas, and grasslands have essentially the same structure and composition as did these vegetation types in the pre-1880 reference period.

The key ecological process that was missing for most of the past century—fire—has returned, and the natural dynamic among woodlands, grasslands, and savannas has been at least partially restored. If fires continue to burn at the frequency and extent that we have seen in the past 25 years, then net juniper expansion and grassland conversion will likely slow or even stop altogether. And with an increase in the frequency and extent of burning, total grassland area could potentially increase, as fire removes susceptible small trees from places that are now savanna.

Overall, we have high confidence in this assessment. This is primarily because of the unusual wealth of historical and ecological information available for Wupatki NM. Packrat midden analyses and regional tree-ring records provide a centuries-long view of climate and vegetation trends leading up to the modern period; Wupatki NM-specific tree-ring analyses and historical photo comparisons permit us to pinpoint the timing and spatial patterns of major changes in juniper density and cover; climate modeling helps us to assess where the vegetation may be heading; and the occurrence and documentation of recent fires enable us to directly evaluate the role of this key ecological process.

This latter point—the reappearance of fire in the Wupatki NM landscape—deserves special emphasis. Twentieth-century juniper expansion into semiarid grasslands has been observed in much of the Southwest, and fire exclusion has frequently been hypothesized as a major mechanism driving this change. However, as noted in a recent review of piñon-juniper vegetation across the West (Romme et al. 2009), we have lacked the empirical data needed to critically evaluate the role of fire in pre-1880 grasslands and savannas. Junipers usually do not form fire scars, so historical fire frequency cannot be reconstructed in this kind of vegetation as it can, e.g., in ponderosa pine forests. And because fire exclusion has been so pervasive across the Southwest, we have had limited experience observing modern fires in savanna vegetation. The return of fire to Wupatki NM provides a truly exceptional opportunity to understand the natural ecological dynamics of this widespread vegetation type. The lessons we learn in Wupatki NM will be applicable to many other national parks, monuments, and conservation-oriented landscapes throughout the region.

Despite an overall high level of confidence in this assessment, we are somewhat less confident in three of our conclusions. First is our interpretation of plant species composition in Wupatki NM grasslands. No species list exists from before 1880 (note that Ironside (2006) attempted to create such a list from packrat middens, but concluded it could not be done), and the earliest rigorous botanical surveys in the monument were not conducted until well into the 20th century, after decades of grazing impact and fire exclusion. So we can only speculate on how early land use may have altered the species present in today's grasslands.

Regarding more recent trends in grassland composition, a number of floristic inventories in Wupatki NM exist, dating back to the 1940s, many in the form of unpublished reports in agency files. A thorough compilation and analysis of these records could help reveal the extent to which species composition has changed since cessation of grazing in 1989.

A second area of uncertainty has to do with fire effects on the plants, soils, and wildlife of Wupatki NM's grasslands and savannas. Anecdotal observations of areas that burned in the last 20 years (such as our reconnaissance visit in October 2015) suggest full recovery after fire or even stimulation of native grasses and forbs, but we caution that adverse fire effects have been documented in some other Southwestern semiarid grasslands. In the Huachuca Mountains of southeastern Arizona, for example, very short intervals between successive fires (<10 years) resulted in reduced plant cover, production, and species richness on sites having thin, coarse-textured soils (Robinett 1994), although longer fire intervals on better soils generally stimulated plant cover, production, and diversity in that area. Some native species like black grama, which spreads via stolons on the soil surface, could be especially sensitive to fire injury.

A rigorous study of fire effects on the full spectrum of native plant and soil types in Wupatki NM's grasslands and savannas could alert managers to any potential concerns to be expected with continued or increased fire activity in the monument. In a similar vein, fire effects on archaeological sites and other cultural resources might benefit from more thorough assessment at Wupatki NM. The Wildland Fire and Fuels Management Plan for the Flagstaff Area National Monuments (NPS 2008) assumes that fires will be fast moving, low flame-front grassland fires, and that these fires will not impact cultural resources. However, neither of these assumptions has been tested thoroughly, and some fire-caused damage has already been documented (Hough 2004).

Our third uncertainty in this assessment relates to projections of future climate and the likely effects of climate change on vegetation composition and on fire frequency and severity. Ironside's (2006) climate modeling provides a valuable first look at what may be in store for Wupatki NM's ecosystems. As data and methods of climate modeling continue to improve, some new climate change scenarios for the Wupatki NM area may be necessary.

<u>Threats, Issues, and Data Gaps</u>

Almost any new information about the ecology and history of Wupatki NM would be beneficial; indeed, some of the most significant ecological discoveries have been serendipitous. Nevertheless, four kinds of research or analysis may be most urgent for purposes of protection and management of the vegetation and other resources in the western portion of Wupatki NM, listed here in what we think is a descending order of priority:

- Detailed fire effects on vegetation and soils within Wupatki NM, and in the immediately adjacent "fire for resource benefit" management zone on the Coconino National Forest. In particular size/mortality relationships in savanna junipers, post-fire recovery of potentially sensitive species like black grama, any establishment of non-native species in burned areas, and impacts of fire on cultural resources.
- Thresholds in juniper density or cover at which herbaceous growth is suppressed sufficiently to inhibit fire spread under a range of fire weather conditions; and similar relationships between herbaceous cover and the depth of volcanic cinders.
- Trends in grassland floristic composition over the past century (from unpublished reports on file and other sources).
- Continued monitoring for long term changes in grassland plant composition and cover, as the area continues to recover from livestock grazing.
- Locations near Wupatki NM where plant species thought to have been extirpated within the monument by overgrazing, have persisted and could serve as sources for re-establishment within Wupatki NM.

4.9.5. Sources of Expertise

William H. Romme is professor emeritus of fire ecology and a senior research scientist at the Natural Resource Ecology Laboratory, Colorado State University. Paul Whitefield is Natural Resource Specialist for Wupatki, Sunset Crater Volcano, and Walnut Canyon National Monuments, Arizona.

Joining us on the 2015 field trip were Lisa Thomas, Jim DeCoster, and Megan Swan, all ecologists with the National Park Service, Southern Colorado Plateau Network, based at Northern Arizona University in Flagstaff, AZ; these individuals shared their expertise in regional floristics and vegetation patterns. Kirk Anderson, geomorphologist at the Museum of Northern Arizona in Flagstaff, Arizona, and Jim Harrigan, soil scientist with NRCS, educated us about the geology, soils, and volcanic history of the area. All of these individuals discussed observations and hypotheses with us while in the field; their knowledge and insights contributed greatly to our assessment.

4.10. Non-native and Invasive Plants

4.10.1. Background and Importance

Vegetation in Wupatki National Monument (NM) is unique and diverse with "nearly barren beds of cinder and rock outcrops, grassy prairie, open one-seed juniper (*Juniperus monosperma*) savanna, sparsely vegetated badlands, sand dunes, and densely vegetated riparian corridors"(Hansen et al. 2004). Wupatki NM protects one of the few native grasslands in the Southwest that is not being actively grazed (Figure 4.10.1-1; Schelz et al. 2013). While vegetation in Wupatki NM is varied, the landscape is generally sparsely vegetated with between 2% and 15% cover ~~(Hansen et al. 2004). Some areas are even considered~~ naturally barren with <2% cover. These areas include cinder barrens, basalt outcrops, and active river channels near the Little Colorado River (Hansen et al 2004). The introduction of certain non-native species, however, may alter ecosystem structure and function in the monument.

Non-native plants, including tamarisk (*Tamarix* spp.) and camelthorn (*Alhagi maurorum*), occur along streambanks, cheatgrass (*Bromus tectorum*) and other non-native grasses are found along road corridors (Brehl et al. 2008), and patches of prickly Russian thistle (*Salsola tragus)* have colonized some backcountry areas (Decoster and Swan 2016). In areas outside the monument, non-native species have been directly linked to the replacement of dominant native species (Tilman 1999), the loss of rare species (King 1985), changes in ecosystem structure, alteration of nutrient cycles and soil chemistry (Ehrenfeld 2003), shifts in community productivity (Vitousek 1990), reduced agricultural productivity, and changes in water availability (D'Antonio and Mahall 1991).

The damage caused by these species to natural resources is often irreparable, and our understanding of the consequences incomplete. Non-native species are second only to habitat destruction as a threat to wildland biodiversity (Wilcove et al. 1998). Consequently, the dynamic relationships among plants, animals, soil, and water established over many thousands of years are at risk of being destroyed in a relatively brief period. For the National Park Service (NPS), the consequences of these invasions present a significant challenge to the management of the agency's natural resources "unimpaired for the enjoyment of future generations" (NPS 2006b). National parks, like land managed by other organizations, are deluged by new non-native species arriving through predictable (e.g., road, trail, and riparian corridors), sudden (e.g., long-distance dispersal through cargo containers and air freight), and unexpected anthropogenic pathways (e.g., weed seeds in restoration planting mixes). Nonnative plants claim an estimated 1,862 ha (4,600 ac) of public land each year in the United States (Asher

Figure 4.10.1-1. Native grasslands interspersed with one-seed juniper in Wupatki NM. Photo Credit: NPS.

and Harmon 1995), significantly altering local flora. For example, non-native plants comprise an estimated 43% and 36% of the flora of the states of Hawaii and New York, respectively (Rejmanek and Randall 1994). Non-native plants infest an estimated 1 million ha (2.6 million ac) of the 33.5 million ha (83 million ac) managed by the NPS (Welch et al. 2014). Prevention and early detection are the principal strategies for successful invasive non-native plant management. While there is a need for long-term suppression programs to address high-impact species, eradication efforts are most successful for infestations of less than one hectare (2.5 ac) in size (Rejmanek and Pitcairn 2002).

4.10.2. Data and Methods

Several reports have documented non-native plant presence at Wupatki NM (Bateman 1976a as cited in Brehl et al. (2008); Bateman 1987; Brehl et al. 2008; Cinnamon 1983 as cited in Brehl et al. (2008); Cinnamon 1987; Decoster and Swan 2016; Hansen et al. 2004; NPS 2009a; and Schelz et al. 2013). Using the above mentioned reports published since 2008, we developed a comprehensive list of all non-native plant species known to occur in the monument. We drafted an initial list using the Invasive Plant Management Plan and Environmental Assessment (IPMPEA) developed for the three Flagstaff Area National Monuments (i.e., Wupatki NM, Sunset Crater Volcano NM, and Walnut Canyon NM) (NPS 2009a) and then supplemented this list with additional non-native species described in Brehl et al. (2008), Decoster and Swan (2016), and Schelz et al. (2013). This list represents the most current list of non-native plants found within the monument and was used to evaluate non-native plants that occur there. We used five indicators, with a total of eight measures, to determine current condition of non-native plants at Wupatki NM.

<u>NatureServe Invasive Species Impact Rank</u>

The NatureServe database (NatureServe Explorer 2016), which is based on the Invasive Species Assessment Protocol developed by Morse et al. (2004), is a ranking system that categorizes and lists non-native plants for large areas, such as regions (e.g., Great Plains) or states (e.g., Arizona) according to their overall impact on native biodiversity. The invasiveness rank protocol assesses four major categories for each plant (ecological impact, current distribution and abundance, trend in distribution and abundance, and management difficulty) for a total of 20 questions (Morse et al. 2004). A subrank score is developed for each category then an overall Invasive Species Impact Rank or I-Rank score is developed for each species. Based upon the I-Rank value, each species is then placed into one of four categories: species that cause high, medium, low, or insignificant negative impacts to native biodiversity within the area of interest (Morse et al. 2004).

<u>AZ-WIPWG Ecological Impact Rank</u>

The Arizona Wildlands Invasive Plant Working Group (AZ-WIPWG) developed a ranking system that was adapted from the NatureServe I-rank system (Warner et al. 2003). AZ-WIPWG categorized and listed non-native plants occurring in Arizona that are most threatening to wildlands. The final list of species evaluated included invasive, non-native species that threaten wildlands, which are defined as plants that are "(1) not native to, yet can spread into, the wildland ecosystems under consideration, and that also (2) do any of the following within wildland ecosystems - "displace native species, hybridize with native species, alter biological communities, or alter ecosystem processes," (Warner et al. 2003). The criteria for evaluating a species were ecological impact, invasiveness potential, ecological amplitude and distribution, and rating level of documentation for a total of thirteen questions. As with NatureServe's system, a subrank score was developed for each category and an overall Ecological Impact Rank was developed for each species. Each species was then placed into one of three categories: species that cause high, medium, and low ecological impacts on ecosystems and biotic communities. A fourth category termed "evaluated but not listed," includes those species for which the sum effects fall below the thresholds for ranking or for which current information was inadequate to assign a rank. A total of 75 species were evaluated and 71 species were ranked (AZ-WIPWG 2005).

<u>Change in Frequency (%) and Change in Cover (%)</u>

To determine change in cover and frequency of non-native plants from 1977-2011, we relied on Schlelz et al. (2013). Schelz et al. (2013) conducted repeat sampling of vegetation plots established in 1977 by Bateman (1978, 1979, 1980, and 1981) as cited in Schelz et al. (2013). Details of the study design are provided in Schelz et al. (2013) and are described briefly here.

Bateman sampled 36 plots within and around Wupatki NM. Plots were grouped into one of three categories:

within and outside four livestock exclosures (GE), general vegetation community plots (CM), and pairs of plots established within and outside the boundary of the monument (CMF). For the purposes of this assessment, we use only those plots that were established within the monument for a total of 29 plots (Figure 4.10.2-1). In 2011, Schelz et al. (2013) revisited these plots to determine change in plant community composition and cover using the same methods employed during Bateman's studies (Schelz et al. 2013).

Plot configuration differed slightly depending on group type. GE plots (n = 8) were 60 x 60-m (196.9 x 196.9 ft) plots with five 50-m (164 ft) long transects within each plot. CM (n = 17) and CMF (n = 5) plots were smaller than GE plots. These plots were 30 x 30 m (98.4 x 98.4 ft) each with three 30-m (98.4 ft) transects in each plot. In these 29 plots, vegetation cover was measured along each transect using the point-intercept method (Schelz et al. 2013).We reported cover in meters for each non-native plant encountered as reported for 1977 and 2013, change in absolute cover, and change in relative cover. Absolute cover is percent cover of a species that represents the total cover in that plot and relative cover is the percent cover of a species that represents the total cover of all plants in that plot.

Frequency data were collected in 1 x 5-m (3.28 x 16.4 ft) belt transects located along the left side of each of the plot transects (50 belt transects per GE plot and 18 belt transects per CM and CMF plots). We reported data on non-native plant species frequency (% of subplots that contained a non-native species) for 1977 and 2011, as well as change in frequency between the two time periods.

Current Prevalence of Non-native Plants: Cover (%) and Frequency (%)

The Southern Colorado Plateau Inventory and Monitoring Network (SCPN) monitored and reported on vegetation in 54 plots in Wupatki NM during August and September 2012-2014 (Decoster and Swan 2016). Plots were established in two ecologically distinct regions in the monument based on soil type, hydrology, plant communities, disturbance regimes, and responses to disturbances (Decoster and Swan 2016). The two regions were Volcanic Uplands and Loamy Uplands (Figure 4.10.2-1). These two ecological sites were expanded and renamed based on recent soil survey data; however, they largely overlap the former site types known as Limy Uplands (now Volcanic Uplands) and Sandstone Uplands (now Loamy Uplands). These site types represent large areas of the upland grassland and shrubland ecosystems in Wupatki NM.

Volcanic Uplands are grasslands dominated by *Pleuraphis jamesii*, with a large forb component. Loamy Uplands are composed of diverse shrublands, co-dominated by many shrub species, with a large grass component (Decoster and Swan 2013). Details of the study design are provided in Decoster and Swan (2016) and are described briefly below.

Plots were 0.50 ha (1.2 ac) with three parallel 50-m (164 ft) transects spaced 25 m (82 ft) apart. At 10-m (33 ft) intervals along each transect, shrub and herbaceous cover was collected in each of five nested quadrats. Quadrats measured 2 x 5 m (6.5 x 16.4 ft) with four smaller quadrats nested inside measuring 0.01 m^2, 0.1 m^2, 1 m^2, and 5m^2 (0.1 ft^2, 1ft^2, 11ft^2, and 54ft^2).

Percent absolute cover of shrubs and herbaceous vegetation was assigned one of 12 cover classes (e.g., 2-5%, 5-10%, etc.). Absolute cover was estimated at the mid-point of each cover class. Frequency was calculated across plots as the percent of plots where the species occurred.

Current Extent of Target Non-native Plants in High Use Areas: Area (ha)

We used data provided in Brehl et al. 2008 to summarize the current extent (number of hectares) of tamarisk (also known as saltcedar) and camelthorn, as well as other target invasive species in Wupatki NM. Target species were identified as those that were 1) frequently observed along roadsides and developed areas, and 2) known to San Francisco Peaks Weed Management Area members as those which establish high densities and persistent populations in northern Arizona. Other non-native species encountered while searching for target species were also documented but not necessarily mapped. Surveys occurred from August 2003 to September 2004 and were supplemented by additional data collected during 2005. Details of the study design are provided in Brehl et al. (2008) and are described briefly below.

The shoulder of all paved roads in Wupatki NM extending out to a distance of 4.57 m (15 ft) was surveyed for non-native plants by driving the road looking for

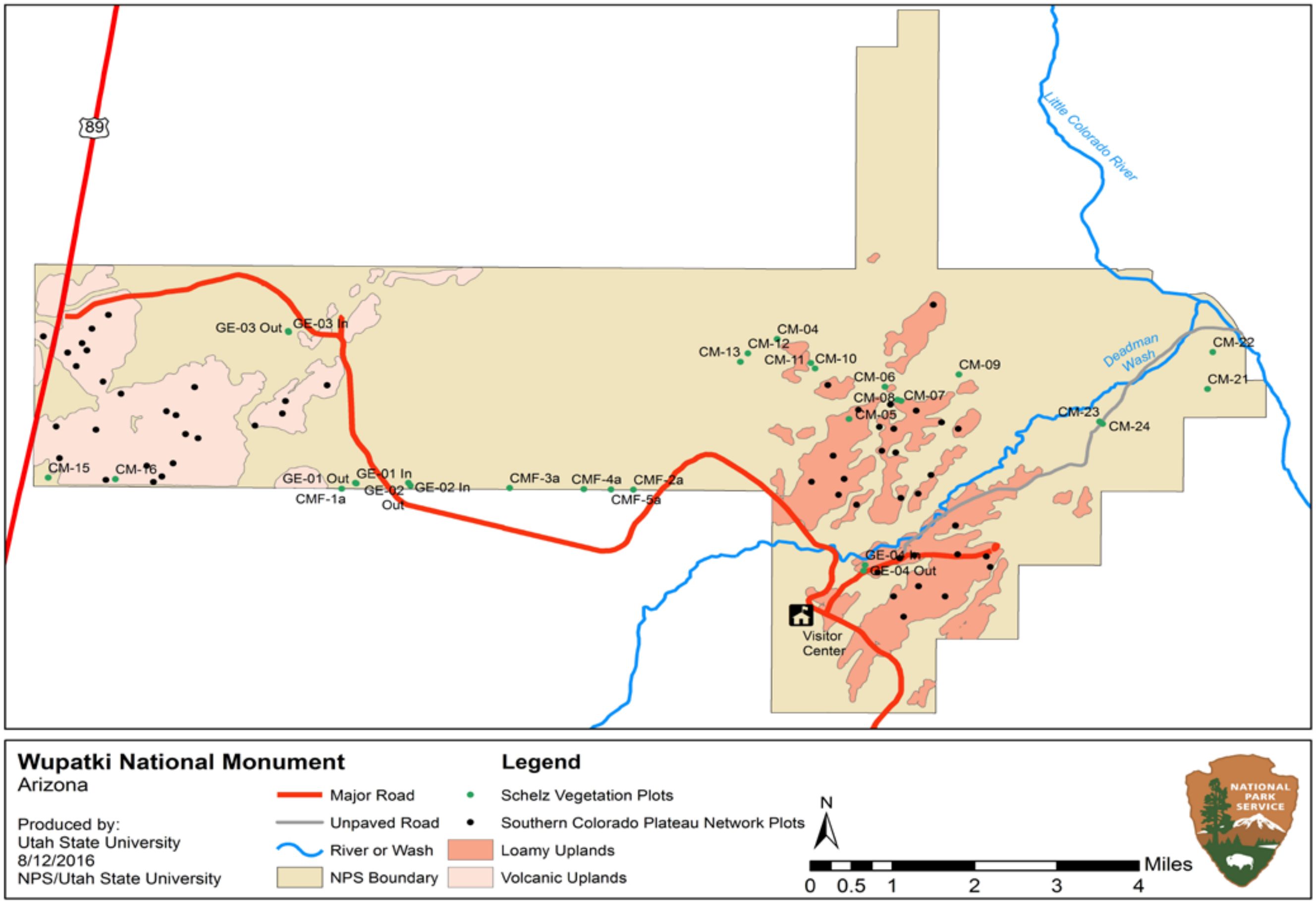


Figure 4.10.2-1. Locations of vegetation monitoring plots in Wupatki NM.

plants and by walking the length of the road along both sides. All non-native plant patches consisting of at least five individual plants covering an approximate area of 10-m^2 (108-ft^2) were collected as points using a handheld global positioning system (GPS). Large patches were mapped by walking the length of the patch and recording them with a GPS. These patches contained at least 11 individuals covering a 10-m^2 (108-ft^2) area. Line and point data were collected for each non-native species encountered.

Visitor use and administrative areas were surveyed using the same criteria described above except that the distance from parking areas, sidewalks, trails and other man-made features ranged from 6 to 30 m (20-100 ft). Populations with between 5-10 individuals covering an area of 10-m^2 (108-ft^2) were mapped as points, while populations greater than 10 plants were mapped as polygons.

All potential tamarisk and camelthorn habitat was surveyed on foot, and patches of each species were mapped using a GPS. One large patch was mapped using geographic information system (GIS) vegetation data produced by Hansen et al. (2004). Potential habitat included ephemeral drainages, springs and seeps, man-made catchments, abandoned mineral quarries, and other disturbed areas. The known location of historically occurring camelthorn and tamarisk locations were also re-surveyed. Points were created for each patch smaller than 5 m^2 (50 ft^2).

The total area or extent of each species mapped was calculated as the sum of the points, which equaled 4.6 m^2 (50 ft^2) for tamarisk and camelthorn, 10 m^2 (108 ft^2) for all other target species, and the sum of the polygons, which equaled 1.4 m^2 (15 ft^2) for every 0.3 m (1 ft) mapped.

Camelthorn and Tamarisk Control

Proportion of Target Area Treated (%)

Tamarisk is a highly competitive shrub that was introduced from Asia as an erosion control agent (GISD 2015). Tamarisk has since invaded riparian areas throughout the western U.S. This invasive species increases soil salinity, alters soil moisture characteristics, and excludes native species where it occurs (GISD 2015). Furthermore, its wind dispersed seeds spread rapidly and cuttings can re-sprout after burning or being buried (GISD 2015). Camelthorn, which has also invaded riparian areas in the western U.S., is a short, heavily-thorned shrub that forms monocultures via an extensive laterally growing root system (GISD 2015).

These species have invaded the only riparian area in the monument and have been present since at least 1976 (Brehl et al. 2008). In Wupatki NM, tamarisk and camelthorn have largely replaced native gallery forests of cottonwood (*Populus* spp.) and willow (*Salix* spp.) along the Little Colorado River and Deadman Wash. The eastern boundary of Wupatki NM follows 3.2 km (2 mi) of the Little Colorado River and approximately 20.2 ha (50 ac) of highly degraded riparian corridor occur within the boundary.

We used data collected during these studies in addition to vegetation mapping efforts (Brehl et al. 2008 and Hansen et al. 2004) to determine the proportion of the targeted area of Deadman Wash that has been treated by either mechanical or chemical means. To determine the targeted area for treatment and restoration we used the Invasive Riparian Shrubland vegetation class mapped by Hansen et al. (2004) and subset this to the Deadman Wash area up to the monument boundary. The Invasive Riparian Shrubland map class was dominated by tamarisk and camelthorn with remnant patches of coyote willow (*Salix exigua*), broom snakeweed (*Gutierrezia sarothrae*), southern goldenbush (*Isocoma pluriflora*), and western wheatgrass (*Pascopyrum smithii*) (Hansen et al. 2004). We then overlaid the target area with polygons of the mapped area of tamarisk and camelthorn that were treated by either chemical (herbicide) or mechanical (chainsaw stump-cut) methods using GIS data provided by Wupatki NM staff.

4.10.3. Reference Conditions

Table 4.10.3-1 summarizes the condition thresholds for measures in good condition, those warranting moderate concern, and those warranting significant concern. Reference conditions were developed jointly by Natural Resource Condition Assessment staff, NPS staff, and SCPN staff.

4.10.4. Condition and Trend

Table 4.10.4-1 lists the total non-native plant species known to occur in Wupatki NM. The list includes species identified in the IPMPEA (NPS 2009a), Brehl et al. (2008), Decoster and Swan (2016), and Schelz et al. (2013). In Table 2 of the IPMPEA, 25 species were listed as occurring in Wupatki NM. Between the three other studies, we found an additional 14 species. Ten of these species were not listed in the IPMPEA and five species were listed as occurring in either Sunset Crater Volcano NM or Walnut Canyon NM, but not in Wupatki NM. This resulted in a total of 40 non-native species known to occur in Wupatki NM. However, the two species of sweetclover (*Melilotus* spp.) were listed as distinct species by AZ-WIPWG as well as in the IPMPEA, but were listed as synonyms of the same species in the United States Department of Agriculture's PLANTS Database (USDA 2016). Additionally, a plant listed in Brehl et al. (2008) was identified as similar to but not confirmed as Redroot pigweed (*Amaranthus retroflexus*). This indicates there are at least 38 non-native plants in Wupatki NM.

Threadstem carpetweed (*Mollugo cerviana*) and silverleaf nightshade (*Solanum elaeagnifolium*) were the only species reported in Decoster and Swan (2016) that were not reported elsewhere, which indicates new non-native species have been introduced since the IPMPEA was published. All other species were identified during non-native plant surveys conducted from 2003-2005 (Brehl et al. 2008). For all species added to the initial IPMPEA list, we searched the USDA PLANTS database for plant name synonyms to ensure the genus or species name had not changed, which could have accounted for these differences (USDA 2016).

<u>NatureServe Invasive Species Impact Rank</u>

Of the 40 non-native species listed in Table 4.10.4-1, 19 have not been assessed by NatureServe. Of the remaining 21 species, two were given a low/insignificant rank, one was given a low rank, two were given a medium rank, nine were given a medium/low rank, three were given a high/medium rank, three were given a high rank, and one was given a high/low rank.

Species with the highest rank were Russian olive (*Elaegnus angustifolia*) and cheatgrass. Of lesser rank, but still assigned a high/medium rank were Russian knapweed (*Acroptilon repens*), diffuse knapweed (*Centaurea diffusa*), and salt lover (*Halogeton

Table 4.10.3-1. Reference conditions used to assess non-native and invasive plants.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Potential to Alter Native Plant Communities	NatureServe Invasive Species Impact Rank	No non-native species with a high innate ability to alter ecosystem structure and function and/or only a few species with a medium or low ability to alter ecosystem structure and function are present.	Many non-native species with medium or one or two species with a high ability to alter ecosystem structure and function are present.	Many non-native species with medium or many species with a high ability to alter ecosystem structure and function are present.
	AZ-WIPWG Ecological Impact Rank			
Change in Non-native Plants (1977-2011)	Change in Cover (%)	No change or a reduction in non-native plant frequency/ cover.	Slight increase in non-native plant frequency/cover.	Substantial increase in non-native plant frequency/cover..
	Change in Frequency (%)			
Current Prevalence of Non-native Plants	Cover (%)	0% over several years.	Between 1% and 4% over several years.	>5% over several years.
	Frequency (%)	Non-native plants are found in <25% of all plots surveyed.	Non-native plants are found in 25%-50% of all plots surveyed.	Non-native plants are found in >50% of all plots surveyed.
Current Extent of Target Non-native Plants	Area (ha)	Distribution is sparse and limited in extent with low potential for spreading.	Found in small, localized patches with moderate potential for spreading.	Non-native species dominate the area in which they are found, and the potential for spreading is high.
Camelthorn and Tamarisk Control	Proportion of Target Area Treated, Controlled, or Confined	> 50% (of target area treated/controlled/ confined).*	20% to 50% (of target area treated/controlled/ confined).*	< 20% (of target area treated/ controlled/confined).*

* Reference condition thresholds were developed by Mark Szydlo, Biologist for the Flagstaff Area National Monuments.

glomeratus). Russian olive, cheatgrass, and Russian knapweed were also considered as priority species for park management. Diffuse knapweed was listed as a priority species for management but was not listed as occurring in Wupatki NM in the IPMPEA. Species considered a management priority, but assigned a medium or low rank by NatureServe included camelthorn, prickly lettuce (*Lactuca serriola*), white sweetclover (*M.* alba), yellow sweetclover (*M. officinalis*), and common mullein (*Verbascum thapsus*). Since the majority of species were ranked as medium or lower and only two species were assigned a high rank, we consider this measure to warrant moderate concern.

<u>AZ-WIPWG Ecological Impact Rank</u>

Eighteen species listed in Table 4.10.4-1 were evaluated by AZ-WIPWG. Two of these species were evaluated but not listed, which indicates low potential for invasion; however, both species were listed as priority species in the IPMPEA. These were goathead (*Tribulus terrestris*) and common mullein. Of the species that were ranked, six were ranked high, nine were ranked medium, and one was ranked low. As expected, species with a high AZ-WIPWG rank were also considered management priorities in the monument. These include Russian knapweed, red brome (*B. rubens*), cheatgrass, Russian olive, and tamarisk. Some of the medium ranked species were also listed as a management priority in the IPMPEA. It's important to note that not all species known to occur in Wupatki NM were included in the IPMPEA and several were therefore not assigned a management priority. However, three of these species were considered a management priority for the other two parks in which they occur. These include diffuse knapweed, bull thistle (*Cirsium vulgare*), and dalmatian toadflax (*Linaria dalmatica*). These were ranked as medium, low, and medium by AZ-WIPWG, respectively. In general, the two ranking systems were consistent, although the AZ-WIPWG system ranked more species as high than the NatureServe system. Since nearly 40% of non-native plants were evaluated by AZ-WIPWG and several were given a high or medium ecological impact rating, we consider this measure to warrant significant concern.

<u>Change in % Non-native Plant Cover (1977-2011)</u>

Three of the 29 plots reported in Schelz et al. (2013) contained non-native plants (Table 4.10.2-2). These were CM-10, CM-15, and CM-16. All three plots

Table 4.10.4-1. List of non-native plant species documented in Wupatki NM.

Scientific Name	Common Name	Invasive Plant Management Plan	NatureServe Invasive Species Impact Rank	AZ-WIPWG Ecological Impact Rank
Acroptilon repens	Russian knapweed	Priority	High/Medium	High
Alhagi maurorum	Camelthorn	Priority	Medium/Low	Medium
Amaranthus albus	Prostrate Pigweed	–	NA	NA
Amaranthus blitoides	Mat amaranth	–	NA	NA
Amaranthus **cf.** *retroflexus*[1]	Redroot pigweed	Not Listed in Plan	NA	NA
Ambrosia acanthicarpa	Bursage	Not Listed in Plan	NA	NA
Ambrosia artemisiifolia	Ragweed	Not Listed in Plan	NA	NA
Bromus rubens	Red Brome	Priority	NA	High
Bromus tectorum	Cheatgrass	Priority	High	High
Centaurea diffusa	Diffuse knapweed	Not Listed for Park	High/Medium	Medium
Chenopodium album	Lambsquarters	Not Listed for Park	NA	NA
Cirsium vulgare	Bull thistle	Not Listed for Park	Medium/Low	Low
Convolvulus arvensis	Field bindweed	–	Medium/Low	Medium
Conyza canadensis	Horseweed	Not Listed in Plan	NA	NA
Elaeagnus angustifolia	Russian olive	Priority	High	High
Erodium cicutarium	Storksbill	–	Medium/Low	Medium
Halogeton glomeratus	Salt lover	–	High/Medium	NA
Kochia scoparia	Mexican burning bush	–	Low	NA
Lactuca serriola	Prickly lettuce	Priority	Low/Insignificant	NA
Linaria dalmatica	Dalmatian toadflax	Not Listed for Park	NA	Medium
Marrubium vulgare	Horehound	Priority	Medium/Low	NA
Melilotus alba[2]	White sweetclover	Priority	Medium/Low	Medium
Melilotus officinalis	Yellow sweetclover	Priority	Medium/Low	Medium
Mollugo cerviana	Threadstem carpetweed	Not Listed in Plan	NA	NA
Polypogon monspeliensis	Rabbitfoot grass	–	High/Low	NA
Populus nigra	Lombardy poplar	Not Listed in Plan	Low/Insignificant	NA
Portulaca oleracea	Purslane	Priority	NA	NA
Rumex obtusifolius	Bitter dock	Not Listed for Park	NA	NA
Salsola kali	Russian thistle/tumbleweed	Priority	NA	NA
Salsola tragus	Prickly Russian thistle	Priority	NA	Medium
Sisymbrium altissimum	Tumble mustard	–	NA	NA
Solanum elaeagnifolium	Silverleaf nightshade	Not Listed in Plan	NA	NA
Sonchus arvensis	Sow thistle	Not Listed in Plan	Medium/Low	NA
Tamarix chinensis	Five-stamen tamarisk	Not Listed in Plan	NA	High
Tamarix ramosissima	Tamarisk, Saltcedar	Priority	High	High
Taraxacum officinale	Dandelion	–	NA	NA
Tragopogon dubius	Common salsify	–	Medium/Low	NA
Tribulus terrestris	Goathead	Priority	NA	Evaluated but NA
Ulmus pumila	Siberian Elm	Not Listed in Plan	Medium	Medium
Verbascum thapsus	Common mullein	Priority	Medium	Evaluated but NA

Note: NA indicates that the plant has not been assessed.

[1] Species was similar to but not confirmed *A. retroflexus*.

[2] USDA Plants (2016) lists this species as a synonym of *M. officinalis*, but these are listed as separate species in NPS (2009) and AZ-WIPWG (2005).

contained Russian thistle (*Salsola kali*) and one plot (CM-15) also contained Mexican burning bush (*Kochia scoparia*). In all but one plot, (CM-10), Russian thistle increased in cover between 1977 and 2011. The remaining 27 plots did not contain Russian thistle during either date.

Two of the three plots that contained non-native species were located near the main road (Highway 89) into the monument, which likely contributed to dispersal to these plots. NatureServe ranked Mexican burning bush as low for invasiveness. AZ-WIPWG did not assign this species a rank. Russian thistle has yet to be ranked by NatureServe and was not ranked by AZ-WIPWG but is considered a priority species by Wupatki NM. These data indicate that two non-native species became established in two of 29 plots since 1977. When considering all 29 plots however, non-native plants rarely occurred in 1977 and data suggest that non-native plants, as measured in these plots, continued to be rare through 2011. Therefore, we consider the condition for this measure to be good.

Change in Frequency (%)

Although two species of non-native plants occurred in at least three of the 29 plots, none were detected in belt transect surveys (Schelz et al. 2013). These data indicate that non-native plants are rare in Wupatki NM, at least measured in these plots. Therefore, we consider the condition for this measure to be good.

Current Cover of Non-native Plants (%)

Five non-native species were detected between the two ecological site types (Table 4.10.4-3). These were Mexican burning bush, prickly Russian thistle, purslane (*Portulaca oleracea*), threadstem carpetweed, and silverleaf nighshade. Four species were found in Volcanic Uplands and three species were found in Loamy Uplands. Prickly Russian thistle and threadstem carpetweed were found in both site types. This represents the first record of carpetweed and nightshade in the monument. Four of the five non-native species found exhibited relatively low cover and represent a minor component of the vegetative community of both ecological sites. In Volcanic Uplands, prickly Russian thistle was the dominant plant species in plots sampled during 2012, even when considering native species (Decoster and Swan 2016).

Overall, cover of non-native plants averaged 0.5% over the three years and two site types, which indicates good condition. However, prickly Russian thistle dominates Volcanic Upland sites. Although their study was not meant to determine change over time, Decoster and Swan (2013) observed a steady increase in this species in the ten plots sampled during 2007-2009. Furthermore, this species is listed as having a medium invasiveness rank by AZ-WIPWG and is considered a park management priority. Therefore, we consider this measure to be in good condition to warranting to moderate concern.

Current Frequency of Non-native Plants (%)

Prickly Russian thistle was the most widespread species in Volcanic Uplands (Table 4.10.4-3). This species occurred with less frequency in Loamy Uplands, although was still widespread (26% to 64.5% of plots). The remaining species occurred less frequently. Across years and site type, frequency averaged 31%, which indicates moderate concern for this measure.

Area (ha) of Target Non-native Plants

The extent of target non-native species is shown in Figure 4.10.4-1 and summarized in Table 4.10.4-4. The greatest extent of non-native plants was mapped in the Wupatki Basin. Wupatki Basin was distantly followed by road corridors, abandoned materials quarries, and visitor use and administrative areas in terms of total area of non-native species. This result was not surprising since the Wupatki Basin represents the largest area surveyed in the monument and includes sensitive riparian and dry wash habitat that is vulnerable to invasion. Although the greatest extent of non-native plants were mapped in Wupatki Basin, only two species were represented: tamarisk and camelthorn. Nine species were mapped along road corridors, five were mapped in visitor use and administrative areas, and two species were mapped in abandoned materials quarries. This study shows that, aside from drainages,

Table 4.10.4-2. Change in absolute and relative cover of non-native plants in Wupatki NM.

Plant	Plot	1977 (m)	2011 (m)	Change in Absolute Cover (%)	Change in Relative Cover (%)
Mexican burning bush	CM-15	0	0.98	+0.63	+1.07
Russian thistle	CM-10	0.09	0.00	-0.10	-0.56
	CM-15	0	34.78	+22.39	+38.14
	CM-16	0	38.04	+42.27	+70.09

Source: Schelz et al. (2013).

the most problematic area for non-native plants was the road corridor. Approximately 30.9 ha (76.4 ac) of road corridor were surveyed during this study and 3.41 ha (8.43 ac) of non-native plants were mapped in this area, representing 11% of the road corridor.

Brehl et al. (2008) mapped (28.7 ha / 71 ac) tamarisk and camelthorn, most of which occurred along Deadman Wash near the confluence with the Little Colorado River. Tamarisk was relatively widespread in areas other than Deadman Wash such as ephemeral drainages and springs, but was limited in cover. Camelthorn was also relatively widespread in the Wupatki Basin ,with small, scattered patches along the road corridor. All other species represented less than 1 ha (2.5 ac), except for cheatgrass, which was mapped in approximately 1.4 ha (3.5 ac) of road corridor.

Non-native tamarisk and camelthorn dominated Deadman Wash and the Little Colorado River corridor. Also nine species, which were ranked at least a medium invasiveness by AZ-WIPWG or NatureServe, occurred along the road. As a result, we consider this measure to warrant moderate to significant concern.

Tamarisk and Camelthorn Control (Proportion of Area)

Approximately, 11 ha (26 ac) of invasive riparian shrubland were mapped in the target area of Deadman Wash and Little Colorado River (Figure 4.10.4-2). The mapping effort did not completely capture the area of tamarisk and camelthorn that occurs there so we combined the area mapped by Hansen et al. (2004), the area mapped by Brehl et al. (2008), and the area controlled to determine the total target area of camelthorn and tamarisk in Deadman Wash. This resulted in 22 ha (55 ac). Tamarisk was controlled in 5 ha (13 ac), which represents 24% of the total target area. Camelthorn was controlled in 13 ha (33 ac), which represents 60% of the total target area (Figure 4.10.4-3).

Treatment efforts created growing space around three small remnant patches of coyote willow, which were discovered in 2004 at the base of the basalt bluff that defines the southeast channel bank. The willows have since survived and are being monitored to see whether they spread laterally into the opened area via vegetative runners. During the 2013 growing season, the non-native, introduced tamarisk beetle (*Diorhabda carinulata))* arrived at the Deadman Wash and the Little Colorado River. The beetle was introduced as a biological control agent for tamarisk, which was approved as a biocontrol agent in 2001 by USDA Animal and Plant Health Inspection Service (APHIS) (Hultine et al. 2010). Tamarisk plants were rapidly defoliated, but 100% mortality is not anticipated based upon observations in the adjacent San Juan River corridor.

A concurrent study by Springer and Schaller (2012) indicated the lack of a shallow water aquifer, which will limit the ability of native vegetation to thrive. Therefore, tamarisk eradication efforts have shifted from total eradication to maintaining 4 ha (10 ac) of remaining mature tamarisks to ensure the availability of deciduous woody vegetation as wildlife habitat, at least until a sufficient amount of native deciduous woody vegetation becomes established. Camelthorn is now the primary target species. Areas where tamarisk plants have been removed will continue to be revegetated with native grasses and shrubs using "dryland" methods that promote seed germination and survival. Since more than half of all camelthorn and a quarter of tamarisks has been controlled in Deadman Wash, we consider the condition for this measure as good to moderate concern.

Table 4.10.4-3. Absolute foliar cover and plot frequency of non-native plants by site type in Wupatki NM.

Species	Volcanic Uplands (2012)		Loamy Uplands (2013)		Volcanic Uplands (2014)	
	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Mexican burning bush	0.002	25	–	–	–	–
Prickly Russian thistle	4.570	100	0.003	26.1	0.072	64.5
Purslane	0.004	25	–	–	–	–
Silverleaf nightshade	–	–	0.054	15.6	–	–
Threadstem carpetweed	0.004	8.4	0.001	15.6	<0.001	5.6
Average	1.45	40	0.02	19	0.04	35

Source: Decoster and Swan (2016).

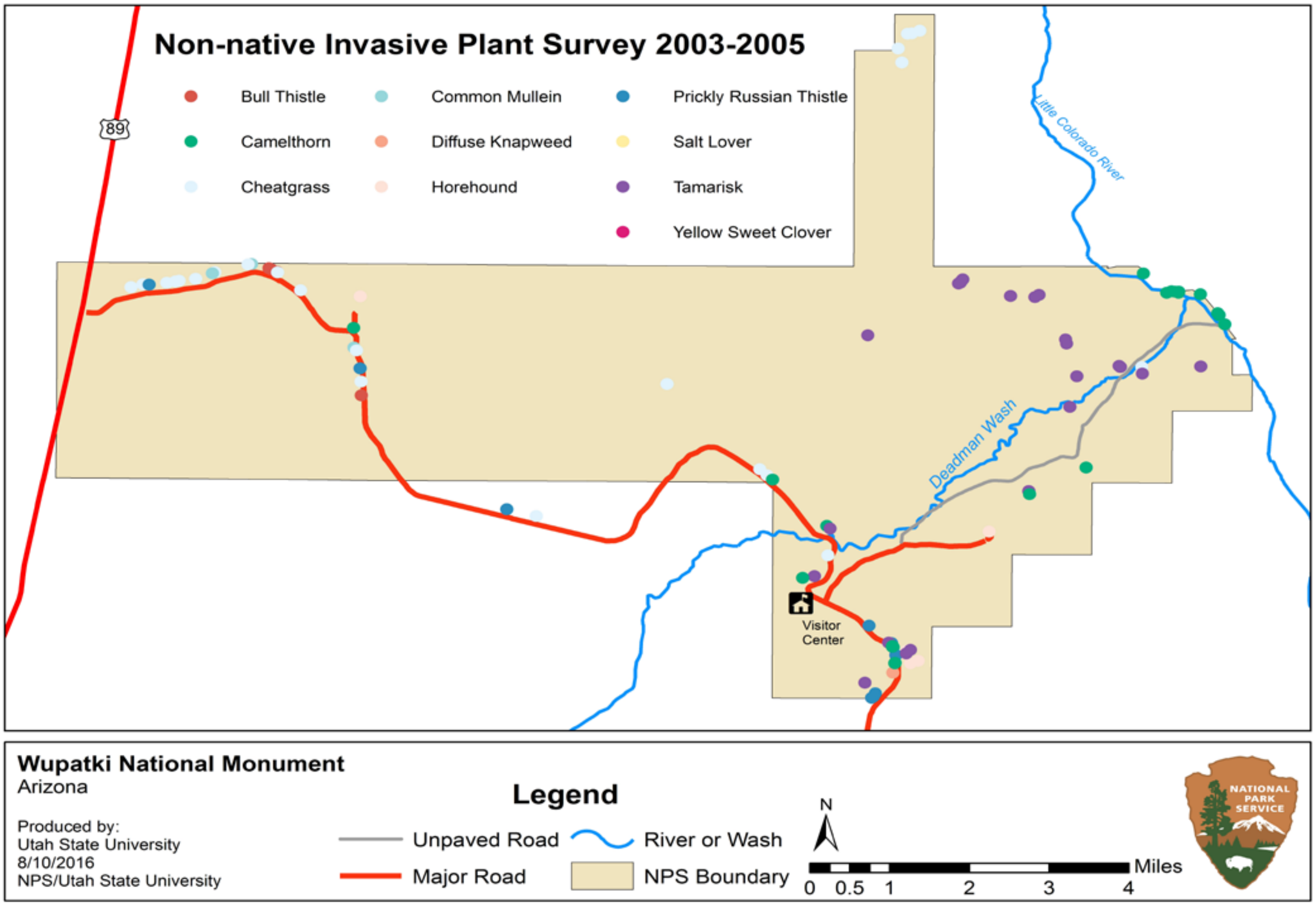


Figure 4.10.4-1. Non-native and invasive plant species mapped during 2003-2005 in Wupatki NM.

Table 4.10.4-4. Area of target non-native plant species mapped during 2003-2005 in Wupatki NM.

Common Name	Roadside Corridors ha (ac)	Wupatki Basin ha (ac)	Visitor & Administrative Areas ha (ac)	Abandoned Materials Quarries ha (ac)	Total ha (ac)
Bull thistle	0.130 (0.322)	–	–	–	0.130 (0.322)
Camelthorn	0.926 (2.287)	8.518 (21.048)	< 0.01 (0.014)	1.024 (2.530)	10.480 (25.879)
Cheatgrass	1.409 (3.482)	–	–	–	1.409 (3.482)
Diffuse knapweed	0.001 (0.002)	–	0.001 (0 .002)	–	0.002 (0.005)
Salt lover	–	–	0.728 (1.800)	–	0.728 (1.8)
Horehound	0.034 (0.085)	–	0.108 (0.267)	–	0.142 (0.352)
Common mullein	0.046 (0.113)	–	–	–	0.046 (0.113)
Prickly Russian thistle	0.763 (1.885)	–	–	–	0.763 (1.885)
Five-stamen tamarisk	0.001 (0.002)	20.314 (50.198)	0.003 (0.007)	0.068 (0.167)	20.386 (50.375)
Yellow sweetclover	0.100 (0.248)	–	–	–	0.100 (0.248)
Total	3.41 (8.43)	28.83 (71.25)	0.85 (2.09)	1.091 (2.697)	34.180 (84.461)

Source: Table 2 in Brehl et al. (2008).

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Overall, we consider the condition of non-native and invasive plants to warrant moderate concern in Wupatki NM. This condition rating was based on five indicators and eight measures, which are summarized in Table 4.10.4-5. Those measures for which confidence in the condition rating was high were weighted more heavily than measures with medium confidence.

Factors that influence confidence in the condition rating include age of the data (<5 yrs unless the data are part of a long-term monitoring effort), repeatability, field data vs. modeled data, and whether data can be extrapolated to other areas in the monument. Based on these factors, we assigned high confidence to all but three measures. Although the Schelz et al. (2013) study spanned 33 years, there were only two years of data collection (1977 and 2011), and the latter date occurred five years ago. Since this study represents the only long-term study on vegetation change in the monument, we did not assign an overall trend for non-native and invasive plants. We also assigned medium confidence to the current extent of non-native plants measure since mapping efforts were based on data collected during 2003-2005 and may not reflect current condition (Brehl et al. 2008).

Overall, these studies reveal that at least 38 non-native plants occur in the monument and most are restricted to the road corridor, dry washes, and riparian areas. Many of these species were assigned at least a medium invasiveness rank by either AZ-WIPWG or NatureServe and at least three species occur over relatively large areas. These species are prickly Russian thistle, camelthorn, and tamarisk. For these reasons, non-native and invasive plants warrant moderate concern in Wupatki NM. Key uncertainties of these studies include how non-native plant cover and frequency have changed over time and the current extent of non-native species. Substantial annual variation in non-native plant cover may occur as a result of precipitation, but these patterns are not well understood in the monument.

Threats, Issues, and Data Gaps

Schelz et al. (2013) identified five primary threats caused by the introduction of non-native plants. These include the loss of native vegetation, lowering of the water table, loss of use by native wildlife, loss of the cultural landscape, and loss of culturally significant plants. Of all the stressors on native vegetation, climate change has the most potential to influence community composition, vegetation structure, and species richness (Schweiger et al. 2010). And climate change can, in turn, influence the spread of invasive plants.

The western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall (Prein et al. 2016). Since 1974 there has been a 25% decrease in precipitation, a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016). However, native plants may not be able to take advantage of short duration, intense precipitation events followed by long intervals of drought. Furthermore, non-native plants tend to

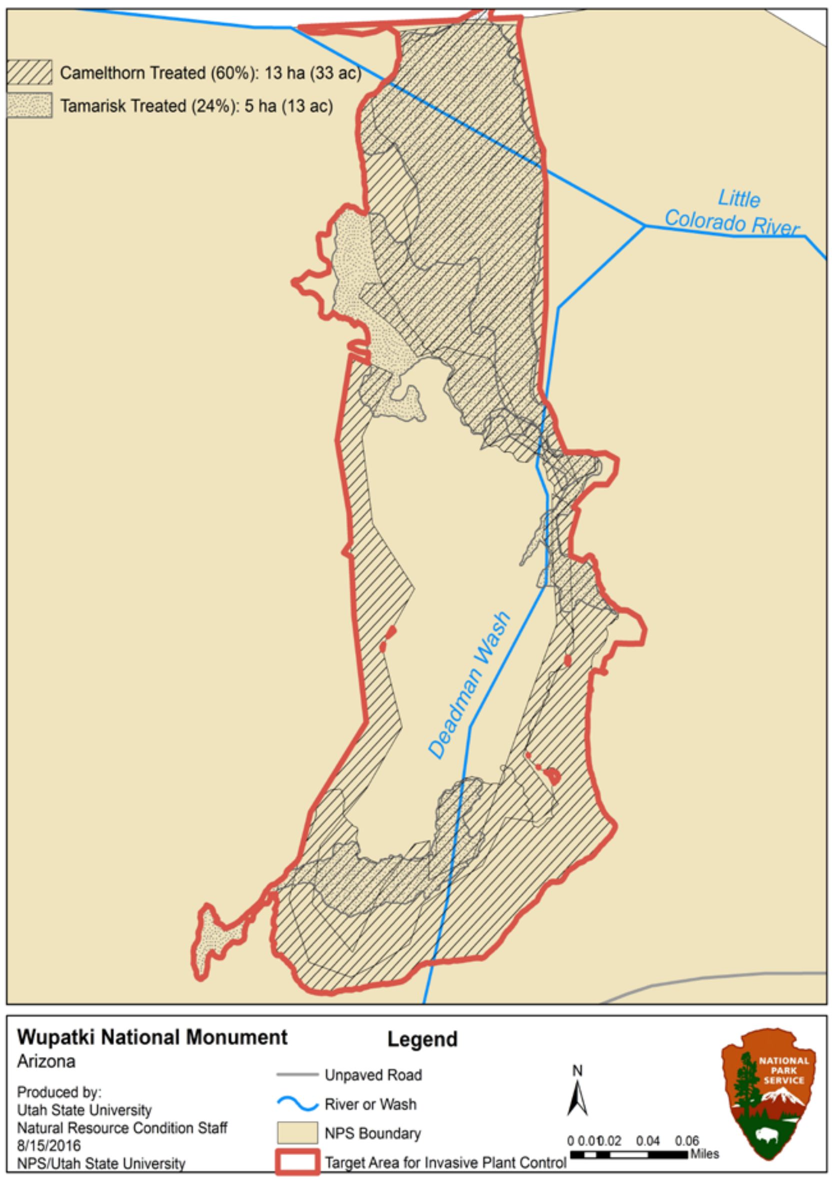


Figure 4.10.4-2. Tamarisk and camelthorn control effort in Wupatki NM.

Figure 4.10.4-3. Burn piles for tamarisk and camelthorn control in Wupatki NM. Photo Credit: NPS.

increase following periods of heavy rain (Schelz et al. 2013). Some species, such as Russian thistle, go virtually undetected in normal or drought years, then increase dramatically in years with greater than normal rainfall, especially with an increase in precipitation during July (Schelz et al. 2013). Once established, invasive plants can be extremely difficult to control and most will never be completely eradicated.

The introduction and spread of invasive plants is also influenced by road corridors, trails, and disturbances. The road corridor in Wupatki NM serves as a mechanism for dispersal and non-native plants growing there may even benefit from road surface runoff (Schelz et al. 2013). No surprisingly, the highest number of non-native species were found along Wupatki NM's only paved road in comparison to other areas in the monument (Brehl et al. 2008). Non-native plants were less common in backcountry areas owing to restricted access. Furthermore, the few unpaved roads in the monument are infrequently used by visitors (NPS 1996). These factors help limit the spread of invasive species in Wupatki NM.

Aside from roads, the most problematic areas for non-native species are Wupatki NM's drainages, particularly along Deadman Wash and the Little Colorado River. Camelthorn, and especially tamarisk, dominate this region and their presence has had significant and detrimental effects on ecosystem structure and function. Even though the trend has improved, it is reflective of a point in time soon after treatment, and additional control or eradication efforts will be required to maintain this status (J. Conn, Southwest Exotic Plant Management Team Manager, pers. comm.). Livestock grazing through 1989, when the boundary fence was completed, contributed the invasion of non-native plants and impaired the structure of the streambank (Schelz et al. 2013). The presence of tamarisk and camelthorn has resulted in altered stream flows, increased soil salinity and soil compaction, and contributed to the loss of native cottonwood and willow communities. These non-native species have deepened the Little Colorado River channel, which may have also constricted flow in Deadman Wash leading to sediment accumulation at the confluence (unpublished data).

A study, which investigated depth to groundwater in Deadman Wash, revealed that the perched aquifer was much deeper than anticipated, however soils were saturated during the growing season (Springer and Schaller 2012). Depth to groundwater has likely declined as a result of tamarisk invasion, reduced recharge during the extended drought period that began in 1996, and a fine surface clay layer that has

Table 4.10.4-5. Summary of non-native and invasive plants indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Potential to Alter Native Plant Communities	NatureServe Invasive Species Impact Rank		Since the majority of species were ranked as medium or lower and only two species were assigned a high rank, we consider this measure to warrant moderate concern. No data on trend in species rank were available. Confidence in this condition rating is high.
	AZ-WIPWG Ecological Impact Rank		Of the 38 non-native species found in Wupatki NM, 15 species were assigned a rank: six were ranked high, nine were ranked medium, and one was ranked low. Since nearly 40% of non-native plants were evaluated by AZ-WIPWG and several were given a high or medium ecological impact rating, we consider this measure to warrant significant concern. No data on trend in species rank were available. Confidence in this condition rating is high.
Change in Non-native Plants (1977-2011)	Change in Cover (%)		Only two non-native species occurred in 29 plots and change in overall cover was low. Therefore, we consider the condition for this measure to be good. The data indicate unchanging conditions. Confidence in this condition rating is medium since the study is based on only two years of data.
	Change in Frequency (%)		Although two non-native species occurred in at least three of the 29 plots, none were detected in belt transect surveys. These data indicate that non-native plants are rare in Wupatki NM, at least measured in these plots. Therefore, we consider the condition for this measure to be good. The data indicate unchanging conditions. Confidence in this condition rating is medium since the study is based on only two years of data.
Current Prevalence of Non-native Plants	Current Cover (%)		Non-native plant cover averaged 0.5% over the three years and two site types, which indicates good condition. However, prickly Russian thistle dominates Volcanic Upland sites. Furthermore, this species is listed as having a medium invasiveness rank by AZ-WIPWG and is considered a management priority in the monument. Therefore, we consider this measure as good to moderate concern. There are no trend data for this measure. Confidence in this condition rating is high.
	Current Frequency (%)		Across years and site type, frequency averaged 31%, which indicates moderate concern for this measure. There are no trend data for this measure. Confidence in this condition rating is high.
Current Extent of Target Non-native Plants	Area Mapped (ha)		Non-native tamarisk and camelthorn dominated Deadman Wash and the Little Colorado River corridor and nine species occurred along the road, all of which were ranked at least a medium invasiveness rank by AZ-WIPWG or NatureServe. Therefore, we consider this measure to warrant moderate to significant concern. There are no trend data for this measure. Confidence in this condition rating is low since data were collected 13-15 years ago.
Camelthorn and Tamarisk Control	Treated Area (ha)		Since more than half of all camelthorn and a quarter of tamarisk has been controlled in Deadman Wash, we consider the condition for this measure as good to moderate concern. The remaining tamarisk will not be eradicated as it provides some of the only deciduous woody vegetation in the drainage. The trend is improving. Confidence in this condition rating is high.

Table 4.10.4-5 continued. Summary of non-native and invasive plants indicators, measures, and condition rationale .

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Overall Condition			Overall, we consider the condition for non-native and invasive plants in Wupatki NM to warrant moderate concern. Percent cover, frequency, and mapping data indicate relatively low occurrence for most species. However, at least three species were widespread, including prickly Russian thistle in the Volcanic Uplands, and tamarisk and camelthorn in the Wupatki Basin. The number of non-native plants with a high invasiveness rank indicates the potential for some species to spread. Only one study examined trends, but this was based on only two years of data. Therefore, we did not assign an overall trend for this assessment. Confidence in the overall condition rating is medium.

inhibited water infiltration. However, simply removing tamarisk would not be sufficient to return the wash and riparian area to its natural state. Standing live tamarisks now provide some of the only deciduous woody vegetation available to breeding birds (refer to the riparian assessment for more details). However, the tamarisk leaf beetle has completely defoliated the monument's tamarisk stand each of the last three years (2014-2016). According to Mark Szydlo's, Biologist for the Flagstaff Area National Monuments, visual estimates, there are dead branches on >90% of all tamarisk plants within the stand. He did not observe a single tree without any dead branches. While the beetle may provide sufficient control, it will be slow likely occurring over the next decade.

4.10.5. Sources of Expertise

No outside experts were consulted for this assessment. Assessment authors are Lisa Baril, science writer, Utah State University, and Paul Whitefield, Natural Resource Specialist for the Flagstaff Area National Monuments.

4.11. Earthcracks and Blowholes

4.11.1. Background and Importance

The topography within Wupatki National Monument (NM) is shaped by episodes of tectonic-scale geologic deformation in the western United States over the last 65 million years, causing extensive crustal folding, deep faulting, and uplift in north-central Arizona. Rapid uplift associated with the rise of the Colorado Plateau began around 5 million years ago and continues to occur. More recent and localized fracturing, faulting, and uplift is also likely related to volcanism in the surrounding San Francisco Volcanic Field. Among the resulting regional structural features is the Black Point Monocline, along with the more localized Doney Mountain Fault, which essentially divides the national monument in half (Babenroth and Strahler 1945, McCormack 1989, Billingsley et al. 2007a,b). The monocline continues to rise and deform, creating an extensive network of visible fractures and minor offset faults in the surface sedimentary rock formations (Pearce 1998). Some of these have laterally expanded to form unique, open subterranean "earthcrack" fissures (Colton 1938, Lamar 1964, Huntoon 1965, Bridgemon 1975, Cave Research Foundation [CRF] 1976). The fracture and fissure system is widely interconnected, allowing air currents to move within, driven both by surface/sub-surface temperature differences and atmospheric pressure fluctuations. As a result, air currents "breathe" at unique "blowhole" openings (Figure 4.11.1-1) (Schley 1961, Sartor and Lamar 1962, Lamar 1964) that are identified as "traditional cultural properties" by associated Native American tribes (NPS 2013b).

Wupatki NM's earthcrack system is due to its structural tectonic origin, instead of the typical karst cave formation process. The earthcrack caves also comprise one of the most fragile ecosystems within the national monument (NPS 2013b), supporting a unique community of cave-adapted species. Two endemic species of blind pseudoscorpions have been described (Muchmore 1981), and recent arthropod inventories (Wynne 2014, Wynne 2015) have resulted in the discovery of as many as five additional endemic taxa (Wynne pers. comm. to Whitefield 2016, two manuscripts in preparation). Townsend's big-eared bats, (*Corynorhinus townsendii*), (Figure 4.11.1-2), listed as a species of conservation concern within Arizona's Heritage Data Management System (Arizona Game and Fish Department [AGFD] 2013), utilize the monument's earthcracks for winter hibernacula (Gustavson 1964, CRF 1976, Bain 1986). A rare mineral, minute crystals of soda nitre ($NaNO_3$), was also documented in one of the earthcracks during a mineralogical survey in the 1970s (CRF 1976, Hill et al. 1977). This interconnected system of fractures

Figure 4.11.1-1. When hot, low-pressure air is above ground, cool air rushes out from a series of massive earth cracks beneath the surface, creating blowholes, until the air pressure is equal above and below. Photo Credit: © R. Ruess.

extends well beyond Wupatki NM, possibly up to 64 km (40 mi). As cave resources, these earthcracks receive additional protection under the NPS Organic Act (NPS 1916), the Federal Cave Protection Act (1988), and the National Parks Omnibus Management Act of 1998 and must be managed to protect and mitigate threats.

4.11.2. Data and Methods

In 1964, Lamar described the geology of the blowholes, including developing evidence that their air movements occur via an extensive subterranean system of interconnected fractures, and developing evidence that the earthcracks and blowholes are not related to typical karst type cave formation processes. In a companion study in 1964, Sartor mapped blowholes and dry, blowing wells over a 4,900 sq km (1,900 sq mi) area surrounding Wupatki, and inferred most of them are aligned along known regional fault lines. Sartor attempted to document air movement using a tracer chemical, from a blowhole at Wupatki to another blowhole located 38 km (24 mi) away, although the experiment was likely compromised. Sartor also calculated the subterranean void within the regional bedrock required to account for such a volume of air movement would be at least 7 billion cubic feet. Most recently, Pearce mapped and correlated the orientation of the surface fracture and faulting patterns in the sedimentary geologic formations, and described the structural and tectonic geologic processes in the Wupatki area, including the ongoing crustal extensional stress over the last 30 million years that formed the six earthcracks. CRF (1976) surveyed and diagrammed physical characteristics of five of the six earthcracks, using a pocket transit and measuring tapes. The smallest feature sketched was approximately 12 m (40 ft) deep by 24 m (80 ft) long. The longest explored reach was 455 m (1495 ft), and the deepest was 152 m (500 ft), which is among the deepest caves known within Arizona (NPS 2013b).

Beginning in 2011, Dr. Jut Wynne, Cave Ecologist, Northern Arizona University (NAU), and Paul Whitefield, Natural Resource Specialist, Flagstaff Area National Monuments, began collaborating on proposals and agreements to assess and inventory the cave biology of the Wupatki NM earthcracks, which included producing accurate maps of the caves. The biologicl surveys organized by Dr. Wynne have thus far been completed at four earthcracks in two phases. Instruments used for mapping the earthcrack physical characteristics included a Leica© laser range finder, Suunto®compass and Suunto® inclinometer (Wynne 2014). A cave numbering system was developed and is referenced throughout this assessment to protect these sensitive resources.

Figure 4.11.1-2. The Townsend's big-eared bat occurs at Wupatki NM. Photo Credit: © Robert Shantz.

Phase I remapping effort included three caves, two of which were the smallest and least complex caves (WUPA 01 and 04) within the monument, occurring over a three day period beginning on 05 April 2013 (Wynne 2014). Only the upper chamber of the third earthcrack (WUPA 02) was remapped during the Phase I effort. Phase II focused on remapping the longest earthcrack (WUPA 06) in July 2014 (Wynne 2015). Phase III is tentatively funded in 2018 and 2019, to complete the remaining two earthcracks (WUPA-03 and WUPA-05) and the lower chambers of WUPA 02 will be mapped (NPS 2013b). The characteristics of the mapped earthcracks are summarized in Table 4.11.2-1. No other undocumented or notable unique natural or cultural features were encountered during the surveys (NPS 2013b).

