National Park Service
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Natural Resource Stewardship and Science

Casa Grande Ruins National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/SODN/NRR—2019/1979

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Blooming Saguaro cactus. Photo Credit: © Utah State University.

ON THE COVER

Casa Grande Ruins National Monument. Photo Credit: NPS.

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Natural Resource Condition Assessment

Natural Resource Report NPS/SODN/NRR—2019/1979

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program, administered by the National Park Service's (NPS) Water Resources Division, provides a multidisciplinary synthesis of existing scientific data and knowledge about current conditions of important national park natural resources through the development of a park-specific report. The NRCA process for Casa Grande Ruins National Monument (NM) began with a January 2018 conference call and an on-site scoping meeting held in May 2018.

Nine of the monument's natural resources, grouped into four broad categories, were selected for condition assessment reporting. The categories included landscapes, air and climate, water, and biological integrity, (i.e., wildlife and vegetation resources).

The monument's upland vegetation/soils and soil crusts are currently in good condition, whereas, the landscape-scale resources such as viewshed, groundwater, night sky, air quality, and others were found to be of moderate or significant concern. The exception included mammals, whose condition is unknown at present due to the lack of a repeat survey for comparison.

Acknowledgements

We thank Archeologist/Chief of Resource Stewardship & Facilities Management, Alycia Hayes, for providing data, reports, and reviews. We also are indebted to the National Park Service Sonoran Desert Inventory and Monitoring Network (SODN) staff, Andy Hubbard, Kristen Bonebrake, Sarah Studd, and Evan Gwilliam for their assistance in gathering data; establishing indicators, measures, and reference conditions; and for reviewing drafts of the assessments and chapters. For some of the resources evaluated, an initial condition assessment draft was provided.

SODN's inventory and monitoring data informed current conditions for several of the park's natural resource topics. Kara Raymond, hydrologist with the NPS Southern Arizona Office, provided expert reviews and information for most assessment topics.

Phyllis Pineda Bovin, NPS Intermountain Region Office NRCA Coordinator, assisted with overall project facilitation and served as subject matter expert review manager. Jeff Albright, NPS NRCA Program Coordinator, provided programmatic guidance.

And finally, to all of the additional reviewers and contributors, who are listed in Appendix A, we thank you. Your contributions have increased the value of Casa Grande Ruins National Monument's report.


The Casa Grande Ruins. Photo Credit: NPS.

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.

[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.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs. Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

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

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

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning

Close-up of barrel cactus blooms. Photo Credit: NPS.

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/.

[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.

Casa Grande Ruins and protective structure. Photo Credit: © USU.

Introduction and Resource Setting

Introduction

Enabling Legislation/Executive Orders

Casa Grande Ruins National Monument (NM) was initially protected in 1892 as "Casa Grande Ruin Reservation" (NPS 2017a). "This represented one of the first formal efforts of the federal government to protect the nation's archeological heritage" (NPS 2017a). Twenty-six years later, in 1918, it became a national monument and its management was then transferred to the National Park Service (NPS; 2017a). The purpose for establishing the monument was to protect the large multistoried adobe Hohokam structure known as Casa Grande (NPS 2017a).

Supporting the monument's purpose are four significance statements explaining why its "resources and values are important enough to merit designation as a unit of the national park system" (NPS 2017a). These statements are as follows (text excerpted from NPS (2017a)):

1. Casa Grande is the only surviving example of a multistory, freestanding earthen Great House structure from the Hohokam culture. It represents the final evolution of the architectural tradition of the late classic period.
2. The establishment of Casa Grande Ruins National Monument as the first archeological reserve in 1892 initiated the U.S. government's archeological preservation movement. The integrity of the resources remains high due to the early date of the site's establishment.
3. Casa Grande Ruins National Monument is a sacred place for many American Indians who have an affiliation with the Ancestral Sonoran Desert People.
4. Casa Grande Ruins National Monument exemplifies early adaptation to the desert environment by the Ancestral Sonoran Desert People, including use of nearby Gila River and others for creating the most extensive prehistoric irrigation-based agricultural desert society in North America.

Geographic Setting

Casa Grande Ruins NM is located within the City of Coolidge, Arizona, approximately 58 km (36 mi) from Phoenix's Sky Harbor International Airport. The monument is 2.6 km^2 (1 mi^2) in size, and almost square in shape. (Figure 1). It is accessed from Arizona Highways 87/287 and surrounded by residential and commercial developments.

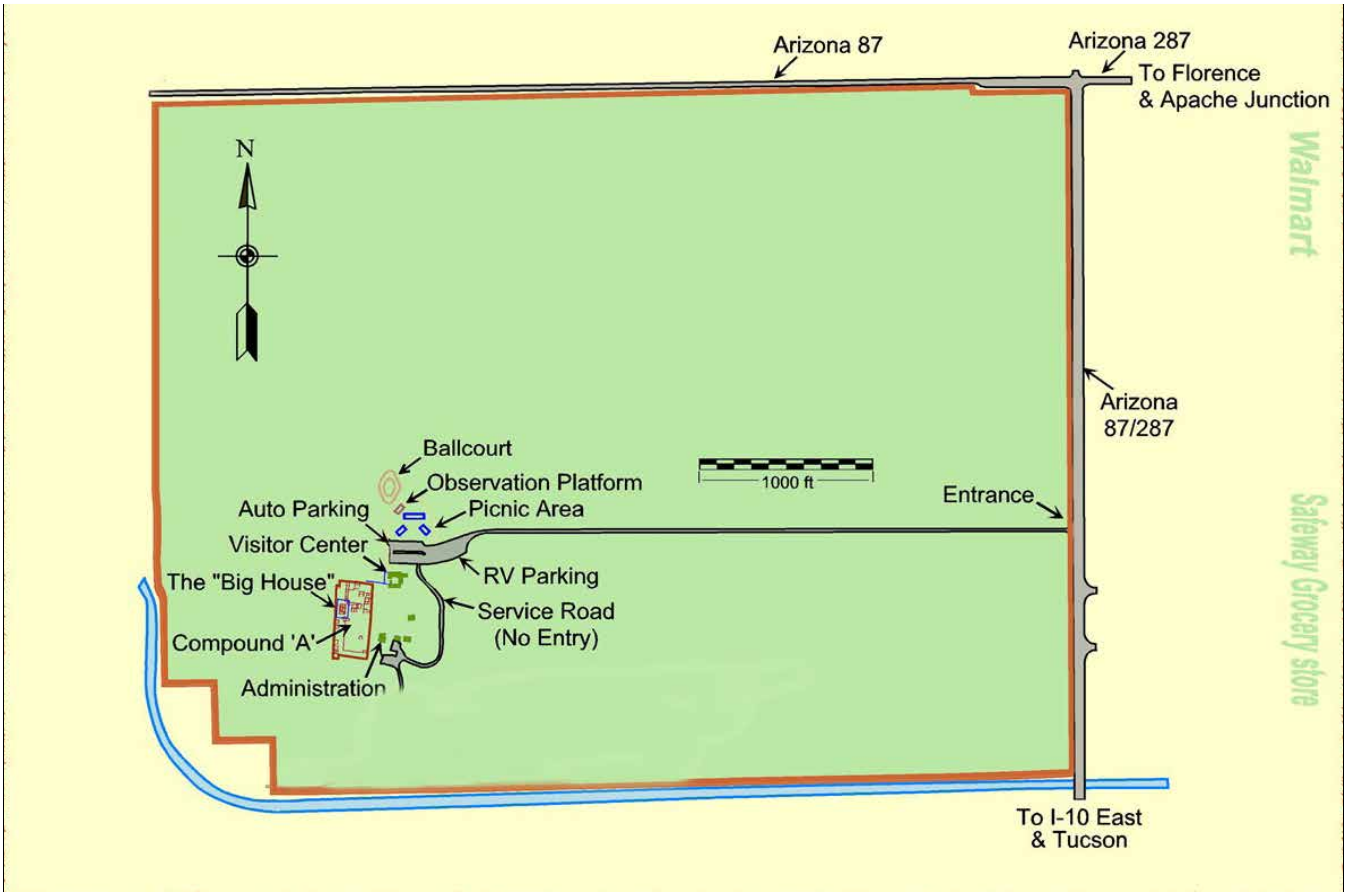


Figure 1. Casa Grande Ruins NM is located in the City of Coolidge, Arizona, along Highways 87/287. Figure Credit: NPS 2018a.

As of April 1, 2010, the population estimate for the City of Coolidge, Arizona was 11,825 (U.S. Census Bureau 2018). The population percent change from 2010 to July 1, 2018 was unavailable since no population estimate was provided for 2018 (U.S. Census Bureau 2018).

Casa Grande Ruins NM has a unique opportunity to study climate and weather patterns in the Sonoran Desert given the fact that three weather monitoring stations are located in or within the vicinity of the monument. A remote automated weather station (RAWS) was installed in 2014 (2014-2019), and a Regional Climate Reference Network station was installed in 2011 (2011 - 2017, 2019). Both are maintained and operated by the NPS Sonoran Desert Inventory and Monitoring Network (SODN). The third station, located near the Great House, is one of the longest-operating weather stations in Arizona, the National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) station #21314 (1906, 1908 - 1916, 1931 - 2018) (Climate Analyzer 2019). NPS SODN (2018b) describes the general climate at the monument as follows:

> The monument experiences climate typical of the Sonoran Desert ecoregion: highly variable, bimodal precipitation with a considerable range in daily and seasonal air temperature and relatively high potential evapotranspiration rates. Approximately 40% of the annual precipitation falls during thunderstorms from July through September, when maximum air temperatures can exceed 104°F and lead to violent (and often localized) rainstorms. The bulk of the remaining annual precipitation falls in relatively gentle events of broad extent from November through March.

Visitation Statistics

Visitation data for Casa Grande Ruins NM are available from 1911-2018 (NPS Public Use Statistics Office 2019). The highest number of visitors was 179,915 in 1987 (Figure 2). The months with the highest average

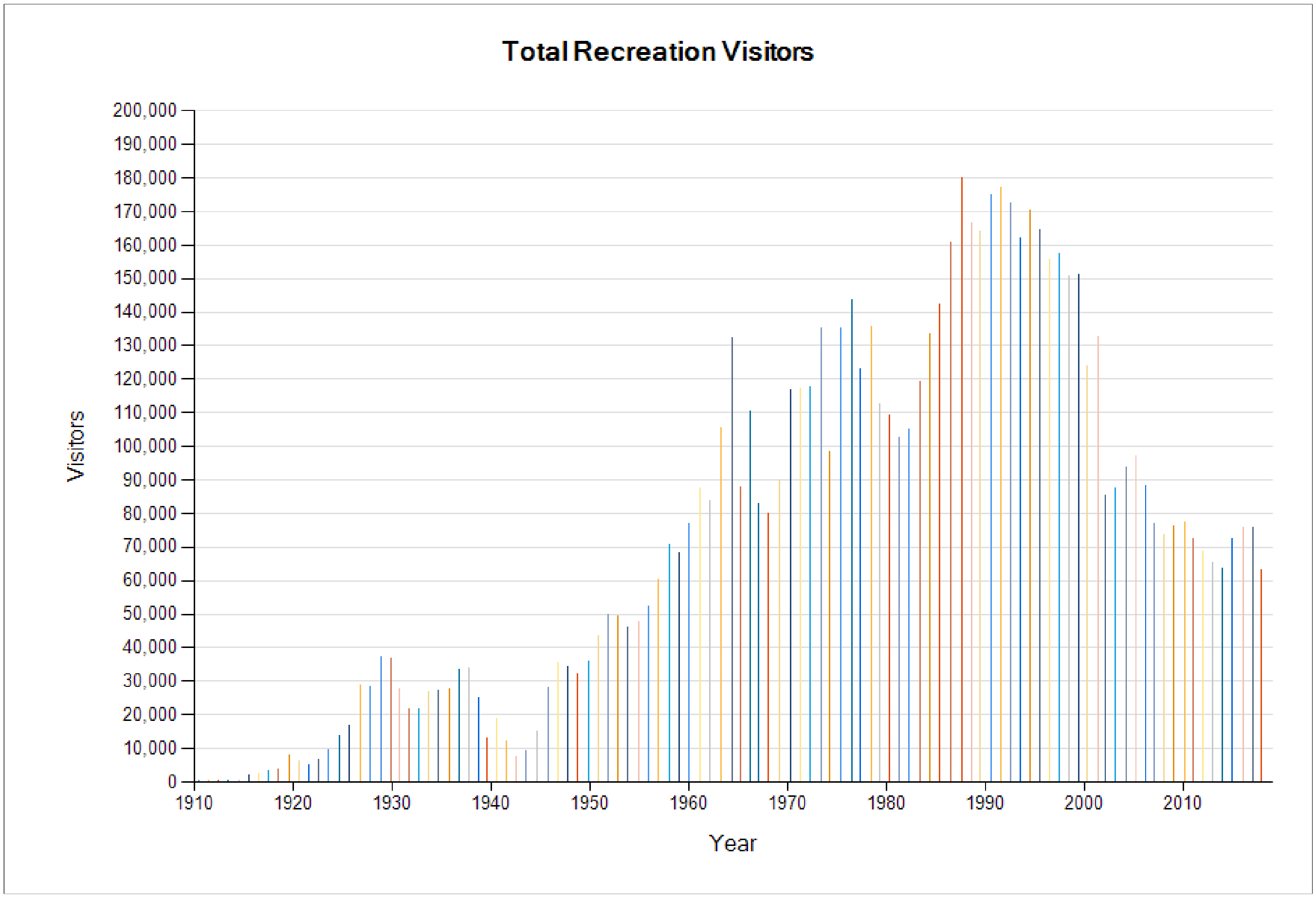


Figure 2. **Total number of annual visitors to Casa Grande Ruins NM from 1911-2018. Figure Credit: NPS Public Use Statistics Office 2019.**

number of visitors are February and March based on data collected from 1979-2018 (NPS Public Use Statistics Office 2019).

Natural Resources

Ecological Units and NPScape Landscape-scale

Casa Grande Ruins NM is located in the Basin and Range physiographic province within the NPS SODN. The topography is characterized by level valley floors surrounded by mountains. The monument also lies within the Sonoran Desert ecoregion (Figure 3), spanning 22.3 million ha (55 million ac), dominated by the desert biome or ecoregion (NPS SODN 2018a).

Most of Casa Grande Ruins NM's natural resources (e.g., viewshed, night sky, soundscape, air quality, wildlife, etc.) are affected by landscape-scale processes. Landscape-scale metrics can provide a broader perspective and 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), however, most parks are not large enough to encompass self-contained ecosystems for the resources found within their boundaries. When feasible, landscape-scale indicators and measures were included in the national monument's condition assessments to provide an ecologically relevant, landscape-scale context for reporting resource conditions. NPS NPScape metrics were used to report on the landscape-scale measures, providing a framework for conceptualizing human effects (e.g., housing densities, road densities, etc.) on landscapes surrounding the monument (NPS 2014a,b).

Resource Descriptions

An overview of Casa Grande Ruins resources is summarized by NPS SODN (2018b) as follows:

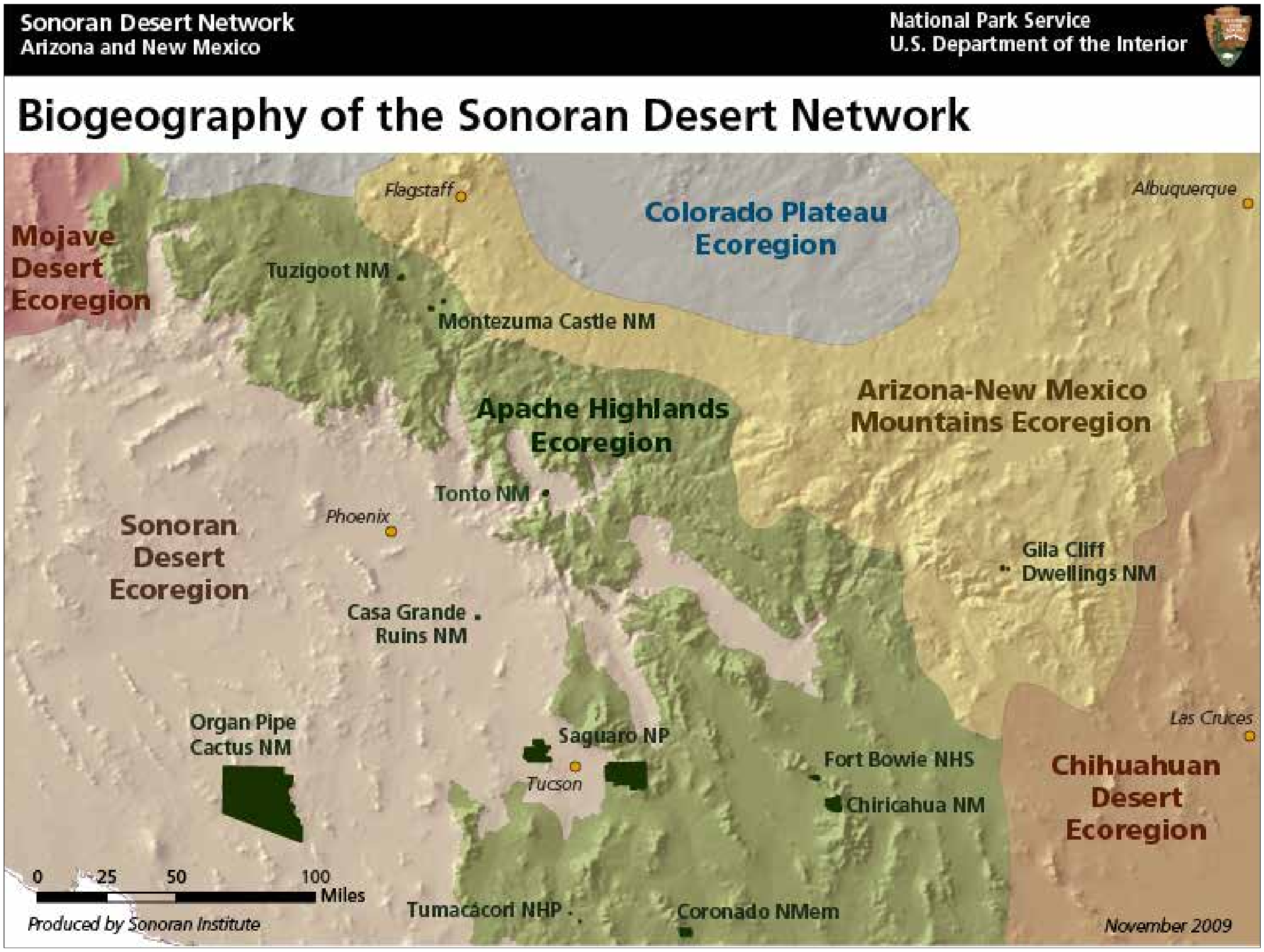


Figure 3. Casa Grade Ruins NM is located in Arizona's Sonoran Desert and is one of 11 park units within the NPS Sonoran Desert Inventory and Monitoring Network. Figure Credit: NPS SODN.

The monument lies on an alluvial deposit composed of Quaternary-age gravel, sand, and silt. The alluvium thickness increases from 400 feet at the Gila River to more than 1,200 feet in Coolidge; alluvium at the monument is approximately 800–1,200 feet thick.

Soils at and near the monument are classified at Hyperthermic Arid soils, which have a mean annual soil temperature of greater than 72°F and receive less than 10 inches of annual precipitation on average. Coolidge sandy loam comprises over 80% of the soil. The rest is the Laveen loam soil type. Both soil types have less than 15% rock fragments by volume, are considered well-drained, and have a slight risk of water erosion. The soils at the proposed expansion areas adjacent to and near the current monument are also Laveen loams and Coolidge sandy loams. At the proposed Adamsville unit, there are four soil map units: Coolidge sandy loam; Denure sandy loam (1–3% slopes); Gunsight-Pinamt complex (–8% slopes); and Laveen loams. The Gunsight-Pinamt complex soils have 35–60% rock fragments by volume. Soil properties have important consequences for vegetation composition, persistence and productivity.

Open spaces on the soils are covered by biological soil crusts, a community of cyanobacteria, algae, lichens and bryophytes. Biological soil crusts provide key ecosystem functions. They increase resistance to erosion by water and wind, contribute organic matter, and fix atmospheric nitrogen. Cyanobacteria weave through the upper few millimeters of soil, binding together soil particles.

In the Sonoran Desert, cyanobacteria dominate the crust community. Lichens are a composite, symbiotic organism composed of a fungus and either a cyanobacteria or a green algae, and occur on the soil surface. Bryophytes, which also occur on the soil surface, are small, non-vascular plants, including mosses and liverworts.

The distribution and species composition of biological soil crusts is influenced by soil chemistry and disturbance. The recovery of biological soil crusts from disturbance depends on factors such as the climatic regime and type of disturbance. Generally, crusts recover slowly in areas with high annual temperature and low annual precipitation, such as Casa Grande Ruins National Monument. Biological soil crusts follow a recovery sequence in which, typically, cyanobacteria first colonize a site, followed by cyanolichens, other lichens, and then moss.

Casa Grande Ruins National Monument is composed primarily of desert shrubland dominated by creosotebush (*Larrea tridentata*). In some areas, these plants are spaced about 2–3 m apart, with no other shrub species present. In other areas, shrubs, such as wolfberry (*Lycium fremontii, Lycium andersonii*), cattle saltbush (*Atriplex polycarpa*), triangle bur ragweed, (*Ambrosia deltoidea*), desertbroom (*Baccharis sarothroides*), or littleleaf ratany (*Krameria erecta*) grow in association with creosote. The ground between shrubs usually appears barren.

Velvet mesquite (*Prosopis velutina*) and barrel cactus (*Ferocactus wislizenii*) are scattered throughout the shrubland, with the barrel cactus usually growing singly and the mesquite frequently in clumps of a few to several individuals. Perennial herbaceous vegetation is notably sparse in the monument, with purple threeawn grass (*Aristida purpurea*) and desert globemallow (*Sphaeralcea ambigua*) found only occasionally.

Resource Issues Overview

Like many places, the Southwest is already experiencing the impacts of climate change. 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 (34 °F) (greatest in winter months) and more than double the number of four-day periods of extreme heat. The western U.S., especially the Southwest, has also experienced 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).

Monahan and Fischelli (2014) evaluated which of 240 NPS parks have experienced extreme climate changes during the last 10-30 years, including Casa Grande Ruins NM. Twenty-five climate variables (i.e., temperature and precipitation) were evaluated to determine which ones were either within <5th percentile or >95th percentile relative to the historical range of variability (HRV) from 1901-2012. Results for Casa Grande Ruins NM were reported as follows:

- Six temperature variables were “extreme warm” (annual mean temperature, maximum temperature of the warmest month, minimum temperature of the coldest month, mean temperature of the driest quarter, mean temperature of the warmest quarter, mean temperature of the coldest quarter).
- No temperature variables were “extreme cold.”
- One precipitation variable was “extreme dry” (precipitation of the driest quarter).
- No precipitation variables were “extreme wet.”

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 4. 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

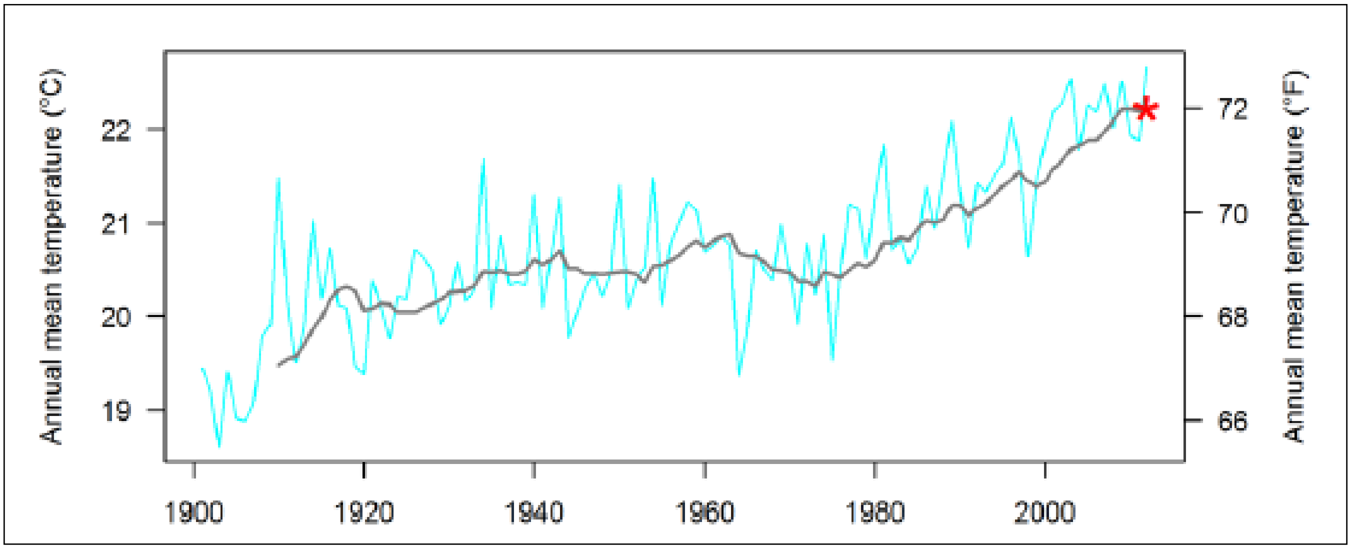


Figure 4. **Time series used to characterize the historical range of variability and most recent percentile for annual mean temperature at Casa Grande Ruins NM (including areas within 30-km [18.6-mi] of the park's boundary). Figure Credit: Monahan and Fisichelli (2014).**

have already begun shifting beyond the HRV, with the 2003-2012 decade representing the warmest on record for the national monument.

Climate predictions are that the Southwest will likely continue to become warmer and drier with climate change (Garfin et al. 2014, Monahan and Fisichelli 2014). Kunkel et al. (2013) estimate that temperatures could rise between 2.5 °C (37 °F) and 4.7 °C (40 °F) for 2070-2099 (based on climate patterns from 1971-1999). Monahan and Fisichelli (2014) state that "climate change will manifest itself not only as changes in average conditions, but also as changes in particular climate events (e.g., more intense storms, floods, or drought). Extreme climate events can cause widespread and fundamental shifts in conditions of park resources."

According to NPS SODN (2018b), additional issues of concern relative to natural resources include "adjacent land use, groundwater depletion, and invasive exotic plants. Conflicts between natural and cultural resources are another issue. Both native and non-native species have damaged and threatened cultural resources at the park since the early 1930s. Even mammals and birds that might not normally be considered pests, such as native round-tailed ground squirrels (*Spermophilus tereticaudus*), threaten archeological structures and sites by burrowing, nesting, feeding, and roosting on or near them." Details pertaining to these and additional resource threats, concerns, and data gaps are included in each Chapter 4 condition assessment.

Resource Stewardship

Management Directives and Planning Guidance

In addition to the NM'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 the SODN, I&M NPScape Program for landscape-scale measures, Air Resources Division for air quality, and the Natural Sounds and Night Skies Program for the soundscape and night sky assessments.

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. Casa Grande Ruins NM is part of the SODN, which includes 10 additional parks. Through a rigorous multi-year, interdisciplinary scoping process, SODN 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 to help managers "make sound decisions about the future (NPS SODN 2017).

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 5).

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 Casa Grande Ruins NM in 2017 (NPS 2017a) and was used to identify some of

Figure 5. **The relationship of NRCAs to other National Park Service planning reports.**

the primary natural features throughout the park for the development of its NRCA.

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 each Chapter 4 assessment includes a SotP condition summary, with an overall summary by topic presented in Chapter 5.

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 park staff. After each indicator is chosen, a target value is determined and the current condition is compared to the desired condition. An RSS has not been completed for the national monument.

Status of Supporting Science

Available data and reports varied depending upon the resource topic. The existing data used to assess the condition of each indicator and/or to develop reference conditions are described in each of the Chapter 4 assessments in this report.

Field tour at Casa Grande Ruins National Monument during the NRCA scoping meeting. Photo Credit: NPS.

Study Scoping and Design

The Natural Resource Condition Assessment (NRCA) for Casa Grande Ruins National Monument (NM) was coordinated by the National Park Service (NPS) Intermountain Region Office (IMRO), Utah State University (USU), and the Colorado Plateau Cooperative Ecosystem Studies Unit through task agreement, P17AC00796. The NRCA scoping process was a collaborative effort between the staffs of Casa Grande Ruins NM, NPS Sonoran Desert Inventory and Monitoring Network (SODN), the NPS IMRO NRCA Coordinator, and USU's NRCA team.

Preliminary scoping for Casa Grande Ruins NM's NRCA began on January 10, 2018 with a conference call. Prior to the call, USU staff reviewed the monument's foundation document (NPS 2017a) and website (NPS 2018a), SODN's website (NPS SODN 2018b), and the NPS integrated resource management applications (IRMA portal; NPS 2018b). Additionally, the NPS Natural Resource Stewardship and Science Directorate (NRSS) divisions provided data for night sky, soundscape, air quality, geology, and climate change topics (NPS NRSS 2018).

Based on the information gathered, a preliminary list of potential focal resources for the monument's NRCA was developed and discussed during the January conference call. Casa Grande Ruins NM's conference call participants, Archeologist/Chief of Resource Stewardship & Facilities Management, Alycia Hayes, SODN Program Manager, Andy Hubbard, and Southern Arizona Office Hydrologist, Kara Raymond, discussed and refined the list of resources, and identified additional reports and datasets.

After the call, USU NRCA writers reviewed reports and datasets to determine a logical study plan of the prioritized resources. USU writers then developed the Phase I draft indicators, measures, and reference condition tables for the nine preliminary focal resources selected by monument staff, reflecting the proposed NRCA study plan. Note that non-native invasive plants were used as an indicator and measures to evaluate the condition of vegetation instead of addressing non-native plants as a stand-alone topic. The draft Phase I tables served as the primary discussion guide during Casa Grande Ruins NM's on-site NRCA scoping workshop.

The monument's NRCA workshop and field outing was held over a two day period from May 8-9, 2018 at the park (a list of meeting participants is included in Appendix A). During the workshop, meeting participants reviewed, discussed, and refined the Phase I tables, which formed the basis of USU's study plan for the monument's NRCA report. Additional datasets and reports were further identified and gathered for the selected focal resources. Monument staff also identified threats, issues, and data gaps for each natural resource topic, which are discussed in each of the nine Chapter 4 condition assessments.

Study Design

Indicator Framework, Focal Study Resources and Indicators

An NRCA report represents a unique assessment of key natural resource topics for each park. Casa Grande Ruins NM's NRCA focal resources, indicators, and measures are listed in Tables 1 – 4. The associated threats for each topic are listed in Table 5. Due to USU's timeline and budget constraints, this list of resources *does not* include every natural resource of interest to monument staff, rather the list is comprised of the natural resources and processes that were of greatest interest/concern to monument staff at the time of this effort.

Table 1. Casa Grande Ruins 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
	Scenic and Historic Integrity	Conservation Status
Night Sky	Sky Brightness	All-sky Light Pollution Ratio (ALR)
	Sky Brightness	Vertical Maximum Illuminance (milli-Lux)
	Sky Brightness	Horizontal Illuminance (milli-Lux)
	Sky Brightness	Zenith Sky Brightness (msa)
	Sky Quality	Bortle Dark Sky Class
Soundscape	Sound Level	% Time Above Reference Sound Levels
	Sound Level	% Reduction in Listening Area
	Geospatial Model	L_{50} Impact

Table 2. Casa Grande Ruins 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
	Level of Ozone	Human Health
	Level of Ozone	Vegetation Health
	Wet Deposition	Nitrogen
	Wet Deposition	Sulfur
	Wet Deposition	Mercury and Predicted Methylmercury Concentration

Table 3. Casa Grande Ruins NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for water.

Resource	Indicator	Measure
Ground-water	Water Level	Depth to Groundwater (m)

The selected natural resources were grouped using the NPS Inventory & Monitoring (I&M) Program's "NPS Ecological Monitoring Framework" (NPS 2005), which is endorsed by the Washington Office NRCA Program as an appropriate framework for listing resource components, indicators/measures, and resource conditions. Additionally, SODN's Vital Signs Plan (Mau-Crimmins et al. 2005), and the RM-77 NPS Natural Resource Management Guideline (NPS 2004) are all organized similarly to the I&M framework.

Reporting Areas

The primary focus of the condition assessment reporting area was within Casa Grande Ruins NM's legislative boundary; however, some of the data and analyses encompassed areas beyond its boundary. Natural resources assessed at the landscape level included viewshed, night sky, soundscape, and air quality.

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 assistance in condition reporting. Following the NPS NRCA guidelines (NPS 2010a), each Chapter 4 condition assessment includes five sections (listed

Table 4. Casa Grande Ruins NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for biological integrity.

Resource	Indicators	Measures
Upland Vegetation and Soils	Erosion Hazard	Bare Ground Cover (%)
	Erosion Hazard	Soil Aggregate Stability (Class)
	Erosion Features	Extent of Affected Area by Feature Type (%)
	Plant Community Resistance and Resilience	Foliar Cover Dead Plants in the Field Layer (%)
	Plant Community Resistance and Resilience	Foliar Cover of Dead Plants in the Subcanopy (%)
	Saguaro Cacti Occupancy	Nurse Plant Cover (%)
	Fire Regime	Herbaceous Cover (%)
	Non-native Plant Dispersal and Invasion	New Species Detections
	Non-native Plant Dispersal and Invasion	Species New to a Plot
	Non-native Plant Dispersal and Invasion	Total Cover (%)
	Non-native Plant Dispersal and Invasion	Buffelgrass Cover (%)
	Non-native Plant Dispersal and Invasion	Red Brome Cover (%)
Soil Crusts	Mature Biological Soil Crust	Cover
	Physical Soil Crust	Cover
Birds	Species Occurrence	Presence/Absence
	Species Occurrence	Presence of Species of Concern
	Burrowing Owl	Abundance /Population Density
	Burrowing Owl	Reproductive Success
Mammals	Species Occurrence	Presence/Absence
	Species Occurrence	Nuisance Species Presence
	Species Occurrence	Conservation Concern
	Nuisance Species Occurrence	ASMIS Impact Score
	Nuisance Species Occurrence	Presence/Absence of Active Burrows

below), with a condensed literature cited section included at the end of the full report.

1. The background and importance section of each condition assessment provides information regarding the relevance of the resource to the national monument.
2. The data and methods section describe the existing datasets and methodologies used for evaluating the indicators/measures for current conditions.
3. The reference conditions section describe the good, moderate concern, and significant concern definitions used to evaluate the condition of each measure.
4. The condition and trend section provides a discussion for each indicator/measure based on the reference condition(s). Condition icons are presented in a standard format consistent with State of the Park reporting (NPS 2012b) and served as visual representations of condition/trend/level of confidence for each measure. Table 6 shows the condition/trend/confidence level scorecard used to describe the condition for each assessment, Table 7 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 concern; 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 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 to 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.

Table 5. **Resource condition assessment topic threats and stressors.**

Resource	Threat/Stressor
Viewshed	Cell towers and radio/television towers and planned housing developments Increased height of canal berm Air quality Potential development along periphery, especially to the west Existing development Traffic control devices at entrance gate Increased population growth (fastest growing county in Arizona)
Night Sky	Air quality Lights from surrounding development Traffic light to be installed at entrance to monument Encroaching lights from nearby communities as well as larger, more distant cities such as Phoenix Road traffic
Soundscape	Surrounding development Overflights Traffic
Air Quality	Air pollution from vehicle exhaust, agriculture, general dust, and dust from haboob dust storms Pesticide use in bordering agricultural fields Pinal County has some of the poorest air quality in the state Climate change
Groundwater	Local and regional climate change Subsidence Persistent region-wide drought since 2000s Reduced flows in Gila River
Vegetation and Soils	Isolated patch of desert vegetation surrounded by intensively altered land (e.g., agricultural, residential, and commercial development) which may inhibit dispersal of native vegetation Long-term decline in water table Climate change (reduced water availability, increase in temperature) Non-native plants, especially introductions from weedy agricultural fields and other developed land bordering the monument, including roads and irrigation canals Non-native plant control pesticide drift from nearby fields may impact non-target vegetation in the monument Air pollution from vehicle exhaust, agriculture, dust Likely that the clay pan no longer exists Groundwater is inaccessible to plant roots Persistent region-wide drought since 2000s
Soil Crusts	Trampling by humans Dust storms and deposition of agricultural dust
Birds	Non-native species Climate change
Mammals	Adjacent development resulting in fragmentation Feral/free-roaming dogs and cats Impacts to cultural resources from burrowing mammals Lack of predators, especially medium carnivores

Table 6. 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.				

Table 7. 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.

5. The sources of expertise list the individuals who were consulted. Assessment author(s) are also listed in this section for each condition assessment.

After the report is published, a disk containing a digital copy of the published report, copies of the literature cited (with exceptions listed in a READ ME document), original GigaPan viewshed images, reviewer comments and writer responses if comments weren't included, and any unique GIS datasets created for the purposes of the NRCA is sent to Casa Grande Ruins NM staff and the NPS IMRO NRCA Coordinator.

Gilded flicker in saguaro cactus cavity. Photo Credit: NPS.

Natural Resource Conditions

Chapter 4 delivers current condition reporting for the nine important natural resources and indicators selected for Casa Grande Ruins National Monument'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.

Viewshed

Background and Importance

The conservation of scenery was 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 (2006) 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 strives 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.

Viewsheds are considered an important part of the visitor experience at Casa Grande Ruins National Monument (NM), and features on the visible landscape influence a visitor's enjoyment, appreciation, and understanding of the area's significance (NPS 2017a). Much of the landscape surrounding Casa Grande Ruins NM is developed (NPS 2017a). The more distant views remain, but the monument's location within an urban setting impacts the viewshed and the night sky environments, both of which are of cultural significance to the Ancestral Sonoran Desert People (NPS 2017a). Within the monument's boundaries, however, visitors are provided opportunities to literally "visualize" their connection to the area's previous inhabitants. The monument contains important cultural features of the Hohokam, including the Great House, Ball Court, and even smaller objects such as pottery fragments (NPS 2017a). The views offered at Casa Grande Ruins NM represent much more than just scenery; they represent a way to better understand the connection between the past and the present. 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.

Data and Methods

The indicator (scenic and cultural integrity) and measures (conspicuousness of non-contributing features, extent of development, and conservation status) used for assessing the condition of Casa Grande Ruins NM's viewshed were based on studies related to perceptions people hold toward various features and attributes of scenic landscapes. The scenic and cultural integrity indicator is defined as the state of naturalness or, conversely, the state of disturbance created by

Viewshed at Casa Grande Ruins NM. Photo Credit: © K. Struthers.

modern 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. In general, there has been 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, modern 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. Visitor preferences can be influenced by a variety of factors including cultural and historical 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 were perceived more positively when they were 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, fine scale features, and vegetative screening. These characteristics, along with distance from non-contributing features, and movement and noise associated with observable features on the landscape, are discussed below.

Three key observation points were selected by Casa Grande Ruins NM staff and were chosen based on viewsheds that are accessible to the public, are located upon a prominent landscape feature, and are inclusive of cultural resources, natural resources, and scenic views (Figure 6). We used panoramic images collected at these three locations in addition to geographic information system (GIS) analyses of modeled visible areas overlaid with housing density, road density, and land management datasets to evaluate viewshed conditions from the monument.

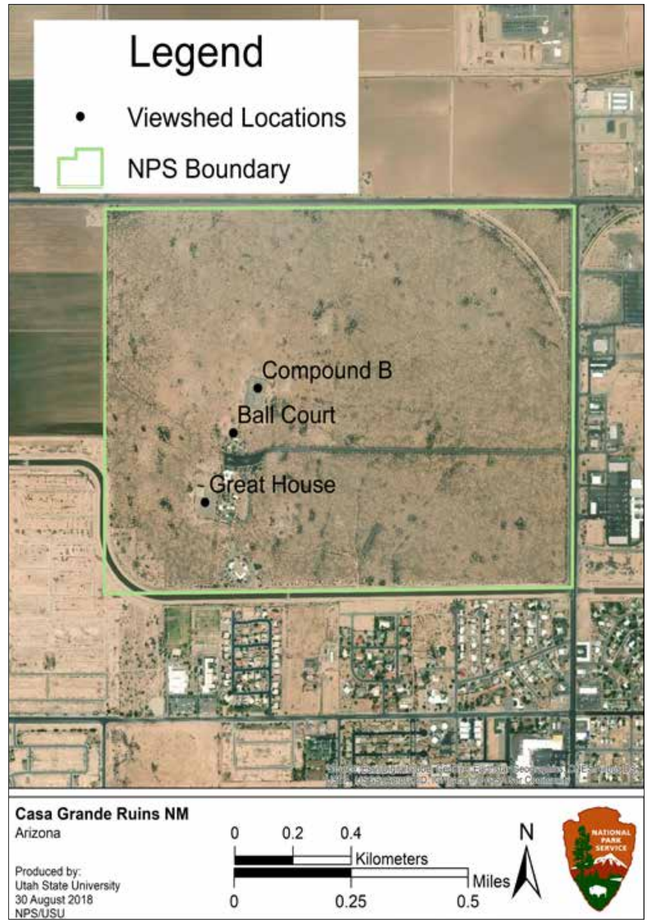


Figure 6. Viewshed locations.