<u>Summary of Earthcrack Surveys at Wupatki NM</u>

Dr. Wynne is currently leading a systematic and repeatable biological inventory of the earthcracks, to establish a baseline for long term monitoring of the cave biota and microclimates. These data will help park and national forest managers and researchers evaluate options for restoring the entrances at three earthcracks to more natural conditions (WUPA-02, 03, and 04); reduce tumbleweed accumulations; monitor for potential impacts from recreational

Table 4.11.2-1. Characteristics of mapped earthcrack caves/fissures at Wupatki NM.

Cave Number	Cave Research Foundation (1976)	Wynne (2014, 2015)	Total Length/Depth Surveyed by Wynne	Characteristics
WUPA 01	Mapped	April 2013 Plan View Survey Map Created	Passage: 57 m Vertical Extent: 20 m	Smallest and Least Complex; Formed in Kaibab Limestone (Permian)
WUPA 02 [1]	Mapped	April 2013 Plan and Profile View [2] Survey Maps Created for Upper Chamber only	Passage: 100 m Vertical Extent: 41 m	Deepest and entrance was modified by infilling the entrance with large boulders supported by bailing wire, and fence posts. (J. Wynne, pers. comm. January 2017)
WUPA 03 [1]	Mapped	Not surveyed during Wynne (2014, 2015) study.	–	Deepest [3] (152.4 m) [500 ft]) and Most Altered
WUPA 04	Mapped	April 2013 Plan and Profile View Survey Maps Created	Passage: 107 m Vertical Extent: 35 m	Smallest and Least Complex; Formed in Kaibab Limestone (Permian); Entrance modified by an attempt to infill cave with boulders (J. Wynne, pers. comm. January 2017)
WUPA 05 [1]	Never mapped	–	–	Smallest, Least Complex and Most Remote
WUPA 06	Mapped	July 2014 Plan View Survey Map Created	Passage: 523 m Vertical Extent: 59 m	N/A

[1] Proposed for Phase III monitoring. WUPA 02 Phase III mapping effort will be for the lower chambers only (NPS 2013b).

[2] WUPA 02 profile view map was created in April 2013 but was included in Wynne (2015) report appendix 6A.

[3] One of the deepest caves in Arizona (NPS 2013b).

caving; understand potential effects of climate warming; and most recently, monitor for the potential spread of white-nose syndrome (WNS) to the bat fauna. Prior to this most recent collaboration, the last data collected occurred in 1985, over 25 years earlier, to identify the winter roosts of Townsend's big-eared bats (*Corynorhinus townsendii* formerly *Plecotus townsendii*) in the Wupatki area (Bain 1986).

The earliest survey occurred in 1963 when park ranger, Terry Gustafson, netted bats at three locations throughout the monument, which included one earthcrack. He noted that "several earthcracks were explored" during the effort, although those locations were not reported. In 1960, Schley (1961a) collected air flow data at one of the blowholes within the monument. Colton made the earliest published account of entering the earthcracks in 1938. From August 1975 through February 1976, the CRF (1976) explored and surveyed the earthcracks within the monument and prepared initial diagrams of five of the six earthcracks, described their geology, recorded mineralogical observations, inventoried invertebrates and vertebrates, recorded archaeological and historical features, and measured soil and surface temperatures, along with relative humidity. In 1977, Hill and others published on the observations of relatively rare soda niter crystals in two of the earthcracks made during the CRF survey the year before. Dr. William Muchmore from the University of Rochester described the spider and pseudoscorpion specimens collected during the CRF (1976) effort and published the results in the Journal of Arachnology in 1981 (Muchmore 1981).

For the earthcracks/blowholes condition assessment, we primarily relied upon the results from Wynne's (2014, 2015) survey and monitoring efforts to report on condition for three indicators and five measures since these data represent the most current information. Some of the previous studies' results documenting cave species will be included in summary tables.

The first indicator, earthcrack species occurrence, includes measures on the presence or absence of bats and arthropods.

Bats Presence/Absence

During the summer of 1963 park ranger, Terry Gustafson, surveyed several earthcracks as part of a bat inventory project. Only one bat was seen during his surveys. Gustafson (1963) added a report that "about 20 bats hanging from the walls of another earthcrack [were observed] during the previous winter" (p. 4), although the earthcrack was not identified.

In September 1975 and January 1976, CRF scientists surveyed for bats in five of the accessible earthcracks, although no data were collected on the number of bats present.

Beginning in late 1984 and during the winter of 1985-1986, park volunteer James Bain (1986), conducted a winter roost survey for the Townsend's big-eared bat in Wupatki NM earthcracks recording counts of observed bats. This effort represented the most comprehensive bat survey at that time.

The most recent bat surveys were conducted during the winters of 2013 and 2014 at WUPA 01 and 04, and in 2015 at four earthcracks (WUPA 01, 02, 04, and 06), two of which were surveyed in 2013 and 2014 (Wynne 2014, 2015). Scientists visually scanned the walls and ceilings of the earthcracks, counting and mapping all bats within each roost. They also visually examined all of the bats for evidence of WNS and photographed a subset of ones encountered to later examine for the presence of WNS.

Arthropods Presence/Absence

During three site visits (one each in September 1975, November 1975, and January 1976), CRF scientists examined five of the accessible earthcracks/fissures as part of their baseline survey, documenting the presence of invertebrates. Some specimens were collected for later identification by Muchmore (1981). No data were collected on the number of invertebrates present, only species identifications were made, if possible, during the three site visits (CRF 1976).

The next survey for cave-dwelling arthropods was conducted by Dr. Wynne's team of scientists using bait sampling, leaf-litter traps, and opportunistic sampling in 2013 at two fissures (WUPA 01 and 04) and in 2014 at two fissures/cracks (WUPA 02 and 06). The survey occurred during the summer monsoon season when high relative humidity and moist conditions have a higher likelihood of drawing cave-adapted species out of the mesocaverns (Wynne 2014). Refer to Wynne (2014, 2015) reports for more details on the arthropod collection methods.

The second indicator, occurrence of *Pseudogymnoascus destructans* and/or WNS is based on a presence/absence measure.

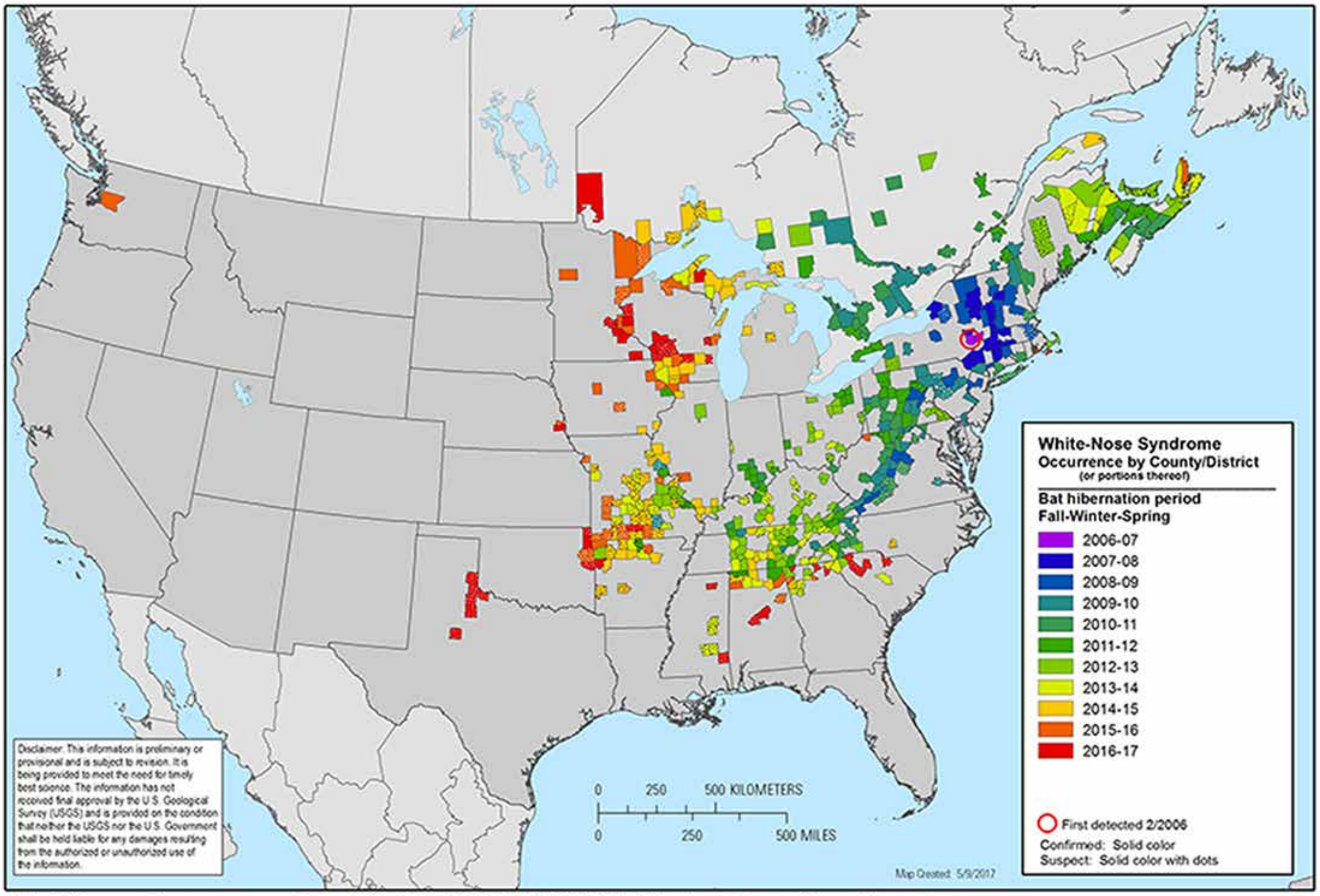
Pseudogymnoascus destructans and/or WNS Presence/Absence

White-nose syndrome (WNS), a disease that affects hibernating bats, has resulted in the mortality of millions of bats in North America (USFWS 2017). WNS is named for the white fungus, originally known as *Geomyces destructans*, but now called *Pseudogymnoascus destructans* (USFWS 2017), that grows on the muzzle and other parts of bats' bodies (USFWS 2017). The disease is thought to spread primarily through direct contact between bats, but it is also believed possible to spread the fungus to new hibernacula on shoes, clothing or gear (USFWS 2015).

In the U.S., the occurrence of WNS has been confirmed in eight species of bats, and the fungus has been observed on an additional seven species but no diagnostic sign of WNS has been documented (USFWS 2017). Of these species that have been afflicted with WNS, five are known to occur at Wupatki NM: big brown bat (*Eptesicus fuscus*), eastern small-footed bat (*Myotis leibii*), Yuma myotis (*Myotis yumanensis),* silver-haired bat (*Lasionycteris noctivagans)*, and Townsend's big-eared bat (*Corynorhinus townsendii*), with the first three species representing the ones with confirmed cases of WNS and the latter two observed with the fungus but not confirmed as having the disease. An additional species that has been documented with the fungus but without signs of WNS, eastern red bat (*Lasiurus borealis*), is listed on the park's NPSpecies list but noted as unconfirmed (NPS 2016b). Currently, the closest state to Arizona with confirmed cases of WNS is Texas (Figure 4.11.2-1, USFWS 2017).

Sediment samples were collected on 23 and 24 October 2014 to determine presence of P. destructans. The cave sediment samples and replicate samples (10 per earthcrack) were collected throughout each cave. The samples were assayed with the more general ITS1-qPCR, which "detects members of the diverse genera *Pseudogymnoascus* and *Geomyces*" (Wynne 2015, p. 12) to provide a wider survey of the earthcrack microbiomes.

Additional winter surveys included visual examination of bats and photographing the bats. These photos were later reviewed to assess whether WNS was present. We used the results of Wynne (2014, 2015) to report the presence/absence of WNS and/or the fungus.



Citation: White-nose syndrome occurrence map - by year (2017). Data Last Updated: 5/9/2017. Available at: https://www.whitenosesyndrome.org/resources/map.

Figure 4.11.2-1. Map showing the occurrence of WNS, dated 5/9/17. Figure Credit: © www.whitenosesyndrome.org.

The earthcrack meteorology indicator includes two measures, temperature and relative humidity.

<u>Temperature and Relative Humidity</u>

Caves are divided into four habitats based upon zones that differ by varying amounts of light and climate conditions (e.g., temperature, moisture, relative humidity, and air flow). The amount of light and effects from surface climate conditions decrease from the entrance to the deepest zone(s), respectively.

Portable, HoboPro© U-23-001 remote data loggers were placed along the length and depth of four earthcracks, providing one full year of hourly temperature and relative humidity data. Locations included directly on the cave floor and within the wall and ceiling cracks/fissures. Data were collected from August 30, 2013 - October 24, 2014 from 11 and 12 data loggers at WUPA 01 and 04, respectively and from August 28, 2014 - October 2015 (day was not provided) from 11 data loggers each at WUPA 02 and 06 (Wynne 2014, 2015).

4.11.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.11.3-1. References are described for resources in good, moderate concern, and significant concern conditions for each of the indicators and measures.

4.11.4. Condition and Trend

<u>Bats Presence / Absence</u>

With the exception of two individuals in the genus *Myotis* (one in 2014 and one in 2015, biologists are unable to determine to the species level without handling them), all bats observed in Wupatki's earthcracks/fissures were Townsend's big-eared bats. Gustafson (1964) observed and collected one Townsend's big-eared bat during the summer near the bottom of earthcrack WUPA 04.

During the fall (September) of 1975 and winter (January) of 1976 CRF surveys, Welbourne observed several roosting Townsend's big-eared bats in four of the five earthcracks surveyed, including the same earthcrack where Gustafson collected his specimen.

Table 4.11.3-1. Reference conditions for earthcracks and blowholes.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Earthcrack Meteorology	Temperature and Humidity	Temperature and humidity conditions in caves are within their natural range of variability.	Temperature and humidity conditions in caves have a slight departure from their natural range of variability.	Temperature and humidity conditions in caves have been altered from their natural range of variability.
Earthcrack Species Occurrence	Presence / Absence	The bat and arthropod fauna at the national monument in recent/current years is approximately the same as in past years (no species that would be expected to occur at the park appear to have been lost).	The bat and arthropod fauna at the national monument in recent/current years is less than it has been in past years (some species have been lost/ not detected in recent years).	The bat and arthropod fauna at the national monument in recent/current years is less than it has been in past years (species have been lost, especially those that were considered common in the past).
Occurrence of *Pseudogymnoascus destructans* and/or WNS	Presence / Absence	We consider condition to be good if there is no known occurrence of *P. destructans* or WNS.	–	We consider condition to be of significant concern if *P. destructans* has been detected, either the fungus itself or symptoms of WNS in bats.

During Welbourne's second survey, hibernating Townsend's big-eared bats were observed in WUPA 01 and 03, indicating these locations are hibernacula (CRF 1976). Bain (1986) documented the presence of the highest number of Townsend's big-eared bats counted, 32 plus, during November 1985 at WUPA 06. Bain also documented the winter use of several Townsend's big-eared bats in torpor in five of the six earthcracks/fissures in Wupatki NM. Bain (1986) identified two additional winter roosts for the Townsend's big-eared bat in Wupatki NM (refer to the report for more details).

Wynne (2014) documented hibernating Townsend's big-eared bats at WUPA 01 (11, which included one *Myotis sp*., in 2013 and 13 in 2014) and WUPA 04 (3 in 2015 and 5 in 2014). With continued monitoring during the winter of 2015, Wynne (2015) documented hibernating Townsend's big-eared bats; 13 at WUPA 01, 2 at WUPA 02, which included one *Myotis sp*., 4 at WUPA 04, and 6 at WUPA 06.

The time of year and type(s) of data collected during the different earthcrack bat surveys varied, in addition to the fact that the last survey prior to Wynne's (2014, 2015) effort was almost 30 years ago, makes it difficult to report on any aspect of the species encountered except presence/absence and counts (if included), which are summarized in Table 4.11.4-1. Bain did record more bats in WUPA 06, which may be due to differences in time of season sampled, but is more likely due to warmer winters associated with climate change (J. Wynne, 12 January 2017, pers. comm.). While the continued use of WUPA 04 by the Townsend's big-eared bat appears likely given the fact that at least one was observed during all five surveys, spanning from the summer of 1963 to February 2015, it is difficult to assign a condition status, especially since systematic and repeatable surveys were not implemented until recently by Whitefield and Wynne. As a result, the condition for the bats species occurrence in Wupatki NM's earthcracks is unknown.

<u>Arthropods Presence/Absence</u>

During the CRF (1976) survey work, opportunistic collections resulted in identifying 19 arthropods. This included the discovery of two endemic pseudoscorpion species (Welbourn 1976, Wellbourn 1979) that were identified by Dr. Muchmore at the University of Rochester and published in the *Journal of Arachnology* in 1981. Of the insects observed, cave crickets (*Ceuthophilus spp.*) were most common, although data were not sufficient to determine overall distribution (CRF 1976). In general, scientists noted that the fauna (including vertebrates) were sparse (CRF 1976). The reported 'sparseness' was more likely due to the sampling techniques used (i.e., opportunistic searches), which was inadequate for sampling these systems than the lack of fauna. In addition, they sampled during the wrong time of year.

During Wynne's 2013/2014 arthropod surveys at WUPA 01 and 04, eight orders were identified, representing a minimum of 25 morphospecies. During

Table 4.11.4-1. Townsend's big-eared bat surveys in earthcracks/fissures at Wupatki NM.

Cave Number	Gustafson (1964)	Cave Research Foundation / Welbourne (1976)	Bain (1986)	Wynne (2014)	Wynne (2015)
WUPA 01	–	Sept. 1975: only roosting individuals Jan. 1976: hibernating individuals	Nov. 1985: 1 in torpor Dec. 1985: 2 in torpor	Mar. 10, 2013: 11 hibernating (includes 1 *Myotis* sp.) Feb. 9, 2014: 11 hibernating	Feb. 17, 2015: 13 hibernating [3]
WUPA 02	–	None observed	Dec. 1985: 2 in torpor, near entrance	–	Feb. 18, 2015: 2 hibernating (includes 1 *Myotis* sp.) [3]
WUPA 03	–	Sept. 1975: only roosting individuals Jan. 1976: hibernating individuals	None observed	–	–
WUPA 04	Summer 1963: 1 specimen collected at 30.5 m (100 ft) [1]	Sept. 1975: only roosting individuals	Dec. 1985: 9, some in torpor, near entrance	Mar. 10, 2013: 3 hibernating Feb. 9, 2014: 5 hibernating	Feb. 17, 2015: 4 hibernating [3]
WUPA 05	–	–	Nov. 1985: 1 in torpor	–	–
WUPA 06	–	Sept. 1975: only roosting individuals	Dec. 1984: 2 in torpor Nov. 1985: 2 in torpor and 32+ roosting	–	Feb. 17, 2015: 6 hibernating [2, 3]

Source: Whitefield (2012) for all accounts except Wynne (2014, 2015).

[1] Don Morris relates having observed about 20 bats hanging from the walls of another earthcrack during the previous winter (1962/1963) (Gustavson 1964).

[2] During 2015, the survey was discontinued due to not disturbing a bat where survey ropes needed to be placed (Wynne 2015).

[3] During winter counts, bats and photographs of bats were examined for evidence of WNS. Sediment samples were also collected within these same earthcracks to determine the presence/absence of the fungus-causing WNS, *Pseudogymnoascus destructans.*

Wynne's 2014 arthropod surveys at WUPA 02 and 06, nine orders were identified, representing a minimum of 29 morphospecies. Presently, arthropod specimesn collected during the 2013/2014 effort are still being analyzed. Wynne and others will examine differences across cave arthropod communities once all caves have been sampled and the analysis is complete. A general summary of the arthropod surveys is presented in Table 4.11.4-2.

Thus far, a total nine orders of cave-dwelling arthropods have been identified. Through Dr. Wynne's work, about 29 morphospecies have been identified. This number will either increase or decrease slightly once lower level taxonomic IDs have been made. Most specimens have been sent to taxonomic specialists so the lowest level identifications may be made. Bernard and Wynne (in review) recently described a presumed endemic species of Collembola from Wupatki NM; however, further understanding of cave-dwelling collembola is limited at this time. Condition of arthropod species occurrence at Wupatki NM is currently unknown.

Presence / Absence of *Pseudogymnoascus destructans* and/or WNS

During the 2014 and 2015 winter bat counts, none of the examined bats or photographs of bats revealed visible evidence suggestive of WNS. Laboratory DNA analysis of the cave sediment samples for WNS-causing *P. destructans* fungal spores was recently completed at the University of New Hampshire, and none of the samples tested positive. This measure is currently in good condition.

Temperature and Humidity

The results of the temperature and relative humidity data were not presented in Wynne (2014, 2015). However, these data will provide baseline cave climate information that will help park management and researchers to identify cave temperature zones and monitor for future changes in cave climate. These data

Table 4.11.4-2. Consolidated list of arthropod species accounts in surveyed earthcracks/fissures at Wupatki NM.

Cave Number	Cave Research Foundation (1976)	Muchmore (1981) *	Wynne (2014)	Wynne (2015)
WUPA 01	Sept. 1975 and Jan. 1976: 11 arthropod *spp*. listed	Identified new species, *Archeolarca welbournii* (Holotype and paratype females)	Aug. 30 - 31, 2014 (Direct searches) and Aug. 8 - Sept. 31, 2014 (trapping): 8 orders / 25 morphospecies, with WUPA 04 results	–
WUPA 02	Jan. 1976: 7 arthropod *spp*. listed	Identified new species, *Archeolarca welbournii* (Three paratype females) and *Pseudogarypus hypogeous* (Female, male, and tritonymph)	–	Aug. 24 - 28, 2014 (bait) and Aug. 28 - Sept. 7 (trapping), 2014: 9 orders / 29 morphospecies, with WUPA 06 results
WUPA 03	Nov. 1975 and Jan. 1976: 7 arthropod *spp*. listed	Identified new species, *Archeolarca welbournii* (One male and two female paratypes)	–	–
WUPA 04	Sept. 1975: 5 arthropod *spp*. listed	Identified new species, *Archeolarca welbournii* (Paratype male from "lower level, dark zone")	Aug. 30 - 31, 2014 (Direct searches) and Aug. 8 - Sept. 31, 2014 (trapping): 8 orders / 25 morphospecies, with WUPA 01 results	–
WUPA 05	–	–	–	–
WUPA 06	Sept. and Nov. 1975: 8 arthropod *spp*. listed	Identified new species, *Pseudogarypus hypogeous*. (Holotype female and trytonymph)	–	Aug. 30 - 31, 2014 (Direct searches) and Aug. 8 - Sept. 31 (trapping), 2014: 8 orders / 25 morphospecies, with WUPA 02 results

Secondary Source: Whitefield (2012) for all accounts except Wynne (2014, 2015). Secondary source (i.e., compilation) was checked against original sources were

*Species identified by Muchmore (1981) were collected during the CRF (1976) survey.

will also useful for assessing the potential for WNS survival and enabling advanced planning to deter WNS infection as monitoring continues. The condition of the monitored earthcracks' climatic conditions is currently unknown with no trend information.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

For assessing the condition of the national monument's earthcracks/fissures and blowholes, we used three indicators with five measures, which are summarized in Table 4.11.4-3. Overall, we consider the condition of the earthcracks at the national monument to be largely unknown, except for the absence of *P. destructans* (the fungus that causes WNS). The absence of this epizootic is presently a positive result. However, this will likely change in the near future, and confidence level is medium due to the fact that not all earthcracks and fissures have been surveyed. Park staff are working with a team of scientists to implement a long-term monitoring framework for the earthcrack system within the monument that will supply information and data necessary for implementing proactive management strategies. The key uncertainty in the overall condition is lack of repeatable long-term data pertaining to the biotic and abiotic earthcrack features.

Threats, Issues, and Data Gaps

Through the collaborative effort with Dr. Wynnne, within the next few years, park staff will help develop a comprehensive paper. The paper will address outstanding issues pertaining to the eearthcracks and hopefully, WNS will still be absent. During the most recent surveys, Dr. Wynne reports that in four of the five primary cracks, no artifacts remain. Periodic re-survey of the biota within the earthcracks is needed to confirm the continued existence of rare and endemic species, which is occurring through Dr. Wynne's study efforts. It is possible that additional endemic, cave-adapted species occur but have yet to be documented.

Table 4.11.4-3. Summary of earthcracks and blowholes indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Earthcrack Meteorology	Temperature and Humidity		Park management has implemented a long-term monitoring program, and as a result, baseline data have been gathered in four earthcracks. This is important since conditions are favorable for the WNS-causing fungus, *P. destructans*. Data have yet to be reported so at this time, condition is assigned an unknown status and a low confidence level.
Earthcrack Species Occurrence	Presence/ Absence		Data that were systematically collected are presently being analyzed so at this time, condition is unknown. Cave arthropods are often difficult to detect. While these surveys advance the knowledge base, they should be considered baseline in nature. More work will be required to more accurately characterize cave-dwelling arthropod communities. Continued monitoring of bat populations is underway. The fifth year of monitoring will occur in 2017.
Occurrence of *P. destructans* and/or WNS	Presence / Absence		The monitoring work of Wynne (2014, 2015) observed 32 bats during the 2013/2014 winter in two earthcracks and 25 bats during the 2015 winter in four earthcracks for WNS. None of the examined bats showed evidence of WNS and/or the fungus, *P. destructans*. In addition, all of the sediment samples collected and analyzed were negative for the presence of *P. destructans*. Currently, we consider the condition for this indicator/measure to be good; however, awareness and concern for bats at the national monument remains high as this fungus and disease continues spread from east to west across North America. Since bats are social animals and they roost switch, if WNS was found in one earthcrack, it would be in all. As a result, we have high confidence in this measure's condition.
Overall Condition			Overall, we consider the condition of the earthcracks at the national monument to be unknown (until results from the analyses have been received), except for the absence of WNS, which is good. The overall confidence level in the data is medium until results have been received from which to assess other measures' conditions.

The entrance to one of the most extensive earthcrack fissures occurs on adjacent Coconino National Forest land, while about two thirds of it reaches underneath Wupatki. This cave is known to cavers and is the most vulnerable to degradation from recreational activity, with access occurring on adjacent lands. However, over the past three years, Wynne and others did not encounter garbage or other obvious negative impacts (Dr. Wynne, pers. comm.). The fissure is also most vulnerable to the inadvertent introduction of *P. destructans* fungus, the cause of WNS in bats. Given the proximity of the six earthcracks, if *P. destructans* is introduced, it would most likely spread to the other earthcracks.

Some of the deepest reaches in some of the earthcracks may respond to surface climatic conditions, which may be altered as the climate continues warming. Continued monitoring of the cave climate is needed to identify cave temperature zones and to monitor for changes.

Cavers are accessing the reach of WUPA 04 beneath Wupatki NM, since it is accessible via the adjacent national forest. At least two other closed fissures within Wupatki remain known to cavers and are probably entered more often than monument staff knows (Paul Whitefield, Natural Resource Specialist, pers. comm.). Continued systematic surveys are needed to develop a long-term monitoring framework to help understand the effects of recreational caving, potential impacts from climate change warming, and most recently to understand the potential for spread of WNS.

4.11.5. Sources of Expertise

This assessment was added to Wupatki NM's NRCA report after its on-site NRCA workshop, with the understanding that it would be limited in scope. As a result, and with the permission of park staff, the majority of information was taken directly from various documents previously drafted by Wupatki NM park staff.

4.12. Birds

4.12.1. Background and Importance

The National Park Service's mission is to manage park resources "unimpaired for future generations." Protecting and managing some of our nation's most significant natural resources requires basic knowledge of the condition of ecosystems and species that occur in national parks. Birds are a highly visible component of many ecosystems (Figure 4.12.1-1). They are considered good indicators of ecosystem health because they can respond quickly to changes in resource and environmental conditions (Canterbury et al. 2000, Bryce et al. 2002). Relative to other vertebrates, birds are also highly detectable and can be efficiently surveyed with the use of numerous standardized methods (Bibby et al. 2000, Buckland et al. 2001). Changes in bird population and community parameters can be an important element of a comprehensive, long-term monitoring program, such as that being implemented for the Southern Colorado Plateau Inventory and Monitoring Network (SCPN) parks (including Wupatki National Monument [NM]; Holmes et al. 2015). Another compelling reason to monitor birds in SCPN parks is that birds themselves are inherently valuable. The high aesthetic and spiritual values that humans place on native wildlife are acknowledged in the agency's Organic Act: "to conserve . . . the wildlife therein . . . unimpaired for the enjoyment of future generations." Bird watching, in particular, is a popular, longstanding recreational pastime in the United States and forms the basis of a large and sustainable industry (Sekercioglu 2002). Hundreds of species of birds occur in the American Southwest, as do some of the best birdwatching opportunities.

Personnel with the SCPN and Wupatki NM chose grassland as a target ecosystem for vegetation and bird community monitoring in the park (Holmes and Johnson 2012). Grassland habitat, composed largely of perennial grasses and shrubs, constitutes a large portion of the monument and faces threats from climate change and non-native plant species (Holmes and Johnson (2012). The SCPN began bird monitoring during the breeding season at Wupatki NM in 2008, and they conduct surveys every three years. To date, surveys have been conducted in 2008, 2011, and 2014 (Holmes and Johnson 2016).

This condition assessment addresses birds at Wupatki NM through the use of data from the SCPN triennial breeding season surveys, as well as through the use of other studies and surveys that have been conducted in the park. Information is presented on the overall number and types of species that have been recorded in the park, including any species that are federally listed as endangered or threatened or otherwise considered sensitive species. Immediately below, we provide a

Figure 4.12.1-1. Horned lark is a common bird species at Wupatki NM. Photo Credit: © Robert Shantz.

brief history of the study and inventory of birds in the park prior to the 2008-2014 network monitoring. Note that while the network surveys focus on birds in grassland habitat, some of the other studies/surveys occurred in or also included other habitat types. Threats faced by birds in Wupatki NM are addressed in the last section of this condition assessment.

One of the first main studies/surveys used for this assessment was that described in the series of studies overseen by Gary Bateman (1976a, 1978, 1980) of Northern Arizona University. This series of documents addressed various aspects of Wupatki and Sunset Crater Volcano NMs' vegetation and wildlife. Avian studies were conducted in the springs/summers of 1976 and 1977 in three habitat types in Wupatki NM, grassland, juniper-grassland, and cold desert shrub habitat (Beatty and Balda 1976, Beatty 1978). This effort documented a total of about 33 species during surveys, and the researchers discussed species composition and diversity and habitat use.

Bateman (1976a) reported that prior to their effort, little had been done to study birds at the national monument. Although a study had been conducted on birds at the park in the 1930s, by Z. Bradley and L. Hardgrave, the unpublished manuscript could not be found. After the Bateman/Northern Arizona University work and up to the network monitoring in 2008, only a few studies/survey efforts were conducted on birds in the park. These included a 1997-1998 study of breeding bird species along a grassland-juniper woodland successional gradient at the park and at a study site outside of the park (Rosenstock 1999), and surveys for birds along the Little Colorado River in 2002-2004 (Yavapai College Elderhostel 2002, 2003, and 2004). Rosenstock (1999) observed a total of 16 species within the national monument during his work, and Yavapai College Elderhostel observed a total of 68 species over their three years of surveys. Additionally, park personnel have monitored particular raptor species (prairie falcon [*Falco mexicanus*], golden eagle [*Aquila chrysaetos*], and great horned owl [*Bubo virginianus*]) for nesting activity and success in some years. All of the sources of data used in this assessment are described in greater detail in the Data and Methods section that follows.

4.12.2. Data and Methods

For this assessment of birds at Wupatki NM, we used one indicator of condition, species occurrence, with three measures, focusing on which bird species have been documented at the national monument. To assess species occurrence at the national monument, we used the surveys of: Beatty and Balda (1976) and Beatty (1978); Rosenstock (1999); Yavapai College Elderhostel (2002, 2003, 2004); and Holmes and Johnson (2012, 2013, 2016). We created a list of species from these survey/research efforts, as well as the NPSpecies list for the park (NPS 2016b) to obtain a complete list of species for the park. The NPSpecies list contained a large number of species that were not recorded during any of the four specific survey/research efforts. Because the resources used to compile the list may have included periods throughout the year (especially the NPSpecies list), and because some species detected could just be passing through the park, the list of species is not confined to species that breed within the park.

Temporal Comparison of Species Presence/Absence

It should be noted that while three of the four survey efforts focused on or included grassland habitat, the fourth focused on habitat along the Little Colorado River and/or Deadman Wash. For this reason, we used only the three survey/research efforts in grassland and related habitats for the temporal comparison of species presence/absence. These three survey efforts are from 1976 and 1977 (Beatty and Balda [1976] and Beatty [1978]); 1997-1998 (Rosenstock [1999]); and 2008, 2011, and 2014 (Holmes and Johnson [2012, 2013, 2016]). Under this measure, we compared the list of species recorded under each of the first two survey/research efforts to the most recent effort, that by the SCPN. All three of these efforts were conducted during the breeding season. At this point in time, three surveys have been conducted under the SCPN monitoring program spanning six years, and we treated the three separate surveys as one effort for this measure. Eventually, the SCPN bird community monitoring dataset will be extensive enough to quantitatively assess trends in bird communities (Holmes and Johnson 2012).

We acknowledge that this comparison is qualitative and simplistic, but believe it is useful for examining whether there were any major differences in species occurrence between the earlier and later time periods. It should also be noted that there may have been some differences in the three sampling efforts, such as in the sampling locations used and the survey methods. For example, it is not clear from the reports (Beatty and

Balda [1976] and Beatty [1978]) exactly where in the park birds were surveyed in 1976 and 1977.

Comparison of Most Common Species in SCPN Surveys in 2008, 2011, & 2014

As with the first measure, this second measure is also a qualitative and crude one. Under this second measure, we examined the results of the three individual SCPN surveys (in 2008, 2011, and 2014) to see whether the species detected in the highest numbers were fairly consistent among the years or whether they changed substantially. Some differences among the years might be expected; rather, we were interested in any major or surprising differences that could indicate cause for concern. As already noted, in the future, analyses will be conducted on the SCPN data to study potential changes in bird communities over time. However, such quantitative analyses have not yet been conducted.

Presence of Species of Conservation Concern

The third measure used in this assessment focused on the species that occur or have occurred at Wupatki NM that are considered species of conservation concern at either national or regional scales. Note that we use the phrase "species of conservation concern" in a general sense; it is not specifically tied to use by any one agency or organization. We took the overall list of species for the national monument previously described (based on the four survey efforts spanning 1976-2014, and the NPSpecies list from 2016), and compared it to multiple species of conservation concern lists (e.g., a federal list of endangered and threatened species, those of Greatest Conservation Need in Arizona). The specific lists we used are described below.

Species of Conservation Concern Background

There have been a number of agencies and organizations that focus on the conservation of bird species. Such organizations may differ, however, in the criteria they use to identify and/or prioritize species of concern based on the mission and goals of their organization. They also range in geographic scale from global organizations, such as the International Union for Conservation of Nature (IUCN), who maintains a "Red List of Threatened Species," to local organizations or chapters of larger organizations. This has been, and continues to be, a source of potential confusion for managers and others who need to make sense of and apply the applicable information. In recognition of this, the U.S. North American Bird Conservation Initiative (NABCI) was created in 1999; it represents a coalition of government agencies, private organizations, and bird initiatives in the United States working to ensure the conservation of North America's native bird populations. Although there remain a number of sources at multiple geographic and administrative scales for information on species of concern, several of which are presented below, the NABCI has made great progress in developing a common biological framework for conservation planning and design.

One of the developments from the NABCI was the delineation of Bird Conservation Regions (BCRs) (NABCI 2014). Bird Conservation Regions are ecologically distinct regions in North America with similar bird communities, habitats, and resource management issues (Figure 4.12.2-1). Wupatki NM is primarily within the Southern Rockies-Colorado Plateau BCR (BCR-16), but the extreme western portion of the park is within the Sierra Madre Occidental BCR (BCR-34; Figure 4.12.2-2). Sunset Crater Volcano NM and Walnut Canyon NM are both within the Sierra Madre Occidental BCR, but the former is close to the edge of the Southern Rockies-Colorado Plateau BCR.

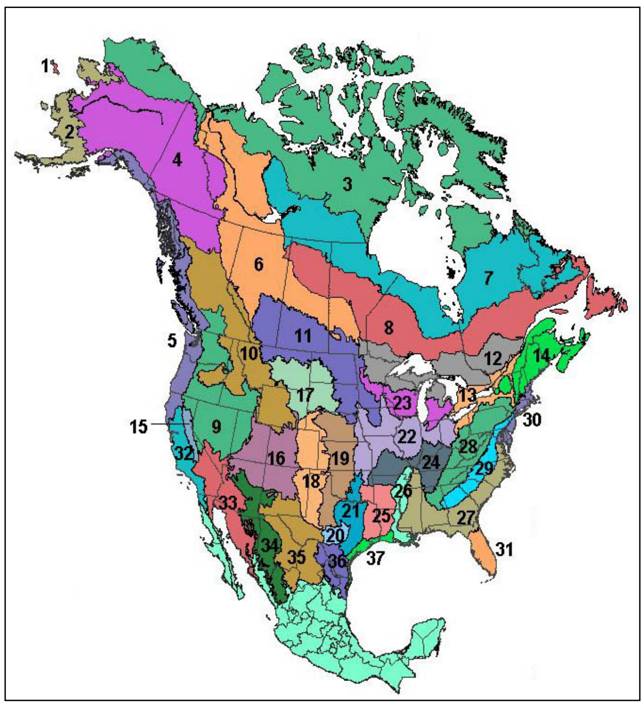


Figure 4.12.2-1. Bird Conservation Regions in North America. Figure Credit: USFWS (2008).

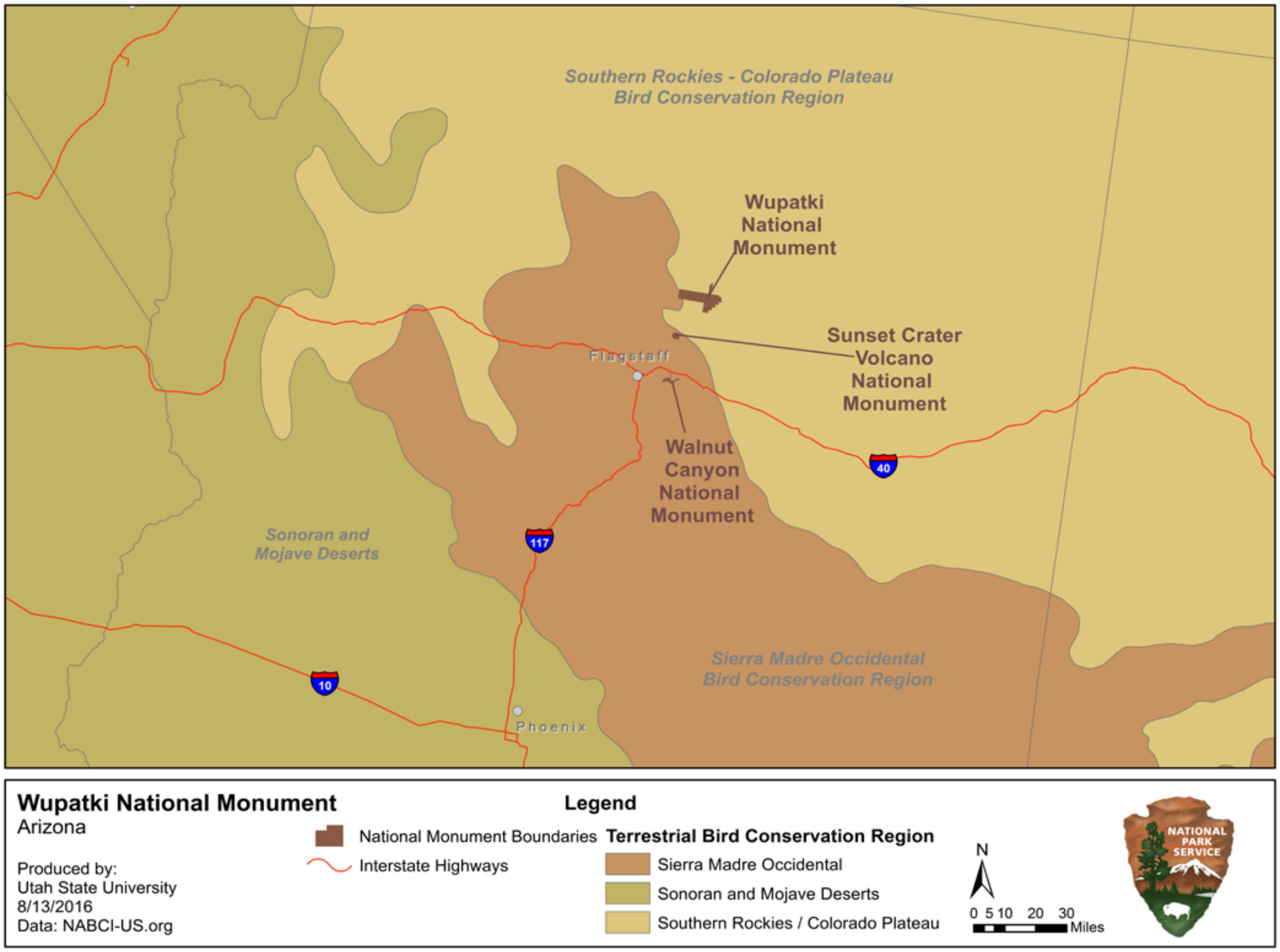


Figure 4.12.2-2. Wupatki NM is located in the Southern Rockies - Colorado Plateau Bird Conservation Region.

Conservation Organizations Listing Species of Conservation Concern

Below we identify some of the organizations/efforts that list species of conservation concern; these are the listings we used for this condition assessment. Appendix G presents additional details on each of the organizations/efforts. Note that in addition to the U.S. Fish and Wildlife Service (USFWS) maintaining a list of endangered and threatened species (first bullet below), they maintain a list of species protected under the Migratory Bird Treaty Act (MBTA; USFWS 2016a). This Act, which protects 1,026 birds, regulates "the taking, possession, transportation, sale, purchase, barter, exportation, and importation of migratory birds" (USFWS 2013). Although we did not compare the list of birds that have been recorded at Wupatki NM to this extensive list, the MBTA is discussed in Appendix G, and some of the lists that we reviewed include birds protected under the MBTA (see bullets below). An updated list of species protected under the MBTA can be found in USFWS (2013).

- U.S. Fish & Wildlife Service: Under the Endangered Species Act (ESA), the USFWS lists species as threatened, endangered, or candidates for listing (USFWS 2016b).
- USFWS: This agency also developed lists of birds of conservation concern according to: the Nation, USFWS Region, and BCR (USFWS 2008). These listings include both migratory and non-migratory bird species (beyond those already designated as federally threatened or endangered). Bird species considered for inclusion on the lists include: nongame birds; gamebirds without hunting seasons; and ESA candidate, proposed endangered or threatened, and recently delisted species.
- North American Bird Conservation Initiative (NABCI): A team of scientists from this group

identified U.S. bird species most in need of conservation action (Rosenberg et al. 2014). A Watch List is published every few years, and the 2014 Watch List contains 233 species. Most of the species are protected by the MBTA, and some are protected by the ESA. The Watch List has two primary levels of concern: a "Red Watch List," which contains species with extremely high vulnerability due to small population, small range, high threats, and rangewide declines; and a "Yellow Watch List," which contains species that are either range restricted (small range and population) or are more widespread but with concerning declines and high threats (Rosenberg et al. 2014).

- Partners in Flight (PIF): This is a cooperative effort among federal, state, and local government agencies, as well as private organizations. PIF has adopted BCRs as the geographic scale for updated regional bird conservation assessments. At the scale of the individual BCRs, there are species of Continental Importance (Continental Concern [CC] and Continental Stewardship [CS]) and Regional Importance (Regional Concern [RC] and Regional Stewardship [RS]). We included only the CC and RC species in our assessment. The lists for BCR 16 and 34 were obtained online (Partners in Flight Science Committee 2012).
- AZ Species of Greatest Conservation Need (SPGN): Under Arizona's State Wildlife Action Plan (2012-2022), SGCN have been designated in the state (Arizona Game and Fish Department [AGFD] 2012). Of the 347 vertebrate SGCN statewide, 145 are birds. The plan includes three tiers, Tier 1A, 1B, and 1C. Of the 145 birds considered SGCN, 12 are Tier 1A, 56 are Tier 1B, and 77 are Tier 1C. Tier 1A contains "those species for which the Department has entered into an agreement or has legal or other contractual obligations, or warrants the protection of a closed season. Tier 1B represents the remainder of the vulnerable species. Tier 1C contains those species for which insufficient information is available to fully assess the vulnerabilities and therefore need to be watched for signs of stress. This tier replaces the species of unknown status from the Comprehensive Wildlife Conservation Strategy" (AGFD 2012). Species listed as federally endangered, threatened, or candidate species, and those considered "endangered wildlife" by the State are Tier 1A species. We compared the list of species for Wupatki NM to the list of birds of SGCN in the State plan; we report only birds in the two highest tiers (except we note 1C species when they also appeared on at least one other of the lists we reviewed).

<u>Data Sources</u>

The following paragraphs provide brief summaries of the primary sources of data used for this assessment: surveys by Beatty and Balda (1976) and Beatty (1978), part of the Bateman/Northern Arizona University project; Rosenstock (1999); Yavapai College Elderhostel (2002, 2003, 2004); and Holmes and Johnson (2012, 2013, 2016). It should be noted that while some of the efforts described surveyed in more than one habitat type, we generally combined survey results from a given study into one species list per study.

Beatty and Balda (1976) and Beatty (1978)

These surveys were part of the "Natural Resource Survey and Analysis of Sunset Crater and Wupatki National Monuments" conducted by Northern Arizona University (Bateman, Project Director). The avian surveys were conducted in the breeding seasons of 1976 and 1977 in three habitat types in Wupatki NM, grassland, juniper-grassland, and cold desert shrub habitat (overall sampling periods from April-June; Beatty and Balda 1976, Beatty 1978). The locations of the sampling sites are unclear. The researchers surveyed birds in each of the habitat types while moving along a 1.61-km (1 mi) transect on consecutive days. By sampling out to a distance of 125 m (410 ft) on each side of the transect, they sampled a total area of 40 ha (100 acres) in each study area. Surveys were conducted in juniper-grassland and grassland for 10 days each, and in cold desert shrub for nine days. Information was recorded on bird distance from the transect, position in the foliage, vocalizations, and gender (when possible). Also note that the 1978 report mentioned having surveyed birds at the Little Colorado River for five days in August and September of 1977. Although Beatty (1978) summarized the findings of this work, the table listing the birds observed was missing from the report.

Rosenstock (1999)

In 1997-1998, Rosenstock (1999) surveyed breeding birds in Wupatki NM as part of his study to determine the effects of juniper woodland expansion on breeding birds in northern Arizona grasslands. He studied breeding birds along a successional gradient ranging from open grassland to mid-aged juniper woodland. His study site at Wupatki NM, however, did not include mid-aged juniper woodland because a large enough area of this type could not be found. The study site at the national monument was located in the north-central portion of the park and included three successional stages: open, uninvaded grasslands lacking juniper; grassland undergoing early stages of juniper establishment (with scattered, small junipers younger than 25 years); and developing woodland with a higher density of trees about 50-75 years in age. The researcher looked at breeding bird species composition and abundance of individual species. Within each successional stage at Wupatki NM, the researcher used four randomly chosen, 1-km- (0.62-mi-) long transects. There were five sampling points (250 m [820 ft]) apart) along each transect, and each point was sampled on three occasions in each of the two years (in June). Breeding bird abundance was estimated through the use of distance sampling (Buckland et al. 1993, as cited by Rosenstock 1999), in which each bird detected is recorded, as is the linear distance between the sampling point and the bird.

Yavapai College Elderhostel (2002-2004)
The Yavapai College Elderhostel, led by Randy Miller, surveyed for birds in Wupatki NM along the Little Colorado River in May of 2002 and 2003 and April of 2004. The surveys occurred in areas that are in or near large stands of tamarisk (*Tamarix* spp.; Yavapai College Elderhostel 2002). In general, the sampling locations were in the vicinity of Deadman Wash and Black Falls crossing. Few details of the surveys were provided by Yavapai College Elderhostel (2002), but the "methodology included 8-10 person transects at 100 meter (328 ft) intervals which were assigned station point numbers on all sides of tamarisk stands and through the interior of the largest stand" at the confluence of Deadman Wash and the Little Colorado River. The individuals conducting the surveys recorded species, the numbers of birds by species, gender, bird activity, and habitat descriptions. A total of four sites were surveyed, with two located inside of the park. One of the sites was located outside of the park and about 6.4 km (4 mi) downstream from the other sites (and in different habitat; Mark Szydlo, Biologist, Wupatki NM), so it was not included in our assessment. The remaining site was located outside of the park but in relatively close proximity to the park boundary, and with habitat that is similar to that within the park. Therefore, we included this site in the assessment, but we made note of birds that were recorded in this site only.

SCPN Surveys / Holmes and Johnson (2012, 2013, 2016)
As mentioned previously, the SCPN began bird monitoring at Wupatki NM in 2008, and surveys have been conducted twice since then (in 2011 and 2014). During each year of sampling, surveys are conducted in 100 permanent plots (or Variable Circular Plot count stations; Holmes and Johnson 2016) in grassland habitat (Figure 4.12.2-3). During a VCP count, all birds seen or heard during the 8-minute sampling period are recorded. Specifically, the researchers record the following: the species, mode of detection, gender (if known), and the distance to the bird from the sampling plot center. Table 4.12.2-1 shows the survey timeframes for each year of sampling to date. Habitat sampling conducted in conjunction with the monitoring is described in Holmes and Johnson (2016). Holmes and Johnson (2012, 2013, and 2016) include results for each of the corresponding years of sampling, including information on observed species richness, average number of individuals detected per species, and the proportion of plots in which each species is detected (i.e., frequency). We present some of this information in the condition assessment. The long-term plan for this effort is to monitor changes in bird species abundance, distribution, and habitat metrics over time, with trend analyses conducted once an appropriate amount of data have been collected (Holmes and Johnson 2012).

NPSpecies List (NPS 2016b)
The list of birds for the national monument from NPSpecies was also reviewed (NPS 2016b; obtained from IRMA in March 2016). We used the list as supporting information and for the inclusion of additional species not recorded in the four primary bird survey efforts.

4.12.3. Reference Conditions
Reference conditions for this assessment are shown in Table 4.12.3-1. Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the indicator's measures. The reference conditions are relatively general in nature due to the qualitative and simplistic approach of the assessment. Our confidence in each

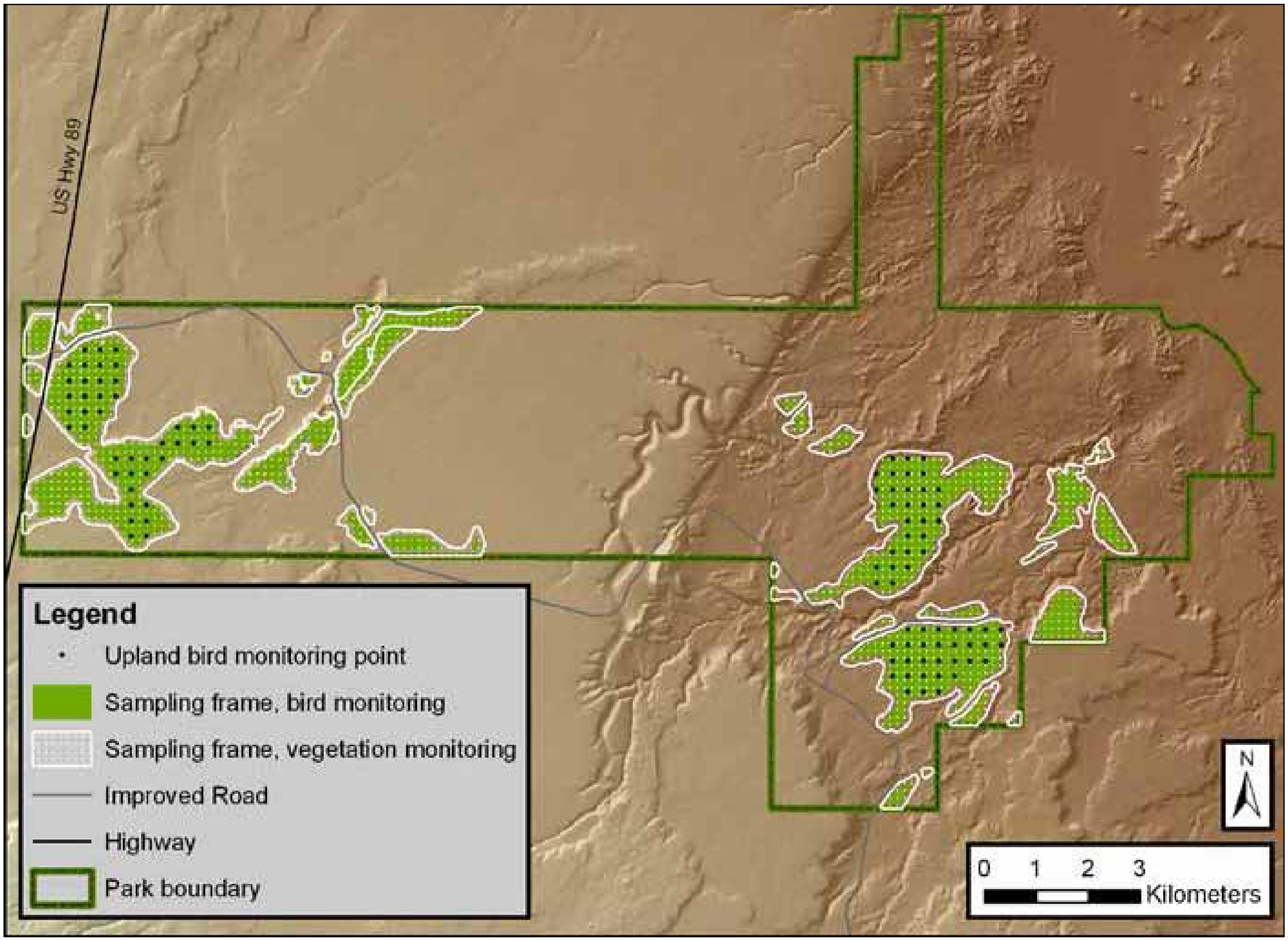


Figure 4.12.2-3. SCPN bird monitoring points at Wupatki NM. Figure Credit: Holmes and Johnson (2016).

measure of the assessment is addressed in the next section.

4.12.4. Condition and Trend

A total of 174 species have been recorded at Wupatki NM or otherwise appear on the NPSpecies list for the park (NPS 2016b; Appendix H). As shown in the appendix, a total of 33 species was recorded by Beatty and Balda (1976) and Beatty (1978). Sixteen species were documented by Rosenstock (1999). A total of 68 species were recorded along the Little Colorado River (Yavapai College Elderhostel 2002, 2003, 2004), and most recently, a total of 60 species have been recorded during the three years of SCPN surveys (Holmes and Johnson 2012, 2013, 2016). A total of 92 species were reported during these four different survey/research efforts, which means that a large number of the species in the appendix were reported only on the NPSpecies list (82 species). For many of these 82 species, NPS (2016b) listed references for the records as two Southwest Parks and Monuments Association reports ("Birds of Wupatki and Sunset Crater National Monuments") from 1990 and 1993. As noted previously, three of the species listed in the appendix, prairie falcon, golden eagle, and great horned owl, are

Table 4.12.2-1. Survey periods and dates and number of VCP counts for SCPN bird monitoring at Wupatki NM.

Year	Survey Period	Survey Dates	# VCP counts
2008	1	4-21 to 5-7	100
	2	5-19 to 5-31	100
	3	6-16 to 6-25	100
2011	1	5-2 to 5-5	100
	2	5-31 to 6-6	100
2014	1	4-29 to 5-4	100
	2	6-10 to 6-14	100

Source: Holmes and Johnson (2012, 2013, 2016).

Table 4.12.3-1. Reference conditions used to assess birds.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Species Occurrence	Temporal Comparison (Changes over Time)	We considered condition good if all, or nearly all, birds detected during earlier surveys were detected during recent surveys by SCPN.	We considered condition to be of moderate concern if several bird species that were detected during earlier surveys were not detected during recent SCPN surveys.	We considered condition to be of significant concern if a large number of birds detected during earlier surveys were not detected during recent SCPN surveys, particularly if those species had previously been considered common at the park.
	Changes in Most Common Species in SCPN Surveys	The list of the most commonly detected native species was fairly consistent among the years, potentially indicating stability in the grassland bird community.	The list of the most commonly detected native species showed a moderate level of variation among the years, with no obvious sampling-related reason.	The list of the most commonly detected native species varied substantially among the years (with no obvious sampling-related reason), potentially indicating instability in the grassland bird community.
	Presence of Species of Conservation Concern	A moderate to substantial number of species of conservation concern occur at the national monument, meaning that the park provides important habitat for these species and contributes to their conservation.	A small number of species of conservation concern occur at the national monument.	No species identified as species of conservation concern have been recorded in the national monument.

monitored in the park during the breeding season (see later section for more information).

Temporal Comparison of Species Presence/Absence

All 16 of the species observed in 1997-1998 by Rosenstock (1999) have been observed by Holmes and Johnson during the SCPN surveys. For the surveys conducted by Beatty and Balda (1976) and Beatty (1978), if we compare only the sites they considered grassland or juniper-grassland habitat to the SCPN survey results, the majority (78%) of the birds observed in the 1976-1977 study were observed in the recent SCPN surveys. The five species that were not observed by SCPN were all recorded by the earlier surveys in juniper-grassland habitat. The five species are juniper titmouse (*Baeolophus ridgwayi*), gray vireo (*Vireo vicinior*), Wilson's warbler (*Wilsonia pusilla*), northern rough-winged swallow (*Stelgidopteryx serripennis*), and American crow (*Corvus brachyrhynchos*). Although four of the species are within their general breeding range while in the park (according to Cornell Lab of Ornithology [2015]), Wilson's warbler is not. The SCPN surveys by Holmes and Johnson (2012, 2013, and 2016) recorded 30 species not recorded by the two earlier survey efforts. This includes two of the three non-native species observed in the park (Eurasian collared-dove [*Streptopelia decaocto*] and house sparrow [*Passer domesticus*]).

Based on this rough comparison, there are no obvious concerns for species occurrence in the national monument. Although a few species were observed in the earlier surveys but not in the SCPN surveys (five species total), a much larger number (30) has been recorded in the recent surveys. It is not entirely clear, but some differences may exist in the habitats, locations, sampling methods, and/or effort among the three survey/research efforts that could lead to some differences in survey results. Additionally, there can be year to year differences in survey results, such as due to weather/climate conditions in some years.

Based on our reference conditions, we consider condition under this measure to be good. The trend appears to be unchanging, but because the comparison was rough and there were differences in the three sets of surveys, we consider it unknown. Our confidence in the assessment is medium.

Comparison of Most Common Species in SCPN Surveys in 2008, 2011, & 2014

Our comparison of the 10 most commonly detected species (i.e., those detected in the highest numbers) indicated that the black-throated sparrow (*Amphispiza bilineata*) was the most commonly detected species in each year of the surveys, and six other species were also in the top ten each year (Table 4.12.4-1). The remaining species in the table, although not in the top 10 every year, were recorded in every year of the three surveys. According to Holmes and Johnson (2012), the bird community in the grasslands sampled consisted mainly of species that are typical of the region's grasslands and shrublands. The species detected in the highest number during each year of monitoring (i.e., black-throated sparrow) favors habitat that is semi-open and has evenly spaced shrubs and trees (Johnson et al. 2002, as cited by Holmes and Johnson 2012). Using our reference conditions, we consider condition under this measure to be good because the species detected in the highest numbers were fairly consistent among the years. The trend appears to be unchanging at this time, although it is only based on three sampling efforts over a total of six years. Our confidence in the assessment is medium because of its simplistic approach and the fact that we focused primarily on the top 10 species each year.

Although not part of this measure, the following information from the Holmes and Johnson reports is also of interest. In addition to the typical grassland bird species observed, species typically associated with pinyon-juniper habitats were recorded (e.g., pinyon jay [*Gymnorhinus cyanocephalus*], Scott's oriole [*Icterus parisorum*], and gray flycatcher [*Empidonax wrightii*]; Holmes and Johnson 2012). As noted by the researchers, pinyon-juniper woodlands occur in substantial areas adjacent to the park. Other species detected during the surveys were probably migrants passing through the national monument (e.g., western tanager [*Piranga ludoviciana*], western wood-pewee [*Contopus sordidulus*], and Townsend's solitaire [*Myadestes townsendi*]; Holmes and Johnson 2012).

Table 4.12.4-1. The ten most commonly detected species during SCPN surveys in grassland habitat at Wupatki NM.

Proportion Of All Detections		
2008	2011	2014
Black-throated sparrow (20.8%)	Black-throated sparrow (22.2%)	Black-throated sparrow (23.2.7%)
Horned lark (16.0%)	Horned lark (16.0%)	Northern mockingbird (14.4%)
Northern mockingbird (13.2%)	Northern mockingbird (12.3%)	Horned lark (13.6%)
Brewer's sparrow (10.9%)	Brewer's sparrow (7.9%)	Eastern meadowlark (10.5%)
Eastern meadowlark (6.7%)	Eastern meadowlark (7.6%)	Brewer's sparrow (10.3%)
Common raven (4.0%)	Common raven (4.5%)	Common raven (5.3%)
Pinyon jay (3.7%)	Pinyon jay (3.7%)	Mourning dove (5.3%)
Mourning dove (3.1%)	Mourning dove (3.2%)	Say's phoebe (1.8%)
Vesper sparrow (2.8%)	Loggerhead shrike (2.9%)	Loggerhead shrike (1.7%)
Chipping sparrow (2.7%)	Lark sparrow (2.4%)	Ash-throated flycatcher (1.5%)

Source: Holmes and Johnson (2012, 2013, 2016).

<u>Presence of Species of Conservation Concern</u>

There are 47 species that have been recorded during one or more of the four surveys/studies at Wupatki NM (or that otherwise appear on the NPSpecies List for the park) that are listed as species of conservation concern on one or more of the lists described in Section 4.12.2 (Table 4.12.4-2). Twenty-two of the species were recorded in one or more of the four survey efforts, including seven species that were recorded in three or four of the surveys (Appendix G).

- USFWS / Listed Species: It appears that no federally listed (i.e., currently listed) bird species have been recorded at Wupatki NM. Table 4.12.4-2 includes the willow flycatcher (*Empidonax traillii*), but only the southwest willow flycatcher (*Empidonax traillii extimus*) is listed under the ESA. The willow flycatcher has not been recorded during any of the four survey efforts at the park we used, but the species is included on the NPSpecies List for the park. That record does not indicate that it is for the endangered subspecies. We included it in the table to present all information related to the species, and because the overall species and subspecies appear on other species of conservation concern lists. The endangered subspecies is known to occur in Coconino County (USFWS 2016c).
- USFWS / Birds of Conservation Concern: There are 29 species that have been recorded at the national monument that have been identified by USFWS as having the greatest conservation

Table 4.12.4-2. Bird species detected during Wupatki NM surveys and those on the 2016 NPSpecies list that are of conservation concern.

Species	Federal[1]	US Fish & Wildlife Service				NABCI[2]	Partners in Flight National Conservation Strategy[3]				State (AGFD)[4]
	USFWS	National	Region 2	BCR 16	BCR 34	2014 Watch List	BCR 16		BCR 34		Species of Greatest Conservation Need
							CC	RC	CC	RC	
Abert's towhee [5]	–	–	–	–	–	–	–	–	–	–	1B
American kestrel	–	–	–	–	–	–	–	–	–	X	–
Bald eagle [6]	–	X	X	X	X	–	–	–	–	–	1A
Bendire's thrasher	–	X	X	X	X	Yellow	X	X	X	X	1C
Black-throated gray warbler	–	–	–	–	X	–	–	X	–	X	1C
Black-throated sparrow	–	–	–	–	–	–	–	–	–	X	–
Brewer's sparrow	–	X	–	X	–	–	–	X	–	–	1C
Broad-tailed hummingbird	–	–	–	–	–	–	–	–	–	X	–
Burrowing owl	–	–	X	X	–	–	–	–	–	–	1B [7]
Calliope hummingbird	–	X	–	–	–	–	–	–	–	–	–
Canyon towhee [5]	–	–	–	–	X	–	–	–	–	–	–
Cassin's finch	–	–	–	X	–	Yellow	X	X	–	–	–
Cassin's kingbird	–	–	–	–	–	–	–	–	–	X	–
Chestnut-collared longspur	–	–	X	X	X	Yellow	–	–	–	–	1C
Clark's nutcracker	–	–	–	–	–	–	–	X	–	–	–
Common nighthawk	–	–	–	–	–	–	–	X	–	X	1B
Common poorwill	–	–	–	–	–	–	–	X	–	–	1C
Costa's hummingbird	–	X	X	–	–	–	–	–	–	–	1C
Evening grosbeak	–	–	–	–	–	–	–	–	–	X	1B
Ferruginous hawk	–	–	–	X	–	–	–	X	–	–	1B
Golden eagle	–	–	X	X	–	–	–	X	–	X	1B
Gray catbird	–	–	–	–	–	–	–	–	–	–	1B
Gray vireo	–	X	X	X	X	Yellow	X	X	X	X	1C
Juniper titmouse	–	–	–	X	–	–	–	–	–	X	1C
Lark bunting [8]	–	–	X	–	X	–	–	–	–	–	–
Lesser yellowlegs	–	X	X	–	–	Yellow	–	–	–	–	–
Lewis's woodpecker	–	X	X	X	X	Yellow	–	X	–	X	1C
Loggerhead shrike	–	X	X	–	–	–	–	X	–	–	–

[1] Federally Listed Species Codes
T = Threatened E = Endangered

[2] NABCI- 2014 Watch List
Red List or Yellow List

[3] PIF NCS Categories
CC = Continental Concern RC = Regional Concern

[4] Species of Greatest Conservation Need
1A, 1B, or 1C (lowest category)

[5] Species not on the NPSpecies List, but listed by one or more of the surveys/studies.

[6] Species was formerly on the Endangered Species List but was delisted due to recovery.

[7] The AGFD (2012) listing refers to the subspecies (western burrowing owl), which occurs in Arizona.

[8] Lark Bunting is “unconfirmed” on the NPSpecies list and not recorded by any of the surveys/studies reviewed. However, NPS (2016) indicates a voucher specimen is available for the record.

Table 4.12.4-2 continued. Bird species detected during the four sets of Wupatki NM surveys and those on the 2016 NPSpecies list that are of conservation concern.

Species	Federal[1]	US Fish & Wildlife Service				NABCI[2]	Partners in Flight National Conservation Strategy[3]				State (AGFD)[4]
	USFWS	National	Region 2	BCR 16	BCR 34	2014 Watch List	BCR 16		BCR 34		Species of Greatest Conservation Need
							CC	RC	CC	RC	
Long-billed curlew	–	X	X	X	–	Yellow	–	–	–	–	–
Macgillivray's warbler	–	–	–	–	–	–	–	–	–	–	1B
Mountain bluebird	–	–	–	–	–	–	–	X	–	–	1C
Mountain plover	–	X	X	X	X	Red	–	–	–	–	1B
Northern goshawk	–	–	–	–	–	–	–	–	–	X	1B
Peregrine falcon [6]	–	X	X	X	X	–	–	–	–	–	1A [9]
Phainopepla	–	–	–	–	X	–	–	–	–	X	1C
Pinyon jay	–	X	X	X	X	Yellow	X	X	X	X	1B
Plumbeos vireo [5]	–	–	–	–	–	–	–	–	–	X	–
Prairie falcon	–	–	–	X	–	–	–	X	–	X	1C
Rufous hummingbird	–	X	–	–	–	Yellow	–	–	–	–	–
Sage sparrow	–	–	–	–	–	–	–	X	–	–	1C
Savannah sparrow	–	–	–	–	–	–	–	–	–	–	1B
Sharp-shinned hawk	–	–	–	–	–	–	–	–	–	X	–
Short-eared owl	–	X	–	–	–	–	–	–	–	–	–
Swainson's hawk	–	X	–	–	–	–	–	–	–	X	1C
Virginia's warbler	–	X	–	–	–	Yellow	X		X	–	1C
Willow flycatcher [10]	E [11]	X [12]	–	X [12]	–	Red [11]	–	–	–	–	1A [11]
Yellow warbler	–	–	–	–	–	–	–	–	–	–	1 B

[1] Federally Listed Species Codes
T = Threatened E = Endangered

[2] NABCI- 2014 Watch List
Red List or Yellow List

[3] PIF NCS Categories
CC = Continental Concern RC = Regional Concern

[4] Species of Greatest Conservation Need
1A, 1B, or 1C (lowest category)

[5] Species not on the NPSpecies List, but listed by one or more of the surveys/studies.

[6] Species was formerly on the Endangered Species List but was delisted due to recovery.

[7] The AGFD (2012) listing refers to the subspecies (western burrowing owl), which occurs in Arizona.

[8] Lark Bunting is "unconfirmed" on the NPSpecies list and not recorded by any of the surveys/studies reviewed. However, NPS (2016) indicates a voucher specimen is available for the record.

[9] The AGFD (2012) listing refers to the subspecies (American peregrine falcon [*Falco peregrinus anatum*]), which occurs in the state & county.

[10] Species is listed on the NPSpecies list only, and noted as occasional and migratory (NPS 2016).

[11] Listing is for the extimus subspecies only (*Empidonax traillii extimus*, the southwestern willow flycatcher).

[12] Listing is for a non-ESA-listed subspecies or population of willow flycatcher.

need at a National, USFWS Regional, or BCR geographic scale (USFWS 2008).

- NABCI: There are 11 species (not including the southwest willow flycatcher, discussed under the first bullet) that have been recorded in the national monument (or otherwise occur on the NPSpecies list) that are included on the NABCI 2014 Watch List. Two species, Bendire's thrasher (*Toxostoma bendirei*) and mountain plover (*Charadrius montanus*), are on the Red List. The other nine species are on the Yellow List.
- PIF: Twenty-six of the bird species in Table 4.12.4-2 are listed by PIF as either CC or RC (recall we did not include the stewardship categories). Seventeen species were listed for BCR-16 and

19 species were listed for BCR-34. Nine of the species were listed for both BCRs.
- Arizona SGCN: Fifteen of the species listed in Table 4.12.4-2 are considered Tier 1A or 1B SGCN in Arizona (excluding southwest willow flycatcher, which has not specifically been recorded in the park). Five of the species appear only on this list. Additional species are considered Tier 1C, but we only show those species if they were also included on at least one of the other species of conservation concern lists.

Raptor Species and Nesting Surveys

Nesting surveys are conducted by park personnel for three raptor species at Wupatki NM. These species are the prairie falcon, golden eagle, and great horned owl. The first two species are in our species of conservation concern table, while the third is not. Park personnel provided a summary of nesting surveys for these three species for the years 2006-2016 (Table 4.12.4-3).

For the two most recent years, 2015 and 2016, prairie falcons were observed nesting in the park. Over the years surveyed, prairie falcon and great horned owl nests have been recorded and monitored in the Deadman Wash area.

This measure is somewhat different than the other two measures in that the focus is on the bird species for which the national monument can play a role in their conservation. Twenty-two of the species recorded during one or more of the four survey efforts reviewed for the assessment (including prairie falcon and golden eagle, discussed above) are considered species of conservation concern on one or more lists. Thirteen of these species have been observed in the SCPN surveys. Twenty-five additional species of conservation concern appear on the NPSpecies list. In accordance with our reference conditions, we consider condition for this measure to be good. The trend is unknown. We have medium to high confidence in this aspect of the assessment.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

For assessing the condition of the national monument's birds, we used one indicator with three measures, which are summarized in Table 4.12.4-4. A total of 95 species have been recorded during the four survey efforts reviewed in this assessment, and an additional 74 species occur on the NPSpecies list for the park. Many of the species were observed in the park's grasslands, but additional species were reported in habitat along the Little Colorado River near the eastern boundary of the park. The most recent surveys, those conducted under the SCPN bird community monitoring program, detected a total of 60 species, with many of the same species observed each year thus far. This bird monitoring effort is conducted every three years in Wupatki NM's grasslands, and eventually the accumulated data will be quantitatively analyzed to study trends over time.

Table 4.12.4-3. Summary of raptor nesting surveys at Wupatki NM, 2006-2016.

Year	Prairie Falcon	Golden Eagle	Geat Horned Owl
2006	not surveyed	0	not surveyed
2007	not surveyed	0	not surveyed
2008	2 nests 4 fledges	0	3 nests 8 fledges
2009	not surveyed	0	not surveyed
2010	not surveyed	0	not surveyed
2011	not surveyed	0	1 nest 2 fledges
2012	0	0	not surveyed
2013	0	0	0
2014	0	0	not surveyed
2015	1 nest 1 fledge	0	0
2016	1 nest (no fledges reported)	0	not surveyed

Source: Mark Szydlo, Biologist, Wupatki NM.

Under the first measure, we conducted a rudimentary comparison of the species observed during the Beatty and Balda (1976) and Beatty (1978) surveys, as well as the Rosenstock (1999) surveys, and those observed during the three years of SCPN surveys (Holmes and Johnson 2012, 2013, 2016). We found no particular concerns from the comparisons. All of the species recorded by Rosenstock (1999) were also recorded by Holmes and Johnson (2012, 2013, 2016), and only five species observed by Beatty and Balda (1976) and Beatty (1978) were not observed by Holmes and Johnson. Furthermore, 30 species have been observed by the SCPN surveys that were not observed by the earlier surveys. Three non-native species have been

Table 4.12.4-4. Summary of birds indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Temporal Comparison (Changes over Time)		A comparison between the species observed during the three surveys/studies in grassland habitat indicated that only five species were observed in the older surveys but not in the more recent surveys (SCPN), and 30 species were observed in the SCPN surveys but not in the earlier surveys. No particular concerns exist for species occurrence based on this rudimentary comparison, and condition is good. Based on the limited comparison and potential differences in the various surveys, trends are unknown at this time. Confidence in the measure is medium.
	Changes in Most-Common Species in SCPN Surveys		Our comparison of the 10 most commonly detected species during SCPN surveys indicated that seven of the top 10 species were in the top 10 every year. The remaining top 10 species were also recorded in every year, even if not in the top every year. Condition is considered good because the species detected in the highest numbers were fairly consistent among the years. The trend appears to be unchanging at this time. Our confidence in the assessment is medium because of its simplistic nature and because it is based on only three surveys to date.
	Presence of Species of Conservation Concern		Of the 174 species of birds that occur on the NPSpecies list, 47 are species of conservation concern on one or more government/organization lists. Twenty-two of these species were observed by at least one of the four surveys in the park, and 13 of these were recorded during SCPN surveys. Condition for this measure is good, as the national monument provides habitat for a number of species in particular need of conservation. Trends are unknown; confidence in the assessment is medium to high.
Overall Condition			There are relatively current data (2014) on birds in grasslands at the national monument, but none in other areas of the park (e.g., along the Little Colorado River). Four survey/study efforts at the park spanned a time period from 1976 to 2014, but differences existed in the four studies. Overall condition of birds under the three measures is good. Trends are varied, and we have medium confidence in the assessment. Future assessments will benefit from additional years of SCPN surveys, as well as quantitative analyses of trends.

noted as occurring in the park, but only two have been recorded during the surveys. The two species (Eurasian collared-dove and house sparrow) have been recorded in only very low numbers (1-3) during one or two of the SCPN surveys. Therefore, they do not appear to represent a threat to native species at this time.

A comparison of the species most commonly detected (or detected in the highest numbers) in each of the three years of SCPN surveys in grassland habitat indicated that there is consistency in these most common species. Seven species have been among the top 10 in every year.

Several species on the bird list for Wupatki NM are considered species of conservation concern by one or more of the governmental or organizational lists we reviewed for the assessment. Of these 47 species, 22 have been recorded in one or more of the four survey efforts; 25 of the species are on the NPSpecies list for the park but have not been recorded during the four survey efforts. Seven of the species (e.g., Bendire's thrasher [*Toxostoma bendirei*], golden eagle, and loggerhead shrike [*Lanius ludovicianus*]) were recorded in three or four of the surveys. Providing habitat for these species, whether it is during the breeding or non-breeding season, contributes to their conservation.

We considered condition to be good for each of the three measures under the species occurrence indicator. We considered confidence to be medium for two and medium to high for the third. Two of the measures, the first and the last, had an unknown trend, but the second is considered unchanging at this time. Overall, we consider the condition of birds at Wupatki NM to be good, and we have medium confidence in the overall assessment. Based on the information available, it is clear that Wupatki NM provides valuable habitat to a variety of bird species, including species typical of grasslands, as well as species using other habitats (e.g., those more typical of pinyon-juniper habitats and those using riparian areas). The park also provides habitat for nesting raptors, such as golden eagles and prairie falcons.

The key uncertainties in this assessment are with regards to the variations in the survey methods among all three surveys (for grasslands) and in the locations sampled. Additionally, birds have not been surveyed along the Little Colorado River in more than 10 years. Although we provided an overall species list, showing which species were recorded by which survey, in the appendix, two of the measures focus on birds in grassland habitats.

Threats, Issues, and Data Gaps

Grassland habitat is protected in Wupatki NM, but grasslands across the country are and have been subject to substantial modification. One initiative monitors grassland health across the continent by monitoring grassland obligate birds, as summarized and discussed in Holmes and Johnson (2016). By examining 24 grassland obligate breeding birds, some of which occur at the national monument, the NABCI, U.S. Committee (2014) found that their indicator for grasslands decreased by almost 40% since 1968, although the decline leveled off in the 1990s. Some grassland species, however, have continued to decline, including the eastern meadowlark (*Sturnella magna*), a species in the top five most detected species at Wupatki NM during all three years of SCPN monitoring. Aridlands are also monitored under the NABCI effort using 17 obligate birds. The aridlands indicator has experienced a 46% decline since 1968, and one of the fastest declining species in this group is Bendire's thrasher, a species that has been recorded during the 1976 and 1977 surveys in the park, as well as in all three of the SCPN survey years.

As Holmes and Johnson (2012) pointed out, grassland habitat faces threats including those from climate change and non-native plant species invasions. Grassland habitat at Wupatki NM has also changed over the years, with an expansion of juniper (*Juniperus monosperma*) trees in at least some areas of the park in the 1900s (Romme and Whitefield 2017). The expansion of juniper into grasslands and savannas may benefit species using juniper habitats, but disadvantage obligate grassland species requiring more open habitat. In general, changes in the composition and structure of grassland habitat could lead to changes in the distribution and abundance of grassland bird species (Holmes and Johnson 2012). It appears, however, that the expansion of juniper over the last century has slowed, or potentially stopped since around 1990 (Romme and Whitefield 2017).

4.12.5. Sources of Expertise

No outside experts were consulted for this condition assessment. This section was written by biologist and writer Patty Valentine-Darby, Utah State University.

4.13. American Pronghorn (*Antilocapra americana americana*)

4.13.1. Background and Importance

The American pronghorn (*Antilocapra americana americana*) is one of three native ungulate species that occurs in Wupatki National Monument (NM). Although three subspecies of pronghorn occur in Arizona, American pronghorn is the most abundant and is found primarily in the north-central part of the state (Arizona Game and Fish Department [AGFD] 2013; Figure 4.13.1-1). The other two subspecies occur in the southeastern and southwestern parts of the state (Chihuahuan pronghorn [*A.a. mexicana*] and Sonoran pronghorn [*A.a. sonoriensis*], respectively) and are not addressed in this assessment. Both pronghorn and the grassland ecosystem they depend upon within Wupatki NM are identified as key resource values in the General Management Plan/Environmental Impact Statement for Wupatki NM (National Park Service [NPS] 2002) and are identified as fundamental resources in the Foundation Document for Wupatki NM (NPS 2015a).

Level, open grassland areas are the preferred habitat of American pronghorn, but they also make use of rolling hills and mesa tops with less than 20% slopes (AGFD 2013b). Other habitats (e.g., open forests, woodlands, and sparse deserts) may also be used. Pronghorn are nomadic animals that may move long distances to search for food and water that vary in availability over time (Yoakum and O'Gara 2000 as cited in National Park Service [NPS] and AGFD 2014). Other or related movement factors include drought, winter storms, and human disturbances (Ockenfels et al. 1997). Pronghorn are herbivores, and various studies (summarized in Bright and van Riper III [(2000]) indicate that pronghorn select forbs (broad-leaved herbaceous plants) to eat when available, and they feed on browse (leaves and twigs of woody plants) and grass during other periods.

The home range size of pronghorns has been estimated from 52-104 km^2 (20-40 mi^2; AGFD 2013b), but somewhat larger home range sizes have been reported in the national monument and vicinity (Ockenfels et al. 1997).The majority of pronghorn in Arizona occur in areas between 915-2,135 m (3,000-7,000 ft) in elevation, although some occur at higher elevations in summer months (Ockenfels et al. 1997; AGFD 2013b). An historic expansion of juniper into open grasslands has occurred across the Southwest, including the mid-elevation life zone across the northern and eastern flanks of the San Francisco Mountains in northern Arizona (Jameson 1962, Johnson 1962, Ironside 2006). This has increasingly concerned conservation biologists (Cinnamon 1988b, Rosenstock and van Riper III 2001) because of the declining and imperiled

Figure 4.13.1-1. American pronghorn buck. Photo Credit: © Robert Shantz.

species within the southwestern United States dependent on open grasslands.

According to the 2013 *Arizona Statewide Pronghorn Management Plan* (AGFD 2013b), pronghorn in the state occupy about 54,390 km^2 (21,000 mi^2) of habitat and number about 11,000 post-hunt adults. The species was once thought to number around 35 million across the continent, but their populations were reduced starting in the late 1800s due to over-hunting and habitat loss (NPS and AGFD 2014). In Arizona, pronghorn numbers were believed to be about 45,000 in the late 1800s (Knipe 1944 as cited by NPS and AGFD 2014). In recent years, the numbers were estimated at 7,500 in 2002 (AGFD unpublished data as cited by NPS and AGFD 2014), and 11,000 in 2007 (AGFD 2007). Reasons for population declines in recent years are believed to be habitat loss and habitat fragmentation due to extensive development in the state over the past three decades (Brown and Ockenfels 2007 as cited by NPS and AGFD 2014). Pronghorn are particularly sensitive to crossing highways, and this has contributed to isolation of populations and interference with seasonal migrations (Dodd et al. 2011; AGFD 2011a). Fences are often located along highway right-of-ways (ROW) and on rangelands, and pronghorn prefer not to jump over them, but to crawl under the lowest wire strand (NPS and AGFD 2014); this can prevent their crossing if the lowest wire is too low (Ockenfels et al. 1997, Bright and van Riperv III 2000). Highways are also a problem for pronghorn because of the associated traffic, and because pronghorn are active mostly during the day, they must face crossing highways during daytime hours when traffic is typically greater (Dodd et al. 2011).

Wupatki NM is on the eastern perimeter of the Coconino Plateau, on which occurs one of the largest remaining expanses of pronghorn habitat in the state (NPS and AGFD 2014; Figure 4.13.1-2). Pronghorn within a portion of this area are in the AGFD Game Management Unit (GMU) 7. Wupatki NM provides protected habitat (i.e., no hunting, grazing, development pressure) for the species within GMU 7 that has been recovering from livestock grazing since 1989 (Kuehnert 1989, Schelz et al. 2013). Pronghorn may use the national monument during any season, but the greatest concentrations of animals are in the winter and spring (Bright and van Riper III 2000). Most of their summer range is outside of the monument (Bright and van Riper III 2000), and access to surface water and summer forage is important to sustaining the population, especially during years when precipitation is low.

Drost (2009) described pronghorn within the national monument as reaching herds of 20 animals on occasion. Although they seasonally utilize the western half of the Wupatki Basin, pronghorn are usually found in the grasslands west of the Doney Cliffs (Drost 2009).

4.13.2. Data and Methods

To assess the condition of American pronghorn at Wupatki NM, we used two indicators. The first indicator used is pronghorn occurrence, and its measure is pronghorn abundance in the national monument and vicinity. The second indicator used is habitat quality, and its measures are 1) condition of pronghorn habitat (vegetation communities) within the national monument, and 2) permeability of fences and roads within the national monument and surrounding area.

Information used to assess American pronghorn condition in Wupatki NM includes: population estimates by the AGFD; telemetry studies of pronghorn that utilize habitat within the monument and adjacent areas; a series of studies on vegetation change within the monument, habitat condition information from studies of grassland-juniper dynamics over the last 700 years, along with the vegetation assessment of this report; and information on efforts that have been taken within and around the monument to increase landscape-level habitat connectivity.

<u>Abundance within Wupatki NM and Vicinity</u>

To assess condition under this measure, we used data from the AGFD on pronghorn numbers in the GMU 7 population. GMU 7 is divided into two parts, GMU 7E and GMU 7W (Figures 4.13.2-1 and 4.13.2-2), and the pronghorn within the two units are managed and monitored as one population. Wupatki NM is located within GMU 7E, which is bisected (north to south) by U.S. Highway 89 (U.S. 89). Fenced highways present significant barriers to pronghorn movements (Dodd et al. 2011, NPS and AGFD 2014). Pronghorn research using telemetry in the general vicinity of the park from 1992-1994 and from 2007-2009 has shown that U.S. 89, with parallel ROW fencing installed at 15 m (50 ft) from pavement edge on both sides of the

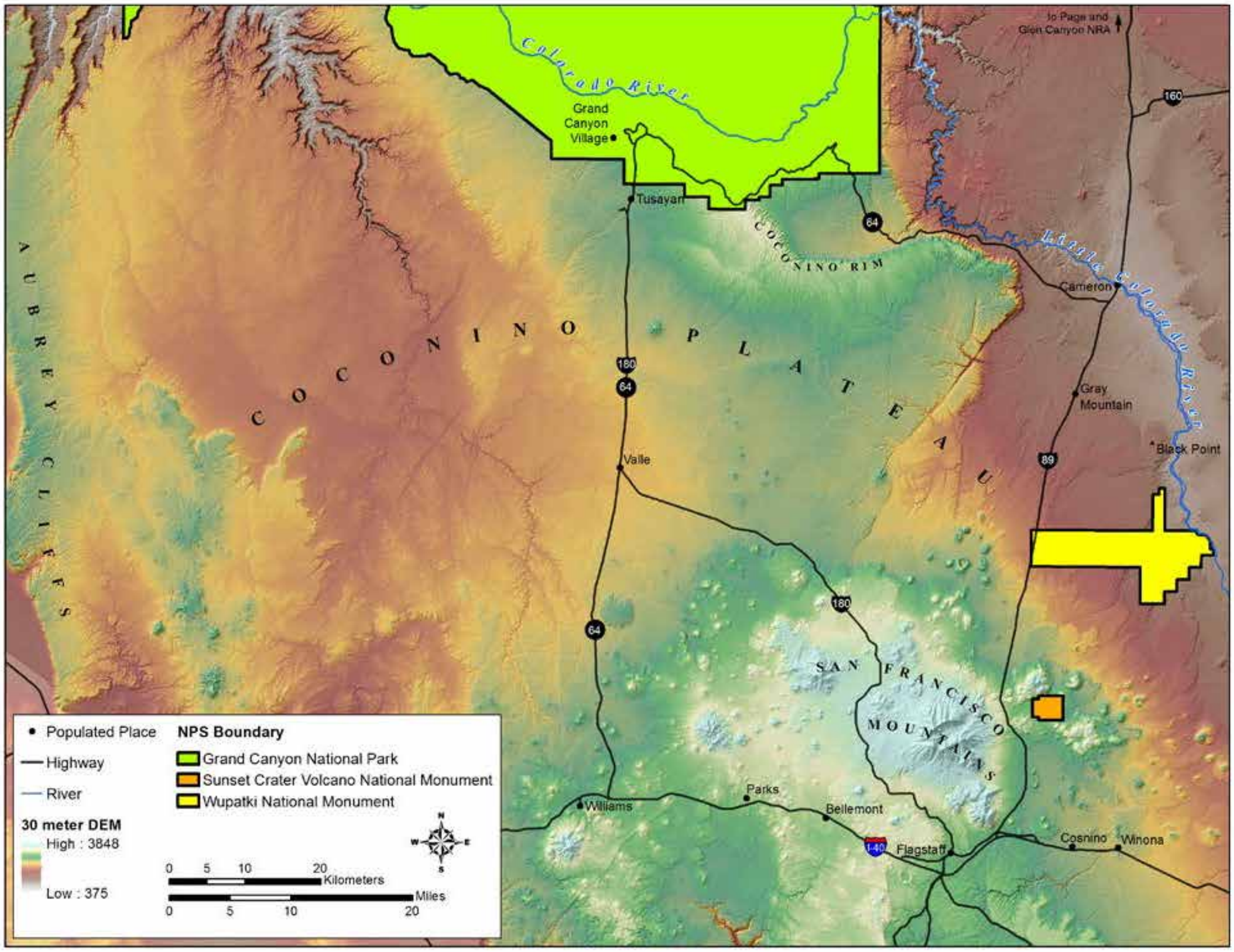


Figure 4.13.1-2. Map of Coconino Plateau in north-central Arizona. Figure Credit: NPS.

highway, near the western boundary of Wupatki NM, is a barrier to the pronghorn population. (Ockenfels et al. 1997, Bright and van Riper III 2000, Dodd et al. 2011). Pronghorn on each side of the highway have often approached the highway ROW fence but animal crossings are considered very rare events (Dodd et al. 2011). Note that this topic is addressed in greater detail in the Condition section of the assessment.

The herd on the east side of U.S. 89 ranges east to the Little Colorado River and south to Interstate 40, and the herd on the west side of U.S. 89 extends west to U.S. 180 (Dodd et al. 2011). Figure 4.13.2-3 shows the range of pronghorn east of U.S. 89 based on telemetry data from 54 collared pronghorn collected during 2007-2009 (AGFD unpublished data provided to the Natural Resource Program, Flagstaff Area National Monuments). It would be most desirable for this assessment to have population data specifically for GMU 7E, and for the herd east of U.S. 89, but only data on the entire GMU 7 population was available from AGFD.

The AGFD surveys pronghorn approximately every year (AGFD 2013b). For this condition assessment, we obtained the most recent estimates available, extending back for about 10 years. Unpublished data from 2006-2016 were provided by AGFD to Paul Whitefield (Natural Resource Specialist, Flagstaff Area National Monuments) in September of 2016. The information included: summary data on survey results by year (i.e., number of bucks, does, and fawns observed during aerial surveys, as well as the number of groups); population estimates by year using a computer population model; and population estimates by year using a double count method. The file also contained graphics that are updated every year.

Figure 4.13.2-1. Map showing AGFD GMU 7W. Figure Credit: AGFD (https://www.azgfd.com/hunting/units/flagstaff/7/).

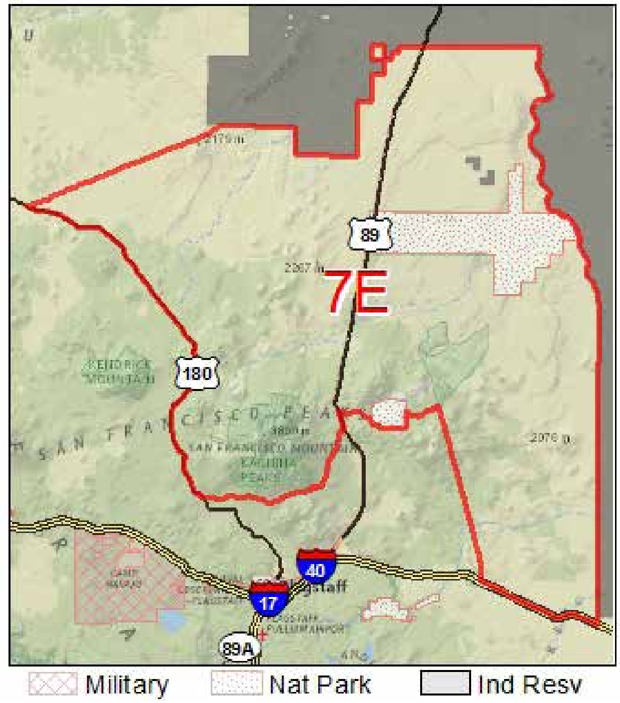


Figure 4.13.2-2. Map showing AGFD GMU 7E. Figure Credit: AGFD (https://www.azgfd.com/hunting/units/flagstaff/7/).

AGFD also provided to P. Whitefield raw survey data from 1961 to 2016 to the Natural Resource Program, Flagstaff Area National Monuments. These raw data for the entire GMU 7 consisted of the number of males, females, and juveniles counted each year, as well as the number of groups and male to female and juvenile to female ratios.

AGFD (2013) describes the surveys/management program for the species. We include part of their description of the survey effort and population estimates here:

> "Pre-hunt fixed-wing aircraft surveys are conducted each year to obtain pronghorn age and sex ratios as well as population estimates using simultaneous double count methodology. The observed buck to doe and fawn to doe ratios are used for the duel purposes of a) assessing the unit's age and sex ratios in relation to hunt guideline criteria for the purposes of buck-only hunting opportunity, and b) obtaining age and sex ratio inputs for population modeling. The precision of the survey data set is evaluated through statistical confidence interval analysis.... Population estimates for pronghorn management units are modeled by computer simulation using surveyed buck to doe and fawn to doe ratios as well as hunter-reported harvest data. Yearly mortality rates for adult males and females as well as young are initially entered within the model using accepted normal ranges from published studies, but these values are tested and adjusted along with starting numbers of bucks and does to derive a best-fit relationship between observed and model-calculated buck to doe ratios. While computer simulation models are valuable tools in estimating populations for management purposes, they are only as accurate as the input data (survey and harvest) and assumptions (starting numbers, mortality rates) entered. Unfortunately, many of our data inputs and assumptions lack the accuracy and precision for reliable model estimates, and therefore should only be taken as gross estimates and not as absolute numbers. A final confounding factor is that very few of our management units represent truly closed populations. Immigration and emigration of pronghorn is unmeasured adding another limitation to modeling accuracy…. The statewide pronghorn population estimate is

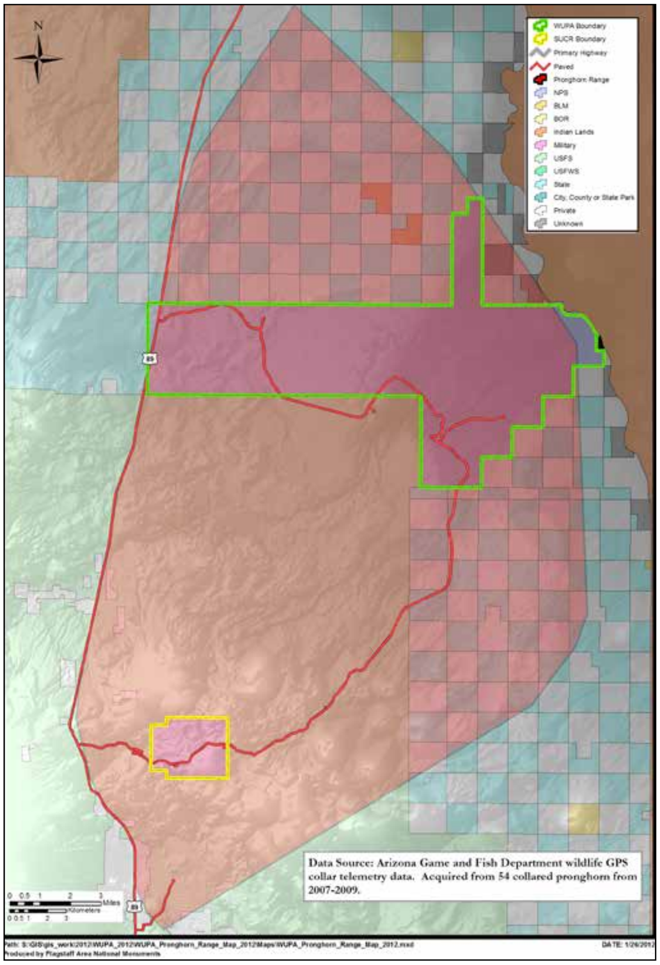


Figure 4.13.2-3. The range of pronghorn east of U.S. 89 based on telemetry data collected during 2007-2009 (area in light red). Figure Credit: NPS.

> primarily based on the sum of regional and management unit estimates and not on a stand-alone statewide model simulation."

In addition to population estimates for GMU 7 from AGFD, we also used descriptive information on pronghorn occurrence and abundance within the park and vicinity to support this indicator/measure.

Data on Pronghorn Habitat Use within Wupatki NM: Background for this Indicator

Past research has shown that pronghorn tend to use habitat on the west side of the Doney Cliffs (compared to the east side) the most. The most recent observation data collected specifically on pronghorn within Wupatki NM are from a 2004 study by park personnel. Holton et al. (2005) monitored pronghorn from January to August of 2004 along the main access road, which runs through the monument roughly east to west, to guide decisions regarding the placement of visitor facilities (turnouts) along the road (Holton et al. 2005). Pronghorn use was highest between mile marker 0.5 (near U.S. 89) and mile marker 4.0, accounting for about 89% of all recorded pronghorn locations (Holton et al. 2005).

Bright and van Riper III (2000) developed a vegetation map representative of pronghorn habitat types within and surrounding Wupatki and tested for utilization of the vegetation types using telemetry location data from 17 pronghorn, from October 1992 through September 1994. The vegetation map included the following cover classes: grassland, shrub-grassland, open juniper grassland (juniper cover <20%), open juniper shrubland (juniper cover <20%), closed juniper woodland (juniper cover >20%), cold desert shrubland, and badlands/outcrop. The researchers found that pronghorn use of the vegetation types was different from what would be expected based on area of type available, and that differences occurred by gender and season.

Bright and van Riper III (2000) found that during all seasons, pronghorn showed a preference for grasslands (in which shrubs comprised less than 20% of the vegetation). Pronghorn avoided closed juniper woodlands (juniper cover >20%), cold desert shrublands, and badlands/outcrop during all seasons; the height and density of trees and shrubs are thought to reduce pronghorn visibility and mobility. The preference for shrub-grasslands (shrubs 20-30%) differed according to gender and season. Females used these areas during the spring and summer, which is also the period of fawning in this part of the state. As suggested by the authors, the greater occurrence of shrubs may provide suitable fawning areas and fawn cover. Shrub-grasslands were also used more than expected during the winter by both genders. The researchers suggested that this was probably because forb abundance was seasonally decreasing and animals changed to browse (i.e., leaves and twigs of woody plants) for food (which had been observed by other authors). Female pronghorn also used open juniper shrublands during the spring and winter, possibly for evergreen forage during the winter and for fawning sites/cover during the spring (Bright and van Riper III 2000). Figure 4.13.2-4 shows the distribution of these preferred habitat types within the monument, derived from interpretation of 1996 aerial photographs (Hansen et al. 2004). Note that the most comparable cover classes in Hansen et al. (2004) are for juniper cover greater than or less than 25%, instead of greater than or less than 20% as used by Bright and van Riper III (2000). This approximation is still useful for portraying optimum pronghorn habitat within the monument.

Also of interest was the seasonal component of the use of Wupatki NM and the adjacent ranch lands. Bright and van Riper III (2000) described it as below:

> "Most of the pronghorn had home ranges utilizing the grazed Babbitt (CO Bar) Ranch property and the ungrazed Wupatki NM, but focused use of these areas at different times of the year. During the winter, pronghorn utilized the Monument as often or more frequently than the CO Bar Ranch. However during spring and summer, animals were more common on the ranch property. The ranch had permanent water sources available to animals while the Monument had none. Ranch vegetation was predominately grassland while the Monument contained grasslands, shrub-grasslands and open juniper habitats. These two differences and the seasonal requirements of pronghorn can readily explain movements between the ranch and Monument that we observed. It appears that pronghorn are utilizing the ranch as summer range in a large part due to the availability of free-standing water. However, they must also use the Monument for winter range, exploiting its browse habitats."

While the majority of the collared animals in 1992-1994 moved seasonally onto the adjacent CO Bar Ranch, the Bright and van Riper III (2000) data also showed that individual pronghorn moved through a south-north corridor along the east side of U.S. 89 to the Bonito Park area just west of Sunset Crater Volcano NM. In the Dodd et al. study (2011), the movements of 28 collared pronghorn were also monitored from 2007-2009 on the east side of U.S. 89 (AGFD unpublished data). Based upon the location patterns for individual animals, many had annual movement patterns similar to animals in the 1992-1994 study. In both datasets, animals moved seasonally to and from the CO Bar Ranch, while others ranged southeastward towards the Strawberry Crater, Black Bottom Crater, and Roden Crater areas.

NPS staff at Wupatki NM also frequently observe pronghorn and pronghorn tracks in the southern and western areas of the Wupatki Basin. Monument staff have also spot checked and reported observations of pronghorn in Bonito Park during spring and summer months since 2009, including documentation of a pronghorn lamb/fawn in June 2011 (wildlife observation record on file, Natural Resource Program, Flagstaff Area National Monuments). We provided this information on where, when, and how American pronghorn use Wupatki NM in this section to provide a context for our use of the two measures under this indicator- habitat (vegetation communities) within the national monument and permeability of fences and roads within the national monument and surrounding area.

Habitat (Vegetation Communities) for Pronghorn in Wupatki NM

To assess condition under this measure, we primarily relied on the habitat/vegetation framework in the national monument that was developed during a rapid assessment conducted for the vegetation condition assessment of this report. We also reviewed reports on pronghorn habitat in the state or region, especially Ockenfels et al. (1996), as supporting and background information.

In the 1990s, Ockenfels et al. (1996) evaluated relative habitat quality for American pronghorn within the national monument and GMU 7E, and placed it into a larger, statewide context. The study was part of the development, testing, and validation of a landscape-level pronghorn habitat evaluation model for Arizona (Ockenfels et al. 1996). The model was ground-based, and radio-collared pronghorn were used to test and validate the system. The primary criteria used to determine habitat suitability and relative quality were terrain and type of vegetation. Secondary criteria included the availability of water, the distribution and type (structure) of fences, and the level of human disturbance or development. Habitat was evaluated and placed into one of six habitat quality classes: 1) high with no significant management problems, 2) high with one or more management problems, 3) moderate, 4) low, 5) poor, or 6) unsuitable. The authors found that, based on the locations of radio-collared animals, they were able to successfully distinguish between moderate, low, poor, and unsuitable habitat quality, but had difficulty determining high quality habitat. Ockenfels et al. (1996) considered most of the

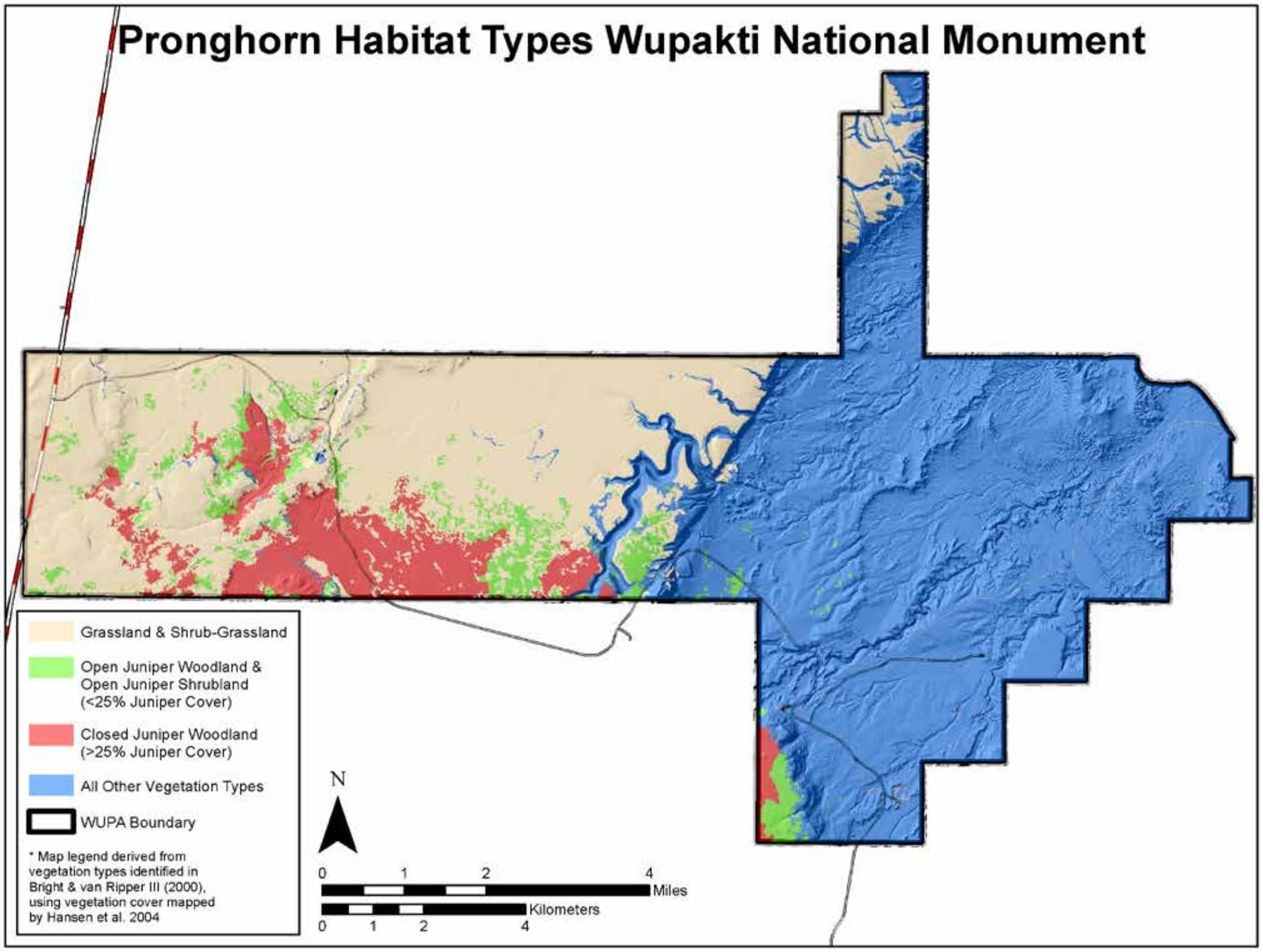


Figure 4.13.2-4. Pronghorn habitat types within Wupatki NM. Figure Credit: NPS.

habitat that fell within Wupatki NM to be of moderate quality and low quality based on the evaluation model. It should be noted that the following factors were considered in the evaluation and could have lowered the rating for the national monument area- tree densities too great, shrub densities too great, presence of fences, and distance to water. Although this work was conducted more than 20 years ago and was a landscape-level approach to be applied across the state, the habitat within and immediately adjacent to Wupatki NM has not dramatically changed since 1996 for quality indicators such as juniper cover (Hansen et al. 2004, Ironside 2006, Parker 2009), understory species composition (Jameson 1962, Cinnamon 1988b, Rosenstock and van Riper III 2001, Schelz et al. 2013), available water sources, or conversion of land to other uses. Therefore, Ockenfels' habitat quality assessment remains useful supporting information for this assessment.

To assess current condition of habitat, we relied most heavily on key findings from prior studies on juniper establishment and cover change (Hassler 2006, Parker 2009), herbaceous understory composition and cover (Jameson 1962, Cinnamon 1988b, Hansen et al. 2004, Ironside 2006, DeCoster et al. 2009, DeCoster and Swan 2011, DeCoster and Swan 2016, and Schelz et al. 2013), and wildland fire occurrence records and observations (burn area GIS files, GIS Program, Flagstaff Area National Monuments). Each of these information/data sources are described in the following sections as they pertain to pronghorn habitat quality.

In preparing the vegetation condition assessment, a field visit to the monument was made on 22-23 October 2015; field visit participants included William Romme (Colorado State University), Paul Whitefield (Natural Resource Specialist, Flagstaff Area National Monuments), three ecologists with the Southern Colorado Plateau Network (SCPN; Lisa Thomas, Jim DeCoster, and Megan Swan), Kirk Anderson, an archaeologist/geomorphologist/soil scientist at Northern Arizona University, and Jim Harrigan, a soil scientist with the Natural Resources Conservation Service, Flagstaff Field Office. Three major vegetation types in the western portion of the national monument (i.e., west of Doney Cliffs) were the focus of the assessment: grasslands, dynamic juniper savannas, and persistent juniper woodlands. The following excerpt is from the vegetation assessment from this effort.

> "...these three vegetation types do not differ much in their species composition. Indeed, a similar suite of herbs and shrubs is found in all three types. Rather, we distinguish the three vegetation types on the basis of (i) the size of juniper trees and their influence on adjacent herbaceous growth, (ii) the abundance of fine fuels, mostly grasses, and whether these fine fuels are arranged in a continuous manner or are separated by patches of bare ground, and (iii) the ease with which a fire could sweep through an area under either moderate or severe fire weather conditions (i.e., conditions of fuel moisture, temperature, and wind)."

Romme's three vegetation types may be aligned with the vegetation cover types included in the Bright and van Riper III (2000) pronghorn habitat selection analysis and along with Parker's (2009) aerial photography analysis of grassland and juniper cover change from 1936 to 1997 (Figure 4.13.2-5.). Table 4.13.2-1 provides a crosswalk between the comparable vegetation and pronghorn habitat types from these three references. By adopting this framework, we are able to assess pronghorn habitat change due to grassland-juniper dynamics over the last 80 years. Although there are a couple of discrepancies between the three reports, a close review of the written cover type descriptions in the reports provides a practical means of resolving them, by lumping according to: (1) The ability of the herbaceous understory to carry a wildfire in open juniper stands; and (2) The juniper cover threshold where pronghorn begin to avoid habitat (20%). The largest discrepancy is between Parker's Class 5 (juniper cover 15 – 30%) and Class 6 (juniper cover >30%). We decided to lump Class 5 into the savanna/open juniper type because a comparison of the 2007 – 2009 pronghorn telemetry locations (Dodd et al. 2011, AGFD unpublished data) shows that some of the collared pronghorn routinely move through woodlands with juniper cover in the 20 – 30% range within the southern half of Parker's study area.

Permeability of Fences & Roads within Wupatki NM and Surrounding Area

The available pronghorn telemetry data from Bright and van Riper III (2000) and Dodd et al. (2011) clearly demonstrate that very few pronghorn individuals spend their entire lives within the monument. The majority of animals routinely move as far as 24 km (15 mi) from Wupatki NM in order to survive, and the ability of pronghorn to move to and from adjacent lands is crucial to conserving this species within the monument. This measure focuses on the difficulty that pronghorn can have crossing range fences and roads. This measure deals with habitat accessibility, and can be viewed as relating to habitat quality (see Ockenfels et al. 1996, described above).

The habitat fragmentation effect of conventional range fencing must have been a management concern at the time the Wupatki NM northern boundary was first fenced, between 1987 and 1989 (Kuehnert 1989). At that time, the new fence divided the original Antelope Prairie-White Prairie Pasture, utilized as part of the CO Bar Ranch, in half. All reliable drinking water sources were on the north (CO Bar) side of the new fence, and access to water for pronghorn on the south (Wupatki NM) side would have been cut-off. In order to mitigate the impact, the lowest wire strand on the Antelope Prairie-White Prairie span of fence was constructed to facilitate pronghorn passage - the lowest strand of wire was smooth (non-barbed), and strung at least 50 cm (10 in) above the ground. Five years later, Bright and van Riper III (2000) reported that pronghorn readily crossed the modified northern boundary fence, compared to far fewer crossings on the conventional southern boundary fence, with four-stranded barbed-wire, and lowest strand 32 cm (12 in) from the ground. From October 1999 through May 2000, Ticer et al. (2002) also documented that the number of pronghorn crossings under range fences on the nearby Espee Ranch and Cataract Ranch increased significantly when the lower two strands were modified with polyvinyl chloride (PVC) passes. In the most recent telemetry study (Dodd et al. 2011), the number of fence approaches with successful crossings was also significantly greater on modified versus unmodified fences (AGFD unpublished data).

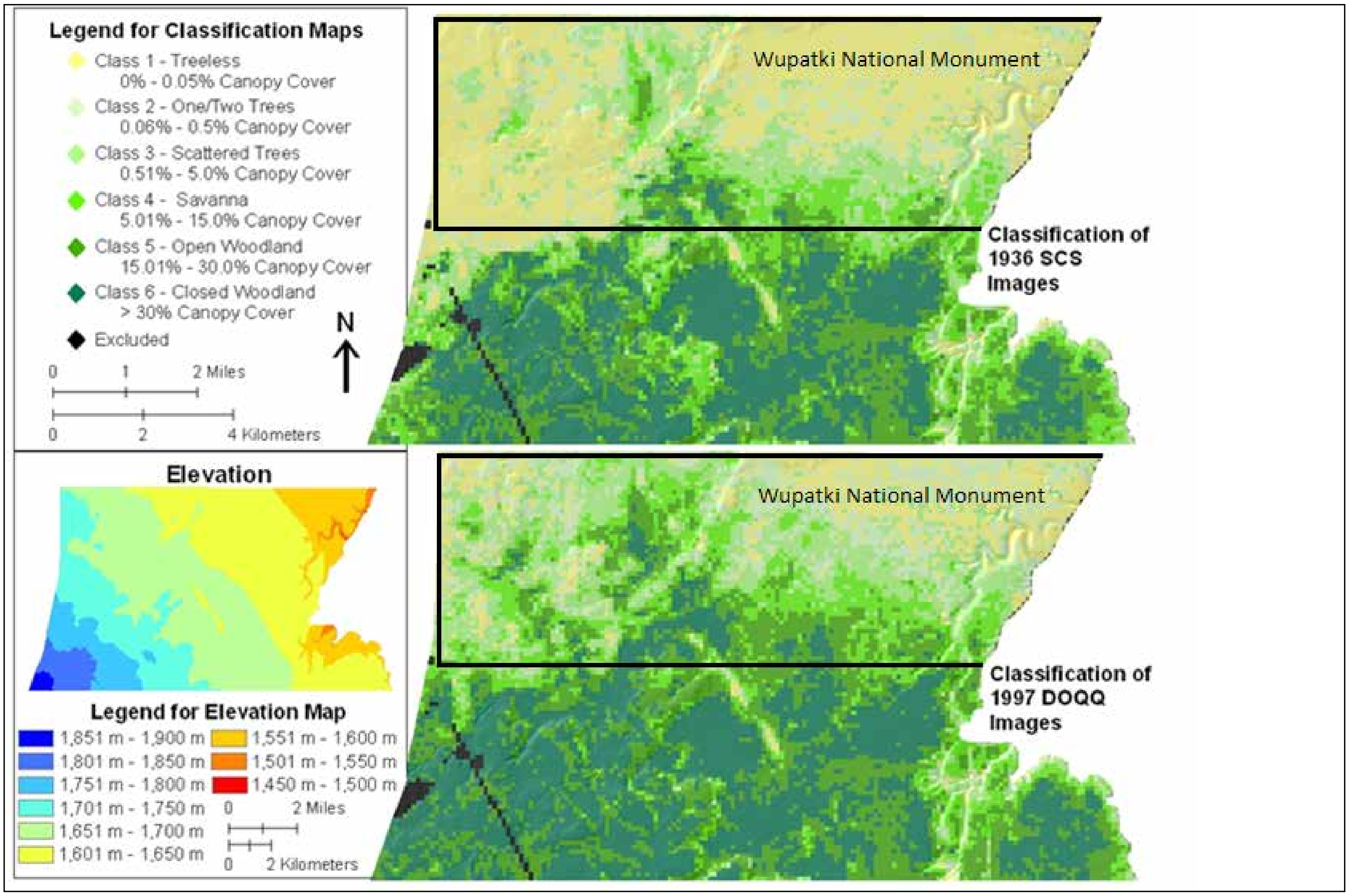


Figure 4.13.2-5. Comparison of juniper cover change from 1936 to 1997, using repeat aerial photography interpretation. The Wupatki NM boundary around the western grassland-juniper vegetation has been added to aid with interpretation. Figure Credit: Parker (2009).

Highways and roads are also acknowledged as movement barriers and a major cause of pronghorn habitat fragmentation. Ockenfels et al. (1997) and Bright and van Riper III (2000) documented that the Wupatki NM entrance road did not greatly interfere with pronghorn movements, as collared animals were routinely detected on both sides of the road. This is attributed to such factors as narrower paved surface, lower traffic volume (especially from late fall through early spring when park visitation is low), slower speed limit, and lack of ROW fencing. However, the 2000 report noted the habitat barrier effect of U.S. 89 on pronghorn. In 2004, the Arizona Department of Transportation (ADOT) began long-range planning to widen U.S. 89 to a four-lane highway. To address concerns over further fragmentation of the GMU 7E pronghorn population, Dodd et al. (2011) conducted a telemetry study of 37 pronghorn (28 captured on the east side of U.S. 89) from January 2007 to December 2008 along 45 km (28 mi) of the highway. They found that only one of the collared pronghorn crossed the highway during the entire tracking period. Thirty animals, however, approached the highway to within 0.24 km (0.15 mi; yet did not cross). A concurrent genetic analysis also found the pronghorn sub-populations separated by the highway were genetically differentiated, indicating restricted gene flow (Sprague 2010, Sprague and Gagnon [no date], Theimer et al. 2012).

Continuing with the ADOT and AGFD cooperative study of pronghorn movements in the Wupatki area, in December 2008, the NPS removed 4 km (2.5 mi) of ROW fencing on both sides of U.S. 89 through Wupatki NM. AGFD monitored 14 collared animals during 2009, with 8 individuals crossing the highway (NPS and AGFD 2014). With the ROW fence removed, some pronghorn crossed back and forth a number of times each. Building upon the results of cooperative research and multiple land manager projects to modify range and highway ROW fences, a partnership of state and federal agencies, private ranches, and nonprofit

Table 4.13.2-1. Summary of comparable open grassland and juniper cover classes.

Bright and van Riper III (2000)		Parker (2009)		Romme (2016)	
Pronghorn Habitat Type	Juniper Cover	Juniper Cover Class	Juniper Cover	Condition Assessment Type	Description
Open Grassland Shrubland-Grassland	0-5%	Class 1: Treeless Class 2: 1 or 2 Trees Class 3: Scattered Trees	0-5%	Grassland	No junipers
Open Juniper Grassland Open Juniper Shrubland	5-20%	Class 4: Savanna Class 5: Open Woodland	5-30%	Dynamic Savanna	Primarily grassland, small to medium juniper trees; most trees < 100 years old; well-developed grassland matrix able to sustain spreading wildfire
Closed Juniper Woodland	>20%	Class 5: Closed Woodland	>30%	Persistent Woodland	Moderate to dense juniper; trees 140 to 700 years old; large bare ground patches surrounding juniper trees deter wildfire from spreading

organizations has been working together since 2013 to increase pronghorn habitat connectivity at the landscape scale (NPS and AGFD 2014). The area for this effort includes 6,993 km^2 (2,700 mi^2), from the Little Colorado River on the east to the Aubrey Cliffs on the west, and from the San Francisco Mountains in the south to the South Rim of the Grand Canyon in the north. This effort includes planning for potential pronghorn crossing structures across U.S. 89, which would be the first such structures for the species in the state (NPS and AGFD 2014).

Efforts to make fences more permeable to pronghorn include activities taken on NPS lands. These management efforts affect the overall condition of the habitat for pronghorn, including their accessibility to the habitat, and so we include this as a habitat condition measure. For information on Wupatki NM's activities to make fences within the park and along its boundaries more permeable to pronghorn, we used information from NPS and AGFD (2014), a summary of fence modifications from 1989 - December 2016 (Table 4.13.2-2), and GIS data from Flagstaff Area National Monuments showing the exact locations of fence and U.S. 89 ROW modifications within the national monument and on adjacent lands (i.e., Coconino National Forest, Arizona State Trust lands, and Babbitt Ranches; Figure 4.13.2-6).

4.13.3. Reference Conditions

Table 4.13.3-1 summarizes the reference conditions for each measure used in the American pronghorn assessment. Reference conditions are provided for resources (i.e., pronghorn abundance or condition of habitat) in good condition, those warranting moderate concern, and those warranting significant concern.

4.13.4. Condition and Trend

<u>Pronghorn Abundance within Wupatki NM & Vicinity</u>

AGFD provided data on survey results (i.e., number of bucks, does, and fawns observed during surveys) and population estimates to Paul Whitefield (Natural Resource Specialist, Wupatki NM) in September of 2016. We were advised by AGFD that it is most appropriate to examine the population estimates for general population trends rather than focusing on the actual estimates in any given year. Figure 4.13.4-1 shows the population estimates for the entire GMU7 population (7W and 7E, and on both sides of U.S. 89) for 2006-2016. Estimates from both methods, the computer population model and the double count method, used by AGFD are shown. As seen from the figure, the estimated total population (including fawns) has been between about 550 and 750 individuals over the past decade based on the computer population model. Based on the estimated number of adults only, there has been a 7% decrease in the adult population over the 10-year period (data analysis provided by AGFD).

The double count population estimate shown in the figure appears to show more variability. However, summary information provided by AGFD indicates that based on the two methods, they consider the population trend to be stable at the present time.

Table 4.13.2-2. Summary of Wupatki NM boundary and highway right-of-way fence modifications and pronghorn crossing monitoring efforts.

Year	Fence Modification and Monitoring
1987-1989	Wupatki boundary fence completed to exclude livestock from adjacent lands (Kuehnert 1989). The northern fence along CO Bar Ranch was constructed with pronghorn-friendly wiring (Bright and van Riper III 2000).
ca. 1999-2000	Additional multi-kilometer/multi-mile reaches of the northern and southwestern boundary fence are modified with 5 PVC passes per kilometer (8 PVC passes per mile).
2000-2008	As an Eagle Scout Project in cooperation with the AGFD and ADOT, 0.16 km (0.10 mi) of highway ROW fence is removed along the U.S. 89 road corridor through Wupatki NM. The fence removal site is spot checked for pronghorn crossing activity from April through October, 2000, as indicated by matching track-sets on both sides of the highway. Sets of matching tracks are recorded on June 17, June 28, and July 3, indicating three potential successful pronghorn crossing events (Anderson 2000).
2004-2012	Most of the Wupatki boundary fence is rebuilt. In the most suitable pronghorn habitat, 40 km (25 mi) of boundary fence is rebuilt to pronghorn-friendly standards: T-post spacing = 16 feet; lowest strand of smooth wire, strung at least 16 inches above the ground. Five PVC "pronghorn passes" are installed per kilometer (8 per mi) in most areas within open grassland and open woodland habitat.
2009 - Dec. 2016	4 km (2.5 mi) of ROW fence are removed from both sides of U.S. 89 through the monument. Pronghorn telemetry data collected from 2007 through 2010 documented a large increase in the number of pronghorn crossings.
2011 - Dec. 2016	The NPS utilizes youth corps crews to clear tumbleweed along the entire 4.8 km (3 mi) of western boundary fence, which had piled on the upwind side to the top wire and so thick the fence was largely impassable to wildlife.
2013	The lowest strand of wire is completely removed from 3.2 km (2 mi) of interior livestock driveway fencing in sloping grassland habitat in the northeastern (Crack-in-Rock) area of the monument.
2013	Three miles of unnecessary ROW fence along the Wupatki entrance road (FR545) are completely removed by public land corps crew.
2015 - Dec. 2016	GPS mapping and description of fence construction specifications is being completed to assess the potential for pronghorn-friendly modifications on an additional six miles of Wupatki NM boundary fence, between Doney Mountain and Woodhouse Mesa. The data has not been reviewed to develop a project proposal.
2015 - Dec. 2016	GPS mapping and description of fence construction specifications is being completed to assess the need for pronghorn-friendly modifications within the Dove Tank Pasture of the Coconino National Forest, between Wupatki NM and Sunset Crater Volcano NM.

The AGFD also provided a data file containing raw survey results from 1961-2016 for GMU 7. The numbers provided are not population estimates, but the actual numbers of animals counted during the aerial surveys. Although such raw data should be viewed with substantial caution, the dataset provides a look at survey results over a moderately long time period (at least in a wildlife population monitoring context)-- 55 years. To display the data, we calculated a simple 10-year rolling average of the total number of pronghorn counted each year (Figure 4.13.4-2). The 10-year rolling averages ranged from approximately 200 to 400 over this time period (with a low of 212 for 1973-1982, and a high of 393 for 1990-1999). Additionally, there was one year in the dataset that also provided survey results for GMU 7E individually; in this year (2011), a total of 296 pronghorn were observed in all of GMU 7, with 15 of the individuals observed in GMU 7E.

Above, we presented the most recent data available for pronghorn in GMU 7, including those that use the monument. However, these estimates included the pronghorn on both the east and west sides of U.S. 89 and in both 7E and 7W. It would have been most useful to have population estimates for GMU 7E only, but these data were not available. Also, although we were able to present long-term data from AGFD to examine the number of pronghorn observed during AGFD surveys, these figures are raw numbers. Based on the population data and analysis provided by AGFD, it appears that there has been a slight decrease in the adult population estimate in GMU 7 since 2005, but that the decrease does not indicate an overall downward population trend. Because we do not have data specific to the GMU 7E area (or area to the east of U.S. 89), we take a conservative approach and conclude the condition for pronghorn in the vicinity of the monument based on this measure is unknown

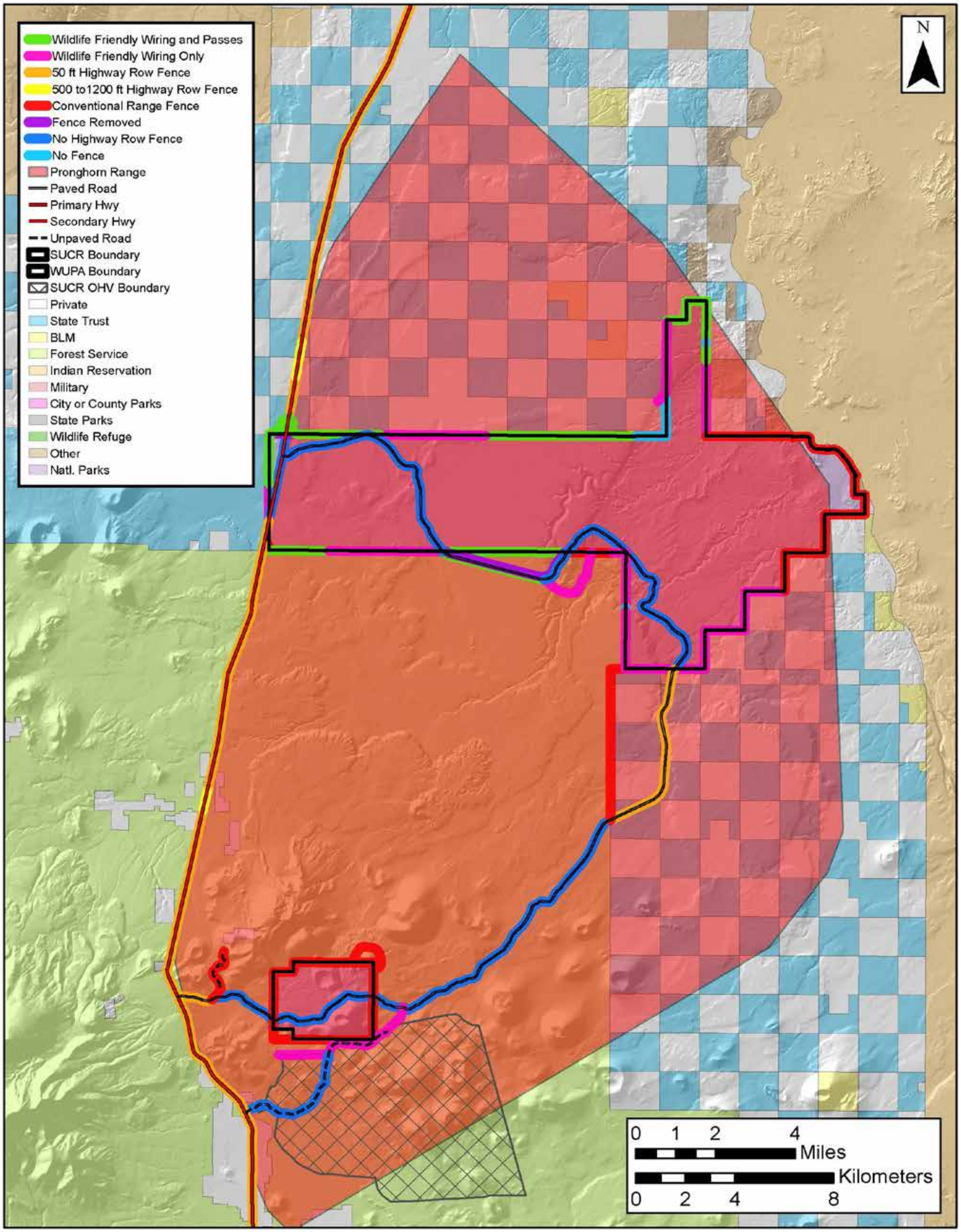


Figure 4.13.2-6. Fence modifications and other features in Wupatki NM and vicinity within the pronghorn range east of U.S. Highway 89. Figure Credit: NPS.