The first measure is the conspicuousness of non-contributing features, which was evaluated using high-quality panoramic photos of the three key observation points. Photos were taken on 23 May 2018 with a Canon PowerShot digital camera mounted to a GigaPan Epic 100 system. At each location, a set of photos was collected from the four cardinal directions (i.e., north to east, east to south, south to west, and west to north). The images for each direction were then stitched together into a single high-resolution panoramic image using GigaPan Stitch software. These photos portray the viewshed from an observer's perspective and provide a means of assessing the non-contributing features on the landscape. Non-contributing features were qualitatively evaluated based on groups of characteristics of human-made features, the first of which is distance to objects in the viewshed.

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. For this assessment, we have used the distance classes that have been recently used by the NPS:

- *Foreground* = 0-0.8 km (0-0.5 mi) from key observation point
- *Middle ground* = 0.8-5 km (0.5-3 mi) from key observation point
- *Background* = 5-97 km (3-60 mi) from key observation point.

Over time, different agencies have adopted minor variations in the specific distances used 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.

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

We considered the features on the landscape surrounding Casa Grande Ruins NM as belonging to one of six size classes (Table 8), 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 is the third characteristic we considered in this assessment. 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 (Figure 7). 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 was consistent with the findings of Kearney et al. (2008) who found that darker color was one of the factors contributing

Table 8. 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

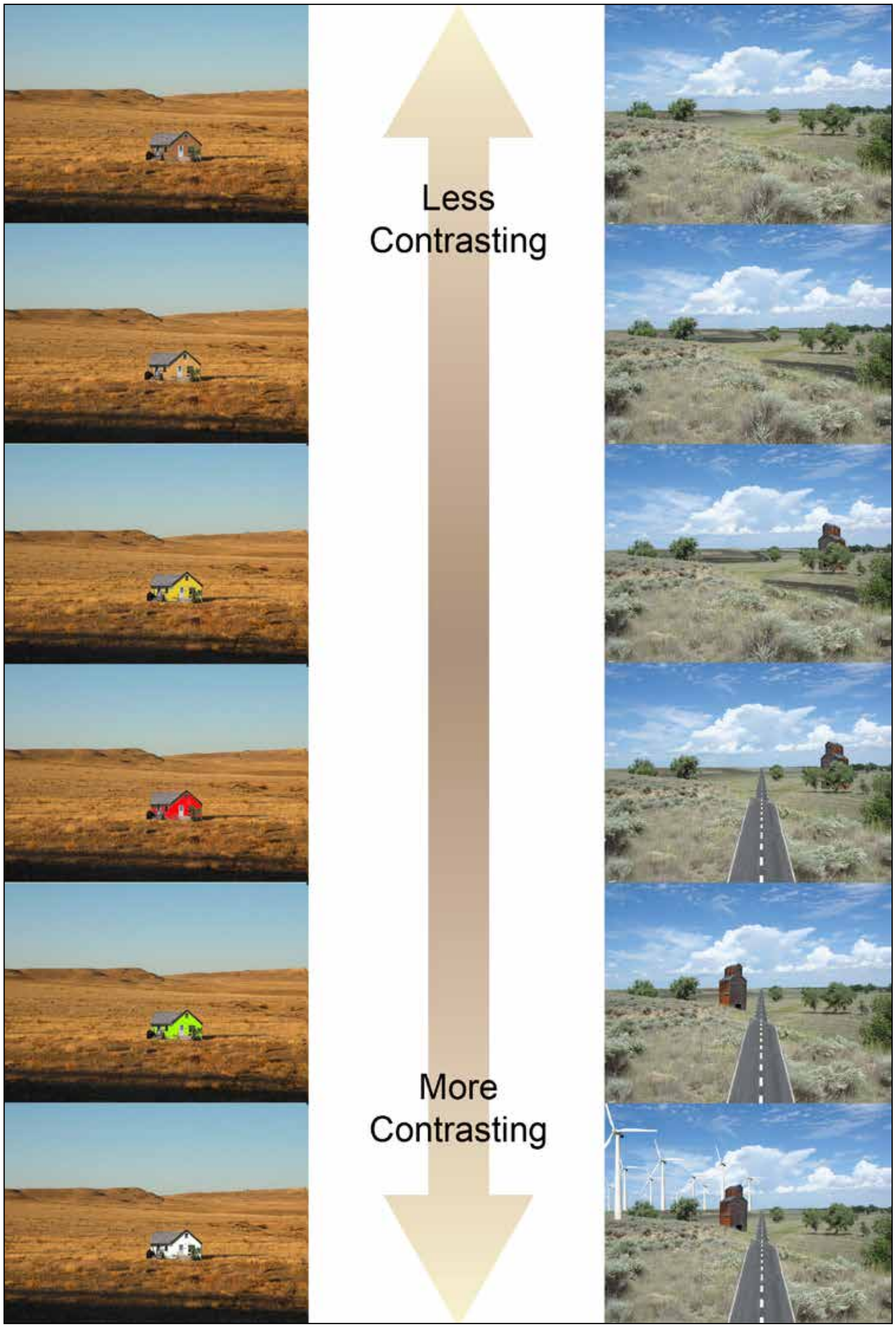


Figure 7. Graphic illustration of how color (left) and shape (right) can influence whether features were in harmony with the environment, or were in contrast.

to a feature blending in with its environment and therefore preferred.

Some research indicates 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 influence how they are perceived (Ribe 2005). The Visual Resource Management Program of the Bureau of Land Management (BLM 2016), for example, places considerable focus on design techniques that minimize visual conflicts with features such as roads and power lines 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.

Lastly, noise and movement can both influence how a landscape is perceived, particularly by attracting attention to a particular area of a viewshed (Hetherington et al. 1993). 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).

In summary, these four characteristics do not act independently with respect to their influence on the conspicuousness of features; rather, they tend to have a hierarchical effect (Figure 8). 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 characteristics.

The second component of the conspicuousness of non-contributing features included a geographic

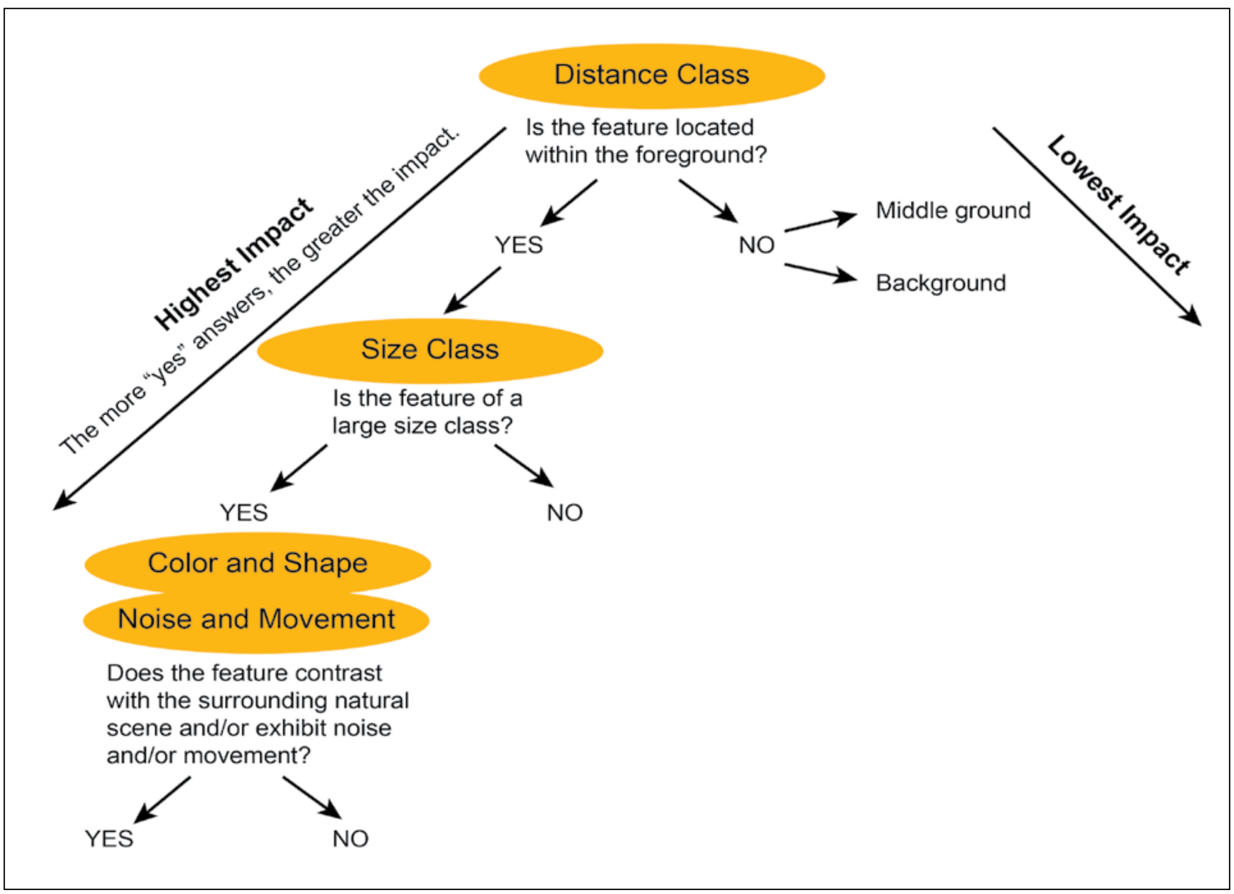


Figure 8. Conceptual framework for hierarchical relationship of characteristics that influence the conspicuousness of features within a viewshed.

information system (GIS) analysis of the visible and non-visible areas from each of the three key observation points. Viewshed analyses were conducted using ArcGIS's Spatial Analyst Viewshed tool. We identified the viewshed area of analysis (AOA) as a 98 km (61 mi) area surrounding each of the observation points. The viewshed analyses were calculated for this area since it represents the distance to which the average observer may distinguish manmade features depending on the abovementioned characteristics (USFS 1995). We used the USGS's National Elevation Datasets (NED) at 1/3 arc-second resolution (approximately 10 m/32.8 ft resolution) to determine which areas should be visible from each observation point based on elevation within the AOA (USGS 2018). The viewshed analysis for each location was used to support the GigaPan images described for the previous measure. The three AOAs were then combined to create a composite viewshed. Composite viewsheds are a way to show multiple viewsheds as one, providing an overview of the visible/non-visible areas across all observation points. The analysis assumes 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 B. The composite viewshed was used to support the following two measures (i.e., extent of development and conservation status).

The extent of development provides a measure of the degree to which the viewshed was 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 considered two key factors in extent of development: road density and housing density.

Data for these two factors were derived from NPScape—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 2016, Monahan et al. 2012). NPScape data include seven major categories (measures), three of which were used in the viewshed condition assessment: housing (NPS 2014a), roads (NPS 2014b), and conservation status (NPS 2014c). These metrics were used to evaluate resource conditions from a landscape-scale perspective and to provide information pertaining to threats and conservation opportunities related to scenic views surrounding Casa Grande Ruins NM (NPS 2016). NPScape data are consistent, standardized, and collected in a repeatable fashion over time, and yet were flexible enough to provide analyses at many spatial and temporal scales. The NPScape datasets used in this analysis were described in the sections that follow.

The U.S. Census Bureau's TIGER/Line (Topologically Integrated Geographic Encoding and Referencing) shapefiles (U.S. Census Bureau 2017) were used to calculate the road density within the monument's AOA. TIGER/Line products were last updated 1 January 2017 (U.S. Census Bureau 2017). We downloaded the All Roads shapefile, which includes primary, secondary, local neighborhood roads, rural roads, city streets, and vehicular trails (4WD) (U.S. Census Bureau 2017). New road density rasters, feature classes, and statistics were generated from these data. Finally, the road density output was overlaid with the composite viewshed from the three key observation locations in order to visualize density within the monument's viewshed.

The NPScape 2010 housing density metrics were 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 were grouped into six classes as shown in Table 9. 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. The 2010 output was overlaid with the composite viewshed from the three key observation locations in order to visualize housing

Table 9. Housing density classes.

Grouped Housing Density Class	Housing Density Class (units / km^2)
Urban-Regional Park	Urban-Regional Park
Commercial / Industrial	Commercial / Industrial
Urban	>1,235
Suburban	146-1,234
Exurban	7-145
Rural and Private Undeveloped	0-6

density within the monument's viewshed. Using the output from this analysis, we also calculated the percent change in housing density from 1970 to 2010 using ArcGIS Spatial Analyst's Raster Calculator tool.

The last measure we used was the conservation status of lands surrounding the monument. 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 the NPS boundary), as well as opportunities (e.g., connectivity and networking of protected areas)." The USGS's GAP Analysis Program's Protected Area Database (PAD) provides GIS data on public land ownership and conservation lands in the U.S. (USGS GAP 2016). The lands included in the PAD were assigned one of four GAP Status codes based on the degree of protection and management mandates. Casa Grande Ruins NM is considered GAP Status 1, which is described as follows, along with the remaining three categories:

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 2012).

NPScape's conservation status toolset was used to clip the PAD-US version 1.4 (USGS GAP 2016) to the monument's AOA, and then to recalculate the GAP Status and broad land ownership categories (e.g., federal, state, tribal, etc.) within the AOA (NPS 2014c). Finally, the conservation status output was overlaid with the composite viewshed from the three key observation locations in order to determine which GAP Status lands and lands by agency were most likely to be visible from the monument.

Reference Conditions

We used qualitative reference conditions to assess the scenic and cultural integrity of Casa Grande Ruins NM's viewshed, which are presented in Table 10. Measures are described for resources in good condition, moderate concern condition, or significant concern condition.

Condition and Trend

The GIS viewshed analysis for each of the three key observation points is shown in Figure 9. The viewshed was virtually identical from all three locations. This is because of the monument's small size, proximity of the three locations to one another, and the relatively flat topography of the landscape within the AOA. The viewshed includes much of the foreground (not shown due to scale), the middle ground, and some of the background in all directions.

Below, we qualitatively assessed whether the GIS analyses for each of the three key observation locations

Table 10. Reference conditions used to assess viewshed.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Scenic and Cultural Integrity	Conspicuousness of Non-contributing Features	The distance, size, color and shape, and movement and noise of the non-contributing features blended into the landscape.	The distance, size, color and shape, and movement and noise of some of the non-contributing features were conspicuous and detracted from the natural and cultural aspects of the landscape.	The distance, size, color and shape, and movement and noise of the non-contributing features dominated the landscape and significantly detracted from the natural and cultural aspects of the landscape.
	Extent of Development	Road and housing densities were low, with minor to no intrusion on the viewshed.	Road and housing densities were moderate, with some intrusion on the viewshed.	Road and housing densities were high with significant intrusion on the viewshed.
	Conservation Status	Scenic conservation status was high. The majority of land area in the monument's viewshed was considered GAP Status 1 or 2.	Scenic conservation status was moderate. The majority of land area in the monument's viewshed was considered GAP Status 3.	Scenic conservation status was low. The majority of land area in the monument's viewshed was considered GAP Status 4.

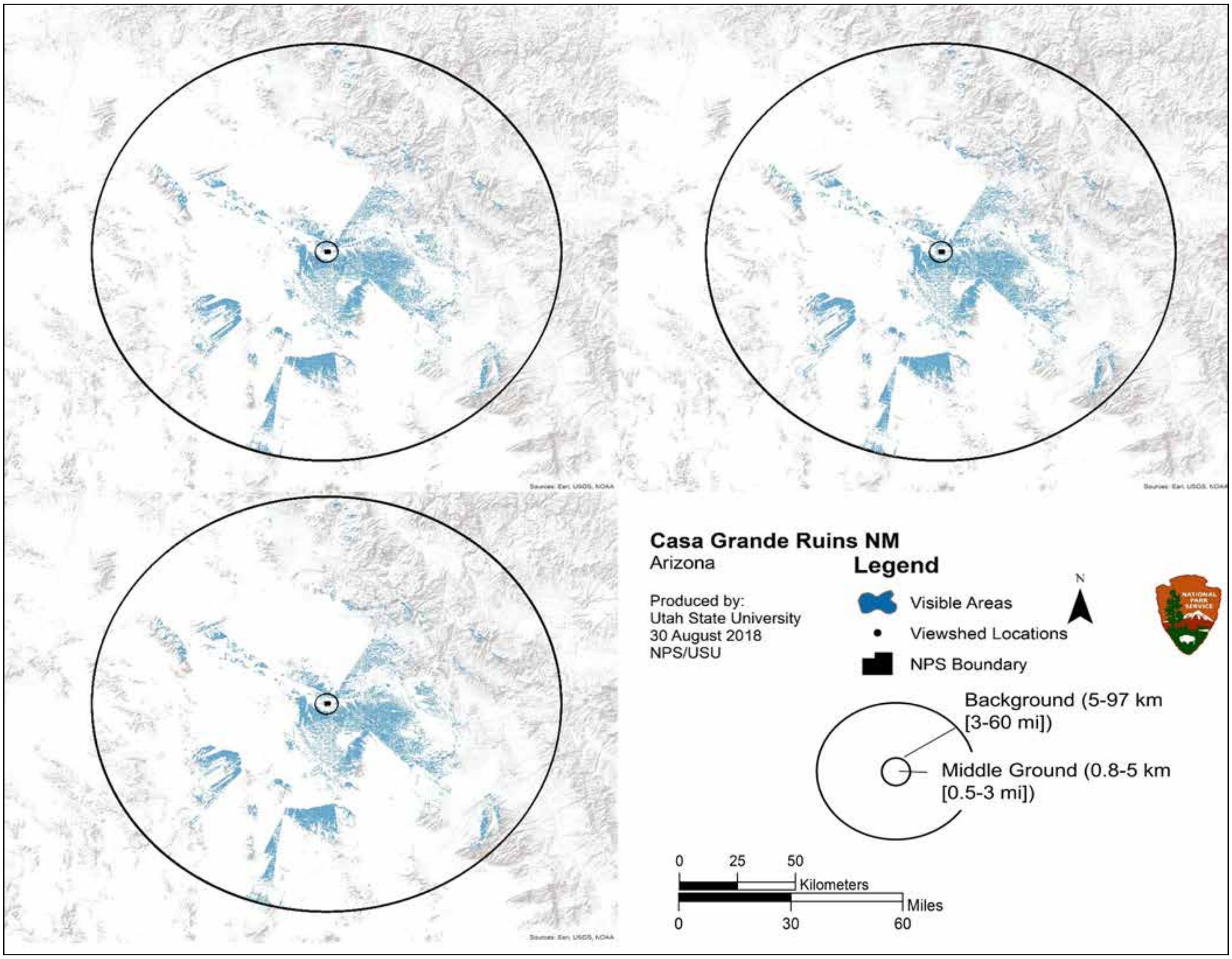


Figure 9. The viewshed analysis from each of the three key observation locations.

shown in Figure 9 agree with the panoramic images. We also describe non-contributing features in each set of panoramas beginning with Compound B.

The stitched GigaPan images for the Compound B key observation location are shown in Figures 10 and 11. The panoramas were taken from atop a platform mound that was originally constructed by the Hohokam more than 900 years ago (NPS 2017c). The Hohokam then constructed plazas atop the 3-m (10-ft) tall base platform (NPS 2017c). Due to extensive erosion and deterioration of the cultural features at this location, the plaza has been backfilled with sand and gravel to protect the remaining features. Thus, the mounds are about 1 m (5 ft) taller today than they were historically. Although the mounds are taller, they still offer views similar to what the Hohokam people would have experienced. Today, public access is limited to guided tours because of the sensitive cultural features present at this location.

From north to east and east to south (Figure 10) the monument is visible out to approximately 0.5-1.0 km (0.3-0.7 mi). Vegetation in the foreground is dominated by creosotebush (*Larrea tridentata*). While creosotebush is native, the plant community of the monument has shifted to more drought-tolerant species as the water table has dropped (Buckley et al. 2009). Beyond the monument and in the middle ground are numerous urban structures in the city of Coolidge, Arizona in which the monument is located. Visible non-contributing features include buildings and power lines and poles. Most conspicuous is the San Carlos Irrigation Project, an electric utility company located northeast of the monument. In the background, peaks in San Tan Mountain Regional Park are visible with the Superstition Mountain range

Figure 10. **The north to east (top) and east to south (bottom) viewshed from Compound B.**

Figure 11. **The south to west (top) and west to north (bottom) viewshed from Compound B.**

The Florence stage coach at the south side of Casa Grande between 1888-1899 (CG-5030). Photo Credit: NPS.

at the farthest extent of the viewshed. Similar views are offered from south to west and west to north (Figure 11) except that the Great House, visitor center, parking area, picnic area, and other NPS structures are visible in the foreground. Some of these structures are historic, including the protective structure over the Great House, the Great House itself, and the visitor center, which is barely visible through the trees (NPS 2018c). The picnic area and associated structures, such as railings and retaining walls are not considered historic. The Sacaton Mountains are visible in the distance to the west.

The viewshed from the Ball Court from north to east (Figure 12) is similar to the viewshed from Compound B. Creosotebush is dominant in the foreground with an ocotillo (*Fouquieria splendens*) in the forefront of the image. Peaks in the San Tan Mountain Regional Park are visible with the Superstition Mountains in the background. Compound B is also visible from this location. Because this viewpoint is lower than Compound B, fewer modern structures in the middle ground outside the monument are visible, although the roofs of some buildings are obvious because of their shape and color. Power poles are also obvious as is the San Carlos Irrigation Project.

From the east to south, large trees block the distant views (Figure 12). The trees and shrubs around the visitor center were planted and include blue paloverde (*Parkinsonia florida*), velvet mesquite (*Prosopis velutina*), Sonoran paloverde (*Parkinsonia praecox*), desert willow (*Chilopsis linearis*), desert

Figure 12. The north to east (top) and east to south (bottom) viewshed from the Ball Court.

ironwood (*Olneya tesota*), and littleleaf false tamarind (*Lysiloma watsonii*) (Buckley et al. 2009). All of these planted species are native to Arizona according to the U.S. Department of Agriculture's (USDA) PLANTS database (USDA PLANTS 2018) and **Buckley et al. (2009)**. The panorama also includes non-contributing features such as the picnic area, including shade shelters, a walkway, railings, and interpretive signs. While none of these features are considered historic, their presence helps visitors enjoy and learn about the monument.

From south to west, the Great House is visible with sparse vegetation cover (Figure 13). From west to north the viewshed includes the cultural Ball Court, which is the depression visible in the foreground. The Ball Court served as a community sports center for the Hohokam more than 1,000 years ago (NPS 2017d). The Sacaton Mountains are visible in the background in addition to numerous power poles.

Figure 14 shows the Great House, an interpretive sign, cultural features of Compound A, and the visitor center in the north to east viewshed. Few non-contributing features are visible in this direction because the middle ground, where most of the non-contributing features are located, is obscured by vegetation and structures within the monument. A few power poles are visible, however. The more distant San Tan Mountain Regional Park and the Superstition Mountains are also visible. From east to south, the administration building, which was historically the superintendent's residence and the first administration building constructed in the monument, is visible. The structure is considered of local significance as are the maintenance structures visible to the south (NPS 2018c). Non-contributing features include a carport, power poles and lines.

From south to north, the viewshed includes the contributing features of Compound A and parts of the historic protective structure over the Great House (Figure 15). In addition, non-contributing features, such as an interpretive sign and pathways are visible in the foreground. The foreground also includes vegetation within the monument, power poles and lines in the middle ground, and the Sacaton Mountains in the background.

In summary, the GIS viewshed analysis, which did not account for vegetation or man-made structures, shows that there are distant views surrounding the monument in all directions. Some views extend at least 60 miles.

Figure 13. The south to west (top) and west to north (bottom) viewshed from the Ball Court.

Figure 14. The north to east (top) and east to south (bottom) viewshed from the Great House.

Figure 15. The south to west (top) and west to north (bottom) viewshed from the Great House.

This is supported by the panoramic images, which show distant mountain ranges in all photos. However, the panoramas also show a significant number of non-contributing features that detract from the overall viewshed. These features were almost exclusively located in the middle ground, reflecting the extensive development surrounding the monument. As a result, the conspicuousness of non-contributing features is of significant concern. Confidence is high. Since these panoramas are baseline images, trend is unknown.

The second measure, extent of development, was evaluated using road density and housing density. Figure 16 shows road density by various classes. Total road density within the 98 km (61 mi) AOA surrounding the monument was 2.0 km/km^2. Road density within the monument's viewshed was relatively high. The high road density in the AOA suggests that roads have the potential to detract from the monument's viewshed, but the panoramic images contain few roads. This is probably because of the flat landscape of the monument and surrounding region and features located in the foreground that block views of roads.

Based on data compiled in NPScape (Monahan et al. 2012), housing densities surrounding the monument were low (Table 11). The majority of all housing consisted of rural and private undeveloped lands (70%). The white spaces within the 98 km (61 mi) boundary shown in Figure 17 indicate no census data; thus, housing densities could not be calculated for these areas. However, these data originated with the U.S. Census Bureau, and units with unknown densities were probably not reported, which likely indicates undeveloped areas. Most of the monument's viewshed was located within these white spaces and in rural and private undeveloped areas. From 1970 to 2010, 55% of the AOA showed no change in housing density, while approximately 45% of the AOA showed an increase in

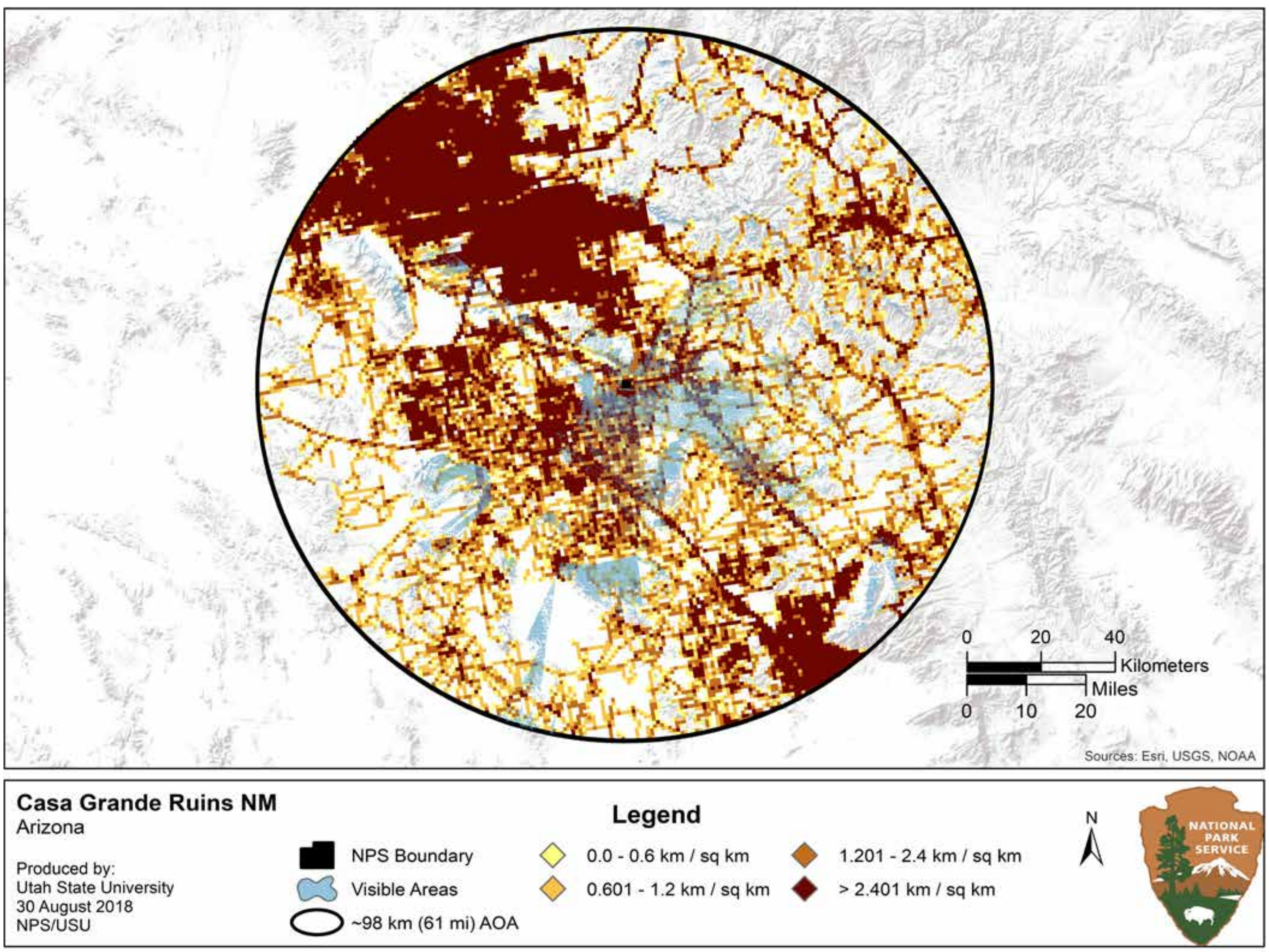


Figure 16. **Road density and visible areas in and around Casa Grande Ruins NM.**

Table 11. Housing densities within a 98 km (61 mi) buffer around Casa Grande Ruins NM.

Density Class	Area (km^2)	Percent
Rural and Private Undeveloped	10,797	70
Exurban	1,846	12
Suburban	1,184	8
Urban	84	<1
Urban-Regional Park	591	4
Commercial/Industrial	982	6
Total Area	15,454	100

housing density. Less than 1% of the AOA declined in housing density.

To summarize the extent of development measure, road density was high and areas of high road density should be visible according to the viewshed analysis. Housing density was mostly rural or private undeveloped, including in the viewshed analysis. The panoramas, however, show the opposite (few roads and high development). The discrepancy is likely because an elevation raster was used as the only input in the viewshed analysis. For this relatively flat landscape, housing and vegetation play a greater role in determining which areas are visible. Nevertheless, the data from this analysis warrant moderate concern, but confidence is medium. Trend in housing density, which is related to road density, increased in 45% of the AOA. Therefore, trend is deteriorating.

The following summarizes the condition for the third and final measure—conservation status. Figure 18 shows the amount of land within the composite viewshed and AOA. Of the total AOA, 90% was categorized in one of the four GAP status classes. Approximately 82% of land area within the AOA was within GAP Status 4 (42%) (no known protections) and GAP Status 3 (40%) (permanently protected lands managed for multiple uses. Only 8% of land within the AOA was GAP Status 1 (permanently protected lands managed for biodiversity and natural processes) or GAP Status 2 (permanently protected lands managed for biodiversity but with suppression of disturbances).

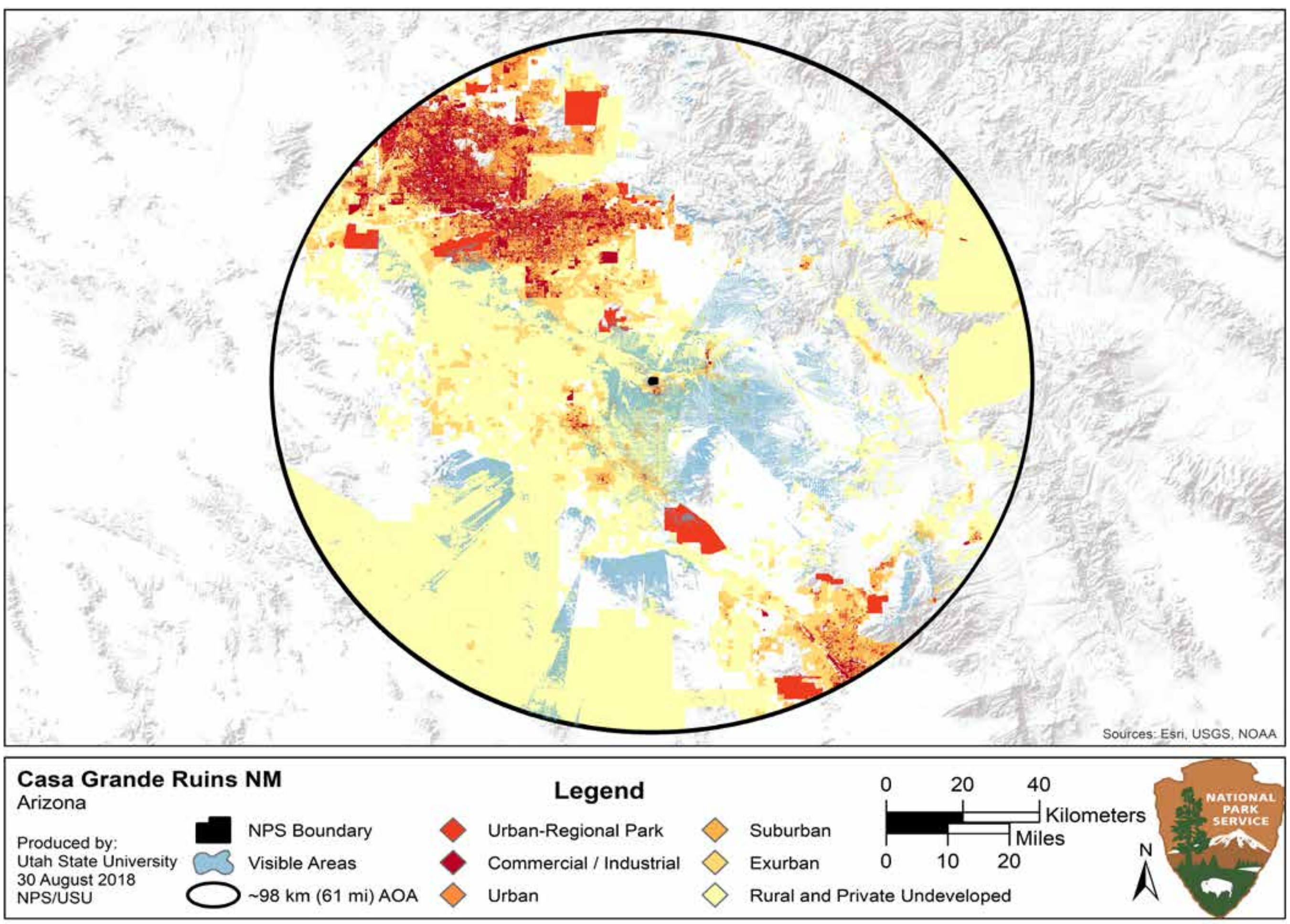


Figure 17. Housing density within and around Casa Grande Ruins NM.

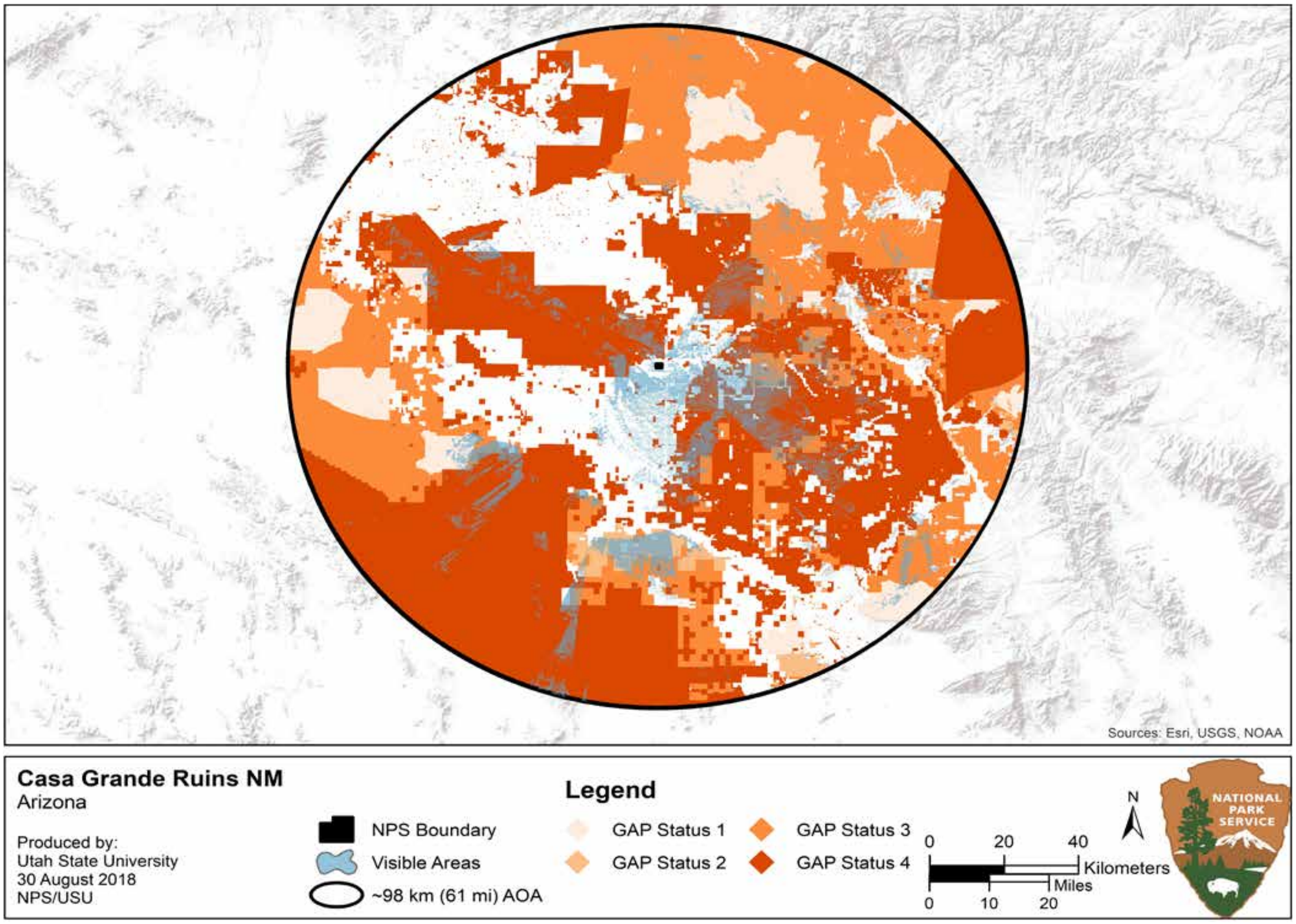


Figure 18. **GAP status lands within and around Casa Grande Ruins NM.**

The remaining 10% of land was not classified in any of the GAP status categories, which indicates private land. Casa Grande Ruins NM's viewshed is primarily within private lands, and GAP Status 3 and 4 lands.

Figure 19 shows the management agencies that administer land within the AOA. The BLM administers the largest land area within the AOA (25%), followed by the Bureau of Indian Affairs (BIA) (22%), and the U.S. Forest Service (21%). Most of the remaining lands (~22%) classified within the AOA are state, county, or city lands. The white spaces indicate private lands. Areas visible from the monument were located largely within city, BIA, and BLM lands.

Overall, there are few areas where scenic conservation status is high. Many of the land management agencies responsible for the lands that were visible from the three observation locations were within GAP Status 3-4. Therefore, we consider conservation status to be of significant concern. Trend is unknown. Although confidence in the GAP Status and land management agency data is high, the viewshed analysis has medium confidence. A finer scale DEM coupled with an offset to account for vegetation height and structures would possibly increase accuracy.

Casa Grande visitor center circa 1934 (CG-0466). Photo Credit: NPS.