Table 4.13.3-1. Reference conditions used to assess American pronghorn.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Pronghorn Occurrence	Abundance within Wupatki NM & Vicinity	Pronghorn abundance in the park and vicinity (e.g., on the east side of Highway 89) has remained approximately the same or increased over time.	Pronghorn abundance in the park and vicinity (e.g., on the east side of Highway 89) has decreased somewhat over time.	Pronghorn abundance in the park and vicinity (e.g., on the east side of Highway 89) has decreased substantially over time.
Habitat Quality	Habitat (Vegetation Communities) for Pronghorn in Wupatki NM	Habitat used by pronghorn is available and in moderate to good condition or quality in the park (and is not declining over time).	Habitat used by pronghorn is either becoming less available, or its condition/ quality is declining over time.	Either suitable habitat is not available within the park, or habitat is in poor condition/ quality.
	Permeability of Fences & Roads within Wupatki NM & Surrounding Area (on the East Side of U.S. 89)	Most fences within and on the boundary of the park are permeable to pronghorn, and, therefore, allow movements within the park and to adjacent (off-park) habitat.	A moderate number or areas of fences within and on the boundary of the park are not permeable to pronghorn.	Fences within and on the boundary of the park are not permeable to pronghorn, and therefore significantly limit pronghorn movements.

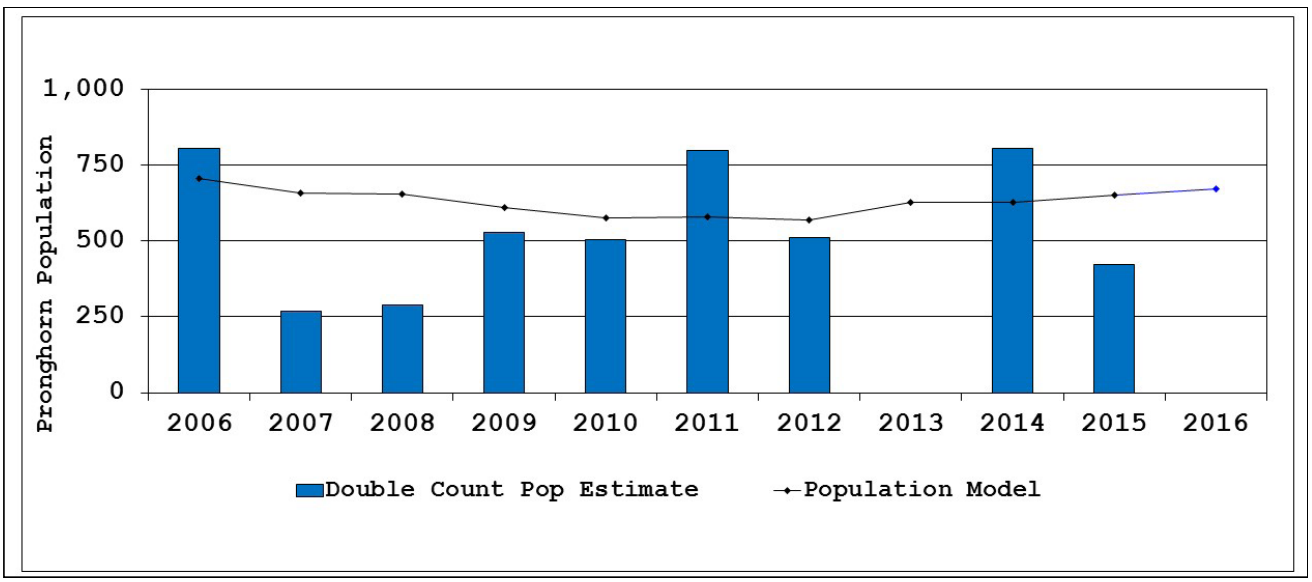


Figure 4.13.4-1. AGFD GMU 7 pronghorn population estimates from 2006-2016. Figure Credit: AGFD.

at this time. We consider confidence in this measure to be low to medium since some data are available.

Five years ago, Dodd et al. (2011) discussed the separation of the two herds on either side of U.S. 89, and noted some particular concern for the herd on the east side, because "since 2003, the fawns:doe ratio on the west side of U.S. 89 has averaged 0.45 compared to only 0.27 on the east side." Additionally, Dodd et al. (2011) reported that based on the observations of their research team, as well as other biologists that have worked with the herds near U.S. 89, the herd on the east side of the highway had "noticeably declined over the past ten or more years..." In 2008, it was loosely estimated there were as few as 140 animals in this area (AGFD pers. comm., as cited by NPS and AGFD 2014).

Climatic/weather conditions have affected pronghorn in this area and on the larger Coconino Plateau. These conditions include an extreme drought event from 2000-2002 (Breshears et al. 2005, Gonzalez 2014, NPS and AGFD 2014). Although not evident in the data provided by AGFD, northern Arizona pronghorn herds reportedly never fully recovered from a severe winter storm in 1967, with up to 80% mortality

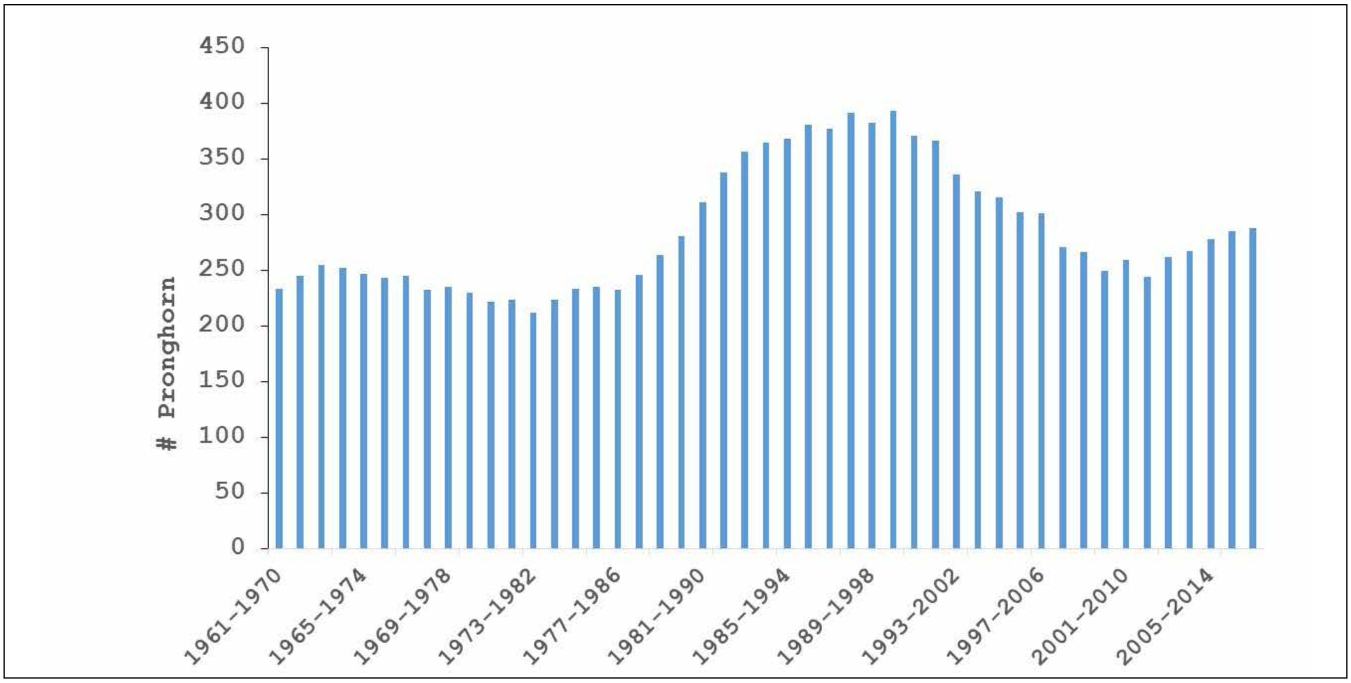


Figure 4.13.4-2. The 10-year rolling average of the total number of pronghorn counted during AGFD aerial surveys, 1961-2016. Data Source: AGFD.

when animals were driven by deep snow into fenced highways and froze to death (White 1969 as cited by Ockenfels et al. 1997).

Again, because we have no current information that focuses on pronghorn carrying capacity or consistent and accurate population estimates on the east side of U.S. 89, we conclude a condition of unknown. However, there appear to be concerns for pronghorn in the vicinity of Wupatki NM because the herd is largely isolated from those west of U.S. 89, and at least as of several years ago, the recruitment rate on the east side was substantially lower than the west side (based on fawns:doe ratios). Concerns about in-breeding (Sprague 2010) have been somewhat alleviated since pronghorn movements across U.S. 89 have increased since 2008, when the ROW fence was removed within the monument. However, this may be a short term improvement, which is further discussed in the Threats and Issues section.

Habitat (Vegetation Communities) for Pronghorn within Wupatki NM

Although livestock grazed on the national monument until 1989 (Kuehnert 1989), Wupatki NM was described by Dodd et al. (2011) as supporting "relatively pristine native bunchgrass grasslands that provide reference conditions for historical grasslands and offer a seed source for dispersal to surrounding habitats (ADOT 2006)." In a state-wide grassland condition assessment conducted by The Nature Conservancy (2004), the grasslands in the Wupatki area were rated as "High Quality Native Grasslands" (Figure 4.13.4-3).

Although the condition of current grasslands, dynamic savannas, and persistent woodlands is good, there is considerable concern over the relative cover changes, in terms of preferred pronghorn habitat, over the last 130 years. Using repeat aerial photography analysis, Parker (2009) compared juniper cover change from 1936 through 1997 within a 13,490 ha (33,335 ac) study area (see Figure 4.13.2-5). The analysis included the large area of contiguous pronghorn habitat within western Wupatki NM, along with a similar-sized area adjacent to the monument's southern boundary. The figure shows that junipers expanded downslope into former grasslands within Wupatki NM, and junipers increased in size and number in savannas (converting former savannas to woodland). Table 4.13.4-1 shows Parker's (2009) results, organized to match the preferred pronghorn habitat types in Bright and van Riper III (2000).

Across the total study area, open grassland habitat for pronghorn (Parker's cover Classes 1, 2, and 3) declined by more than 2,000 ha (4,942 ac) from 1936 through 1997. The reduction represents a relative cover change within 15% of the total analysis area, but a comparative loss of 31% of the most preferred pronghorn habitat over the 60 year study period. The results also show the total area of open juniper habitat (Parker's Cover Classes 4 and 5) increased by more than 1,000 ha (2,471 ac), a comparative increase of 27% for this habitat type. This change is mostly attributed to expansion of juniper trees into grasslands over the 60 year time frame. Lastly, the area of closed juniper woodland, which is largely avoided by pronghorn, increased by more than 900 ha (2,234 ac) by 1997. This represents a relative cover change of about 7% of the total analysis area over the 60 year period, but a relative 32% increase in closed woodland by 1997, which is a primary concern for the conservation of pronghorn habitat. The long-term conversion from grassland and dynamic savanna, utilized by pronghorn, to persistent woodland, which is avoided by pronghorn, represents a loss of functional habitat. In addition, because wildfire no longer functions as a periodic natural disturbance in persistent woodland stands (because large, bare ground patches surrounding juniper trees deter wildfire from spreading) to maintain or restore open vegetation conditions, this conversion probably cannot be undone without intensive management intervention such as mechanical juniper removal; such treatments could have undesirable impacts to cultural resources and be contrary to wilderness management policy (see vegetation assessment by Dr. Romme and P. Whitefield in this report).

This overall decrease in open grasslands and woodland expansion over the past 100+ years is attributed to the downslope expansion of juniper savanna into former open grassland since the 1930s. It should be noted that in Figure 4.13.2-5 most of the observable change between the different habitat types occurred within the northern half of the analysis area within Wupatki NM. Also, a vast expanse of open grassland habitat continues to persist on adjacent lands to the north of the analysis area and adjacent to the northern monument boundary. As discussed in depth in the vegetation assessment of this report, juniper expansion was well underway before the 1930s, based upon ground-based repeat photographs of the area dating to as early as 1907, and likely began during the 1890s based upon juniper tree age data in Hassler (2006). The expansion probably occurred primarily due to the lack of spreading wildfire because of interaction between heavy livestock grazing (which dispersed juniper seeds across the landscape, reduced competition between the herbaceous layer and juniper seedlings (Johnson 1962), and removed the herbaceous fuels to carry fire), active fire suppression by land managers, and decadal-scale climate variation that favored the germination and establishment of juniper during the 20th century (Ironside 2006). As a result, the landscape today has changed from what likely existed pre-settlement.

However, according to the vegetation condition assessment, it appears that the rate of downslope expansion of new trees in the national monument's grasslands slowed by 1990-1995. Since 1996, climatic conditions have been drier, and the series of wildfires since 1995 have reduced juniper cover within the dynamic savanna type. Since livestock were excluded from the monument in 1989, there has been somewhat of a recovery in herbaceous fine fuels (Schelz et al. 2013). Although a multitude of lightning-ignited fires have been documented since the 1950s, a greater number of acres have burned since 1989 within the western half of the national monument. Six wildfires burned in 1995, 2000, 2002, 2013, and 2016, with burn areas ranging from 57 ha (140 ac) to 570 ha (1,400

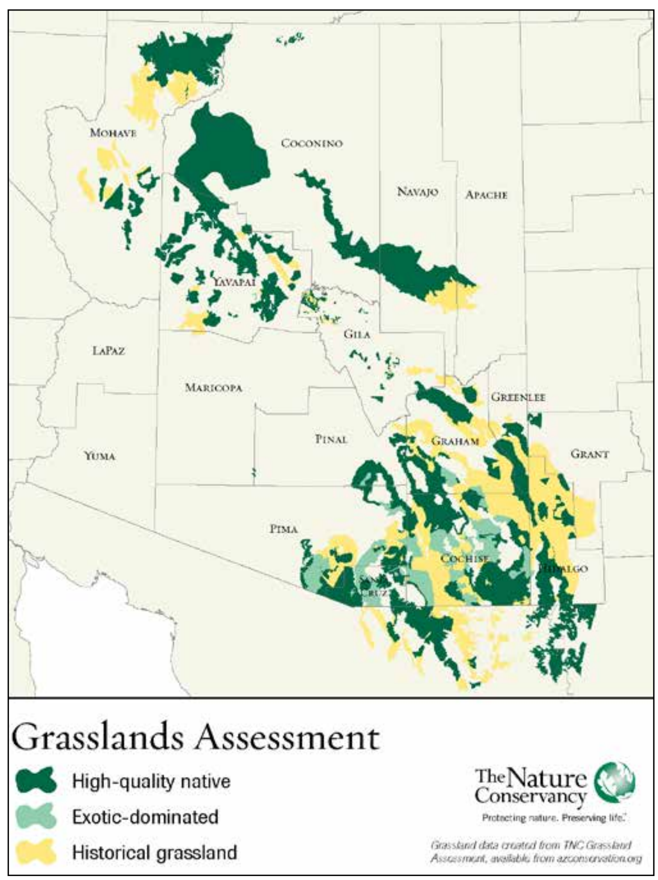


Figure 4.13.4-3. Arizona grassland condition assessment. Figure Credit: The Nature Conservancy (2004).

Table 4.13.4-1. Summary of comparable pronghorn habitat change.

Bright and van Riper III (2000) Habitat Selection Analysis		Parker (2009) 1937-1997 Juniper Cover Analysis Results			
Pronghorn Habitat Type	Juniper Cover Class	1936 Hectares (% of total cover)	1997 Hectares (% of total cover)	Total Change 1936 to 1997 Hectares (% of total cover)	Relative Habitat Change Since 1936
Open Grassland & Shrubland-Grassland	Class 1 + Class 2 + Class 3 (0 to 5%)	6,569 (48.7%)	4,553 (33.8%)	- 2,016 (- 14.9%)	- 31%
Open Juniper Grassland & Open Juniper Shrubland	Class 4 + Class 5 (5 to 30%)	3,992 (29.6%)	5,067 (37.6%)	+ 1,075 (+ 8.0%)	+ 27%
Closed Juniper Woodland	Class 6 (>30%)	2,929 (21.6%)	3,870 (28.5%)	+ 941 ha. (+ 6.9%)	+ 32%
TOTAL	–	13,490 (100%)	13,490 (100%)	N/A	–

ac) of grassland and dynamic juniper savanna (NPS wildland fire incident records and burn area GIS files). Note that since the FMP was finalized in 2009, incident commanders have used more passive tactics to contain a fire using roads, natural mesa rock outcrops, open drywash channels, and the monument's boundary fence, while fires continued to burn. Most fires were extinguished within hours by natural rainfall from summer monsoon thunderstorms before direct attack tactics were needed. On the response to pre-2009 fires, more direct attack tactics were required (P. Whitefield, Resource Management Specialist, pers. comm.). As described in the vegetation assessment, none of the native grasses and forbs appeared to be negatively affected by the recent fires, as they re-sprouted from surviving roots and rhizomes or germinated from soil seed banks.

As stated in the vegetation assessment, "If fires continue to occur as they have in the past 20 years, Wupatki NM's grasslands may be relatively stable in composition and spatial extent..." Some variables, however, are whether periodic fires will continue to occur, and whether climate change could negatively affect grassland plant species survival. As discussed previously with regards to grasslands, juniper expansion has slowed in the past 25 years. Further, this process (i.e., juniper expansion) may end in the near future, "as periodic fires are again burning through the grasslands and dynamic savannas, and a changing climate is becoming less conducive to juniper establishment and survival." A slowing or cessation of juniper expansion would be desirable for the monument's grasslands and pronghorn, but any climate change-related survival effects to grassland plants would be undesirable.

Summary of Condition for this Measure

Based on our reference conditions and the information presented here (and in the vegetation condition assessment), we consider condition under this measure to be good, with a high level of confidence. The current ecological condition of both grasslands and dynamic juniper savannas is considered good. Therefore, the primary habitat used by pronghorn within the national monument is available and in good condition. Although the extent of grasslands may have declined somewhat over the past century or more due to the expansion of juniper (transforming some grasslands into juniper savannas), it appears that this expansion has slowed or even stopped. Also, the cessation of grazing and at least a partial return of a more natural fire regime over the past ~20 years is a positive development (from an ecological perspective).

The area of pronghorn habitat converted to persistent juniper woodland (cover greater than 25-30%), if driven by modern land use, is of some conservation concern, given that fire will likely not return these stands to suitable pronghorn habitat. This is because the large, bare patches of ground surrounding juniper trees deter wildfire from spreading. However, the relative areas of open grassland, dynamic savanna, and persistent woodland within the western half of Wupatki NM have remained relatively stable for the last two to three decades. The rate of juniper infill has slowed and is likely to be partially checked by natural wildfires in the future. Although the trend towards a more open habitat condition appears relatively stable (or even increasing) in recent years, we consider the trend to be unknown due to the uncertainties discussed in this section.

Permeability of Fences & Roads within Wupatki NM and Surrounding Area

Fences that extend too low to the ground are barriers to pronghorn movement. A large number of fence modifications (removing and reconstructing fence sections) have been made to address this issue in Wupatki NM and the surrounding area. Fence modifications started in 1999, including the first installation of pronghorn passes (described below) on the monument's northern boundary fence, and removal of a 366-m (1,200-ft) span of ROW fence along U.S. 89. Within the monument, modifications to fences have been made primarily in the western, grassland-juniper savanna habitat, including along U.S. 89 through the park (Figure 4.13.2-6).

Some fence modifications have been made by removing bottom, barbed, lines of fencing below 40.6 cm (16 in) from the ground, and replacing them with smooth wire at more than 40.6 cm (16 in) off the ground (NPS and AGFD 2014); this type of modification is referred to as "wildlife friendly wiring" (shown in pink in Figure 4.13.2-6). As stated previously, this modification allows pronghorn to pass under the fences, which is what they prefer to do (as opposed to jumping over fences like other ungulates). Another type of fence modification is the use of "pronghorn passes" along with the "friendly" wiring; these areas are shown in the Figure 4.13.2-6 in green. About eight passes per mile are installed in pronghorn habitat. The passes use PVC tubing over the fence wiring (Figure 4.13.4-4). Also, an interior fence that was no longer needed along the park entrance road (i.e., the purple line in Figure 4.13.2-6) was removed (NPS and AGFD 2014). Modifications are also being planned along and near the entrance road (from U.S. 89) to Sunset Crater Volcano NM.

Another significant modification to U.S. 89 fencing is the removal or set back of ROW fencing from the pavement edges to provide pronghorn the opportunity to cross fences and roadways individually [Dodd et al. 2011]; P. Whitefield, Natural Resource Specialist, Flagstaff Area National Monuments, pers. comm.). A total of five projects have been completed along U.S. 89 (i.e., two within the park [in blue in Figure 4.13.2-6], two to the north on the CO Bar Ranch [in yellow in the figure], and one to the south in the Coconino National Forest [in yellow]). NPS staff and their partners are also evaluating other stretches of fencing outside of the park (between Wupatki and Sunset Crater Volcano NMs) for potential modification (P. Whitefield, Natural Resource Specialist, Flagstaff Area National Monuments, pers. comm.).

Even though we focused on the national monument and the area around it to assess condition, we also considered the entire pronghorn range east of U.S. 89 (shaded in light red in Figure 4.13.2-6). Within this area is an expanse of largely unfragmented habitat on the Dove Tank Pasture of the Peaks Allotment on the Coconino National Forest, between Wupatki NM and Sunset Crater Volcano NM (P. Whitefield, Natural Resource Specialist, Flagstaff Area National Monuments, pers. comm.). However, also within the overall area, is suburban development south of Sunset Crater Volcano NM, and "ranchette" development to the east of the pronghorn range shown in Figure 4.13.2-6. While the first area mentioned supports connectivity of the landscape for pronghorn, the other two areas fragment the habitat. Although some connectivity impediments exist, pronghorn are able to move from land north of Wupatki NM to that south of Sunset Crater Volcano NM (see Figure 4.13.2-6).

We consider condition under this measure to be good, due to: 1) the substantial number of fence modifications made along the sides of the national monument and outside of the park; 2) the large area of habitat positively affected through increased connectivity; and 3) the recent, partial restoration of pronghorn population connectivity across U.S. 89 (with fence removals and modifications), and the potential for outbreeding and restored gene flow. The location and number of these fence modifications (Table 4.13.4-2) allows pronghorn a large number of opportunities for moving on and off the monument to surrounding lands. Because many of these changes are relatively recent, and more modifications may be made in the future, we consider the trend to be increasing. Our confidence in the assessment is high given the telemetry study conclusions showing the actual effectiveness of range fence and highway ROW crossing modifications over the last 25 years.

Figure 4.13.4-4. A photo of a fence pass to facilitate pronghorn movements. Photo Credit: NPS.

Overall Condition and Trend, Confidence Level, and Key Uncertainties

For assessing the condition of American pronghorn within and in the vicinity of the national monument, we used two indicators with a total of three measures, which are summarized in Table 4.13.4-3. Overall, we consider pronghorn condition at the monument to be in unknown to good condition. The reason for the divided condition, with part being unknown, is because we used two very different indicators, and we concluded condition under one to be unknown at this time. The first, "unknown" indicator focused on the pronghorn itself, while the second indicator focused on pronghorn habitat (especially within the national monument). We were unable to conclude a more defined condition for the first indicator (abundance within Wupatki NM and vicinity), because the AGFD monitors and manages all pronghorn within GMU 7 as one population. Estimates for the sub-population or herd on the east side of U.S. 89 were not available. On the other hand, we were able to determine condition for the quality of pronghorn habitat indicator (with two measures) because recent information was available on the habitat within the national monument through the efforts made within and outside of the monument to make roadway, boundary, and rangeland fencing more pronghorn-friendly. Overall, we consider confidence in the assessment to be medium, with varied trends.

Uncertainties for the first indicator include the AGFD data applying to the entire GMU 7 population rather than focusing only on the GMU 7E population and/or only the herd on the east side of U.S. 89 (which has essentially been separated from the herd on the west side of the highway). As pointed out by AGFD (2013), there are also inherent uncertainties in their aerial surveys (e.g., animals may be harder to see/detect in some habitats) and analyses.

Uncertainties with the second indicator are primarily associated with trends. It appears that the rate of establishment of new trees in the monument's grasslands and juniper savannas has slowed, and may have stopped, due to climatic conditions that are less conducive to juniper establishment, as well as the return of periodic fires. However, there is some uncertainty as to whether periodic fires will continue to occur, and the occurrence of future climatic conditions.

Threats, Issues, and Data Gaps

As also discussed in the birds assessment of this report, grassland habitat across the country has been

Table 4.13.4-2. Summary of Wupatki NM boundary fences.

Boundary Fence Type	Length (meters)	Percent of total boundary fence length (78,455 meters)
Range Fence with Wildlife-friendly Wiring and 6 PVC Passes per km (8 per mi)	23,919	30%
Range Fence with Wildlife-friendly Wiring Only	31,443	40%
Range Fence Removed as part of U.S. 89 ROW modification on adjacent CO Bar Ranch	1,103	1.4%
Conventional Range Fence	17,779	23%
U.S. 89 with parallel ROW Range Fence	1,053	1.3%
No Fence Required (steep terrain)	3,158	4%
Total	78,455	100%
Total combined length with some form of increased pronghorn permeability	56,465	71.4%

Table 4.13.4-3. Summary of American pronghorn indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Pronghorn Occurrence	Abundance within Wupatki NM & Vicinity		Pronghorn may use the monument at any time during the year, but especially during winter and spring. Survey and population estimate data from AGFD indicate the population of pronghorn within GMU 7 has been relatively stable from 2005 to 2015 (a relatively short period of time), with computer population model estimates between 550 and 750 individuals. No population estimates are available for GMU 7E specifically, or for the sub-population east of U.S. 89. Therefore, condition is unknown at this time, and confidence is low to medium. However, there are concerns for the herd east of U.S. 89 because the fawns:doe ratio was reoprted to be lower than that on the west side of U.S. 89 over several years (Dodd et al. 2011), and the herd east of U.S. 89 appeared to decline over the previous decade (Dodd et al. 2011). There are also concerns over genetic isolation.
Habitat Quality	Habitat (Vegetation Communities) for Pronghorn in Wupatki NM		The current ecological condition of both grasslands and dynamic juniper savannas in Wupatki NM is good, so the primary habitat used by pronghorn within the national monument is available and in good condition. Although the extent of grasslands may have declined somewhat over the past century or more due to the expansion of juniper (transforming some grasslands into juniper savannas), it appears that this expansion has slowed or even stopped. Also, grazing ended in 1989, and there has been some return to a more natural fire regime. Although the trend appears relatively stable (or even increasing) in recent years, we consider trend unknown due to some uncertainties. Confidence in the measure is high.
	Permeability of Fences & Roads within Wupatki NM & Surrounding Area		Because of the number of fence modifications (or removals) made on and near the national monument, and the area of habitat with increased connectivity for pronghorn, we consider condition under this measure to be good. The location and number of the fence modifications/removals/set-backs allows pronghorn increased opportunities for moving on and off the park from/to surrounding lands. Because some of these changes are relatively recent, and additional modifications could be made in the future (e.g., between Wupatki and Sunset Crater Volcano NMs), we consider the trend to be increasing. Our confidence in the assessment is high.
Overall Condition			We used very different indicators in this assessment of American pronghorn, with the first focusing on the animal itself and the second focusing on its habitat. Overall, based on the indicators and measures we used, we consider the condition of pronghorn in the vicinity of Wupatki NM to be unknown (i.e., the first indicator) to good (i.e., the second indicator). The unknown factor comes from the lack of population data specific to the sub-population east of U.S. Highway 89. Concerns exist for this herd. Overall confidence is medium and trends are varied.

subject to substantial modification and degradation over the last century. Authors for the vegetation assessment pointed out that semi-arid grasslands in good condition like those within the national monument are rare in the state and in the Southwest. One potential future threat to grassland habitat within the monument (and elsewhere) is climate change, although this is an area of uncertainty. The effects of drought and higher temperatures could be of concern for the monument's and region's grasslands (e.g., Wu et al. 2012 as cited in the vegetation assessment). Changes in climate variables were studied by Monahan and Fisichelli (2014), who found that during the most recent 30-year period, annual mean temperature, maximum temperature of the warmest month, and mean temperature of the warmest quarter have been within the 95th percentile of the historical range of conditions at Wupatki NM since 1901 (i.e., considered "extreme" values/conditions). Also, three variables for precipitation (annual precipitation, precipitation of the driest month, and precipitation of the driest quarter) were considered "extreme dry."

Habitat fragmentation and habitat loss are believed to have contributed to decreases in the pronghorn population over recent decades (Brown and Ockenfels 2007 as cited by NPS and AGFD 2014). Although Wupatki NM and its partners have made efforts to mitigate habitat fragmentation in the vicinity of the monument and within the "east of U.S. 89" pronghorn range by modifying and removing fences on and off the monument, these threats may continue (or potentially, increase) outside of the monument for the GMU 7 pronghorn population. For example, in 2004, ADOT began long-range planning to expand U.S. 89 to four lanes from around the southern monument boundary northward to Cameron, Arizona (ADOT 2006). The effect on the ability of pronghorn to cross a four-lane highway is currently being assessed (NPS and AGFD 2014). If a wider highway exacerbates habitat fragmentation effects, and long-term fence modification efforts are not sufficient to mitigate the effects, an overpass may be the only effective means of maintaining connectivity. For the pronghorn east of U.S. 89, Wupatki NM comprises only a portion of its range, so habitat conditions outside of the monument are also obviously of great importance to the population. According to Ockenfels et al. (1997), human encroachment into high elevation parks and meadows east of U.S. 89 may be affecting fawning and summer range of pronghorn in the area. The habitat connectivity assessment in this report addressed connectivity of the landscape within an ecologically-relevant 30 km (18.6 mi) area surrounding all three Flagstaff Area National Monument boundaries.

Although awareness of the effects of highways and fences on pronghorn, and efforts to better connect pronghorn habitat, are positive developments, concern exists over genetic effects from fenced highways. A recent effort to study this was conducted along U.S. 89 and Arizona State Route (S.R.) 64 (Sprague 2010, Sprague and Gagnon no date, Theimer et al. 2012). Tissue samples were collected in 2006-2009 from pronghorn along these highways by researchers and in the overall study area by hunters. The researchers found that three sub-populations were defined, largely according to U.S. 89 and S.R. 64 (meaning that the two roads largely separated the animals into three different groups). While the results indicated that the gene pools of the sub-populations diverged, no evidence was found of a loss of genetic diversity within sub-populations or individuals. However, the authors cautioned that genetic declines in some or all of the sub-populations could potentially occur in the future given the gradual nature of the process and the projected traffic volume increases along the roads (Sprague 2010, Sprague and Gagnon no date). Sprague (2010) recommended that highway development in the areas (e.g., projects to increase the number of lanes) include the creation of pronghorn overpass structures to allow pronghorn to cross the highway.

It is also possible that the efforts (fence modifications, set-backs, and removals) that have been undertaken to date near the monument and across the Coconino Plateau are already benefitting animals in the area. A pronghorn telemetry study is currently underway to study the effects of these actions (NPS and AGFD 2014).

Additionally, water was identified as a "key habitat attribute" for pronghorn according to Ockenfels et al. (1997) and Bright and van Riper III (2000) and concerns about surface water decline have been expressed in NPS records since the 1930s, with at least three proposals to develop artificial water catchments within or immediately adjacent to the boundary since the 1980s. Another "key habitat attribute" of concern, identified by Ockenfels et al. (1997) and Bright and van Riper III (2000), is the relatively depauperate grassland flora.

Important data gaps include a re-analysis of existing telemetry data to identify the most utilized habitat areas within the monument and surrounding landscape. This could inform the development of a pronghorn habitat suitability map and carrying capacity within GMU 7E (at a minimum on the east side of U.S. 89).

Continued assessment of juniper cover increase/decrease within the monument and adjacent pronghorn habitat could provide a more accurate understanding of the juniper cover threshold above which pronghorn fully avoid. This may also be designed to better identify quality habitat by documenting the composition and seasonal availability of for age/browse within these areas, providing a better understanding of forage needs and distribution. Understanding the availability and use of ephemeral surface waters is also important. These sources may evaporate faster as the climate continues warming, and there may be a need to mitigate the negative effects by installing artificial catchments.

4.13.5. Sources of Expertise

This assessment was based on existing reports about American pronghorn, as well as: survey and population data provided in September of 2016 by the AGFD; the vegetation assessment authored by Dr. W. Romme and P. Whitefield; and fence modification data and information provided by Paul Whitefield, Natural Resource Specialist, and Michael Jones, GIS Program Manager/IT Liaison, both with Flagstaff Area National Monuments. Dr. Romme is Professor Emeritus of fire ecology and senior research scientist in the Natural Resource Ecology Laboratory at Colorado State University, Fort Collins, CO. The assessment was written by Patty Valentine-Darby, Biologist and Science Writer, Utah State University and Paul Whitefield, Natural Resource Specialist for the Flagstaff Area National Monuments.

4.14. Wupatki Pocket Mouse (*Perognathus amplus cineris*)

4.14.1. Background and Importance

The Wupatki pocket mouse (*Perognathus amplus cineris*) is an endemic subspecies that is known to occur only within habitat at Wupatki National Monument (NM) and adjacent lands within the Little Colorado River Basin. This subspecies of the Arizona pocket mouse (*Perognathus amplus*) was discovered for the first time in the 1930s at Wupatki pueblo remains (Hoffmeister 1986, as cited by National Park Service [NPS] 2009).

The Wupatki pocket mouse (Figure 4.14.1-1) is listed as a species of greatest conservation need (Tier 1B [out of Tiers 1A-1C]) in Arizona's State Wildlife Action Plan 2012-2022 (Arizona Game and Fish Department [AGFD] 2012) and a species of concern in the 2003 Wupatki General Management Plan (NPS 2009b). It is also identified as a species of concern for the Navajo Nation (a Group 4 species; Navajo Nation Department of Fish and Wildlife 2008) and the U.S. Forest Service (sensitive species; AGFD 2011b). The national monument contains the largest area of protected habitat for the subspecies within its range (Drost 2009, NPS 2009b). Landowners surrounding the monument include the Navajo Nation, the U.S. Forest Service (Coconino National Forest), and private ranches.

Perognathus amplus, the Arizona pocket mouse, is one of five species in the genus *Perognathus* found in the state (AGFD 2011b). The species *amplus* is divided into four subspecies, two of which are found in Arizona. In addition to *P. a. cineris* (the Wupatki pocket mouse), the subspecies *P. a. amplus* occurs in Arizona (AGFD 2011b). According to research by McKnight (1995, as cited in Rieck (2013)), the Wupatki pocket mouse is evolutionarily the oldest subspecies of Arizona pocket mouse (Rieck 2013).

The Wupatki pocket mouse differs in appearance from the other Arizona pocket mouse subspecies because of its relatively shorter hind feet, its smaller skull and body, and its darker coloration (Hoffmeister 1986, as cited by Rieck 2013). Based on information from Hoffmeister (1986), AGFD (2011) reports the subspecies as having variable color, with those in cinder soil around Wupatki NM darker to more closely matching the cinder soil.

The overall distribution of the Wupatki pocket mouse is from the Wupatki Basin area northward to the Echo Cliffs near Marble Canyon (NPS 2009b). Rieck (2013) further described the range as being in the north to Navajo Spring, east to Echo Cliffs, west to the Colorado River, and south to the Wupatki NM area. In the Wupatki Basin in the eastern part of the

Figure 4.14.1-1. Wupatki pocket mouse. Photo Credit: © Jean Marie Loverich Rieck.

monument, the mouse was found to occur in saltbush desert scrub vegetation (Drost 2009). Because of the limited range and geographic isolation of the Wupatki pocket mouse, it is vulnerable to extirpation (NPS 2009b).

The Wupatki pocket mouse is a solitary rodent that is most active at night, although it may forage during the day (AGFD 2011b). The mice eat seeds primarily, but they also may eat insects and green vegetation. Members of the species remain in their burrows starting in the fall with the onset of cooler temperatures, and they become inactive until the return of warmer temperatures in the spring (AGFD (2011). Their body temperatures decrease and their metabolic rates slow when they become inactive in their burrows. However, individuals may arouse during this period to eat seeds they have stored. Their breeding season begins in March or April after the winter inactive period (Hoffmeister 1986, as cited by Rieck 2013). The population size of the species may fluctuate substantially by year, "depending on the amount of precipitation the previous winter, and therefore, presumably, the availability of seeds" (AGFD 2011b).

Drost (2009) conducted an inventory of mammals at Wupatki NM in the early to mid 2000s. During the inventory, Wupatki pocket mouse individuals were captured in a variety of habitats, including badlands and dry washes in the Wupatki Basin, canyons in the Doney Cliffs, and (a few records) in medium-elevation grassland sites around Doney Mountain (NPS 2009b). Drost (2009) captured a total of 40 individuals during sampling, which made this animal the most numerous nocturnal mammal in his trap sampling (random and overall sampling).

Prior to a more recent study by Rieck (2013) and others, habitat requirements of the subspecies were considered poorly understood (NPS 2009b, Rieck 2013). In 2011 and 2012, Rieck conducted work in coordination with the park to try to learn more about the habitat needs of the Wupatki pocket mouse. The researcher studied factors associated with the presence and abundance of the Wupatki pocket mouse and another species (the silky pocket mouse [*Perognathus flavus*]) within Wupatki NM and its vicinity using live-trapping. She conducted small mammal trapping in 48 sites based on elevation, which was used as a proxy for temperature, vegetation/soil type, and land use (Rieck 2013).

4.14.2. Data and Methods

Information and data on the Wupatki pocket mouse occurrence at Wupatki NM are available only from two sources: Drost (2009) and Rieck (2013). Most of the data are from the more recent study, which serves as the foundation for our assessment. The two measures of species occurrence are site occupancy by vegetation/soil type and presence and relative abundance by vegetation type.

<u>Site Occupancy by Vegetation/Soil Type</u>

Site occupancy uses data from Rieck (2013). In general, occupancy is defined as the proportion of sampling units, sites, patches, or habitat units occupied by a species (Bailey and Adams 2005).

Rieck (2013) estimated occupancy (i.e., probability of site occupancy) in four vegetation/soil types within and surrounding the park using data from 2011 and 2012. The small mammal trapping locations (described in greater detail in the Primary Data Sources section below) were assigned to one of the four vegetation/soil types based on dominant plant type, plant density, and soil type. These four types are as follows, and are described in the Condition section of the assessment: grassland/thin gravel; dense shrub/deep cinder; sparse shrub/shale; and grass mix/cinder gravel.

<u>Presence and Relative Abundance by Vegetation Type</u>

Presence and relative abundance by vegetation type is the second measure used to assess condition of the Wupatki pocket mouse. This measure is also based on the Rieck (2013) study. Specifically, the measure is the average number of mice captured per trap night by vegetation type. The data used for the assessment were collected in the summer of 2011. The vegetation types were seven of the most widespread types in the monument according to Rieck (2013): black grama; galleta; saltbush; Mormon tea; rabbitbrush; sand sage; and juniper scrub. These types are described in more detail in the Condition section.

Although the trapping methods used for this measure are the same as described for the first measure, data used for the analysis were only from 2011. In 2011, Rieck (2013) trapped at 17 locations in the national monument and at 15 locations to the north and south of the monument, with three to nine trapping locations per vegetation type. The following paragraph is directly from Rieck (2013) and describes the analysis:

> To determine whether Wupatki pocket mouse abundance differed among the seven vegetation types, we calculated the number of captures per trap night at each site and then performed a one-way Analysis of Variance followed by Tukey's test for pairwise comparisons using each site as a replicate for its vegetation type. We did not account for detection probability of the species in the design and analysis of our study due to our small sample size, a single year of data, and lack of resources to make repeated visits to the sites.

Primary Data Sources- Rieck (2013)

In the summer of 2011, Rieck (2013) conducted live-trapping at 32 locations- 17 in the national monument, seven on ranchlands to the north, and eight on national forest to the south of the national monument. In the summer of 2012, she conducted trapping at an additional seven locations within the national monument and at nine additional locations about 30 km (18 mi) north of the monument on Navajo Reservation lands. Figure 4.14.2-1 shows the locations of all 48 trapping locations. The researcher used 22 trap stations at each location, placing Sherman live-traps about 15 m (49 ft) apart and alternating the use of one and two traps at each station. Traps were used on three consecutive nights for a total of 99 trap nights per site. Individual animals were marked (using colored, indelible markers) so they could be identified if recaptured.

Rieck (2013) also used data collected by Drost (2009) during 2002-2004 to examine whether distribution is linked with elevation (and thus, potentially, to temperature; Rieck 2013). The elevations in the analysis ranged from 1,300 - 1,750 m (4,265 - 5,741 ft). She also used her data to look at whether land use might affect mouse distribution by comparing the capture of mice at trapping sites within the monument and in private lands adjacent to the north side of the park.

To study the potential effects of land use (cattle grazing) on Wupatki pocket mouse distribution, the researchers conducted sampling in sites within the monument and outside of the monument at the same time. Three sites were sampled in ungrazed galleta grassland within the monument, and five sites were sampled in galleta grassland north of the park boundary on private land (where cattle had grazed in the winter months). The grazed and ungrazed sites were at the approximate same elevations (within 30 m (98 ft)) and in proximity to one another.

Rieck (2013) used Program PRESENCE (ver.5.5; Hines 2012) to analyze models of species presence and estimate site occupancy with three site covariates (vegetation/soil characteristics, elevation, and land use type) and four detection covariates (week, year, temperature and precipitation) (Rieck 2013). Rieck (2013) further described the modeling methods as shown below. We refer the reader to the Rieck report for additional modeling and analysis details.

> Program PRESENCE uses actual data to generate a likelihood model based on probability that a species is present at a site (using presence-only data) (Mackenzie et al. 2002). Site and detection covariates are included in likelihood models to see if and how much each covariate contributes to detection of the species (Mackenzie et al. 2002). Site covariates are factors that remain constant and pertain to the characteristics of the site and are hypothesized to have an effect on the detection of the species (Donovan and Hines 2007). Detection covariates are factors that may have an effect on the detection of the species but do not pertain to characteristics of the site and may be variable within sites or survey sessions (Kalies et al. 2012, Mackenzie et al. 2002).

4.14.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.14.3-1. Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the indicator's two measures.

4.14.4. Condition and Trend

Based on her modeling, Rieck (2013) found that all three site covariates were important for the Wupatki pocket mouse, especially "vegetation/soil" and "land use."

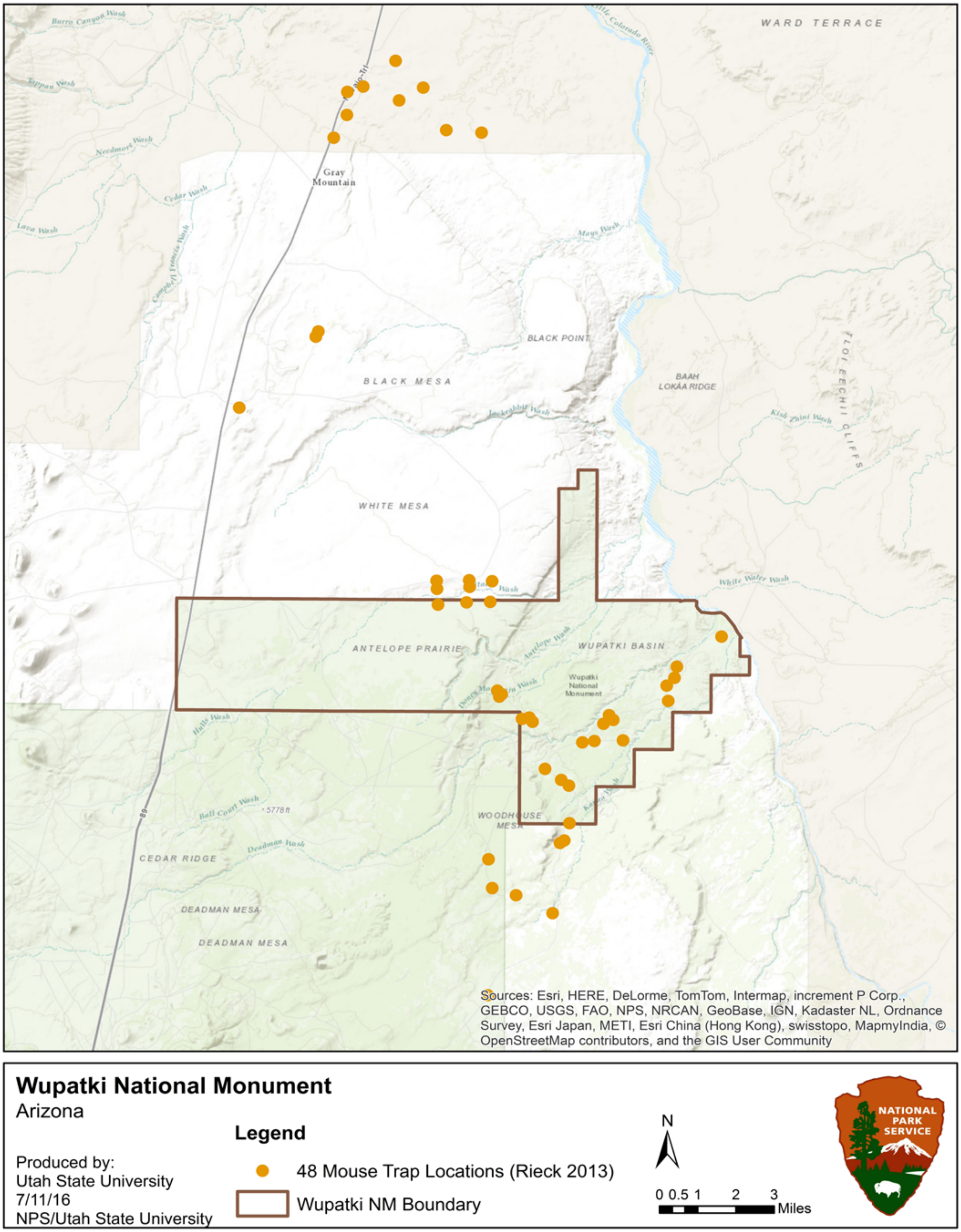


Figure 4.14.2-1. Wupatki pocket mouse trapping locations (48) used by Rieck (2013) in 2011-2012.

Table 4.14.3-1. Reference conditions used to assess Wupatki pocket mouse.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Species Occurrence	Site Occupancy by Vegetation/Soil Type	Subspecies occupies multiple locations or vegetation/soil types in the park, with some probability of site occupancy (psi) levels relatively high.	Subspecies occupies either few locations or vegetation/soils types in the park at relatively high levels, or species occupies multiple locations or vegetation/soil types but psi levels may be relatively moderate or low.	Subspecies occupies few locations or vegetation/soil types in the park and psi levels are relatively low.
	Presence & Relative Abundance by Vegetation Type	Subspecies occurs in a number of vegetation types sampled, with abundance being relatively high in at least some of the sites.	Subpecies occurs in some of the vegetation types sampled, but abundance is relatively high in few or none of the sites.	Subspecies occurs in relatively low numbers in all vegetation types sampled in the park.

Based on her sampling in 24 sites within Wupatki NM and 24 sites outside of the national monument, Rieck (2013) found that the Wupatki pocket mouse was mainly associated with non-grassland vegetation/soil types between 1,450-1,550 m (4,760-5,085 ft) in elevation inside the park where anthropogenic land use occurred at minimal levels. Land use activities such as grazing have not occurred within the national monument since 1989 (Drost 2009). In comparison, the other species she studied, the silky pocket mouse, was most abundant in grassland vegetation/soil types at elevations above 1,550 m (5,085 ft); also, this species appeared to be relatively unaffected by land use (Rieck 2013). The researchers found that the two types of mice were found together less frequently than would be expected by chance.

Site Occupancy by Vegetation/Soil Type

Wupatki pocket mice were found at 67% of the sites sampled on and off the national monument (32 of 48 sites). They were captured at 22 of the 24 sites within the park (92%), and at 10 of the 24 sites outside of the park (42%).

The mean model-averaged probability of site occupancy (psi) for the Wupatki pocket mouse was highest (i.e., 0.999) in "dense shrub/deep cinder" vegetation/soil, and lowest (0.172) in the "grassland/thin gravel" vegetation/soil type (Figures 4.14.4-1 and 4.14.4-2). The psi's were also fairly high in "grass mix/cinder gravel" (~0.84) and "sparse shrub/shale" (~0.75). Note that the numbers are noted as approximations because they were estimated (by us) from a figure in Rieck (2013). It is also important to note that the psi values presented are based on all 48 sites, so they include sampling locations outside of the park as well as within it. However, also note that occupancy of sites was higher inside of the park than outside of it. Table 4.14.4-1 provides descriptions of the four vegetation/soil types per Rieck (2013).

The current condition of the site occupancy by vegetation/soil type for the Wupatki pocket mouse is good. The mouse was captured at 92% of the locations sampled within the park, and the mean model-averaged psi was high or fairly high in three of the four vegetation/soil types sampled. No information on trends is available, and our confidence in the assessment is medium, because the data are now over five years old.

Presence and Relative Abundance by Vegetation Type

Presence and relative abundance by vegetation type was the second measure used to assess condition of the Wupatki pocket mouse. As previously described, this measure is also based on the Rieck (2013) study and dataset (although it uses data from 2011 only), so it is another way of looking at occurrence of the subspecies within the park. It is very much related to the first measure (i.e., not based on an entirely different dataset). Again, the analysis includes trap locations within and outside of the national monument. The seven vegetation types analyzed are described in Table 4.14.4-2.

The researchers captured 73 Wupatki pocket mice at 19 of the 32 sites sampled in 2011 within and around the national monument (Rieck 2013). Only two of the 17 sites within the park had 0 captures over the 1,056 total trap-nights. There was a significant difference in the number of mice per trap night among the seven

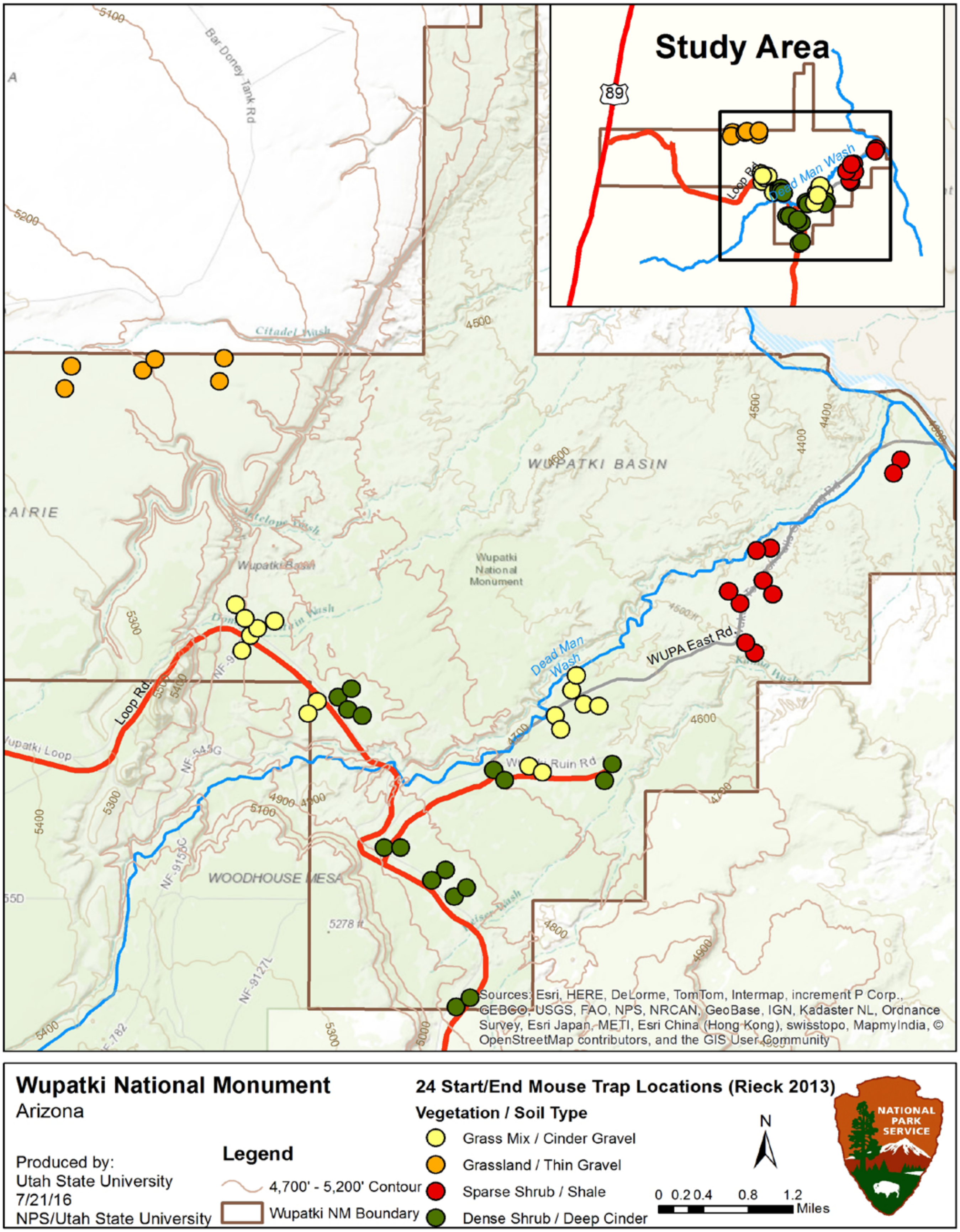


Figure 4.14.4-1. Rieck's (2013) 24 Wupatki pocket mouse sampling locations within the park according to the four vegetation/soil types.

vegetation types (Rieck 2013). The number of Wupatki pocket mice per trap night was significantly higher in black grama sites and significantly lower in sites in juniper scrub, saltbush, and galleta sites. However, the results showed no significant difference in the number of mice per trap night among black grama and three other shrub-dominated types- sand sage, rabbitbrush, and Mormon tea. The average number of Wupatki pocket mice per trap night for all seven vegetation types ranged from <0.005 to approximately 0.055. However, note that Rieck (2013) concluded that their findings in some cases were probably confounded by the effects of elevation and land use. For example, all of the juniper scrub habitats sampled were above 1,570 m (5,150 ft) in elevation, so the lower mouse abundance in this type may have been due to effects of elevation (due to temperature) rather than vegetation (Rieck 2013).

Figure 4.14.4-2. Dense shrub/deep cinder vegetation and soil type. Photo Credit: NPS.

Using the reference conditions described in Table 4.14.3-1, the condition of the presence and relative abundance by vegetation type for the Wupatki pocket mouse is good. The mouse was captured at 88% of the sites within the park (15 of 17), occurring in a number of vegetation types sampled, with abundance being relatively high in at least some of the sites/vegetation types. Again, no information on trend is available, and our confidence in the assessment is medium because the data are now over five years old. Also, as noted above, this aspect of the Rieck (2013) analysis may have been confounded by the effects of elevation and land use.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

To assess the condition of the Wupatki pocket mouse at the national monument, we used one indicator with two measures, which are summarized in Table 4.14.4-3. The two measures are related because they

Table 4.14.4-1. Descriptions of the four vegetation/soil types used by Rieck (2013) to analyze Wupatki pocket mouse sampling data.

Vegetation/Soil Type	Dominant Plant Type	Soil Type
Grassland/Thin Gravel	Bunch grasses common to the Great Basin, such as black grama (*Bouteloua eriopoda*), galleta (*Pleuraphis jamesii*), needle-and-thread (*Hesperostipa comate*), and alkali sacaton (*Sporobolus airoides*).	a thin covering of limestone and cinder gravel (approximately 1-5 cm (0.4-1.97 in) diameter) over silt limestone soil
Grass Mix/Cinder Gravel	A combination of black grama (*Bouteloua eriopoda*) and needle-and-thread (*Hesperostipa comate*) grasses and shrubs (25-40% vegetative cover) such as broom snakeweed (*Gutierrezia sarothrae*), rubber rabbitbrush (*Ericameria nauseosa*), shadscale (*Atriplex confertifolia*), fourwing saltbush (*Atriplex canescens*), and Mormon tea (*Ephedra viridis*).	deeper cinder/limestone gravel (4-8 cm (1.6-3.15-in))
Dense Shrub/Deep Cinder	Dense (25-40% vegetative cover) shrub cover including mound saltbush (*Atriplex obovata*), fourwing saltbush (*Atriplex canescens*), Mormon tea (*Ephedra viridis*), bush muhly (*Muhlenbergia porteri*), Apache plume (*Fallugia paradoxa*), and crispleaf buckwheat (*Eriogonum corymbosum*).	a deep covering (8-12 cm (3.15-4.7 in) of black, pea-sized or smaller cinders that often formed dunes (especially in the southern areas of Wupatki NM)
Sparse Shrub/Shale	Sparse (2-15% vegetative cover) shrubs such as mound saltbush (*Atriplex obovata*), fourwing saltbush (*Atriplex canescens*), Mormon tea (*Ephedra viridis*), crispleaf buckwheat (*Eriogonum corymbosum*), shadscale (*Atriplex confertifolia*), and sometimes bush muhly (*Muhlenbergia porteri*).	soft, sedimentary silt with a surface covering of shale "plates" (about 15 to > 30 cm-diameter (5.9 to > 11.8 in) diameter)

Table 4.14.4-2. Descriptions of the seven vegetation types used by Rieck (2013).

Vegetation Type	Dominant Plant Species *
Black Grama	Black grama, Mormon tea, broom snakeweed, rabbitbrush, needle-and-thread grass, mound saltbush, four-wing saltbush, and juniper
Galleta	Galleta grass, broom snakeweed, needle-and-thread grass, mound saltbush, and four-wing saltbush
Saltbush	Mormon tea, shadscale, mound saltbush, and four-wing saltbush
Mormon Tea	Mormon tea, Apache plume, mound saltbush, and four-wing saltbush
Rabbitbrush	Rabbitbrush, broom snakeweed, mound saltbush, four-wing saltbush, and black grama
Sand Sage	Sagebrush, Mormon tea, Apache plume, mound saltbush, and four-wing saltbush
Juniper Scrub	Black grama, broom snakeweed, rabbitbrush, and juniper

* Only common names of plants are provided, but nearly all scientific names are provided in Table 4.14.4-1.

are based largely on the same dataset; they are really two different ways of examining condition. Overall, based on the information available, we consider the subspecies at Wupatki NM to be in good condition. Our confidence in the assessment is medium because the data are now over five years old. Trends in condition are unknown. The sampling conducted by Rieck (2013) and Drost (2009) provides a sound baseline for future monitoring of the Wupatki pocket mouse in the national monument.

Our confidence in this condition assessment is medium, primarily because the data upon which it is based are not current. We also consider confidence as medium because the numbers presented for both measures include sites outside of Wupatki NM. The main issue that Rieck (2013) pointed out in her study was that her findings regarding vegetation type may have been confounded by the effects of elevation and land use. However, regardless of how the data were analyzed, a number of Wupatki pocket mice were captured at the majority of sites within the national monument, as well as a considerable number of sites outside of the monument.

Threats, Issues, and Data Gaps

As with other species of wildlife in the Southwest, concerns exist over potential adverse effects to the Wupatki pocket mouse due to climate change (Rieck 2013). A recent study shows that the desert Southwest, already a dry region, has become drier, shifting the region into an overall drier climate pattern (Prein et al. 2016). Temperature has also increased in the region (Hansen et al. 2014, Prein et al. 2016). Increased temperature has the potential to shift biomes northward and higher in elevation. The range of the Wupatki pocket mouse could be affected by relatively

Table 4.14.4-3. Summary of Wupatki pocket mouse indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Wupatki Pocket Mouse Occurrence	Site Occupancy by Vegetation/ Soil Type		Current condition of the Wupatki pocket mouse under this measure is good. The mouse was captured at 92% of the locations sampled within the park (22 of 24 sites), and the mean model-averaged psi was high or relatively high in three of the four vegetation/soils types sampled. No information on trends is available. Our confidence in the assessment is medium, because the data are now over five years old.
	Presence & Relative Abundance by Vegetation Type		Condition of the mouse under this measure is good. The mouse was captured at 88% of the sites within the park (15 of 17), and it occurred in a number of vegetation types sampled, with abundance being relatively high in at least some of the sites/vegetation types. Again, no information on trends is available, and our confidence in the assessment is medium, because the data are now over five years old. Also, this aspect of the Rieck (2013) analysis may have been confounded by the effects of elevation and land use.
Overall Condition			The two measures used to assess current condition are not independent, because they are based on the same data set. The current condition of the Wupatki pocket mouse is good, but we have only medium confidence in the assessment because the data are 4-5 years old. Trends in condition are unknown. The sampling conducted by Rieck (2013; and Drost 2009) provides a sound baseline for future monitoring of Wupatki pocket mouse occurrence in the national monument.

rapid changes in climate (Rieck 2013). Changes could interact with the temperature and moisture limits of the mouse, as well as the plant communities composing its habitat (Rieck 3013). Because a sensitivity to colder temperatures may limit the upper elevational range of the Wupatki pocket mouse, climate change may allow the subspecies to shift to higher elevations than it historically occurred. However, as Rieck (2013) found along the northern boundary of Wupatki NM, human land use (such as livestock grazing) may constrain such a shift. Based on her research in the park, Rieck (2013) suggested that additional research might help to better understand the Wupatki pocket mouse's distribution with regards to vegetation type. She was not able to cleanly distinguish the effect of vegetation type from elevation or land use (Rieck 2013). A study on the diet of the mouse would more closely tie its distribution in the park to particular plants.

4.14.5. Sources of Expertise

No outside experts were consulted for this assessment, but it was based on the research conducted by Rieck (2013) and Drost (2009) at the national monument. Patty Valentine-Darby, Biologist and Writer/Editor with Utah State University, authored the assessment.

Flagstaff Area National Monuments' Natural Resource Management Specialist, Paul Whitefield, demonstrates how a modified fence allows wildlife, such as American pronghorn, to move across the landscape. Photo Credit: NPS.

Chapter 5. Discussion

5.1. Overall Condition Summary

The Colorado Plateau Ecoregion has the highest density of national parks, monuments (including the Flagstaff Area National Monuments (NMs)), and recreational areas than any other location in the United States (AZGFD 2006). However, despite the high number, land managers are increasingly recognizing resource impacts from activities occurring outside their jurisdictions, underscoring the fact that no single agency (or group of agencies) can conserve species survival needs alone. Instead, these protected lands need to be linked with their surrounding landscapes, working together as a whole, especially given the very real threats of climate change and increasing habitat fragmentation.

This landscape-scale influence on Wupatki NM's natural resources is apparent for some of its condition ratings that are summarized in Table 5.1-1. For example, even though most of the monument's evaluated resources were in good condition, including viewshed, night sky, and most of the biological topics, the water-based resources have been negatively impacted, primarily due to activities occurring outside the monument's boundary.

Impacts from over-grazing and human water use along the entire length of the Little Colorado River have decreased surface and ground water flows—a scare resource that all living species rely upon. In turn, the decreased flows have affected channel morphology, sedimentation, and erosion at the monument. In addition, adjacent floodplains have been extensively infested with non-native camelthorn (*Alhagi maurorum*) and monoculture thickets of tamarisk (*Tamarix spp.*), also influencing riparian habitat conditions, both within and outside Wupatki NM.

These types of land-use impacts surrounding Wupatki NM, coupled with impacts from climate change and the ever-increasing population in the greater-Flagstaff, AZ area, make it imperative for land managers to understand resource needs from a landscape-scale perspective if resource sustainability is to be achieved. This is already a familiar concept and management strategy for the Flagstaff Area NM resource management staff. The monument staff have worked in partnership with several agencies and stakeholders to proactively manage Wupatki, Walnut Canyon, and Sunset Crater Volcano NMs' resources in such a way that maintains and/or improves resource conditions.

Table 5.1-1. Overall condition summary of Wupatki NM's natural resources.

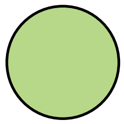
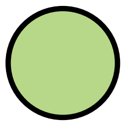
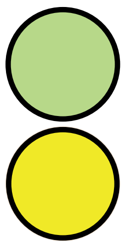
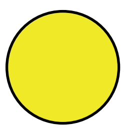
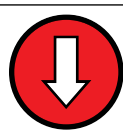
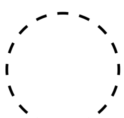
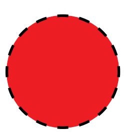
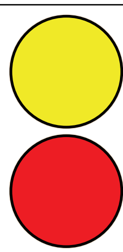
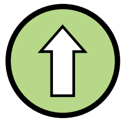
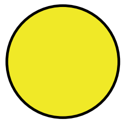
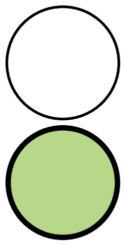
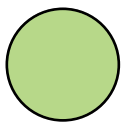
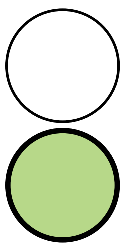
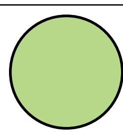
Priority Resource or Value	Condition Status/Trend	Summary of Overall Condition Rating
Viewshed		Viewsheds are an important part of the visitor experience at national parks, and features on the landscape influence the enjoyment, appreciation, and understanding of a particular region. At Wupatki NM, few human-made features are visible within the monument's assessed viewshed. Both housing and road densities are low, resulting in a good condition rating. There are no data available to determine overall trend. Instead, these data may serve as a baseline to make future comparisons. Confidence in this condition rating is medium since the majority of data used were based on models.
Night Sky		Wupatki NM preserves a dark night sky rarely found in other regions, an attribute acknowledged by its designation as an International Dark Sky Park in 2016. Of the five measures used to assess condition, three are good and two are unknown due to lack of reference conditions. Field data were collected over a 11-year period (2002-2012), and there were only three data points from which to assess condition. Trend is unknown; however, confidence in the data is high.
Soundscape		Natural sounds and the absence of human-caused noise are important resources to national park visitors and wildlife. In Wupatki NM, sound levels rarely exceeded 45 dBA, which is the maximum recommended noise level for bedrooms, indicating a quiet environment. Overall, the soundscape at Wupatki NM ranges from good condition to warranting moderate concern. Confidence is the data is high but trend is unknown at this time.
Air Quality		The air we breathe is important for good human health, as well as maintaining viable conditions for wildlife, vegetation, soil, and water quality. It also affects our ability to see scenery. Of the various measures used to assess the air quality at Wupatki, wet deposition is good, visibility is of moderate concern, and ozone levels are of significant concern for both human and vegetation health. The only trend is for visibility, which is improving. The overall confidence in the data is medium due to interpolated values.
Sunset Crater Tephra Layer		The Sunset Crater tephra layer is loose and unconsolidated covering an actively mobile surface sediment that provides a tenuous substrate for plant communities. The layer continues to be transported downwind and downslope towards the Little Colorado River, which is of significant concern with a deteriorating trend. Confidence in the data is high.
Geomorphic Stability		This assessment was based on the geomorphic stability of intermittent, ephemeral streams (i.e., dry wash systems) in Wupatki Basin and on Antelope Prairie within the national monument. Data are limited to non-existent for this resource, resulting in an unknown condition and represents a data gap for park managers.
Seeps, Springs, and Surface Water		Surface water at Wupatki NM occurs as springs, seeps, ephemeral pools, dry washes, and rivers. Water is a rare but critically important resource for humans, wildlife, and plants. Of the four measures used to assess condition, only one, depth to groundwater, could be evaluated. It is of significant concern but improving. The conditions of the remaining measures is unknown because of the age of the available data. The trend is unknown for this resource and the confidence level is low.
Little Colorado River Riparian Corridor		The Little Colorado River (LCR) and the Deadman Wash (DMW) riparian area is a source of water and habitat for plants and animals in Wupatki NM. The measures evaluated the hydrology, vegetation, physical processes (erosion/deposition), and avian wildlife of the area. In some cases, individual measures applied only to the LCR or DMW. While conditions of individual measures vary, the overall rating is of moderate to significant concern, with medium confidence and an unknown trend.

Table 5.1-1 continued. Overall condition summary of Wupatki NM's natural resources.

Priority Resource or Value	Condition Status/Trend	Summary of Overall Condition Rating
Vegetation		The western half of Wupatki NM is covered by a mosaic of semiarid grasslands, juniper woodlands, and juniper savannas. Throughout the Southwest, intact grasslands that are in good condition are relatively rare and are of particular wildlife conservation value. Overall, Wupatki's vegetation communities are considered to be in good condition, including its grasslands, with a high confidence level and improving trend.
Non-native and Invasive Plants		Non-native invasive plants (NNIPs) have the ability to alter ecosystem structure and function. Mapping data indicate relatively low occurrence for most NNIPs at Wupatki NM. Of the 38 known to occur in the monument, the most problematic are tamarisk and camelthorn in the Wupatki Basin. The overall condition warrants moderate concern, with medium confidence and an unknown trend.
Earthcracks and Blowholes		The earthcrack system at Wupatki NM was shaped by geologic forces over the last 65 million years. These subterranean features support a unique community of cave-adapted species and one of the most fragile ecosystems within Wupatki. A research project of the biota within the earthcracks is underway. Through the project's efforts, it is known that white-nose syndrome is absent from the bats surveyed in the earthcracks, but until data are fully analyzed, condition is split between unknown and good, with an unknown trend.
Birds		Birds are good indicators of ecosystem health because they can respond quickly to changes in resource and environmental conditions. One hundred seventy-four birds occur on Wupatki's species list, with 47 considered to be of conservation concern. The overall condition of birds is good and of a medium confidence level. Trends are varied between the measures.
American Pronghorn		The American pronghorn is considered to be one of Wupatki NM's key resources and has been observed reaching herds of 20 animals on occasion in the monument. The assessment included three measures resulting in an unknown to good condition, with medium confidence. Trend is unknown, although recent efforts by monument staff and partnership agencies have improved pronghorn permeability across the landscape.
Wupatki Pocket Mouse		The Wupatki pocket mouse is an endemic subspecies that is known to occur only within Wupatki NM and on adjacent lands within the Little Colorado River Basin. The condition of the mouse in Wupatki NM is good, with medium confidence level and an unknown trend.

An excellent example is the fence modifications that have been made along Wupatki's boundary as well as at other locations outside the monument. These modifications have facilitated the movement of American pronghorn (*Antilocapra americana*) across the landscape, which is a species of high conservation value for Wupatki NM (NPS 2015a).

5.2. Habitat Connectivity Importance

Some of the greatest threats to wildlife species and biodiversity around the globe are from habitat loss and fragmentation associated with land use changes (Turner 1989, US General Accounting Office 1994, Trzcinski et al. 1999, Fahrig 2003 as cited in Monhan et al. 2012). This loss increases the risk of species extirpation or extinction; thus, maintaining connectivity of habitat is an integral part of protecting species (Crooks and Sanjayan 2006). In general, a connected landscape increases population viability for numerous species (Beier and Noss 1998) but also maintains or improves conditions of abiotic resources such as scenic views, natural quiet, and dark night skies— resources that most park visitors value and appreciate and that certain wildlife species require for their survival.

In 1980, the National Park Service (NPS) reported that over 50% of threats to park resources were from activities occurring outside park boundaries. Surrounding development, such as roads and railroads, housing/business developments, and air pollution were the most frequently cited concerns (NPS 1980). To further exacerbate these threats, specifically to national park resources, Davis and Hansen's (2011) study of land use change trajectories noted that lands surrounding national parks were altered at a more rapid rate than national averages.

Unfortunately, after almost 40 years, the concerns cited in NPS (1980) and Davis and Hansen (2011) are even more relevant and threatening to park resources today. The reality is that very few national parks are large enough to encompass a self-contained ecosystem to adequately conserve species' life cycle needs (Monahan et al. 2012). Thus, partnerships that focus on landscape-scale conservation goals are critical for achieving resource sustainability.

5.2.1. Arizona and Coconino County Population

Throughout the state of Arizona, the population is expected to increase from almost 6.5 million in 2010 to more than 14 million by 2050 (Arizona Department of Transportation [ADOT] 2010, U.S. Census Bureau 2011, both as cited by AGFD 2011a). This same source notes that the population of Coconino County, where the Flagstaff Area National NMs are located, may increase by more than 50% by the year 2050. Based on 2010-2015 data, the populations of both Coconino County and Flagstaff, AZ have increased over the five-year period since April 2010, increasing 3.5% and 6.4%, respectively (U.S. Census Bureau 2016a).

5.2.2. Preserving State-wide and Coconino County Habitat Connectivity

In 2004, a group of concerned land managers and biologists from federal, state, and regional agencies, along with researchers from Northern Arizona University (NAU) formed the Arizona Wildlife Linkages Workgroup (AWLW). The workgroup identified critical areas that would help preserve Arizona's diverse natural resources in the midst of the state's rapid population growth. They identified and mapped large areas of protected habitat (i.e., habitat blocks) and the potential linkages (i.e., matrix) between these blocks. This effort became known as the *Arizona Missing Linkage*s project, identifying 152 statewide coarse-level linkage zones (AWLW 2006). The Deadman Mesa – Gray Mountain linkage was the only one associated with any of the national monuments, with Wupatki NM's western boundary accounting for 3% of the linkage area along Highway 89 (AWLW 2006).

Following AWLW's statewide effort, in 2009 and 2010 the Arizona Game and Fish Department (AGFD), in partnership with Coconino County and the AWLW, developed a *Wildlife Connectivity Assessment Report* for Coconino County (AGFD 2011a). The goal of this was to facilitate the maintenance and enhancement of wildlife connectivity throughout the county. The linkages identified were intended to be used as a starting point to assist future finer-scale evaluations of habitat connectivity throughout the county. Several of the linkages identified in Coconino County are associated with the three Flagstaff Area NMs.

Coconino County encompasses an area of 48,332 km^2 (18,661 mi^2), with Wupatki, Walnut Canyon, and Sunset Crater Volcano NMs protecting a little over 170 km^2 (~65.6 mi^2) of public land combined. And while the national monuments are managed as one administrative unit, they are separated by approximately 17.7 km (11 mi) between Walnut Canyon NM and Sunset Crater Volcano NM and about 17.1 km (10.6 mi) between Sunset Crater Volcano NM and Wupatki NM (as a straight line distance from the northern boundary of the first stated monument to the southern boundary of the second monument). The physical separation of the monuments, some of which support the same wildlife species, presents unique management challenges and opportunities, which is why monument staff were interested in evaluating the habitat connectivity between the three national monuments as part of their NRCA effort.

According to Monahan et al. (2012), "the importance of habitat area and pattern is readily apparent for parks, but it is nonetheless difficult to identify a small suite of metrics that adequately describe area and pattern characteristics in ways that generally inform decisions on how to manage park resources. Many people want to know, for example, whether large intact patches of habitat still exist, without reference to any particular species or other resource. [However,] the most important habitat features vary according to question, species, or issue. For example, structural connectivity measures physical attributes without any consideration to species or ecological function. [Conversely], functional connectivity measures landscape attributes, such as land cover type, elevation, distance from roads, etc., that are relevant to an identified species or process.” As a result, habitat connectivity “is shaped by both pattern and the attributes of what is moving” (Monahan et al. 2012). It is within this functional connectivity context that NAU scientists developed tools to assist others in evaluating habitat connectivity on a landscape-scale. While NRCAs are not designed to report on conditions outside a park’s boundary, an evaluation such as this can serve as an initial step to identify areas that may be of high conservation value, thereby, working “for connectivity than against fragmentation” (Beier et al. 2008).

5.3. Habitat Connectivity Methods

5.3.1. Arizona CorridorDesigner and Area of Analysis Characteristics

Identifying functional habitat connectivity between the three national monuments required several steps throughout the analysis process. These steps or descision points are listed in Appendix I, Table I-1, using a framework from lessons learned during NAU’s *Arizona’s Missing Linkages* (AWLW 2006) and *South Coast Wildlands 2003-2006* (Penrod et al. 2006) wildlife linkages projects. NAU conservation biologists and GIS analysts developed this decision framework along with two GIS toolboxes, CorridorDesigner and Arizona CorridorDesigner (2007-2013) (Beier et al. 2008, Majka et al. 2007), to guide end-users in creating “a transparent, rigorous rationale for a linkage design.”

To begin the Flagstaff Area NMs’ connectivity evaluation process, an area of analysis (AOA) needed to be determined. Through an extensive literature review of ecologically-relevant AOAs, Monahan et al. (2012) identified a 30 km (18.6 mi) radius from a park’s boundary as sufficient for meeting most park’s natural resource survival needs (NPS 2011c). Following this guidance, a dissolved 30 km buffer surrounding each monument’s boundary served as the entire AOA, totaling 7,489 km² (2,891.5 mi²) (Figure 5.3.1-1, Table 5.3.1-1). The land within each monument’s legislated boundary served as the habitat blocks from which the matrix or connectivity between the monuments was evaluated. Each individual monument and its surrounding 30 km (AOA) is discussed in more detail within its respective NRCA report, although a certain degree of overlap exists between the three monuments’ habitat connectivity discussions given the nature of the topic.

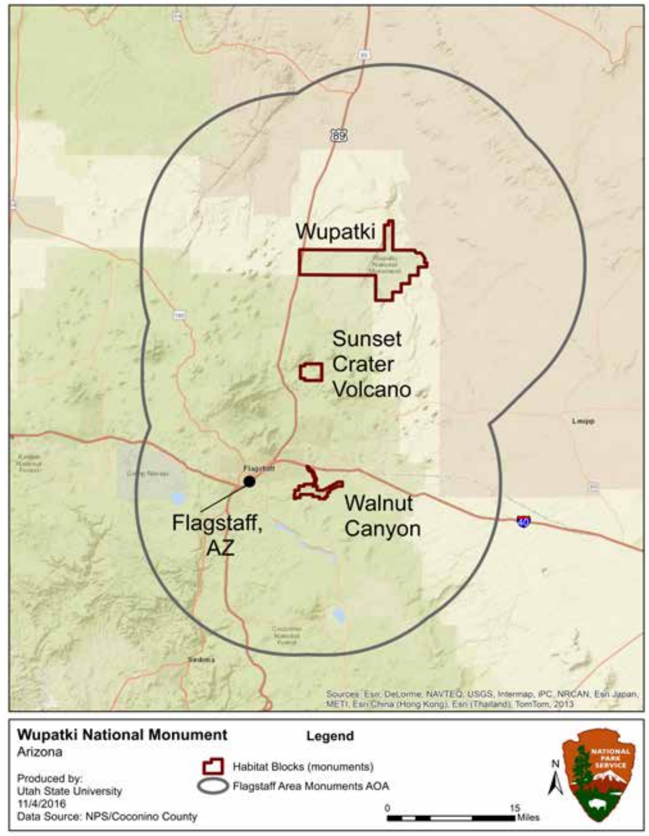


Figure 5.3.1-1. The entire area of analysis for Flagstaff Area NMs’ habitat connectivity evaluation is 7,489 km².

Wupatki NM encompassed the largest 30 km AOA (shown in thicker black polygon in all subsequent figures), totaling 4,917 km² (1,898 mi²) or 65.7% of the entire Flagstaff Area AOA. Wupatki NM’s 30 km AOA extended just north of Cameron, AZ beyond the intersection of Highways 89 and 64 to the east, approximately 30.6 km (19 mi) into the Navajo Reservation and 11.3 km (7 mi) west of Leupp, AZ. Wupatki’s AOA encompassed all of Sunset Crater Volcano NM and extended 5.6 km (3.5 mi) north of Flagstaff, AZ then to the west, including the majority of San Francisco Mountain and a portion of Highway 180. Information specific to Walnut Canyon and

Table 5.3.1-1. Area of analysis summary.

Area	Sq. km	Sq. Miles	% Total
Entire AOA	7,489	2,891.5	100
Wupatki NM	4,917	1,898	65.7
Sunset Crater Volcano NM	3,254	1,256	43.4
Walnut Canyon NM	3,607	1,393	48.1
Area of Overlap	1,096	423	14.6

Sunset Crater Volcano NMs is also presented in Table 5.3.1-1 but will be further discussed within each of their respective NRCA reports.

The U.S. Geological Survey (USGS) (2016e) Gap Analysis Program (GAP) Protected Areas Database (PAD)-US version 1.4 conservation status metric was used to calculate the percentage of Flagstaff Area NMs' 30 km AOA that is classified as GAP status 1-4 categories (1 = highest protection, 4 = lowest protection) (refer to Appendix I for category definitions) and the percentage of broad ownership categories (e.g., federal, state, tribal, etc.). According to Monahan et al. (2012), "the percentage of land area protected provides an indication of conservation status and offers insight into potential threats (e.g., how much land is available for conversion and where it is located in relation to a park's boundary), as well as offers insights into potential opportunities (e.g., connectivity and networking of protected areas)."

Within the entire Flagstaff Area AOA, 42,606 hectares (ha) (105,282 ac) (5.7%) of land is designated as permanently protected and managed for biodiversity (dark and light green areas shown in Figure 5.3.1-2). Disturbance events on 39.5% of the permanently protected lands are allowed, whereas events are suppressed on the remaining 60.5% of those permanently protected lands. Another 331,835 ha (819,983 ac) (44.3%) of land within the entire AOA is managed for multiple uses, such as logging, mining, etc. (yellow areas shown in Figure 5.3.1-2). The U.S. Forest Service (USFS) and Bureau of Indian Affairs are the primary agencies managing 363,302 ha (897,739 ac) (48.5%) and 242,425 ha (599,046 ac) (32.4%) of the land throughout Flagstaff Area NMs 30 km AOA.

The conservation status of lands specifically within Wupatki's 30 km AOA is largely comprised of lands with no known mandate for protection (gray areas on Figure 5.3.1-2), accounting for 86.3% of land within its AOA. This percentage does not include the 42,338 ha (104,620 ac), shown in white on Figure 5.3.1 2, because those lands are not included in the GAP status dataset. The white areas represent potentially unprotected or privately held land and include the city of Flagstaff, AZ. In other words, the 30 km AOA surrounding Wupatki NM contains the lowest percentage of protected land when compared to the other two monuments, but this does not necessarily imply more development.

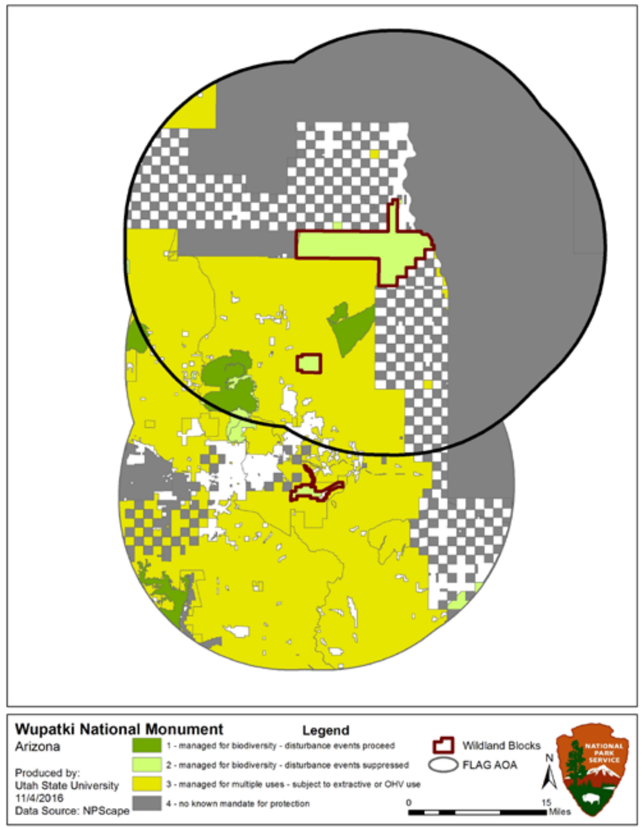


Figure 5.3.1-2. The conservation status of lands within the entire area of analysis surrounding Flagstaff Area NMs.

5.3.2. Arizona CorridorDesigner Models

The Arizona CorridorDesigner toolbox was developed to assess habitat suitability and size of breeding areas for 16 mammal and 12 herpetofauna Arizona wildlife species. In turn, these models are used to develop wildlife corridor models. For Wupatki NM, seven native wildlife species (American badger (*Taxidea taxus*), American black bear (*Ursus americanus*), American pronghorn, black-tailed jack rabbit (*Lepus californicus*), kit fox (*Vulpes macrotis*), mountain lion (*Puma concolor*), and mule deer (*Odocoileus hemionus*), which are listed on its species list (NPS 2016b) were selected to evaluate habitat connectivity between its boundary and Sunset Crater Volcano and Walnut Canyon NMs. These species and their associated selection criteria are presented in Table 5.3.2-1. Kit fox is the only species of concern, listed as a species of greatest conservation need in Arizona (AGFD 2012).

The Arizona CorridorDesigner toolbox outputs for each species included three models that were mapped at a 30 m x 30 m (98 ft x 98 ft) resolution: 1) habitat

Table 5.3.2-1. Arizona CorridorDesigner wildlife species selected for Wupatki NM's habitat connectivity assessment and their associated habitat factors.

Common Name	Scientific Name	Species Selection Criteria	Land Cover	Elevation	Topography	Distance From Roads
			Percent (%)			
American badger	*Taxidea taxus*	Large home range; many protected lands are not large enough to ensure species' life cycle.	65	7	15	13
American black bear	*Ursus americanus*	Requires habitat variety; low population densities makes them vulnerable to habitat fragmentation.	75	10	10	5
American pronghorn	*Antilocapra americana*	Susceptible to habitat fragmentation and human development; sensitive to barriers.	45	0	37	18
Black-tailed jack rabbit	*Lepus californicus*	Important seed dispersers and prey for other species; frequently killed by vehicles.	70	10	10	10
Kit fox*	*Vulpes macrotis*	Susceptible to habitat conversion and fragmentation.	75	0	15	10
Mountain lion	*Puma concolor*	Requires a large area of connected landscapes to support even minimum self sustaining populations.	70	0	10	20
Mule deer	*Odocoileus hemionus*	Important prey species; road systems may affect the distribution and welfare of species.	80	0	15	5

* Listed as a Species of Greatest Conservation Need in Arizona (AGFD 2012).

suitability models (HSM), 2) patch models (PM), and 3) corridor models (CM). Four datasets were used to create a HSM for each species: 1) Southwest Regional Gap Analysis Project (SWReGAP) land cover (USGS 2004), (2) U.S. Geological Survey's (USGS 2016a) National Elevation Dataset (NED) digital elevation model (DEM), (3) topography, and (4) distance from roads.

Subject matter experts assisted with identifying attributes within each dataset that served as proxies for each of the species survival needs, including cover, food, hazard avoidance, reproductive habitat needs, etc. If an expert was unavailable, three biologists independently reviewed the scientific literature and assigned scores then compared their results to calculate an average score.

The SWReGAP land cover dataset was categorized into 46 vegetation classes creating 10 broad categories, such as evergreen forest or grassland-herbaceous vegetation. By grouping the closely related vegetation types, the accuracy of the models improved (Beier et al. 2008). Using the entire Flagstaff Area NM 30 km AOA, the SWReGAP's land cover dataset was clipped, and resulted in all 10 land cover types occurring within the AOA (Figure 5.3.2-1). Shrub-scrub (tan), grassland-herbaceous (light green), and evergreen

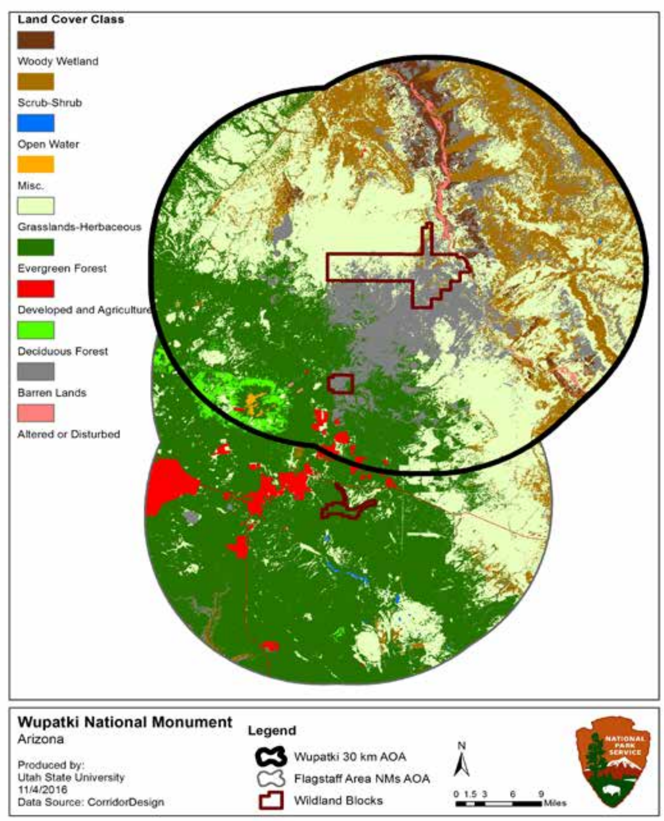


Figure 5.3.2-1. Land cover classes within the Flagstaff Area NM 30 km area of analysis.

forest (dark green) are the dominant land cover types throughout the AOA and are situated along a northwest to southeast gradient from north to south. The main land cover types within Wupatki NM's 30 km AOA were shrub-scrub, grassland-herbaceous, barren land, (representing the volcanic-derived landscape between Sunset Crater Volcano and Wupatki), and evergreen forest.

Using the USGS (2016a) NED DEM, topographic features such as aspect and slope were analyzed to create topographic position categories (i.e., canyon bottom, flat-gentle slopes, steep slopes, and ridgetop; Figure 5.3.2-2). These features were ranked for each species based on their survival needs. For example, Ockenfels et al. (1996) noted that pronghorn avoid canyon walls due to the increased likelihood of mountain lion predation and instead prefer flat to gently rolling terrain where they are able to easily detect predators. This topographic preference is shown in Table 5.3.2-1, with the highest topography rank of 37% assigned to pronghorn, reflecting its sensitivity to this feature.

Elevations were identified for each species also using the USGS (2016a) NED DEM. And finally, distance to nearest roads was used as a proxy for disturbance avoidance. Beier et al. (2008) suggested not including crossing structures in the habitat connectivity evaluation process since it "forces the position of a modeled corridor, which may in fact be a suboptimal location."

Four scores, based on a scale of 1 (best habitat) to ten (worst habitat), were assigned to each grouping or class of attributes within each of the four datasets for a given species. Each 30 m x 30 m pixel was assigned a score between 1 and 10 then each factor was weighted by a factor between 0 - 100%, summing to 100%. The four weighted scores were combined using a weighted geometric mean to "better reflect situations in which one factor limits wildlife movement in a way that cannot be compensated for by a lower resistance for another factor" (UWFWS 1981 as cited in Beier et al. 2008). This scoring process created the HSMs for each species, which were then used to create the PMs and CMs (refer to Beier et al. 2008 for a detailed account of the methodology involved in developing these models).

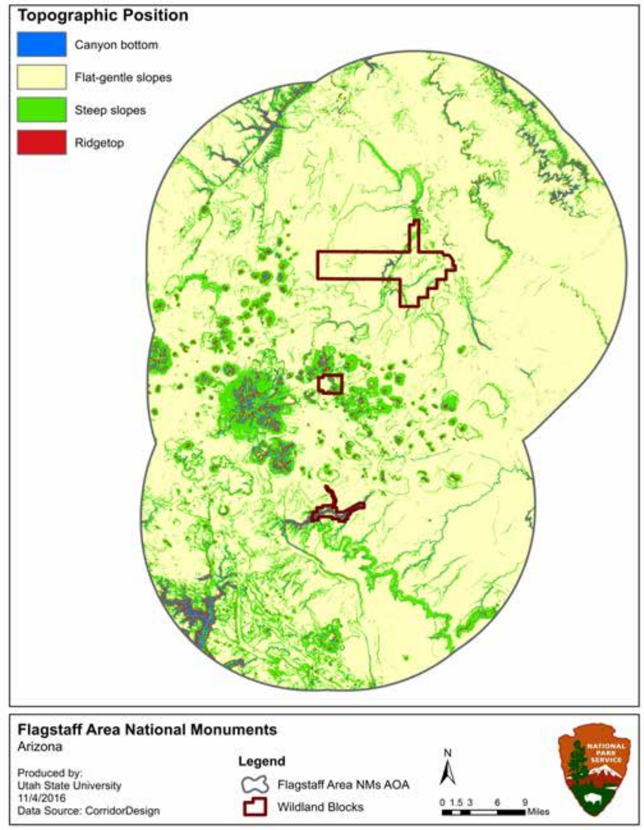


Figure 5.3.2-2. Topographic position within the Flagstaff Area NM 30 km area of analysis.

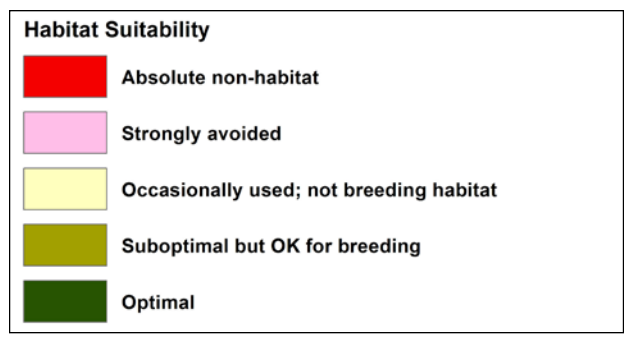


Figure 5.3.2-3. Five classes were used in each species' habitat suitability model.

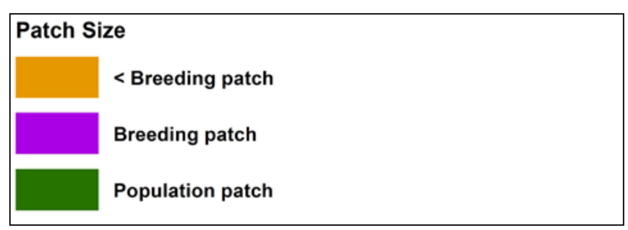


Figure 5.3.2-4. Three classes were used in each species' patch model.

The HSMs identified five classes of habitat suitability for each species based on the weighted habitat factors. The five classes, shown in Figure 5.3.2-3, ranged from absolute non-habitat to optimal. Areas of habitat large enough to support breeding populations were identified using neighborhood analysis, creating PMs. The PMs were grouped by size into three classes: less than (<) breeding patch, breeding patch, and population patch as shown in Figure 5.3.2-4. The population patch was the largest area of the three classes and represented the ability to support the breeding requirements of a given species for 10 or more years, even if isolated from interaction with other populations of the species (Majka et al. 2007). The breeding patch represented a "core" area for each species. A breeding patch was smaller than a population patch, but large enough to occasionally support a single breeding event and serve as a potential "stepping stone" within a corridor linkage (Beier et al. 2008).

Finally, the third model type, CM, was created by identifying well-connected pixels in the HSMs and PMs that represented the easiest area for a particular species to move through. This is based on the assumption that the habitat requirements for each species survival are the same ones needed for their movement patterns (Beier et al. 2008). The habitat patches within the wildland blocks (i.e., monuments) were used as the corridor terminuses, and the travel cost was mapped as increasingly wide polygons sliced into 11 different widths (i.e., 0.1%, 1-10%). The smallest slice (i.e., 0.1%) represented the least amount of effort or resistance for a species to move through. As the corridor widths increased so did practical constraints that would affect realistic conservation efforts by land managers. As a result, each species largest corridor width was selected based on its home range size, using information provided in Majka et al. (2007). Finally, all selected CM slices were unioned (and minimally trimmed only when an area represented one species but suitable habitat was available nearby within the remaining corridor), showing potential areas of connectivity to facilitate movements of the selected species. The output for this phase of the evaluation process is referred to as the preliminary linkage design (PLD).

5.4. Preliminary Linkage Design Results

The PLD for Wupatki NM, shown in Figure 5.4.1-1, resulted in two primary areas linking Wupatki NM to Walnut Canyon and Sunset Crater Volcano NMs. Majka et al. (2007) suggested not modeling corridors for species where no habitat patches exist within the wildland blocks (i.e., monuments). As a result, Wupatki's PLD is based on the unioned CMs for badger, pronghorn, mountain lion, and mule deer. Corridors were not created for kit fox and black-tailed jack rabbit since they are listed as present only in Wupatki NM. However, the preliminary results favored species dependent on grasslands, which would benefit both the kit fox and black-tailed jack rabbit. In addition, black bear was not included in Wupatki's linkage design because the best habitat is located south of Walnut Canyon and west of Wupatki and Sunset Crater Volcano NMs. Including it would have confounded Wupatki's PLD by creating additional strands only serving black bear. Furthermore, these additional strands were located in areas designated as 'absolute non-habitat' for bear. Instead Walnut Canyon NM's PLD will include results for the black bear CM.

The dominant land cover classes within Wupatki NM's 30 km AOA included woody wetland, scrub-shrub, and grasslands and herbaceous cover types, which support the life cycles of species including pronghorn, black-tailed jack rabbit, kit fox, mountain lion, and to a lesser extent, black bear. Sunset Crater NM's volcanic landscape, classified as barren, is located throughout Wupatki NM's eastern area and to the south extending to Sunset Crater Volcano NM. There is evergreen forest habitat within Wupatki's 30 km AOA to the southwest and altered and disturbed land, representing tamarisk throughout the Little Colorado River. All of the species' habitat suitability and patch size models, except for pronghorn, classified the barren landscape between Wupatki and Sunset Crater Volcano NMs as 'non-habitat' or 'strongly avoided' (refer to both sets of maps for all species in Appendix I). This resulted in almost all corridor models avoiding this particular area.

Two primary linkage routes were identified, with one located west of Wupatki and one located east of the monument. The western strand is comprised of evergreen forest, which is the predominant land cover type between Wupatki and Sunset Crater Volcano. Whereas, the eastern strand was predominantly comprised of the grassland/herbaceous cover type, with a little evergreen forest, scrub-shrub, barren, and disturbed (i.e., Highway 180) cover types represented.

The western linkage connects Wupatki NM's western boundary to three locations along Sunset Crater

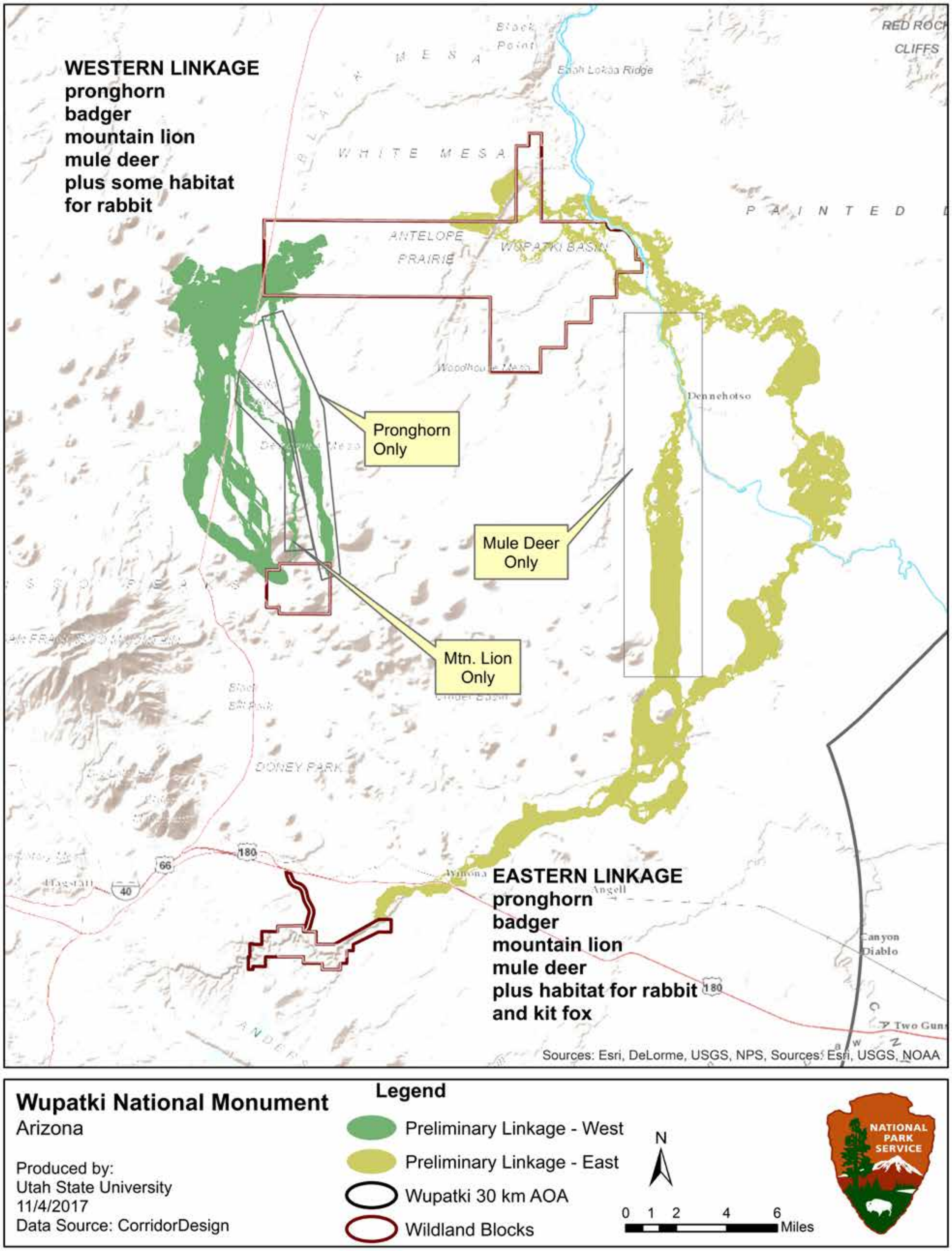


Figure 5.4.1-1. Preliminary linkage design for Wupatki NM only.

Volcano's northern boundary, with the primary linkage located at Sunset Crater Volcano's northwestern corner. Pronghorn, badger, mountain lion, mule deer, and some habitat for black-tailed jack rabbit are included in the wider linkage area west of Highway 89, shown in Figure 5.4.1-1. This strand crosses Highway 89, approximately 3.2 km (2 mi) north of the entrance road to Sunset Crater Volcano NM and approximately 3.6 km (2.25 mi) south of Sacred Peak subdivision. The middle linkage strand is for mountain lion only and the easternmost strand, traversing through the volcanic landscape with interspersed grasslands, is for pronghorn only. Both black bear and kit fox were not represented in the results for the western PLD. The majority of the 17.7 km (11 mi) western PLD is in the Coconino Forest, although none of the PLD is located in the Strawberry Crater Wilderness Area.

The easternmost PLD between Wupatki and Walnut Canyon NMs begins at the northern boundary of Walnut Canyon's northeastern corner and extends approximately 14.5 km (9 mi) through Coconino Forest until it reaches mixed ownership of private and state lands. It continues another 0.64 km (0.4 mi) until it splits into two strands just south of Leupp Road. The left strand of the eastern PLD is for mule deer only and follows the western edge of tribal land eventually paralleling the Little Colorado River. The easternmost split strand, extending approximately 40.2 km (25 mi) all within tribal land, represents connectivity for pronghorn and badger. This strand also includes a kit fox breeding population patch, designated as suboptimal to optimal habitat. While Arizona's habimap does not include Wupatki as part of the kit fox's distribution (AGFD 2015), it appears to have high enough quality habitat for the kit fox's survival needs, especially in the northwestern portion of the monument (refer to HSM and PM figures in Appendix I). While the left strand was identified for mule deer only, it was retained since it shared the same corridor area as the other species mentioned from Walnut Canyon NM until splitting just south of Leupp Road.

Both the Wupatki to Walnut Canyon and Wupatki to Sunset Crater Volcano strands include habitat for black-tailed jack rabbit, although the easternmost strand from Wupatki to Walnut Canyon contains more suitable habitat. The habitat north of Sunset Crater Volcano's boundary is considered to be adequate enough for 'occasional use' but not for breeding purposes. Similar to the kit fox, there is breeding habitat for the rabbit in the northwest area of Wupatki NM. In general, the eastern PLD for badger and pronghorn were nearly identical, representing similar habitat preferences within the herbaceous-grassland cover type. The easternmost strand of Wupatki's PLD is east of the area identified as low-moderate quality for pronghorn by Ockenfels et al. (1996).

Ockenfels et al. (1996) evaluated a landscape-level habitat model for pronghorn within Arizona Game and Fish Department's Game Management Units (GMU). GMU 7E, which encompasses Wupatki and Sunset Crater Volcano NMs (refer to the American pronghorn assessment in this report for GMU maps) was included in the 1996 study. Vegetation types and terrain were the primary criteria used to develop the model. Ockenfels et al. (1996) also included locations of water, fences, and human developments as model modifiers. They identified six classes of habitat suitability based on the aforementioned data and validated the model by locating 84 adult pronghorn over a 2-4 year period in four GMUs. They used both experienced and inexperienced observers as a comparison to determine whether the quality of pronghorn habitat could be consistently identified. Ockenfels et al. (1996) found that determining high quality habitat was the most difficult. Two maps were produced for GMU 7E, showing the locations of pronghorn relative to the habitat quality rank. When comparing the Ockenfels et al. (1996) maps to the PLD results, they are both consistent in showing that the volcanic terrain between Wupatki and Sunset Crater Volcano NMs is mostly avoided. The highest number of observed pronghorn during the Ockenfels et al. (1996) study was in the northwestern - north central portion of Wupatki NM and north of its northern boundary. Ockenfels et al. (1996) map also showed pronghorn paralleling U.S. Highway 89. An interesting observation is that the PLD was not trained with actual highway crossing structures as recommended by Beier et al. (2008), but shows what appears to be a higher concentration of pronghorn gathering along Highway 89 just northwest of Sunset Crater Volcano NM, perhaps suggesting a natural crossing but barrier. The easternmost strand of the PLD for pronghorn actually extends beyond the GMU 7E boundary into tribal land so does not align with the pronghorn locations in the Ockenfels et al. (1006) report. Observers were not able to access all lands during the study, which may be the reason for the difference between the modeled

PLD versus what is shown on the Ockenfels et al. (1996) maps.

Wupatki's 30 km AOA encompassed 15 of the coarse-level linkages identified in the *Wildlife Connectivity Assessment Report* for Coconino County (AGFD 2011a) (Figure 5.4.1-2; refer to Appendix I for summary of these linkages). County linkages 17 and 32 overlapped with the PLD's western strands and linkages 15 and 17 overlapped with the PLD's eastern strands. Linkage 15 includes portions of Wupatki NM and the Navajo Reservation and was identified as important for pronghorn, small mammals, and herpetofauna along the Little Colorado River, which ironically was also identified as a threat for some species' crossing. Coconino County linkage 17 is the largest and includes the grassland north and east of San Francisco Peaks, east of Anderson Mesa. This linkage identified habitat for pronghorn, Gunnison's prairie dog (*Cynomys gunnisoni*), jackrabbit, golden eagle (*Aquila chrysaetos*), milk snakes, birds, and bats. The final linkage, 32, included San Francisco Peaks – Sunset Crater and O'Leary Peak, and identified habitat for elk (*Cervus canadensis*), northern goshawk (*Accipiter gentilis*) and mountain lion. The threats identified within these three Coconino County linkages as they relate to the PLD are discussed in the Threats section.

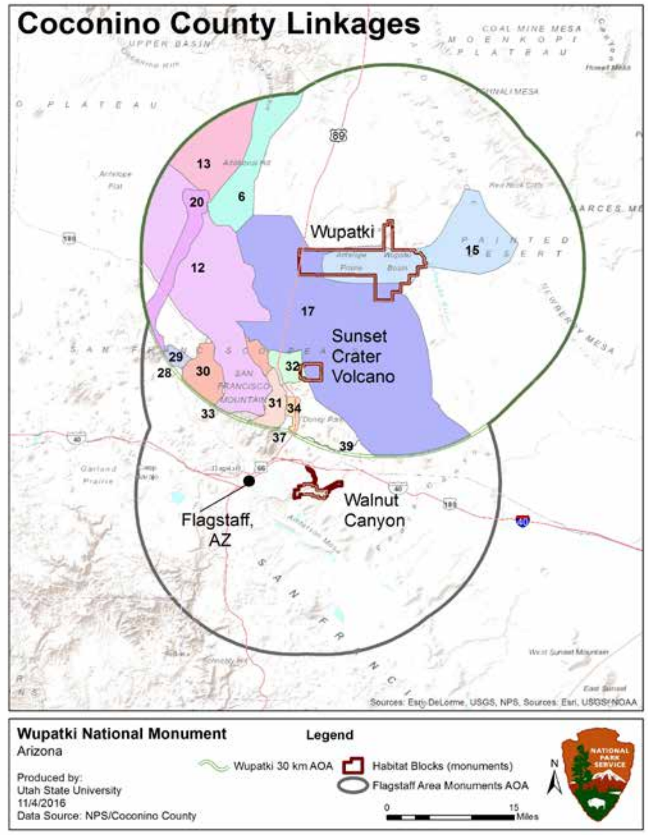


Figure 5.4.1-2. Fifteen Coconino County wildlife linkages were located within Wupatki NM's 30 km AOA.

As with any model, there are several inherent assumptions and uncertainties. A model is intended to serve as a proxy, and in this assessment, each model is based on the premise that the landscape factors and weights selected for each species' habitat preferences remain the same for their movement needs. To the extent that this assumption is true, the models are more likely to provide accurate results. To further compound uncertainty, the error inherent in any dataset also affects the accuracy of results. And finally, the size and configuration of suitable habitat patches were not further analyzed for each species nor were any of the potential corridor routes ground-truthed, such as checking areas for new developments and/or barriers such as freeways, canals, and major fences that are only a pixel or two in width in the model and likely not captured in the analyses.

Instead, the PLD should be viewed as a starting point for a more in-depth investigation where specific conservation targets and goals, such as habitat restoration or barrier removal, can be identified and included in the overall linkage design. In addition, information such as wildlife passage locations, water sources, and telemetry data could be added to create a comprehensive linkage evaluation. According to Beier et al. (2008), the results obtained from the Arizona CorridorDesigner tools "should only be relied upon with corroboration of the methods, assumptions, and results by a qualified independent source," suggesting areas for field surveys and more detailed analysis to guide decisions about conservation goals.

Beier et al. (2008) included the following steps for creating a comprehensive linkage design from preliminary results:

- determine if you need to include focal species for which you could not build a corridor model
- remove redundant strands
- determine other conservation goals that should be included
- mitigate barriers (such as locating highway wildlife crossings)
- evaluate the land management in and adjacent to the mapped area.

In addition, an increasing number of studies are finding that habitat density has a great effect on wildlife populations (Monahan et al. 2012). "Among terrestrial species, Lande (1987) suggests that species with a large dispersal range, high fecundity,and high survivorship, may be able to persist when suitable habitat covers only 25-50% of the landscape, while species with low demographic potential may be lost when as much as 80% of the landscape remains suitable habitat" (as cited in Monahan et al. 2012). Grassland or forest density metrics could be added to a more-detailed, ground-truthed linkage design for further refinement and evaluation. Based on Stegner et al. (2017) findings of mammalian diversity in protected areas within the Colorado Plateau, certain wildlife such as pronghorn, mountain lion, and several water-dependent species are less common than what they expected when compared to historic range maps. In addition, all of the Flagstaff Area NMs showed a lower present-day mammal diversity when compared to historic records and current NPSpecies lists. Several factors likely confound these findings, but it is an aspect to consider when developing a final linkage design.

As the population within the city of Flagstaff continues to increase and sprawl toward the Flagstaff Area NMs, increased habitat fragmentation will also likely continue (NPS 1996). The effects of habitat fragmentation as a result of development are varied and range from the direct mortality of animals on roads to the genetic isolation of wildlife populations that have become fragmented (AGFD 2011a). Roadways are a well-known cause of fragmentation (e.g., Corlatti et al. 2009), especially fenced highways.

The wildlife barriers identified within the three Coconino County linkages that are located within Wupatki NM's PLD include U.S. Highways 89 and 180, BNSF Railroad, and Leupp Road (AGFD 2011a). Among the native ungulates, pronghorn appear to be particularly sensitive to crossing highways, and this has contributed to isolation of populations and interference with seasonal migrations (Dodd et al. 2011, AGFD 2011a). In a two-year telemetry study of 37 pronghorn (about one-half captured on each side of U.S. Highway 89, which runs through the west side of Wupatki NM, researchers found that only one of the collared pronghorn crossed the road during the tracking period (Dodd et al. 2011); thirty animals, however, approached the highway to within 0.24 km (0.15 mi). Recent genetic work found that the pronghorn herd on each side of the highway differed from the other genetically, indicating restricted gene flow (Sprague 2010). Building upon these results, a partnership of state and federal agencies, private ranches, and nonprofit organizations began working together in 2013 to increase pronghorn habitat connectivity at the landscape level (NPS & AGFD 2014). Efforts to make fences more permeable to pronghorn included activities taken on NPS lands and on adjacent Coconino National Forest, Arizona State Trust lands, and Babbitt Ranches lands.

However, in 2004, ADOT began long-range planning to expand U.S. 89 to four lanes from around the southern monument boundary northward to Cameron, Arizona (ADOT 2006). The effect on the ability of pronghorn to cross a four-lane highway is currently being assessed (NPS and AGFD 2014). If a wider highway exacerbates habitat fragmentation effects, and long-term fence modification efforts are not sufficient to mitigate the effects, an overpass may be the only effective means of maintaining connectivity.

In addition, as the human population continues to increase surrounding the greater-Flagstaff area, associated development, including more roads and housing, will likely degrade and/or permanently convert natural habitat if the needs of wildlife are not considered as part of the planning process and ethos.

To examine the population increase within the Flagstaff Area NM and Wupatki NM AOAs, four projected housing density rasters (100 m resolution) for 1970, 2010, 2050, and 2100, (Figure 5.4.1-3) were evaluated using Theobald's (2005) Spatially Explicit Regional Growth Model (SERGoM) (NPS 2014a). SERGoM forecasts changes on a decadal basis using county specific population estimates and variable growth rates that are location-specific. Distribution of projected growth was based on accessibility to the nearest urban core, defined as development >100 ha (247 ac). The model assumed that housing density would not decline, which is consistent with population projections throughout all of Arizona. ArcGIS Spatial Analyst's 'extract by mask' tool was used to clip the raster to the AOAs and a summary of the results is listed in Table 5.4.1-1. Most of the area within both AOAs has been classified as rural and is expected to remain as such through the year 2100, especially within Wupatki's 30 km AOA. Unfortunately, development is predicted to be higher in areas surrounding Walnut

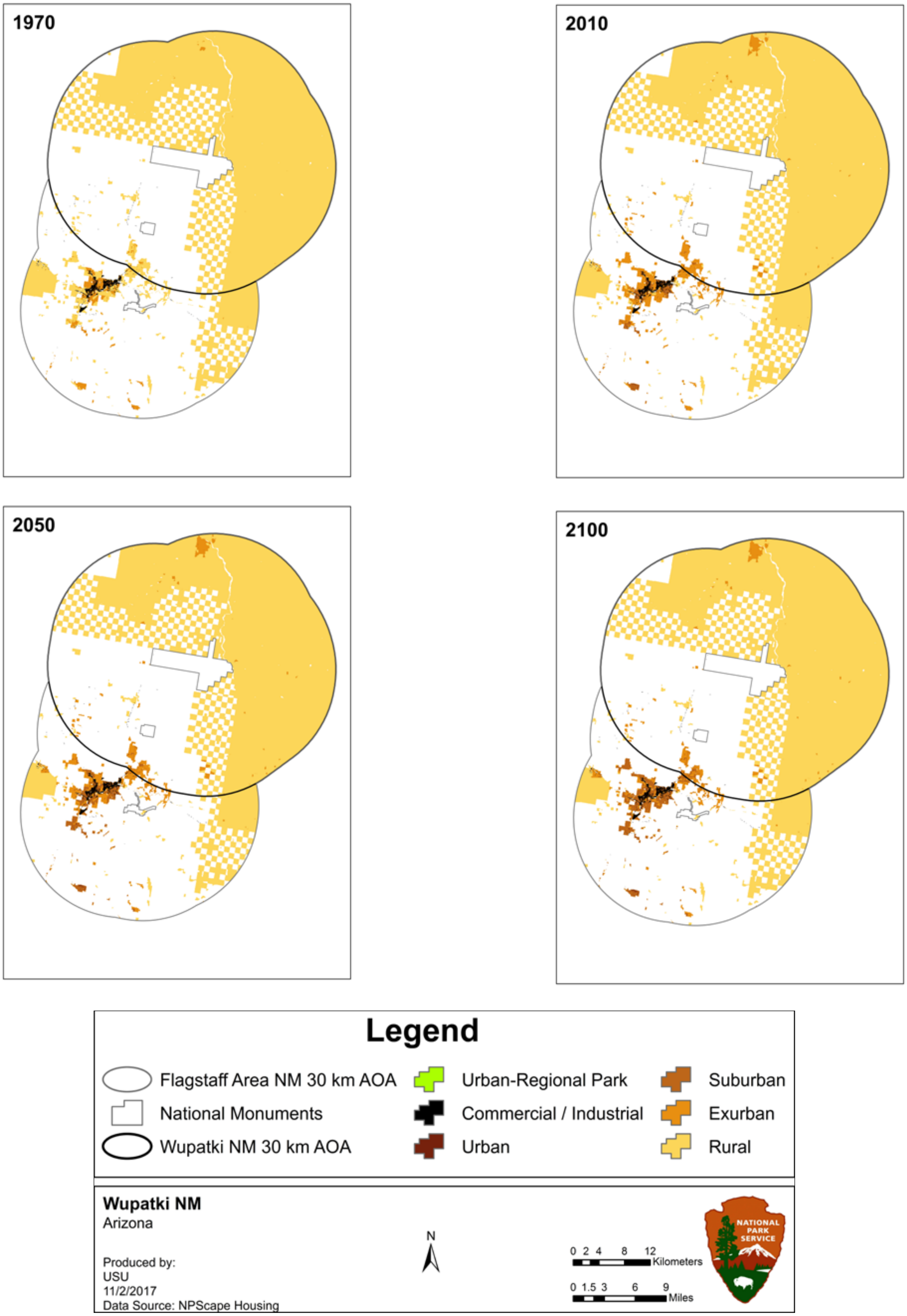


Figure 5.4.1-3. **Spatially Explicit Regional Growth Model (SERGoM v3) housing density for four decades surrounding Flagstaff Area NMs, including Wupatki NM. Data Sources: Theobold (2005) and NPS (2014a).**

Table 5.4.1-1. Housing density classes.

Grouped Housing Density Class	% Area in Wupatki NM's 30 km AOA				% Area in Flagstaff Area NMs' 30 km AOA			
	1970	2010	2050	2100	1970	2010	2050	2100
Rural	99.8	97.8	97.7	97.6	97.7	93.6	93.2	93.1
Exurban	0.002	2.1	2.2	2.1	1.5	4.8	4.3	3.3
Suburban	0	.06	0.13	0.29	0.09	0.85	1.8	2.8
Urban	0	0	0	0	0.004	0.04	0.05	0.06
Commercial / Industrial	0.03	0.03	0.03	0.03	0.67	0.67	0.67	0.67

Sources: Theobold (2005) and NPS (2014a).

Canyon and Sunset Crater Volcano NMs due to their proximity to the city of Flagstaff (i.e., existing development).

This preliminary linkage design is intended to assist resource managers and stakeholders to manage along ecological rather than political boundaries, promoting stewardship by comprehensively addressing resource needs in ways that lead to sustainability and cost-effectiveness. As such, this information should be used in conjunction with the more detailed information of individual monitoring and research programs at Wupatki NM.

The National Park System Advisory Board (NPSAB) identified "conservation at the landscape scale" as an important model to help guide NPS planning and management activities. According to NPSAB, transitioning from a model of standalone national parks into one of innovative partnering to protect landscapes that transcend administrative boundaries will help parks achieve shared conservation goals (NPSAB 2012a,b). This is not a new management concept or approach for the Flagstaff Area NM resource management staff even though this habitat connectivity evaluation is an initial attempt to identify and describe the potential finer-scale linkages between the Flagstaff Area NMs.

The many potential benefits of safeguarding habitat connectivity and corridors include allowing for the natural behavior of species to range across the landscape in their use of foraging or breeding sites; allowing for the dispersal of individuals from their natal ranges; increasing the immigration rate to an area, which could help maintain genetic variation within populations; providing habitat within corridors for resident species and those passing through; and facilitating shifts in the range of a population due to climate change (Crooks and Sanjayan 2006).

The available pronghorn telemetry data from Bright and van Riper III (2000) and Dodd et al. (2011) clearly demonstrate that very few pronghorn individuals spend their entire lives within Wupatki NM. The majority of animals routinely move as far as 24 km (15 mi) from the monument in order to survive, and the ability of pronghorn, and other wildlife, to move to and from adjacent lands is crucial to conservation management.

Through years of sound scientific practice, AZGD biologists gathered data on pronghorn movements in the herds north of Flagstaff, AZ. While the pronghorn are built for speed, they are not well-designed for jumping, and as a result, barriers such as barbed wire fences can (and have) severely impeded their movements across the landscape. The fence improvements made by Flagstaff Area NMs staff and partners is an excellent example of how to apply sound science to management action to improve resource conditions at the landscape-level. Robert Frost wrote, "good fences make good neighbors," and it's landscape-scale efforts such as this that will ensure the survival of national park species for which managers are mandated to protect for the "wildlife therein" and "future generations."

This chapter was authored by Kim Struthers, NRCA Coordinator for Utah State University projects.

Literature Cited

Abatzoglou, J. T. and A. P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences 113: 11770-11775.

Allen, E.B., L.E. Rao, R.J. Steers, A. Bytnerowicz, and M.E. Fenn. 2009. Impacts of atmospheric nitrogen deposition on vegetation and soils in Joshua Tree National Park. Pages 78–100 in R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, and D.M. Miller, editors. The Mojave Desert: Ecosystem processes and sustainability. University of Nevada Press, Las Vegas, Nevada.

Anderson, B.A 1990. The Wupatki Archaeological Inventory Survey Project, Final Report. Professional Paper No. 35, Southwest Cultural Resource Center, Division of Anthropology, National Park Service, Santa Fe. 500 p.

Anderson, K.C. 2003. Sunset Crater and Cinder Mulch Agriculture. Archaeology Southwest 17(1):8.

Anderson, K.C. 2006. Prehistoric cinder-mulch agriculture in the Flagstaff area: A Synthesis of ideas. In Sunset Crater Archaeology: The history of a volcanic landscape. Prehistoric settlement in the shadow of the volcano, edited by M. D. Elson. Anthropological Papers. vol. 37. Center for Desert Archaeology, Tucson.

Anderson, S. 2000. Project Report, Troop 98, Route 66 District, Flagstaff Arizona. Manuscript on file, Natural Resource Program, Flagstaff Area National Monuments.

Anderson, Kirk C., R.S. Graham, and S.G. Wells. 2002. Pedogenesis of vesicular horizons, Cima Volcanic Field, Mojave Desert, California. Soil Science Society of America Journal, Vol. 66, p. 878-887.

Anderssen, S.H., R.B. Nicolaisen, and G.W. Gabrielsen. 1993. Autonomic response to auditory stimulation. Acta Paediatrica 82:913-918.

Adriaensen, F., J. P. Chardon, G. deBlust, E. Swinnen, S. Villalba, H. Gulinck, and E. Matthysen. 2003. The application of 'least-cost' modeling as a functional landscape model. Landscape and Urban Planning 64:233–247 as cited in Beier et al. (2008).

Arizona Department of Environmental Quality (ADEQ). 2007. Little Colorado Water Quality Assessments. Little Colorado River Watershed. Draft, February 2007. Publication number EQR 07-02.

Arizona Department of Transportation (ADOT). 2006. U.S. 89 Antelope Hills – Junction U.S. 160 final environmental assessment and section 4(f) evaluation. Environmental and Enhancement Group, Phoenix, Arizona as cited by Dodd et al. (2011).

Arizona Department of Transportation (ADOT). 2010. Statewide transportation planning framework, Final Report. Available at http://www.bqaz.gov/StatewideTransportationPlanningFramework.asp as cited by Arizona Game and Fish Department (2011).

Arizona Department of Water Quality Standards. 2016. Water quality standards for surface water. Available at: http://www.azdeq.gov/ (accessed 5 September 2016).

Arizona Game and Fish Department (AGFD). 2006. Arizona's wildlife comprehensive management strategy: 2005-2015. Available at: http://www.azgfd.gov/pdfs/w_c/cwcs/downloads/Section1IntroductionExecSummary.pdf (accessed 7 November 2016).

Arizona Game and Fish Department (AGFD). 2007. Pronghorn management plan. Game Management Branch, Phoenix, Arizona.

Arizona Game and Fish Department (AGFD). 2011a. The Coconino County wildlife connectivity assessment: report on stakeholder input. AGFD, in partnership with Coconino County and the Arizona Wildlife Linkages Workgroup.

Arizona Game and Fish Department (AGFD). 2011b. Wupatki pocket mouse (*Perognathus amplus* *cineris*). Unpublished abstract compiled and edited by the Heritage Data Management System.

Arizona Game and Fish Department (AGFD). 2012. Arizona's State Wildlife Action Plan. 2012-2022. Phoenix, Arizona. Available at: http://www.azgfd.gov/w_c/swap.shtml (accessed August 2016).

Arizona Game and Fish Department (AGFD). 2013a. Arizona's Heritage Data Management System. Available at: http://www.azgfd.gov/w_c/edits/species_concern.shtml (accessed 22 August 2016).

Arizona Game and Fish Department (AGFD). 2013b. Arizona statewide pronghorn management plan. Arizona Game and Fish Department, Phoenix, Arizona. 96 pp.

Arizona Game and Fish Department (AGFD). HabiMap Arizona. Available at: http://habimap.org/ (accessed November 2016).

Arizona-Sonora Desert Museum. 2016. Tamarisk, saltcedar, athel tree (*Tamarix* spp.). Invaders of the Sonoran Desert Region. Available at: http://www.desertmuseum.org/invaders/invaders_tamarisk.php (accessed August 31, 2016).

Arizona Wildlands Invasive Plant Working Group (AZ-WIPWG). 2005. Invasive non-native plants that threaten wildlands in Arizona: a categorized list developed by the AZ-WIPWG. Tucson, AZ. Available at: http://sbsc.wr.usgs.gov/research/projects/swepic/swvma/InvasiveNon-NativePlantsThatThreatenWildlandsInArizona.pdf (accessed 16 August 2016).