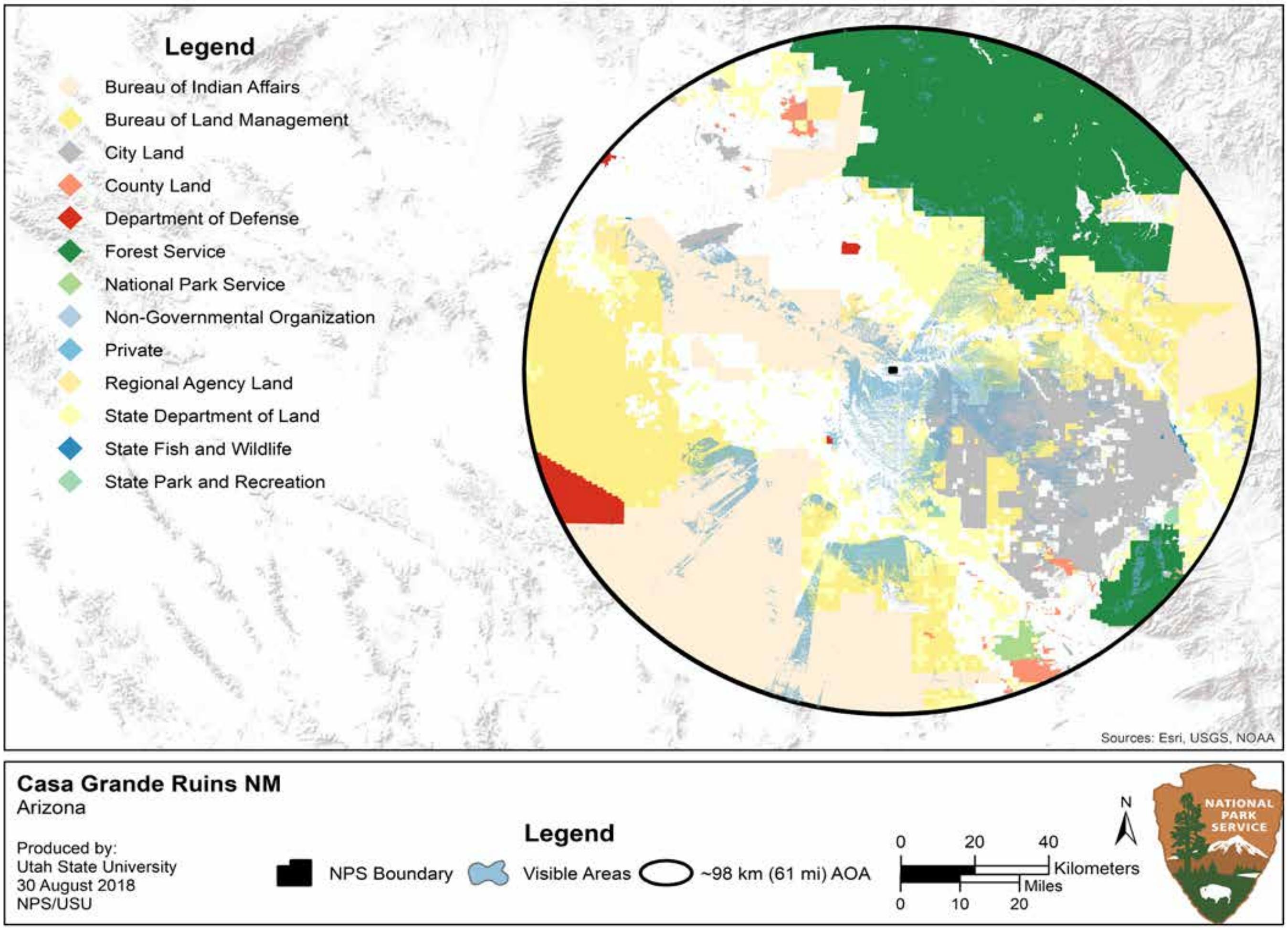


Figure 19. **Lands managed by various agencies within and around Casa Grande Ruins NM.**

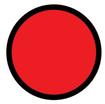
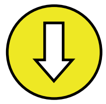
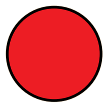
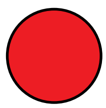
Overall Condition, Threats, and Data Gaps

Based on this assessment, the viewshed condition at Casa Grande Ruins NM is of significant concern (Table 12). There were many non-contributing features in the monument's viewshed, mostly in the middle ground, as observed from the three key observation locations. Because this assessment represents baseline conditions, we could not report on trend. Two of the three measures were assigned medium confidence and one was assigned high confidence. Factors that influence confidence level include age of the data (<5 years unless the data were part of a long-term monitoring effort), repeatability, field data versus modeled data, and whether data can be extrapolated to other areas in the monument. We assigned medium confidence to extent of development and conservation status measures because the viewshed analysis was based entirely on modeled data with a relatively coarse resolution DEM and did not account for vegetation or other factors that may have influenced the viewshed analysis. Thus, the overall confidence is medium. The viewshed analysis should not be used for planning purposes until ground-truthed.

Potential threats to Casa Grande Ruins NM's viewshed include development within the AOA, increased air and vehicle traffic, and atmospheric dust and smog as a result of climate change (NPS 2017a). The haze index, which is a measure of visibility as described in the air quality assessment in this report, warrants moderate concern at Casa Grande Ruins NM. Factors that influence air quality may also influence the viewshed and night sky conditions. In fact, the condition for the night sky at the monument warrants moderate concern. Light and air pollution from the City of Coolidge, Arizona as well as more distant cities affect day and night visibility.

The panoramas show a relatively intact landscape along the monument's western boundary, but that could change if the land adjacent to the monument was developed. There is also the possibility of a traffic

Table 12. Summary of the viewshed indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Scenic and Historic Integrity	Conspicuousness of Non-contributing Features		There were few non-contributing features in the foreground and background but numerous non-contributing features in the middle ground. Non-contributing features included power poles and lines, housing and buildings, and the San Carlos Irrigation Project. Because of their color, shape, size, and close proximity to the monument, these features intruded on the viewshed and detracted from the cultural aesthetic of the landscape.
	Extent of Development		The composite viewshed showed that road density within the viewshed is high but housing density is low. This is in contrast to the panoramas which show few roads, but a high amount of development, at least in the middle ground. The housing analysis showed that 45% of the AOA had increased in development since 1970.
	Conservation Status		There were few areas where scenic conservation status was high. Most (82%) of the AOA was considered GAP Status 3 or 4 with only 8% of the AOA in GAP Status 1 or 2. Many of the land management agencies responsible for the lands that were visible from Casa Grande Ruins NM's key observation points allow for extractive uses or were private lands.
Overall Condition	Summary of All Measures		While the distant views remain intact, views in the middle ground have been significantly altered. Because of the proximity of non-contributing features in the viewshed, these features are highly visible and detract from the cultural aesthetic of the monument. Furthermore, many of the lands managed in the AOA, including the distant lands with good views, allow for extractive uses. Lastly, the vegetation in the monument has been altered as a result of groundwater withdrawals and past grazing practices. Although the historic vegetation is unknown and the Hohokam most certainly altered native plant life in the area, the current changes to the landscape indicate a significant departure from historic conditions.

control installation at the entrance station to the monument. Pinal County in which the monument is located is the third largest in Arizona (U.S. Census Bureau 2018). The other two counties are Maricopa and Pima Counties, which include Phoenix and Tucson, respectively. The monument is located between these two urban centers.

Sources of Expertise

Assessment author was Lisa Baril, wildlife biologist and science writer, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A. Note that the measures and methods used for assessing the condition of the national monument's viewshed are different from the measures/methods recommended by the NPS Visual Resources Program in the Air Resources Division under 2018 draft guidance that post-dates this viewshed assessment. Please contact the NPS Visual Resource Program for more information: visual_resources@nps.gov.

Night Sky

Background and Importance

Natural dark skies are a valued resource within the NPS as reflected in NPS management policies (NPS 2006), which highlights 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 2010b). Additionally, in an estimated 20 national parks, stargazing events are the most popular ranger-led program (NPS 2010b).

The value of night skies goes 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 (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.

At Casa Grande Ruins National Monument (NM) celestial phenomena partially influenced the architecture of the Great House (NPS 2017a). Its four walls align with the cardinal directions and holes in the walls align with the setting sun during the summer solstice and the rising sun during the spring and fall equinoxes (NPS 2017a). One opening aligns with a rare lunar event that occurs only every 18.6 years when the moon appears to remain fixed in the sky (NPS 2017a). Although the specific purpose of the Great House remains unknown, it is likely that celestial events were important in Hohokam culture (NPS 2017a).

A time lapse photograph of the night sky with the Great House in the foreground. Photo Credit: NPS.

Data and Methods

The 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 national parks (Duriscoe et al. 2007). In this assessment, we characterize the night sky environment in Casa Grande Ruins 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 (ALR), vertical maximum illuminance, horizontal illuminance, and zenith sky brightness. The Bortle Dark Sky Scale 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.

NSNSD scientists conducted an assessment of Casa Grande Ruins NM's night sky condition from the northwestern corner of the monument on four nights during 2007 (9 January, 16 January, 14 March, and 15 March) (Figure 20). Data in March were essentially collected during the same night: one before midnight and one after midnight. Field data were collected using a charge-coupled device (CCD) camera, and the all-sky light pollution ratio was modeled using satellite imagery.

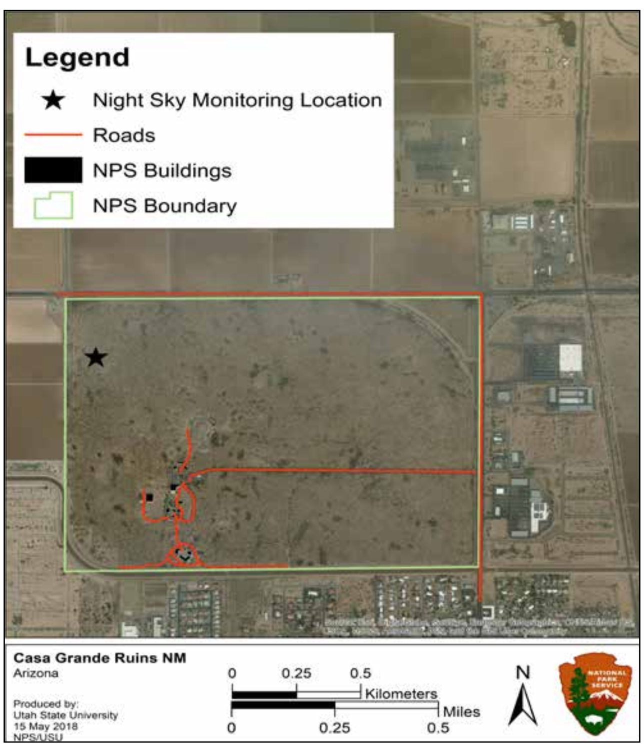


Figure 20. Map of the night sky monitoring location in Casa Grande Ruins NM.

The ALR is the average anthropogenic sky luminance presented as a ratio over natural conditions (Moore et al. 2013). 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 advances in modeling the natural components of the night sky allow separation of anthropogenic light from natural features, such as the Milky Way. 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 (Moore et al. 2013). 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 (Moore et al. 2013).

ALR is a convenient and robust measure and 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 (Moore et al. 2013). Modeled ALR data were based on 2015 National Oceanic and Atmospheric Administration (NOAA) and 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 2018).

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) (Duriscoe 2016). 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 (Duriscoe 2016). Vector measures of illuminance (horizontal and vertical) are important in describing the appearance of three-dimensional objects on the landscape and their relative visibility (Duriscoe 2016).

Vertical illuminance is the integration of all light striking a vertical plane from the point of the observer (Duriscoe 2016). In light-polluted areas, the azimuth direction associated with the maximum vertical illuminance will often correspond to the direction of the maximum sky brightness, typically at the core of the dominating urban light dome. 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 (Duriscoe 2016). 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 only near the horizon.

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

Zenith sky brightness describes the amount of light observed in the night sky overhead (Duriscoe 2016). 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 NSNSD 2016a). As with maximum vertical and horizontal illuminance, we reported the observed zenith sky brightness in addition to its corresponding LPR.

The Bortle Dark Sky Scale was proposed by John Bortle (Bortle 2001) based on 50 years of astronomical observations (Figure 21). Bortle's qualitative approach uses a nine-class scale (Table 13) that requires a basic knowledge of the night sky and no special equipment (Bortle 2001, Moore 2001, White et al. 2012). 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

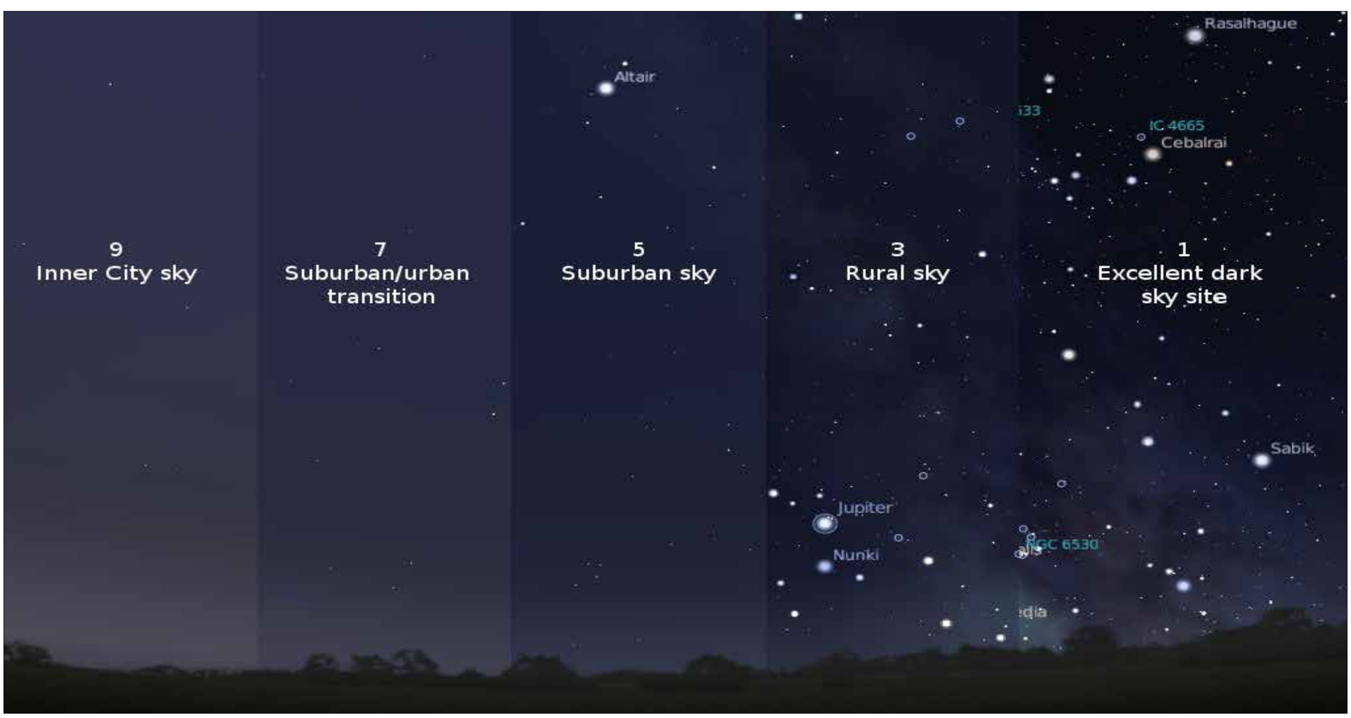


Figure 21. **A graphic representation of the Bortle Dark Sky Scale. Figure Credit: Bortle 2001.**

Table 13. 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).

suitable for conditions ranging from the darkest skies to the brightest urban areas (Moore 2001).

Reference Conditions

Table 14 summarizes the condition thresholds for measures in good, moderate concern, and significant concern condition. 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 2010b). Casa Grande Ruins NM is considered an urban NPS unit, or area with at least 90% of its property located within an urban area (Moore et al. 2013). For urban NPS units the thresholds separating reference conditions of good, moderate concern, and significant concern are less stringent than those for non-urban NPS units because on already altered urban skies, there is less sensitivity to the effects of additional light pollution.

The threshold for night skies in good condition is an ALR <2.00 and the threshold for warranting moderate concern is ALR 2.00-18.00. An ALR >18.00 would warrant significant concern (Moore et al. 2013).

Although no thresholds for maximum vertical illuminance have been set at this time, the NPS Night Skies Program recommends a reference condition of 0.4 milli-Lux (Moore et al. 2013) 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).

As with maximum vertical illuminance, no thresholds for horizontal illuminance have been set at this time. The NPS Night Skies Program 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 (Moore et al. 2013).

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 of the year (the position of the Milky Way), and the activity of the sun, which can increase "airglow"—a kind of faint aurora (NPS NSNSD 2016a). For the minimum night sky brightness measure, the darkest part of a natural night sky is generally found near the zenith (NPS NSNSD 2016a). 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 10x; thus a 19.5 msa sky would be 10x brighter than natural conditions (NPS NSNSD 2016a). Minimum night sky brightness values of 21.4 to 22.0 msa are generally considered to represent natural (unpolluted) conditions (Duriscoe et al. 2007).

A night sky with a Bortle Dark Sky Scale Class 1 is considered to be in the best possible condition (Bortle 2001); unfortunately, a sky that dark is so rare that few observers have ever witnessed it (Moore 2001). Urban

Table 14. **Reference conditions used to assess the night sky.**

Indicators	Measures	Good	Moderate Concern	Significant Concern
Sky Brightness	All-sky Light Pollution Ratio (ALR)*	ALR <2.00 (<156 nL average anthropogenic light in sky)	ALR 2.00-18.00 (156-1404 nL average anthropogenic light in sky)	ALR >18.00 (>1404 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 Illuminance	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)*	≥21.20	19.70-21.19	<19.70
Sky Quality	Bortle Dark Sky Class*	1-4	5-6	7-9

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

park skies with a Bortle Class 4 or darker are considered to be in good condition, Bortle Class 5-6 warrants moderate concern, and Bortle Class greater than 7 warrants significant concern. At Class 4 and higher, many night-sky features become indistinguishable from the sky background due to artificial lights (either within or outside the park). Bortle Class 7 and higher have a significantly degraded aesthetic quality that may introduce ecological disruption (Moore et al. 2013).

Condition and Trend

Modeled data by the NPS Night Skies Program show a median park-wide ALR of 10.93, which corresponds to 1,093% brighter than average natural conditions (Table 15). Figure 22 shows the modeled ALR for the region surrounding Casa Grande Ruins NM. The figure shows that the monument is most influenced by lights from Phoenix, Arizona 70 km (44 mi) to the northwest and Tucson, Arizona 104 km (65 mi) to the southeast. Although the town of Casa Grande, Arizona 24 km (15 mi) to the southwest and the town of Coolidge, Arizona in which the monument is located also influence the night sky at Casa Grande Ruins NM, the light domes from Phoenix and Tucson overwhelm the lights from these smaller cities. Figure 23 show the anthropogenic light sources for 15 March 2007, which is representative of the other dates during which these images were collected (images for other dates can be obtained from NSNSD's night sky monitoring database (NPS NSNSD 2016b). The image is shown in false color with yellow, red, and white corresponding to brighter sky and blue, purple, and black corresponding to darker sky and shows significant amount of light sources along the horizon.

Ground-based ALRs varied from 8.35 to 9.69, which corresponds to a range of 835% to 969% brighter than average natural conditions (Table 15). Based on reference conditions, all values (ground-based and modeled) are within the moderate concern condition rating. Confidence in this condition rating is medium since field measurements were collected in 2007 (i.e., more than 10 years ago) and because of the inherent uncertainties in the modeled data. Trend could not be determined.

Observed maximum vertical illuminance ranged from 5.26 to 5.98 milli-Lux (Table 15). After subtracting the natural components specific to those measurements, the corresponding LPR is 1,168% and 1,385% brighter than average natural conditions. All four measurements exceeded the NPS Night Skies Program recommendation of 0.4 milli-Lux; however, since there are no set reference conditions for good, moderate concern, or significant concern, no condition was assigned to this measure. Confidence is low due to lack of reference conditions. Trend could not be determined.

Observed horizontal illuminance ranged from 4.29 to 5.24 milli-Lux (Table 15). After subtracting the natural components specific to those measurements, the corresponding LPR for these values is 444% and 571% brighter than average natural conditions. The NPS Night Skies Program recommends a threshold of 0.8 milli-Lux, which was exceeded on all monitoring dates. However, since there are no set reference conditions for good, moderate concern, or significant concern, no condition was assigned to this measure. Confidence is low due to lack of reference conditions. Trend could not be determined.

Zenith sky brightness varied from 20.05 to 20.37 msa (Table 15). The corresponding LPRs for these values are 461% and 449% brighter than average natural conditions. All values warrant moderate concern. Confidence in the condition rating is medium since data were collected more than 10 years ago. Trend could not be determined.

NPS Night Skies Program observers estimated the night sky quality to Bortle Class 7 on 16 January 2007 and Class 6 on 14-15 March 2007 (Table 15. Bortle Class 6 warrants moderate concern and

Table 15. Night sky measurements collected at Casa Grande Ruins NM.

Date	All-sky Light Pollution Ratio	Observed Maximum Vertical Illuminance (milli-Lux)	Observed Horizontal Illuminance (milli-Lux)	Observed Zenith Sky Brightness (msa)	Bortle Class
Modeled Park-wide	10.93	–	–	–	–
9 January 2007	9.51	5.98	5.24	20.05	–
16 January 2007	9.69	5.56	5.11	20.16	7
14 March 2007	8.80	5.35	4.70	20.22	6
15 March 2007	8.35	5.26	4.29	20.37	6

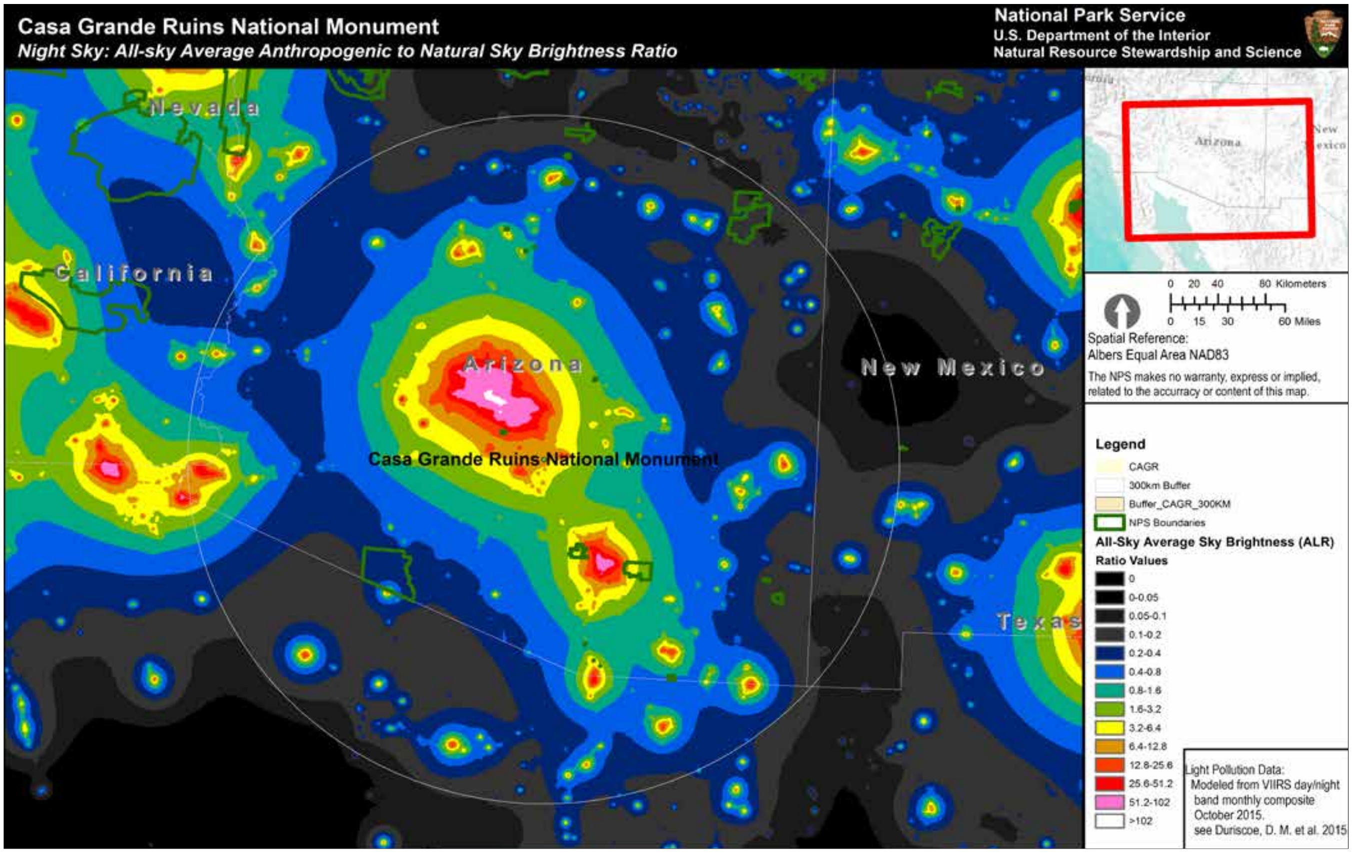


Figure 22. **Modeled ALR map for Casa Grande Ruins NM. Figure Credit: NPS Natural Sounds and Night Skies Division.**

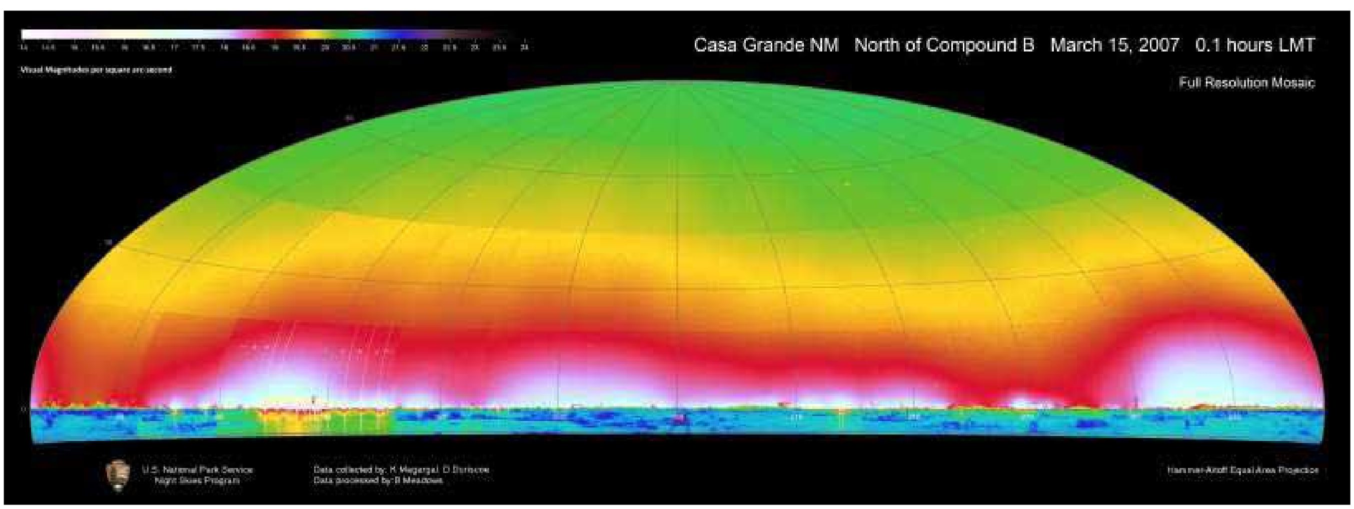


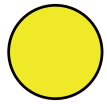
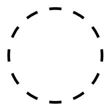
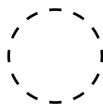
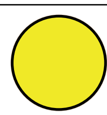
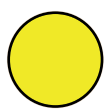
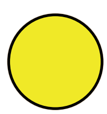
Figure 23. **Panoramic all-sky mosaic of all light sources on 15 March 2007 at Casa Grande Ruins NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.**

corresponds to a bright suburban sky. Bortle Class 7 warrants significant concern and corresponds to a suburban-urban transition. Since two of the three values were Class 6, the condition rating warrants moderate concern. Confidence in the condition rating is medium since this measure is subjective and observer-dependent. Trend could not be determined.

Overall Condition, Threats, and Data Gaps

The overall condition for the night sky at Casa Grande Ruins NM is of moderate concern based on the two measures of sky brightness and the single measure of sky quality (Table 16). Maximum vertical and horizontal illuminance conditions were unknown and therefore, not included in determining overall

Table 16. Summary of night sky indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Sky Brightness	All-sky Light Pollution Ratio (ALR)		Modeled park-wide ALR was 10.93. Ground based ALRs ranged from 8.35 to 9.69. All values warrant moderate concern. Confidence in this condition rating is medium since the last monitoring date was more than ten years ago (i.e., 2007). Trend could not be determined.
	Vertical Maximum Illuminance (milli-Lux)		Observed maximum vertical illuminance ranged from 5.26 to 5.98 milli-Lux. The corresponding light pollution ratio was estimated as 1,168% to 1,385% brighter than average natural conditions for these two values. All four measurements exceeded the NPS Night Skies Program recommendation of 0.4 milli-Lux; however, there are no established reference conditions so the condition is unknown. Confidence is low due to lack of reference conditions. Trend could not be determined.
	Horizontal Illuminance (milli-Lux)		Observed horizontal illuminance ranged from 4.29 to 5.24 milli-Lux. The corresponding light pollution ratio ranged from 444% to 571% brighter than average natural conditions for these two values. The NPS Night Skies Program recommends a threshold of 0.8 milli-Lux, which was exceeded on all monitoring dates. However, there are no established reference conditions so the condition is unknown. Confidence is low due to lack of reference conditions. Trend could not be determined.
	Zenith Sky Brightness (msa)		Zenith sky brightness varied from 20.05 to 20.37 msa. Based on these data, this measure of illuminance warrants moderate concern. Confidence is medium since the data were collected more than ten years ago. Trend could not be determined.
Sky Quality	Bortle Dark Sky Class		NPS Night Skies Program observers estimated the night sky quality to class 7 on 16 January 2007 and class 6 on 14-15 March 2007. Bortle Class 6 corresponds to a bright suburban sky (moderate concern) while class 7 corresponds to a suburban-urban transition (significant concern). We assigned a moderate concern rating since two of the three values were Bortle Class 6. Confidence is medium since this measure is subjective and observer-dependent, and data were collected more than 10 years ago. Trend could not be determined.
Overall Condition	Summary of All Measures		Overall, the night sky at Casa Grande Ruins NM warrants moderate concern based on the three measures with reference conditions. Confidence in the condition rating is medium since a majority of the data were collected more than ten years ago. Overall trend could not be determined. Additional data are needed to determine how or if the night sky has changed in the monument since measurements were collected.

condition. Confidence in the condition rating is medium since all measures for which there was a condition rating were assigned medium confidence. Trend could not be determined. A key uncertainty is whether night sky brightness and quality have changed since measurements were collected in 2007.

Arizona contains some of the darkest night skies in the U.S. The International Dark-Sky Association (IDA), whose mission is to protect dark night skies world-wide, has awarded dark sky designations to three communities and eight state and national parks throughout the state (IDA 2018). The bordering states of New Mexico and Utah also contain numerous IDA designations. Casa Grande Ruins NM is just south of the Colorado Plateau which alone contains 17 dark sky designations for parks, monuments, and communities (IDA 2018). The relatively low population density and high elevation of many areas in Arizona enhance dark night skies in the state. Furthermore, there are many communities in Arizona dedicated to protecting dark night skies. For example, by mid-2017 night lighting in Tucson, Arizona was reduced by 7% after thousands of street lights were converted to more energy-efficient and night sky-friendly lighting (Barentine 2018).

Worldwide, the Earth's artificial outdoor lighting has increased by 2.2% per year between 2012 and 2016 (Kyba et al. 2017). Encroaching lights from nearby developed areas (e.g., Coolidge, Arizona and Casa

Grande, Arizona) and the urban expansion of more distant cities (e.g., Phoenix, Arizona) may continue to degrade the dark night sky in the monument. Atmospheric dust and pollution from these and other major metropolitan areas may degrade the visibility of stars and other celestial features. The haze index, which is a measure of visibility, warrants moderate concern at Casa Grande Ruins NM (refer to the air quality assessment in this report).

Furthermore, the monument is bordered by roads and urban development to the north and east with the potential for development to the west and south. Given the monument's urban setting, the intrusion of nearby nighttime lighting is expected but nevertheless may impact wildlife and the cultural history of the area. Not only does nocturnal light pollution affect natural and cultural aspects of the monument, but light pollution also degrades the aesthetics of the night sky environment.

Data gaps include the lack of measurements since 2007. Additional data would be useful in tracking changes over time and with support efforts to reduce nighttime lighting in the surrounding communities. Although there are currently no night sky programs at the monument, and the monument is closed at night, Casa Grande Ruins NM staff have a telescope and interest in pursuing night sky programs. These types of programs can be used to increase awareness regarding the importance of the night sky to native cultures, wildlife, and for aesthetics.

Sources of Expertise

The NPS Natural Sounds and Night Skies Division helps parks manage the night sky in a way that protects park resources and the visitor experience. 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, visit the NPS NSNSD website (NPS NSNSD 2018). Assessment author is Lisa Baril, science writer, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Soundscape

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). 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) (2006) require preservation of parks' natural soundscapes and restoration of degraded soundscapes to natural conditions wherever possible. Additionally, the 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 historic 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 varies depending on the species and other conditions, documented responses of wildlife to noise include increased heart

Rona Yellowrobe performs at the 2013 American Indian Arts Fest at Casa Grande Ruins NM. Photo Credit: © Ronnie Ziemba.

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

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.

Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources. The reference sound pressure represents the minimum threshold of human hearing (20 micropascals). The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported as decibels (dB). A-weighting is applied to sound levels in order to account for the sensitivity of the human ear (Harris 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz. Because sound levels (or sound pressure levels, SPL) are measured on a logarithmic scale, every 10 dB increase 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 24). 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).

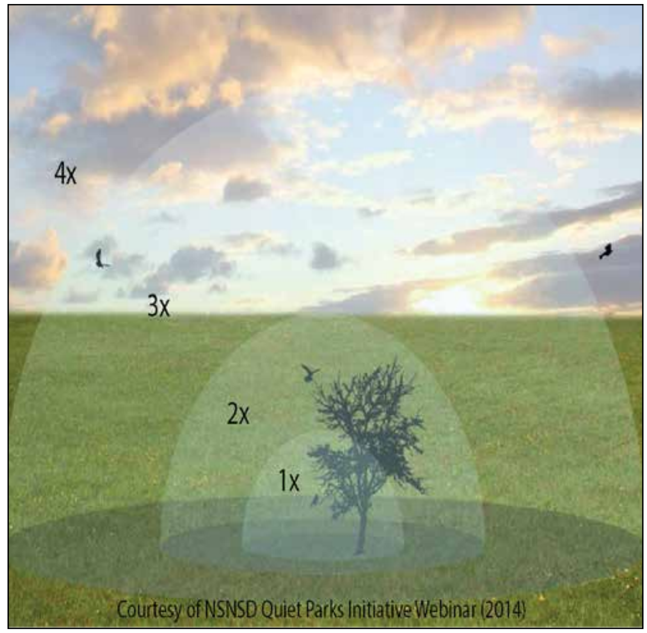


Figure 24. A 6 dB reduction in background noise level would produce a 4x increase in listening area. Figure Credit: © Ted E. Dunn.

Data and Methods

In 2010, baseline acoustical monitoring data for Casa Grande Ruins NM were collected by the Volpe National Transportation Systems Center at the request of the NPS Natural Sounds and Night Skies Division (NSNSD). Acoustical monitoring systems were deployed at one location for 28 days during September (Schulz et al. 2014). The purpose of the soundscape inventory was to "characterize existing sound levels and estimate natural ambient sound levels, as well as identify audible sound sources" (Schulz et al. 2014). In this assessment, we used two indicators with a total of three measures.

The first indicator (sound level) was assessed using two measures, the first of which was the percent time above reference sound level. The percent time above reference sound level is the amount of time that the sound level exceeds specified decibel values (Schulz et al. 2014). Human responses to sound levels can serve as a proxy for potential impacts to other vertebrates because humans have more sensitive hearing at low frequencies than most species (Dooling and Popper 2007). Table 17 summarizes sound levels that relate to human health and speech, as documented in the scientific literature.

Table 17. Sound level values (dB (LAeq, 1s)) related to human health and speech.

dB (LAeq,1s)	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: Schulz et al. (2014).

The first, 35 dB (LAeq, 1s), is designed to address the health effects of sleep interruption. LAeq, 1s refers to the A-weighted 1-second time averaged sound level. To generate this metric, the average sound level for a measurement period was calculated from many 1-second measurements. Recent studies suggest that sound events as low as 35 dB (LAeq, 1s) 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 dB (LAeq, 1s) (Berglund et al. 1999). The third value, 52 dB (LAeq, 1s), is based on the U.S. Environmental Protection Agency's (USEPA) speech interference threshold for speaking in a raised voice to an audience at 10 m (33 ft) (USEPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB (LAeq, 1s), provides a basis for estimating impacts on normal voice communications at 1 m (~3 ft). Hikers and visitors viewing scenic vistas in the monument would likely be conducting such conversations. Schelz et al. (2014) determined the percent of time sound levels were above these four reference levels for both day (7:00 am to 7:00 pm) and night (7:00 pm to 7:00 am) within Casa Grande Ruins NM.

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 dB (LAeq), and further, 20% of studies documented impacts below 50 dB (mean LAeq).

The second measure of sound level was the percent reduction in listening area. 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 levels 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 24 (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.

For this measure, we calculated the percent reduction in listening area from the natural ambient sound level (LAnat) using data provided by Schulz et al. (2014). The natural ambient sound level refers to all naturally occurring sounds and excludes all anthropogenic noise; it is an estimate of the LA50 that would occur in the absence of human-caused noise (NPS NSNSD 2014). LA50 refers to the level of sound exceeded fifty percent of the time at a given location. However, the natural ambient sound level was only available for daytime hours. Therefore, we used the sound level exceeded 90% of the time (LA90) as a proxy for the natural ambient level for nighttime hours, which is an acceptable practice (Acoustical Society of America [ASA] 2009, Ambrose and Florian 2006). The LA90 value refers to the level of sound exceeded 90% of the time at a given location; it is an estimate of the background against which individual sounds are heard (NPS NSNSD 2014). We calculated reduction in listening area by determining the difference between the LA50 and LAnat (daytime) or LA90 (nighttime) values using a formula provided by NPS NSNSD.

Lastly, the single measure of the geospatial model indicator was the LA_{50} impact. The geospatial model estimates 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 m (886 ft) resolution model predicts daytime sound levels during midsummer. 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 LA_{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 conditions.

Reference Conditions

Table 18 summarizes the condition thresholds for measures in good condition, those warranting moderate concern, and those warranting significant concern.

For the percent time above reference sound level measure, we used a sound level threshold of 45 dB (LAeq, 1s), which corresponds to the World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund et al. 1999). In a literature review of wildlife response to sound levels, Shannon et al. (2015) found that of 68 studies, four reported wildlife response to noise as low as 40 dB (LAeq, 1s), but most studies reported responses above 45 dB (LAeq, 1s). Ideally, reference conditions would be based on the percent time above the natural ambient sound level found in the monument (Rossman 2004), which was 29.7 dB (LAeq, 1s) for daytime hours (Schulz et al. 2014). However, Schulz et al. (2014) only reported the percent time above for the four sound levels referenced in Table 17.

The percent of time above 45 dB was modified from Rossman (2004). Because Casa Grande Ruins NM is an urban unit, we modified criteria for the development management zone. A 10% time above was recommended for minor impact (good condition), and a 25% time above was recommended for major

Table 18. Reference conditions used to assess the soundscape at Casa Grande Ruins NM.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Sound Level	% Time Above Reference Sound Level	Sound levels do not exceed 45 dB[2] for more than 10% of day or nighttime hours.	Sound levels exceed 45 dB for more than 10% but no more than 25% of day or nighttime hours.	Sound levels exceed 45 dB for more than 25% of day or nighttime hours.
	% Reduction in Listening Area[1]	Listening area was reduced by ≤75% over natural ambient sound levels. (Difference between LA_{50} & LA_{nat} or LA_{90} is ≤6)[3]	Listening area was reduced by 75 to 94% over natural ambient sound levels. (Difference between LA_{50} & LA_{nat} or LA_{90} is >6 and ≤12)[3]	Listening area was reduced by >94% over natural ambient sound levels. (Difference between LA_{50} & LA_{nat} or LA_{90} is >12)[3]
Geospatial Model	LA_{50} Impact[1] (Mean LA_{50} impact [dB])	≤6 Listening area reduced by ≤75%	>6 but ≤12 Listening area reduced by 75-94%	>12 Listening area reduced by >94%

[1] National Park Service Natural Sounds and Night Skies Division thresholds for urban parks. Urban parks are those with at least 90% of their land located within an urban area (Turina et al. 2013).