Arizona Wildlife Linkages Workgroup (AWLW). 2006. Wildlife linkages. Avaialble at: https://www.azdot.gov/business/environmental-planning/programs/wildlife-linkages (accessed 7 November 2016).

Asher, J. A., and D. W. Harmon. 1995. Invasive exotic plants are destroying the naturalness of U.S. Wilderness areas. International Journal of Wilderness 1:35–37.

Aveni, A. E. 2003. Archaeoastronomy in the ancient Americas. Journal of Archaeological Research 11:149-191.

Babenroth, D.L., and A.N. Strahler. 1945. Geomorphology and structure of the East Kaibab Monocline, Arizona and Utah. Geologic Society of America Bulletin, Vol 56, pp 107-150.

Bailey, L., and M. Adams. 2005. Occupancy models to study wildlife. Fact Sheet. U.S. Geological Survey.

Bain J.R. 1986. Winter roosts of Townsends big-eared bat, *Plecotus townsendii* (Vespertilionidae), in Wupatki National Monument and vicinity, Arizona.

Baker, W.L. 2009. Fire ecology in Rocky Mountain landscapes. Island Press, Washington, D.C.

Barber, J.R., K. R. Crooks, K. M. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. 2010. Trends in Ecology and Evolution 25.3:180-189.

Baron, J.S., C.T. Driscoll, J.L. Stoddard, and E.E. Richer. 2011. Empirical critical loads of atmospheric nitrogen deposition for nutrient enrichment and acidification of sensitive U.S. lakes. Bioscience. American Institute of Biological Sciences, 61(8):602-613.

Bateman, Gary C. 1976a. Natural Resource Survey and Analysis of Sunset Crater Volcano and Wupatki National Monuments. Ms on file Wupatki National Monument. Report prepared by Northern Arizona University, Contract No. 950134 as cited in NPS (1996).

Bateman, Gary C. 1976b. Amphibians and Reptiles of Sunset Crater Volcano and Wupatki National Monuments. In natural resource survey and analysis of Sunset Crater Volcano and Wupatki National Monuments. Ms on file Wupatki National Monument. Report prepared by Northern Arizona University, Contract No. 950134 as cited in NPS (1996).

Bateman, Gary C. 1978. Natural resource survey and analysis of Sunset Crater and Wupatki National Monuments, Phase II. Prepared for the Office of Natural Resources Management, Southwest Region, National Park Service. Northern Arizona University, 86001 as cited in Schelz et al. (2013).

Bateman, Gary C. 1979. Natural resource survey and analysis of Sunset Crater Volcano and Wupatki National Monuments, Preliminary Report (Phase III). Prepared for the Office of Natural Resource Management, Southwest Region, National Park Service. Ms on file, Wupatki National Monument, Flagstaff, Arizona as cited in Schelz et al. (2013).

Bateman, Gary C. 1980. Natural resource survey and analysis of Sunset Crater and Wupatki National Monuments, Phase III. Prepared for the Office of Natural Resources Management, Southwest Region, National Park Service. Northern Arizona University, 86001 as cited in Schelz et al. (2013).

Bateman, Gary C. 1981. Natural resource survey and analysis of Sunset Crater and Wupatki National Monuments, Phase IV. Prepared for the Office of Natural Resources Management, Southwest Region, National Park Service. Northern Arizona University, 86001 as cited in Schelz et al. (2013).

Beatty, L. 1978. Studies of avian communities. In G.C. Bateman and others, 1978, Natural resource survey and analysis of Sunset Crater and Wupatki National Monuments. Final report (Phase II), February 1978. Department of Biological Sciences, Northern Arizona University, Flagstaff.

Beatty, L. and R.P. Balda. 1976. Studies of avian communities. In G.C. Bateman and others, 1976, Natural resource survey and analysis of Sunset Crater and Wupatki National Monuments. Final report, December 1976. Department of Biological Sciences, Northern Arizona University, Flagstaff.

Beier, P., and R.F. Noss. 1998. Do habitat corridors provide connectivity? Conservation Biology 12(6): 1241-1252.

Beier, P., D.R. Majka, and W.D. Spencer. 2008. Forks in the road: Choices in procedures for designing wildland linkages. Conservation Biology, Volume 22, No. 4, 836–851.

Bell, M.D. In Review. Ozone sensitive plant species on National Park Service and U.S. Fish and Wildlife Service Lands: An update to results from the 2003 Baltimore ozone workshop. Natural Resource Report NPS/NRARD/NRR-X/Y. Available at: https://irma.nps.gov/NPSpecies/Reports/Systemwide/Ozone-Sensitive%20Species%20in%20a%20Park (accessed October 10, 2016).

Bergeson, B. n.d. Reptiles of Wupatki National Monument. checklist, on file Wupatki National Monument.

Berglund, B., T. Lindvall, and D.H. Schwela (eds.). 1999. WHO. Guidelines for community noise. World Health Organization, Geneva.

Berlin, G.L., Ambler, J.R., Hevly, R.H., Shaber, G.G. 1977. Identification of a Sinagua agricultural field by aerial thermography, soil chemistry, pollen/plant analysis, and archaeology. American Antiquity 42, 588–600.

Bernard, E.C. and J.J. Wynne. In review. *Disparrhopalites naasaveqw* n. sp. from caves at Wupatki National Monument, Arizona, synonymy of Dietersminthurus Palacios-Vargas, Cuéllar & Vázquez, 1998 with Disparrhopalites Stach, 1956 and composition of Songhaicinae (Collembola: Sminthuridae).

Bibby, C. J, N. D. Burgess, D. A. Hill, and S. Mustoe. 2000. Bird census techniques. Second ed. London: Academic Press.

Billingsley, G.H., S.S. Priest, and T.J. Felger. 2007a. Geologic map of Wupatki National Monument and vicinity, Coconino County, northern Arizona. U. S. Geological Survey Scientific Investigations Map 2958 and pamphlet.

Billingsley, G.H., S.S. Priest, and T.J. Felger. 2007b. Geologic map of the Cameron 30' x 60' quadrangle, Coconino County, northern Arizona. U. S. Geological Survey Scientific Investigations Map 2977 (scale 1:100,000) and pamphlet.

Bills, D.J., Flynn, M.E., and Monroe, S.A. 2007. Hydrogeology of the Coconino Plateau and adjacent areas, Coconino and Yavapai Counties, Arizona (ver. 1.1, March 2016): U.S. Geological Survey Scientific Investigations Report 2005–5222.

Blyth, C. P. 1995. The Cenozoic evolution of Wupatki National Monument. Master's Thesis. Northern Arizona University, Flagstaff, AZ.

Bortle, J. E. 2001. Introducing the Bortle DarkSky Scale. Sky and Telescope February:126-129.

Bowker, M.A. and J. Belnap. 2013. Spatial modeling of biological soil crusts to support land management decisions: Indicators of range health and conservation-restoration value based upon the potential distribution of biological soil crusts in Montezuma Castle, Tuzigoot, Walnut Canyon, and Wupatki National Monuments, Arizona. United States Geological Survey, Flagstaff, AZ.

Bowker, M. A., Belnap, J., and Miller, M. E. 2007. Spatial modeling of biological soil crusts to support land management decisions: Indicators of range health and conservation-restoration value based upon the potential distribution of biological soil crusts in Montezuma Castle, Tuzigoot, Walnut Canyon, and Wupatki National Monuments, Arizona: U.S. Geological Survey.

Brehl, et al. 2006. Atlas of wildland fire events in the Flagstaff Area National Monuments, National Park Service.

Brehl, M., C. Parker, and P. Whitefield. 2008. Non-native invasive plant surveys and recommendations 2003-2005: Wupatki National Monument. National Park Service, Flagstaff, Arizona.

Brennan, T.C. 2015. Online field guide to the reptiles and amphibians of Arizona. By Thomas C. Brennan, 2008-2012. Available at: http://www.reptilesofaz.org/ (accessed 15 July 2016).

Breshears, D. D., N. S. Cobb, P. M. Rich, K. P. Price, C. D. Allen, R. G. Balice, W. H. Romme, J. H. Kastens, M. L. Floyd, J. Belnap, J. J. Anderson, O. B. Myers, and C. W. Meyer. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences 102(42):15144-15148.

Bridgemon R.R. 1975. Earth Crack Investigation at Wupatki National Monument, Arizona. Pages 23-25. In Author unknown. Cave Research Foundation 1975 Annual Report. Cave Research Foundation.

Bright, J.L., and C. van Riper III. 2000. Pronghorn home ranges, habitat selection, and distribution around water sources in northern Arizona. USGS Technical Report FRESC/COPL/2000/18, U.S. Geological Survey, Flagstaff, Arizona, USA.

Broadman, E. and K.C. Anderson. 2013. A soil chronosequence from loess deposits on late pleistocene lava flows, Northern Arizona, USA: Results from The San Francisco Volcanic Field REU, Paper presented at the Geological Society of America Meetings, Denver, CO.

Brooks, M.L. 2003. Effects of increased soil nitrogen on the dominance of alien annual plants in the Mojave Desert. Journal of Applied Ecology. 40:344–353.

Brown, D. E. 1994. Biotic communities: southwestern United States and northwestern Mexico. University of Utah Press, Salt Lake City, UT.

Brown, G.B. 1996. Direct crop production evidence from prehistoric agricultural fields. Masters Thesis, Northern Arizona University, Flagstaff, 194 p.

Brown, B.T. and R.R. Johnson. 1989. Ecology and management of riparian breeding birds in tamarisk habitats along the Colorado River in Grand Canyon National Park, Arizona. In Tamarisk Control in Southwestern United States, Proceedings of Tamarisk Conference, University of Arizona, Tucson, September 2 and 3, 1987.

Brown D.E. and Ockenfels R.A. 2007. Arizona's pronghorn antelope: a conservation legacy. Arizona Antelope Foundation, Phoenix, Arizona as cited by NPS and AGFD (2014).

Brown, K.W. and N.J. Rosenberg. 1975. Annual windbreaks boost yields. Crops and Soils, No. 27, 8-11.

Brush, Robert O.; Palmer, James F. 1979. Measuring the impact of urbanization on scenic quality: land use change in the northeast. In: Elsner, Gary H., and Richard C. Smardon, technical coordinators. 1979. Proceedings of our national landscape: a conference on applied techniques for analysis and management of the visual resource [Incline Village, Nev., April 23-25, 1979]. Gen. Tech. Rep. PSW-GTR-35. Berkeley, CA. Pacific Southwest

Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture: p. 358.

Bryce, S. A., R. M. Hughes, and P. R. Kaufmann. 2002. Development of a bird integrity index: Using bird assemblages as indicators of riparian condition. Environmental Management 30:294–310.

Buckland, S.T., D.R. Anderson, K.P. Burnham, and J.L. Laake. 1993. Distance sampling: Estimating abundance of biological populations. Chapman and Hall, New York, New York as cited by Rosenstock (1999).

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: Estimating abundance of biological populations. Oxford, U.K.: Oxford University Press.

Budde, P.J., Frakes, B. J., Nelson, L., and U. Glick. 2009. Technical guide for NPScape data and processing. Inventory & Monitoring Division, National Park Service, Fort Collins, Colorado.

Bureau of Land Management (BLM). 2016. Visual resource management. U.S. Department of the Interior, Bureau of Land Management. Washington, DC. Available at: http://www.blm.gov/nstc/vrm/8400. html (accessed 22 September 2016).

Canterbury, G. E., T. E. Martin, D. R. Petit, L. J. Petit, and D. F. Bradford. 2000. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. Conservation Biology 14:544–558.

Carles, L. J., I. L. Barrio, and J. Vicente de Lucio. 1999. Sound influence on landscape values. Landscape and Urban Planning 43:191-200.

Carothers, Steven and Nancy Goldberg. 1976. Biology of Wupatki and Sunset Crater Volcano region. Plateau, Vol. 4. N2 pp. 14-21 as cited in NPS (1996).

Cave Research Foundation (CRF). 1976. Wupatki National Monument earth cracks. Cave Research Foundation.

Christensen, P.K. 1982. The hydrogeology of Sunset Crater and Wupatki National Monuments, Coconino County, Arizona. Master of Science thesis. Northern Arizona University.

Cinnamon, S. K. 1983. Camelthorn census pre-control camelthorn plots. Unpublished report on file, Flagstaff Area National Monuments, Flagstaff, Arizona as cited in Brehl et al. 2008.

Cinnamon, S. K. 1987. Wupatki National Monument Tamarisk and camelthorn eradication program 1983-88. In: Tamarisk Control in the United States, Proceedings of Tamarisk Conference, University of Arizona, Tucson.

Cinnamon, S. K. 1988a. The vegetation community of Cedar Canyon, Wupatki National Monument as influenced by prehistoric and historic environmental change. Thesis, Northern Arizona University.

Cinnamon, S. K. 1988b. Grazing terminated at Wupatki National Monument. Unpublished manuscript, on file with the NPS Archive Collections, Museum of Northern Arizona.

Cinnamon, S.K. 1989. Wupatki National Monument tamarisk and camelthorn eradication program 1983-1988. In Tamarisk control in Southwestern United States, Proceedings of Tamarisk Conference, University of Arizona, Tucson, September 2 and 3, 1987.

Cinzano, P., and F. Falchi. 2014. Quantifying light pollution. Journal of Quantitative Spectroscopy and Radiative Transfer 139: 13-20.

Climate Analyzer. 2016. Temperature and precipitation data from COOP station 29542 and associated graphs from website. Available at: http://www.climateanalyzer.org/four/wupatki/wupatki/graph_choices (accessed 9 November 2016).

Clough, G. 1982. Environmental effects on animals used in biomedical research. Biological Reviews 57:487-523.

Coggins, G.C. 1987. Protecting the wildlife resources of national parks from external threats. Land and

Water Law Review, 22, 1-27 as cited in Monahan et al. 2012.

Colton, H.S. 1932. Sunset Crater: The Effect of a volcanic eruption on the ancient pueblo people. Geographical Review 22:582590.

Colton, H.S. 1937. Some notes on the original condition of the Little Colorado River: a side light on the problems of erosion. Museum of Northern Arizona Museum Notes. Volume 6, No. 6, Northern Arizona Society of Science and Art, Inc.

Colton H.S. 1938. The exploration of limestone solution cracks. Museum Notes, Museum of Northern Arizona. 10: 29-32.

Colton, H.S. 1960. Black Sand, Prehistory in Northern Arizona. University of New Mexico Press, Albuquerque.

Colton, H.S. 1965. Experiments in raising corn in the Sunset Crater ashfall area east of Flagstaff, Arizona. Plateau 37(3):7779.

Corlatti, L., K. Hacklander, and F. Frey-Roos. 2009. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. Conservation Biology 23(3): 548-556.

Cornell Lab of Ornithology. 2015. All about birds. Available at: https://www.allaboutbirds.org/guide (accessed 26 August 2016).

Crooks, K.R., and M. Sanjayan (eds). 2006. Connectivity conservation. Cambridge University Press. New York.

D'Antonio, C. M., and B. E. Mahall. 1991. Root profiles and competition between the invasive, exotic perennial, *Carpobrotus edulis*, and two native shrub species in California coastal scrub. American Journal of Botany 78:885–894.

Davey, C. A., K. T. Redmond, and D. B. Simeral. 2006. Weather and Climate Inventory, National Park Service, Southern Colorado Plateau Network. Natural Resource Technical Report NPS/SCPN/NRTR—2006/007. National Park Service, Fort Collins, Colorado.

Davis, C.R. & Hansen, A.J. 2011 .Trajectories in land use change around U.S. national parks and their challenges and opportunities for management. Ecological Applications Vol. 21(8): 3299-3316.

DeCoster, J. K., and M. C. Swan. 2009. Integrated upland vegetation and soils monitoring for Wupatki National Monument. 2008 summary report. NPS, Natural Resource Program Center, Fort Collins, CO.

DeCoster, J. K., and M. C. Swan. 2011. Integrated upland vegetation and soils monitoring for Wupatki National Monument: 2009 summary report. Natural Resource Data Series NPS/SCPN/NRDS—2011/174. National Park Service, Fort Collins, Colorado.

DeCoster, J. K., and M. C. Swan. 2016. Integrated upland vegetation and soils monitoring for Wupatki National Monument: 2012–2014 summary report. Natural Resource Data Series NPS/SCPN/NRDS—2016/1039. National Park Service, Fort Collins, Colorado.

Dickard, M., M. Gonzalez, W. Elmore, S. Leonard, D. Smith, S. Smith, J. Staats, P. Summers, D. Weixelman, and S. Wyman. 2015. Riparian area management: Proper functioning condition assessment for lotic areas. Technical Reference 1737-15. U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO.

Dodd, N.L., J.W. Gagnon, S. Sprague, S. Boe, and R.E. Schweinsburg. 2011. Assessment of pronghorn movements and strategies to promote highway permeability: US Highway 89. Final Report 619, April 2011. Arizona Department of Transportation (ADOT) Research Center. 84 pp.

Donovan, T.M., and J. Hines. 2007. Exercises in occupancy modeling and estimation. Available at:http://www.uvm.edu/envnr/vtcfwru/spreadsheets/occupancy.htm, as cited by Rieck (2013).

Dooling, R., and A. Popper. 2007. The effects of highway noise on birds. Rockville, MD: Environmental BioAcoustics LLC.

Downnum, Christian, E. (ed). 2012. Histat"sinom: ancient peoples in a land without water, School for Advanced Research, Santa Fe.

Drost, C. 2009. Inventory of mammals at Walnut Canyon, Wupatki, and Sunset Crater National Monuments. Natural Resource Technical Report NPS/SCPN/NRTR—2009/278. National Park Service, Fort Collins, Colorado.

Duffield, W., Riggs, N., Kaufman, D., Champion, D., Fenton, C., Forman, S., McIntosh, W., Hereford, R., Plescia, J., Ort, M. 2006. Multiple constraints on the age of a Pleistocene lava dam across the Little Colorado River at Grand Falls, Arizona. Geological Society of America Bulletin 118, 421–429.

Duriscoe, D. M. 2013. Measuring anthropogenic sky glow using a natural sky brightness model. Mon. Not. R. Astron. Soc. 125:1370-1382.

Duriscoe, D. 2016. Photometric indicators of visual night sky quality derived from all-sky brightness maps. Journal of Quantitative Spectroscopy and Radiative Transfer 181: 33-45.

Duriscoe, D., C. B. Luginbuhl, and C. A. Moore. 2007. Measuring night sky brightness with a wide-field CCD camera. Publications of the Astronomical Society of the Pacific 119:192-213.

Dwyer, D. D., and R. D. Pieper. 1967. Fire effects on blue grama-pinyon-juniper rangeland in New Mexico. Journal of Range Management 20:359-362.

E&S Environmental Chemistry, Inc.. 2009. Nitrogen screening project - sensitive vegetation. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2170016 (accessed October 14, 2016).

Edmonds, R. L., J. K. Agee, and R. I. Gara. 2011. Forest health and protection. Waveland Press Inc., Long Grove, IL.

Edwards, J.S. 2007. Soil fertility and prehistoric agriculture in the Sunset Crater Area. In: Elson, M.D. (Ed.), Sunset Crater Archaeology: The history of a volcanic landscape. Environmental analyses. Anthropological Papers 33. Center for Desert Archaeology, Tucson, pp. 47–70.

Ehrenfeld, J. G. 2003. The effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems 6:503–523.

Elson, M.D. (Ed.) 2011. Sunset Crater archaeology: the history of a volcanic landscape-prehistoric settlement in the shadow of the volcano. Anthropological Papers No. 37, Center for Desert Archaeology, Tucson.

Elson, M. D., and M. H. Ort. 2003. Collaborative research at Sunset Crater Volcano. Archaeology Southwest 17(1):4-6.

Elson, M.D., M.H. Ort, K.C. Anderson, and J.M. Heidke, 2007. Living with the volcano: the 11th Century AD eruption of Sunset Crater. In J. Gratten and R. Torrence (Ed.), Living under the shadow: cultural impacts of volcanic eruptions, Left Coast Press, Walnut CA., p. 107-132.

Elson, M.D., M.H. Ort, S.J. Hesse, W.A. Duffield. 2002. Lava, corn, and ritual in the northern Southwest. American Antiquity Vol. 67, 119–135.

Elson, M.D., Ort, M.H., Sheppard, P.R., Samples, T.L., Anderson, K.C., May, E.M., and Street, D.J., 2011, Sunset Crater Volcano. In M.D. Elson (ed.) Sunset crater archaeology: The history of a volcanic landscape. Prehistoric settlement in the shadow of the volcano, Anthropological Papers No. 37, Center for Desert Archaeology, Tucson, p. 103-129.

Emerson, F. W. 1932. The tension zone between the grama grass and piñon juniper associations in northeastern New Mexico. Ecology 13:347-358.

Environmental Systems Research Institute (ESRI). 2014. North America detailed streets. Compiled by TomTom (2007), Inc., distributed by ESRI. Redlands, CA.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution, and Systematics, 34, 487–515 as cited in Monahan et al. (2012).

Federal Aviation Administration (FAA) and National Park Service (NPS). 2014. Reporting information for commercial air tour operations over national park units. Annual Report. April 29, 2014.

Federal Aviation Administration (FAA) and National Park Service (NPS). 2015. Reporting information for commercial air tour operations over national park units. Annual Report. October 8, 2014.

Federal Aviation Administration (FAA) and National Park Service (NPS). 2016. Reporting information for commercial air tour operations over national park units. Annual Report. May 13, 2014.

Fischer, J.L. 1986. Microhabitat selection by small mammals on the basis of temperature. Ms on file Northern Arizona University, Flagstaff as cited in NPS (1996).

Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology 8:629-644.

Fletcher, R., and W. A. Robbie. 2004. Chapter 6: Historic and current conditions of southwestern grasslands. Pages 120-129 in: Finch, D. M. (editor), Assessment of grassland ecosystem conditions in the southwestern United States. Volume 1. USDA Forest Service General Technical Report RMRS-GTR-135-vol. 1.

Floyd, M. L., and M. Colyer. 2003. Beneath the trees: shrubs, herbs, and some surprising rarities. Pages 31-60 in Floyd, M. L. (editor), Ancient piñon-juniper woodlands: a natural history of Mesa Verde country. University Press of Colorado.

Fowler, D., J.A. Pyle, J.A. Raven, and M.A. Sutton. 2013. The global nitrogen cycle in the twenty-first century: Introduction. Philosophical Transactions of the Royal Society B: Biological Sciences, 368(1621), 20130165. Available at: http://doi.org/10.1098/rstb.2013.0165 (accessed October 10, 2016).

Fowlie, J. 1965. Snakes of Arizona. Fallbrook, California. On file Wupatki National Monument as cited in NPS (1996).

Francis, Clinton D., N.J. Kleist, C.P. Ortega, and A. Cruz. 2012. Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. Proc. R. Soc. B. Vol. 279. No. 1739. The Royal Society.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2014. Ch. 20: Southwest, in J. M. Melillo, T. C. Richmond, and G. W. Yohe, eds. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 462-486. doi:10.7930/J08G8HMN. Available at: http://nca2014.globalchange.gov/report/regions/southwest%0D (accessed 9, November 2016).

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. 2013. Assessment of climate change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Garstang, R. H. 1986. Model for artificial night-sky illumination. Publication of the Astronomical Society of the Pacific 98:364-375.

Ginter, D., and R. Marquetti. 2016. Using remote sensing data to map juniper response to drought induced mortality. Oral presentation, symposium on Pinyon-juniper habitats: Status and management for wildlife, Albuquerque, NM, Oct. 12-14, 2016. Available at: https://nhnm.unm.edu/sites/default/files/nonsensitive/news-files/4-Ginter-Using%20Remote%20Sensing%20Data%20to%20Map%20Juniper%20Response%20to%20Drought.pdf.

Global Invasive Species Database (GISD). 2015. Species profile *Tamarix ramosissima*. Available at: http://www.iucngisd.org/gisd/species.php?sc=72 (accessed 10 August 2016).

Gobster, P. H. 1999. An ecological aesthetic for forest landscape management. Landscape Journal 18: 54-64.

Gonzalez, P. 2014. Climate change summary, Wupatki National Monument, Arizona. Natural Resource

Stewardship and Science, U.S. National Park Service, Washington, DC.

Grady, K. 2012. Investigator's annual report. Little Colorado River rehabilitation cooperative project. Two-page report.

Grady, K. 2014. Deadman Wash hydrology assessment. Wupatki National Monument final report. Northern Arizona University. Three pages.

Graham, T. B. 2001. Survey of aquatic macroinvertebrates and amphibians at Wupatki National Monument, Arizona, USA: an evaluation of selected factors affecting species richness in ephemeral pools. Hydrobiologia 486: 215-224.

Graham, J. 2011. Wupatki National Monument: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2011/416. National Park Service, Fort Collins, Colorado.

Grand Canyon Wildlands Council (GCWC) (2002) Inventory of 100 Arizona strip springs, seeps and natural ponds: final project report. Arizona Water Protection Fund, Phoenix, AZ

Gustafson T.A. 1964. The bats of Wupatki National Monument, Coconino County, Arizona. University of Arizona. Thesis.

Haas G.E., and T.J. Wakefield. 1998. National parks and the American public: a summary report of the National Parks Conservation Association, conducted by Colorado State University, Fort Collins, Colorado.

Han, K. T. 2010. An exploration of relationships among responses to natural scenes: Scenic beauty, preference and restoration. Environment and Behavior 42(2):243-270.

Hansen, M., J. Coles, K. A. Thomas, D. Cogan, M. Reid, J. Von Loh, and K. Schulz. 2004. United States-National Park Service Vegetation Mapping Program: Wupatki National Monument, Arizona, Vegetation Classification and Distribution. Final Report. U.S. Geological Survey, Southwest Biological Science Center. Flagstaff, Arizona.

Hansen, A.J., N. Piekielek, C. Davis, J. Haas, D.M. Theobald, J.E. Gross, W.B. Monahan, T. Olliff, and S.W. Running. 2014. Exposure of U.S. National Parks to land use and climate change 1900–2100. Ecological Applications 24:484-502.

Hanson, S.L. 2008. Age determination of lava flows at Wupatki National Monument. A report submitted to Western National Parks Association in fulfillment of WUPA Research Grant Number #07-17. Western National Parks Association, Tucson, Arizona, USA.

Haralabidis A.S., K. Dimakopoulou, F. Vigna-Taglianti, M. Giampaolo, A. Borgini, M.L. Dudley, G. Pershagen, G. Bluhm, D. Houthuijs, W. Babisch, M. Velonakis, K. Katsouyanni, and L. Jarup. 2008. Acute effects of night-time noise exposure on blood pressure in populations living near airports. European Heart Journal Advance Access. Published online February 12, 2008.

Harris, C. M. 1998. Handbook of Acoustical Measurements and Noise Control, 3rd edition. McGraw-Hill, New York.

Hassler, F. C. Jr. 2006. Dynamics of juniper invaded grasslands and old-growth woodlands at Wupatki National Monument, northern Arizona, USA. Thesis, Northern Arizona University.

Hereford, R. 1984. Climate and ephemeral-stream processes: twentieth-century geomorphology and alluvial stratigraphy of the Little Colorado River, Arizona. U.S. Geological Survey, Flagstaff, AZ.

Hereford, R., R.H. Webb, and S. Graham. 2002. Precipitation history of the Colorado Plateau region, 1900–2000: U.S. Geological Survey Fact Sheet 119-02, 4 p., Available at: http://pubs.usgs.gov/fs/2002/fs119-02/ as cited by USGS (2011).

Hetherington, J., T.C. Daniel. and T.C. Brown. 1993. Is motion more important than it sounds?: The medium of presentation in environmental perception research. J. Environmental Psychology. 13: 283-291.

Hill, Carol A. and P. Gary Eller. 1977. Soda-Niter in North Central Arizona Earth Cracks. NSS Bulletin. 39(4):113-116.

Hines, J. 2012. Program PRESENCE v5.5. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland as cited by Rieck (2013).

Hoffmeister, D.F. 1986. Mammals of Arizona. University of Arizona Press, Tucson, Arizona (as cited by Rieck (2013) and NPS (2009)).

Holmes, J.A. and M.J. Johnson. 2012. Bird community monitoring for Wupatki National Monument: 2008 summary report. Natural Resource Data Series NPS/SCPN/NRDS—2012/330. National Park Service, Fort Collins, Colorado.

Holmes, J.A. and M.J. Johnson. 2013. Bird community monitoring for Wupatki National Monument: 2011 summary report. Natural Resource Data Series NPS/SCPN/NRDS—2013/466. National Park Service, Fort Collins, Colorado.

Holmes, J.A. and M.J. Johnson. 2016. Bird community monitoring for Wupatki National Monument: 2014 summary report. Natural Resource Data Series NPS/SCPN/NRDS—2016/1034. National Park Service, Fort Collins, Colorado.

Holmes, J.A., M.J. Johnson, C.L. Lauver, J.R. Norris, A.E.C. Snyder, and L.P. Thomas. 2015. Habitat-based bird community monitoring protocol for the Southern Colorado Plateau Network. Natural Resource Report NPS/SCPN/NRR-2015/1041. National Park Service, Fort Collins, Colorado.

Holton, P. B. 2007. Upland free water availability and wildlife. Thesis. Northern Arizona University, Flagstaff, AZ.

Holton, B., S. Michelson, and J. Cannella. 2005. Pronghorn (*Antilocapra americana*) and Golden Eagle (*Aquila chrysaetos*) monitoring relative to the Wupatki-Sunset Loop Road in Wupatki National Monument. Unpublished draft report, Flagstaff Area National Monuments, National Park Service, Flagstaff. **Do not distribute**.

Hooten, J.A., Ort, M.H., and Elson, M.D. 2001. Origin of cinders in Wupatki National Monument: Technical Report No. 2001-12, Desert Archaeology Inc. 20p.

Horton, J.S., and C.J. Campbell. 1974. Management of phreatophyte and riparian vegetation for maximum multiuse values. USDA Forest Service Res. Pap. RM 117. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, as cited by Christensen (1982).

Hough, I. 2004. Fire effects research and preservation planning at Wupatki and Walnut Canyon National Monuments, northeast Arizona. Manuscript included in Appendix L, Wildland Fire and Fuels Management Plan, Flagstaff Area National Monuments.

Houts, A. N., Licciardi, J., Lapo, K., Kurz, M.D. and Curtice, J.M. 2013. Cosmogenic ^{3}He surface exposure dating of sp cinder cone and lava flow in northern Arizona, USA: Results from the San Francisco Volcanic Field REU Program, Paper presented at the Geological Society of America Meetings, Denver, CO.

Hultine, K.R., J. Belnap, C. van Riper III, J.R. Ehleringer, P.E. Dennison, M.E. Lee, P.L. Nagler, K.A. Snyder, S.M. Uselman, and J.B. West. 2010. Frontiers in Ecology and Environment 8:467-474.

Huntoon, P. 1965. General reconnaissance of the earth cracks, Coconino County, Arizona. Cave Notes 7: 37.

Inouye, R.S. 2006. Effects of shrub removal and nitrogen addition on soil moisture in sagebrush steppe. Journal of Arid Environments. 65: 604–618.

International Dark Sky Association (IDA). 2016. International dark sky places. Available at: http://darksky.org/idsp/ (accessed July 6, 2016).

Ironsides, K.E. 2006. Climate change research in the national parks: paleoecology, policy, and modeling the future. Masters Thesis, Northern Arizona University.

Jacobs, B.F., W.H. Romme, and C.D. Allen. 2008. Mapping "old" vs. "young" piñon-juniper stands with a predictive topo-climatic model. Ecological Applications 18:1627-1641.

Jameson, D. A. 1962. Effects of burning on a galleta – black grama range invaded by juniper. Ecology 43:760-763.

Jensen, H. W., F. Durand, J. Dorsey, M. M. Stark, P. Shirley, and S. Premoze. 2006. A physically-based night sky model. Proceedings of the 28th annual conference on computer graphics and interactive techniques. Available at: http://graphics.stanford.edu/~henrik/papers/nightsky/nightsky.pdf (accessed 20 July 2016).

Johnsen, T. N. Jr. 1962. One-seed juniper invasion of northern Arizona grasslands. Ecological Monographs 32:187-207.

Johnson, G. W., J. D. Anderson, and D. Godwin. 2008. A guidebook for the Blue Ridge Parkway Scenery Conservation System. Draft. National Park Service, Asheville, North Carolina.

Johnson, M.J., C. Van Riper, and K.M. Pearson. 2002. Black-throated Sparrow (*Amphispiza bilineata*), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology. Available at: http://bna.birds.cornell.edu/bna/species/637 as cited by Holmes and Johnson (2012).

Kalies, E.L., B.G. Dickson, C.L. Chambers, and W.W. Covington. 2012. Community occupancy responses of small mammals to restoration treatments in ponderosa pine forests, northern Arizona, USA. Ecological Applications 22:204–217 as cited by Rieck (2013).

Kaltenborn, B. P. and T. Bjerke. 2002. Associations between environmental value orientations and landscape preferences. Landscape and Urban Planning 59:1-11.

Kaplan, R. and S. Kaplan. 1989. The experience of nature: A Psychological Perspective. Cambridge University Press, Cambridge, UK.

Kaseloo PA. 2006. Synthesis of noise effects on wildlife populations. In: Proceedings of the 2005 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 33-35.

Kearney, A. R., G. A. Bradley, C. H. Petrich, R. Kaplan, S. Kaplan, and D. Simpson-Colebank. 2008. Public perception as support for scenic quality regulation in a nationally treasured landscape. Landscape and Urban Planning 87:117-128.

King, W. B. 1985. Island birds: Will the future repeat the past? Pages 3–15 in P. J. Moors, ed., Conservation of Island Birds. International Council for Bird Preservation. Cambridge: Cambridge University Press.

Kinney, P. L. 2008. Climate change, air quality, and human health. American Journal of Preventative Medicine 35: 459-467.

Knipe, T. 1944. The status of antelope herds of northern Arizona. federal aid in wildlife restoration project 9-R report. Arizona Game and Fish Department, Phoenix. Arizona as cited by NPS and AGFD (2014).

Kohut, R.J. 2004. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Colorado Plateau Network.

Kohut, R.J. 2007. Ozone risk assessment for Vital Signs Monitoring Networks, Appalachian National Scenic Trail, and Natchez Trace National Scenic Trail. NPS/NRPC/ARD/NRTR—2007/001. National Park Service, Fort Collins, Colorado.

Kreamer, D. K. and A. Springer. 2008. The hydrology of desert springs in North America. Aridland Springs in North America. Pages 35-48 in L. E. Stevens and V. J. Meretsky, editors. Aridland springs in North America: ecology and conservation. The University of Arizona Press, Tucson, Arizona.

Kuehnert, J. 1989. A summary of involvement between the CO Bar Ranch and Wupatki National Monument, 1924 to present. Unpublished manuscript, Northern Arizona University, in the archive collections for the Flagstaff Area National Monuments, Museum of Northern Arizona, Flagstaff.

Kunkel, K. E, L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. T. Redmond, and J. G. Dobson. 2013. Regional climate trends and scenarios for the U.S. national climate assessment.

Part 5. Climate of the Southwest U.S. National Oceanic and Atmospheric Administration, Technical Report NESDIS 142-5, Washington, DC. Available at: https://www.ncdc.noaa.gov/news/us-regional-climate-trends-and-scenarios (accessed 5 November 2016).

Kunzmann, M.R., and R.R. Johnson. 1989. Introduction. In Tamarisk control in Southwestern United States, Proceedings of Tamarisk Conference, University of Arizona, Tucson, September 2 and 3, 1987.

Lamar D.L. 1964. Geology of the Wupatki blowhole system. Plateau. 37(1):35-40.

Lande, R. 1987. Extinction thresholds in demographic models of territorial populations. American Naturalist, 130, 624–635 as cited in Monahan et al. (2012).

Lapo, K., Licciardi, J., Houts, A. N., Kurz, M.D., and Curtice, J.M. 2013. Cosmogenic ^{3}He surface exposure dating of Strawberry Crater in Northern Arizona, USA: Results from The San Francisco Volcanic Field REU Program, Paper presented at the Geological Society of America Meetings, Denver, CO.

Learning Centers of the American Southwest (LCAS). 2010. Grasslands. Available at: http://www.southwestlearning.org/download_product/1298/0).

Lehmann, C.M.B., and D.A. Gay. 2011. Monitoring long-term trends of acidic wet deposition in U.S. precipitation: Results from the National Atmospheric Deposition Program. Power Plant Chemistry (13)7: 378-385.

Leopold, A. 1924. Grass, brush, timber, and fire in southern Arizona. Journal of Forestry 22:1-10.

Levick, L., J. Fonseca, D. Goodrich, M. Hernandez, D. Semmens, J. Stromberg, R. Leidy, M. Scianni, D. P. Guertin, M. Tluczek, and W. Kepner. 2008. The ecological and hydrological significance of ephemeral and intermittent streams in the arid and semi-arid American Southwest. U.S. Environmental Protection Agency and USDA/ARS Southwest Watershed Research Center, EPA/600/R-08/134, ARS/233046.

Lichvar, R.W., D.L. Banks, W.N. Kirchner, and N.C. Melvin. 2016. The National wetland plant list: 2016 wetland ratings. Phytoneuron 2016-30: 1-17. Published 28 April 2016. ISSN 2153 733X. State of Arizona 2016 Wetland Plant List.

Lichvar, R.W., N.C. Melvin, M.L. Butterwick, and W.N. Kirchner. 2012. National wetland plant list indicator rating definitions. U.S. Army Corps of Engineers. ERDC/CRREL TN-12-1.

Longcore, T. and C. Rich. 2004. Ecological light pollution. Frontiers in Ecology and the Environment 2: 191-198.

Lynch, E., D. Joyce, and K. Fristrup. 2011. An assessment of noise audibility and sound levels in U.S. National Parks. Landscape Ecology 26:1297-1309.

Mackenzie, D.I., J.D. Nichols, G.B. Lachman, S. Droege, J.A. Royle, and C.A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255 as cited by Rieck (2013).

Majka, Dan., Jeff Jenness, and Paul Beier. 2007. CorridorDesigner: ArcGIS tools for designing and evaluating corridors. Available at: http://corridordesign.org (accessed 14 September 2016).

Malm, W.C. 1999. Introduction to visibility. Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO.

Marozas, Bryan A. 1983. The use of aerial photography from Wupatki National Monument, Arizona for the discovery and analysis of prehistoric agricultural fields and related features. Unpublished Masters Thesis, Department of Anthropology, Northern Arizona University, Flagstaff.

Maule, S.H. 1963. Corn growing at Wupatki. Plateau 36(1):2932.

McCormack, D.C. 1989. The geology of Wupatki National Monument. Unpublished M.S. Thesis, Northern Arizona University, Flagstaff Arizona.

McDonald, C. D., R.M. Baumgartner, and R. Iachan. 1995. National Park Service aircraft management studies (US Department of Interior Rep. No. 94-2). Denver, CO: National Park Service.

McFadden, L.D., S.G. Wells, and J.C. Dohrenwend. 1986. Influences of Quaternary climatic changes on processes of soil development on desert loess deposits of the Cima Volcanic Field, California. Catena 13:361–389.

McFadden, L.D., S.G. Wells, and M.J. Jercinovich. 1987. Influences of eolian and pedogenic processes on the origin and evolution of desert pavements. Geology 15:504–508.

McKnight, M.L. 1995. Mitochondrial DNA phylogeography of *Perognathus amplus* and *Perognathus longimembris* (Rodentia: Heteromyidae): a possible mammalian ring species. Evolution 49:816, as cited by Rieck (2013).

McLaughlin, K.E. and H.P. Kunc. 2013. Experimentally increased noise levels change spatial and singing behavior. Biology letters 9.1 (2013): 20120771.

Mennitt, D., K. Fristrup, K. Sherrill, and L. Nelson. 2013. Mapping sound pressure levels on continental scales using a geospatial sound model. Proceedings from Internoise Conference, Innsbruck, Austria, September 15-18, 2013.

Monahan, W. B. and N. A. Fisichelli. 2014. Climate exposure of U.S. national parks in a new era of change. PLoS ONE 9(7):e101302. doi:10.1371/journal.pone.0101302. Available at: http://dx.plos.org/10.1371/journal.pone.0101302 (accessed 8 November, 2016).

Monahan, W. B., J. E. Gross, L. K. Svancara, and T. Philippi. 2012. A guide to interpreting NPScape data and analyses. Natural Resource Technical Report NPS/NRSS/NRTR—2012/578. National Park Service, Fort Collins, Colorado. Available at: http://science.nature.nps.gov/im/monitor/npscape/interpguide.cfm (accessed 8 November, 2016).

Moore, C. A. 2001. Visual estimations of night brightness. George Wright Forum 18:4655.

Moore, C. A., J. M. White, and F. Turina. 2013. Recommended indicators of night sky quality for NPS state of the park reports, interim guidance. Natural Sounds and Night Skies Division, WASO-Natural Resource Stewardship and Science. July 10, 2013.

Morse, L.E., J.M. Randall, N. Benton, R. Hiebert, and S. Lu. 2004. An invasive species assessment protocol: evaluating non-native plants for their impact on biodiversity. Version 1. NatureServe, Arlington, Virginia.

Muchmore W.B. 1981. Cavernicolous species of *Larca*, *Archeolarca*, and *Pseudogarypus* with notes on the genera, (Pseudoscorpionida, Garypidae and Pseudogarypidae). The Journal of Arachnology. 9:47-60.

National Aeronautics and Space Administration (NASA). 2016. NASA Day/Night Band Product. Available at: http://viirsland.gsfc.nasa.gov/Products/DNB.html (accessed 7 July 2016).

National Park Service (NPS) Organic Act. 1916. (16 USC1). Available at: http://www.nature.nps.gov/naturalsounds/laws_policies (accessed 22 September 2016).

National Park Service (NPS). 1980. State of the Parks, 1980: A report to the congress. Washington, D.C.: National Park Service, U.S. Department of Interior.

National Park Service (NPS). 1994. Report to Congress. Report on effects of aircraft overflights on the National Park System.

National Park Service (NPS). 1996. Resources management plan, Flagstaff area national monuments: Wupatki, Sunset Crater Volcano, and Walnut Canyon National Monuments. Flagstaff, AZ.

National Park Service (NPS). 2002. Environmental impact statement and general management plan: Wupatki National Monument, Arizona. Flagstaff, Ariz.: U.S. Dept. of the Interior, National Park Service (NPS). 2004. Natural Resource Management Reference Manual #77. Available at: http://www.nature.nps.gov/rm77/(accessed 23 July 2016).

National Park Service (NPS). 2005. NPS ecological monitoring framework.

National Park Service (NPS). 2006a. Vital signs monitoring plan for the Southern Colorado Plateau Network. Appendix C: Southern Colorado Plateau Network Water Resources. Denver, CO.

National Park Service (NPS). 2006b. Management Policies 2006: The guide to managing the National Park System. Washington, DC. 180 pp.

National Park Service (NPS). 2007. Cultural landscape inventory: Wupatki NM visitor center historic district, Wupakti National Monument. Flagstaff, AZ.

National Park Service (NPS). 2008. Fire and fuels management plan, Wupatki National Monument.

National Park Service (NPS). 2009a. Invasive plant management plan and environmental assessment: Flagstaff National Monuments - Wupatki National Monument, Walnut Canyon National Monument and Sunset Crater Volcano National Monument. Flagstaff, Arizona.

National Park Service (NPS). 2009b. Distribution and habitat of Wupatki pocket mouse, a rare endemic small mammal. PMIS #87463.

National Park Service (NPS). 2010a. Stargazing in parks. NPS Natural Resource Program Center Air Resources Division Night Sky Program. Available at: http://www.nature.nps.gov/night (accessed 15 July 2016).

National Park Service (NPS). 2010b. Standard NRCA report outline – annotated version 3.1. 4p.

National Park Service (NPS). 2011a. Program brief: Inventory and monitoring program. U.S. Department of the Interior, National Park Service, Natural Resource Program Center, Inventory and Monitoring Division, Fort Collins, Colorado.

National Park Service (NPS). 2011b. NPScape: Monitoring landscape dynamics of U.S. National Parks. Natural Resource Program Center, Inventory and Monitoring Division. Fort Collins, Colorado. Available at: http://science.nature.nps.gov/im/monitor/npscape/.

National Park Service (NPS). 2011c. NPScape NPS boundary-derived areas of analysis SOP: Park, 3km, and 30km areas of analysis. National Park Service, Natural Resource Program Center. Fort Collins, Colorado. Available at: http://science.nature.nps.gov/im/monitor/npscape/citation.cfm. (accessed October 3, 2016).

National Park Service (NPS). 2012a. A call to action: preparing for a second century of stewardship and engagement. Washington, D.C.

National Park Service (NPS). 2012b. Stewardship plan: Deadman Wash. National Park Service, Wupatki National Monument. Flagstaff, Arizona.

National Park Service (NPS). 2013a. Wupatki National Monument acoustical monitoring report 2010. Prepared by U.S. Department of Transportation. Research and Innovative Technology Administration. John A. Volpe National Transportation Systems Center. Environmental Measurement and Modeling Division, RVT-41. NPS/NRSS/NTR-2013/764. Fort Collins, CO.

National Park Service (NPS). 2013b. Inventory cave biota & provide restoration planning information for unique earthcrack caves. PMIS proposal 199137. Last updated 19 January 2016.

National Park Service (NPS). 2013c. Heiser Spring restoration project at Wupatki NM. Available at: http://www.southwestlearning.org/products/project-summary/heiser-spring-restoration-project-summary (accessed 27 August 2016).

National Park Service (NPS). 2014a. NPScape Standard Operating Procedure: Housing Measure – Current and Projected Housing Density. Version [2016-10-03]. National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado. Available at: http://science.nature.nps.gov/im/monitor/npscape/citation.cfm. (accessed October 3, 2016).

National Park Service (NPS). 2014b. NPScape Standard Operating Procedure: Roads Measure – Road Density, Distance from Roads, and Area without Roads. Version [2016-10-03]. National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado. Available at: http://science.nature.nps.gov/im/monitor/npscape/citation.cfm. (accessed October 3, 2016).

National Park Service (NPS). 2014c. Restore riparian vegetation and maintain channel stability on 24 acres of river corridor. Wupatki National Monument. PMIS 209450.

National Park Service (NPS). 2015a. Foundation document: Wupatki National Park. National Park Service, Denver, Colorado. 72p.

National Park Service (NPS). 2015b. NPScape NPS boundary-derived areas of analysis SOP: Park, 3km, and 30km areas of analysis. National Park Service, Natural Resource Program Center. Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2224677 (accessed 19 July 2016).

National Park Service (NPS). 2016a. Flagstaff area national monument's International Dark Sky Park designation nomination package. Submitted to: International Dark Sky Association, Tucson, AZ.

National Park Service (NPS). 2016b. NPSpecies list for Wupatki National Monument. Full list with details. Available at: https://irma.nps.gov/npsecies (accessed March 2016).

National Park Service (NPS). 2016c. NPScape: monitoring landscape dynamics of U.S. National Parks. Natural Resource Program Center, Inventory and Monitoring Division. Fort Collins, Colorado. Available at: http://science.nature.nps.gov/im/monitor/npscape/(accessed June 1, 2016).

National Park Service Air Resources Division (NPS-ARD). 2002. Air quality in the national parks, second edition. Lakewood, Colorado.

National Park Service Air Resources Division (NPS-ARD). 2003. Air atlas summary tables for I&M parks. Available at:: http://www.nature.nps.gov/air/Permits/ARIS/networks/docs/SummariesAirAtlasRevised11072003.pdf (accessed October 10, 2016).

National Park Service Air Resources Division (NPS-ARD). 2005. Redesignation of clean air areas. Available at: http://www.nature.nps.gov/air/Regs/redesig.cfm (accessed October 10, 2016).

National Park Service Air Resources Division (NPS-ARD). 2010. Air quality in national parks: 2009 annual performance and progress report. Natural Resource Report NPS/NRPC/ARD/NRR—2010/266. National Park Service, Denver, Colorado.

National Park Service Air Resources Division (NPS-ARD). 2012a. Clean Air Act and regulations. Available at: http://www.nature.nps.gov/air/Regs/cleanAir.cfm (accessed October 10, 2016).

National Park Service Air Resources Division (NPS-ARD). 2012b. Ozone effects on vegetation. Available at: http://www.nature.nps.gov/air/AQBasics/ozoneEffects.cfm (accessed October 10, 2016).

National Park Service Air Resources Division (NPS-ARD). 2012c. Ozone effects on tree growth. Available at: http://www.nature.nps.gov/air/AQBasics/TreeGrowth/index.cfm (accessed October 10, 2016).

National Park Service Air Resources Division (NPS-ARD). 2012d. Wet deposition monitoring. Available at: http://www.nature.nps.gov/air/Monitoring/wetmon.cfm (accessed October 10, 2016).

National Park Service Air Resources Division (NPS-ARD). 2015a. National Park Service Air Quality Analysis Methods: September 2015. Natural Resource Report NPS/NRSS/ARD/NRR–2015/XXX. National Park Service, Denver, Colorado. Available at: http://www.nature.nps.gov/air/data/products/docs/DRAFT_NPS-AirQualityAnalysis_Methods_09-11-2015.pdf (accessed October 10, 2016).

National Park Service Air Resources Division (NPS-ARD). 2015b. Guidance for evaluating air quality in Natural Resource Conditions

Assessments. Available at: http://www.nature.nps.gov/air/planning/docs/20150916_Guidance-For-Evaluating-AQ-In-NRCA.pdf (accessed October 10, 2016).

National Park Service Air Resources Division (NPS-ARD). 2016a. Air quality in parks. Available at: http://www.nature.nps.gov/air/Permits/aris/index.cfm (accessed October 4, 2016).

National Park Service Air Resources Division (NPS-ARD). 2016b. Air quality conditions and trends by park. Available at: http://nature.nps.gov/air/data/products/parks/index.cfm (accessed October 4, 2016).

National Park Service Air Resources Division (NPS-ARD). 2016c. Mercury/toxics data and information for Flagstaff Area NMs, provided by Jim Cheatham, NPS Air Resources Division, to Lisa Baril, Utah State University, via email on August 9, 2016 and from Ksienya Taylor review, 3/1/2017.

National Park Service Natural Sounds and Night Skies Division (NSNSD). 2014. NRSS Monthly Webinar - Reducing the Noise Impacts of Park Operations Presentation. Copy no longer accessible.

National Park Service (NPS) Public Use Statistics Office. 1993. Wupatki National Monument public use counting and reporting instructions. Available at: https://irma.nps.gov/Stats/FileDownload/932 (accessed 10 November 2016).

National Park Service (NPS) Public Use Statistics Office. 2017. NPS visitor use statistics. Annual park visitation (all years) and visitation by month and year. Available at: https://irma.nps.gov/Stats/Reports/ReportList (accessed 8 March 2017).

National Park Service Southern Colorado Plateau Network (SCPN). 2014. Monitoring activities by park. Available at: http://science.nature.nps.gov/im/units/scpn/parks/index.cfm (accessed 26 October 2016).

National Park Service Southern Colorado Plateau Network (SCPN). 2016. Climate summary charts. Available at: https://science.nature.nps.gov/im/units/scpn/climate/climate.cfm/ (accessed 20 February 2017).

National Park Service (NPS) and Arizona Game and Fish Department (NPS and AGFD). 2014. Study Plan: Restoring landscape connectivity for American pronghorn between three Northern Arizona parks: Wupatki National Monument, Sunset Crater Volcano National Monument, and Grand Canyon National Park. A cooperative agreement study by the National Park Service and Arizona Game and Fish Department. PMIS #188952. 18 pp.

National Park System Advisory Board (NPSAB). 2012a. Planning committee report. Available at: http://www.nps.gov/resources/upload/Task-1-Planning-Committee-Report.pdf (accessed June 1, 2015).

National Park System Advisory Board (NPSAB). 2012b. Appendix E notes on new models for the National Park System. 18 pp.

National Parks Omnibus Management Act of 1998. 1998. Available at: https://www.nps.gov/gis/data_standards/omnibus_management_act.html (accessed 22 August 2016).

NatureServe Explorer. 2016. Plants/Animals data search. Available at: http://explorer.natureserve.org/servlet/NatureServe?init=Species (accessed 12 August 2016) .

Navajo Nation Department of Fish and Wildlife. 2008. Navajo endangered species list. Resources Committee Resolution No. RCS-41-08. Available at: http://nnhp.nndfw.org/endangered.htm (accessed 14 July 2016).

Neff, J. C., A. P. Ballantyne, G. L. Farmer, N. M. Mahowald, J. L. Conroy, C. C. Landry, J. T. Overpeck, T. H. Painter, C. R. Lawrence, and R. L. Reynolds. 2008. Increasing eolian dust deposition in the western United States linked to human activity. Nature Geoscience 1: 189-195.

North American Bird Conservation Initiative (NABCI), U.S. Committee. 2014. The state of the birds 2014 report. U.S. Department of Interior, Washington, D.C.

Ockenfels, R.A., C.L. Ticer, A. Alexander, and J.A. Wennerlund. 1996. A landscape-level pronghorn habitat evaluation model for Arizona. Final report. Technical Report Number 19, Federal Aid in Wildlife Restoration Project W-78-R. Arizona Game and Fish Department, Research Branch.

Ockenfels, R.A., C. van Riper III, and W.K. Carrel. 1997. Home ranges and movements of pronghorn in northern Arizona. Pp. 45-62, In: Proc. 3rd Biennial Conference of Research on the Colorado Plateau, (C. Van Riper III, and E.T. Deshler, Eds.). 97/12, 2 NPS Transactions and Proceedings Series NPS/NRNAU/NRTP-56.

O'Connor, Z. 2008. Facade colour and aesthetic response: examining patterns of response within the context of urban design and planning in Sydney, University of Sydney: Sydney, Austraila.

O'Connor, Z. 2009. Facade colour and judgements about building size. In D. Smith, P. Green-Armytage, M. A. Pope, and N. Harkness (Eds.) AIC 2009: Proceedings of the 11th Congress of the International Colour Association, Sydney.

Ort, M. H., M. D. Elson, K.C. Anderson, W. A. Duffield, and T. L. Samples. 2008. Variable effects of cinder-cone eruptions on agrarian human populations: a tale of two eruptions in the American Southwest. Journal of Volcanology and Geothermal Research 176:363-376.

Parker, C. L. 2009. Evaluating juniper canopy cover change from 1936-1997 around Wupatki National Monument using repeat aerial photography. Thesis, Northern Arizona University.

Panjabi, A. O., E. H. Dunn, P. J. Blancher, W. C. Hunter, B. Altman, J. Bart, C. J. Beardmore, H. Berlanga, G. S. Butcher, S. K. Davis, D. W. Demarest, R. Dettmers, W. Easton, H. Gomez de Silva Garza, E. E. Iñigo-Elias, D. N. Pashley, C. J. Ralph, T. D. Rich, K. V. Rosenberg, C. M. Rustay, J. M. Ruth, J. S. Wendt, and T. C. Will. 2005.

Partners in Flight. 2005. Handbook on species assessment. Partners in Flight Technical Series No. 3. Rocky Mountain Bird Observatory. Available at: (http://www.rmbo.org/pubs/downloads/Handbook2005.pdf).

Partners in Flight Science Committee. 2012. Species assessment database, version 2012. Available at: http://rmbo.org/pifassessment (accessed 4 August 2016).

Pearce A. 1998. Reconnaissance study of the fracture system in Wupatki National Monument and vicinity, northern Arizona. Thesis.

Pellant, M., P. Shaver, D.A. Pyke, and J.E. Herrick. 2005. Interpreting indicators of rangeland health, version 4. Technical Reference 1734- 6. U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. BLM/ WO/ST-00/001+1734/ REV05. 122 pp. Available at: http://www.blm.gov/ nstc/ library/pdf/1734-6rev05.pdf.

Penrod, K., Cabanero, C., Beier, P., Luke, C., Spencer, W., Rubin, E., Sauvajot, R., Riley, S., Kamrat, D., 2006. South Coast missing linkages project: a linkage design for the Santa Monica-Sierra Madre Connection. South Coast Wildlands, Idyllwild, USA.

Persons, T.B. and C.A. Drost. 2001. Mapping and biological reconnaissance of earth crack and blowhole features at Wupatki National Monument, Arizona. Unpublished report to the National Park Service, Flagstaff Area National Monuments, Colorado Plateau Field Station, Northern Arizona University, Flagstaff, Arizona.

Persons, T.B., and E.M. Nowak. 2006. Inventory of amphibians and reptiles in Southern Colorado Plateau National Parks: U.S. Geological Survey, Southwest Biological Science Center, Colorado Plateau Research Station, Open File Report 2006-1132. 186 p.

Porter, E., and A. Wondrak-Biel. 2011. Air quality monitoring protocol and standard operating procedures for the Sonoran Desert, Southern Plains, and Chihuahuan Desert networks. Version 2.00. Natural Resource Report NPS/SODN/ NRTR—2011/390. National Park Service, Fort Collins, Colorado.

Prein, A. F., G. J. Holland, R. M. Rasmussen, M. P. Clark, and M. R. Tye. 2016. Running dry: the U.S.

Southwest's drift into a drier climate. Geophysical Research Letters 43: 1-8.

Prichard, D., J. Anderson, C. Correll, J. Fogg, K. Gebhardt, R. Krapf, S. Leonard, B. Mitchell, and J. Staats. 1998. A user guide to assessing proper functioning condition and the supporting science for lotic areas. Technical reference 1737-15. Bureau of Land Management, Denver, Colorado.

Rao, L.E., E.B. Allen, and T. Meixner. 2010. Risk-based determination of critical nitrogen deposition loads for fire spread in southern California deserts. Ecological Applications 20:1320–1335.

Ratcliff, F. 1972. Contour and contrast. Scientific American 226: 91-101.

Reheis, M.C. 1999. Dust deposition and its effect on soils – A progress report, pp. 120-131, In, Desert Winds: Monitoring wind-related surface processes in Arizona, New Mexico, and California, Breed, C.S and Reheis, M.C., eds. USGS Professional Paper 1598-G, United States Printing Office, Washington.

Rejmanek, M., and M. J. Pitcairn. 2002. When is eradication of exotic pest plants a realistic goal? Pages 249–253 in C. R. Veitch and M. N. Clout, eds., Turning the tide: The eradication of invasive species. IUCN SSC Invasive Species Specialist Group. Gland, Switzerland and Cambridge, U.K.: IUCN.

Rejmanek, M., and J. M. Randall. 1994. Invasive alien plants in California: 1993 summary and comparison with other areas in North America. Madrono 41:161–177.

Reynolds, A.C., J. Quade, J.L. Betancourt. 2012. Strontium isotopes and nutrient sourcing in a semi-arid woodland. Geoderma 189-190 (2012) 574–584.

Ribe, R. G. 2005. Aesthetic perceptions of green-tree retention harvests in vista views: The interaction of cut level, retention pattern, and harvest shape. Landscape and Urban Planning 73:277-293.

Rich, T. D., C. J. Beardmore, H. Berlanga, P. J. Blancher, M. S. W. Bradstreet, G. S. Butcher, D. W. Demarest, E. H. Dunn, W. C. Hunter, E. E. Iñigo-Elias, J. A. Kennedy, A. M. Martell, A. O. Panjabi, D. N. Pashley, K. V. Rosenberg, C. M. Rustay, J. S. Wendt, T. C. Will. 2004. Partners in Flight North American Landbird Conservation Plan. Cornell Lab of Ornithology. Ithaca, NY.

Rieck, J.M.L. 2013. Factors affecting the distribution of two species of pocket mouse in Northern Arizona. Master of Science Thesis, Northern Arizona University.

Rittenour, T, Karlov, R. E., Broadman, E., Lapo, K., Houts, A. N., Landis, H., Anderson, K. C., Licciardi, J., Riggs, N., Ort, M.H. 2015. How old are the SP and Strawberry volcanic vents and flows in the San Francisco Volcanic Field, Arizona? New evidence from soils, OSL dated loess, and He-3 exposure dating. Paper presented at the Geological Society of America Meetings, Baltimore, MD.

Roberts, A. 1986. Contribution of the southwest parks and monuments association to the Wupatki ethnohistorical research project, phase II: Results of funding for the collection of oral history. Southwest Parks and Monuments Association, Tucson, AZ.

Robinett, D. 1994. Fire effects on southeastern Arizona plains grasslands. Rangelands 16:143-148.

Romme, W, C. Allen, J. Bailey, W. Baker, B. Bestelmeyer, P. Brown, K. Eisenhart, L. Floyd-Hanna, D. Huffman, B. Jacobs, R. Miller, E. Muldavin, T. Swetnam, R. Tausch, and P. Weisberg. 2009. Historical and modern disturbance regimes of piñon-juniper vegetation in the western United States. Rangeland Ecology and Management 62:203-222.

Romme. W. and P. Whitefield. 2017. Dynamics of the grassland-savanna-woodland ecosystem at Wupatki National Monument, Arizona. 35 pages.

Rosenberg, K.V., D. Pashley, B. Andres, P.J. Blancher, G.S. Butcher, W.C. Hunter, D. Mehlman, A.O. Panjabi, M. Parr, G. Wallace, and D. Wiedenfeld. 2014. The state of the birds 2014 Watch List. North American Bird Conservation Initiative, U.S. Committee. Washington, D.C. Available at: https://

abcbirds.org/birds/watchlist/ (accessed August 2016).

Rosenstock, S.S. 1999. Effects of juniper woodland expansion on breeding birds in grasslands of Northern Arizona. Technical Guidance Bulletin No. 1-December 1999. Arizona Game and Fish Department, Phoenix.

Rosenstock, S.S., and C. van Riper III. 2001. Breeding bird responses to juniper woodland expansion. Journal of Range Management, 54: 226–232.

Royal Commission on Environmental Pollution. 2009. Artificial light in the environment. The Stationery Office Limited, London.

Ryan, R. L. 2006. Comparing the attitudes of local residents, planners, and developers about preserving rural character in New England. Landscape and Urban Planning 75: 5-22.

Salzer, M.W. and R.S. Kipfmueller. 2005. Reconstructed temperature and precipitation on a millennial timescale from tree-rings in the southern Colorado Plateau, U.S.A. Climatic Change 70, 465-487.

Sankey, J. B. and A. E. Draut. 2014. Gully annealing by aeolian sediment: field and remote-sensing investigation of aeolian-hillslope-fluvial interactions, Colorado River corridor, Arizona, USA. Geomorphology 220: 68-80.

Sartor J.D. 1964. Meteorological investigations of the Wupatki blowhole system. Plateau. 37(1):26-34.

Sartor J.D. and Lamar D.L. 1962. Meteorological-geological investigations of the Wupatki blowhole system. RM-3139-RC. The RAND Corporation. Santa Monica, CA.

Schauman, S. 1979. The countryside visual resource. In Proceedings of our national landscape: a conference on applied techniques for analysis and management of the visual resource, General Technical Report PSW-35, Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Berkely, California.

Schelz, C. 2012. Stewardship plan, Deadman Wash. National Park Service. 8 pages.

Schelz, C., R. Hiebert, and C. Montano. 2013. Long-term vegetation trends in Wupatki National Monument, 1977–2011. Prepared for the National Park Service, Flagstaff Area National Monuments, Resources Management Division, Flagstaff, AZ.

Schley R.A. 1961. Diurnal air flow through an earth crevice, Wupatki National Monument. Plateau. 33(4):105-111.

Schoeneberger, P.J., Wysocki, D.A. Benham, E.C. and , W.D. 2012. Field book for describing and sampling soils. 2. Lincoln: Natural Resources Conservation Service, National Soil Science Center.

Schussman, H., and D. Gori. 2004. An ecological assessment of the Bureau of Land Management's current fire management plans: materials and recommendations for future fire planning. Report published by The Nature Conservancy.

Schwartz, S., and Gary Bateman. 1978. Studies of selected mammalian population. In Natural resource survey and analysis of Sunset Crater Volcano and Wupatki National Monuments. Final Report Phase II. Ms on file Wupatki National Monument as cited in-text as Bateman and Schwartz (1978) in NPS (1996).