[2] Note that all dB levels referenced in the table are LAeq, 1s.

[3] When the L_{nat} sound level is not available, the L_{90} may be used in its place to represent the natural ambient sound level (ASA 2009).

impact (significant concern). For moderate concern, we set the percent time above 45 dB to >10% but <25%. The reference conditions used for this measure are protective of the monument's natural soundscape but also allow for unnatural sounds, which are expected to occur in urban areas.

For the percent reduction in listening area measure, a 75% or less reduction would indicate good condition, while a more than 94% reduction in listening area would warrant significant concern (Turina et al. 2013; see Table 18). Casa Grande Ruins NM is considered an urban unit, or a monument with at least 90% of its land located within an urban area. Urban areas tend to have higher ambient sound levels than non-urban areas (Turina et al. 2013). Therefore, the thresholds separating reference conditions for urban parks are less stringent than for those located in non-urban areas.

As with the previous measure, we used thresholds for urban parks for the LA_{50} impact measure (Turina et al. 2013). An LA_{50} impact of 6 dB or less would be considered good condition, while an LA_{50} impact of more than 12 dB would warrant significant concern. Reference conditions for this measure were developed by Turina et al. (2013) (Table 18).

Condition and Trend

Figure 25 shows the percent of time sound levels were above specific values at the monitoring station during daytime (7 a.m. - 7 p.m.) and nighttime (7 p.m. - 7 a.m.) hours. During daytime hours, September sound levels mainly exceeded the 35 dB metric, with 50.5% of daytime hours above this level. Sound levels exceeded the 35 dB metric 62.4% of the nighttime hours. For both day and night hours, the percent time above dropped rapidly after 35 dB with only 8.5% (day) and 6.2% (night) of sound levels exceeding 45 dB.

In summary, sound levels did not exceed the 45 dB reference threshold for more than 10% of either day or nighttime hours. Therefore, this measure is in good condition. Confidence in this condition rating is medium because data were collected nine years prior to publication of this assessment (i.e., data collected in 2010). No trend data were available.

Although sound levels met the requirements for good condition, according to Schulz et al. (2014), nearly all sound sources were attributed to human-caused noise, at least during daytime hours. Sources of daytime anthropogenic noise within the monument included aircraft (42% of all sound sources) and other human noise (53% of all sound sources), which may include

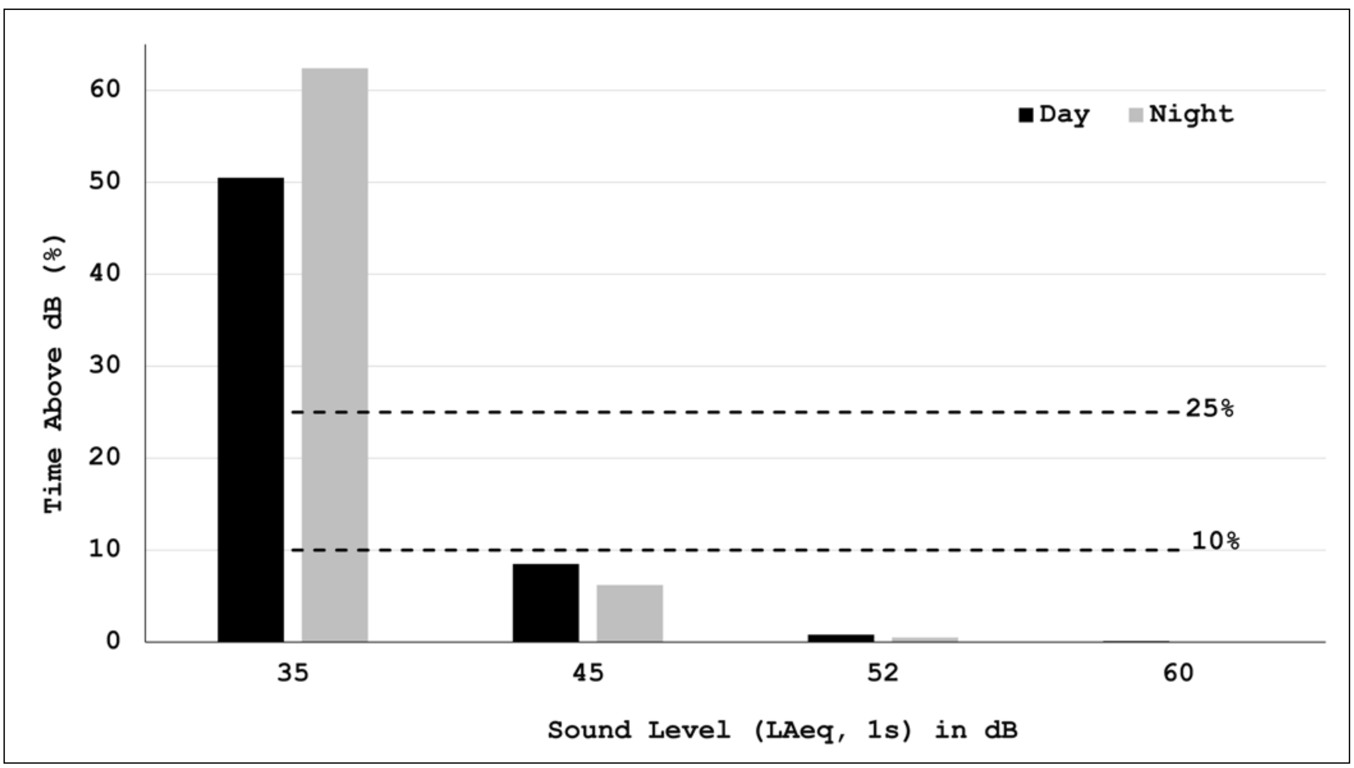


Figure 25. **Percent time above reference sound levels at Casa Grande Ruins NM.**

cellular phones and vehicles. Only 5% of total daytime sound sources were natural, noise-free sounds.

The reduction in listening area analysis is shown in Table 19. The table shows the LA_{50} and LA_{nat} or LA_{90} sound levels for both daytime and nighttime hours, as well as the impact value (i.e., the difference), reduction in listening area, and condition. Based on the analysis, the reduction in listening area was somewhat less for night (68%) compared to the day (74%). Since both values were less than 75%, the condition was good for both day and night. However, both values, especially daytime values, approached the threshold for moderate concern. Confidence in our condition rating is medium because data were collected nine years prior to publication of this assessment. Trends are unknown.

Figure 26 shows the modeled mean impact sound level map for the national monument and the surrounding area. The modeled mean impact was 13.3 dB above natural conditions but ranged from 10.87 dB (moderate concern) in the least impacted areas to 15.1 dB (significant concern) (Table 20). The map depicts the areas most influenced by human-caused sounds as the lighter areas. The existing and natural acoustic environment condition maps for the monument are shown in Figures 27 and 28, respectively. Average values represent the average LA_{50} value occurring within the national monument boundary, and since this value is a mean, visitors may experience sound

Table 19. Existing ambient sound levels at Casa Grande Ruins NM and results of the % reduction in listening area analysis.

Time of Day	LA_{50} (dB)	LA_{nat} or LA_{90} (dB)	Impact (dB)	Reduction in Listening Area (%)
Day	35.5	29.7[1]	5.8	74
Night	36.5	31.6[2]	4.9	68

[1] L_{nat}

[2] L_{90}

Table 20. Summary of the modeled minimum, maximum, and average LA_{50} measurements in Casa Grande Ruins NM.

Acoustical Environment	Min. (dB)	Max. (dB)	Avg. (dB)
Natural	26.8	27.2	27.0
Existing	37.9	42.1	40.3
Impact	10.9	15.1	13.3

Source: Data were provided by E. Brown, NPS NSNSD.

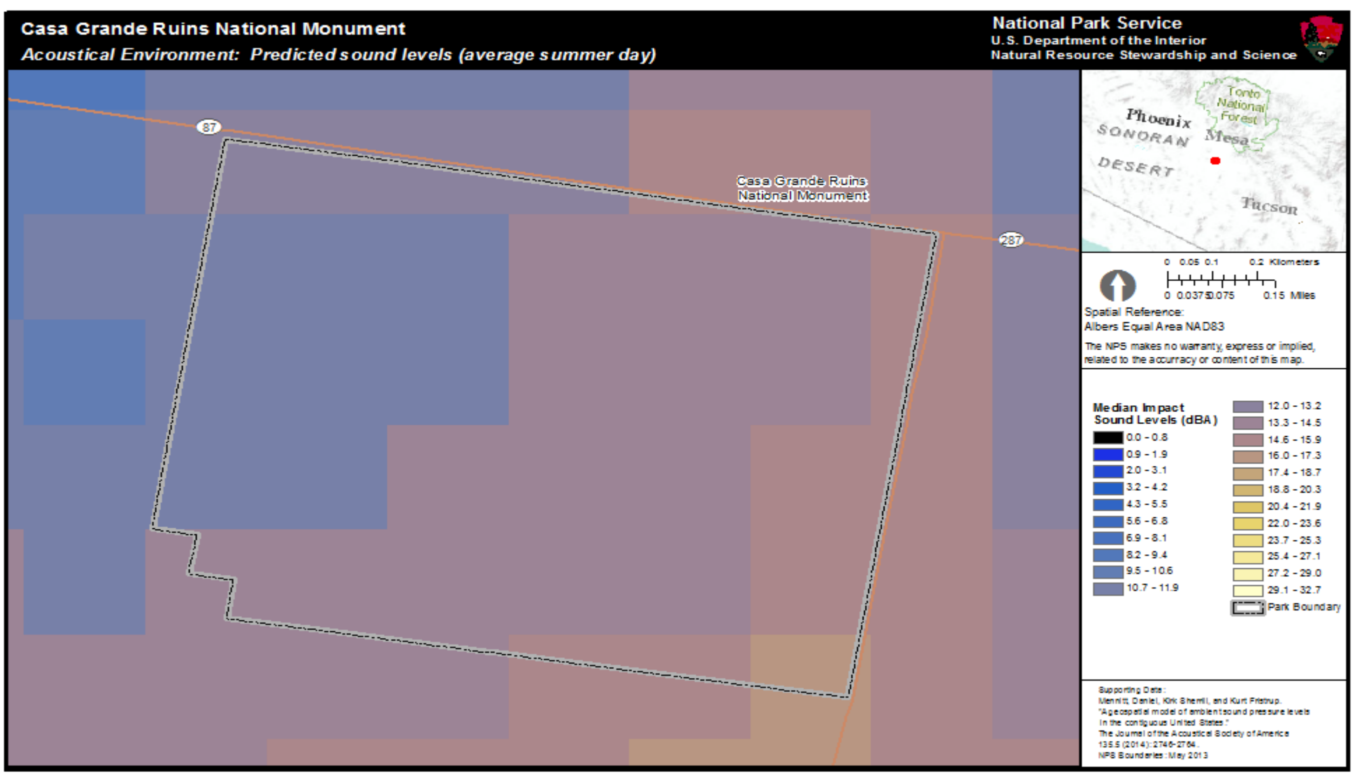


Figure 26. The modeled mean impact sound level at Casa Grande Ruins NM. Lighter colors represent higher impact areas. Figure Credit: NPS NSNSD/Emma Brown.

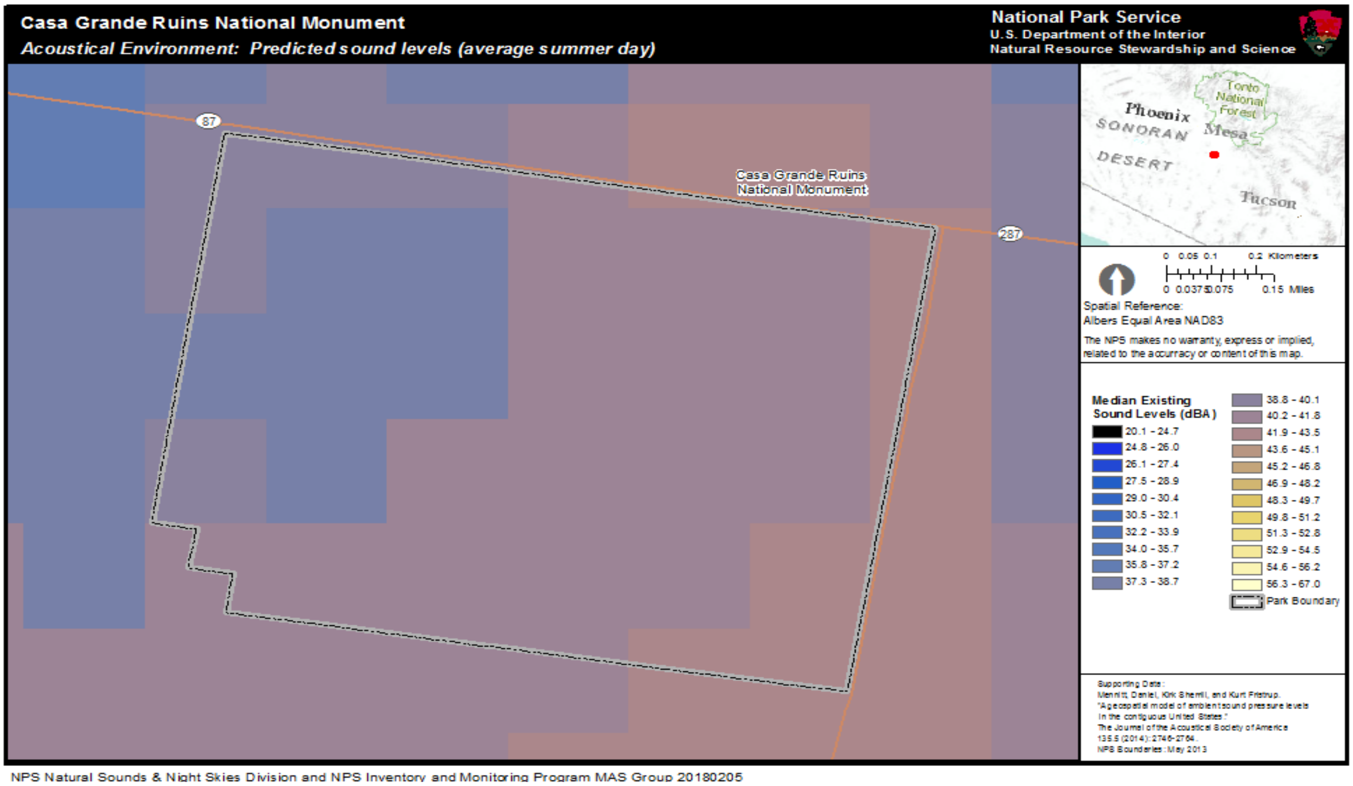


Figure 27. **The modeled L_{50} existing sound level at Casa Grande Ruins NM. Lighter colors represent higher impact areas. Figure Credit: NPS NSNSD/Emma Brown.**

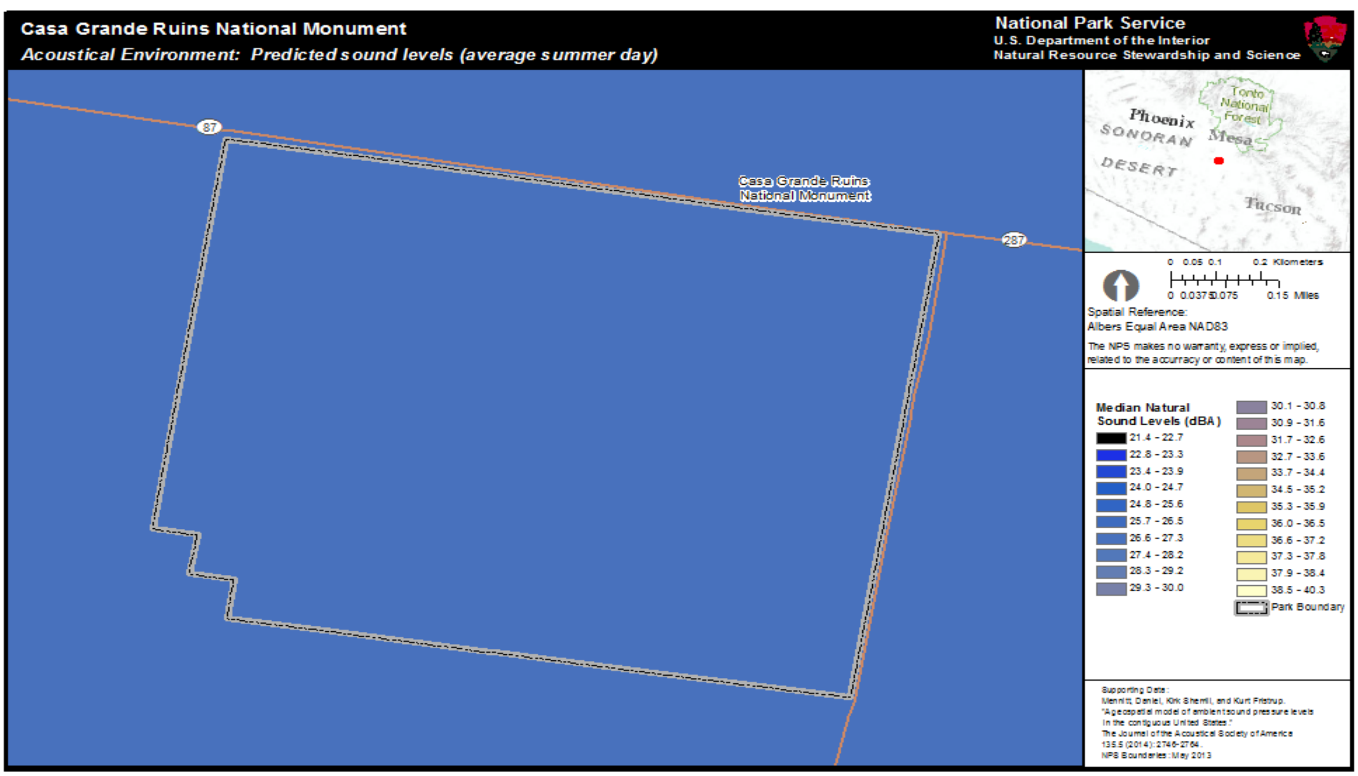


Figure 28. **The modeled L_{50} natural sound level at Casa Grande Ruins NM. Lighter colors represent higher impact areas. Figure Credit: NPS NSNSD/Emma Brown.**

levels higher and lower than the average LA_{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 LA_{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 dB (although acoustical conditions vary by area and depend on vegetation, landcover, elevation, climate, and other factors). The modeled estimates for Casa Grande Ruins NM were well below 41 dB. Mennitt et al. (2013) also stated that "an impact of 3 dB suggests that anthropogenic noise is noticeable at least 50% of the hour or more." The modeled average impact result for the national monument was more than 12 dB (it was 13.3 dB); thus, the LA_{50} impact was considered to be of significant concern according to the reference thresholds developed by Turina et al. (2013) for urban units. This value corresponds to a reduction in listening area of 95%. Since these data were modeled, confidence is medium. Trend could not be determined based on these data.

The percent reduction in listening area and the LA_{50} impact provide complementary ways of assessing the influence of sound levels in the monument. If these two measures were based on the same data, their respective conditions would have also been the same. However, different data were used for each. The percent reduction in listening area was calculated from measurements collected in the monument during a 28-day period in September 2010. The single site was located in one of the least noisy places in the monument (refer to Figure 8 in Schulz et al. 2014). On the other hand, data from 479 parks, including Casa Grande Ruins NM, were used to build the impact model for the entire conterminous U.S. (NPS NSNSD 2017). Furthermore, the model included explanatory variables such as location, climate, landcover, hydrology, wind speed, and proximity to noise sources (e.g., roads, railroads, and airports) as previously mentioned. The model also provided a range of values for the entire monument, whereas the *in situ* measurements only apply to the location in which they were collected. While reasonably accurate, the model may differ from actual conditions, with an average range of error between 1.7 dB in urban areas to 3.1 dB in natural areas (NPS NSNSD 2017). These reasons may account for differences in conditions between these two measures.

Overall Condition, Threats, and Data Gaps

Overall, we consider the soundscape at Casa Grande Ruins NM to warrant moderate concern based on the two indicators with a total of three measures, which are summarized in Table 21. All measures were assigned medium confidence because data were collected in 2010 (nine years prior to publication of this report) or were modeled. Trends could not be determined based on a single month of data. A key uncertainty is how the monument's soundscape may have changed over time.

Casa Grande Ruins NM's foundation document reports that the monument's acoustic environment is becoming more impacted by noise from traffic, agricultural activities, and general population increases (NPS 2017a). The foundation document also cites the potential for a new hotel and service station near the monument's boundary; such activities would involve the operation of heavy machinery, which would increase noise during construction (NPS 2017a). As development outside and along the periphery of the monument increases, anthropogenic noise is expected to increase over the long-term. In urban units such as Casa Grande Ruins NM, anthropogenic impacts to the soundscape are expected. However, natural soundscapes are important for Native American ceremonies, which occasionally occur at the monument. Furthermore, a natural soundscape is important to the visitor experience of the cultural landscape and can help visitors identify with the region's previous inhabitants.

In addition to influencing the human experience of the landscape, anthropogenic sound (and its frequency) can influence the behavior and ability of wildlife to function naturally on the landscape. 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). But response to noise was found to be highly variable between taxonomic

Table 21. Summary of the soundscape indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Sound Level	% Time Above Reference Sound Levels		Condition was good under this measure, because, for the majority of the time, sound levels were under 45 dB (LAeq, 1s) (the World Health Organization's recommendation for maximum noise level in bedrooms). It should be noted, however, that the 45 dB (LAeq, 1s) metric was exceeded to some extent (<10% of the time) both day and night. The 52 dB (LAeq, 1s) metric (speech interference threshold for speaking in a raised voice to an audience at 10 m [32.8 ft) was exceeded <1% of the time.
	% Reduction in Listening Area		The reduction in listening area was slightly less for the nighttime compared to the daytime. However, the condition for both day and night was good since the reduction in listening area was less than 75%, although both values approached thresholds for moderate concern (74% for day and 68% for night).
Geospatial Model	L_{50} Impact		The modeled average impact sound level for the national monument was 13.3 dB above natural conditions, but ranged from 10.87 dB in the least impacted areas to 15.1 dB in the most impacted areas. Since the modeled average impact result for the monument was above 12, the LA_{50} Impact warrants significant concern. This level of sound impact corresponds to a reduction in listening area of 95%.
Overall Condition	Summary of Measure		While sound levels were relatively low for the majority of the time, sound sources were almost entirely composed of noise (e.g., aircraft and other human sounds). The reduction of listening area was high, but within good condition for the monument's urban setting. The LA_{50} impact model, however, estimated a median reduction in listening area of 95% across the monument. Key data gaps and uncertainties include trends over time and how the monument might partner with local communities to reduce noise pollution.

groups and varied with behavior type (e.g., vocalizing vs. foraging) (Shannon et al. 2015).

Changes in vocal communication is one of the most common and readily observed biological responses to human noise. 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 mammals, amphibians, and insects, which also rely on vocal communication for breeding and territorial defense. Other responses 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, 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). Data gaps include the lack of information regarding trends. Noise has almost certainly increased since the monument was established in 1892, and anthropogenic noise is expected to continue to increase.

Sources of Expertise

NPS NSNSD scientists help parks preserve and restore acoustic environments, increase scientific understanding, and inspire public appreciation of acoustic resources. 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 was Lisa Baril, Biologist and Science Writer, Utah State University. Sources of expertise include the reviewers listed in Appendix A.

Air Quality

Background and Importance

The National Park Service's (NPS) Organic Act, Air Quality Management Policy 4.7.1 (NPS 2006), and the Clean Air Act (CAA), guide the NPS to protect air quality and any air quality related values (e.g., scenic, biological, cultural, and recreational resources) within national parks that may be impaired from air pollutants.

Among 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] 2018a).

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).

While Casa Grande Ruins National Monument (NM) is designated as a Class II airshed, NPS management policies do not distinguish between the levels of protection afforded to any park of the National Park System (NPS 2006). All units of the National Park System are managed to protect resources for the benefit of the current and future generations.

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

The NPS ARD (NPS ARD) program uses USEPA's NAAQS, natural visibility goals and ecological thresholds as benchmarks to assess current conditions of visibility, ozone, and atmospheric deposition

A clear blue sky at Casa Grande Ruins NM. Photo Credit: © USU.

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. Particulate matter (e.g. soot, dust, and sulfate and nitrate particles) and certain gases in the atmosphere can create haze and reduce visibility. Ozone is a gaseous constituent of the atmosphere produced by reactions of nitrogen oxides (NO_x) from vehicles, powerplants, industry, 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, 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 2018b).

Ozone is also phytotoxic, causing foliar damage to plants (NPS ARD 2018c). Ozone penetrates leaves through stomata (openings) and oxidizes plant tissue, which alters physiological and biochemical processes (NPS ARD 2018c). Once the ozone is inside the plant's cellular system, the chemical reactions can cause cell injury or even death but more often reduces the plant's resistance to insects and diseases, limits growth, and lowers reproductive capability (NPS ARD 2018c).

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 for plants exists when a species is 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 (NPS ARD 2018c).

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. Mercury or toxins can also be deposited to ecosystems (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 2018c). 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 (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).

According to the USEPA (2017), in the United States, roughly two thirds of all sulfur dioxide (SO_2) and one quarter of all nitrogen oxides (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 (USEPA 2017), including at Casa Grande Ruins 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 2018d).

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).

Data and Methods

The approach we used to assess the condition of air quality within Casa Grande Ruins NM's airshed was developed by the NPS ARD for use in Natural Resource Condition Assessments (NPS ARD 2018e). NPS ARD uses three indicators with a total of six measures. The indicators are visibility (one measure), level of ozone (two measures), and wet deposition (three measures) (Table 22). NPS ARD uses all available data from NPS, USEPA, state, and/or tribal monitoring stations to interpolate air quality values. Even though the data were derived from all available monitors, data from the closest stations "outweigh" the rest.

The haze index is the single measure of the visibility indicator used by NPS-ARD. Visibility is monitored through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program (NPS ARD 2010) and annual average measurements for Group 50 visibility (i.e,. days during which the visibility is between the 40th and 60th percentiles) 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 Casa Grande Ruins NM's boundaries is reported as the visibility condition from this national analysis. There were no on-site or nearby monitors with which to assess trend. Representative monitors to evaluate trends must be within 30.5 m (100 ft) or 10% of maximum and minimum elevation of the park and at a distance of no more than 150 km (93 mi).

The second indicator (ozone) is monitored across the U.S. through air quality monitoring networks operated by the NPS, USEPA, states, and others. Aggregated ozone data were acquired from the USEPA Air Quality System (AQS) database. Note that prior to 2012, monitoring data were also obtained from the USEPA Clean Air Status and Trends Network (CASTNet) database. No ozone data were available from monitors within 10 km (7 mi) of the monument, which is the distance, which NPS ARD considers representative for calculating trends (Taylor 2017).

Table 22. Summary of indicators and their measures.

Indicators	Measures
Visibility	Haze Index
Level of Ozone	Human Health, Vegetation Health
Wet Deposition	Nitrogen, Sulfur, Mercury, Predicted Methylmercury Concentration

The first measure of ozone is related to human health and is referred to as the annual 4th-highest 8-hour concentration. The primary NAAQS for ground-level ozone was set by the USEPA based on human health effects. Annual 4th-highest daily maximum 8-hour ozone concentrations were averaged over a 5-year period at all monitoring sites. Five-year averages were 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 was the maximum estimated value within its boundaries derived from this national analysis.

The second measure of ozone is related to vegetation health and is referred to as the 3-month maximum 12-hour 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. The annual index (W126) 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 from March to September was reported in "parts per million-hours" (ppm-hrs) and was used for vegetation health risk from ozone condition assessments. Annual maximum 3-month 12-hour W126 values were averaged over a 5-year period at all monitoring sites with at least three years of complete annual data. Five-year averages were 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 was the maximum value within its boundaries derived from this national analysis.

The indicator of atmospheric wet deposition was evaluated using three measures, two of which are nitrogen and sulfur. Nitrogen and sulfur were monitored across the United States as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). Wet deposition was used as a surrogate for total deposition (wet plus dry), because wet deposition was the most widely available monitored source of nitrogen and sulfur deposition data. Values for nitrogen (N) from ammonium and nitrate and sulfur (S) from sulfate wet deposition were 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 was averaged over a 5-year period at monitoring sites with at least three years of annual data. Five-year averages were 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 were reported from this national analysis. To maintain the highest level of protection in the park, the maximum value was assigned a condition status. NPS ARD considers stations located within 16 km (10 mi) of a park as representative for calculating trends (Taylor 2017).

The third measure of the wet deposition indicator was evaluated using a mercury risk status assessment matrix. The matrix combines estimated 3-year average (2013-2015) mercury wet deposition (ug/ m^2 yr) and the predicted surface water methylmercury concentrations at NPS Inventory & Monitoring parks. Mercury wet deposition was monitored across the United States by the Mercury Deposition Network (MDN). Annual mercury wet deposition measurements were averaged over a 3-year period at all NADP-MDN monitoring sites with at least three years of annual data. Three-year averages were then interpolated across all monitoring locations using an inverse distance weighting method to estimate 3-year average values for the contiguous U.S. The maximum estimated value within park boundaries derived from this national analysis was used in the mercury risk status assessment matrix. NPS ARD considers wet mercury deposition monitoring stations located farther than 16 km (10 mi) outside the range that is representative for calculating trends (Taylor 2017). There were no representative wet deposition monitoring stations for the monument

Conditions of predicted methylmercury concentration in surface water were 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 was the highest value derived from the hydrologic units that intersect the park. This value was used in the mercury risk status assessment matrix.

It is important to consider both mercury deposition inputs and ecosystem susceptibility to mercury methylation when assessing mercury condition, because atmospheric inputs of elemental or inorganic mercury must be methylated before they are biologically available and able to accumulate in food webs (NPS ARD 2018d). 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 (Taylor 2017).

Reference Conditions

The reference conditions against which current air quality parameters were assessed are identified by Taylor (2017) for NRCAs and listed in Table 23.

A haze index estimate of less than 2 dv above natural conditions indicates a “good” condition, estimates

Table 23. 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
Predicted Methylmercury Concentration (ng/L)	< 0.038	≥ 0.038 and .< 0.053	≥ 0.053 and < 0.075	≥ 0.075

Source: Taylor (2017)

Note: NPS ARD includes very good and very high standards. To conform with NRCA guidance, very low was considered good and very high was considered significant concern condition.

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.

The human health ozone condition thresholds were based on the 2015 ozone standard set by the USEPA (2016) 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 was less than or equal to 54 ppb, which is in line with the updated Air Quality Index breakpoints; "moderate concern" if the ozone concentration was between 55 and 70 ppb; and of "significant concern" if the concentration was greater than or equal to 71 ppb.

The vegetation health W126 condition thresholds were based on information in the USEPA's Policy Assessment for the Review of the Ozone NAAQS (USEPA 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.

ARD recommends a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation; this level was considered good; 7-13 ppm-hrs was considered to be of "moderate" concern; and >13 ppm-hrs was considered to be of "significant concern" (Taylor 2017).

For nitrogen and sulfur, 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 was 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."

Ratings for mercury wet deposition and predicted methylmercury concentrations can be evaluated using the mercury condition assessment matrix shown in Table 24 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 (Taylor 2017).

Condition and Trend

The values used to determine conditions for all air quality indicators and measures are listed in Table 25.

The estimated 5-year (2011-2015) values for Casa Grande Ruins NM's haze index measure of visibility (6.2 dv) fell within the moderate concern condition rating, which indicates visibility was degraded from the good reference condition of <2 dv above the natural

Table 24. 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: Taylor (2017).

Table 25. Condition and trend results for air quality measures at Casa Grande Ruins NM.

Visibility (dv)	Ozone: Human Health (ppb)	Ozone: Vegetation Health (ppm-hrs)	N (kg/ha/yr)	S (kg/ha/yr)	Mercury (µg/m²/yr) and Predicted Methylmercury (ng/L)
Moderate Concern (6.2) (2011-2015)	Moderate Concern (70.1) (2011-2015)	Significant Concern (13.9) (2011-2015)	Significant Concern (1.0*) (2011-2015)	Good (0.4) (2011-2015)	Moderate Concern (3.7, 0.12) (2013-2015)

* Value is within the range normally considered moderate concern, but ecosystems at the monument may be particularly sensitive to nitrogen-enrichment effects. Thus, the condition has was elevated to significant concern (NPS ARD 2018f).

Sources: NPS ARD (2018f, 2018g)

condition (Taylor 2017). There were not sufficient on-site or nearby monitors with which to determine trends. Confidence in this measure is medium because estimates were based on interpolated data from more distant visibility monitors. 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 vary by region but often include ammonium sulfate, coarse mass, and organic carbon. Ammonium sulfate originates mainly from coal-fired power plants and smelters, and organic carbon originates primarily from combustion of fossil fuels and vegetation. Sources of coarse mass include dust from roads, agriculture, construction sites, mining operations, and other similar activities. Data on the contribution of visibility impairing particulates for the monument were not available.

Data for the human health measure of ozone were derived from estimated five-year (2011-2015) values of 70.1 parts per billion (ppb) for the 4th highest 8-hour concentration, which resulted in a condition rating warranting moderate concern (NPS ARD 2018f). Trend could not be determined because there were not sufficient on-site or nearby monitoring data. The level of confidence is medium because estimates were based on interpolated data from more distant ozone monitors.

Ozone data used for the W126 vegetation health measure of the condition assessment were derived from estimated five-year (2011-2015) values of 13.9 parts per million-hours (ppm-hrs). This value warrants significant concern (NPS ARD 2018f). Trend could not be determined because there were not sufficient on-site or nearby monitoring data. Our level of confidence in this measure is medium because estimates were based on interpolated data from more distant ozone monitors. There are no ozone sensitive plant species in Casa Grande Ruins NM (Bell, In Review).

Wet N deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 1.0 kg/ha/yr. This would normally result in a condition rating of moderate concern; however, the condition rating was elevated to significant concern because ecosystems at Casa Grande Ruins NM may be more vulnerable to the adverse effects of excess nitrogen deposition (NPS ARD 2018f). No trends could be determined given the lack of nearby monitoring stations. Confidence in the condition is medium because estimates were 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.

Wet S deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 0.4 kg/ha/yr, which resulted in a good condition rating (NPS ARD 2018f). No trends could be determined given the lack of nearby monitoring stations. Confidence in the assessment is medium because estimates were based on interpolated data from more distant deposition monitors. For further discussion of sulfur, see below.

Sullivan et al. (2011a,b) studied the risk from acidification from acid pollutant exposure and ecosystem sensitivity for SODN parks, which included Casa Grande Ruins 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. Note that a more recent report (Sullivan et al. 2016) is available, but because it contains errors, we used data from the earlier report instead (NPS ARD, K. Taylor, planning and data analyst, comments to draft assessment, 10 December 2018).

These risk rankings for the monument were considered moderate for acid pollutant exposure, very low for ecosystem sensitivity, and moderate for park protection for an overall 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, very high for ecosystem sensitivity, and moderate for park protection for an overall risk of moderate. Potential effects of nitrogen deposition include the disruption of soil nutrient cycling and impacts to the biodiversity of some plant communities, including alpine communities, grasslands and meadows, arid and semi-arid communities, and wetlands.

Using three datasets, Landscape Fire and Resource Management Planning Tools Project (LANDFIRE), National Wetlands Inventory (NWI) cover data, and National Land Cover Data (NLCD), nitrogen-sensitive vegetation for the monument was identified (E&S Environmental Chemistry, Inc. 2009). In Casa Grande Ruins NM, the LANDFIRE dataset mapped 87% of the monument as arid and semi-arid nitrogen-sensitive areas. No nitrogen-sensitive communities were identified by NWI or NLCD.

Since the mid-1980s, nitrate and sulfate deposition levels have declined throughout the United States (NADP 2018a). Regulatory programs mandating a reduction in emissions have proven effective for decreasing both sulfate and nitrate ion deposition, primarily through reductions from electric utilities, vehicles, and industrial boilers. In 2007, the NADP/NTN began passively monitoring ammonium ion concentrations and deposition across the U.S. in order to establish baseline conditions and trends over time (NADP 2018b). In 2012 hotspots of ammonium deposition were concentrated in the midwestern states in large part due to the density of agricultural and livestock industries in that region (NADP 2018b). It seems reasonable to expect a continued improvement or stability in sulfate and nitrate deposition levels because of CAA requirements, but since ammonium levels are not currently regulated by the EPA, they may continue to remain high in certain areas (NPS ARD 2010). However, once baseline conditions for ammonia are established, those data may be used to support regulatory statutes.

The 2013-2015 wet mercury deposition was low at the monument with a value of 3.7 micrograms per square meter per year (NPS ARD 2018g). The predicted methylmercury concentration in park surface waters was estimated to be 0.12 ng/L (USGS 2015), a very high concentration (NPS ARD 2018g). When both measures are available (i.e., wet mercury deposition and predicted methylmercury concentration), the mercury status assessment matrix shown in Table 24 can be used to determine overall mercury/toxics status (Taylor 2017). The matrix indicates a condition of moderate concern for the combined effects of wet mercury deposition and predicted methylmercury at Casa Grande Ruins NM and unknown trend. However, the level of confidence in this measure is low, because the 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.

Overall Condition, Threats, and Data Gaps

For assessing the condition of air quality, we used three air quality indicators with a total of six measures (Table 26). The indicators/measures for this resource were intended to capture different aspects of air quality. Based on the indicators and measures, we consider the overall condition of air quality at Casa Grande Ruins NM to be of moderate concern.

Overall confidence level is medium because all estimates were based on interpolated data from more distant monitors. As mentioned above, the confidence levels for wet mercury deposition and predicted methylmercury concentration were low because the estimates were based on interpolated or modeled data rather than in-park studies. Those measures for which confidence in the condition rating was medium were weighted more heavily in the overall condition rating than measures with low confidence. No measures were assigned high confidence. Because trend information was not available, we did not assign an overall trend for air quality at the monument. A key uncertainty of this assessment is knowing the effect(s) of air pollution,

Table 26. Summary of air quality indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Visibility	Haze Index		Visibility warrants moderate concern at Casa Grande Ruins NM. This is based on NPS ARD benchmarks and the 2011-2015 estimated visibility on mid-range days of 6.2 deciviews (dv) above estimated natural conditions. There were no trend data because there were no on-site or nearby monitors. The level of confidence is medium 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 moderate concern. This status is based on NPS ARD benchmarks and the 2011-2015 estimated ozone of 70.1 parts per billion (ppb). Trend could not be determined because there were not sufficient on-site or nearby 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 13.9 parts per million-hours (ppm-hrs). The W126 metric relates plant response to ozone exposure. Trend could not be determined because there were not sufficient on-site or nearby 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		Estimated wet nitrogen deposition of 1.0 kilograms per hectare per year (kg/ha/yr) during 2011-2015 would normally warrant moderate concern, but because ecosystems in the park were rated as having high sensitivity to nutrient enrichment effects relative to all Inventory & Monitoring parks, the condition rating was elevated to significant concern. Trend could not be determined because there were not sufficient on-site or nearby 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 warrants moderate concern. This status is based on NPS ARD benchmarks and the 2011-2015 estimated wet sulfur deposition of 0.4 kilograms per hectare per year (kg/ha/yr). Ecosystems in the park were rated as having very low sensitivity to acidification effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011a, Sullivan et al. 2011b). Trend could not be determined because there were not sufficient on-site or nearby monitoring data. The confidence level is medium because estimates are based on interpolated data from more distant deposition monitors.
	Mercury and Predicted Methylmercury Concentration		For 2013-2015, wet mercury deposition was estimated at 3.7 micrograms per square meter per year (low) and predicted methylmercury concentration in park surface waters was very high (0.12 nanograms per liter). Trends could not be determined. Confidence in the measure is low because estimates were based on interpolated or modeled data rather than in-park studies; there are no park-specific studies examining contaminant levels in taxa from park ecosystems. The two variables are used to determine the overall condition of moderate concern at the national monument.
Overall Condition	Summary of All Measures		Overall, we consider air quality at Casa Grande Ruins NM to warrant moderate concern. All measures except for mercury deposition/predicted methylmercury concentration were assigned medium confidence due to the lack of nearby or on-site monitors. The measure with a low confidence level (for mercury/toxics) warrant moderate concern. Trend data were not available. As described, confidence in the various measures was varied, but we consider overall confidence to be medium. Overall trends are unknown.

Note: Condition summary text was primarily excerpted from NPS ARD (2016, 2018b).

especially of nitrogen deposition, on ecosystems in the monument as well as trends in air quality.

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 2006). For example, air quality in Casa Grande Ruins NM plays an important role in maintaining the high-quality scenic vistas and clear night skies of the national monument (NPS 2017a). Good visibility allows visitors to literally "visualize" their connection to nature and the culture of Ancestral Sonoran Desert People (NPS 2017a).

Air pollutants found in national parks are generated from activities outside protected areas and include vehicles, planes, and trains; power plants, oil refineries, factories, and other industrial facilities; agriculture, cities, and wood burning fire places; and from natural sources such as wind-blown dust, wildfires, and volcanos (NPS ARD 2018h). Despite the fact that air pollutants originate outside of these protected areas, they can and do impact national parks due to wind (NPS ARD 2018h). Although the USEPA requirements for Arizona power plant emission reductions have reduced ozone and fine particulates in the state over the last decade (NPS 2017a), these pollutants remain high in and around the monument.

In 2009 and 2010, coarse particulate concentrations were five times fine particulate matter (Clements et al. 2014). Particulate matter was also high during later summer monsoon season when strong winds create haboob dust storms (Clements et al. 2014, NPS 2017a). Concentrations of coarse particulate matter are often highest during the spring and autumn when tilling and harvesting occurs. More recently, NPS ARD found that human-health risk from particulate matter (PM 10) warrants moderate concern at the monument (NPS ARD, K. Taylor, planning and data analyst, comments to draft assessment, 10 December 2018). Particulate matter data were derived from the measured three-year average (2014-2016) 2nd maximum 24-hour PM 10 concentration of 87.7 micrograms per cubic meter (NPS ARD, K. Taylor, planning and data analyst, comments to draft assessment, 10 December 2018).

In an analysis of 33 national parks across the U.S., Keiser et al. (2018) found that average annual 8-hour ozone concentrations did not differ significantly from ozone levels in major metropolitan areas. While ozone levels have improved in both parks and cities, improvements have been more modest in parks (Keiser et al. 2018). In metropolitan areas, air quality has improved since about 1990, but in national parks, air quality did not improve until after 2000. The authors speculate that this may have been the result of the 1999 USEPA Haze Rule, which called for stricter regulations to improve air quality in national parks and wilderness areas (Keiser et al. 2018). Keiser et al. (2018) also showed that on days with higher levels of ozone, visitation in parks was lower than on days with lower ozone levels, probably as a result of USEPA air quality index warnings issued by the NPS or reduced visibility, which may have discouraged visitation. Although Casa Grande Ruins NM was not part of the study, air quality in nearby Phoenix, Arizona is one of the poorest in the nation (Keiser et al. 2018) and likely influences air quality in the monument. As of 2018, the monument is in an area designated by the USEPA as nonattainment for the 1987 PM10 24-hour average standard (150 micrograms per cubic meter) (NPS ARD, K. Taylor, planning and data analyst, comments to draft assessment, 10 December 2018).

Monahan and Fisichelli (2014) found climate for the monument and surrounding region departed from the natural range of variation. One effect of climate change is an increase in wildfire activity (Abatzoglou and Williams 2016). Fires contribute a significant amount of trace gases and particles into the atmosphere that affect local and regional visibility and air quality (Kinney 2008). Wildfires have increased across the western U.S., and there is a high potential for the number of wildfires to grow as climate in the Southwest becomes warmer and drier (Abatzoglou and Williams 2016). Warmer conditions also increase the rate at which ozone and secondary particles form (Kinney 2008). Declines in precipitation may also lead to an increase in wind-blown dust (Kinney 2008). Weather patterns influence the dispersal of these atmospheric particulates. Because of their small particle size, airborne particulates from fires, motor vehicles, power plants, and wind-blown dust may remain in the atmosphere for days, traveling potentially hundreds of miles before settling out of the atmosphere (Kinney 2008). The Foundation Document for Casa Grande Ruins NM (NPS 2017a) suggested that increased communication with neighboring farms and communities regarding the importance of high air quality for dark night skies and for preserving the monument's viewshed, would allow for continued public enjoyment of the monument.

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. Email NPS ARD (airresources@nps.gov) for more information. The assessment was written by Lisa Baril, biologist and science writer at Utah State University.

Groundwater

Background and Importance

The National Park Service (NPS) Sonoran Desert Inventory and Monitoring Network (SODN) monitors groundwater across 10 of its 11 network parks, including Casa Grande Ruins National Monument (NM), to better understand current condition and patterns of change over time (Filippone et al. 2014). Groundwater not only sustains plant life and wildlife at seeps and springs, but it also the primary water source for humans across the southwestern U.S. (Stromberg et al. 1996). Aquifers are recharged through snowmelt in the mountains, percolation of winter and summer precipitation, and infiltration of surface water from rivers and streams (Raymond and Filippone 2018). Groundwater may remain below the ground surface for months, years, or even centuries before resurfacing (Raymond and Filippone 2018).

Nowhere is water more important than where it is rare, and in the southwestern U.S., water is not only rare, but it is also in high demand. Arizona's Department of Water Resources (ADWR) manages both ground and surface waters in the state. Casa Grande Ruins NM is located within the Pinal Active Management Area (AMA) (Raymond and Filippone 2018). The Pinal AMA includes five groundwater sub-basins (Figure 29). The Eloy groundwater sub-basin lies beneath the monument, and is one of the most actively developed groundwater areas in the AMA (ADWR 2010). About half of the land in the AMA is under tribal ownership, but most of the land located around the monument is privately-owned agricultural land (ADWR 2010). The primary goal of the Pinal AMA is to manage groundwater resources to sustain the agricultural economy for as long as is feasible (ADWR 2010).

Raymond and Filippone state that

> the Eloy groundwater subbasin occupies a pair of hydrologically connected structural depressions formed by relatively impermeable bedrock (Hammett 1992). The bedrock depressions are filled with 800 to 1000+ feet of sediments in the area (Richard et al. 2007). Measurements in the early 20th century indicated that water-level elevations were similar for both shallow and deep wells indicating horizontal and vertical hydrologic connection (Hammett 1992).

However, since the early 20th century, the Eloy sub-basin has been in a groundwater deficit (ADWR 2010). While the Central Arizona Project (CAP)—a 541-km (336-mi) canal system that delivers water from the Colorado River to central and southern Arizona—has reduced groundwater deficits near the

Decadent velvet mesquite trees in Casa Grande Ruins NM. Photo Credit: © P. Pineda Bovin.

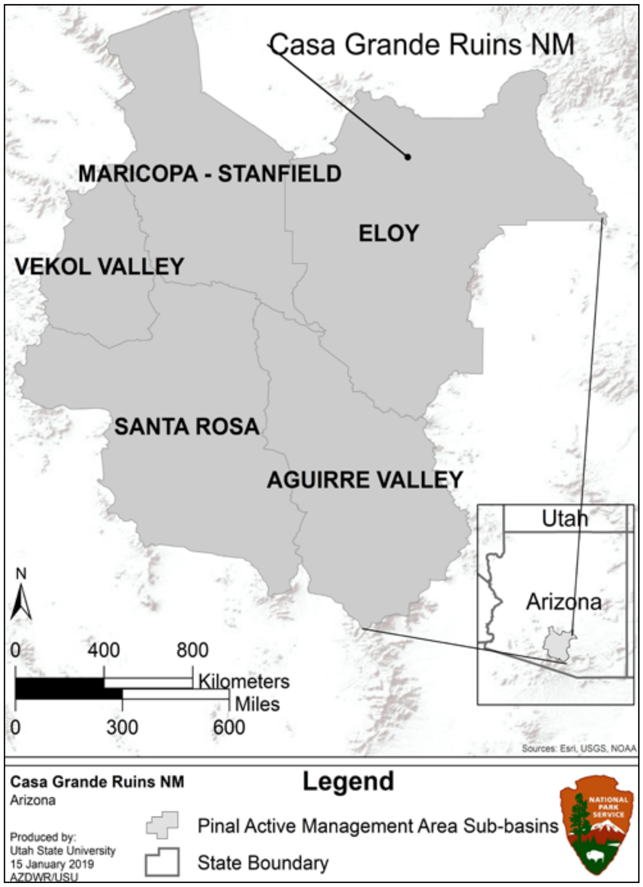


Figure 29. The Eloy subbasin within the Pinal AMA.

canal, groundwater elsewhere, including around Casa Grande Ruins NM, has not been replenished at the rate it is being extracted (ADWR 2010). The groundwater deficit has led to the replacement of velvet mesquite (*Prosopis velutina*) bosque to creosotebush (*Larrea tridentata*) in the monument (Judd et al. 1971, Buckley et al. 2009). Historically, mesquite bosques stretched for hundreds of kilometers along the Gila River and other southwestern rivers, with lateral extensions of up to 10 km (6 mi) (Stromberg 1993). But like in the monument, many of these mesquite bosques have been eliminated because of long-term groundwater withdrawals (Stromberg 1993).

Data and Methods

For this assessment, we used one indicator of water level condition: depth to groundwater. Depth to groundwater is a measure of how close the water table is to the Earth's surface (USGS 2016). The lower the depth to groundwater, the more available water is to plants. The ADWR monitors groundwater at several wells outside the monument's boundary, two of which are included in SODN's monitoring program (Filippone and Raymond 2018). At well #621935, depth to groundwater data have been collected annually since 1977 (41 years). This well is screened at a depth of 250 m (820 ft) and is located approximately 1.6 km (1.0 mi) west of the monument (Filippone and Raymond 2018). Data for well #621937 were collected intermittently from 1949 to 2013 (n = 14). This well is screened at a depth of 338 m (1,110 ft) and is located just outside the monument along the western boundary. Both wells are owned by the San Carlos Irrigation Project (SCIP). Although a third well (#629148) is located inside the monument, there are only three depth to groundwater measurements, and the well has not been accessible since the 1980s (refer to Figure 3-1 in Raymond and Filippone 2018 for map of wells). This well served as the monument's primary water source from 1931 until 1952, after which the monument was connected to the City of Coolidge water supply (Raymond and Filippone 2018). Since this well is no longer accessible and there are only three measurements available, we did not include these data. Data for the two wells included in this assessment were downloaded from ADWR's data portal on 14 January 2019 (ADWR 2018).

Reference Conditions

Reference conditions were based on the depth to groundwater required to maintain velvet mesquite. Although restoration of mesquite is not feasible due to changes in groundwater levels, using the depth to groundwater that is necessary for maintaining this species provides some context for how the water table has changed from historic conditions. Although mesquite is a deeply-rooted species capable of hydraulic lift (McIntyre et al. 2018), beyond a certain depth, mesquite can no longer access groundwater. Stromberg et al. (1992, 1996) found that velvet mesquite trees and shrubs were in good condition when depth to groundwater was ≤8 m (26 ft), but mesquite became increasingly water stressed up to 18 m (59 ft) (moderate concern condition) (Table 27).

Table 27. Reference conditions used to assess groundwater at Casa Grande Ruins NM.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Water Level	Depth to Groundwater (m)	≤8 m	9-18 m	> 18 m

Source: Stromberg et al. (1992, 1996).

Creosote is the dominant plant species in the monument. Photo Credit: NPS.

At >18 m (>59 ft) (significant concern condition), mesquite trees were under sublethal stress, and depths greater than 30 m (98 ft) resulted in mortality (Stromberg et al. 1992).

Condition and Trend

Depth to groundwater averaged 34.3 m (112.5 ft) at well #621935 (Figure 30) and 34.0 m (111.5 ft) at well #621937 (Figure 31). Average values at both wells were in the range of mortality for velvet mesquite, but values in some years occurred within the range of sublethal water stress. No values occurred within the range considered good condition. In 1983, 1993, and 2007 groundwater gained as a result of regional flooding and infiltration of excess water from the Gila River (Filippone and Raymond 2018), but these rare events are not sufficient to influence groundwater levels over the long-term. These results suggest that current groundwater levels are at minimum 16 m to 26 m (53-85 ft) lower than they were when mesquite bosque dominated the monument. These results are of significant concern. A simple linear regression indicated no trend in groundwater levels over time for well #621935 (R^2 (52) = 0.00, p = 0.92) or for well #621937 (R^2 (13) = 0.10, p = 0.28). Confidence in the

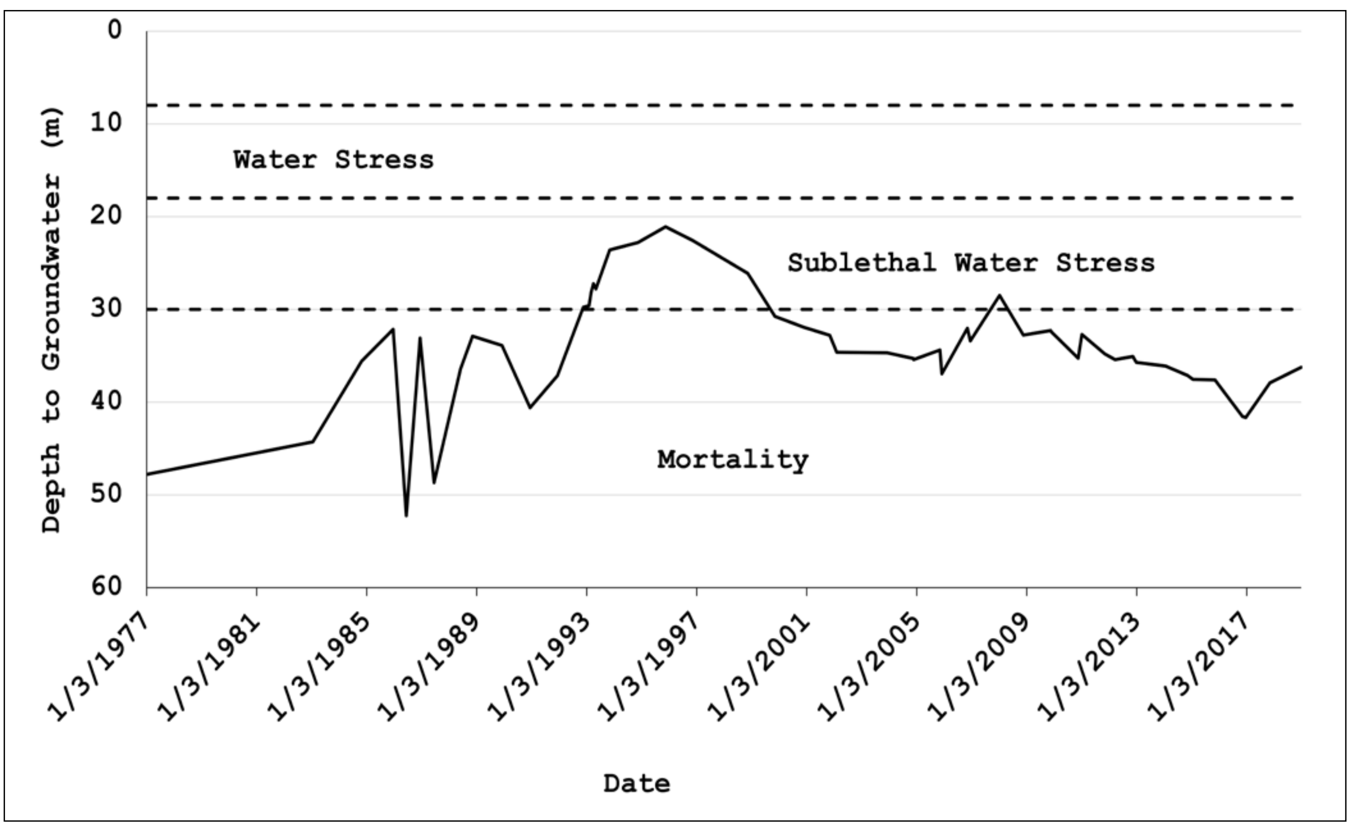


Figure 30. Groundwater levels measured annually at well # 621935 from 1977 to 2018.

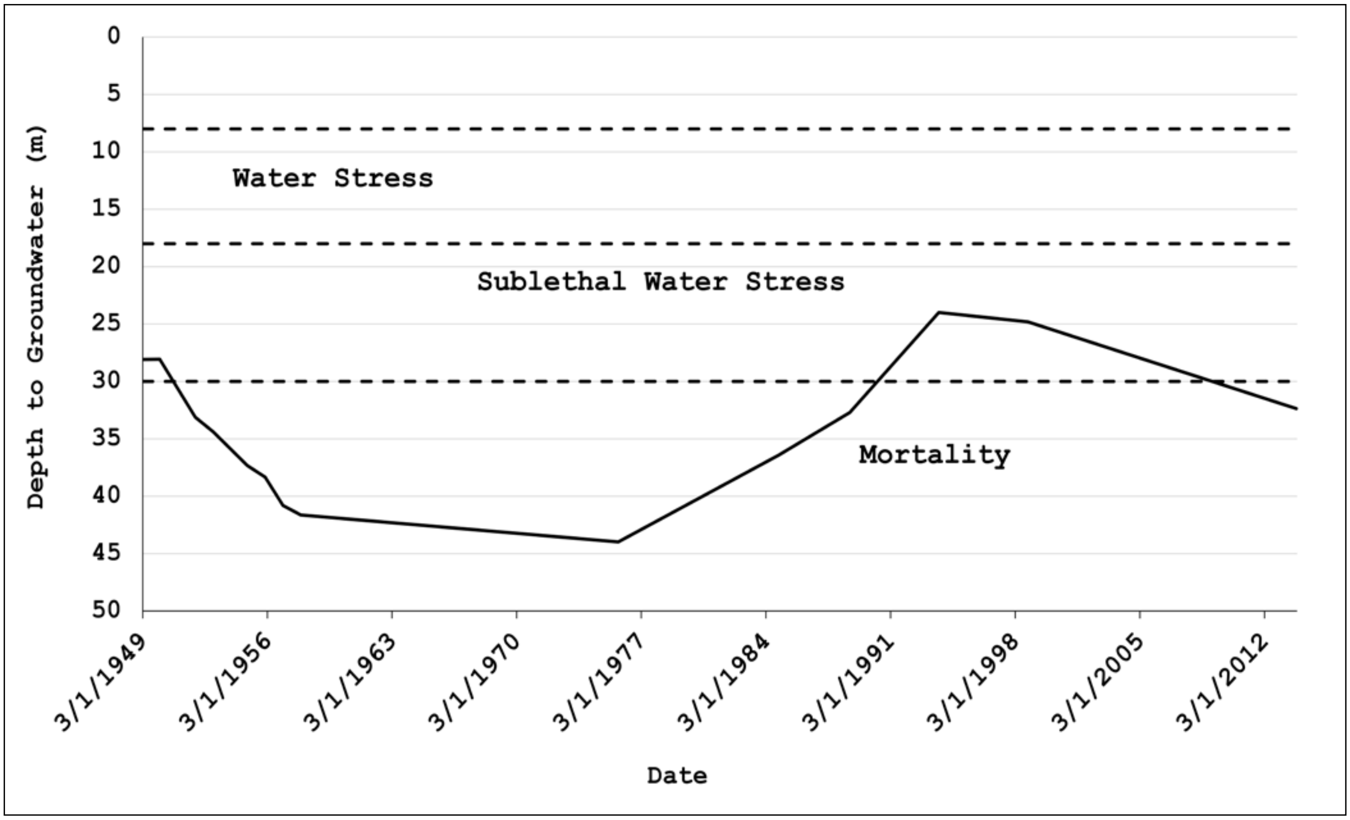


Figure 31. **Groundwater levels measured intermittently at well # 621937 from 1949 to 2013.**

condition rating is high because of the availability of long-term data.

Overall Condition, Threats, and Data Gaps

This assessment was based on one indicator with a single measure (Table 28). Groundwater in and around the monument is well below that which can sustain a mesquite bosque community. There are no surface water sources in the monument, and data show that groundwater levels are inadequate for maintaining even deeply rooted species. Thus, plants must access water through precipitation and surface soil moisture, but the extent to which soils are able to hold moisture is unknown (McIntyre et al. 2018). It is unlikely, given current and growing demands on water resources in Arizona, that groundwater levels will return to historic conditions.

The Eloy sub-basin is in a groundwater deficit, with more water pumped from the aquifer than is replenished (ADWR 2010). Groundwater recharge of the Eloy sub-basin occurs primarily from underflow into the basin and from infiltration of surface water in the Gila River (ADWR 2010). The Gila River flows 966 km (600 mi) from the border of New Mexico west across Arizona, but several dams and diversions along its length have altered natural flows, turning this once perennial stretch near the monument into one that flows intermittently (ADWR 2014).

While some of the pressure on groundwater resources has been partially mitigated by the CAP (i.e., the diversion of groundwater from the Colorado River into the AMA), the demands on water resources will continue to grow as the population grows. In the Pinal AMA the population is projected to increase from 99,143 in 2000 to over 624,128 residents by 2030 (ADWR 2010). Most (96%) of the water in the AMA is allocated to agriculture, and 45% of the agricultural demand is met with groundwater (ADWR 2010). Not only is the demand on groundwater resources growing, but a changing climate will and has already made water resources in the region less available.

Arizona has been in a drought since 2000 (Filippone and Raymond 2018), and dry conditions are expected to persist in the southwestern U.S. as the climate continues to warm (Garfin et al. 2014). Although temperature changes in the Sonoran Desert are unidirectional (i.e., increasing), changes in predicted

Table 28. Summary of groundwater indicators, measures, and condition rationale.

Indicator	Measure	Condition/ Trend/ Confidence	Rationale for Condition
Water Level	Depth to Groundwater (m)		Depth to groundwater averaged 34.3 m (112.5 ft) at well # 621935 and 34.0 m (111.5 ft) at well # 621937. Average values at both wells were in the range of mortality for velvet mesquite during most of the 41 and 64 years of data for each of the wells. No values occurred within the mild water stress range or within the range considered good condition.
Overall Condition	Summary of All Measures		Not only is the current groundwater level well below the threshold to maintain mesquite but continued loss of water resources threatens the current creosotebush community. A soil survey that addresses the soil-water holding capacity will help inform potential outcomes of a drier climate. Loss of groundwater has led to subsidence in the region, which threatens the structural integrity of cultural features in the monument. Water is a limited and non-renewable resources that has and continues to decline across the southwestern U.S.

precipitation have been more variable (Garfin et al. 2014). Reduced winter and spring precipitation is predicted across southern Arizona under current climate change scenarios (Garfin et al. 2014), with an increase in extreme precipitation events (Easterling et al. 2017). During drought conditions, aquifers are not likely to gain, and more intense rainfall may lead to increased runoff rather than recharge (Taylor et al. 2012), especially if plants and soil crusts decline in cover since they help capture and retain moisture (Ferrenberg et al. 2015, Munson et al. 2012). Furthermore, enhanced evapotranspiration from desert blooms have been shown to consume much of the water surplus during periods of intense rainfall (Scanlon et al. 2005).

Creosotebush, which is one of the driest Sonoran Desert plant community types, is expected to decline with a decrease in winter precipitation (Munson et al. 2012). However, declines are dependent on the water-holding capacity of soils in the monument, but a soil survey specific to the monument is lacking (McIntyre et al. 2018). Excavation of the caliche soil layer to build the Great House and other structures, construction of irrigation canals, and the maintenance of agricultural fields during occupation by the Hohokam between AD 950 and 1450 altered the natural landscape and soil layer to some extent, as did grazing during the early 20th century (Clemenson 1992). These activities likely compacted soils, which may have reduced water infiltration. Water that is closer to the soil surface is more susceptible to evaporation (McIntyre et al. 2018). Thus, even the "new normal" creosotebush community is threatened by drier conditions.

Declines in the water table have also led to fissures, or tension cracks that develop as groundwater is depleted (KellerLynn 2018). Earth fissures result in irreversible subsidence, whereby the ground settles into the spaces once occupied by groundwater. Subsidence has occurred throughout the Eloy sub-basin and has the potential to affect the stability of structures in the monument, especially sensitive structures such as the Great House (KellerLynn 2018). Although Coolidge, Arizona, in which the monument is located, is not a priority area for mapping of fissures by the USGS (KellerLynn 2018), the potential for changes in geology to affect monument structures is high. Fissures were observed in the Eloy sub-basin as early as 1929, and according to KellerLynn (2018), there is a fissure within 10 km (6 mi) of the monument.

Aquifers worldwide were charged thousands of years ago with little recharge having occurred since (Taylor et al. 2012). Prior to the late Pleistocene glaciation, aquifers were recharged under this cooler climate and to a lesser extent during the early Holocene (Taylor et al. 2012). While this fossil groundwater is resilient to current changes in climate, continued withdrawals are unsustainable. Climate change not only influences how much water is available to recharge aquifers but also influences the amount humans require for irrigation (Taylor et al. 2012), and recharge rates are not likely to keep pace with human needs.

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Upland Vegetation and Soils

Background and Importance

The National Park Service (NPS) Sonoran Desert Inventory and Monitoring Network (SODN) surveys upland vegetation and soils across 10 of its 11 network parks, including Casa Grande Ruins National Monument (NM), to better understand current condition and patterns of change over time (Hubbard et al. 2012). Terrestrial vegetation comprises 99% of the earth's biomass, and plants are the primary producers of life on Earth (Hubbard et al. 2012). Monitoring vegetation and soils can help scientists recognize subtle shifts in ecosystem structure and function.

Casa Grande Ruins NM lies within the Sonoran Desert ecoregion with vegetation and soils that are more typical of thornscrub than desert (McIntyre et al. 2018). A near monoculture of creosotebush (*Larrea tridentata*) dominates the monument with a sparse understory comprised of annual plants (Buckley et al. 2009). In addition to creostoebush, other woody plants were once common in the monument, including large patches of velvet mesquite (*Prosopis velutina*) and paloverde (*Parkinsonia microphylla*) (McIntyre et al. 2018).

Although most changes to native plants and soils occurred during the last 100 years, changes to the monument's plant community began with the occupation of the Hohokam between AD 950 and 1450 (Clemensen 1992). Excavation of the local caliche soil layer to build the Great House and other structures, construction of irrigation canals, and the maintenance of agricultural fields altered the natural landscape to some extent. However, the most significant changes to the monument's native vegetation occurred during the early 20th century.

Roughly 50 years of cattle grazing in and around the monument trampled native vegetation, compacted soils, and altered plant species composition (Clemensen 1992). Grazing was discontinued in 1934 when a fence was erected around the monument, but much of the damage had already been done. During the early 1900s, locals also physically removed mesquite for firewood and fence posts (Clemensen 1992). Although grazing and physical removal contributed to declines in mesquite, the ultimate cause of mesquite die-off was the long-term withdrawal of groundwater in the region (Filippone and Raymond 2018). Groundwater depletion also led to soil subsidence in some areas of the monument (Reichhardt 1992). Hence, the tall stands of velvet mesquite that were reported as growing all around the Great House as late as 1877 are absent today (Clemenson 1992). Rea (1997) states they were in the north part of the park, which is where we have a large standing dead mesquite grove.

Upland vegetation and soil crust cover in Casa Grande Ruins NM. Photo Credit: © USU.

Data and Methods

This assessment is based on six indicators with a total of 12 measures (McIntyre et al. 2018). The six indicators are erosion hazard, erosion features, plant community resistance and resilience, Saguaro cacti (Carnegia gigantea) occupancy, fire regime, and non-native plant dispersal and occupancy. Data were collected as part of SODN's upland vegetation and soils monitoring program (Hubbard et al. 2012). In 2008, three plots were established in the monument, and in 2011, three additional plots were established to monitor stabilization efforts on near-surface archaeological sites (McIntyre et al. 2018). Thus, the initial 2008 plots are referred to as "monitoring plots" and the three plots established in 2011 are referred to as "stabilization plots" (McIntyre et al. 2018). Monitoring plots were read in 2008 and 2013, and stabilization plots were read in 2011 and 2016 (McIntyre et al. 2018).

Plots were 20 x 50-m (66 x 164 ft) with six, 20-m (66-ft) transects established every 10 m (33 ft) along the plot's long edge. The transects divide the plot into five subplots. Vegetation and soils were measured in all of the following three layers: field (0-.05 m [<1.6 ft]), subcanopy (>0.5-2.0 m [1.6-6.6 ft]), and canopy (>2.0 m [6.6 ft]). For brevity, we include a brief description of each measure and why it is important rather than specific sampling details. Data collection methods for each measure are described in Hubbard et al. (2012) and McIntyre et al. (2018).

The first measure of the erosion hazard indicator is bare ground cover. The amount of bare ground (without overhead vegetation) is a measure of erosion potential since most soil loss occurs in unprotected bare patches (Hubbard et al. 2012). As the amount of bare ground increases, the velocity of surface water flow and erosion due to wind also increases. Vegetation, soil crusts, litter, and rock cover help protect against rapid soil loss. Since many cultural resources are located near or at the soil surface, erosion is of particular concern in Casa Grande Ruins NM (McIntyre et al. 2018). Soil crusts were addressed in a separate assessment in this report.

The second measure of erosion hazard is soil aggregate stability. Soil aggregate stability is a measure of resistance to erosion (Hubbard et al. 2012). Soil aggregate stability was classified on a scale ranging from 1 (least stable) to 6 (most stable) (Herrick et al. 2005). "Surface soil aggregates play a critical role in the movement of water, nutrients, and gases through the soil–atmosphere interface and in resisting wind and water erosion. Soil aggregate stability provides insight into current and past site disturbance and is an efficient measure of site stability in the context of potential management actions" (Hubbard et al. 2012).

The single measure of erosion features, is the extent of area by feature type, which was surveyed in the three monitoring plots as follows (Nauman 2011):

> Erosion features were described using a semi-quantitative scheme to estimate approximate extent (%) of affected areas [in each plot]. Estimated erosion classes were as follows: 0%, 1–5%, 6–25%, 26–50%, 51–75%, and >75%. Recorded features included tunneling, sheeting, rilling, gullying, pedestal development, terracette occurrence, and burrowing activity. Sheet, rill, and gully features are direct indicators of erosion, while the other features are precursors to water erosion or signs of susceptibility. Erosion observations were used to indicate site stability and help identify any other measured features that might be associated with increased erosion.

The two measures of the plant community resistance and resilience indicator are foliar cover of dead perennial plants in the field layer and foliar cover of dead perennial plants in the subcanopy layer. These two measures address the ability of plant communities to recover (resistance) and recruit (resilience) after a disturbance (McIntyre et al. 2018). Dead plants included only those that were still rooted in the ground (Hubbard et al. 2012). Low levels of dead plants indicate higher site stability, especially if dead cover declines rapidly following a disturbance.

The single measure of Saguaro cacti occupancy is nurse plant cover. The Saguaro cactus is an iconic species of the Sonoran Desert, but the growth and survival of Saguaro cactus seedlings depend on the cool and moist microenvironment created beneath the canopy of taller vegetation, such as velvet mesquite and paloverde (McIntyre et al. 2018). These protective plants are known as nurse plants. Effective nurse plants are those that are at least 2.0 m (6.6 ft) tall (McIntyre et al. 2018).

The fire regime indicator was evaluated using herbaceous cover. Herbaceous cover includes annual and perennial forbs and grasses (i.e., fuel loads). In the Sonoran Desert, native forbs and grasses are naturally sparse. With historically low fuel loads, fires were rare or even absent in the Sonoran Desert, but the invasion of fire-adapted, non-native annuals has altered the natural fire regime in some areas. In a positive feedback loop, the presence of non-native annuals increases fire risk. In turn fire increases the abundance of non-native annuals (Hubbard et al. 2012). Because most native Sonoran Desert plants are sensitive to fire, native communities may be replaced by non-native species following a fire.

Finally, the non-native plant indicator included five measures. The first measure (new species detections) addresses the invasion by a species not previously detected anywhere in the monument. A new non-native species may not necessarily become problematic, but it is important to detect new non-native plants before they spread. The second measure (new species to a plot) addresses the spread of non-native species already present in the monument. An uncommon species could become common as it competes with native species. Once a species begins to spread, usually as a result of specific environmental conditions (e.g., high rainfall), it may become difficult to control. This measure provides an effective way to monitor changes in the spread of non-native species over time. The third measure is percent cover, or the area over which a species or group of species occurs. In this case, it was used to monitor non-native species. The last two measures are cover of buffelgrass (*Cenchrus ciliaris*) and cover of red brome (*Bromus rubens*). These two species are especially problematic non-native species because they compete with native species, alter natural fire regimes, and spread after wildfire. Their presence can transform Sonoran desert shrublands into grassland-dominated systems (McIntyre et al. 2018).

Reference Conditions

Reference conditions are described for resources in good and moderate/significant concern conditions for each of the 12 measures (Table 29). Reference conditions for all measures except "extent of affected area by feature type" were based on Management Assessment Points (MAPS) developed by SODN (McIntyre et al. 2018). MAPS "represent preselected points along a continuum of resource-indicator values where scientists and managers have together agreed that they want to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns" (Bennetts et al. 2007). MAPS do not define management goals or thresholds. Rather, MAPS "serve as a potential early warning system,"

Table 29. Reference conditions used to assess upland vegetation and soils in Casa Grande Ruins NM.

Indicators	Measures	Good	Moderate Concern/Significant Concern
Erosion Hazard	Bare Ground Cover (%)	Bare ground with no overhead vegetation is ≤ 20%.	Bare ground with no overhead vegetation is > 20%
	Soil Aggregate Stability (Class)	Average surface soil aggregate stability is ≥ Class 3.	Average surface soil aggregate stability is < Class 3.
Erosion Features	Extent of Affected Area by Feature Type (%)	Rills are common, but pedestals, terracettes, and gullies are absent.	In addition to rills, terraccettes, pedestals, and/or gullies are common.
Plant Community Resistance and Resilience	Foliar Cover of Dead Plants in the Field Layer (%)	≤15%	>15%
	Foliar Cover of Dead Plants in the Subcanopy (%)	≤5%	>5%
Saguaro Cacti Occupancy	Nurse Plant Cover (%)	≥10%	<10%
Fire Regime	Herbaceous Cover (%)	≤35%	>35%
Non-native Plant Dispersal and Invasion	New Species Detections	0	≥1
	Species New to a Plot	0	≥1
	Total Cover (%)	≤5%	>5%
	Buffelgrass Cover (%)	≤1%	>1%
	Red Brome Cover (%)	≤1%	>1%

Sources: McIntyre et al. (2018) and Cassady (2007).

where managers may consider possible actions and options (Bennetts et al. 2007).

Reference conditions for "extent of affected area by feature type" were derived from the U.S. Department of Agriculture's Natural Resources Conservation Service (USDA NRCS) ecological site description that applies to Casa Grande Ruins NM (Cassady 2007). Ecological site descriptions are based on soil survey data, historical plant community type, disturbance regime, and other factors (USDA NRCS 2018).

The reference conditions used to assess the current condition of vegetation and soils are based on the "new normal" plant community in the monument since a return to historical conditions is infeasible given regional water demands and a changing climate (McIntyre et al. 2018).

Condition and Trend

For 11 of the following 12 measures we included only the most recent data as reported in McIntyre et al. 2018 (both years of data were reported for "extent of affected area by feature type"). Paired t-tests between the two time periods was used to determined trend for the 11 measures (McIntyre et al. 2018). Confidence for each of the following 12 measures is medium because of the small number of plots sampled ($n = 6$), data for monitoring plots were collected more than five years ago (i.e., 2013), and there have been only two rounds of sampling to date.

Bare ground cover averaged 15% ± 3 SE (standard error) in the three monitoring plots and 50% ± 11 SE in the stabilization plots during the most recent round of sampling (Table 30). Soil substrate cover did not change between the two time periods for monitoring plots ($p \geq 0.09$) or for stabilization plots ($p \geq 0.08$). These results indicate good condition for monitoring plots and moderate/significant concern condition for stabilization plots.

Soil aggregate stability averaged 4.9 ± 0.2 SE in the monitoring plots and 4.0 ± 0.1 SE in the stabilization plots (Table 30). These values indicate moderately stable to stable soils in monitoring plots and moderately stable to somewhat unstable soils in stabilization plots. Neither the monitoring ($p = 0.37$) nor the stabilization plots ($p = 0.16$) changed between the two time periods. The condition for this measure is good. Trend is unchanging.

For the extent of affected area by feature type, there was no evidence of tunnelling, terracettes, rills, or gullies during either time period in the three plots (Table 31). There was, however, some evidence of burrowing in all three plots during both time periods. Minor sheet erosion was found in only one plot during 2013 and pedestals were evident in two plots in 2013. Although most erosion features were absent, the consistent yet small amount of burrowing and evidence of pedestals and sheet erosion suggests moderate/significant concern in monitoring plots. There may be a slight increase in erosion features so trend is deteriorating. For stabilization plots, this measure is unknown.

For the two measures of resistance and resilience, SODN reported only trace amounts of standing dead

Table 30. Summary of upland plant and soils monitoring data in Casa Grande Ruins NM.

Indicators	Measures	Monitoring Plots 2013	Stabilization Plots 2016
Erosion Hazard	Bare Ground Cover (%)	15 ± 3	50 ± 11
	Soil Aggregate Stability (Class)	4.9 ± 0.2	4.0 ± 0.1
Plant Community Resistance and Resilience	Foliar Cover of Dead Plants in the Field Layer (%)	0.1 ± 0.1	0.3 ± 0.3
	Foliar Cover of Plants in the Subcanopy (%)	0.1 ± 0.1	0
Saguaro Cacti Occupancy	Nurse Plant Cover (%)	0	0
Fire Regime	Herbaceous Cover (%)	10 ± 5	4 ± 2
Non-native Plant Dispersal and Invasion	New Species Detections	0	0
	Species New to a Plot	0	0
	Total Cover (%)	0	0
	Buffelgrass Cover (%)	0	0
	Red Brome Cover (%)	0	0

Source: McIntyre et al. (2018).

Table 31. Erosion area class by feature type at monitoring plots in Casa Grande Ruins NM.

Plot-Year	Tunneling (% of plot)	Pedestals (% of plot)	Terracettes (% of plot)	Burrowing (% of plot)	Sheet (% of plot)	Rill (% of plot)	Gully (% of plot)
1-2008	0	0	0	<5	0	0	0
1-2013	0	0	0	<5	0	0	0
2-2008	0	0	0	<5	0	0	0
2-2013	0	6-25	0	<5	0	0	0
3-2008	0	0	0	<5	0	0	0
3-2013	0	<5	0	<5	<5	0	0

plants in the field layer and in the subcanopy layer (Table 30). These values were well within MAP for a good condition rating. Cover by lifeform, including dead plants, did not change over time in either vegetation layer ($p \geq 0.15$).

No nurse plants were detected during SODN's sampling (Table 30). Although nurse plant species do occur in the monument, none were tall enough to serve as nurse plants. More importantly, no Saguaro cactus plants were detected during SODN's sampling efforts, although there were some Saguaro cactus plants outside of sampling plots (McIntyre et al. 2018). Cover did not change over time for either monitoring plots ($p \geq 0.20$) or stabilization plots ($p \geq 0.15$). These results warrant moderate/significant concern. Trend is unchanging.

Herbaceous cover (fire regime) was limited to annual grasses and forbs. Herbaceous perennials were absent. Annual grass and forb cover decreased by about 9% and 8%, respectively, in monitoring plots; but these declines were not significant ($p > 0.20$). Annuals were absent in stabilization plots in 2011, but annual grasses were present on two plots in 2016. Recent estimates of herbaceous cover suggest good condition for this measure (Table 30). Trend is unchanging.

No new species of non-native plant were detected in either plot type or sampling event. Because there were no new species detected using SODN's sampling methods, no species were new to any of the six plots and total cover was 0%. Therefore, the condition is good for all five measures of the non-native plants indicator. Trend is unchanging.

Overall Condition, Threats, and Data Gaps

We used six indicators and 12 measures (summarized in Table 32) to assess the condition of upland vegetation and soils at Casa Grande Ruins NM. Measures without a condition rating were not used to assess overall condition. Although there appeared to be some issues with erosion in both plot types and Saguaro cactus nurse plant cover was absent, all remaining measures indicate good condition. Therefore, the overall condition is good. Trend is unchanging and confidence is medium. The overall confidence level is medium because of the small number of plots sampled, data for monitoring plots were collected more than five years ago, and there have been only two rounds of sampling thus far. However, these plots will be monitored over the long-term with sampling events every five years (Hubbard et al. 2012).

It's important to note that this condition rating is in light of the "new normal" for the monument. The mesquite bosque woodlands that once dominated the monument have been replaced by a near monoculture of drought-tolerant creosotebush. However as previously mentioned, a return to historical conditions is not feasible given long-term groundwater declines (McIntyre et al. 2018).