Schweiger, O., J. C. Biesmeijer, R. Bommaro, T. Hickler, P. E. Hulme, S. Klotz, I. Kühn, M. Moora, A. Nielsen, R. Ohlemüuller, T. Petanidou, S. G. Potts, P. Pyšek, J. C. Stout, M. T. Sykes, T. Tscheulin, M. Vilà, G. Walther, C. Westphal, M. Winter, M. Zobel, and J. Settele. 2010. Multiple stressors on biotic interactions: how climate change and alien species interact to affect pollination. Biological Reviews 85: 777-795.

Schwinning, S., B.I. Starr, N.J. Wojcik, M.E. Miller, J.E. Ehleringer, and R.L. Sanford. 2005. Effects of nitrogen deposition on an arid grassland in the Colorado plateau cold desert. Rangeland Ecology and Management. 58: 565–574.

Sekercioglu, C. H. 2002. Impacts of birdwatching on human and avian communities. Environmental Conservation 29:282–289.

Selin, N.E. 2009. Global biogeochemical cycling of mercury: a review. Annual Review of Environment and Resources 34:43.

Selye, H. 1956. The stress of life. New York: McGraw-Hill.

Shannon, G., M. F. McKenna, L. M. Angeloni, K. R. Crooks, K M. Fristrup, E. Brown, K. A. Warner, M. D. Nelson, and C. White. 2015. A synthesis of two decades of research documenting the effects of noise on wildlife. Biological Reviews.

Sheibley, R.W., M. Enache, P.W. Swarzenski, P.W. Moran, and J.R. Foreman, 2014. Nitrogen deposition effects on diatom communities in lakes from three national parks in Washington State. Water, Air, & Soil Pollution 225:1857.

Sheppard, S. R. J. 2001. Beyond visual resource management: Emerging theories of an ecological aesthetic and visible stewardship. In Sheppard, S. R. J. and H. W. Harshaw, Eds., Forests and Landscapes: Linking Ecology, Sustainability and Aesthetics. CABI Publishing, New York.

Sheppard, P. R., A. C. Comrie, G. D. Packin, K. Angersbach, and M. K. Hughes. 2002. The climate of the US Southwest. Climate Research 21: 219-238.

Smiley, T. 1958. The geology and dating of Sunset Crater, Flagstaff, Arizona. In: Anderson, R.Y., Harshbarger, J.W. (Eds.), Guidebook of the Black Mesa Basin, Northeastern Arizona. New Mexico Geological Society, Ninth Field Conference, pp. 186–190.

Society for the Study of Amphibians and Reptiles (SSAR). 2016. SSAR species name database. Available at: https://ssarherps.org (accessed 7 December 2016).

Soil Survey Staff. 2014. Kellogg Soil Survey Laboratory Methods Manual. Soil Survey Investigations Report No. 42, Version 5.0. R. Burt and Soil Survey Staff (ed.). U.S. Department of Agriculture, Natural Resources Conservation Service.

Sprague, S.C. 2010. Highways and pronghorn population genetics in northern Arizona pronghorn. Thesis, Northern Arizona University, Flagstaff, Arizona.

Sprague, S.C., and J.W. Gagnon. No date. Highways and pronghorn population genetics across Northern Arizona. Wildlife Field Notes, Volume 5, Arizona Game and Fish Department. Two-page fact sheet. Available at: https://www.azgfd.com/PortalImages/files/contracts/WFN_V5.pdf (accessed August 18, 2016).

Springer, A. and L. Schaller. 2012. Hydrogeological investigations and water table monitoring at Deadman Wash and Little Colorado River. Final Report to Wupatki National Monument. Northern Arizona University, Flagstaff, Arizona.

Springer, A. E. and L. E. Stevens. 2008. Spheres of discharge of springs. Hydrogeology Journal 17: 83-93.

Springer, A., L.E. Stevens, and R. Harms. 2006. Inventory and classification of selected national park service springs on the Colorado Plateau. Report submitted to Lisa Thomas, Southern Colorado Plateau I&M Network, and Dr. Angela Evenden, Northern Colorado Plateau I&M Network.

Stegner, M.A., D.S. Karp, A.J. Rominger, and E.A. Hadly. 2017. Can protected areas really maintain mammalian diversity? Insights from a nestedness analysis of the Colorado Plateau. Biological Conservation 209: 546-553.

Stevens, L.E. 2002. Exotic tamarisk on the Colorado Plateau. Land Use History of North America Colorado Plateau as cited by Stumpner 2004.

Stumpner, P. 2004. Hydrogeological investigations and water table monitoring recommendations: Deadman Wash and Little Colorado River confluence area, Wupatki National Monument, Arizona. National Park Service, Fort Collins, Colorado.

Sullivan, T.J., G.T. McPherson, T.C. McDonnell, S.D. Mackey, and D. Moore. 2011a. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: Southern Colorado

Plateau Network (SCPN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/372. National Park Service, Denver, Colorado.

Sullivan, T. J., T. C. McDonnell, G. T. McPherson, S. D. Mackey, and D. Moore. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: Southern Colorado Plateau Network (SCPN). Natural Resource Report NPS/NRPC/ARD/NRR2011/330. National Park Service, Denver, Colorado.

Templeton, D. and Sacre. 1997. Acoustics in the built environment: Advice for the design team. 2nd edition. D. Templeton (editor). Architectural Press: Boston, Massachusetts.

The Federal Cave Protection Act. 1988. United States Code: 16 USC Sec. 4301 Title 16 Chapter 63.

The Nature Conservancy (TNC). 2005. The importance of grasslands in northern Arizona. Available at: http://www.landsward.nau.edu/document_forms/Final%20Grasslands%20Brochure%202005%201%20MB.pdf.

The Nature Conservancy (TNC). 2017. Grassland assessment - 2004. Available at: http://azconservation.org/projects/grasslands/(accessed January 31, 2017).

Theimer, T., S. Sprague, E. Eddy, and R. Benford. 2012. Genetic variation of pronghorn across U.S. Route 89 and State Route 64. Final Report 659 prepared for: Arizona Department of Transportation in cooperation with U.S. Department of Transportation Federal Highway Administration. 43 pp.

Theobald, D.M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10:32. Available at: http://www.tetonwyo.org/compplan/LDRUpdate/RuralAreas/Additional%20Resources/Theobald2005.pdf (accessed 22 September 2016).

Thomas, B. E. 2003. Water-quality data for Walnut Canyon and Wupatki National Monuments, Arizona-2001-02. United States Geological Survey. Tuscon, AZ.

Thomas, L.P., M.N. Hendrie (editor), C.L. Lauver, S.A. Monroe, N.J. Tancreto, S.L. Garman, M.E. Miller. 2006. Vital Signs Monitoring Plan for the Southern Colorado Plateau Network. Natural Resource Report NPS/SCPN/NRR-2006/002. National Park Service, Southern Colorado Plateau Network, Northern Arizona University, Flagstaff, Arizona.

Ticer, C.L., J.C. Devos Jr., W. Cordasco, and R.A. Ockenfels. 2002. Pronghorn use of modified fences In northern Arizona. Proceedings of the 20th Annual Pronghorn Antelope Workshop, March 17-20, 2002.

Tilman, D. 1999. The ecological consequences of changes in biodiversity: A search for general principles. Ecology 80:1455–1474.

Travis, S.E. 1990. The prehistoric agricultural landscape of Wupatki National Monument. In: Anderson, B.A. (Ed.), The Wupatki archeological inventory survey project: final report. Professional Paper No. 35, Southwest Cultural Resource Center, Division of Anthropology, National Park Service, Santa Fe, 4.1-4.54.

Turina, F., E. Lynch, and K. Fristrup. 2013. Recommended indicators and thresholds of acoustic resources quality NPS State of the Park reports interim guidance- December 2013. National Park Service Natural Sounds and Night Skies Division.

Trzcinski, M.K., Fahrig, L. and Merriam, G. 1999. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. Ecological Applications, 9, 586–593 as cited in Monahan et al. (2012).

Turner, M.G. 1989. Landscape ecology: the effect of pattern on process. Annual Review of Ecology and Systematics, 20, 171-197 as cited in Monahan et al. (2012).

U.S. Census Bureau. 2011. 2010 Census Data. Available at: http://2010.census.gov/2010census/data/ as cited by Arizona Game and Fish Department (2011).

U.S. Census Bureau. 2016a. Current population reports. Available at: http://www.census.gov/prod/2/pop/p25/p25-1131.pdf (accessed 27 June 2016).

U.S. Census Bureau. 2016b. Quick facts: Flagstaff city, Arizona. Available at: http://www.census.gov/quickfacts/table/PST045215/0423620 (accessed 27 June 2016).

U.S. Department of Agriculture (USDA). 2016. PLANTS database. Natural Resources Conservation Service. Available at: http://plants.usda.gov/java/ (accessed 12 August 2016).

U. S. Department of Agriculture (USDA), Natural Resources Conservation Service, and United States Department of the Interior, National Park Service. 2015. Soil survey of Wupatki National Monument, Arizona. Available at :http://soils.usda.gov/survey/printed_surveys/ (accessed on 16 September 2016).

U. S. Department of Agriculture (USDA), Natural Resources Conservation Service. 2016. National soil survey handbook, title 430-VI. Available at: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054242 (accessed 16 September 2016).

U.S. Environmental Protection Agency (USEPA). 1974. Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety. EPA, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 2014. Policy assessment for the review of the ozone national ambient air quality standards. EPA-452/R-14-006. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Available at: http://www.epa.gov/ttn/naaqs/standards/ozone/data/20140829pa.pdf (accessed October 10, 2016).

U.S. Environmental Protection Agency (USEPA). 2016a. National ambient air quality standards (NAAQS). Available at: https://www.epa.gov/criteria-air-pollutants/naaqs-table (accessed October 10, 2016).

U.S. Environmental Protection Agency (USEPA). 2016b. Acid rain. Available at: https://www.epa.gov/acidrain/what-acid-rain (accessed October 10, 2016).

U.S. Environmental Protection Agency (USEPA). 2016c. STOrage and RETrieval and water quality eXchange. Available at: https://www.epa.gov/waterdata/storage-and-retrieval-and-water-quality-exchange (accessed 6 September 2016).

U.S. Environmental Protection Agency (USEPA). 2016d. Table of regulated drinking water contaminants. Available at: https://www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants (accessed 5 October 2016).

U.S. Federal Register. 1964. Wilderness Act. Public Law 88-577. Available at: http://wilderness.nps.gov/document/wildernessAct.pdf (accessed 8 November, 2016).

U.S. Federal Register. 1970. Clean Air Act. Public Law 95-124. Pages 5673-5965. Available at: http://www2.epa.gov/laws-regulations/summary-clean-air-act (accessed 8 November 2016).

U.S. Fish and Wildlife Service (USFWS). 1981. Standards for the development of suitability index models. Division of Ecological Services, Government Printing Office, Washington, D.C.

U.S. Fish and Wildlife Service (USFWS). 2008. Birds of Conservation Concern 2008. United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, Virginia.

U.S. Fish and Wildlife Service (USFWS). 2013. General Provisions; revised list of migratory birds; Final Rule. 50 CFR Parts 10 and 21. Federal Register, Vol. 78, No. 212, November 1, 2013.

U.S. Fish and Wildlife Service (USFWS). 2015. White-nose syndrome.org: a coordinated response to the devastating bat disease. Available at: https://www.

whitenosesyndrome.org (accessed 18 August 2016).

U.S. Fish and Wildlife Service (USFWS). 2016a. Migratory Bird Treaty Act, Birds Protected. USFWS webpage, last updated September 16, 2015. Available at: http://www.fws.gov/birds/policies-and-regulations/laws-legislations/migratory-bird-treaty-act.php (accessed 8 February 2016).

U.S. Fish and Wildlife Service (USFWS). 2016b. Listed species believed to or known to occur in Arizona. Environmental Conservation Online System. Available at: http://ecos.fws.gov/ecp0/reports/specieslistedbystatereport?state=AZ&status=listed (accessed 15 August 2016).

U.S. Fish and Wildlife Service (USFWS). 2016c. Species profile for Southwestern willow flycatcher (*Empidonax traillii extimus*). Environmental Conservation Online System. Available at: https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=B094 (accessed 5 August 2016).

U.S. Fish and Wildlife Service (USFWS). 2017. White-nose syndrome: the devastating disease of hibernating bats in North America. Available at: https://www.whitenosesyndrome.org/about-white-nose-syndrome (accessed 1 June 2017).

U.S. Forest Service (USFS). 1992. Report to Congress. Potential impacts of aircraft overflights of National Forest System Wildernesses.

U.S. Forest Service (USFS). 1995. Landscape aesthetics: a handbook for scenery management. Agricultural Handbook 710.

U.S. General Accounting Office. 1994. Activities outside park borders have caused damage to resources and will likely cause more. U.S. Government Printing Office, GAO/RCED-94-59 as cited in Monahan et al. (2012).

U.S. Geological Survey (USGS). 1982. 1:100,000-scale metric topographic map of Flagstaff, Arizona.

U.S. Geological Survey (USGS) National Gap Analysis Program. 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University. Available at: http://swregap.org/data/landcover/.

U.S. Geological Survey (USGS). 2011a. A dryland river transformed- the Little Colorado, 1936-2010. Fact sheet 2011-3099. 4 pages.

U.S. Geological Survey (USGS). 2011b. A summary of the relationship between GAP Status Codes and IUCN Definitions. Available at: http://gapanalysis.usgs.gov/blog/iucn-definitions/(accessed November 2016).

U.S. Geological Survey (USGS). 2014. Water resources of the United States, boundary descriptions and names of regions, subregions, accounting units and cataloging units. Available at: http://water.usgs.gov/GIS/huc_name.html#Region15 (accessed 8 November 2016).

U.S. Geological Survey (USGS). 2015. Predicted surface water methylmercury concentrations in National Park Service Inventory and Monitoring Program Parks. Last modified February 20, 2015.

U.S. Geological Survey (USGS). 2016a. USGS NED n33w111 1/3 arc-second 2013 1 x 1 degree IMG: U.S. Geological Survey: Reston, VA. Available at: http://ned.usgs.gov/, http://nationalmap.gov/viewer.html (accessed 22 September 2016).

U.S. Geological Survey (USGS). 2016b. Water properties and measurements. Available at: http://water.usgs.gov/edu/waterproperties.html (accessed 5 September 2016).

U.S. Geological Survey (USGS). 2016c. National water information system: web Interface. Data for USGS 09401000, Little Colorado River at Grand Falls, Arizona. Available at: http://waterdata.usgs.gov/az/nwis/inventory/?site_no=09401000&agency_cd=USGS&amp (accessed October 4, 2016).

U.S. Geological Survey (USGS). 2016d. Little Colorado River at Grand Falls, AZ 09401000. USGS, Grand Canyon Monitoring and Research Center website. Available at: http://www.gcmrc.gov/discharge_qw_sediment/station/GCDAMP/09401000 (accessed October 3, 2016).

U.S. Geological Survey (USGS), Gap Analysis Program (GAP). 2016e. Protected Areas Database of the United States (PAD-US), version 1.4 Combined Feature Class. Available at: http://gapanalysis.usgs.gov/padus/data/download/ (accessed November 2016).

University of California Weed Research & Information Center (UCWRIC). 2013. Saltcedar and tamarisk. A weed report from the book *Weed Control in Natural Areas in the Western United States*. Available at: http://wric.ucdavis.edu/information/crop/natural%20areas/wr_T/Tamarix.pdf. (accessed 31 August 2016).

Valentine-Darby, P., A. Mathis, K. Struthers, D. Shorrock, L. Baril, and N. Chambers. 2016. El Malpais National Monument: Natural resource condition assessment. Natural Resource Report NPS/SCPN/NRR—2016/1301. National Park Service, Fort Collins, Colorado.

Vaughan, Terry. 1976. Mammals of Sunset Crater Volcano and Wupatki National Monument. In natural resource survey and analysis of Sunset Crater and Wupatki National Monuments. Report prepared by Northern Arizona University, Contract No. 950134. Ms on file Wupatki National Monument as cited in NPS (1996).

Virden, R. J. and G. J. Walker. 1999. Ethnic/racial and gender variations among meanings given to, and preferences for, the natural environment. Leisure Sciences 21:219-239.

Vitousek, P. M. 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Oikos 57:7–13.

Waring, G. 2006. Hopi corn and volcanic cinders: a test of the relationship between tephra and agriculture in Northern Arizona. In Sunset Crater Archaeology: The History of a Volcanic Landscape. Environmental Analyses, edited by M. D. Elson, pp. 71-83. Anthropological Papers No. 33. Center for Desert Archaeology, Tucson.

Warner, Peter J., Carla C. Bossard, Matthew L. Brooks, Joseph M. DiTomaso, John A. Hall, Ann M. Howald, Douglas W. Johnson, John M. Randall, Cynthia L. Roye, Maria M. Ryan, and Alison E. Stanton. 2003. Criteria for categorizing invasive non-native plants that threaten wildlands. California Exotic Pest Plant Council and Southwest Vegetation Management Association.

Welch, B.A., Geissler, P.H., and Latham, Penelope, 2014, Early detection of invasive plants—principles and practices: U.S. Geological Survey Scientific Investigations Report 2012–5162, 193 p., http://dx.doi.org/10.3133/sir20125162.

Welbourn W.C. 1976. Preliminary report on the fauna of the earth cracks. Wupatki National Monument earth cracks. Cave Research Foundation. Yellow Springs, OH.

Welbourn W.C. 1979. Invertebrate Fauna of the Earth Cracks of Wupatki National Monument. Pages 387-391. In Linn RM: proceedings of the first conference on scientific research in the national parks. New Orleans, LA. November 9-12, 1976. National Park Service. Washington, DC. National Park Service transactions and proceedings series.

White, R.W. 1969. Antelope winter kill, Arizona style. Proceedings of the Western Association of Game and Fish Agencies 49:251-254 as cited by Ockenfels et al. (1997).

White, J., D. Duriscoe, and C. Moore. 2012. Bortle Dark-Sky Scale: key for the summer sky, latitudes 30° to 50° North. NPS Natural Sounds and Night Skies Division.

Whitefield, Paul. 2012. WUPA earthcrack species accounts compilation. Internal park document.

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. Bioscience 48:607–615.

Wondrak-Biel, A. 2005. Aesthetic conservation and the National Park Service. Yellowstone Science 13(3):1.

Wu, Z., P. Dijkstra, G. W. Kock, and B. A. Hungate. 2012. Biochemical and ecological feedbacks in grasslands responses to warming. Nature Climate

Change 2:458-461 as cited in the Grasslands-Juniper assessment.

Wynne, J.J. 2014. Final Report: Mapping, biological inventory, and microclimate data for two earth-crack caves at Wupatki National Monument, Phase 1. Submitted under Task Agreement NAU-407, Colorado Plateau Cooperative Ecosystems Studies Unit, Northern Arizona University, Flagstaff. Internal report to the Natural Resource Program, Flagstaff Area National Monuments.

Wynne, J.J. 2015. Final Report: Mapping, biological inventory, and microclimate data for two earth-crack caves at Wupatki National Monument, Phase 2. Submitted under Task Agreement NAU-449, Colorado Plateau Cooperative Ecosystems Studies Unit, Northern Arizona University, Flagstaff. Internal report to the Natural Resource Program, Flagstaff Area National Monuments.

Yavapai Colledge Elderhostel. 2002. Wupatki NM Little Colorado River bird survey. Data provided on three sites via August 27, 2002 letter from Randy Miller to Paul Whitefield.

Yavapai Colledge Elderhostel. 2003. Wupatki NM Little Colorado River bird survey. Data provided on three sites via August 18, 2003 letter from Randy Miller to Paul Whitefield.

Yavapai Colledge Elderhostel. 2004. Wupatki NM Little Colorado River bird survey. Data provided on four sites via July 13, 2004 letter from Randy Miller to Paul Whitefield.

Yoakum, J.D., and B.W. O'Gara. 2000. Pronghorn. Pages 559–577 in S. Demarais and P. R. Krausman, editors. Ecology and management of large mammals in North America. Prentice Hall, Upper Saddle River, New Jersey as cited in NPS and AGFD (2014).

Zaimes, G. and others. 2007. Understanding Arizona's riparian areas. AZ1432. University of Arizona, Arizona Cooperative Extension.

Zube, E. H., J. L. Sell, and J. G. Taylor. 1982. Landscape perception: Research, application, and theory. Landscape Planning 9:1-33.

Appendix A. Wupatki NM Mammal, Reptile, and Amphibian Species Lists

Listed below are the mammal species that have been recorded at Wupatki National Monument (NM). Sources used for the list were the Certified NPSpecies list for the national monument (NPS 2016b, dated March 23, 2016), and Drost (2009). Species listed by Drost (2009) were those recorded by him: 1) during field work in 2003-2005; and 2) based on his review of museum data and other sources. Species in the list below are separated by mammal group (i.e., order). A total of 53 species have been documented in the park, with non-native species shown in bold font. The list of species was compared with lists of federally threatened and endangered species and those of Greatest Conservation Need (SGCN) in the state (Arizona Game and Fish Department [AGFD] 2012).

Table A.1. Wupatki NM mammals list.

Group	Common Name	Scientific Name	Listed by Drost (2009)
Ungulates	Domestic cattle (non-native)	Bos taurus	X
	Domestic goat [1] (non-native)	Capra hircus	X
	Domestic sheep (non-native)	Ovis aries	X
	Elk (non-native)	Cervus canadensis (or elaphus) [2]	X
	Mule deer	*Odocoileus hemionus*	X
	Pronghorn [4]	*Antilocapra americana americana*	X
Carnivores	American badger	*Taxidea taxus*	X
	American black Bear [3]	*Ursus americanus*	–
	Bobcat	*Lynx rufus*	X
	Coyote	*Canis latrans*	X
	Gray fox	*Urocyon cinereoargenteus*	X
	Kit fox [4]	*Vulpes macrotis*	X
	Mountain lion	*Puma concolor*	X
	Northern raccoon	*Procyon lotor*	X
	Western spotted skunk [1]	*Spilogale gracilis*	X
Lagomorphs	Black-tailed jackrabbit	*Lepus californicus*	X
	Desert cottontail	*Sylvilagus audubonii*	X
Bats	Big brown bat [5]	*Eptesicus fuscus*	X
	Big free-tailed bat [6]	*Nyctinomops macrotis*	X
	Brazilian (or Mexican) free-tailed bat [4]	*Tadarida brasiliensis*	X
	California Myotis	*Myotis californicus*	X
	Eastern small-footed bat	*Myotis leibii*	–
	Eastern red bat	*Lasiurus borealis*	–
	Fringed myotis	*Myotis thysanodes*	X
	Hoary bat [5]	*Lasiurus cinereus*	X

[1] Species was listed by Drost (2009) but not NPS (2016b).

[2] NPS (2016b) lists the elk as *Cervus elaphus*, while Drost (2009) lists it as *C. canadensis*.

[3] Species was listed by NPS (2016b) but not Drost (2009).

[4] Listed as a Species of Greatest Conservation Need (SGCN, Tier 1A or 1B [out of 1A-1C]) with the State (AGFD 2012). None of the species are federally-listed as endangered or threatened.

[5] NPS (2016b) considers this species as "unconfirmed."

[6] NPS (2016b) considers this species as "in review."

[7] Local subspecies is Wupatki pocket mouse (*P. amplus cineris*), which also considered a SGCN.

[8] NPS (2016b) considers this species as "probably present."

[9] Species not included on the Drost (2009) list. It is noted as either probably present or unconfirmed by NPS (2016b).

Table A.1 continued. Wupatki NM mammals list.

Group	Common Name	Scientific Name	Listed by Drost (2009)
Bats *continued*	Long-eared myotis	*Myotis evotis*	–
	Long-legged myotis	*Myotis volans*	–
	Pallid bat	*Antrozous pallidus*	X
	Silver-haired bat	*Lasionycteris noctivagans*	X
	Spotted bat [4]	*Euderma maculatum*	X
	Townsend's big-eared bat, Western big-eared bat	*Corynorhinus townsendii*	X
	Western pipistrelle	*Pipistrellus hesperus*	X
	Western small-footed bat [6]	*Myotis ciliolabrum*	X
	Yuma myotis [4,5]	*Myotis yumanensis*	X
Rodents	Arizona pocket mouse [4, 7]	*Perognathus amplus* [7]	X
	Arizona woodrat	*Neotoma devia*	X
	Botta's pocket gopher	*Thomomys bottae*	X
	Brush mouse	*Peromyscus boylii*	X
	Canyon mouse	*Peromyscus crinitus*	X
	Cliff chipmunk [8]	*Tamias dorsalis*	X
	Deer mouse	*Peromyscus maniculatus*	X
	Gunnison's prairie dog [4]	*Cynomys gunnisoni*	X
	North American porcupine	*Erethizon dorsatum*	X
	Northern grasshopper mouse	*Onychomys leucogaster*	X
	Ord's kangaroo rat	*Dipodomys ordii*	X
	Pinyon mouse	*Peromyscus truei*	X
	Plains pocket mouse	*Perognathus flavescens*	X
	Rock pocket mouse	*Chaetodipus intermedius*	X
	Rock squirrel	*Spermophilus variegatus*	X
	Silky pocket mouse	*Perognathus flavus*	X
	Spotted ground squirrel	*Spermophilus spilosoma*	X
	Stephens's woodrat [4]	*Neotoma stephensi*	X
	Western harvest mouse	*Reithrodontomys megalotis*	X
	Western white-throated woodrat	*Neotoma albigula*	X
	White-tailed antelope squirrel	*Ammospermophilus leucurus*	X
Insectivores	Crawford's desert shrew [9]	*Notiosorex crawfordi*	–
Carnivores	Striped skunk	*Mephitis mephitis*	–
	Eastern spotted skunk	*Spilogale putorius*	–
	Long-tailed weasel	*Mustela frenata*	–
	Ringtail	*Bassariscus astutus*	–

[1] Species was listed by Drost (2009) but not NPS (2016b).

[2] NPS (2016b) lists the elk as *Cervus elaphus*, while Drost (2009) lists it as *C. canadensis*.

[3] Species was listed by NPS (2016b) but not Drost (2009).

[4] Listed as a Species of Greatest Conservation Need (SGCN, Tier 1A or 1B [out of 1A-1C]) with the State (AGFD 2012). None of the species are federally-listed as endangered or threatened.

[5] NPS (2016b) considers this species as "unconfirmed."

[6] NPS (2016b) considers this species as "in review."

[7] Local subspecies is Wupatki pocket mouse (*P. amplus cineris*), which also considered a SGCN.

[8] NPS (2016b) considers this species as "probably present."

[9] Species not included on the Drost (2009) list. It is noted as either probably present or unconfirmed by NPS (2016b).

Note: When common names of Drost (2009) and NPS (2016b) did not match, we used those from Drost.

Sources used for Wupatki NM's reptile and amphibian species list were NPSpecies (NPS 2016b, dated March 23, 2016) and Persons and Nowak (2006). Species listed by Persons and Nowak (2006) were those recorded by their field sampling efforts (in 2001-2003) and others' past, reliable observations or specimens. A total of 27 species have been documented in the park (noted as present), with an additional five species that may occur (unconfirmed). No non-native species have been observed. The list of species was compared with lists of federally threatened and endangered species and those of Greatest Conservation Need in the State (Arizona Game and Fish Department 2012, species designated as Tier 1A or 1B), but no such species were identified. Scientific names follow Brennan (2015); a number of changes have been made to scientific names since the Persons and Nowak report.

Table A.2. Wupatki NM reptiles list.

Common Name	Scientific Name	Occurrence [1]
Black-necked garter snake	Thamnophis cyrtopsis	Unconfirmed
Common kingsnake	*Lampropeltis getula*	X
Desert spiny lizard	*Sceloporus magister*	X
Eastern collared lizard	Crotaphytus collaris	X
Eastern fence lizard (also known as Plateau lizard)	*Sceloporus undulatus*	X
Glossy snake	*Arizona elegans*	X
Gopher snake (or Bullsnake)	Pituophis catenifer	X
Greater short-horned Lizard	*Phrynosoma hernandesi*	X
Lesser earless lizard	*Holbrookia maculata*	X
Little striped whiptail [2]	*Aspidoscelis inornata* [2]	X
Long-nosed leopard lizard	*Gambelia wislizenii*	X
Long-nosed snake	*Rhinocheilus lecontei*	Unconfirmed
Milk snake	*Lampropeltis triangulum*	X
Nightsnake	*Hypsiglena torquata* [3]	X
Ornate tree lizard	*Urosaurus ornatus*	X
Plateau striped whiptail	*Aspidoscelis velox*	X
Prairie rattlesnake [4]	*Crotalus viridis*	X
Sagebrush lizard	*Sceloporus graciosus*	Unconfirmed
Side-blotched lizard	*Uta stansburiana*	X
Smith's (or Southwestern) black-headed snake	*Tantilla hobartsmithi*	Unconfirmed
Striped whipsnake	*Coluber taeniatus*	X
Western banded gecko	*Coleonyx variegatus*	X
Western ground snake	*Sonora semiannulata*	X
Western patch-nosed snake	*Salvadora hexalepis*	X
Western terrestrial garter snake	*Thamnophis elegans*	Unconfirmed
Tiger (or Western) whiptail	*Aspidoscelis tigris*	X

[1] Occurrence from Persons and Nowak (2006) and NPS (2016b).

[2] This species (common name or scientific name) was not listed by Brennan (2015). This species is also known as *Cnemidophorus inornatus*.

[3] Some resources, such as Brennan (2015) use the species name *chlorophaea* for this snake.

[4] Common name is listed as western rattlesnake in Persons and Nowak (2006), but the species has been reclassified as the prairie rattlesnake (*C. viridus*) vs. the western rattlesnake (*C. oreganus*) (SSAR 2016).

Table A.3. Wupatki NM amphibians list.

Common Name	Scientific Name	Occurrence *
Great plains toad	*Anaxyrus cognatus*	X
Mexican spadefoot	*Spea multiplicata*	X
Plains spadefoot	*Spea bombifrons*	X
Red-spotted toad	*Anaxyrus punctatus*	X
Tiger salamander	*Ambystoma tigrinum*	X
Woodhouse's toad	*Anaxyrus woodhousii*	X

* Occurrence from Persons and Nowak (2006) and NPS (2016b).

Appendix B. Scoping Meeting Participants and Report Reviewers

Table B.1. Scoping meeting participants.

Name	Affiliation and Position Title
Dr. Kirk Anderson	Museum of Northern Arizona, Geomorphologist (presented assessment approach for Sunset Crater Tephra Layer)
Lisa Baril	Utah State University, Wildlife Biologist and Writer/Editor
Dr. Mark Brunson	Utah State University ,Professor and Principal Investigator
Kayci Cook-Collins	Flagstaff Area National Monuments, Superintendent
Michael M. Jones	Flagstaff Area National Monuments, GIS Specialist
Lisa Leap	Flagstaff Area National Monuments, Chief of Resources
Karla Mingus	Flagstaff Area National Monuments, Compliance Specialist
Kim Struthers	Utah State University, NRCA Project Coordinator and Writer/Editor
Mark Szydlo	Flagstaff Area National Monuments, Biologist
Lisa Thomas	NPS Southern Colorado Plateau Inventory and Monitoring Network, Program Manager
Patty Valentine-Darby	Utah State University, Biologist and Writer/Editor
Paul Whitefield	Flagstaff Area National Monuments, Natural Resource Specialist

Table B.2. Report reviewers.

Name	Affiliation and Position Title	Section(s) Reviewed or Other Role
Jeff Albright	National Park Service Water Resources Division, Natural Resource Condition Assessment Series Coordinator	Washington-level Program Manager
Phyllis Pineda Bovin	National Park Service Intermountain Region Office, Natural Resource Condition Assessment Coordinator	Regional Program Level Coordinator and Peer Review Manager
Donna Shorrock	National Park Service Intermountain Region Office, Natural Resource Condition Assessment Coordinator (former)	Regional Program Level Coordinator and Peer Review Manager
Kelly Adams and Todd Wilson	National Park Service, Grants and Contracting Officers	Executed Agreements
Fagan Johnson	National Park Service Inventory & Monitoring Division, Web and Report Specialist	Washington-level Publishing and 508 Compliance Review
Lisa Leap	National Park Service Flagstaff Area National Monuments, Chief of Resources	Park Expert Reviewer
Paul Whitefield	National Park Service Flagstaff Area National Monuments, Natural Resource Specialist	Park Expert Reviewer
Mark Szydlo	National Park Service Flagstaff Area National Monuments, Biologist	Park Expert Reviewer
Gwenn M. Gallenstein	Flagstaff Area National Monuments / Museum of Northern Arizona, Museum Curator (Acting Chief)	Sunset Crater Tephra Layer and Vegetation
Lisa Thomas	National Park Service Southern Colorado Plateau I&M Network, Program Manager	All Condition Assessments
Megan Swan	National Park Service Southern Colorado Plateau I&M Network, Botanist and Acting Program Manager	Sunset Crater Tephra Layer and Vegetation Assessments
Mark Meyer	National Park Service Air Resources Division, Visual Resource Specialist	Viewshed Assessment
Li-Wei	National Park Service Natural Sounds and Night Skies Division, Research Scientist	Night Sky Assessment and Data
Emma Brown	National Park Service Natural Sounds and Night Skies Division, Acoustical Resource Specialist	Soundscape Assessment and Data

Table B.2 continued. *Report reviewers.*

Name	Affiliation and Position Title	Section(s) Reviewed or Other Role
Jim Cheatham	National Park Service Air Resources Division, Park Planning & Technical Assistance	Air Quality Assessment and Data
Ksienya Pugacheva	National Park Service Air Resources Division, Natural Resource Specialist	Air Quality Assessment
Dr. Jut Wynne	Northern Arizona University, Assistant Research Professor	Earthcracks and Blowholes Assessment
Stephen Monroe	Northern Arizona University, Senior Research Specialist	Springs, Seeps, and Surface Water and Little Colorado River Corridor Assessments
Tim Connors	National Park Service Geologic Resources Division,Geologist	Sunset Crater Tephra Layer Assessment
Susan Southard	Natural Resources Conservation Service Soil Science Division, Soil Scientist	Sunset Crater Tephra Layer Assessment
Jeff Conn	National Park Service Southwest Exotic Plant Management Team, Manager	Non-native Invasive Plants Assessment
Mike Wrigley	National Park Service Intermountain Region Office, Biological Resources Chief	Birds, Pronghorn, and Wupatki Pocket Mouse Assessments
Dr. Kirk Anderson	Museum of Northern Arizona, Geomorphologist	Presented preliminary indicators/ measures at NRCA scoping meeting, May 19, 2016 and served as subject matter expert and author of Sunset Crater Tephra Layer assessment via Cooperative Agreement Number P14AC00921.
Dr. William H. Romme	Professor emeritus of fire ecology and research scientist in the Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado	Served as subject matter expert and author of Vegetation Assessment via Cooperative Agreement P15AC00777.

Appendix C. Viewshed Analysis Steps

The process used to complete Flagstaff Area National Monuments' viewshed analyses is listed below.

Downloaded 12 of the 1/3 arc second national elevation dataset (NED) grid (roughly equivalent to a 30 m digital elevation model [DEM]) from The National Map Seamless Server (http://seamless.usgs.gov/) (USGS 2016a) and created a mosaic dataset. The x and y values for the NED are in arc seconds while the z data are in meters. The DEMs were reprojected into NAD83 Albers Meter to get all data in meters and into a geographic extent that covered the entire area.

Prepared observation point layers for viewshed analyses by importing GPSd points for all vantage point locations selected for viewshed analysis. Exported data to a shapefile. Added field named "OFFSETA" (type = double) to shapefile and set value to an observer height of 1.68 m (~5'6").

Ran Viewshed Analysis using the Viewshed Tool in ESRI's ArcGIS 10.2, Spatial Analyst Toolbox, ran viewsheds using the following inputs.

- Input raster = 1/3 arc second NED
- Input point observer feature = obs_point.shp.

The rasters were reclassified into visible areas only to create the maps. The Observer Point Tool in Spatial Analyst was used, creating a composite viewshed, which showed all combined visible areas. A 97 km (60 mi) buffer was created surrounding the monument, reprojected into the Albers Equal Area Conic USGS projection, then used as the AOA for the NPS NPScape's housing and road density rasters using NPScape tools (NPS 2011b). A text attribute field was added to the dataset for the area of analysis identifier (NPS 2011c).

Housing (CONUS, Density, SERGoM, 1970 - 2100, Metric Data (ESRI 9.3 File Geodatabase) (Theobald 2005) and road (United States and Canada, Density - All Roads, ESRI, 2005, Metric Data (ESRI 9.3 File Geodatabase) (ESRI 2014) GIS datasets were downloaded from NPScape's website at http://science.nature.nps.gov/im/monitor/npscape/gis_data.cfm?tab=1.

Standard Operating Procedures for both density tools (NPS 2014a,b) were followed based on NPScape instructions: https://irma.nps.gov/DataStore/Reference/Profile/2193329 and https://irma.nps.gov/DataStore/Reference/Profile/2193334.

Appendix D. Geospatial Sound Model Maps

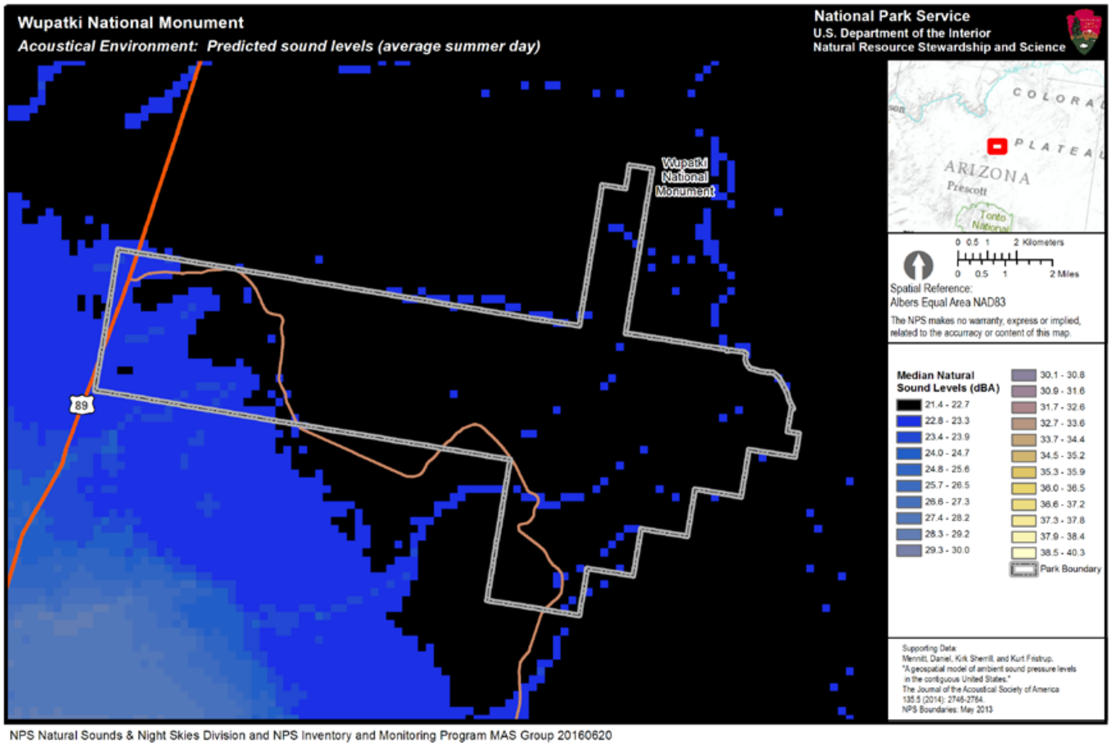


Figure D-1. Natural CONUS soundscape model zoomed to Wupatki NM. Figure Credit: NPS Natural Sounds and Night Skies Division.

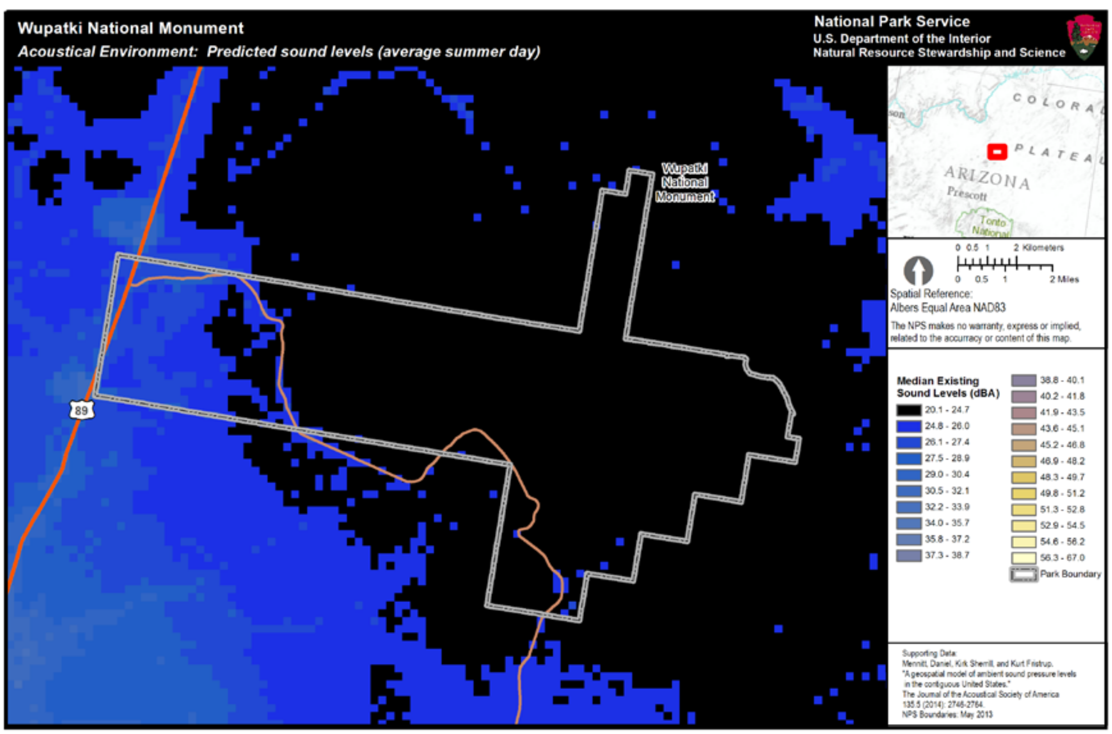


Figure D-2. Existing CONUS soundscape model zoomed to Wupatki NM. Figure Credit: NPS Natural Sounds and Night Skies Division.

Mennitt et al. (2013) developed a geospatial sound model by mapping sound pressure levels on a continental U.S. scale. The model included biological, climatic, geophysical, and anthropogenic factors to assess expected sound pressure levels for natural and existing conditions. The model suggested that the area within and surrounding Wupatki NM had a natural L_{50} dBA average of 22.31 (Figure D-1) and an existing L_{50} dBA average of 23.45 (Figure D-2) (Emma Brown, Acoustical Resource Specialist, NPS Natural Sounds and Night Skies Division, provided Excel spreadsheet with values). The L_{50} represents the sound level reported that is exceeded 50 percent of the stated time period.

The impact of anthropogenic sound sources to the national monument's soundscape, which is the existing L_{50} dBA minus natural L_{50} dBA, was estimated to be an average of 1.2 dBA (map is included in the assessment). For further details refer to the soundscape assessment in this report.

As NSNSD's predictive soundscape model continues to be developed and refined, it is intended to help park staff anticipate impacts by projecting future developments that have the potential to degrade soundscape condition.

Appendix E. Land-use Periods and the Fate of the Cinders Summary

Table E.1. Land use period and cinder fate summary.

Land-use (Time Period)	Fate of the Cinders	References
Pre-Eruption Landscape (100,000 BP-AD 1080)	Numerous volcanic eruptions, e.g. SP, Strawberry, and Doney Craters deposit volcanic tephra across the WUPA landscape; stone pavement formation and soil development; sparse use by native groups, few habitations, mostly hunting and gathering activities.	Billingsley et al. (2007a) Hansen et al. (2004) USDA NRCS (2015) Rittenour et al. (2015)
Sunset Crater Eruption (~ AD 1080-1100)	WUPA covered by ≤ 10 cm ash and lapilli; extreme transportation and erosion by wind reworking cinders into irregular and patchy cover.	Elson et al. (2002)
Prehistoric Land-use - Sinagua Occupation (AD 1100-1300)	Sinagua agricultural features attest to the benefits of the cinder mulch and to Sinagua attempts to control wind erosion; loss of cinder cover postulated as contributing factor to abandonment; junipers reduced in number by wood cutting; influence of droughts on cinder movement unknown; Sum of land-use effects on cinders equivocal.	Anderson (1990) Colton (1960) Downum (2012)
Post-abandonment ecological recovery (AD 1300-1800)	Human land-use is limited, allowing for plants and animals to recover – should reduce cinder erosion; junipers move into grassland and savannas, perhaps increasing cinder movement; influence of droughts on cinder movement unknown; overall cinder stability postulated during this time.	Romme and Whitefieled (2017) Ironsides (2006)
Livestock Grazing (AD 1800-1989)	Navajo sheep grazing and CO Bar cattle grazing reduce grass cover, disrupt soil, pulverize pot sherds and negatively impact archaeological sites; cinder erosion increases, probably extreme in some locations.	Roberts (1986)
NPS Management (AD 1989-2016)	Grazing becomes restricted in 1989 and NPS management restricts visitation, reducing erosion; infrastructure projects disturb soil and increase erosion in isolated locations; paved roads decrease cinder erosion by wind, but increase surface runoff erosion.	Kuehnert (1989)
Future Climate Changes	Future climate change scenarios suggest a warmer climate, but precipitation predictions are equivocal; regardless, therefore, predicting how cinder movement across the landscape is affected by future climate change scenarios is unknown.	–

Appendix F. Details of the Rangeland Assessment Method

Pellant et al. (2005) developed a system for evaluating the condition of rangelands or grasslands, based on two broad indicators and seven measures related to those indicators. This same system was used in the NRCA for El Malpais National Monument, authored by Donna Shorrock, and the two tables below are copied from that report (Valentine-Darby et al. 2016). Table F-1 lists and defines the indicators and measures.

Table F-1. Indicators and measures used to assess the condition of rangelands or grasslands.

Indicator	Measure	Definition
Soil/Site Stability	Soil Cover	Soil cover is the most important dynamic factor affecting water erosion. Most soil loss occurs in areas with uncovered, bare soils; soil cover slows water flow and provides resistance to erosion and greater stability.
	Biological Soil Crust	Biological soil crusts provide key ecosystem functions, such as increasing water and wind erosion resistance, contributing organic matter, and fixing atmospheric nitrogen.
Biotic Integrity	Landscape-scale Diversity	The extent to which landscape-scale diversity reflects spatial pattern of soils and disturbance.
	Local Species Composition	The extent to which species composition within a site (e.g., ecological site) deviates substantially from the expected native species compliment either from exotics or native species.
	General Life Cycles Relative to Disturbance	The proportion of annual, biennial, and perennial species relative to the time since disturbance.
	Relative Proportion of Functional Groups (e.g., graminoid, forbs, shrubs, etc.)	The relative proportions of functional groups relative to what would be expected based on site characteristics (e.g., lack of forbs, excessive shrub density, etc.).
	Relative Proportion of C3 and C4 Species	The relative proportions of C3 and C4 plants relative to what would be expected based on site characteristics.

Source: Pellant et al. (2005).

Appendix G. Background on Bird Species of Conservation Concern Lists

This appendix provides background information on the organizations and efforts to determine species of birds that are in need of conservation. The information presented here supports the Data and Methods of the birds section. One component of the bird condition assessment was to examine species occurrence in a conservation context. We compared the list of species that occur at Wupatki National Monument (NM) to lists of species of conservation concern developed by several organizations. There have been a number of such organizations that focus on the conservation of bird species. Such organizations may differ, however, in the criteria they use to identify and/or prioritize species of concern based on the mission and goals of their organization. They also range in geographic scale from global organizations such as the International Union for Conservation of Nature (IUCN), who maintains a "Red List of Threatened Species," to local organizations or chapters of larger organizations. This has been, and continues to be, a source of potential confusion for managers and others who need to make sense of and apply the applicable information. In recognition of this, the U.S. North American Bird Conservation Initiative (NABCI) was started in 1999; it represents a coalition of government agencies, private organizations, and bird initiatives in the U.S. working to ensure the conservation of North America's native bird populations. Although there remain a number of sources at multiple geographic and administrative scales for information on species of concern, the NABCI has made great progress in developing a common biological framework for conservation planning and design.

One of the developments from the NABCI was the delineation of Bird Conservation Regions (BCRs) (NABCI 2014). Bird Conservation Regions are ecologically distinct regions in North America with similar bird communities, habitats, and resource management issues.

The purpose of delineating these BCRs was to:

- facilitate communication among the bird conservation initiatives;
- systematically and scientifically apportion the U.S. into conservation units;
- facilitate a regional approach to bird conservation;
- promote new, expanded, or restructured partnerships; and
- identify overlapping or conflicting conservation priorities.

G.1. Conservation Organizations Listing Species of Conservation Concern

Below we present a summary of some of the organizations that list species of conservation concern and briefly discuss the different purposes or goals of each organization.

U.S. Fish & Wildlife Service

The Endangered Species Act, passed in 1973, is intended to protect and recover imperiled species and the ecosystems upon which they depend. It is administered by the U.S. Fish and Wildlife Service (USFWS) and the Commerce Department's National Marine Fisheries Service (NMFS). USFWS has primary responsibility for terrestrial and freshwater organisms, while the responsibilities of NMFS are mainly marine wildlife, such as whales, and anadromous fish.

The USFWS also protects birds under the Migratory Bird Treaty Act (MBTA; USFWS 2016a). This act "makes it illegal for anyone to take, possess, import, export, transport, sell, purchase, barter, or offer for sale, purchase, or barter, any migratory bird, or the parts, nests, or eggs of such a bird except under the terms of a valid permit issued pursuant to Federal regulations" (USFWS 2016a). An up-to-date list of the bird species protected by the Act (1,026 birds) can be found in the Federal Register (USFWS 2013). At least one of four criteria need to be met for a species to be listed under the Act: 1) it is covered by the Canadian Convention of 1916, as amended in 1996; 2) it is covered by the Mexican Convention of 1936, as amended in 1972; 3) it is listed in the annex to the Japanese Convention of 1972, as amended; and/or 4) it is listed in the appendix to the Russian Convention of 1976. Note that in the condition assessment, we did not compare the list of species recorded at Wupatki NM to the MBTA list. However, at least some of these species are included in the other species of conservation concern lists we used (see next sections).

USFWS Birds of Conservation Concern

The USFWS has responsibilities for wildlife, including birds, in addition to endangered and threatened species. The Fish and Wildlife Conservation Act, as amended in 1988, further mandates that the USFWS "identify species, subspecies, and populations of all migratory nongame birds (i.e., Birds of Conservation Concern) that, without additional conservation actions, are likely to become candidates for listing under the Endangered Species Act" (USFWS 2008). The agency's 2008 effort, *Birds of Conservation Concern*, is one effort to fulfill the Act's requirements. The report includes both migratory and non-migratory bird species (beyond those federally-listed as threatened or endangered) that USFWS considers the highest conservation priorities. Three geographic scales are included--National, USFWS Regional, and the NABCI BCRs. The information used to compile the lists came primarily from the following three bird conservation plans: the Partners in Flight (PIF) North American Landbird Conservation Plan, the U.S. Shorebird Conservation Plan, and the North American Waterbird Conservation Plan. The scores used to assess the species are based on factors such as population trends, distribution, threats, and abundance.

North American Bird Conservation Initiative

A group of experts from the North American Bird Conservation Initiative (NABCI) determined U.S. bird species most in need of conservation action (Rosenberg et al. 2014). The NABCI publishes a Watch List every few years in conjunction with a state of the birds report. The 2014 Watch List contains 233 species, most of which are protected by the MBTA, and some of which are protected by the ESA. However, some species are in critical need of attention to prevent them from becoming endangered or threatened. By producing the Watch List, NABCI hopes to encourage conservation of species, especially those under the greatest threat of extinction. The Watch List has two primary levels of concern: a "Red Watch List," which contains species with extremely high vulnerability due to small population, small range, high threats, and rangewide declines; and a "Yellow Watch List," which contains species that are either restricted in range (small range and population) or are more widespread but have concerning declines and high threats (Rosenberg et al. 2014). The NABCI team assessed all birds in the U.S. using the PIF Species Assessment Database (www.rmbo.org/pifassessment/; Rosenberg et al. 2014). According to Rosenberg et al. (2014) the database "ranks species according to their vulnerability due to population size, range size (breeding and non-breeding), population trend, and future threats (breeding and non-breeding). Species are included on the Watch List if they exhibit a threshold of high combined vulnerability across all these factors."

Partners in Flight

Partners in Flight is a cooperative effort among federal, state, and local government agencies, as well as private organizations. One of its primary goals, relative to listing species of conservation concern, is to develop a scientifically based process for identifying and finding solutions to risks and threats to landbird populations. Their approach to identifying and assessing species of conservation concern is based on biological criteria to evaluate different components of vulnerability (Panjabi et al. 2005). Each species is evaluated for six components of vulnerability: population size, breeding distribution, non-breeding distribution, threats to breeding, threats to non-breeding, and population trend. The specific process is presented in detail in the species assessment handbook (Panjabi et al. 2005).

The PIF assessments are conducted at multiple scales. At the broadest scale, the North American Landbird Conservation Plan (Rich et al. 2004) identifies what PIF considers "Continental Watch List Species" and "Continental Stewardship Species." Continental Watch List Species are those that are most vulnerable at the continental scale, due to a combination of small and declining populations, limited distributions, and high threats throughout their ranges (Panjabi et al. 2005). Continental Stewardship Species are defined as those species that have a disproportionately high percentage of their world population within a single Avifaunal Biome during either the breeding season or the non-migratory portion of the non-breeding season.

More recently, PIF has adopted BCRs, the common planning unit under the NABCI, as the geographic scale for updated regional bird conservation assessments. These assessments are available via an online database (http://rmbo.org/pifassessment) maintained by the Rocky Mountain Bird Observatory. At the scale of the individual BCRs, these same principles of concern (sensu Continental Watch List Species) or stewardship (sensu Continental Stewardship Species) are applied at the BCR scale. The intention of this approach is to emphasize conservation of species where it is most relevant, as well as the recognition that some species may be experiencing dramatic declines locally even if they are not of high concern nationally, etc. There are two categories (concern and stewardship) each for Continental and Regional levels. The details of the criteria for inclusion in each can be found in Panjabi et al. (2005), and a general summary is as follows. Note that in our Chapter 4 bird assessment, we did not use the two stewardship categories.

Criteria for Species of Continental Importance
A. Continental Concern (CC)
- Species is listed on the Continental Watch List (Rich et al. 2004).
- Species occurs in significant numbers in the BCR.
- Future conditions are not enhanced by human activities.

B. Continental Stewardship (CS)
- Species is listed as Continental Stewardship Species (Rich et al. 2004).
- Relatively high density (compared to highest density regions) and/or a high proportion of the species occur in the BCR.
- Future conditions are not enhanced by human activities.

Criteria for Species of Regional Importance
Regional scores are calculated for each species according to which season(s) they are present in the BCR. The formulae include a mix of global and regional scores pertinent to each season (see Panjabi et al. 2005 for details). The criteria for each category are:

A. Regional Concern (RC)
- Regional Combined Score > 13 (see Panjabi et al. 2005 for details).
- High regional threats or moderate regional threat combined with significant population decline.
- Occurs regularly in significant numbers in the BCR.

B. Regional Stewardship (RS)
- Regional Combined Score > 13 (see Panjabi et al. 2005 for details).
- High importance of the BCR to the species.
- Future conditions are not enhanced by human activities.

Arizona Species of Greatest Conservation Need
Under Arizona's State Wildlife Action Plan (2012-2022), SGCN have been designated in the state (Arizona Game and Fish Department [AGFD] 2012). Of the 347 vertebrate SGCN statewide, 145 are birds. The plan includes three tiers, Tier 1A, 1B, and 1C. Of the 145 birds considered SGCN, 12 are Tier 1A, 56 are Tier 1B, and 77 are Tier 1C. Tier 1A contains "those species for which the Department has entered into an agreement or has legal or other contractual obligations, or warrants the protection of a closed season. Tier 1B represents the remainder of the vulnerable species. Tier 1C contains those species for which insufficient information is available to fully assess the vulnerabilities and therefore need to be watched for signs of stress. This tier replaces the species of unknown status from the Comprehensive Wildlife Conservation Strategy" (AGFD 2012). Species listed as federally endangered, threatened, or candidate species, and those considered "endangered wildlife" by the State are Tier 1A species. We compared the list of species for Wupatki NM to the list of birds of SGCN in the State plan. In Chapter 4, we reported only birds in the two highest tiers (except we noted 1C species when they also appeared on at least one other of the lists we reviewed).

Appendix H. Wupatki NM Bird Lists

Listed in the table below are the bird species recorded at Wupatki National Monument (NM) during breeding season surveys in: 1976 and 1977 (Beatty and Balda 1976, Beatty 1978); 1997-1998 (Rosenstock (1999); 2002-2004 (Yavapai College Elderhostel 2002, 2003, and 2004); and 2008, 2011, and 2014 (Holmes and Johnson 2012, 2013, and 2016). The first two and the fourth survey/study efforts were conducted in grassland and other upland habitats. The third survey effort was conducted in or near tamarisk (*Tamarix* spp.) stands along the Little Colorado River. For descriptions of each survey effort, see the Data and Methods section of the birds condition assessment. Note that while surveys were conducted during the breeding season, the species observed were not necessarily breeding during the surveys in the park (although evidence of breeding was recorded for some species).

A total of 174 species are contained in the table. Of these 174 species, a total of 92 were recorded during one or more of the four surveys/studies reviewed in the condition assessment; the remaining 82 species appear on the NPSpecies list for the park (NPS 2016b). No federally threatened or endangered species are known to occur in the national monument. See the chapter 4 condition assessment for species that are listed as species of conservation concern (a general term) by various governmental and non-governmental organizations. Note that the Yavapai College Elderhostel's surveys are presented last in the table to set them apart from the other three efforts, which occurred in grassland and related upland habitats. Non-native species are shown in the table in bold font.

Table H.1. Wupatki NM birds list.

Common Name	Scientific Name	Beatty and Beatty & Balda (1976, 1977)	Rosenstock (1997-1998)	Holmes and Johnson [SCPN] (2008-2014)	Yavapai College Elderhostel (2002-2004)
Abert's towhee [1]	*Melozone aberti*	–	–	–	X
American coot	*Fulica americana*	X	–	–	–
American crow	*Corvus brachyrhynchos*	X	–	–	–
American goldfinch	*Spinus tristis*	–	–	–	–
American kestrel	*Falco sparverius*	–	–	X	X
American robin	*Turdus migratorius*	–	–	–	–
Anna's hummingbird [1]	*Calypte anna*	–	–	–	X
Ash-throated flycatcher	*Myiarchus cinerascens*	X	X	X	X
Bald eagle	*Haliaeetus leucocephalus*	–	–	–	–
Bank swallow	*Riparia riparia*	–	–	–	–
Barn swallow	*Hirundo rustica*	–	–	X	–
Belted kingfisher	*Ceryle alcyon*	–	–	–	–
Bendire's thrasher	*Toxostoma bendirei*	X	–	X	X [2]
Bewick's wren	*Thryomanes bewickii*	–	–	–	–
Black phoebe	*Sayornis nigricans*	–	–	–	–
Black-chinned hummingbird	*Archilochus alexandri*	–	–	–	X
Black-crowned night-heron	*Nycticorax nycticorax*	–	–	–	–
Black-headed grosbeak	*Pheucticus melanocephalus*	–	–	–	X

[1] Species not on the NPSpecies list (NPS 2016b), but listed by one or more of the four studies/surveys reviewed in the condition assessment.

[2] Recorded in Site 3 only (i.e., and not in Sites 1 or 2) of the Yavapai College Elderhostel survey. Site 3 was located near but outside of park boundaries.

[3] Species noted as "probably present" or "unconfirmed" in NPSpecies (NPS 2016b) (and a reference for the record is given) but not observed by one of the four surveys/studies.

[4] In addition to note 3 above, this species was reportedly observed by Beatty (1978) during surveys along the Little Colorado River. The table presenting the species observed during those fall studies by Beatty (1978) was absent from her report.

[5] National Monument staff conduct nesting surveys for this species.

Table H.1 continued. Wupatki NM birds list.

Common Name	Scientific Name	Beatty and Beatty & Balda (1976, 1977)	Rosenstock (1997-1998)	Holmes and Johnson [SCPN] (2008-2014)	Yavapai College Elderhostel (2002-2004)
Black-necked stilt	*Himantopus mexicanus*	–	–	–	–
Black-tailed gnatcatcher [1]	*Polioptila melanura*	–	–	–	X
Black-throated gray warbler	*Setophaga nigrescens*	–	–	X	X
Black-throated sparrow	*Amphispiza bilineata*	X	–	X	X
Blue grosbeak [1]	*Passerina caerulea*	–	–	–	X
Blue-gray gnatcatcher	*Polioptila caerulea*	–	–	X	–
Blue-winged teal	*Anas discors*	–	–	–	–
Bohemian waxwing	*Bombycilla garrulus*	–	–	–	–
Brewer's blackbird	*Euphagus cyanocephalus*	–	–	X	X [2]
Brewer's sparrow	*Spizella breweri*	X	–	X	X
Broad-tailed hummingbird	*Selasphorus platycercus*	X	–	X	X
Brown creeper	*Certhia americana*	–	–	–	–
Brown-headed cowbird	*Molothrus ater*	X	X	X	X
Bufflehead	*Bucephala albeola*	–	–	–	–
Bullock's oriole	*Icterus bullockii*	–	–	X	X
Burrowing owl	*Athene cunicularia*	–	–	–	–
Bushtit	*Psaltriparus minimus*	–	X	X	X
Calliope hummingbird	*Stellula calliope*	–	–	–	–
Canada goose	*Branta canadensis*	–	–	–	–
Canvasback [3, 4]	*Aythya valisineria*	–	–	–	–
Canyon towhee [1]	*Melozone fusca*	–	–	–	X
Canyon wren	*Catherpes mexicanus*	–	–	–	–
Cassin's finch	*Carpodacus cassinii*	–	–	–	–
Cassin's kingbird	*Tyrannus vociferans*	X	X	X	X
Cassin's sparrow [1]	*Peucaea cassinii*	–	–	X	–
Cedar waxwing	*Bombycilla cedrorum*	–	–	–	–
Chestnut-collared longspur	*Calcarius ornatus*	–	–	–	–
Chipping sparrow	*Spizella passerina*	X	X	X	X
Cinnamon teal	*Anas cyanoptera*	–	–	–	X [2]
Clark's nutcracker	*Nucifraga columbiana*	–	–	–	–
Cliff swallow	*Petrochelidon pyrrhonota*	X	–	–	X
Common nighthawk	*Chordeiles minor*	X	–	X	–
Common poorwill	*Phalaenoptilus nuttallii*	–	–	–	–
Common raven	*Corvus corax*	X	–	X	X
Common yellowthroat	*Geothlypis trichas*	–	–	–	–
Cooper's hawk	*Accipiter cooperii*	X	–	X	–
Cordilleran flycatcher	*Empidonax occidentalis*	–	–	–	X [2]

[1] Species not on the NPSpecies list (NPS 2016b), but listed by one or more of the four studies/surveys reviewed in the condition assessment.

[2] Recorded in Site 3 only (i.e., and not in Sites 1 or 2) of the Yavapai College Elderhostel survey. Site 3 was located near but outside of park boundaries.

[3] Species noted as "probably present" or "unconfirmed" in NPSpecies (NPS 2016b) (and a reference for the record is given) but not observed by one of the four surveys/studies.

[4] In addition to note 3 above, this species was reportedly observed by Beatty (1978) during surveys along the Little Colorado River. The table presenting the species observed during those fall studies by Beatty (1978) was absent from her report.