Although this assessment indicates relatively little has changed since observations began in 2008, the monument's vegetation has been dramatically altered when taking a longer perspective. The average species richness per monitoring and stabilization plot was 1.3 and 1.5 species, respectively (McIntyre et al. 2018). McIntyre et al. (2018) compared species richness across four protected areas in the Sonoran Desert, including Casa Grande Ruins NM. The authors found the monument is unusually species poor when compared with Cabeza Prieta National Wildlife Refuge (~3.5 species/plot), Organ Pipe Cactus NM (~6 species/plot), and Saguaro NP (~13 species/plot) despite similar environmental conditions across these areas.

Table 32. Summary of upland vegetation and soils indicators, measures, and condition rationale.

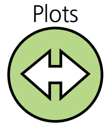
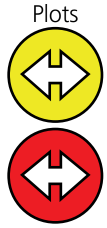
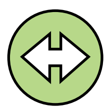
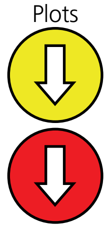
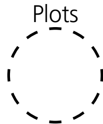
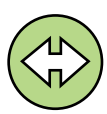
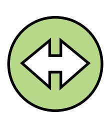
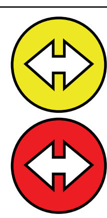
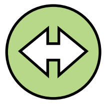
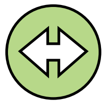
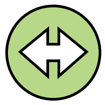
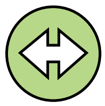
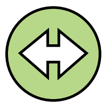
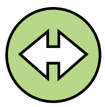
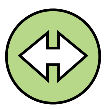
Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Erosion Hazard	Bare Ground Cover (%)	Monitoring Plots  Stabilization Plots 	Bare ground cover averaged 15% ± 3 SE in the three monitoring plots and 50% ± 11 SE in the stabilization plots during the most recent round of sampling. Soil substrate cover did not change between the two time periods for monitoring plots ($p \geq 0.09$) or for stabilization plots ($p \geq 0.08$).
	Soil Aggregate Stability (Class)		Soil aggregate stability averaged 4.9 ± 0.2 SE in the monitoring plots and 4.0 ± 0.1 SE in the stabilization plots. These values indicate moderately stable to stable soils in monitoring plots and moderately stable to somewhat unstable soils in stabilization plots. Neither the monitoring ($p = 0.37$) nor the stabilization plots ($p = 0.16$) changed between the two time periods.
Erosion Features	Extent of Affected Area by Feature Type (%)	Monitoring Plots  Stabilization Plots 	In the three monitoring plots there was no evidence of tunnelling, terracettes, rills, or gullies during either time period. There was some evidence of burrowing in all three plots during both time periods. Sheet erosion was found in only one plot during 2013 and pedestals were evident in two plots in 2013. For stabilization plots, this measure is unknown.
Plant Community Resistance and Resilience	Foliar Cover Dead Plants in the Field Layer (%)		Only trace amounts of standing dead plants were present in the field layer in either plot time or time period. Cover by lifeform, including dead plants, did not change over time in monitoring ($p \geq 0.20$) or stabilization plots ($p \geq 0.15$).
Plant Community Resistance and Resilience	Foliar Cover of Dead Plants in the Subcanopy (%)		As in the field layer, cover of dead plants in the subcanopy was minimal. Cover by lifeform, including dead plants, did not change over time in monitoring ($p \geq 0.20$) or stabilization plots ($p \geq 0.15$).
Saguaro Cacti Occupancy	Nurse Plant Cover (%)		No nurse plants were detected during SODN's sampling. Although those species do occur in the monument, none are tall enough to serve as nurse plants. More importantly, no Saguaro cactus plants were detected during SODN's sampling efforts. Cover did not change over time for either monitoring plots ($p \geq 0.20$) or stabilization plots ($p \geq 0.15$).

Table 32 continued. Summary of upland vegetation and soils indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Fire Regime	Herbaceous Cover (%)		Herbaceous cover was limited to annual grasses and forbs. Herbaceous perennials were absent. Annual grass and forb cover decreased by about 9% and 8%, respectively in monitoring plots; but these declines were not significant ($p > 0.20$). Annuals were absent in stabilization plots in 2011, but annual grasses were present on two plots in 2016.
Non-native Plant Dispersal and Invasion	New Species Detections		No new species of non-native plant were detected in either plot type or sampling event. Therefore, the condition is good. Trend is unchanging.
	Species New to a Plot		Because there were no new species detected park-wide using SODN's sampling methods, no species were new to any of the six plots.
	Total Cover (%)		Total non-native plant cover was 0% in all plots and monitoring periods.
	Buffelgrass Cover (%)		No buffelgrass was recorded during SODN's monitoring efforts.
	Red Brome Cover (%)		No red brome was recorded during SODN's monitoring efforts.
Overall Condition	Summary of All Measures		Although there appeared to be some issues with erosion in both plot types and Saguaro cactus nurse plant cover was absent, all remaining measures indicate good condition. The overall confidence level is medium because of the small number of plots sampled, data for monitoring plots were collected more than five years ago, and there have been only two rounds of sampling thus far. However, these plots will be monitored over the long-term. It's important to note that this condition rating is in light of the "new normal" for the monument. The mesquite bosque woodlands that once dominated the monument have been replaced by a near monoculture of drought-tolerant creosotebush.

One possibility for low species diversity is that the clay pan soil layer is virtually absent, having been excavated for use by the Hohokam in building the Great House and other structures (McIntyre et al. 2018). This soil layer, which is common in desert systems, may have water holding capacity characteristics that enhanced the growth of native vegetation. Low plant diversity in Casa Grande Ruins is also attributed to harsh environmental conditions, particularly the inaccessible water table (McIntyre et al. 2018). Because groundwater is too deep for roots to access, plants must rely on precipitation and retention of soil moisture to meet their water needs. However, Arizona has been in a drought since the early 2000s (Filippone and Raymond 2018).

The same reasons that help explain low native plant diversity could also explain the lack of non-native plants found in SODN's monitoring plots. Harsh environmental conditions, such as that of deserts, limit invasion by non-native plants (Zefferman et al. 2015). Although no non-native plants were encountered through SODN's sampling efforts, there are at least 35 non-native species in the monument (McIntyre et al. 2018). In addition to a harsh environment, other possible reasons for the absence of non-native plants in plots are that SODN's timing does not coincide with the growth of non-natives; most non-natives grow along roadsides and ditches, which were specifically excluded in SODN's sampling protocol; and/or that soils in the plots are poor habitat for non-natives (McIntyre et al. 2018). However, there is the potential for the non-native plants that do occur in the monument to spread or for new non-native plants from outside the monument to invade as conditions change. For example, both red brome and buffelgrass are among the 35 non-native species already present in the monument (McIntyre et al. 2018). If a fire were to occur, both those species would likely spread to other areas of the monument (Hubbard et al. 2012).

Casa Grande Ruins NM is a small, isolated area that is surrounded by agriculture, residential, and commercial development (NPS 2017a). Because the monument is embedded within a highly developed area, pesticide/herbicide drift from nearby agricultural areas, air pollution from vehicle exhaust, agricultural and airborne dust, and local erosion are all potential threats to native plants and soils in the monument (NPS 2017a). In the air quality assessment included in this report, the ozone level as related to plant health warrants significant concern as does nitrogen deposition. A number of studies have been proposed to better understand these threats in the monument, including a detailed soil survey and a germination study to determine how the monument's soils limit recruitment and survival of native plants (McIntyre et al. 2018).

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Soil Crusts

Background and Importance

Physical (inorganic) and biological (organic) soil crusts differ dramatically in their effects on ecosystem processes. These differences arise, in part, from the unique morphology and internal structure of each soil crust type (Belnap 2003). Physical soil crusts (PSC) develop via four primary mechanisms: raindrop impact (most common), compressional forces, such as livestock trampling, salts left behind with the evaporation of soil water, and trapped gas bubbles (Belnap 2003). PSCs can form on any soil type except for those in which fine clays and silts are absent (i.e., very coarse soils). Low soil aggregate stability and soils with low organic matter and high salt concentrations are the most susceptible to PSC development (Belnap 2003). PSCs can inhibit water infiltration by as much as 90%, which increases runoff and soil loss (Belnap 2003). PSCs may also prevent plant establishment (Belnap 2003).

Although PSCs are usually undesirable, they sometimes play an important role in funneling water to existing plants in hyperarid regions (Belnap 2003). In the Central Negev in Israel, PSCs were used funnel water to crops in ancient times, and this method, called runoff farming, was recently reintroduced there (Evenari et al. 1982 as cited in Belnap 2003).

In contrast, biological soil crusts (BSC) are critical desert components, performing a variety of important ecosystem services, including stabilizing soils, , influencing local hydrologic cycles, providing carbon to soils via photosynthesis, fixing atmospheric nitrogen, and increasing the bioavailability of phosphorus (Rosentreter et al. 2007). BSCs are communities of cyanobacteria, green algae, microfungi, mosses, liverworts, and lichens that live on the surface of desert soils (Belnap 2003). BSCs live in all the dryland regions of the world, and in arid and semi-arid environments, these highly specialized communities live in the open spaces between vascular plants (Belnap 2003). In some areas, BSCs represent as much as 70% of the living vegetative cover (Belnap et al. 2001). Because the primary components of biological soil crusts are photosynthetic, they require exposure to sunlight and water for growth and development.

Cyanobacteria and microfungi dominate biological soil crusts in the Sonoran Desert, with gelatinous (nitrogen-fixing) lichens (e.g., Collema), squamulose lichens and short mosses also present (Belnap et al. 2001). After filamentous cyanobacteria and and microfungi stabilize the soil, other species of cyanobacteria, followed by lichens and bryophytes (mosses and liverworts) colonize (Rosentreter et al. 2007). In the Sonoran Desert, most soil crust growth

Mature biological soil crust cover in Casa Grande Ruins NM. Photo Credit: © L. Baril.

occurs during the cool, moist winter (Belnap et al. 2001).

Data and Methods

This assessment is based on two indicators (mature biological soil crusts and physical soil crusts), each with a single measure (% cover). PSC data were collected as part of the National Park Service (NPS) vegetation and soils mapping program (Buckley et al. 2009), and BSC data were collected as part of the NPS Sonoran Desert Inventory and Monitoring Network's (SODN) upland vegetation and soils monitoring program (Hubbard et al. 2012).

The morphological groups used to clarify BSCs include light cyanobacteria, dark cyanobacteria, lichens, and bryophytes (i.e., mosses). The latter three types comprise mature BSCs. Mature BSCs are comprised of late successional species and are a good indicator of disturbance history since they take decades to develop (Belnap 2003).

In 2008, SODN established three monitoring plots in the monument, and in 2011, three additional plots were established to monitor stabilization efforts on near-surface archaeological sites (McIntyre et al. 2018). Thus, the initial 2008 plots are referred to as "monitoring plots" and the three plots established in 2011 are referred to as "stabilization plots" (McIntyre et al. 2018). Monitoring plots were read in 2008 and 2013, and stabilization plots were read in 2011 and 2016 (McIntyre et al. 2018).

Plots were 20 x 50-m (66 x 164-ft) with six, 20-m (66-ft) transects established every 10 m (33 ft) along the plot's long edge. BSC cover was recorded at 40 points, spaced 0.5 m (1.6 ft) apart, per line transect for a total of 240 points per plot (Hubbard et al. 2012). Cover was averaged by plot type (i.e., monitoring vs. stabilization). Although Buckley et al. (2009) also recorded BSC cover, we relied only on McIntyre et al. (2018) data for this measure because BSC cover is part of SODN's long-term monitoring program, whereas the NPS mapping effort was a one-time event.

Physical soil crust (salt flats) formed from repeated freeze-thaw cycles in Death Valley National Park. Photo Credit: © Wing-Chi Poon.

PSC data were collected in 25, 20 x 50-m (66 x 164-ft) plots distributed throughout the monument, including the proposed Adamsville unit (Buckley et al. 2009). The Adamsville unit is a 81-ha (200-ac) area located 4.6 km (4.0 mi) east of the monument containing aboveground prehistoric standing ruins and a ball court that currently belongs to the State of Arizona Land Department (NPS 2009). PSC cover was classified into one of five cover classes. The cover classes were as follows: none (0%), sparse (1-15%), medium (15-35%), common (35-60%), and dominant (>60%). Plot-level data were downloaded from the NPS vegetation mapping program website (NPS 2011b).

Reference Conditions

Reference conditions are described for resources in good, moderate concern, and significant concern condition categories (Table 33). Reference conditions for mature BSCs were based on Management Assessment Points (MAPS) developed by SODN for Casa Grande Ruins NM (McIntyre et al. 2018). MAPS "represent preselected points along a continuum of resource-indicator values where scientists and managers have together agreed that they want to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns" (Bennetts et al. 2007). MAPS do not define management goals or thresholds. Rather, MAPS "serve

Table 33. Reference conditions used to assess soil crusts in Casa Grande Ruins NM.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Mature Biological Soil Crusts	Cover (%)	≥10%	–	<10%
Physical Soil Crusts	Cover (%)	<1-15%	15-35%	>35%

Source: Buckley et al. (2009) and McIntyre et al. (2018).

as a potential early warning system," where managers may consider possible actions and options (Bennetts et al. 2007). Reference conditions for PSCs were derived from Buckley et al. (2009) and reviewed by Cheryl McIntyre, an ecologist/physical scientist with the NPS Chihuahuan Desert Inventory and Monitoring Network. Because Buckley et al. (2009) used five cover classes and reference conditions are based on three categories, we combined "none" and "sparse" (0-15%) for the good reference condition and used the lower threshold for "common" (i.e., 35%) as the upper limit for moderate concern condition. Above 35% PSC cover would be of significant concern.

Condition and Trend

For the two following measures, trend could not be determined because this assessment includes only one or two years of data.

Total BSC cover in Casa Grande Ruins NM was high, averaging roughly 60% in monitoring plots and 40% in stabilization plots (McIntyre et al. 2018). Mature BSC cover was more modest. In monitoring plots, mature BSC cover averaged 9.8% ± 1% in 2008 and 15.2% ± 10% in 2013. In stabilization plots, mature BSC averaged 14% ± 7% in 2016 (data were not reported for 2011) (Table 34). Although these values are within the range of good condition, at least for the second round of sampling, their standard errors are large. Given the >10% cover but large standard errors, we consider mature BSC to be in good condition but with medium confidence in the condition rating. According to McIntyre et al. (2018), BSC cover was highly variable within the two plot types and did not change between the two rounds of sampling for either monitoring ($p \geq 0.29$) or stabilization ($p \geq 0.16$) plots. However, this paired t-test included total BSC cover.

According to the NPS vegetation mapping database, no physical soil crusts were recorded in any of the

Table 34. Mature BSC cover for monitoring and stabilization plots at Casa Grande Ruins NM.

BSC Cover	Monitoring Plots		Stabilization Plots	
	2008	2013	2011*	2016
Bryophytes	0.3	0.0	No Data	~0.8
Lichens	7.0	8.5	No Data	~3.2
Dark cyanobacteria	2.5	6.7	No Data	10.0
Total Mature BSC	9.8	15.2	No Data	14.0

* Data for 2011 stabilization plots were not provided in SODN's excel file nor were these data available in McIntyre et al. (2018).

A scanning electron micrograph showing the cyanobacterial sheath sticking to sand grains (x90). Photo Credit: © USGS.

25 plots (NPS 2011b). Since PSCs were absent, this measure is in good condition, although confidence in the condition rating is low because data for this measure were collected more than 10 years ago (i.e., 2008) and because determining PSC cover was not the primary objective of the study.

Overall Condition, Threats, and Data Gaps

The two measures used to assess the condition of soil crusts are summarized in Table 35. Because confidence in the PSC condition rating is low, the condition was weighted less in determining the overall condition. However, since both measures were considered good, the overall condition is considered good. Trend could not be determined.

BSCs are sensitive to disturbance, especially compressional disturbances such as trampling by livestock, humans, and off-road vehicles (Belnap and Eldridge 2003). In Casa Grande Ruins NM, compressional disturbances pose only a minor threat because the monument is fenced and closed to visitors nightly (NPS 2017a). Trampling from illegal trespass, off-trail travel, or travel outside of the monument's developed areas as part of normal NPS operations may occur. However, the backcountry is inaccessible to visitors unless during a special tour, which is very infrequent and generally only authorized for educational institutions or archeological organizations (A. Hayes, Archeologist/Chief of Resource Stewardship & Facilities Management, Casa Grande Ruins NM, pers. comm. draft review 26 February 2019).

Table 35. **Summary of soil crust indicators, measures, and condition rationale.**

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Mature Biological Soil Crusts	Cover (%)		Total BSC cover was high in the monument with roughly 60% of monitoring plots and 40% of stabilization plots exhibiting BSC cover, and these values did not change significantly from round 1 values. In monitoring plots, mature BSC cover averaged 9.8% ± 1% in 2008 and 15.2% ± 10% in 2013. In stabilization plots, mature BSC averaged 14% ± 7% in 2016 (2011 data were not reported). Although these values are within the range of good condition, at least for the second round of sampling, their standard errors are large and "nearing potential concern" according to SODN.
Physical Soil Crusts	Cover (%)		No physical soil crusts were recorded in any of the 25 vegetation mapping plots in 2008. No current data were available, and this soil crust type is not monitored at the monument.
Overall Condition	Summary of All Measures		Although mature BSCs exhibited greater than 10% cover, the margins of error were large. And while PSCs were not reported during the vegetation mapping project, field data were collected in 2008. The monument is fenced, which reduces the risk of trampling, although off-trail travel occasionally occurs, either illegally or as part of NPS operations. BSCs could take decades or longer to recover from even minor disturbances.

Once disturbed, BSC recovery could take several decades or even hundreds of years, especially if soils exhibit low aggregate stability (Belnap 2003). Soil aggregate stability averaged 4.9 ± 0.2 SE in the monitoring plots and 4.0 ± 0.1 SE in the stabilization plots in 2013 and 2016, respectively (McIntyre et al. 2018). These values indicate moderately stable to stable soils in monitoring plots and moderately stable to somewhat unstable soils in stabilization plots. However, all values met the MAP for good condition (McIntyre et al. 2018).

Other threats include deposition of herbicides, pesticides, and dust, which could prevent BSCs from photosynthesizing or may kill them outright. Herbicides have been shown to impact growth and reproduction in laboratory settings, but the effects seem more pronounced in controlled settings than in the field (Belnap and Eldridge 2003) and differ depending on the type of herbicide used (Zaady et al. 2016). Because the monument is embedded within an agricultural matrix, pesticides and herbicides may drift into the monument, but the extent to which this occurs, if at all, is unknown. Strong winds during late summer also create haboob dust storms, and concentrations of coarse particulate matter are often highest during the spring and autumn when tilling and harvesting occurs (Clements et al. 2014, NPS 2017a). This only affects BSCs if deposited sediment buries them sufficiently to block incoming light. BSCs are also highly susceptible to damage by hot fires (Belnap and Eldridge 2003), although fuel loads are extremely low in the monument; according to the upland vegetation assessment in this report, herbaceous cover, which is a measure of fire hazard, was in good condition and is probably not a significant threat (McIntyre et al. 2018).

These localized threats to BSCs in the monument may be minor compared to that of climate change. Worldwide, carbon dioxide (CO_2) levels have risen, and photosynthesis in biocrust lichens can be limited by CO_2 availability. But while elevated CO_2 levels have the potential to improve conditions for BSCs, the positive effects are unlikely to mitigate the negative effects of increasing temperatures and declines in precipitation, which can kill them outright or greatly slow recovery from disturbance.

In the Sonoran Desert, as in many places in the world, temperatures have and continue to rise. The previous decade (2001-2010) in the southwestern U.S. was the warmest in the 110-year instrumental record, and the current decade is predicted to outpace the last (Garfin et al. 2014). A 10-year experiment of BSCs on the Colorado Plateau found that an increase in temperature reduced moss and lichen cover and increased the cover of light cyanobacteria, essentially transforming the community from a late successional state to an early successional state (Ferrenberg et al. 2015). Interestingly, the effects of climate change were similar to those produced by trampling (Ferrenberg et al. 2015).

At an experimental station in the Iberian Peninsula, a rise in temperature has been shown to significantly decrease the diversity of the BSC community, mostly as a result in the decline of lichens (Escolar et al. 2012). In contrast, mosses increased slightly in abundance under warmer temperatures (Escolar et al. 2012). Warming may also reduce carbon fixation, limiting the ability of the biocrust community to serve as a carbon sink (Ladron de Guevara et al. 2014).

The effects of changes in precipitation on the BSC community are more difficult to determine, partly because predicted changes in precipitation in dryland areas vary substantially. While changes in temperature are unidirectional, precipitation may shift in timing, magnitude, total amount, or all three.

In one study, Belnap et al. (2004) found that small, more frequent rainfall events reduced photosynthetic performance, nitrogenase activity, and the production of radiation-protective pigments, despite the total precipitation remaining the same (Belnap et al. 2004). In another study, Reed et al. (2012) found that more, smaller events resulted in high moss mortality and altered nitrogen cycles. And mature BSCs were the most negatively impacted. A 30% experimental decline in precipitation, however, had no negative effects on cover and physiological performance of BSCs, but the authors caution that moisture inputs from fog, dew, and water vapor may have compensated for the reduction (Escolar et al. 2012).

While BSCs are adapted to low moisture, they are only metabolically active when wet (Belnap et al. 2004). While changes in precipitation throughout the Southwest have been variable, with some places increasing and others decreasing (Garfin et al. 2014), the Sonoran Desert has been in an extended drought since 2000 (Filippone and Raymond 2018). In short, the effects of changes in the magnitude, timing and total rainfall, coupled with an increase in temperature may produce complex effects on the BSC community (Reed et al. 2016). Of note are not only the potential morphological changes to the BSC community as a result of climate change but also the potential for species-level responses. However, species-level data are lacking for the monument's BSC community (McIntyre et al. 2016).

The monument is a near monoculture of sparsely distributed creosotebush (*Larrea tridentata*) (Buckley et al. 2009). The low plant species diversity and cover elevate the important role that BSCs play in nutrient cycling and soil stabilization at Casa Grande Ruins NM (McIntyre et al. 2018). The lack of PSCs, at least as of 2009, also suggests that organic matter is present in sufficient quantities to prevent their development (Belnap 2003).

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Birds

Background and Importance

Changes in bird population and community parameters have been identified as an important element of a comprehensive, long-term monitoring program at Casa Grande Ruins National Monument (NM) (Beaupré et al. 2013). In the bird monitoring protocol for the National Park Service (NPS) Sonoran Desert Inventory and Monitoring Network (SODN) and other networks, Beaupré et al. (2013) describe how landbird monitoring contributes to a basic understanding of park resources and associated habitats as follows:

> Landbirds are a conspicuous component of many ecosystems and have high body temperatures, rapid metabolisms, and occupy high trophic levels. As such, changes in landbird populations may be indicators of changes in the biotic or abiotic components of the environment upon which they depend (Canterbury et al. 2000; Bryce et al. 2002). Relative to other vertebrates, landbirds are also highly detectable and can be efficiently surveyed with the use of numerous standardized methods (Bibby et al. 2000; Buckland et al. 2001).
>
> Perhaps the most compelling reason to monitor landbird communities in parks is that birds themselves are inherently valuable. The high aesthetic and spiritual values that humans place on native wildlife is acknowledged in the agency's Organic Act: "to conserve . . . the wild life therein. . . unimpaired for the enjoyment of future generations." Bird watching, in particular, is a popular, long-standing recreational pastime in the U.S., and forms the basis of a large and sustainable industry (Sekercioglu 2002).

Data and Methods

Casa Grande Ruins NM is dominated by a near monoculture of uniformly distributed creosotebush (*Larrea tridentata*); however, vegetation was historically more diverse, including well-developed velvet mesquite (*Prosopis velutina*) woodlands and barrel cactus (*Ferocactus wislizenii*) along with a variety of other shrubs and succulents (Buckley et al. 2009). Changes in vegetation were driven by a century of groundwater depletion and human alteration of the habitat in and around the monument (Buckley et al. 2009). Although velvet mesquite and barrel cactus persist in the monument, their extent has been substantially reduced. The monument's vegetation is classified as desert scrub and all bird surveys were conducted within this habitat type.

Three great horned owlets and an adult perched on the Great House. Photo Credit: NPS.

This assessment is based on two indicators (species occurrence and burrowing owl [*Athene cunicularia*]) with a total of four measures. The two measures of species occurrence are presence/absence of all species and presence of species of concern. The two measures of burrowing owl are abundance/population density and reproductive success. To assess these measures we relied on bioinventory data collected during 2001 and 2002 (Powell et al. 2006), data collected by SODN from 2007 to 2015, and a study of burrowing owls in and around the monument (Conway et al. 2005) during 2003-2005 and a follow-up study conducted during 2017 and 2018 (Tucson Audubon Society, J. Horst, director of conservation and research, e-mail message, 22 February 2018 and 18 October 2018).

Presence/absence was evaluated using the NPSpecies (NPS 2018d) bird list, which served as our foundation list for the monument. NPSpecies documents the occurrence of wildlife and plants by NPS unit and is typically updated using past surveys, such as those described in this assessment, and expert opinion. The list is included in Appendix C along with additional species reported by NPS staff and visitors and those that appear in the studies described here. For brevity, scientific names in the following tables are provided in Appendix C only.

We compared the NPSpecies list to the checklist of bird species documented for Pinal County, Arizona (Jenness 2018a). The checklist was developed by the Arizona Field Ornithologists in 2018 (Jenness 2018a). Using these lists, we determined how many of the species known to occur in the county also occur in the monument. We also compared the results of the bioinventory and SODN's surveys, both of which are described below.

Powell et al. (2006) surveyed breeding diurnal birds, nocturnal birds, and over-wintering birds during 2001 and 2002. Diurnal breeding birds were surveyed using the variable circular plot (VCP) method. Twelve points were established along one transect. All 12 stations were surveyed in 2001, but only eight were surveyed in 2002 due to time constraints (refer to Figure 5.1 in Powell et al. (2006) for point count locations). Each point was surveyed four times from mid-April to mid-June each year. Points were spaced a minimum of 250 m (820 ft) apart, and counts lasted for eight minutes at each point. Flyovers and birds beyond 75 m (246 ft) from each point count station were excluded from analysis of abundance, but since this measure focuses on presence/absence, we included total species richness. Because surveys began in April, the counts included migratory species in addition to breeding species (Powell et al. 2006).

Powell et al. (2006) also conducted nocturnal bird surveys at a four stations established 300 m (984 ft) apart (refer to Figure 5.1 in Powell et al. (2006) for a map of nocturnal survey locations). The four stations were surveyed three times during 2001 and twice during 2002. Surveys began with a three-minute passive listening period followed by two minutes of alternating broadcast and listening periods each lasting 30 seconds for each of four owl species. The four species were elf owl (*Micrathene whitneyi*), western screech-owl (*Megascops kennicottii*), burrowing owl, and barn owl (*Tyto alba*). Although great horned owls (*Bubo virginianus*) are known to occur in the monument, their calls were not broadcast because of their aggressive behavior toward other owls (Powell et al. 2006). The authors did not report the time of year during which nocturnal surveys were conducted, but they were probably done sometime during the breeding season.

Finally, the line-transect method was used to survey over-wintering birds in the monument. One line transect was divided into subsections of 250 m (820 ft) in length. Each subsection was surveyed by walking a straight line from one end of the section to the other at a pace of about 10 minutes per subsection. All species heard and/or observed while walking the transect were recorded. Lastly, incidental species not observed during VCP, nocturnal, or line transect surveys were noted.

The second survey used to evaluate presence/absence was conducted by SODN. SODN established one transect with one nine points (refer to Figure C.3-1 in Beaupré et al. (2013) for a map of survey locations). Each point was surveyed twice per year from 2007 to 2013 and in 2015 (Beaupré et al. 2013). Surveys were conducted during the first two weeks in May. Each point count station was surveyed for six minutes. SODN's protocol was similar to the VCP method in that points were spaced 250 m (820 ft) apart, flyovers were removed, and birds beyond 75 m (246 ft) from each point count station were excluded (Beaupré et al. 2013). But because this measure focuses on presence/absence, we included a complete list of species observed. SODN data were provided by K. Bonebrake, SODN data manager on 16 November 2017 via e-mail.

Although the two studies used similar methods for diurnal breeding season surveys, they are not directly comparable because of differences in effort (i.e., length of point counts, number of visits, and years surveyed). For this reason, we only compared presence/absence and not abundance. There were no current data with which to compare nocturnal or winter bird surveys. Instead, we compared these data against the certified NPSpecies list for the monument. Although these surveys were likely used, in part, to build the NPSpecies list, it is not unusual for some species to have been excluded, either accidentally or for reasons pertaining to the observation (e.g., questionable observation).

The second measure of species occurrence was the presence of species of concern. In the Arizona Partners in Flight (AZ-PIF) Bird Conservation Plan, 43 species of concern were identified for the state (Latta et al. 1999). The list was based on 11 criteria, which included relative abundance, breeding and wintering distribution, threats, and importance of Arizona to each species (Latta et al. 1999). We cross-referenced this list with the NPSpecies list for the monument (NPS 2018d), 2001-2002 inventory data, and with 2007-2015 SODN monitoring data. The NPSpecies list provided a certified record of the species that have been observed in the monument, while the other surveys/observations provide some measure of persistence over time.

Finally, we describe the studies used to evaluate the two burrowing owl measures. The burrowing owl is a species of open habitats, including grasslands, steppes, deserts, prairies, and agriculture with a range that extends from southwestern Canada to the Yucatan Peninsula (Poulin et al. 2011). Some owl populations do not migrate, including those that breed in the southern parts of California, Arizona, New Mexico, east Texas, and central Mexico (Poulin et al. 2011). Over the last 50 years, however, their range has contracted toward the south and west. In Canada, the burrowing owl is listed as endangered, and in Mexico it is listed as threatened (Poulin et al. 2011). Although the species is not listed by the U.S. Fish and Wildlife Service (USFWS) as threatened or endangered (USFWS 2018a), many states in which burrowing owls occur list the species as one of concern, including the State of Arizona (Latta et al. 1999).

In 2000, a multi-agency project to better understand the demography, migration, and population trends of burrowing owls throughout North America was initiated (Conway et al. 2005). As part of this larger project, Conway et al. (2005) compared demographic traits of owls nesting in "natural" desert habitat in Casa Grande Ruins NM to owls nesting in agricultural fields outside the monument. Data for this study were collected from March 2003 through March 2005. In 2017 and 2018, the Tucson Audubon Society conducted follow-up surveys of nesting owls in the monument (Tucson Audubon Society, J. Horst, director of conservation and research, e-mail message, 22 February 2018 and 18 October 2018).

The entire monument was surveyed for burrowing owls by walking 13 line transects separated by 100 m (328 ft) (Conway et al. 2005). Burrowing owl calls were broadcast continuously during these walking surveys. Surveys were conducted 24-27 March 2003 and 19-28 May 2004. Surveys were conducted at either dawn or dusk when burrowing owls are most active, although burrowing owls are often active throughout the day as well. These surveys provided abundance (total number of owls) and density (number of owls per area) for the monument.

Outside the monument, owls were surveyed by driving all roads within a 48-km (30-mi) radius around Casa Grande Ruins NM. Burrowing owl calls were broadcast at each of 326 point count locations in 2003 and 288 locations in 2004.

A burrowing owl in hand in Casa Grande Ruins NM. Photo Credit: NPS.

In 2003-2004, adult and juvenile burrowing owls were also captured and color banded to identify individuals. Banding data were used to determine annual return rates, migratory status, movement of adults, natal recruitment of juveniles, and burrow fidelity. Re-sight surveys were conducted during the winter of 2004-2005.

All burrows found during walking and road-based surveys were monitored weekly throughout the 2003 and 2004 breeding seasons. An infrared video probe was used to examine the contents of all burrows. Information on nesting activity, including number of eggs, number of young hatched, and number of young fledged, was documented. The nests of burrowing owls are difficult to monitor because they are located more than 2.0 m (6.6 ft) below ground. Therefore, observers considered a nest to be active if an adult was present at the burrow on at least two visits between the date the first egg in the population was laid and the date that the last egg in the population was laid (i.e., the local breeding season). A nest was considered successful if at least one young reached 40 days of age. Fledging success, or productivity, was calculated in two ways. First, active nest productivity was calculated by dividing the total number of young fledged by the total number of active nests. Second, successful nest productivity was calculated by dividing the total number of young fledged by the total number of successful nests.

Reference Conditions

Reference conditions for the four measures are shown in Table 36. Reference conditions are described for resources in good, moderate concern, and significant concern conditions.

Condition and Trend

NPSpecies lists 136 species of bird for the monument (NPS 2018d). Of the 136 species, 115 are considered "present," one species is considered "probably present," and 20 species are "unconfirmed." Four species that are considered "present" are non-native. The non-native species are Eurasian collared-dove (*Streptopelia decaocto*), European starling (*Sturnus vulgaris*), house sparrow (*Passer domesticus*), and rock pigeon (*Columba livia*).

According to the 2018 checklist of birds for Pinal County, 422 species occur in the county and 135 (32%) of them appear on the monument's NPSpecies list, including 116 species considered "present," 18 "unconfirmed" species, and one species that is "probably present." Many of the species documented for the county but not the monument were shorebirds, waterfowl, and wading birds. Since aquatic habitat (i.e., lakes and ponds) is not available in the monument, this

Table 36. Reference conditions used to assess birds.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Presence/ Absence	All or nearly all of the species recorded during early surveys/ observations in the monument were recorded by SODN.	Several bird species recorded during early surveys in the monument were not recorded by SODN (particularly if the species had previously been considered common).	A substantial number of species recorded during early surveys in the monument were not recorded by SODN (particularly if the species had previously been considered common).
	Presence of Species of Concern	A moderate to substantial number of species of conservation concern occur in the monument, which indicates that the NPS unit provides important habitat for these species and contributes to their conservation.	A small number of species of conservation concern occur in the monument.	No species identified as species of conservation concern have been recorded in the monument.
Burrowing Owl	Abundance/ Density	The abundance or estimated population density of burrowing owls has remained high since initial studies.	The abundance or estimated population density of burrowing owls has declined somewhat.	The abundance or estimated population density of burrowing owls has declined substantially.
	Reproductive Success	Reproduction (i.e., nesting success and productivity) has remained high since initial studies.	Reproduction has declined somewhat.	Reproduction has declined substantially.

is not surprising. In fact, the monument is primarily desert scrub, while the county contains a wide diversity of habitats including semidesert grassland, chaparral, and pinyon-juniper (*Pinus-Juniperus*) and pine-oak (*Pinus-Quercus*) woodlands, as well as rivers that support cottonwood (*Populus* spp.) and willow (*Salix* spp.) habitat (Jenness 2018b). More importantly, flood-irrigated agricultural fields support high species richness in the area surrounding the monument (Tucson Audubon Society, J. Horst, director of conservation and research, comments to draft assessment, 18 December 2018).

Powell et al. (2006) reported 82 species during VCP, line transect, nocturnal surveys, and through incidental observations (Appendix C). When considering only those species listed as "present" by NPSpecies, Powell et al. (2006) documented 71% of all bird species known to occur in the monument. Over the two seasons of field work, Powell et al. (2006) documented all of the breeding and resident bird species known to occur in the monument at the time; however, their species accumulation curve suggested that as many as 62 species could be added to the list with more effort. This was based on the ranges and habitat preferences of species known to occur in the region. The authors speculated that these species would represent mostly migrants. Since their survey, 33 additional species have been confirmed for the monument.

During VCP surveys, observers recorded 63 species over the two years of surveys (the authors did not report species richness by year). The most abundant species were Brewer's sparrow (*Spizella breweri*), mourning dove (*Zenaida macroura*), and Gambel's quail (*Callipepla gambellii*). Non-native house sparrows were also common. Nearly all Brewer's sparrows were encountered on a single day, which suggests that they were migrating through. The authors noted that as many as 40% of all species encountered during VCP surveys were using the monument exclusively during migration. Only nineteen species were present throughout the breeding season in both years.

During nocturnal surveys, four species were documented—lesser nighthawk (*Chordeiles acutipennis*), great horned owl, burrowing owl, and barn owl. No elf or western screech-owls were detected.

A hummingbird in Casa Grande Ruins NM. Photo Credit: NPS.

During winter line transect surveys, observers reported 32 species during 2002 with the mourning dove and great-tailed grackle (*Quiscalus mexicanus*) being the most common. More than half of the 32 species (19) were reported by only one or two individuals. The vast majority (85%) of all detections were from only eight species, suggesting a rather low overwintering bird diversity. However, birds are not as easy to detect during the non-breeding season, and this may have been a contributing factor to the apparent dominance by a few species. Eight species were reported during winter surveys that were not reported during migration/breeding surveys. These species included peregrine falcon (*Falco peregrinus*), northern flicker (*Colaptes auratus*), rock wren (*Salpinctes obsoletus*), and blue-gray gnatcatcher (*Polioptila caerulea*), among others.

Lastly, 36 species were observed incidentally, including eight species not reported by VCP, nocturnal, or line transects such as ferruginous hawk (*Buteo regalis*), common poorwill (*Phalaenoptilus nuttallii*), and black-chinned sparrow (*Spizella atrogularis*).

A total of 70 species were observed during SODN's surveys (Appendix C), which is slightly higher than the number of species observed during VCP surveys (63). Mourning dove, red-winged blackbird (*Agelaius phoeniceus*), rock pigeon, and great-tailed grackle were the most commonly detected species. A flock of 33 Franklin's gulls (*Leucophaeus pipixcan*) and a single double-crested cormorant (*Phalacrocorax auritus*) were reported in 2013, neither of which appear on the NPSpecies list. However, both species have been reported in Pinal County (Jenness 2018a). Franklin's gull is listed as an uncommon migrant and the cormorant is listed as a common resident (Jenness 2018a).

Annual richness averaged 34 species over the eight years of surveys, with a maximum richness of 39 species in 2012 and 2013, and a minimum richness of 27 species in 2015 (Figure 32). SODN reported 12 species that were observed in all eight years and 22 species that were observed in at least six years. Many of these species included desert scrub specialty species such as verdin (*Auriparus flaviceps*), Gambel's quail, and gilded flicker (*Colaptes chrysoides*). However, most species (37) occurred in three years or fewer. This suggests that there was high species turnover from year to year.

In summary, Powell et al. (2006) noted that the lack of prior bird surveys made it difficult to put their results into historical context. However, based on earlier species checklists and reports, the authors noted the absence of Crissal thrasher (*Toxostoma crissale*) and northern cardinal (*Cardinalis cardinalis*), which were historically present in the monument. Neither of these species were reported by SODN. It's also possible that species adapted to large mesquite forests would have historically nested in the monument, including Bell's vireo (*Vireo bellii*), yellow-breasted chat (*Icteria virens*), Abert's towhee (*Melzone aberti*), varied bunting (*Passerina versicolor*), and perhaps cactus ferruginous pygmy-owl (*Glaucidium brasilianum*) (Powell et al. 2006). Only the Abert's towhee appears on the NPSpecies list, but it is listed as "unconfirmed."

Powell et al. (2006) and SODN reported 50 species in common during breeding point count surveys. Thirteen species were reported exclusively by Powell et al. (2006) (Table 37), and 20 species were reported exclusively by SODN (Table 38). Of the 13 species observed exclusively during the earlier study, none are listed as common or abundant and all except three species are migratory in NPspecies. Although the survey period also captured some migratory species, the study was intended to survey breeding birds. The three resident and breeding birds were: mallard (*Anas platyrhynchos*), phainopepla (*Phainopepla nitens*), and prairie falcon (*Falco mexicanus*). Other than the phainopepla, point count surveys are not intended to survey waterfowl or raptors. Furthermore, aquatic habitat is absent in the monument. Since all but one species are not adequately surveyed using point count methods (e.g., raptors, waterfowl, migratory species), these results do not suggest a loss of species over time.

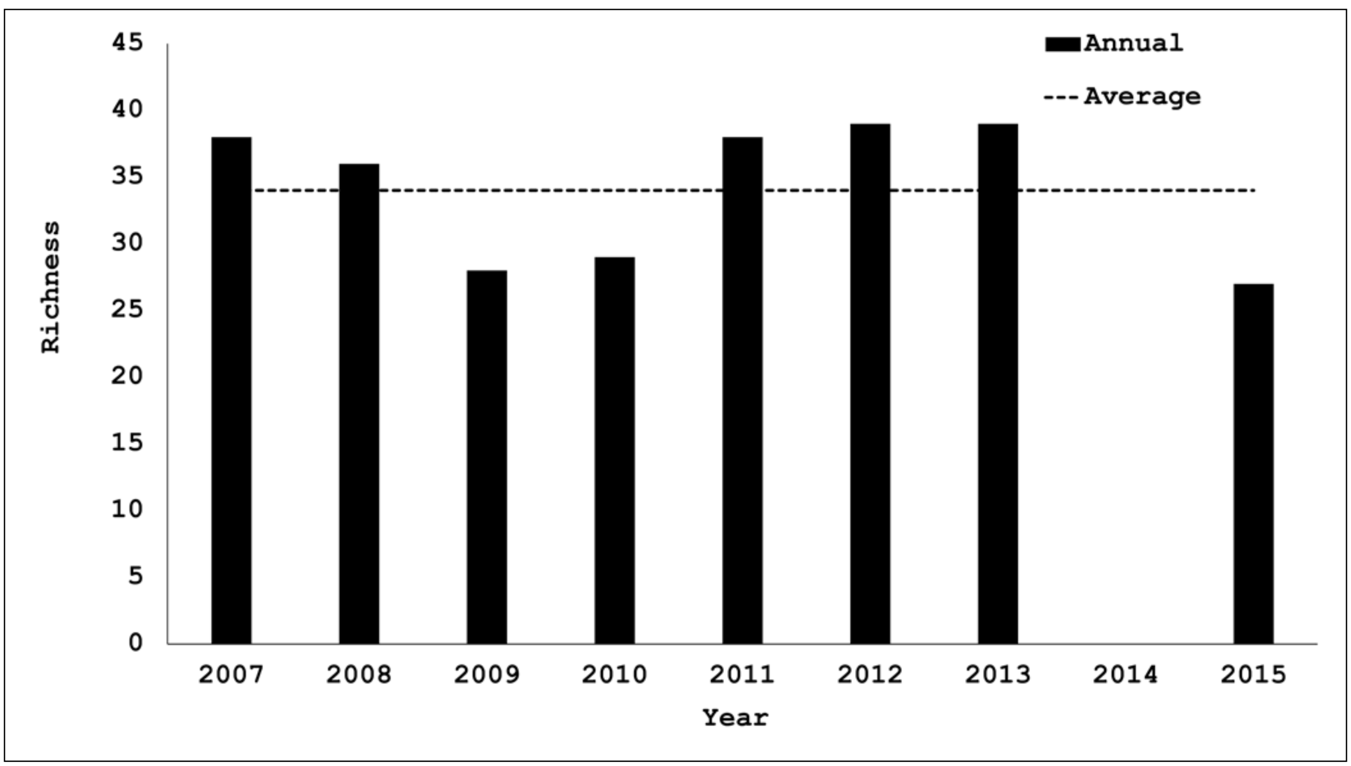


Figure 32. Annual bird richness in desert scrub in Casa Grande Ruins NM (2007-2013 and 2015).

Table 37. Bird species reported during 2001-2002 VCP surveys that were not reported during 2007-2015 SODN surveys.

Species	NPSpecies Abundance	NPSpecies Status
Black-necked stilt	Uncommon	Migratory
Chipping sparrow	Uncommon	Migratory
MacGillivray's Warbler	Uncommon	Migratory
Mallard	Rare	Resident
Nashville warbler	Uncommon	Migratory
Orange-crowned warbler	Uncommon	Migratory
Phainopepla	Uncommon	Breeder
Prairie falcon	Rare	Resident
Sandhill crane	Occasional	Migratory
Vesper sparrow	Uncommon	Migratory
Virginia's warbler	Uncommon	Migratory
Western wood-pewee	Rare	Migratory
Yellow warbler	Uncommon	Migratory

Table 38. Bird species reported during 2007-2015 SODN surveys that were not reported during 2001-2002 VCP surveys.

Species	NPSpecies Abundance	NPSpecies Status
Bank swallow	Uncommon	Migratory
Barn swallow	Uncommon	Migratory
Black-throated sparrow	Uncommon	Breeder
Blue-gray gnatcatcher	Uncommon	Migratory
Bronzed cowbird	Uncommon	Breeder
Brown-crested flycatcher	Uncommon	Breeder
Cassin's kingbird	Uncommon	Migratory
Common poorwill	Uncommon	Breeder
Cooper's hawk	Uncommon	Breeder
Double-crested cormorant	Not Listed	–
Eurasian collared-dove	Uncommon	Resident
Franklin's gull	Not Listed	–
Great egret	Uncommon	Migratory
Great horned owl	Uncommon	Breeder
Hammond's flycatcher	Rare	Migratory
Northern rough-winged swallow	Uncommon	Migratory
Rufous-winged sparrow	Uncommon	Breeder
Violet-green swallow	Uncommon	Migratory
White-faced ibis	Rare	Migratory
Yellow-headed blackbird	Uncommon	Resident

Of the 20 species listed by SODN but not Powell et al. (2006), none are listed as common or abundant and two were not listed by NPSpecies (Table 38). These two species were the double-crested cormorant and Franklin's gull, neither of which are adequately surveyed by point count methods. Of the species that are listed by NPSpecies, nine breed in the monument, six of which can be adequately surveyed by point count surveys (i.e., songbirds).

Overall, 43% of species listed as "present" in NPSpecies were observed during both breeding point count surveys. When considering only breeding birds (i.e., resident and breeding species), which were the target of point count surveys, 68% of the 74 species were observed during both studies. Based on reference conditions, the presence/absence of all species is good. Confidence is medium because of differences between the two studies. We did not determine trends in presence/absence because of these differences.

For the species of concern measure, we found that of the 43 priority bird species identified by the State of Arizona, 17 (11 "present," 5 "unconfirmed," 1 "probably present") are listed by NPSpecies (Table 39). Of the species considered "present," four are considered common. These are Brewer's sparrow, Burrowing owl, Costa's hummingbird (*Calypte costae*), and gilded flicker. However, burrowing owls have declined dramatically in the monument in recent years (Tucson Audubon Society, J. Horst, director of conservation and research, e-mail message, 22 February 2018 and 18 October 2018). The remaining seven species are listed as rare or uncommon. Lastly, about half of the confirmed species of concern pass through the monument during migration only.

Ten species of concern were reported during the bioinventory and eight species were observed during SODN's surveys. Seven of the 17 species listed in Table 39 were observed during both studies. These results suggest that Casa Grande Ruins NM not only provides breeding habitat for several species of concern, but that the monument also provides migration and winter habitat for species of concern. Winter and migration habitat are also important to the persistence of species of concern throughout their ranges. However, the monument probably serves as a short-term stopover during migration owing to limited vegetation diversity and structure and lack of water sources (Powell et al. 2006). None of the species

Table 39. Priority bird species listed by the State of Arizona that do or may occur in Casa Grande Ruins NM.

Species	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	BioInventory (2001–2002)	SODN Surveys (2008-2015)
Band-tailed pigeon	Unconfirmed	–	–	–	–
Black-throated gray warbler	Present	Rare	Migratory	X	–
Brewer's sparrow	Present	Common	Resident	X	X
Burrowing owl	Present	Common	Breeder	X	X
Costa's hummingbird	Present	Common	Breeder	X	X
Ferruginous hawk	Present	Rare	Migratory	X	–
Gilded flicker	Present	Common	Breeder	X	X
Gray flycatcher	Present	Uncommon	Migratory	X	X
LeConte's thrasher	Unconfirmed	–	–	–	–
Lucy's warbler	Present	Uncommon	Breeder	X	X
MacGillivray's warbler	Present	Uncommon	Migratory	X	–
Olive-sided flycatcher	Unconfirmed	–	–	–	–
Rufous-winged sparrow	Present	Uncommon	Breeder	–	X
Sage thrasher	Unconfirmed	–	–	–	–
Sagebrush sparrow	Probably Present	–	–	–	–
Swainson's hawk	Present	Uncommon	Migratory	X	X
Swainson's thrush	Unconfirmed	–	–	–	–

Sources: Latta et al. (1999), NPSpecies (NPS 2018d), Powell et al. (2006), and SODN unpublished data.

Note: X = species present.

listed in Table 39 are threatened or endangered under the USFWS Endangered Species Act (USFWS 2018a).

Based on the NPSpecies list considered "present," 25% of Arizona's species of concern occur in the monument (40% if including all 17 species). Of the six species of concern listed specifically for Sonoran desert scrub, three are absent or have not been confirmed. These are cactus ferruginous pygmy-owl, purple martin (*Progne subis*), and LeConte's thrasher (*Toxostoma lecontei*). Given reference conditions, these results warrant moderate concern. Confidence is medium, however, because many species of conservation concern are rare or secretive, which makes them more difficult to monitor. A more focused study on species of concern is necessary to further evaluate this measure. Nevertheless, these data provide a good baseline for occurrence. Trend was not determined.

For the abundance/density of burrowing owls measure, observers surveying the monument documented 15 burrowing owls in 2003 (6 adult males, 4 adult females, and 5 unknown adults) and 25 owls in 2004 (13 adult males, 1 adult female, and 11 unknown adults) (Table 40). Outside the monument, observers detected 49 burrowing owls in 2003 (13 adult males, seven adult females, 20 unknown adults, 9 juveniles, and 1 unknown age and sex). In 2004, observers detected 32 owls (13 adult males, 6 adult females, and 12 unknown adults).

The density of burrowing owls in the monument was 7.9 owls/km^2 (21.4 mi^2) in 2003 and 13.2 owls/km^2 (35.7 owls/mi^2) in 2004. The area of the monument is 1.9 km^2 (0.7 mi^2) (Beaupré et al. 2013). This density is substantially higher than other populations in California, New Mexico, Arizona and elsewhere (Poulin et al. (2011). We could not report on density for the surrounding agricultural land because the

Table 40. Abundance and density of burrowing owls in and around Casa Grande Ruins NM (2003-2004).

Year	Casa Grande Ruins NM		Outside Casa Grande Ruins NM
	Abundance	Density (owls/km^2)	Abundance
2003	15	7.9	49
2004	25	13.2	32

Source: Conway et al. (2005).

authors did not report the total number of kilometers of road surveyed. Although the study took place within a 48-km (30-mile) radius of the monument, only roadsides within this area were surveyed, but it's possible that owls also nested elsewhere in the study area. Thus, calculating density for the entire area would potentially severely underestimate density.

Based on re-sight data of banded owls in the entire study area, 42% were year-round residents. Of those that migrated, the annual return rate was higher in the monument (56%) outside the monument (44%). In the monument, 30 juvenile owls were banded in 2003. Of these, 33% returned to breed the following year. In contrast, of the 156 juvenile owls banded outside the monument in 2003, only 8% returned to breed the following year. Of the nine adult owls banded in 2003, 33% used the same nest burrow the following year, but 57% of the 35 adults banded outside the monument returned to the same burrow the following year.

In 2017, observers reported just three burrowing owls in the monument (one pair and a single individual) after a thorough survey, without using call playback, looking for owls and active burrows (Tucson Audubon Society, J. Horst, director of conservation and research, comments to draft assessment, 18 December 2018). In 2018, observers also reported one pair and a single individual. Because the abundance of owls had declined to only three owls in 2017, we did not calculate density (i.e., too few owls for reliable estimates).

However, this is still substantially higher than the density of owls in the Imperial Valley, California, where burrowing owl density is one of the highest anywhere (2 pairs/km^2 [5.1 pairs/mi^2]) (Poulin et al. 2011). And at 11 sites monitored in northern Mexico, Conway et al. (2007) found a range of 0.5 owls/km^2 (1.3 owls/mi^2) to 16.5 owls/km^2 (42.7 owls/mi^2). To our knowledge, no follow-up surveys in the agricultural fields outside the monument have been done, but that comparison would be extremely valuable.

The results of these studies are supported by SODN's 2007-2015 surveys in which observers made 26 detections of burrowing owls in 2007 and only six detections in 2015 (Figure 33). However, Powell et al. (2006) only reported 12 detections during 2001 and 2002 VCP (3 when excluding birds farther than 75 m [246 ft]) and estimated abundance at 0.03. Powell et al. (2006) also detected two burrowing owls during winter line-transect surveys and three owls during nocturnal surveys over the two years.

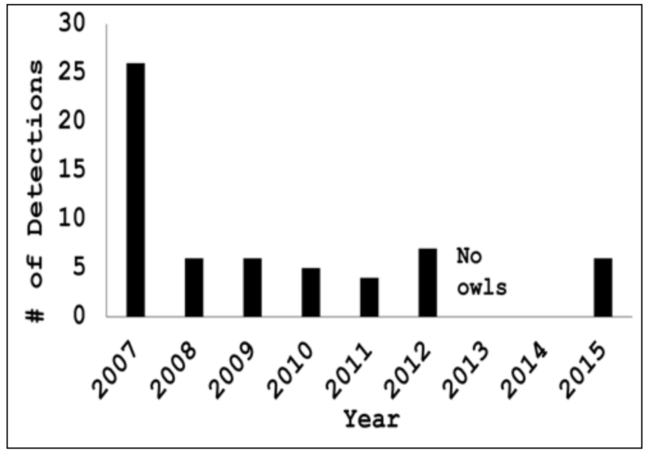


Figure 33. Number of burrowing owl detections during 2007-2013 and 2015 point count surveys.

Based on our reference conditions, these results warrant significant concern for the abundance/density of burrowing owls. Confidence in the condition rating is high. Trend has deteriorated.

Lastly, we summarize burrowing owl reproductive success. During the 2003 to 2004 breeding seasons, observers located and monitored 196 nesting attempts (35 in the monument and 161 in the surrounding agricultural fields) (Table 41). Within the monument, most burrowing owls nested in natural holes dug by round-tailed ground squirrels (*Xerospermophilus tereticaudus*) (77%), but they also used coyote (*Canis latrans*) burrows (8%), badger (*Taxidea taxus*) burrows (8%), and burrows of unknown origin (8%). Outside the monument, owls primarily selected man-made

Table 41. Reproductive success of burrowing owls in and around Casa Grande Ruins NM (2003-2004).

Reproductive Parameter	Casa Grande Ruins NM	Outside Casa Grande Ruins NM
# Nest Attempts	35	161
Nest Success (%)	69	62
# Fledglings/Active Nest	1.46	1.83
# Fledglings/ Successful Nest	2.13	2.80

Source: Conway et al. (2005).

structures such as irrigation canals (39%), but they also used natural burrows, including ground squirrel burrows (31%), pocket gopher (*Geomys bursarius*) burrows (21%), coyote burrows (4%), and badger burrows (5%).

Average nesting success over the two years of study was slightly higher in the monument (69%) than in the surrounding area (62%). Nesting density in the monument averaged 57 nests/km^2 (147.7 nests/mi^2) in 2003 and 126 nests/km^2 (326.4 nests/mi^2). The substantially higher density in 2004 was likely the result of the combined two-year effort in locating nesting burrows and not an increase in nesting density. Although nesting success was higher in the monument than outside the monument, there was no difference in productivity between the two study areas (t = 1.4, df = 184, P = 0.175). In the monument, active nests produced an average if 1.46 fledglings/active nest, while outside the monument, active nests produced 1.83 fledglings/active nest. In contrast, of those nests that were successful, those in Casa Grande Ruins NM produced significantly fewer (t = 2.5, df = 120, P = 0.016) fledglings (2.13 fledglings/successful nest) than those outside the monument (2.80 fledglings/successful nest). The authors speculated that this difference was due to the greater availability of prey in agricultural fields than in the monument (Conway et al. 2005).

In 2017, observers from the Tucson Audubon Society documented just one pair that appeared to initiate a nest at one of the artificial burrow complexes in the northwest quadrant of the monument (Tucson Audubon Society, J. Horst, director of conservation and research, e-mail message, 22 February 2018). Although there appeared to be activity at the nest burrow (e.g., feathers), observers did not verify whether the nest was active or if they fledged young. In 2018, observers verified a single nest attempt (4 eggs) in a natural burrow that failed for unknown reasons (Tucson Audubon Society, J. Horst, director of conservation and research, e-mail message, 18 October 2018). Observers believe that the same pair initiated a second nest in a nearby artificial burrow after the first nest failed. The pair again laid four eggs, three of which hatched. It's possible that the fourth egg also hatched, but the shape of the burrow precluded verification (Tucson Audubon Society, J. Horst, director of conservation and research, e-mail message, 18 October 2018). Observers were unable to return and verify if the three young fledged. Even if the single pair in both years fledged young, the substantial decline in the number of nesting pairs warrants significant concern. Confidence in the condition rating is high and trend has deteriorated.

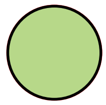
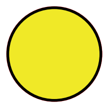
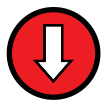
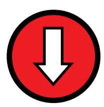
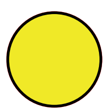
Overall Condition, Threats, and Data Gaps

We used two indicators and four measures to assess the current condition of birds in Casa Grand Ruins NM (Table 42). The results indicate that overall richness is high, at least according to NPspecies. Furthermore, nearly half of all species listed were observed during point count surveys (more than half when considering only breeding species). However, some key species were absent during these surveys, including Crissal thrasher and northern cardinal. Also, some species that may have historically nested in the monument when velvet mesquite was the dominant vegetation type include Bell's vireo, yellow-breasted chat, and Abert's towhee; however, none of these species are found in the monument today. Lastly, the once abundant and highly reproductive burrowing owl has all but disappeared from the monument in recent years. The reasons, however, are unclear but is a common trend throughout this species' range (Poulin et al. 2011).

Based on the four measures, the condition of birds in the monument warrants moderate concern. Confidence in the overall condition rating is medium because of differences between survey methods. Overall trend is unknown. Those measures for which confidence in the condition rating was medium were weighted more heavily in the overall condition rating than measures with high confidence (i.e., burrowing owl). This is because the two burrowing owl measures represent just one species. While the burrowing owl is considered a key species in the monument, the bird community as a whole is more indicative of the condition of birds as a resource.

Key uncertainties are how abundance for common species and species of concern have changed over time. Because of differences in survey methods, we could not compare abundance nor did we attempt to, but this is a necessary step to more effectively monitor bird communities in the monument, and basic point count surveys offer a cost-effective way to do this.

Table 42. Summary of bird indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Presence/ Absence		NPSpecies lists 136 species for the monument, 115 of which are considered present. The remaining species have not been confirmed. Additionally, SODN reported two species that were not listed in NPSpecies. Overall, 43% of species listed as present in NPSpecies were observed during both breeding point count surveys. When considering only breeding season species (i.e., resident and breeding species), which was the target group of the point count surveys, 68% of the 74 species were observed during both studies.
	Presence of Species of Concern		Based on the NPSpecies list considered present, 25% of Arizona's species of concern occur in the monument (40% if including all 17 species). Of the six species of concern listed specifically for Sonoran deserts scrub, three are absent or have not been confirmed. These are cactus ferruginous pygmy-owl, purple martin, and LeConte's thrasher. Species of concern that are present include burrowing owl, gilded flicker, and Costa's hummingbird.
Burrowing Owl	Abundance/ Population Density		In 2003-2004, the density of owls in the monument averaged 115 owls/km^2. In 2017 and 2013, average owl density was just 17 owls/km^2. While these estimates are still higher than for other areas in Mexico and California, owl density within the monument has substantially declined.
	Reproductive Success		In 2003 and 2004 there were a total of 35 nest attempts with 69% success. This was higher than nesting success in the surrounding agricultural fields (61%). However, productivity was lower in the monument than in the surrounding area, probably because of higher prey density in agricultural fields. Nevertheless, productivity was still good in 2003-2004. In contrast, only one pair attempted a nest in 2017 and 2018, but observers could not determine whether they were successful. Regardless of whether they were successful or not, the dramatic decline in the number of breeding pairs to just a single pair in recent years is concerning.
Overall Condition	Summary of All Measures		Although overall richness is high according to NPSpecies and nearly half of all species listed were observed during point count surveys (more than half when only considering the target group of birds). However, some key species were absent in these surveys such as Crissal thrasher and northern cardinal among others. The monument's habitat has changed considerably over time from velvet mesquite woodlands to a near monoculture of creosotebush. Lastly, the burrowing owl has declined dramatically in the monument. This once abundant species has all but disappeared for unknown reasons.

Migratory and other bird species face threats throughout their ranges, including: loss or degradation of habitat due to development, agriculture, and forestry activities; collisions with vehicles and man-made structures (e.g., buildings, wind turbines, communication towers, and electrical lines); poisoning; and landscape changes due to climate change (USFWS 2018b). The federal Migratory Bird Treaty Act protects more than 1,000 species of bird, and many of these species are experiencing population declines because of increased threats within their range (USFWS 2018b). Also, across the U.S., free-ranging domestic cats (*Felis catus*) may be responsible for as many as 2.4 billion bird deaths each year (The Wildlife Society 2011, Loss et al. 2013). NPSpecies lists both domestic cat and dog as "present" (NPS 2018d).

Non-native bird species could also be problematic for native birds. The four species reported for the monument are European starling, Eurasian collared dove, rock pigeon, and house sparrow. While the specific effects of these introduced species on native birds in the monument are unknown, these species likely compete with native birds for nesting habitat, food, and other resources as they do elsewhere (Cabe 1993, Lowther and Cink 2006, Lowther and Johnston 2014, Romagosa 2012).

Aside from habitat loss and non-native species, climate change may be the biggest threat to bird species in and around the monument. Not only do birds respond to changes in vegetation, but they also have heat tolerance thresholds (Wu et al. 2018). However, in a joint study by the NPS and National Audubon Society, researchers found that of 274 NPS units, the projected effects of climate change on birds by 2050 in Casa Grande Ruins NM is low (Schuurman and Wu 2018).

Of the 17 species listed in Table 39, six were included in the climate change study. Climate conditions for burrowing owl was the only projected improvement, while climate conditions for gilded flicker is expected to decline. Conditions for both Costa's hummingbird (winter) and Brewer's sparrow (summer) are expected to remain stable. The projections also included colonization by rufous-winged sparrow (*Peucaea carpalis*) and Swainson's hawk (*Buteo swainsoni*) during the summer. The latter species is currently listed as migratory by NPSpecies, while the rufous-winged sparrow is already listed as "present" during the breeding season according to NPSpecies (NPS 2018d). However, only a single individual was observed in 2008 as reported during SODN surveys. It's important to note that any changes in bird species ranges also depend on the habitat requirements of these species, but the study did not take into account how vegetation may respond to a changing climate.

Key data gaps include the unknown cause(s) for declines in burrowing owls. Although burrowing owls have declined in many locations throughout its range as a result of pesticide use, development, destruction of nesting burrows, human control of species that create natural nesting burrows, and other factors (Poulin et al. 2011), the monument also controls ground squirrels to protect archaeological structures (NPS 2011c), which are the owls' primary prey and provider of nesting burrows. Also, while knowledge of abundance and species richness is valuable, understanding nesting success is a natural extension that would further contribute to understanding the current condition of birds in the monument.

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Mammals

Background and Importance

Casa Grande Ruins National Monument (NM) is located in central Arizona within the Sonoran Desert ecoregion (AGFD 2013). The monument currently supports desert scrub vegetation with low plant diversity, but large stands of velvet mesquite (*Prosopis velutina*) historically dominated the monument (Judd et al. 1971). Long-term groundwater withdrawals have resulted in the replacement of mesquite with drought-adapted creosotebush (*Larrea tridentata*) (Judd et al. 1971, Buckley et al. 2009). The monument's former plant community represented the lateral extension of mesquite bosques that once flourished along the Gila River north of the monument (Judd et al. 1971, Stromberg 1993). Unlike the historically dense velvet mesquite bosques, creosotebush grows in a uniform pattern with large gaps and sparse cover between plants (Buckley et al. 2009).

The effects of plant community changes on mammals in and around Casa Grande Ruins NM are unknown, but mammals depend on plants for cover and forage, and plant community structure and composition influence mammal species composition and abundance. The health, distribution, and diversity of mammals that utilize the Gila River area are important to the monument and surrounding region because mammals serve as both predators and prey, seed dispersers, and grazers. However, mammals in the Sonoran Desert are difficult to study because they are highly mobile and often do not move along traditional migration routes (NPS 2018e). Mammals also exhibit wide variation in territory size depending on the species (e.g., larger mammals require more area) and the distribution of and access to resources. The National Park Service (NPS) Sonoran Desert Inventory and Monitoring Network (SODN) is currently testing protocols to survey medium and large mammals across its 11 network parks; a remote wildlife camera trapping study is being piloted at Casa Grande Ruins NM and six other network parks with the goals of establishing a baseline for mammal occupancy and to monitor changes in the community over time (NPS 2018e).

Data and Methods

To assess the condition of mammals at Casa Grande Ruins NM we used two indicators, species occurrence and nuisance species occurrence, with a total of five measures. The five measures are: presence/absence, species nativity, species of conservation concern, Archeological Site Management Information System (ASMIS) impact score, and the presence/absence of active mammal burrows. The species occurrence presence/absence measure was separated into two groups, small mammals and medium- to large-sized mammals, due to the varying degree of inventory

A fox or coyote den showing displaced pottery sherds in Casa Grande Ruins NM. Photo Credit: © K. Struthers.

and monitoring efforts devoted to each group at the monument.

Casa Grande Ruins NM's baseline inventory for mammals was conducted in 2002 using repeatable study designs and standardized field techniques (Powell et al. 2006). The inventory was part of a regional vascular plant and vertebrate effort that included eight Arizona and New Mexico national parks and monuments within the SODN. Powell et al. (2006) surveyed mammals using three methods. The three methods were: trapping for small mammals with Sherman® live traps, infrared-triggered photography to document medium and large mammals, and incidental observations made by the inventory crew and monument staff for all mammals regardless of size (Powell et al. 2006). And, as previously mentioned, an infrared camera pilot study was conducted in 2017 to develop a long-term protocol for surveying medium and large mammals across SODN parks (described further below). Lastly, we utilized wildlife observation cards submitted by visitors and monument staff during the 1930s to the late 1950s.

To evaluate the condition of the presence/absence of mammals at the monument, we compared the small, medium, and large mammal species recorded by Powell et al. (2006) to the wildlife cards and the 2017 camera trapping effort. For a complete list of species known to occur or that probably occur in the monument, we relied on the NPSpecies list of mammals (NPS 2018d). NPSpecies is a database that is maintained by the NPS and relies on previously published surveys, such as those included in this assessment, and expert opinion, to maintain a record of the presence or potential presence of species in lands managed by the NPS. The NPSpecies list also serves as a reference, especially to highlight potential data gaps of unconfirmed, but species expected to occur within national parks and monuments.

Small mammals include mostly ground-based rodents (e.g., mice, rats, and shrews). Sherman® live-traps were set in nine plots that captured the "slight" variation in vegetation across the monument. Traps were set for one to three nights during one spring trapping session and two autumn trapping sessions. Twenty-five traps were set for seven plots, five traps were set for one plot, and 50 traps were set for the last plot. We also included small mammal species reported via wildlife observation cards during the 1930s to the late 1950s and any small mammal photographs taken during the 2017 camera trapping effort, although this survey is not designed to document small mammals.

To assess the condition of medium-sized (e.g., rabbits, small cats, foxes, and raccoons) and large-sized (e.g., big cats, ungulates, and bears) mammals, we compared the 2002 camera trap survey results (and incidental observations) from Powell et al. (2006) to those from the 2017 camera trap effort (NPS SODN unpublished data). These datasets served to compare species occurrence at two points in time separated by 15 years. We looked for differences in the species observed during the first period but not during the later period to evaluate current condition. As with small mammals, we also included wildlife observation card data.

For the species nativity measure, we used the NPSpecies 'nativeness' designation to identify non-native species in the monument (NPS 2018d). We also included observations of non-native species as documented by the wildlife cards, Powell et al. (2006), and the 2017 camera trapping effort. If any non-native species was identified, it was evaluated for its impact(s) to native species, especially those of conservation concern.

For the presence of species of conservation concern measure, we compared the monument's list of 'present' species to the U.S. Fish and Wildlife Service's federal list of endangered and threatened species that are known to occur in Arizona (USFWS 2018a). We also reviewed species listed as those of greatest conservation need in Arizona (Arizona Game and Fish Department [AGFD] 2012). Under Arizona's Wildlife Action Plan, wildlife species may be listed as Tier 1A or 1B (or 1C although we do not consider those relatively lower-priority species here). Federally listed species and candidate species, as well as those for which a signed conservation agreement exists, or those that require monitoring after delisting, are included in the Tier 1A category and are considered to be of highest conservation priority (AGFD 2012). Tier 1B species are not listed as endangered or threatened by the USFWS, have not been recently removed from the USFWS list of threatened and endangered species, nor are they covered under a conservation agreement in the state of Arizona (AGFD 2012).

Finally, we address the nuisance species indicator using ASMIS data. Nuisance species are those that impact cultural and archeological resources in the monument and can be either native or non-native (NPS 2011c). The integrated pest management plan states that 25 nuisance species have occurred or still occur in the monument, many of which are mammals (NPS 2011c). Of the 25 nuisance species, the round-tailed ground squirrel (*Xerospermophilus tereticaudus*) is considered the most destructive (NPS 2011c). The primary concerns with nuisance species are the displacement and destruction of *in situ* artifacts and damage to cultural structures through digging and burrowing. Some canids are also considered nuisance species because they burrow after ground squirrels. Some canids may also displace artifacts by digging dens during the breeding season.

To assess the impact of nuisance species on archaeological features, we summarized the results of the ASMIS data, which is a tool used to evaluate the condition of cultural resources in lands managed by the NPS (ASMIS 2017). A total of 61 archeological sites were evaluated in fiscal year (FY) 2017 (three front country and 58 backcountry sites). The overall site condition is based on 10 criteria. Each criterion is assigned an impact score ranging between 0 (no evidence of impact) to 3 (>50% of site area affected). Two of the 10 criteria are directly related to animal disturbance: animal/burrowing or digging and animal trails. We summarized these data by the degree of mammal disturbance observed across the 61 sites rather than by the overall site condition because evaluating the effects of nuisance species is the primary objective of this measure.

While the ASMIS data report on the impacts of both past and current mammal disturbance (i.e., active and inactive burrows), the level of current mammal activity is of primary importance to managers at the monument. This measure addresses the presence/absence of active burrows. Current activity of most backcountry sites was assessed from August to November 2017 by a team from the University of Arizona (UA) (NPS 2018e). The UA team assessed whether burrows were active at each site visited and identified which species likely inhabited each burrow (NPS 2018e). Data on the number of burrows at each site was not reported in NPS 2018e; however, approximate numbers at each site visited were provided by Shakunthala Nair (Arizona Pest Management Center at the University of Arizona Extension via email on 7 February 2019), who conducted the survey. To assess the three front country sites, we used notes on burrow activity that were included on the ASMIS data sheets. The three front country sites are Compound A (Great House and historic buildings), Compound B (backfilled plazas just north of Compound A), and the ballcourt (ASMIS 2017).

Reference Conditions

Reference conditions for the five measures are shown in Table 43 and are described for resources in good, moderate concern, and significant concern conditions. Reference conditions for the three species occurrence measures were developed by NRCA staff and reviewed by NPS staff during the scoping meeting on 8 May 2018. Reference conditions for the ASMIS impact score were based on the impacts scale used to monitor sites. A score of 1 indicates minor impact (<10% of site area affected), a score of 2 indicates moderate impact (>10% to <50% of site area affected) and a score of 3 indicates significant impact (>50% of site area affected). Reference conditions for the presence/absence of active mammal burrows were based on management objectives for front country exhibits and sites (zone 3) and backcountry archeological sites (zone 4) as outlined in the Integrated Pest Management Plan environmental assessment (NPS 2011c). According to the plan, the objective for zone 3 is no more than 20 active rodent holes, and the objective for zone 4 is no more than 40 active rodent holes. For this measure, moderate and significant concern conditions were combined.

A round-tailed ground squirrel. Photo Credit: © R. Shantz.

Table 43. Reference conditions used to assess mammals.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Presence/Absence	All or nearly all of the species recorded during early surveys/observations in the monument were recorded during later surveys.	Several species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the monument).	A substantial number of species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the monument).
	Species Nativity	Non-native species are absent.	Non-native species are present but are limited by habitat type and/or do not outcompete or negatively impact native species.	Non-native species are widespread, indicating available habitat, and outcompete or negatively impact native species.
	Species of Conservation Concern	A moderate to substantial number of species of conservation concern occur in the monument, which indicates that the NPS unit provides important habitat for these species and contributes to their conservation.	A small number of species of conservation concern occur in the monument.	No species identified as species of conservation concern occur in the monument.
Nuisance Species Occurrence	ASMIS Impact Score	An impact score of 0 (no impact) or 1 (<10% of site area affected) was assigned to the majority of sites.	An impact score of 2 (10% to 50% of site area affected) was assigned to the majority of sites.	An impact score of 3 (>50% of site area affected) was assigned to a majority of sites.
	Presence/Absence of Active Burrows	No more than 20 active rodent holes in zone 3 and no more than 40 active rodent holes in zone 4.	More than 20 active rodent holes in zone 3 and more than 40 active rodent holes in zone 4.	More than 20 active rodent holes in zone 3 and more than 40 active rodent holes in zone 4.

Condition and Trend

NPSpecies lists 17 species of mammal, 15 of which are considered ‘present’ (Table 44). The two remaining species, both native, are considered ‘probably present.’ All but two of the 17 species are native. The two non-native species are the domestic dog (*Canis familiaris*) and cat (*Felis catus*). An additional six mammals that were identified to genus only were also included in NPSpecies, but because these were not identified to species and are under review, we did not consider them further. Lastly, eight species that were not listed in NPSpecies but were reported by other efforts were included in Table 44. These species are described in the sections below.

Powell et al. (2006) captured 154 individuals from the seven species of small mammal across the 470 trap nights (Table 44). Merriam’s kangaroo rat (*Dipodomys merriami*) was the most widespread and abundant species. The Sonoran Desert pocket mouse (*Chaetodipus penicillatus*) was also widespread and nearly as abundant as the kangaroo rat. The round-tailed ground squirrel was among the least common of the seven species. Based on this effort, Powell et al. (2006) asserted that they captured most of the small mammal species in the monument. However, they suggested that several species could still be or were historically present, including little pocket mouse (*Perognathus longimembris*), Bailey’s pocket mouse (*Chaetodipus baileyi*), cactus mouse (*Peromyscus eremicus*), Arizona cotton rat (*Sigmodon arizonae cienegae*), and the non-native house mouse (*Mus musculus*) (Powell et al. 2006). Other species that were likely present when mesquite bosque dominated the monument and plant density was greater include Botta’s pocket gopher (*Thomomys bottae*), silky pocket mouse (*Perognathus flavus*), banner-tailed kangaroo rat (*Dipodomys spectabilis*), western harvest mouse (*Reithrodontomys montanus*), hispid cotton rat (*Sigmodon hispidus*), and Merriam’s pocket mouse (*Perognathus merriami*) (Powell et al. 2006). Of the ground-dwelling small mammals, only the western harvest mouse was reported prior to Powell et al. (2006) in 1935. The banner-tailed kangaroo rat is listed as ‘present’ by NPSpecies (NPS 2018d) but was not documented by any of the studies included in this assessment.

Table 44. Mammal species recorded at Casa Grande Ruins NM.

Mammal Size	Common Name	Scientific Name	Wildlife Cards	Powell et al. (2006)	2017 Camera Trap	NPSpecies Occurrence (NPS 2018d)
Small	Arizona pocket mouse[1]	*Perognathus amplus*	–	X	–	Present
	Banner-tailed kangaroo rat[1]	*Dipodomys spectabilis*	–	–	–	Present
	Cave myotis[1]	*Myotis velifer*	1941	–	–	Not Listed
	Cliff chipmunk	*Tamias dorsalis*	–	–	–	Present
	Deer mouse	*Peromyscus maniculatus*	1935	X	–	Present
	Merriam's kangaroo rat	Dipodomys merriami	1941	X	–	Present
	Mexican free-tailed bat[1]	*Tadarida brasiliensis*	1930-1947	–	–	Probably Present
	Round-tailed ground squirrel	*Spermophilus tereticaudus*	1936-1958	X	X	Present
	Sonoran Desert pocket mouse	*Chaetodipus penicillatus*	–	X	–	Present
	Southern grasshopper mouse	*Onychomys torridus*	–	X	–	Present
	Western harvest mouse	*Reighrodontomys megalotis*	1935	–	–	Not Listed
	Western mastiff bat[1]	*Eumops perotis*	1933-1957	–	–	Probably Present
	Western white-throated woodrat	*Neotoma albigula*	–	X	–	Present
Medium/Large	American badger	*Taxidea taxus*	–	X	–	Present
	Antelope jackrabbit[1]	*Lepus alleni*	1937-1944	–	–	Not Listed
	Black-tailed jackrabbit	*Lepus californicus*	–	X	X	Present
	Bobcat	*Lynx rufus*	–	–	X	Not Listed
	Collared peccary	*Tayassu tajacu*	1956	–	–	Not Listed
	Coyote	*Canus latrans*	1935-1957	–	X	Not Listed
	Desert cottontail	*Sylvilagus audubonii*	1934-1947	X	X	Present
	Domestic cat[2]	*Felis catus*	–	X	–	Present
	Domestic dog[2]	*Canis familiaris*	–	X	X	Present
	Kit fox[1]	*Vulpes macrotis*	1950-1957	–	X	Not Listed
	Ringtail	*Bassariscus astutus*	1932-1946	–	–	Not Listed
	Striped skunk[3]	*Mephitis mephitis*	1936-1947	X	–	Present

Note: X = species present.

[1] Tier 1B species.

[2] Non-native species.

[3] Unknown skunk species reported on the wildlife cards.

Although Powell et al. (2006) did not net bats, they did survey the Great House repeatedly for roosts, which were absent during all surveys. Clemenson (1992) notes that the Mexican free-tailed bat (*Tadarida brasiliensis*) is the only species known to breed in the monument. In 1944, as many as 5,000 bats roosted in the ruins, and there are numerous records of this species beginning in the 1930s to at least 1947 (Table 44). By 1956, however, this species no longer roosted in the monument (Clemenson 1992). NPSpecies considers the Mexican free-tailed bat 'probably present.' Two other bat species were reported on wildlife observation cards, including the cave myotis (*Myotis velifer*) and the western mastiff bat (*Eumops perotis*). The cave myotis is only known from a single specimen collected from the monument in 1941, while the western mastiff bat was described as numerous from 1933 to at least 1957 according to wildlife observation cards. Powell et al. (2006) list 16 additional species of bat that could be present in the monument.

Incidental observations of small mammals reported by Powell et al. (2006) were rare, with a single observation of a cliff chipmunk (*Tamias dorsalis*) that could have been misidentified. None of the small mammals listed in Table 44 were observed during all surveys/observation efforts. While the 2017 camera trapping effort recorded the round-tailed ground squirrel, the survey was intended for larger mammals and is not suitable to determine the presence of small mammals. The utility of the wildlife observation cards from the 1930 through the 1950s is limited because they are not part of a standardized study. Therefore, Powell et al.'s (2006) inventory represents the only standardized survey of small mammals in the monument. Unfortunately, without an additional survey to compare the presence/absence of small mammals in the monument, the current condition is unknown with an unknown trend.

No large mammals and six medium-sized mammals were observed at the monument in 2002 (Table 44). Powell et al. (2006) state that the camera trapping effort was insufficient for surveying medium and large mammals at the monument, despite the 134 days of camera operations. The camera recorded 17 photographs of desert cottontail rabbits (*Sylvilagus audubonii*) and 10 photographs of black-tailed jackrabbits (*Lepus californicus*). Feral cats and domestic dogs were also observed by monument staff and survey personnel. American badger (*Taxidea taxus*) bones and striped skunk (*Mephitis mephitis*) observations were also reported in Powell et al. (2006).

The 2017 camera trapping effort captured photographs of three of the six species taken during the 2002 camera trapping effort. These species were the black-tailed jackrabbit, desert cottontail, and domestic dog. The 2017 camera trapping effort also captured photographs of bobcat (*Lynx rufus*), kit fox (*Vulpes macrotis*), and coyote (*Canis latrans*). According to the monument's pest management plan, 21 coyote dens were recorded in the monument from 2006 to 2011, suggesting that this species is common (NPS 2011c). The three species not recorded in 2017 that were reported in 2002 were domestic cat, American badger, and striped skunk.

Several species were reported via wildlife cards during the 1930s through the 1950s that have not been reported since. These species include antelope jackrabbit (*Lepus alleni*), collared peccary (*Tayassu tajacu*), and ringtail (*Bassariscus astutus*) (Table 44). Species notably absent from all surveys and observations were raccoon (*Procyon lotor*), hooded skunk (*Mephitis macroura*), white-backed hog-nosed skunk (*Conepatus leuconotus*), gray fox (*Urocyon cinereoargenteus*), and mule deer (*Odocoileus hemionus*) (Powell et al. 2006). Six of the medium and large mammal species listed in Table 44 were not included in NPSpecies. While some of the earlier observations (e.g., ringtail) should be confirmed before updating NPSpecies, more recent observations (e.g., kit fox) warrant changes to NPSpecies. Only the desert cottontail was observed in all three survey/observation efforts.

Because Powell et al. (2006) concluded that the camera trapping effort was insufficient to document medium and large mammals in the monument and the 2017 camera trapping effort is still in the pilot study phase, we conclude that more data are needed to fully evaluate the presence of medium and large mammals in the monument. Therefore, the condition is unknown. Because the condition is unknown, confidence is low and trend is unknown.

For the species nativity measure, we found that two non-native mammals occur in the monument. These two species are the domestic cat and dog. Monument

The presence of kit fox at Casa Grande Ruins NM was confirmed during the 2017 camera trapping effort. Photo Credit: © M. Christiansen.

staff noted that feral cats were observed regularly in 2002 (Powell et al. 2006). No feral cats were reported via the wildlife observation cards nor were feral cats captured on camera during the 2017 effort, although they probably continue to pass through the monument. Domestic dogs were also reported in Powell et al. (2006) as incidental observations, and photos were recorded during the 2017 effort. As with cats, domestic dogs were not reported via the wildlife observation cards.

Although there are no studies of how domestic cats and dogs have specifically affected the monument's wildlife, their presence in other areas have caused and continue to cause substantial disturbance to native species. Throughout the U.S., free-ranging domestic cats may be responsible for more than one billion bird deaths each year (Loss et al. 2013). For small mammals, the predation rate from domestic cats is much higher, ranging between 6.3 and 22.3 billion deaths annually (Loss et al. 2013). Domestic dogs also prey on wildlife, and in addition, transmit diseases, cause disturbances that can result in nest failure, and even hybridize with wild canids (Hughes and Macdonald 2013).

The monument is situated in an urban area, which promotes use of the monument by these non-native species. In general, domestic cats and dogs may become more common as development near the monument's boundary increases. For these reasons, the condition is of significant concern. However, the current trend is unknown and the confidence level is low since there are no monument-specific studies.

For the species of conservation concern measure, we found that seven Tier 1B and no Tier 1A mammal species have been observed at the monument (Table 44). The five small mammals are the Arizona pocket mouse (*Perognathus amplus*), banner-tailed kangaroo rat, Mexican free-tailed bat, western mastiff bat, and cave myotis. The two medium-sized mammals are the kit fox and antelope jackrabbit. Only the Arizona pocket mouse was reported by Powell et al. (2006). The banner-tailed kangaroo rat was is listed as 'present' by NPSpecies but was not reported in other studies or survey efforts, and the Mexican free-tailed bat and western mastiff bat are both listed as 'probably present' by NPSpecies. However, both bat species were reported as roosting and breeding in the Great House during the 1930s and 1940s according to wildlife observation cards, and Mexican free-tailed bats still use the Great House on an irregular basis (NPS, K. Cordova, former Superintendent at Casa Grande Ruins NM, received by Phyllis Pineda Bovin, phone call, 10 January 2018). The first photo documentation of a kit fox was recorded during the 2017 wildlife camera trapping effort but is not listed by NPSpecies. Wildlife observation cards also indicate that kit foxes were present in the 1950s (five reports), and the antelope jackrabbit was reported during the late 1930s to mid-1940s but has not been reported since. Finally, a cave myotis was found dead in the monument in 1941, but this is the only report of that species.

While seven Tier 1B species have been reported in the monument, only three have been reported since the 1950s—Arizona pocket mouse (Powell et al. 2006), kit fox (NPS SODN unpublished data), and Mexican free-tailed bat (NPS, K. Cordova, former Superintendent at Casa Grande Ruins NM, received by Phyllis Pineda Bovin, phone call, 10 January 2018). The monument may still provide habitat for most, if not all, of these species, but without current data that include mammals of all size classes, including bat surveys, the condition is unknown. Because of the unknown condition, confidence is low and trend is unknown.

For the ASMIS impact score, we found that of the 61 archeological sites evaluated in FY 2017, all but two (3%) exhibited evidence of animal digging and burrowing. However, of the 61 sites, 41 (67%) scored an impact of 1 (<10% of site area), 17 sites (28%) scored an impact of 2 (10-50% of site area), and one site (2%) received an impact score of 3 (>50% of site area). Animal trails in these sites were less common. Most sites (79%) scored a 0 for animal trails, 12 (20%) sites scored a 1, and at one site surveyors did not specify whether the trail damage was caused by visitors or wildlife. The 12 sites that exhibited animal trails also contained mammal burrows. Nearly all burrows were created by round-tailed ground squirrels. While evidence of round-tailed ground squirrel occurrence was widespread, damage was minimal. Based on reference conditions, the condition for this measure is good. Confidence in the condition rating is high because the data are recent and the ASMIS method was designed to assess this type of damage. Data for trend were not available.

Lastly, although burrows were found in nearly all sites during the ASMIS survey, ground squirrel activity appeared low. Table 45 lists the 16 backcountry sites with active burrows. Some of the sites contained large burrows that were created by foxes, or coyotes, but none of the larger burrows were occupied during the survey (NPS 2018e). In all, there were 10 sites with active round-tailed ground squirrel burrows and eight sites with inactive canid burrows, which includes two sites with both active ground squirrel burrows and inactive canid burrows. The approximate number of active burrows across backcountry sites ranged from a minimum of 37 to a maximum of 51 (Table 45). The surveyor notes that ground squirrel activity during the survey was very low and underestimated activity.

It's important to note that at the same time as the UA backcountry survey, the U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) removed 100 round-tailed ground squirrels, 86 deer mice, and six cottontail rabbits from the monument (NPS 2018e). This is far fewer than the 300 to 400 squirrels trapped in 2013 (NPS 2018e).

Table 45. Archeological sites with the greatest mammal activity in Casa Grande Ruins NM as observed during autumn of 2017.

Site #	Description of Burrows	Possible Animal Inhabitants	Approximate # of Burrows
9, 10, 11	Active burrows with loose soil around entrance.	Round-tailed ground squirrel	8-10; 10-15
19, 20	Large holes, not active.	Fox or coyote	–
23, 24, 25, 26	Active burrows, with loose soil around entrance.	Round-tailed ground squirrel	15-20
46, 49	Large holes, not active.	Fox or coyote	–
50, 51, 54, 55	Large holes, not active.	Fox or coyote	–
54, 55	Burrows on mounded areas, some with loose soil around entrance.	Round-tailed ground squirrel	2-3
61	Burrows on mounded areas, some with loose soil around entrance.	Round-tailed ground squirrel	2-3

Source: NPS (2018e) and Shakunthala Nair (University of Arizona).

The two front country sites (Compound A, Compound B, and the prehistoric ballcourt) were not surveyed by the UA team, but notes included on the ASMIS data forms indicate numerous active burrows occurred at Compound A. At Compound B, many large and small mammal burrows were observed, but they were suspected of being inactive. No active burrows were observed at the ball court, although there were several small inactive burrows there. Because no estimates of the number of active front country burrows were reported, the condition for zone 3 is unknown and confidence is low. The condition of backcountry sites, however, is of moderate/significant concern because between 37 and 51 active burrows occurred there. Confidence in this condition rating is medium since the values reported are estimates.

Overall Condition, Threats, and Data Gaps

To assess the condition of mammals at Casa Grande Ruins NM, we used two indicators with five measures, which are summarized in Table 46. Because of the lack of repeat surveys at the monument and limited recent data, the overall condition of mammals is unknown. Usually, measures with an unknown condition are not used to evaluate the overall condition, but in this case, the absence of repeat surveys, the age of the inventory data, and the limited recent data indicate that more data are needed to fully evaluate mammals at the monument. As more data are collected during the camera trapping effort, mammal presence/absence can be better evaluated, at least for medium and large mammals.

Most native mammals are susceptible to human development, harassment, habitat loss, poor water quality, and human-influenced mortality. Medium-to large-sized mammals are more prone to stressors related to an accumulation of human activity because their home ranges most likely surpass the monument where ideal habitat is limited. Due to the limited distance of small mammals' home ranges, which most likely confines this group of mammals, monument staff has greater control of eliminating stressors that reside within the monument's boundaries, although some of these native species are considered a nuisance when they occur in archeological sites.

Table 46. Summary of mammal indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Species Presence / Absence		The current condition of presence/absence is unknown because only one inventory has been conducted at the monument. Although there is a follow-up camera trapping effort for medium and large mammals, there are too few data to compare to the earlier data, especially since the earlier data do not accurately reflect the medium and large mammal community at the time of the surveys. No information on trend is available, and our confidence level is low.
	Species Nativity		Two non-native mammals have been documented at the monument. Although no studies of the influence of feral cats and dogs on the monument's native mammal community are available, their impact to native fauna elsewhere is well documented. Because of the uncertainty regarding monument-specific effects, the confidence is low. There are no data to evaluate trends.
	Species of Conservation Concern		While seven Tier 1B species have been reported in the monument, all but one has not been reported since the 1950s. The monument may still provide habitat for most, if not all, of these species, but without current data that include mammals of all size classes, including bat surveys, the condition is unknown. Because of the unknown condition, confidence is low and trend is unknown.
Nuisance Species Occurrence	ASMIS Impact Score		Ground squirrel burrows are present at 97% of archeological sites, and 16% of sites contain active burrows. However, of the 61 sites, 41 (67%) scored an impact of 1 (<10% of site area), 17 sites (28%) scored an impact of 2 (10-50% of site area), and one site (2%) received an impact score of 3 (>50% of site area). So while evidence of round-tailed ground squirrel occurrence was widespread, damage was minimal. There are no data to evaluate trends.
	Presence/ Absence of Active Burrows	Front Country Backcountry	Burrowing activity was observed at all three front country sites, but active burrows were only noted at Compound A. Because the number of active burrows there was not estimated, the condition is unknown and confidence is low. Ten backcountry sites contained active round-tailed ground squirrel burrows with an estimated minimum of 37 to 51 active burrows total. Confidence in the condition rating for backcountry sites is medium because the number of burrows was estimated.
Overall Condition	Summary of All Measures		In most cases, measures without a condition are not used to evaluate overall condition. However, the lack of consistent data and current data for several measures has led to uncertainty regarding the current condition of the native mammal community.

Although native, the round-tailed ground squirrel is the most problematic species of mammal in the monument, causing direct damage to archeological resources through digging and burrowing. Ground squirrels are disproportionately attracted to prehistoric sites because soils there are less compacted and easier to burrow into than elsewhere in the monument (NPS 2018e). A study of round-tailed ground squirrel ecology in the monument found that density there was higher than elsewhere, with a female population of five to 18 residents per 2,500-m^2 plot (Monroe and Koprowski 2014). Ground squirrels also indirectly affect archeological resources by attracting predators such as kit foxes, badgers, coyotes, and domestic dogs, that dig for squirrels. Some of these predators also excavate dens during the breeding season. Other small mammals, such as mice, wood rats, and bats were included as nuisance species in the 2011 integrated pest management plan, but their densities and impacts to archeological resources are less problematic because of lower population sizes and, in the case of bats, the absence of roost sites (NPS 2011c).

Increased development and settlement of humans surrounding the monument can stress native mammals through wildlife corridor displacement, habitat loss and fragmentation, and restricted access to resources (Powell et al. 2006). In 2004, a group of concerned land managers and biologists from federal, state, and regional agencies, along with researchers from Northern Arizona University, 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 protected areas. This effort became known as the *Arizona Missing Linkage*s project, identifying 152 statewide coarse-level linkage zones (AWLW 2006). The Pinal County Wildlife Connectivity Assessment grew out of this effort. In 2010 AGFD partnered with Pinal County to identify important wildlife corridors in the county so that transportation engineers, land-use planners, developers, and biologists could incorporate these considerations into their planning efforts (AGFD 2013). According to HabiMap™, a web-based data viewer created by AGFD to illustrate various wildlife data in Arizona, including wildlife linkages, show that the area surrounding Casa Grande Ruins NM is not within a known wildlife corridor (AGFD 2015). The absence of large mammals (e.g., bears, mountain lion, deer) suggest that habitat fragmentation surrounding the monument has impeded movements for these species.

Historically, the monument may have served as a wildlife corridor when mesquite bosques extending to the Gila River were present. Today however, much of the land in Pinal County is fragmented. Most lands in Pinal County are private (26%) or state trust lands (35%), with federal lands and reservation lands representing 18% and 20% of the county, respectively (AGFD 2013). Pinal County is the third largest in Arizona after Maricopa and Pima counties (U.S. Census Bureau 2018). The monument is located between two urban centers in these two counties: Phoenix, Arizona and Tucson, Arizona. Casa Grande Ruins NM is a small, isolated area that is surrounded by agriculture, residential development, and commercial development (NPS 2017a). The monument is bordered by roads and urban development to the north and east with the potential for development to the west and south. Increasing development serves to further fragment habitat surrounding the monument. Fragmentation results in direct effects on animal populations such as mortality along roadways as well as indirect effects such as separation of populations and subsequent restrictions of gene flow. Many species will not cross barriers such as roads, canals, or residential/commercial development.

With continued camera trap monitoring for medium- and larger-sized mammals and a baseline inventory of small mammals, periodic sampling of "indicator" species within each habitat type may assist managers and scientists in developing status and trends of the mammal community at and around the monument over time. Unfortunately, small mammals can also be a nuisance to the cultural resources at the monument.

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

View of the Great House through branches of a dead velvet mesquite at Casa Grande Ruins NM. Photo Credit: NPS/P. Pineda Bovin.

Discussion

"The land of the Gila River Pima has been so radically altered during the three centuries of European contact that the aboriginal or precontact conditions can scarcely be envisioned today" (Rea 1997). In fact, it's very likely that the historic conditions of the Gila River and associated aquatic habitat, riparian woodlands, grasslands, and mesquite bosques are irreversibly altered. However, prior to European settlement, the area's lush resources sustained the ancient Sonoran Desert people for over 1,000 years. To this day, some of the elders can still recall over 200 plant names (Rea 1997) described in ways that convey the intimate knowledge that is only acquired when deeply connected to a way of life and sense of place.

Through archaeological evidence, it's clear that water played a pivotal role in the creation of villages like Casa Grande and greatly influenced Hohokam culture. The various cultural changes were all tied to the irrigation from the Gila River (Rea 1997). The less than 32.8 m (10 ft) aquifer and arable land that existed during the early settlement years also created an environment that not only sustained but promoted life.

Cultural changes were characterized by increasing population and clustering of caliche pit homes. The ancient Sonoran Desert people excavated the local caliche soil layer to build the Great House (i.e. Casa Grande) around 1350 C.E. (of the Common Era), as well as other structures, and to construct irrigation canals that brought water to their agricultural crops. Crops of squash, corn, cotton, and tobacco were grown as a result of the water that the irrigation system provided (NPS 2018a).

The period of Great House construction throughout the area coincided with canal consolidation (Clemensen 1992). The new water intakes that later became associated with Casa Grande were relocated 29 km (18 mi) upstream of the actual structure (Clemensen 1992) to support the local agricultural practices. The consolidation of the new canal system resulted in changes to the culture's political and religious structures, concentrating power, authority, and people to centers like Casa Grande (Clemensen 1992).

While the maintenance of the agricultural fields altered the natural landscape to some extent, it's believed that the most significant changes to the monument's and surrounding area's native vegetation occurred during the early 20th century. Once the Europeans colonized the land, they altered many of the natural systems that had previously supported the ancient Sonoran Desert people and their Pima descendants. Modifications to the headwaters of the Gila River due to the over-harvesting of beaver (*Castor canadensis*), mining, deforestation, and livestock overgrazing especially impacted the middle and lower portions of the Gila River, forcing a change to the Pima's way of life.

With the removal of beaver, ponds drained or silted in, accelerating streamflow. This in turn conveyed larger water volumes resulting in floods that consisted of muddier waters due to the soil erosion from deforestation and grazing (Rea 1997). These land use practices were too severe to work in concert with the normal biannual flooding cycle of the Gila River, resulting in significant ecological damage (Rea 1997).

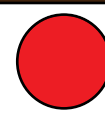
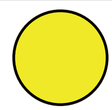
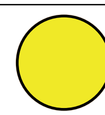
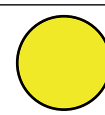
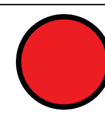
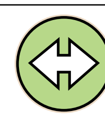
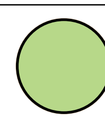
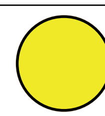
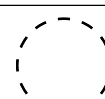
Through the lens of a general understanding of the historic land use practices throughout the local watershed, it's a little easier to understand the source of Casa Grande Ruins NM's natural resource conditions. The monument's current conditions reflect the mismanaged historic uses, especially the water-related ones (Table 47).

We know that abundant water from the Gila River provided the means for the ancient Sonoran Desert people to survive and thrive in this arid, and otherwise inhospitable, environment. The fact is that water continues to play a significant role in shaping civilizations. According to Holden (2014), "…control of water resources today provides an economic advantage that enables food production, …and sustenance for the population (p. 8)." As water resources become increasingly threatened from overuse, pollution, and climate change effects, the advantages of controlling this resource will become just as significant to the future well-being of society as it was to previous civilizations.

As described in Chapter 2, temperatures are becoming warmer and conditions are becoming drier due to climate change (Monahan and Fisichelli 2014), especially in the Southwest (Garfin et al. 2014). These changes will further exacerbate the lowering groundwater level, which is currently of significant concern at the monument (Table 47).

While the upland vegetation/soils and soil crusts are currently considered to be in good condition, the vegetation community is a near-monoculture of creosotebush (*Larrea tridentata*). NPS SODN (2018c) states "park records and early visitor accounts describe velvet mesquite (*Prosopis velutina*) woodlands interspersed with native desert shrublands. By the end of the 1930s, though, descriptions of accelerating

Table 47. Natural resource condition summary for Casa Grande Ruins NM.

Resource	Overall Condition
Viewshed	
Night Sky	
Soundscape	
Air Quality	
Groundwater	
Upland Vegetation and Soils	
Soil Crusts	
Birds	
Mammals	

mesquite mortality on the monument were common." The mortality is attributed to extensive groundwater pumping and mesquite's inability to adapt quickly enough to access groundwater at deeper and deeper levels.

Creosotebush is an extremely drought-tolerant, warm desert shrub that draws moisture from the atmosphere and near-surface soils. Although creosote is relatively resistant to short-term variability in rainfall, multi-year drought conditions, especially during winter, will eventually limit plant growth with a lag effect of about a year (Ng et al. 2015). Water loss threats to this species can be monitored by tracking changes in three-year total rainfall (with winter rainfall as the primary driver) and root zone soil moisture conditions, along with measures of plant health (e.g., leaf-area index).

The monument's low plant diversity is also likely attributable to the excavation of the caliche layer used to build the ancient Sonoran Desert people's structures (NPS SODN 2018c). NPS SODN (2018c) states, "these soil disturbances may have influenced infiltration and/or water-holding properties in the rooting zone. Many perennial plants found in other areas with similar climate conditions appear to be unable to survive and reproduce locally under current conditions. Insufficient soil water may be the key." NPS SODN researchers suggest the following 'next steps' may help illuminate information pertaining to the monument's current ecology:

- A detailed soil survey would provide key information on erosion potential and other important aspects of natural and cultural resource management.
- A small-scale manipulative experiment could help identify causes of the monument's paucity of perennial-plant diversity. A germination experiment, using surface soils and biological soil crusts from within the park, could assess germination and recruitment of expected (but absent) native plants under a variety of microclimates that reflect conditions in the monument.
- A comprehensive, species-level inventory of biological soil crusts would provide an important baseline for these important organisms, and may provide insights into the soil water, fertility, and erosion questions raised in this and other research.

Another threat to the monument's resources, potentially including the Great House, is also related to groundwater depletion resulting in fissures. Local geological hazards, including earth fissures, are monitored by the Arizona Geological Survey (AGS) (AGS 2019). Although the monument is not within any of the AGS's study area boundaries, the AGS has published suggested guidelines for monitoring earth fissures that may be useful to managers at the monument (Arizona Land Subsidence Interest Group 2011).

The reality is that the area surrounding Casa Grade, which once supported an abundance of wildlife, plants, and aquatic life, has undergone significant changes. This is clearly evident as one enters the monument and sees that across the street from the park is Walmart and Safeway grocery stores. These and other residential and commercial developments have impacted the monument's landscape-scale resources such as viewshed, night sky, and soundscape. In addition, the wildlife populations that were once abundant, supporting the ancient Sonoran Desert people's way of life have for all practical purposes become absent. In fact, the area surrounding Casa Grande Ruins NM is not within a known wildlife corridor (AGFD 2015) and is unable to support large mammals such as bears, mountain lion, and deer. AGFD (2015) suggests that habitat fragmentation throughout the area has impeded movements for these species, which in turn, impacts natural controls for nuisance species such as ground squirrels. Historically, the monument may have served as a wildlife corridor when mesquite bosques, extending to the Gila River, were present. Today however, much of the land in Pinal County is fragmented.

All of these environmental changes underscore, and even increase, the monument's value to the local area. Present day Casa Grande Ruins National Monument occupies a 2.6 km^2 (1 mi^2) area of land that has captured the human interest for 1,000s of years and will likely continue to do so for several 1,000 more. It is the continued dedication of monument and Sonoran Desert Inventory and Monitoring staffs, along with numerous partners and friends, who ask and research questions that further explore the mystery and complexity of this national park and its previous inhabitants.

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Appendix A. Scoping Meeting Participants and Report Reviewers

Table A-1. Scoping meeting participants.

Name	Affiliation and Position Title
Lisa Baril	Utah State University, Wildlife Biologist and Writer/Editor
Phyllis Pineda Bovin	National Park Service WASO Denver Service Center Planning Division, Natural Resource Specialist
Mark Brunson	Utah State University, Professor and Principal Investigator
Dave Carney	National Park Service Casa Grande Ruins National Monument, Acting Superintendent
Alycia Hayes	National Park Service Casa Grande Ruins National Monument, Archeologist/Chief of Resource Stewardship & Facilities Management
Dominic Henry	National Park Service Casa Grande Ruins National Monument, Exhibit Specialist
Andy Hubbard	National Park Service Sonoran Desert Inventory and Monitoring Network, Program Manager
Diana Mills	National Park Service Casa Grande Ruins National Monument, Administrative Officer
Kara Raymond	National Park Service Southern Arizona Office, Hydrologist
Katherine Shaum	National Park Service Casa Grande Ruins National Monument, Archeological Technician
Kim Struthers	Utah State University, NRCA Project Coordinator and Writer/Editor
Pam Tripp	National Park Service Casa Grande Ruins National Monument, Acting Chief of Interpretation

Table A-2. Report reviewers.

Name	Affiliation and Position Title	Sections 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 WASO Denver Service Center Planning Division, Natural Resource Specialist	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
Alyssa S. McGinnity	Contractor to National Park Service, Managed Business Solutions, a Sealaska Company	Washington-level Publishing and 508 Compliance Review
Alycia Hayes	National Park Service Casa Grande Ruins National Monument, Archeologist/Chief of Resource Stewardship & Facilities Mgmt.	Park Expert Reviewer
Kara Raymond	National Park Service Southern Arizona Office, Hydrologist	Air Quality, Birds, Soundscape,Upland Veg & Soils, Mammals, Soil Crusts, and Groundwater Assessments
Ksienya Taylor	National Park Service Air Resources Division, Natural Resource Specialist	Air Quality, Viewshed Assessments
Jonathan Horst	Tucson Audubon Society, Director of Conservation and Research and Ecologist	Birds Assessment
Li-Wei Hung	National Park Service Natural Sounds and Night Skies Division, Night Sky 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
Jayne Belnap	U.S. Geological Survey, Research Ecologist	Soil Crusts
Amanda Hardy	National Park Service Biological Resources Division, Wildlife Biologist	Mammals
Don Weeks	National Park Service Intermountain Regional Office, Physical Resources Program Manager	Groundwater
Sarah Studd	National Park Service Sonoran Desert Inventory and Monitoring Network, Vegetation Ecologist	Upland Vegetation Assessment

Appendix B. Viewshed Analysis Steps

The process used to complete Casa Grande Ruins National Monument's viewshed analyses is listed below.

Downloaded six of the 1/3 arc second national elevation dataset (NED) grid (roughly equivalent to a 30 m digital elevation model [DEM]) from U.S. Geological Survey's National Map Viewer (http://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEP%20View#productGroupSearch) (USGS 2018) 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"). ESRI (2016) provides a useful overview of the visibility analysis.

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 area of analysis (AOA) was a 98 km (61 mi) buffer surrounding the monument, reprojected into the Albers Equal Area Conic USGS projection, then overlaid with the National Park Service Inventory & Monitoring NPScape's housing, road, and conservation status tools as described in NPS (2014a,b,c). A text attribute field was added to the AOA for the area of analysis identifier.

Housing (CONUS, Density, SERGoM, 1970 - 2100, Metric Data 9.3 File Geodatabase, Theobald 2005), roads (U.S. Census Bureau 2017 TIGER/Line Shapefiles), and conservation status (NPS 2014c, USGS GAP 2016) GIS datasets were downloaded from NPScape (NPS 2016) and the USGS GAP (USGS GAP 2016) websites. Standard Operating Procedures for all three tools were followed based on NPScape instructions (NPS 2014a,b,c).

Appendix C. Casa Grande Ruins National Monument Bird List

Listed in the table below are the bird species reported for Casa Grande Ruins National Monument (NM) according to NPSpecies (NPS 2018c), Powell et al. (2006), and SODN survey data. Scientific names were updated with the current taxonomy used by the American Ornithological Society (AOS 2018). A total of 138 species are shown in the table, but only the NPSpecies list (136) is certified (i.e., vetted for accuracy). Of the 136 species, 115 are considered "present", one species is considered "probably present", and 20 species are "unconfirmed".

Table C–1. Bird species list for Casa Grande Ruins NM.

Common Name	Scientific Name	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	BioInventory (2001–2002)[3]	SODN Surveys (2007–2015)[4]
Abert's towhee	*Melzone aberti*	Unconfirmed	–	–	–	–
American kestrel	*Falco sparverius*	Present	Uncommon	Breeder	X	X
American pipit	*Anthus rubescens*	Present	Uncommon	Migratory	X	X
American robin	*Turdus migratorius*	Unconfirmed	–	–	–	–
American white pelican	*Pelecanus erythrorhynchos*	Unconfirmed	–	–	–	–
Anna's hummingbird	*Calypte anna*	Present	Common	Breeder	X	X
Ash–throated flycatcher	*Myiarchus cinerascens*	Present	Common	Breeder	X	X
Band–tailed pigeon[1]	*Patagioenas fasciata*	Unconfirmed	–	–	–	–
Bank swallow	*Riparia riparia*	Present	Uncommon	Migratory	–	X
Barn owl	*Tyto alba*	Present	Uncommon	Resident	X	–
Barn swallow	*Hirundo rustica*	Present	Uncommon	Migratory	–	X
Belted kingfisher	*Megaceryle alcyon*	Unconfirmed	–	–	–	–
Bendire's thrasher	*Toxostoma bendirei*	Present	Rare	Breeder	–	–
Bewick's wren	*Thryomanes bewickii*	Present	Rare	Breeder	–	–
Black phoebe	*Sayornis nigricans*	Present	Uncommon	Resident	–	–
Black–chinned hummingbird	*Archilochus alexandri*	Present	Uncommon	Breeder	X	X
Black–chinned sparrow	*Spizella atrogularis*	Present	Occasional	Migratory	X	–
Black–necked stilt	*Himantopus mexicanus*	Present	Uncommon	Migratory	X	–
Black–tailed gnatcatcher	*Polioptila melanura*	Present	Uncommon	Breeder	X	X
Black–throated gray warbler[1]	*Setophaga nigrescens*	Present	Rare	Migratory	X	–
Black–throated sparrow	*Amphispiza bilineata*	Present	Uncommon	Breeder	–	X
Blue–gray gnatcatcher	*Polioptila caerulea*	Present	Uncommon	Migratory	X	X
Brewer's blackbird	*Euphagus cyanocephalus*	Present	Common	Resident	–	–
Brewer's sparrow[1]	*Spizella breweri*	Present	Common	Resident	X	X
Bronzed cowbird	*Molothrus aeneus*	Present	Uncommon	Breeder	X	X
Brown–crested flycatcher	*Myiarchus tyrannulus*	Present	Uncommon	Breeder	–	X

[1] Species of concern (Latta et al. 1999).

[2] Non-native species.

[3] Powell et al. (2006), includes birds observed during all survey methods.

[4] Data provided by K. Bonebrake, SODN data manger.

Note: X = species present.

Table C-1 continued. **Bird species list for Casa Grande Ruins NM.**

Common Name	Scientific Name	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	BioInventory (2001–2002)[3]	SODN Surveys (2007–2015)[4]
Brown–headed cowbird	*Molothrus ater*	Present	Common	Breeder	X	X
Bullock's oriole	*Icterus bullockii*	Present	Uncommon	Migratory	X	X
Burrowing owl[1]	*Athene cunicularia*	Present	Common	Breeder	X	X
Cactus wren	*Campylorhynchus brunneicapillus*	Present	Common	Breeder	X	X
Canyon towhee	*Melozone fuscus*	Present	Uncommon	Breeder	–	–
Cassin's finch	*Haemorhous cassinii*	Unconfirmed	–	–	–	–
Cassin's kingbird	*Tyrannus vociferans*	Present	Uncommon	Migratory	–	X
Cedar waxwing	*Bombycilla cedrorum*	Unconfirmed	–	–	–	–
Chipping sparrow	*Spizella passerina*	Present	Uncommon	Migratory	X	–
Cliff swallow	*Petrochelidon pyrrhonota*	Present	Uncommon	Breeder	X	X
Common ground–dove	*Columbina passerina*	Present	Uncommon	Breeder	–	–
Common poorwill	*Phalaenoptilus nuttallii*	Present	Uncommon	Breeder	X	X
Common raven	*Corvus corax*	Present	Common	Resident	X	X
Cooper's hawk	*Accipiter cooperii*	Present	Uncommon	Breeder	X	X
Costa's hummingbird[1]	*Calypte costae*	Present	Common	Breeder	X	X
Crissal thrasher	*Toxostoma crissale*	Present	Rare	Breeder	–	–
Curve–billed thrasher	*Toxostoma curvirostre*	Present	Uncommon	Breeder	X	X
Dark–eyed junco	*Junco hyemalis*	Unconfirmed	–	–	–	–
Double–crested cormorant	*Phalacrocorax auritus*	Not Listed	–	–	–	X
Dusky–capped flycatcher	*Myiarchus tuberculifer*	Unconfirmed	–	–	–	–
Eastern kingbird	*Tyrannus tyrannus*	Unconfirmed	–	–	–	–
Elf owl	*Micrathene whitneyi*	Present	Uncommon	Breeder	–	–
Eurasian collared–dove[2]	*Streptopelia decaocto*	Present	Uncommon	Resident	–	X
European starling[2]	*Sturnus vulgaris*	Present	Common	Breeder	X	X
Ferruginous hawk[1]	*Buteo regalis*	Present	Rare	Migratory	X	–
Franklin's gull	*Leucophaeus pipixcan*	Not Listed	–	–	–	X
Gambel's quail	*Callipepla gambelii*	Present	Abundant	Breeder	X	X
Gila woodpecker	*Melanerpes uropygialis*	Present	Common	Breeder	X	X
Gilded flicker[1]	*Colaptes chrysoides*	Present	Common	Breeder	X	X
Gray flycatcher[1]	*Empidonax wrightii*	Present	Uncommon	Migratory	X	X
Great blue heron	*Ardea herodias*	Present	Uncommon	Resident	X	–
Great egret	*Ardea alba*	Present	Uncommon	Migratory	X	X

[1] Species of concern (Latta et al. 1999).

[2] Non-native species.

[3] Powell et al. (2006).

[4] Data provided by K. Bonebrake, SODN data manger.

Note: X = species present.

Table C-1 continued. Bird species list for Casa Grande Ruins NM.

Common Name	Scientific Name	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	BioInventory (2001–2002)[3]	SODN Surveys (2007–2015)[4]
Great horned owl	*Bubo virginianus*	Present	Uncommon	Breeder	X	X
Greater roadrunner	*Geococcyx californianus*	Present	Uncommon	Breeder	X	X
Great–tailed grackle	*Quiscalus mexicanus*	Present	Abundant	Resident	X	X
Green–tailed towhee	*Pipilo chlorurus*	Present	Uncommon	Resident	X	X
Hammond's flycatcher	*Empidonax hammondii*	Present	Rare	Migratory	–	X
Harris' hawk	*Parabuteo unicinctus*	Present	Uncommon	Resident	X	–
Hermit warbler	*Setophaga occidentalis*	Present	Unknown	Vagrant	–	–
Hooded oriole	*Icterus cucullatus*	Present	Uncommon	Migratory	–	–
Horned lark	*Eremophila alpestris*	Present	Uncommon	Breeder	X	X
House finch	*Haemorhous mexicanus*	Present	Common	Breeder	X	X
House sparrow[2]	*Passer domesticus*	Present	Common	Breeder	X	X
Inca dove	*Columbina inca*	Present	Uncommon	Breeder	X	X
Killdeer	*Charadrius vociferus*	Present	Uncommon	Breeder	X	X
Ladder–backed woodpecker	*Picoides scalaris*	Present	Uncommon	Breeder	X	X
Lark bunting	*Calamospiza melanocorys*	Present	Common	Resident	X	–
Lark sparrow	*Chondestes grammacus*	Present	Uncommon	Resident	X	X
Lazuli bunting	*Passerina amoena*	Present	Uncommon	Migratory	X	X
Le Conte's thrasher[1]	*Toxostoma lecontei*	Unconfirmed	–	–	–	–
Lesser goldfinch	*Spinus psaltria*	Present	Common	Breeder	X	X
Lesser nighthawk	*Chordeiles acutipennis*	Present	Common	Breeder	X	X
Lincoln's sparrow	*Melospiza lincolnii*	Present	Uncommon	Migratory	–	–
Loggerhead shrike	*Lanius ludovicianus*	Present	Uncommon	Breeder	X	X
Lucy's warbler[1]	*Oreothlypis luciae*	Present	Uncommon	Breeder	X	X
MacGillivray's Warbler[1]	*Geothlypis tolmiei*	Present	Uncommon	Migratory	X	–
Mallard	*Anas platyrhynchos*	Present	Rare	Resident	X	–
Merlin	*Falco columbarius*	Present	Rare	Migratory	X	–
Mountain bluebird	*Sialia currucoides*	Unconfirmed	–	–	–	–
Mourning dove	*Zenaida macroura*	Present	Abundant	Breeder	X	X
Nashville warbler	*Oreothlypis ruficapilla*	Present	Uncommon	Migratory	X	–
Northern cardinal	*Cardinalis cardinalis*	Present	Uncommon	Breeder	–	–
Northern flicker	*Colaptes auratus*	Present	Uncommon	Resident	X	–
Northern harrier	*Circus hudsonius*	Present	Uncommon	Migratory	X	X
Northern mockingbird	*Mimus polyglottos*	Present	Common	Breeder	X	X
Northern pintail	*Anas acuta*	Unconfirmed	–	–	–	–

[1] Species of concern (Latta et al. 1999).

[2] Non-native species.

[3] Powell et al. (2006).

[4] Data provided by K. Bonebrake, SODN data manger.

Note: X = species present.

Table C-1 continued. Bird species list for Casa Grande Ruins NM.

Common Name	Scientific Name	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	BioInventory (2001–2002)[3]	SODN Surveys (2007–2015)[4]
Northern rough–winged swallow	*Stelgidopteryx serripennis*	Present	Uncommon	Migratory	–	X
Olive–sided flycatcher[1]	*Contopus cooperi*	Unconfirmed	–	–	–	–
Orange–crowned warbler	*Oreothlypis celata*	Present	Uncommon	Migratory	X	–
Peregrine falcon	*Falco peregrinus*	Present	Uncommon	Resident	X	–
Phainopepla	*Phainopepla nitens*	Present	Uncommon	Breeder	X	–
Prairie falcon	*Falco mexicanus*	Present	Rare	Resident	X	–
Pyrrhuloxia	*Cardinalis sinuatus*	Present	Uncommon	Breeder	–	–
Red–tailed hawk	*Buteo jamaicensis*	Present	Common	Breeder	X	X
Red–winged blackbird	*Agelaius phoeniceus*	Present	Common	Resident	X	X
Rock pigeon[2]	*Columba livia*	Present	Common	Breeder	X	X
Rock wren	*Salpinctes obsoletus*	Present	Uncommon	Breeder	X	–
Rough–legged hawk	*Buteo lagopus*	Unconfirmed	–	–	–	–
Ruby–crowned kinglet	*Regulus calendula*	Present	Uncommon	Migratory	–	–
Rufous–winged sparrow[1]	*Peucaea carpalis*	Present	Uncommon	Breeder	–	X
Sage thrasher[1]	*Oreoscoptes montanus*	Unconfirmed	–	–	–	–
Sagebrush sparrow[1]	*Artemisiospiza nevadensis*	Probably Present	–	–	–	–
Sandhill crane	*Antigone canadensis*	Present	Occasional	Migratory	X	–
Say's phoebe	*Sayornis saya*	Present	Uncommon	Breeder	X	X
Sharp–shinned hawk	*Accipiter striatus*	Present	Rare	Migratory	–	–
Solitary sandpiper	*Tringa solitaria*	Unconfirmed	–	–	–	–
Swainson's hawk[1]	*Buteo swainsoni*	Present	Uncommon	Migratory	X	X
Swainson's thrush[1]	*Catharus ustulatus*	Unconfirmed	–	–	–	–
Tree swallow	*Tachycineta bicolor*	Present	Uncommon	Migratory	–	–
Turkey vulture	*Cathartes aura*	Present	Common	Resident	X	–
Verdin	*Auriparus flaviceps*	Present	Common	Breeder	X	X
Vermilion flycatcher	*Pyrocephalus rubinus*	Present	Rare	Migratory	–	–
Vesper sparrow	*Pooecetes gramineus*	Present	Uncommon	Migratory	X	–
Violet–green swallow	*Tachycineta thalassina*	Present	Uncommon	Migratory	–	X
Virginia's warbler	*Oreothlypis virginiae*	Present	Uncommon	Migratory	X	–
Western bluebird	*Sialia mexicana*	Unconfirmed	–	–	–	–
Western kingbird	*Tyrannus verticalis*	Present	Uncommon	Breeder	X	X
Western meadowlark	*Sturnella neglecta*	Present	Uncommon	Resident	X	–
Western sandpiper	*Calidris mauri*	Present	Rare	Migratory	–	–
Western screech–owl	*Megascops kennicottii*	Present	Rare	Breeder	–	–

[1] Species of concern (Latta et al. 1999).

[2] Non-native species.

[3] Powell et al. (2006).

[4] Data provided by K. Bonebrake, SODN data manger.

Note: X = species present.

Table C-1 continued. ***Bird species list for Casa Grande Ruins NM.***

Common Name	Scientific Name	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	BioInventory (2001–2002)[3]	SODN Surveys (2007–2015)[4]
Western tanager	*Piranga ludoviciana*	Present	Rare	Migratory	X	X
Western wood–pewee	*Contopus sordidulus*	Present	Rare	Migratory	X	–
White–crowned sparrow	*Zonotrichia leucophrys*	Present	Common	Resident	X	X
White–faced ibis	*Plegadis chihi*	Present	Rare	Migratory	–	X
White–throated swift	*Aeronautes saxatalis*	Present	Rare	Migratory	–	–
White–winged dove	*Zenaida asiatica*	Present	Abundant	Breeder	X	X
Wilson's warbler	*Cardellina pusilla*	Present	Uncommon	Migratory	X	X
Yellow warbler	*Setophaga petechia*	Present	Uncommon	Migratory	X	–
Yellow–bellied sapsucker	*Sphyrapicus varius*	Unconfirmed	–	–	–	–
Yellow–headed blackbird	*Xanthocephalus xanthocephalus*	Present	Uncommon	Resident	–	X
Yellow–rumped warbler	*Setophaga coronata*	Present	Common	Resident	X	X
Zone–tailed hawk	*Buteo albonotatus*	Present	Rare	Migratory	–	–

[1] Species of concern (Latta et al. 1999).

[2] Non–native species.

[3] Powell et al. (2006).

[4] Data provided by K. Bonebrake, SODN data manger.

Note: X = species present.

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