[5] National Monument staff conduct nesting surveys for this species.

Table H.1 continued. Wupatki NM birds list.

Common Name	Scientific Name	Beatty and Beatty & Balda (1976, 1977)	Rosenstock (1997-1998)	Holmes and Johnson [SCPN] (2008-2014)	Yavapai College Elderhostel (2002-2004)
Costa's hummingbird	*Calypte costae*	–	–	–	–
Crissal thrasher	*Toxostoma crissale*	–	–	X	–
Dark-eyed junco	*Junco hyemalis*	–	–	–	–
Double-crested cormorant	*Phalacrocorax auritus*	–	–	–	–
Dusky flycatcher [1]	*Empidonax oberholseri*	–	–	–	X
Eared grebe	*Podiceps nigricollis*	–	–	–	–
Eastern meadowlark	*Sturnella magna*	–	X	X	X [2]
Eurasian collared-dove 1 (non-native)	Streptopelia decaocto	–	–	X	–
European starling (non-native)	Sturnus vulgaris	–	–	–	–
Evening grosbeak	*Coccothraustes vespertinus*	–	–	–	–
Ferruginous hawk	*Buteo regalis*	–	–	–	–
Golden eagle [5]	*Aquila chrysaetos*	X	–	X	X
Gray catbird	*Dumetella carolinensis*	–	–	–	–
Gray flycatcher	*Empidonax wrightii*	X	–	X	X
Gray vireo	*Vireo vicinior*	X	–	–	–
Great blue heron	*Ardea herodias*	–	–	–	–
Great egret	*Ardea alba*	–	–	–	–
Great horned owl [5]	*Bubo virginianus*	–	–	–	–
Greater roadrunner	*Geococcyx californianus*	–	–	X	X
Greater yellowlegs [1]	*Tringa melanoleuca*	–	–	–	X [2]
Great-tailed grackle [1]	*Quiscalus mexicanus*	–	–	–	X
Green-tailed towhee	*Pipilo chlorurus*	–	–	X	X
Green-winged teal	*Anas crecca*	–	–	–	–
Hairy woodpecker	*Picoides villosus*	–	–	–	–
Hepatic tanager	*Piranga flava*	–	–	–	–
Hooded oriole [1]	*Icterus cucullatus*	–	–	–	X
Horned lark	*Eremophila alpestris*	X	X	X	X
House finch	*Carpodacus mexicanus*	X	–	X	X
House sparrow (non-native)	Passer domesticus	–	–	X	X
House wren	*Troglodytes aedon*	–	–	–	–
Indigo bunting [1]	*Passerina cyanea*	–	–	–	X
Juniper titmouse	*Baeolophus ridgwayi*	X	X	–	–
Killdeer	*Charadrius vociferus*	–	–	–	–
Lark bunting [3]	*Calamospiza melanocorys*	–	–	–	–
Lark sparrow	*Chondestes grammacus*	X	X	X	X
Least sandpiper	*Calidris minutilla*	–	–	–	–

[1] Species not on the NPSpecies list (NPS 2016b), but listed by one or more of the four studies/surveys reviewed in the condition assessment.

[2] Recorded in Site 3 only (i.e., and not in Sites 1 or 2) of the Yavapai College Elderhostel survey. Site 3 was located near but outside of park boundaries.

[3] Species noted as "probably present" or "unconfirmed" in NPSpecies (NPS 2016b) (and a reference for the record is given) but not observed by one of the four surveys/studies.

[4] In addition to note 3 above, this species was reportedly observed by Beatty (1978) during surveys along the Little Colorado River. The table presenting the species observed during those fall studies by Beatty (1978) was absent from her report.

[5] National Monument staff conduct nesting surveys for this species.

Table H.1 continued. **Wupatki NM birds list.**

Common Name	Scientific Name	Beatty and Beatty & Balda (1976, 1977)	Rosenstock (1997-1998)	Holmes and Johnson [SCPN] (2008-2014)	Yavapai College Elderhostel (2002-2004)
Lesser goldfinch	*Carduelis psaltria*	–	–	X	X [2]
Lesser nighthawk [1]	*Chordeiles acutipennis*	–	–	–	X
Lesser yellowlegs	*Tringa flavipes*	–	–	–	–
Lewis's woodpecker	*Melanerpes lewis*	–	–	–	–
Loggerhead shrike	*Lanius ludovicianus*	X	X	X	X [2]
Long-billed curlew	*Numenius americanus*	–	–	–	–
Long-billed dowitcher [1]	*Limnodromus scolopaceus*	–	–	–	X [2]
Long-eared owl	*Asio otus*	–	–	–	–
Macgillivray's warbler	*Oporornis tolmiei*	–	–	–	X
Mallard	*Anas platyrhynchos*	–	–	–	–
Merlin	*Falco columbarius*	–	–	–	–
Mountain bluebird	*Sialia currucoides*	–	–	–	–
Mountain chickadee	*Poecile gambeli*	–	–	–	–
Mountain plover	*Charadrius montanus*	–	–	–	–
Mourning dove	*Zenaida macroura*	X	X	X	X
Nashville warbler	*Vermivora ruficapilla*	–	–	–	–
Northern flicker	*Colaptes auratus*	–	–	–	X
Northern goshawk	*Accipiter gentilis*	–	–	–	–
Northern harrier	*Circus cyaneus*	–	–	X	–
Northern mockingbird	*Mimus polyglottos*	X	X	X	X
Northern pygmy-owl [1]	*Glaucidium gnoma*	–	–	X	–
Northern rough-winged swallow [1]	*Stelgidopteryx serripennis*	X	–	–	X
Northern saw-whet owl	*Aegolius acadicus*	–	–	–	–
Northern shrike	*Lanius excubitor*	–	–	–	–
Orange-crowned warbler	*Vermivora celata*	–	–	–	–
Pacific loon	*Gavia pacifica*	–	–	–	–
Peregrine falcon	*Falco peregrinus*	–	–	–	X [2]
Phainopepla	*Phainopepla nitens*	X	–	–	–
Pinyon jay	*Gymnorhinus cyanocephalus*	–	X	X	–
Plumbeos vireo [1]	*Vireo plumbeus*	–	–	–	X
Prairie falcon	*Falco mexicanus*	–	–	X	X
Pygmy nuthatch	*Sitta pygmaea*	–	–	–	–
Red-breasted nuthatch	*Sitta canadensis*	–	–	–	–
Red-breasted sapsucker	*Sphyrapicus ruber*	–	–	–	–
Red-naped sapsucker	*Sphyrapicus nuchalis*	–	–	–	–
Red-tailed hawk	*Buteo jamaicensis*	–	–	X	X
Red-winged blackbird	*Agelaius phoeniceus*	–	–	–	X

[1] Species not on the NPSpecies list (NPS 2016b), but listed by one or more of the four studies/surveys reviewed in the condition assessment.

[2] Recorded in Site 3 only (i.e., and not in Sites 1 or 2) of the Yavapai College Elderhostel survey. Site 3 was located near but outside of park boundaries.

[3] Species noted as "probably present" or "unconfirmed" in NPSpecies (NPS 2016b) (and a reference for the record is given) but not observed by one of the four surveys/studies.

[4] In addition to note 3 above, this species was reportedly observed by Beatty (1978) during surveys along the Little Colorado River. The table presenting the species observed during those fall studies by Beatty (1978) was absent from her report.

[5] National Monument staff conduct nesting surveys for this species.

Table H.1 continued. *Wupatki NM birds list.*

Common Name	Scientific Name	Beatty and Beatty & Balda (1976, 1977)	Rosenstock (1997-1998)	Holmes and Johnson [SCPN] (2008-2014)	Yavapai College Elderhostel (2002-2004)
Rock wren	*Salpinctes obsoletus*	X	–	X	X
Rose-breasted grosbeak	*Pheucticus ludovicianus*	–	–	–	–
Rough-legged hawk	*Buteo lagopus*	–	–	–	–
Ruby-crowned kinglet	*Regulus calendula*	X	–	X	–
Rufous hummingbird	*Selasphorus rufus*	–	–	–	–
Rufous-crowned sparrow [1]	*Aimophila ruficeps*	–	–	X	X
Sage sparrow	*Amphispiza belli*	–	–	–	–
Sage thrasher	*Oreoscoptes montanus*	–	–	X	–
Savannah sparrow	*Passerculus sandwichensis*	–	–	–	–
Say's phoebe	*Sayornis saya*	X	–	X	X
Scott's oriole	*Icterus parisorum*	X	X	X	–
Sharp-shinned hawk	*Accipiter striatus*	X	–	X	–
Short-eared owl	*Asio flammeus*	–	–	–	–
Snowy egret	*Egretta thula*	–	–	–	–
Song sparrow	*Melospiza melodia*	–	–	–	–
Spotted sandpiper	*Actitis macularius*	–	–	–	X [2]
Spotted towhee	*Pipilo maculatus*	–	–	X	X
Summer tanager [1]	*Piranga rubra*	–	–	–	X
Swainson's hawk	*Buteo swainsoni*	–	–	–	–
Townsend's solitaire	*Myadestes townsendi*	–	X	X	–
Tree swallow [3, 4]	*Tachycineta bicolor*	–	–	–	–
Turkey vulture	*Cathartes aura*	–	–	X	X
Vesper sparrow	*Pooecetes gramineus*	–	–	X	–
Violet-green swallow	*Tachycineta thalassina*	X	–	X	X
Virginia's warbler	*Vermivora virginiae*	–	–	–	–
Warbling vireo [1]	*Vireo gilvus*	–	–	X	–
Western bluebird	*Sialia mexicana*	–	–	–	–
Western kingbird	*Tyrannus verticalis*	–	–	X	X
Western meadowlark	*Sturnella neglecta*	–	X	X	X
Western screech-owl	*Megascops kennicottii*	–	–	–	–
Western scrub-jay	*Aphelocoma californica*	–	–	X	–
Western tanager	*Piranga ludoviciana*	–	–	X	X [2]
Western wood-pewee	*Contopus sordidulus*	–	–	X	–
White-breasted nuthatch	*Sitta carolinensis*	–	–	–	–
White-crowned sparrow	*Zonotrichia leucophrys*	–	–	X	X
White-faced ibis	*Plegadis chihi*	–	–	–	–
White-throated sparrow	*Zonotrichia albicollis*	–	–	–	–

[1] Species not on the NPSpecies list (NPS 2016b), but listed by one or more of the four studies/surveys reviewed in the condition assessment.

[2] Recorded in Site 3 only (i.e., and not in Sites 1 or 2) of the Yavapai College Elderhostel survey. Site 3 was located near but outside of park boundaries.

[3] Species noted as "probably present" or "unconfirmed" in NPSpecies (NPS 2016b) (and a reference for the record is given) but not observed by one of the four surveys/studies.

[4] In addition to note 3 above, this species was reportedly observed by Beatty (1978) during surveys along the Little Colorado River. The table presenting the species observed during those fall studies by Beatty (1978) was absent from her report.

[5] National Monument staff conduct nesting surveys for this species.

Table H.1 continued. Wupatki NM birds list.

Common Name	Scientific Name	Beatty and Beatty & Balda (1976, 1977)	Rosenstock (1997-1998)	Holmes and Johnson [SCPN] (2008-2014)	Yavapai College Elderhostel (2002-2004)
White-throated swift	*Aeronautes saxatalis*	–	–	X	X
Williamson's sapsucker	*Sphyrapicus thyroideus*	–	–	–	–
Willow flycatcher	*Empidonax traillii*	–	–	–	–
Wilson's snipe	*Gallinago delicata*	–	–	–	–
Wilson's warbler	*Wilsonia pusilla*	X	–	–	X
Yellow warbler	*Setophaga petechia*	–	–	–	X
Yellow-breasted chat	*Icteria virens*	–	–	–	–
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	–	–	–	–
Yellow-rumped warbler	*Setophaga coronata*	–	–	X	X
TOTAL NUMBER	174 species	33	16	60	68

[1] Species not on the NPSpecies list (NPS 2016b), but listed by one or more of the four studies/surveys reviewed in the condition assessment.

[2] Recorded in Site 3 only (i.e., and not in Sites 1 or 2) of the Yavapai College Elderhostel survey. Site 3 was located near but outside of park boundaries.

[3] Species noted as "probably present" or "unconfirmed" in NPSpecies (NPS 2016b) (and a reference for the record is given) but not observed by one of the four surveys/studies.

[4] In addition to note 3 above, this species was reportedly observed by Beatty (1978) during surveys along the Little Colorado River. The table presenting the species observed during those fall studies by Beatty (1978) was absent from her report.

[5] National Monument staff conduct nesting surveys for this species.

Appendix I. Habitat Connectivity Analysis

The workflow used to complete Flagstaff Area National Monuments' habitat connectivity analysis is listed in Table I-1. Outputs included habitat suitability models (HSM), patch models (PMs), and corridor models (CMs) for each species. Models were based on habitat preferences from four datasets: (1) land cover, (2) elevation, (3) topography, and (4) distance from roads. Depending on a species' particular needs, these preferences were weighted accordingly using the opinions of subject matter experts.

Table I-1. GIS-based habitat connectivity assessment workflow adapted from Beier et al. (2008).

Process / Step	Description	Selection
Define Area of Analysis	The area identified to address wildlife movement needs.	30 km (18.6 mi) ecological buffer (Monahan et al. 2012)
Select Wildland Blocks	Areas of publicly owned or other land expected to remain in a relatively natural condition for at least 50 years.	Flagstaff Area National Monuments: Wupatki NM, Sunset Crater Volcano NM, and Walnut Canyon NM
Select Focal Species	Species that collectively serve as an 'umbrella' for all native species and ecological processes.	Nine native species either found in one or all three monuments with Arizona CorridorDesigner habitat models
Identify Landscape Factors	Landscape factors are based on species' life needs such as food, cover, safety from hazards (e.g. roads), etc.	Land cover, elevation, topography, and distance from roads were selected as the landscape factors for each model.
Identify Landscape Metrics	Categories of landscape factor attributes.	47 land cover classes grouped into 10 categories; topography grouped into 4 topographic positions; elevation ranged from -1 - 3,846 m (3.3 - 12,625 ft); and roads were mapped as a land cover type and calculated as distance to nearest road.
Identify Resistance Values of Each Pixel Class	Establishes the "link between the non-ecological GIS information and the ecological-behavioral aspects of the mobility of the organism or process" (Adriaensen et al. 2003 as cited in Beier et al. (2008)).	Resistance values were based on literature review and expert opinion for each species (refer to Majka et al. (2007) Excel spreadsheet); landscape factor classes were weighted for all 10 species.
Identify Combining Factor Resistances	Method of combining inability to move through an area (i.e., resistance) due to landscape factors.	Weighted geometric mean
Identify Corridor Terminus	The area within a wildland block that ends the modeled corridor.	Habitat patches within monuments
Delineate Habitat Patches	Areas of habitat that can support reproduction by the focal species.	Thresholds for habitat quality, minimum area suitable for breeding, and how edge effects affects each species are identified as patches.
Decide How to Model Corridor Dwellers	A species that requires more than one generation for gene flow to occur between wildland blocks.	Assigned the lowest resistance value to habitat patches.
Decide How Continuous Swaths of Low-Resistance Pixels Are Identified (Travel cost map)	Areas that are easy for a given species to travel within may be disconnected (either by natural or unnatural features) and not form a continuous area or swath. So a method for connecting low resistance pixels (i.e., areas easy to travel) needs to be selected.	Each pixel's cost is calculated as the lowest possible cumulative resistance or travel cost from that pixel to habitat block terminuses.
Identify Corridor Width	For corridor dwellers, width should be substantially more than a home range width and use iterative mapping to identify acceptable number and severity of bottlenecks.	Increasingly wide corridors were displayed as nested polygons in a graded cost map, with each polygon defined by the largest cumulative travel costs allowed. The larger the polygon, the higher the cost.

I.1. Area of Analysis and Habitat Blocks

The NPScape landscape dynamics monitoring project recommended evaluating landscape attributes within a 30 km (18.6 mi) area of analysis (AOA). This scale captured ecological processes, such as wildland fires and some animal movements as well as dispersal patterns (Monahan et al. 2012) of park resources. The habitat blocks or protected areas of interest for maintaining habitat connectivity included the three national monuments: Wupatki, Walnut Canyon, and Sunset Crater Volcano. In total, these monuments protect a little over 17,000 ha (~42,000 ac) of public land and are expected to remain in a natural condition in perpetuity. Each of the three buffers were dissolved, creating one area totaling 7,489 km^2 (2,891.5 mi^2). The monuments comprised 2.3% of the entire AOA.

I.2. Focal Wildlife Species

Animals move within or among habitats to obtain the resources they need for survival (i.e., water, food, cover, and mates), and different species move at different scales (such as mountain lions compared to the Wupatki pocket mice). As a result, some species may be more affected (or affected sooner) by habitat fragmentation. Beier et al. (2008) suggested selecting focal species to serve as an 'umbrella' for the remaining species and natural processes not evaluated when developing habitat linkages/connectivity. Beier et al. (2008) further suggested that species selection include some that are: (1) area-sensitive, (2) habitat specialists, (3) dispersal limited, (4) sensitive to barriers, or (5) otherwise ecologically important. Beier et al. (2008) emphasized that the goal of identifying linkages should be "to conserve or restore a functioning wildland network that maintains ecological processes and provides for the movement of all native species between wildland [habitat] blocks." Table I-2 lists the species selected for habitat connectivity analysis for each national monument and Table I-3 summarizes each species' habitat preferences. Of the 16 mammals and 12 reptile and amphibian parameterized models included as raw data in the Arizona CorridorDesigner toolbox, a total of nine native species were known to occur at either all monuments (5 species)

Table I-2. Arizona CorridorDesigner wildlife species known to occur at one or all Flagstaff Area National Monuments.

Common Name	Scientific Name	Species Selection Criteria	Wupatki	Walnut Canyon	Sunset Crater Volcano
American badger	*Taxidea taxus*	Large home range; many protected lands are not large enough to ensure species' life cycle.	X	X	X
American black bear	*Ursus americanus*	Requires habitat variety; low population densities makes them vulnerable to habitat fragmentation.	X	X	X
American pronghorn	*Antilocapra americana*	Susceptible to habitat fragmentation and human development; sensitive to barriers.	X	X	X
Black-tailed jack rabbit	*Lepus californicus*	Important seed dispersers and prey for other species; frequently killed by vehicles.	X	—	—
Kit fox*	*Vulpes macrotis*	Susceptible to habitat conversion and fragmentation.	X	—	—
Lyre snake	*Trimorphodon biscutatus*	Susceptible to habitat fragmentation.	—	X	—
Mountain lion	*Puma concolor*	Requires a large area of connected landscapes to support even minimum self sustaining populations.	X	X	X
Mule deer	*Odocoileus hemionus*	Important prey species; road systems may affect the distribution and welfare of species.	X	X	X
White-nosed coati	*Nasua narica*	Appears to be dispersal limited.	—	X	—

* Listed as a Species of Greatest Conservation Need in Arizona (AGFD 2012).

Table I-3. Wildlife species habitat preferences.

Common Name	Land Cover	Elevation	Topography	Distance From Roads
American badger	Prefer grasslands and other open habitats	Lower	Flat terrain	No aversion; high mortality
American black bear	Require habitat variety	Often mountainous	Prefer to bed in locations with 20-60% slopes	Movements dependent on food supply; males have greater dispersal
American pronghorn	Areas of grasses and scattered shrubs with rolling hills or mesas	Gentle terrain	Prefer slopes < 30%	Right-of-way fences are major factor limiting movement
Black-tailed jack rabbit	Prefers open country	–	–	Frequently killed by vehicles
Kit fox*	Prefer desert grasslands and desert scrub with sandy soils for digging dens	Variable spatial patterns depending on prey, habitat quality, and precipitation		
Lyre snake	All vegetation types and strongly associated with rocks and outcrops	up to 2,255.5 m (7,400 ft)	Mountain slopes	–
Mountain lion	Found throughout Arizona in rocky or mountainous areas; diverse habitat	304.8 - 914.4 m (1,000-3,000 ft)	Varied	Sensitive to vehicles
Mule deer	In northern Arizona inhabit yellow pine, spruce-fir, buckbrush, snowberry, and aspen habitats	–	Home ranges of mule deer vary depending upon the availability of food and cover	
White-nosed coati	Primarily a forest species	No constraints	No preference	Males tend to be hit by vehicles

Source: Majka et al. (2007)

or at one monument only (4 species). These nine species serve as the "umbrella" for the remaining species known to occur at each of the monuments.

Table I-4. Landscape factor weights used in species habitat models.

Species Common Name	Land Cover	Elevation	Topography	Distance From Roads
	Percentages (%)			
American badger	65	7	15	13
American black bear	75	10	10	5
American pronghorn	45	–	37	18
Black-tailed jack rabbit	70	10	10	10
Kit fox	75	–	15	10
Lyre snake	–	10	80	10
Mountain lion	70	–	10	20
Mule deer	80	–	15	5
White-nosed coati	95	–	–	5

Source: CorridorDesigner Species Scores Excel Spreadsheet (Majka et al. 2007)

I.3. Habitat Suitability and Patch Models

The Habitat Suitability Models (HSMs) were developed using the weighted geometric mean of the parameters selected for each species' life cycle and survival needs from four raster datasets: land cover, elevation, topography, and distance from roads. The factor weights assigned within each data set for each species analyzed are listed in Table I-4. The 30 m x 30 m pixels within each of the four rasters were combined using the geometric mean method to identify resistance through an area. Resistance factors for the parameterized habitat models were linearly stretched to a 0 (worst) – 100 (best) scale. The patch models (PMs) were developed using the results from each species' HSM. The HSMs and PMs for each species analyzed are shown in Figures I-1 through I-18.

I.4. Corridor Models

Corridor models (CMs) were created using the HSMs and PMs for each species to calculate the cumulative movement (travel cost) resistance within a given area. The process included five steps as follows: 1) calculated species patch sizes 2) found starting patches within the first habitat block. If no cores were within the block

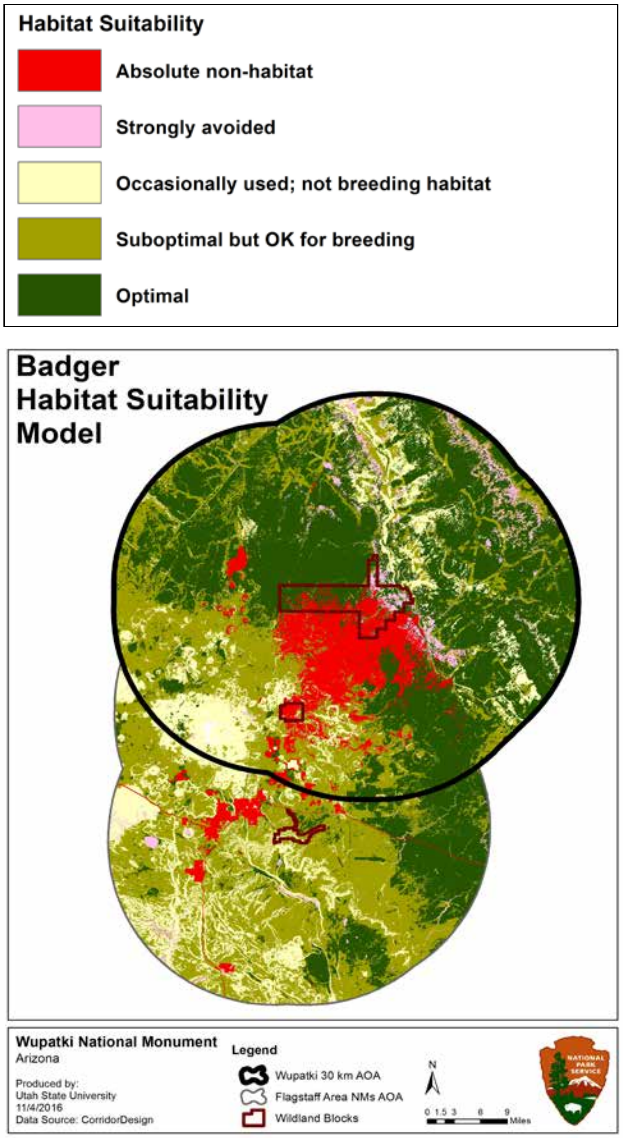


Figure I-1. American badger habitat suitability model.

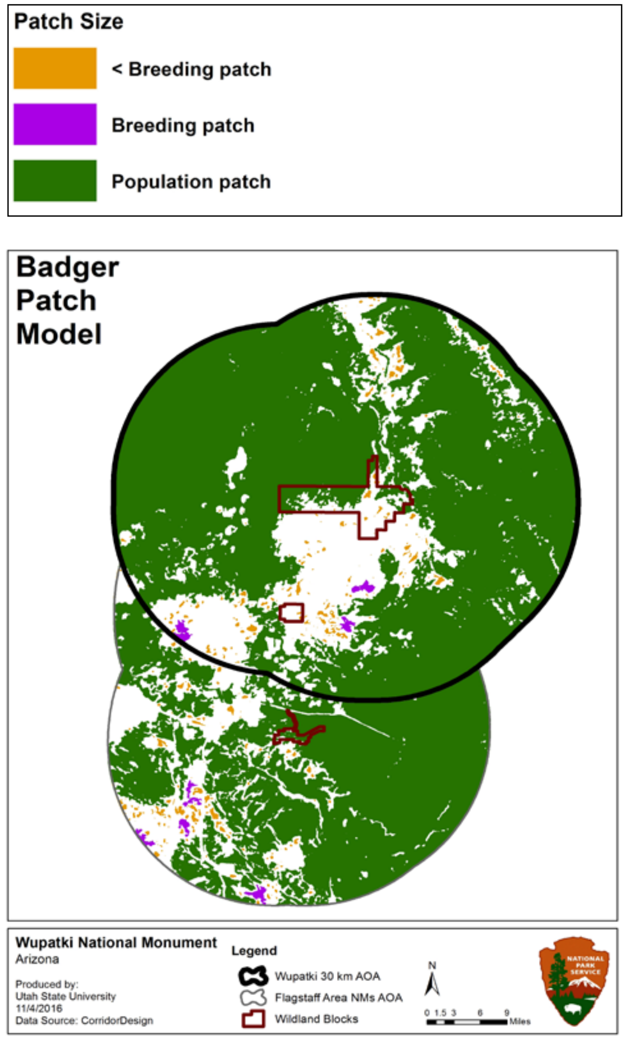


Figure I-2. American badger patch size model.

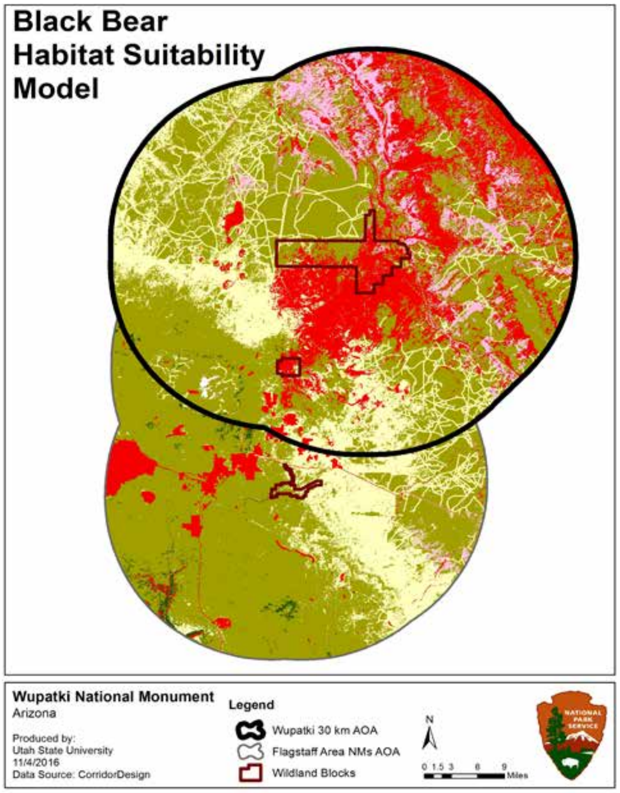


Figure I-3. American black bear habitat suitability model.

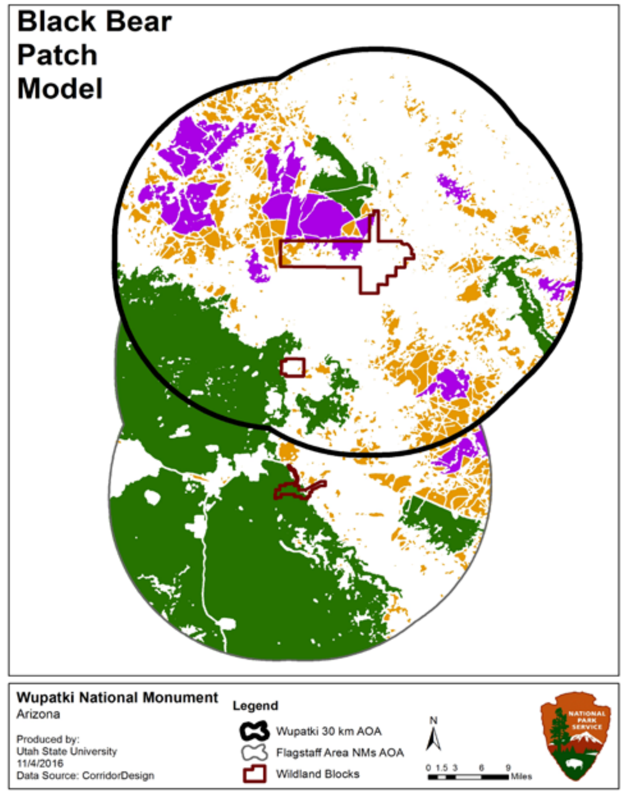


Figure I-4. American black bear patch size model.

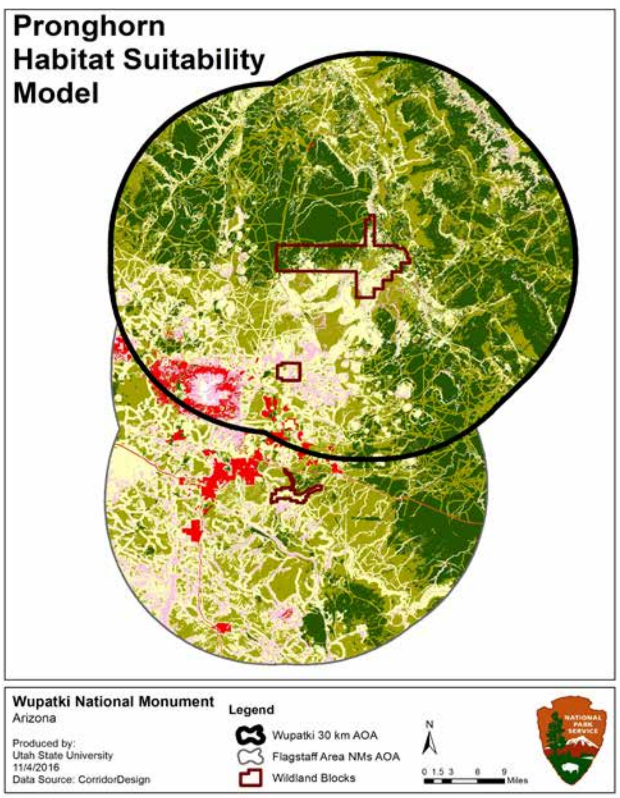


Figure I-5. American pronghorn habitat suitability model.

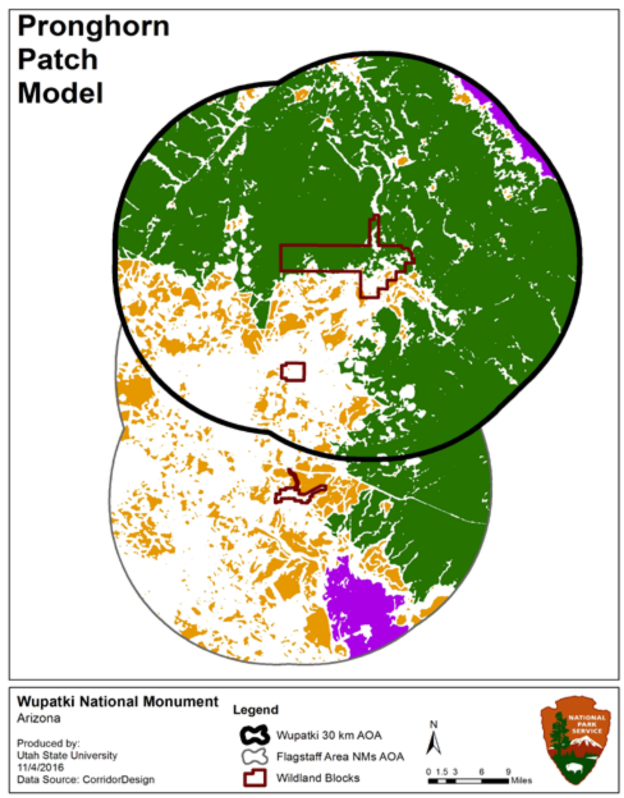


Figure I-6. American pronghorn patch size model.

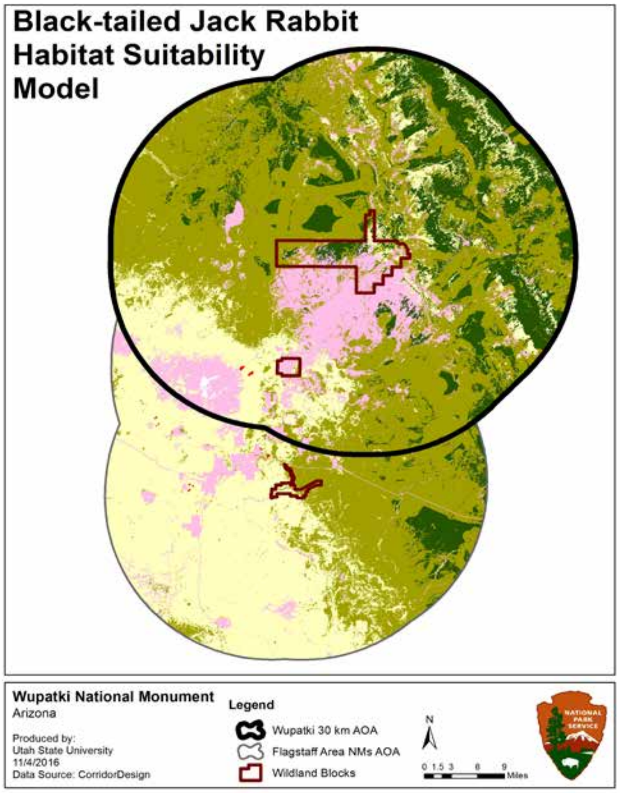


Figure I-7. **Black-tailed jack rabbit habitat suitability model.**

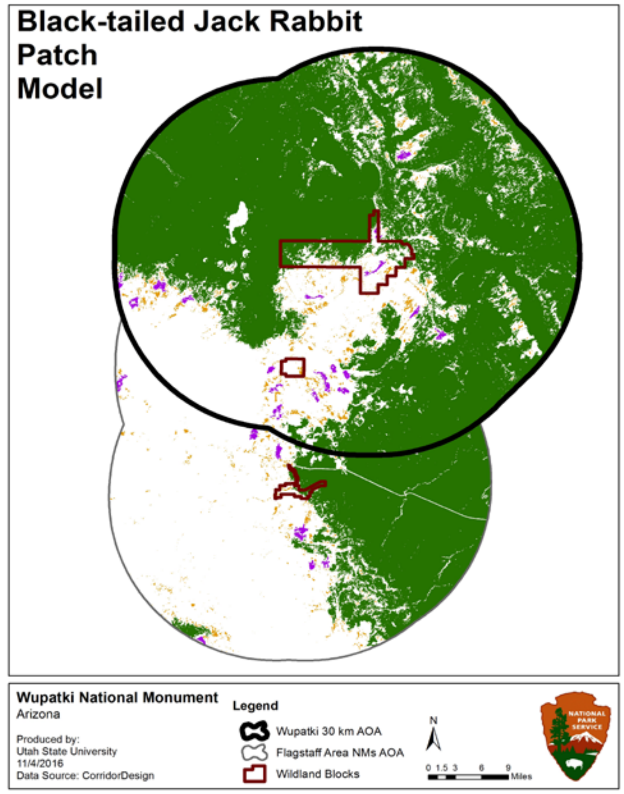


Figure I-8. **Black-tailed jack rabbit patch size model.**

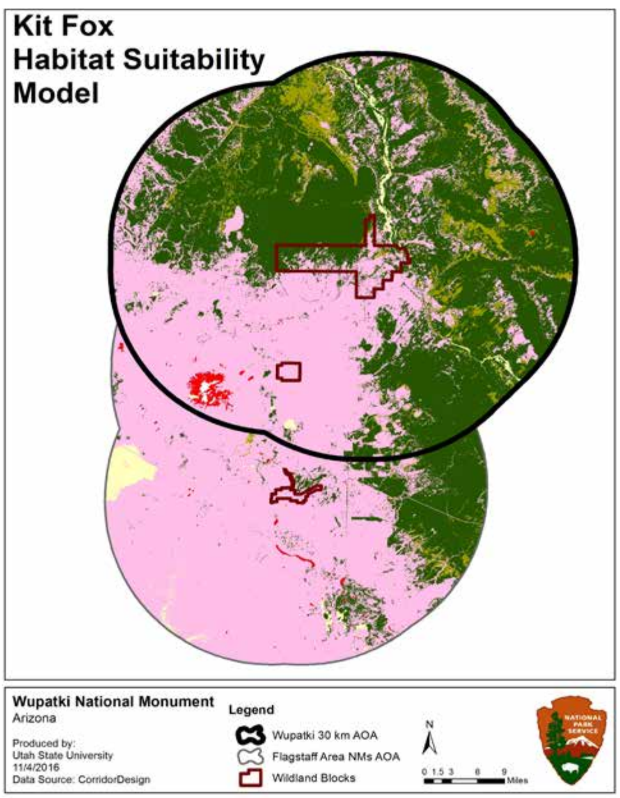


Figure I-9. **Kit fox habitat suitability model.**

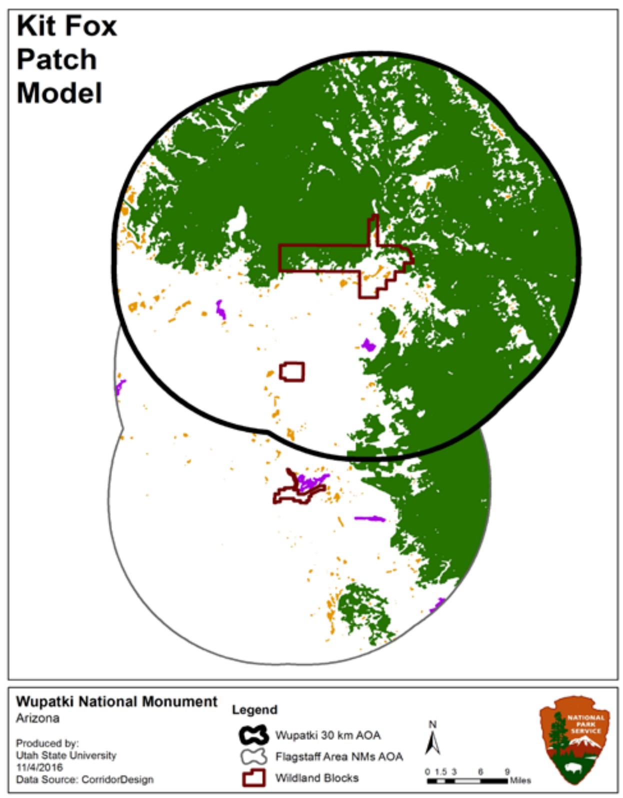


Figure I-10. **Kit fox patch size model.**

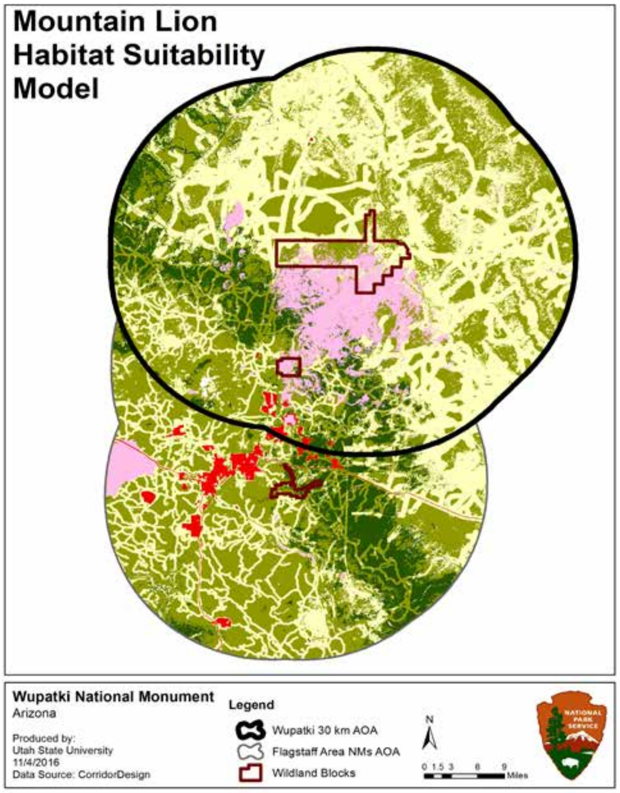


Figure I-11. Mountain lion habitat suitability model.

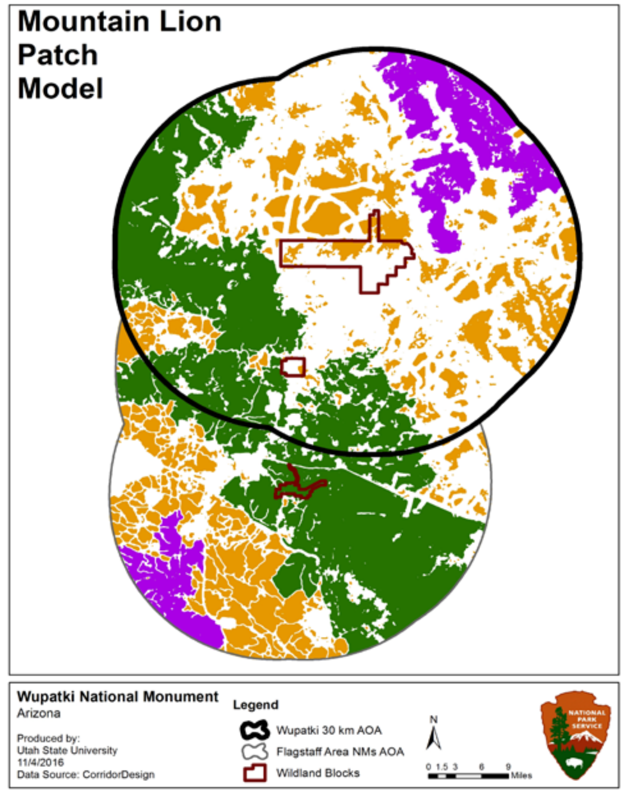


Figure I-12. Mountain lion patch size model.

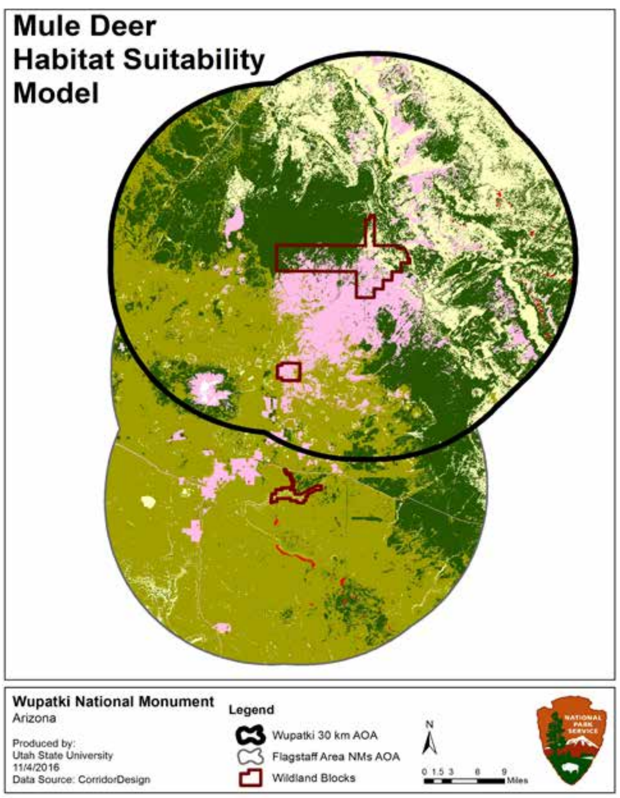


Figure I-13. Mule deer habitat suitability model.

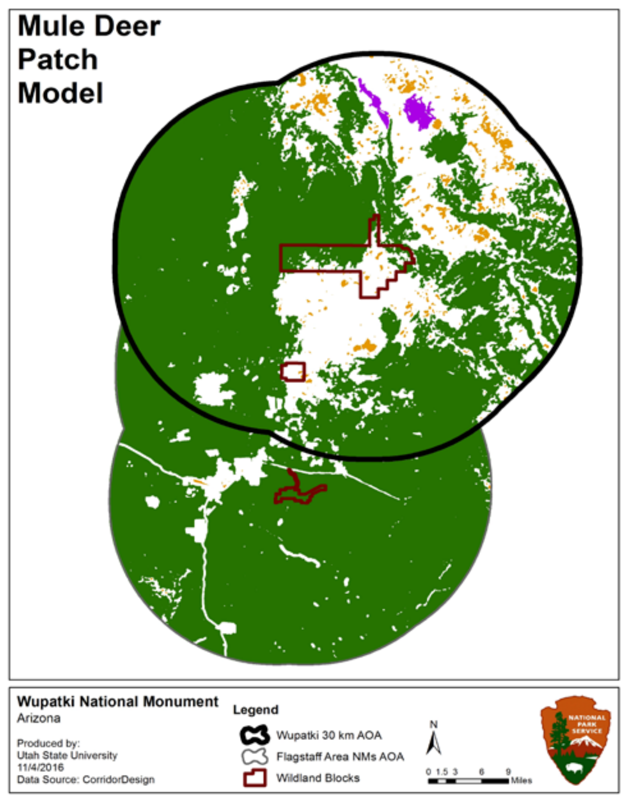


Figure I-14. Mule deer patch size model.

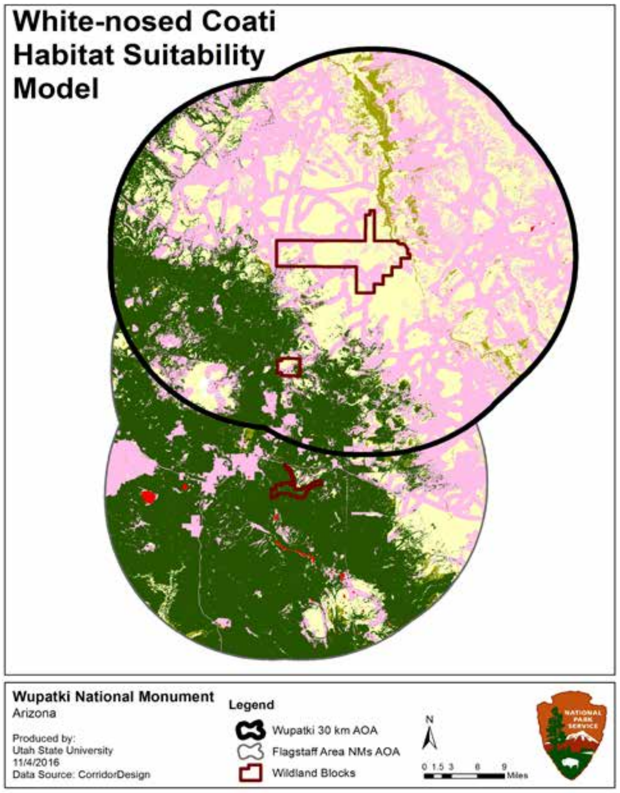


Figure I-15. **White-nosed coati habitat suitability model.**

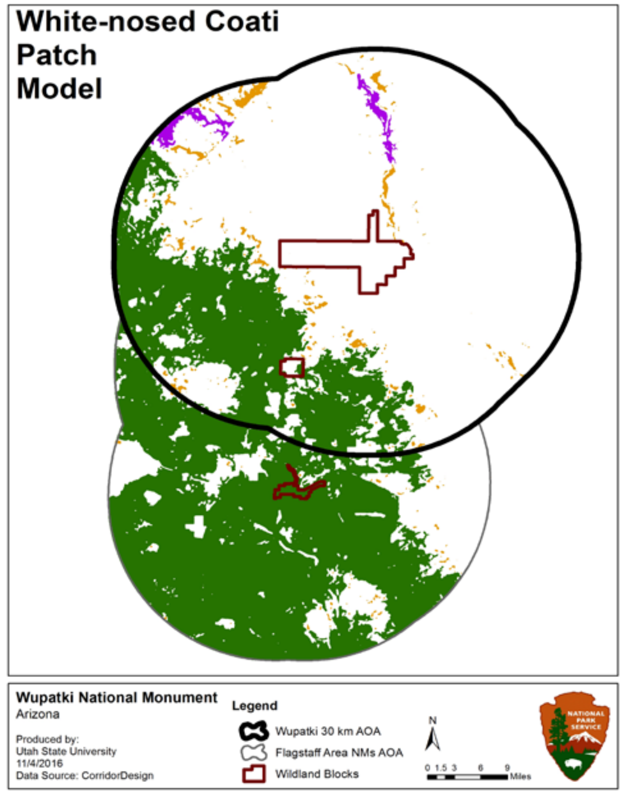


Figure I-16. **White-nosed coati patch size model.**

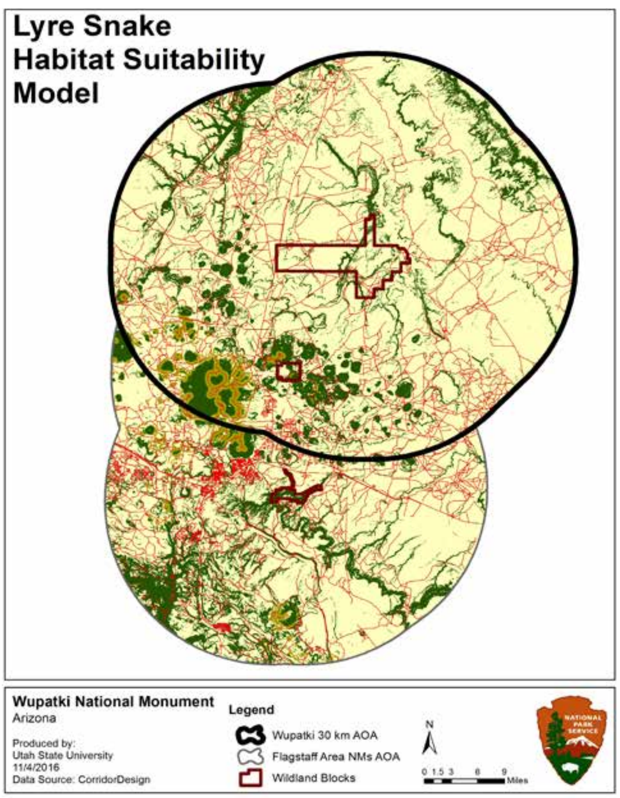


Figure I-17. **Lyre snake habitat suitability model.**

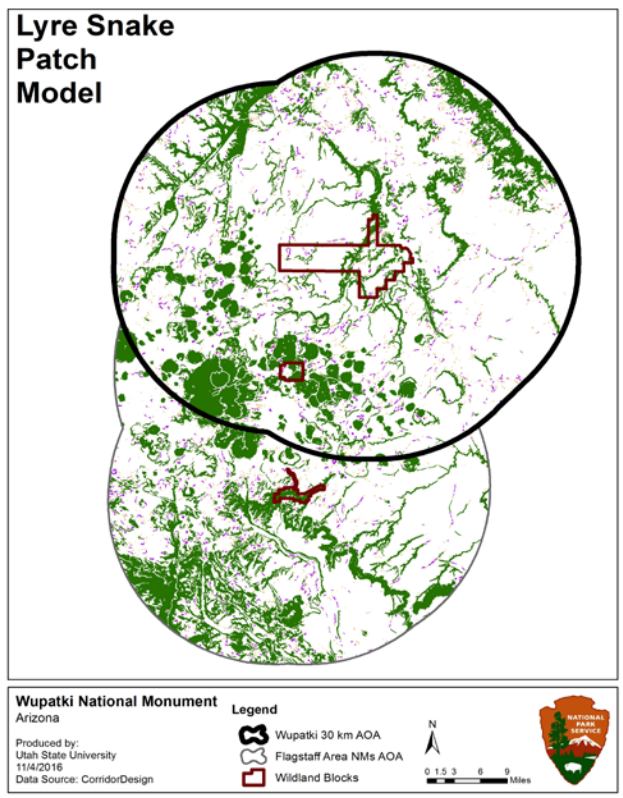


Figure I-18. **Lyre snake patch size model.**

then patches were selected instead. 3) found starting patches within the second habitat block. If no cores were within the block then patches were selected instead. 4) Converted HSM to cost model and calculated cost distance in first and second rasters then combined cost distance rasters into one total accumulative cost grid/corridor model. 5) sliced corridor model into 11 different widths (i.e., 0.1%, 1-10%). The least-cost corridors selected for each species were unioned, producing one preliminary linkage design that showed potential areas of connectivity to facilitate movements of selected species between monuments.

I.5. Degree of Conservation

The linkage design model was used to clip the USGS GAP Protected Areas Database (2016) conservation status dataset. There are four GAP categories that vary based on degree of protection and management mandates. Flagstaff Area NMs are GAP Status 1 lands. All GAP categories are described below.

GAP Status 1: Lands that have permanent protection from conversion of natural land cover and are managed for biodiversity and disturbance events.

GAP Status 2: Lands that have permanent protection from conversion of natural land cover and are managed for biodiversity but disturbance events are suppressed.

GAP Status 3: Lands that have permanent protection from conversion of natural land cover and are managed for multiple uses, ranging from low intensity (e.g., logging) to high intensity (e.g., mining).

GAP Status 4: No known mandate for protection and include legally mandated easements (USGS 2011b).

I.6. Coconino County Wildlife Linkages

A total of 40 wildlife linkages, identified in the *Wildlife Connectivity Assessment Report* for Coconino County (AGFD 2011a), were located within the entire Flagstaff Area NM AOA (Table I-6). Fifteen were within Wupatki's AOA, 35 were within Walnut Canyon's AOA, and 29 were within Sunset Crater Volcano's AOA.

Table I-6. Coconino County wildlife linkages that are within the Flagstaff Area NMs' 30 km AOA.

Area	#	Name	Species	Threats	WUPA	WACA	SUCR
Northern Coconino County	6	Utah - San Francisco Peaks	Raptors, bats	Powerlines, increasing off-highway vehicle use, proposed wind and solar developments, exotic species (cheatgrass, Russian thistle, snakeweed)	X	–	X
	12	South Rim - San Francisco Peaks Woody Ridge / Bellemont Area	mule deer, elk, Gunnison's prairie dog	Hwy 64, development in foothills on north side of the Peaks along FR 418, I-40	X	X	X
	13	Coconino Plateau	Elk, mule deer, pronghorn	Hwy 64	X	–	–
	15	Wupatki National Monument – Navajo Reservation	Pronghorn, small mammals, herpetofauna	Little Colorado River (for some species)	X	–	X
Central Coconino County	17	Grassland north and east of San Francisco Peaks - east of Anderson Mesa	Pronghorn, Gunnison's prairie dog, jackrabbit, golden eagle, milk snakes, birds, bats	Hwy 89A, Leupp Rd, Meteor Crater Rd, FR 69, grazing and shrub encroachment, planned Red Gap pipeline, Grapevine wind development, BSNF Railroad, State Lands	X	X	X
	19	Dog Knobs - Ebert Mtn.-Govt. Prairie	Pronghorn, mule deer, black bear, mountain lion	Highway 180, fencing	–	X	X

Table I-6 continued. ***Coconino County wildlife linkages that are within the Flagstaff Area NMs' 30 km AOA.***

Area	#	Name	Species	Threats	WUPA	WACA	SUCR
Central Coconino County *continued*	20	Mesa Butte - Kendrick	Mountain lion, elk, pronghorn	Highway 180	X	–	X
	21	Garland Prairie - Govt. Prairie	Pronghorn, mule deer, black bear, turkey, elk	Roads, railroad, urban development, I-40	–	X	–
	22	Walnut Canyon - Anderson Mesa - Antelope Park/ Mormon Mtn.	Mountain lion, elk, mule deer, black bear, northern goshawk, Mexican spotted owl, neotropical migratory birds, turkey, northern leopard frog, bats, bald eagle, peregrine falcon, tarantula, gray fox, raccoon, coyote, small mammals, bull snakes	Lake Mary Rd, recreation, crayfish invasion	–	X	X
	23	Youngs and Mormon/Padre Canyons Area	Pronghorn, elk, mule deer, white-tailed deer	Recreation	–	X	X
	25	Mormon Mtn. - Hutch Mtn.	Mexican spotted owl, forest bats, wintering bald eagle, northern leopard frog, other amphibians	High-severity landscape-level fire, forest restoration treatments, Lake Mary Rd	–	X	–
	26	Ashurst/ Kinnikinik - Mormon Lake	Tiger salamander, northern leopard frog, other amphibians	OHV use, Lake Mary Rd	–	X	–
	28	East of Kendrick - Government Hills	Pronghorn	Roads, development, recreation	X	–	X
	29	Kendrick - Hochderfer Hills	Black bear, elk, Mexican spotted owl	Highway 180	X	X	X
	30	San Francisco Peaks - North of Peaks	Mountain lion, pronghorn, elk, mule deer, black bear, badger, northern goshawk, Mexican spotted owl, Gunnison's prairie dog, turkey, northern leopard frog, Mexican vole, bats, neotropical migratory birds	FR 418, OHV use of illegal trails, traffic on FR 151, recreation	X	X	X
	31	San Francisco Peaks - Mt. Elden/Timberline	Mountain lion, deer, bear, northern goshawk, Mexican spotted owl, Gunnison's prairie dog, turkey, bats, neotropical migratory birds	Illegal OHV trails, traffic on Schultz Pass Rd, recreation	X	X	X
	32	San Francisco Peaks – Sunset Crater and O'Leary Peak	Elk, northern goshawk, mountain lion	Mining, off-highway vehicle use, urban development, Sunset National Monument entrance road, Hwy 89	X	X	X
	33	San Francisco Peaks - Observatory Mesa - Bellemont	Elk, mountain lion, mule deer, badger, Gunnison's prairie dog	I-40, urban and suburban development	X	X	X
	34	Elden Spring Road - Landfill	Mule deer, mountain lion, striped skunk, raccoon, gray fox, coyote	Hwy 89 current use and future widening, OHV use, Timberline development, Timberline Trail development and trailhead at Elden Springs Rd	X	X	X

Table I-6 continued. ***Coconino County wildlife linkages that are within the Flagstaff Area NMs' 30 km AOA.***

Area	#	Name	Species	Threats	WUPA	WACA	SUCR
Flagstaff Area	35	Hwy 180 Meadows	Gunnison's prairie dog, ferruginous hawks, burrowing owls, other meadow species	Highway 180, development	–	X	X
	36	Peaks - Woody Ridge	Pronghorn, mountain lion, elk, mule deer, black bear, badger, northern goshawk, Gunnison's prairie dog, Mexican spotted owl, neotropical migratory birds, turkey, leopard frog, Mexican vole, bats, raptors	Highway 180, urban and suburban development, recreation	–	X	X
	37	Elden Foothills	Mountain lion, mule deer, bats	Urban and suburban development, recreation, illegal mountain bike trail use	X	X	X
	38	Turkey Hills - Picture Canyon - Elden Pueblo	Elk, mule deer, turkey, bald eagle, peregrine falcon, neotropical migratory birds, porcupine, bats, Gunnison's prairie dog, bats	Rural development, OHV recreation	–	X	X
	39	Rio de Flag	Neotropical migratory birds, waterfowl, bald eagle, bats	Hwy 89 current use and future widening, OHV use, Timberline development, Timberline Trail development and trailhead at Elden Springs Rd	X	X	X
	40	Woody Ridge	Pronghorn, mountain lion, black bear, elk, mule deer, badger, northern goshawk, Gunnison's prairie dog, Mexican spotted owl, neotropical migratory birds, turkey, leopard frog, Mexican voles, bats	Highway I-40, traffic and recreation along Woody Mountain Rd (FR 231), some fuels reduction treatments Notes: I-40 telemetry data should	–	X	X
	41	Rogers Lake - Volunteer Canyon	Elk, pronghorn, deer, turkey, black bear, mountain lion, northern leopard frog, bald eagle, bats, Gunnison's prairie dog	Recreation, military training	–	X	–
	42	Dry Lake - Rogers Lake	Pronghorn, elk, mule deer, black bear, turkey, Mexican spotted owl, bald eagle, Gunnison's prairie dog, northern goshawk, northern leopard frog, Mexican vole, neotropical migratory birds, bats	Suburban development, recreation, traffic on Woody Mountain Road	–	X	X
	43	Bow and Arrow	Neotropical migratory birds, bats, striped skunk	Urban and suburban development, Lake Mary Rd, Lone Tree Rd, invasive plants	–	X	X
	44	Hoffman Tank Area	Neotropical migratory birds, Gunnison's prairie dog, bats, elk	Suburban and rural development, invasive plants	–	X	X
	45	Peaceful Valley - Campbell Mesa	Bald eagle, neotropical migratory birds, Gunnison's prairie dog, elk, mule deer, porcupine, bats	Suburban development, recreation	–	X	X
	46	Rio de Flag - Walnut Canyon	Mountain lion, bald eagle, northern goshawk, neotropical migratory birds	I-40 expansion	–	X	X

Table I-6 continued. ***Coconino County wildlife linkages that are within the Flagstaff Area NMs' 30 km AOA.***

Area	#	Name	Species	Threats	WUPA	WACA	SUCR
Flagstaff Area *continued*	48	Black Pass	Pronghorn, mountain lion, elk, mule deer, black bear, badger, northern goshawk, Gunnison's prairie dog, Mexican spotted owl, neotropical migratory birds, turkey, leopard frog, Mexican vole, bats	State Route 89A, recreation, some fuels reduction treatments	–	X	–
	49	Sinclair Wash	Neotropical migratory birds, bats	Urban/suburban/commercial development, Milton Avenue, Beulah Road, Interstate 40, invasive plants, trash, stormwater	–	X	X
	50	Oak Cr. Canyon	White-tailed deer, black bear, javelina, elk	Highway 89A, recreation	–	X	X
	51	Schoolhouse Draw - Pumphouse Wash and Fry Canyon	Mountain lion, elk, deer, black bear, hawks, Gunnison's prairie dog, Mexican spotted owl, waterfowl, bald eagle, neotropical migratory birds, turkey, leopard frog, bats	I-17 and Hwy 89, suburban/rural development, OHV use on illegal trails, recreation and traffic along FR 237	–	X	X
	52	Mexican Pocket/ Pumphouse Wash/Village of Oak Creek	Turkey, black bear, elk, mule deer, mountain lion, Abert's squirrel, Mexican spotted owl	Summer dispersed camping, off-highway vehicle use, State Route 89A, forest thinning	–	X	–
	53	Newman Park - Willard Springs	Arizona black rattlesnake, elk, reptiles	I-17, shooting range	–	X	–
	54	Pumphouse Wash - Munds Canyon	Elk, mule deer, turkey	Off-highway vehicle use	–	X	–
South-central Coconino County	55	Anderson Mesa Summer - Winter Range	Pronghorn, elk	Fencing, proposed wind development, conifer encroachment	–	X	–
	56	Robber's Roost / Dutch Tank Area Morman Lk Area	Turkey, elk, javelina	I-17	–	X	–
TOTAL NUMBER OF LINKAGES IN EACH 30 km AOA					15	35	29

Source: AGFD (2011).

NPS 322/143923, March 2018

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov