National Park Service
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Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Salinas Pueblo Missions National Monument

Natural Resource Report NPS/SAPU/NRR—2022/2393

ON THE COVER

View of the mission at Quarai, with the Manzano Mountains behind (SMUMN GSS Photo by Kathy Allen)

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Natural Resource Report NPS/SAPU/NRR—2022/2393

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program aims to provide documentation about the current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. Findings from the NRCA will help Salinas Pueblo Missions National Monument (SAPU) managers to develop near-term management priorities, engage in watershed or landscape scale partnership and education efforts, conduct park planning, and report program performance (e.g., Department of the Interior's Strategic Plan "land health" goals, Government Performance and Results Act).

The objectives of this assessment are to evaluate and report on current conditions of key park resources, to evaluate critical data and knowledge gaps, and to highlight selected existing stressors and emerging threats to resources or processes. For the purpose of this NRCA, staff from the National Park Service (NPS) and Saint Mary's University of Minnesota – GeoSpatial Services (SMUMN GSS) identified key resources, referred to as "components" in the project. The selected components include natural resources and processes that are currently of the greatest concern to park management at SAPU. The final project framework contains nine resource components, each featuring discussions of measures, stressors, and reference conditions.

This study involved reviewing existing literature and, where appropriate, analyzing data for each natural resource component in the framework to provide summaries of current condition and trends in selected resources. When possible, existing data for the established measures of each component were analyzed and compared to designated reference conditions. A weighted scoring system was applied to calculate the current condition of each component. Weighted Condition Scores, ranging from zero to one, were divided into three categories of condition: low concern, moderate concern, and significant concern. These scores help to determine the current overall condition of each resource. The discussions for each component, found in Chapter 4 of this report, represent a comprehensive summary of current available data and information for these resources, including unpublished park information and perspectives of park resource managers, and present a current condition designation when appropriate. Each component assessment was reviewed by SAPU resource managers, NPS Southern Colorado Plateau Network (SCPN) staff, or outside experts.

Existing literature, short- and long-term datasets, and input from NPS and other outside agency scientists support condition designations for components in this assessment. However, in some cases, data were unavailable or insufficient for several of the measures of the featured components. In other instances, data establishing reference condition were limited or unavailable for components, making comparisons with current information inappropriate or invalid. In these cases, it was not possible to assign condition for the components. Current condition was not able to be determined for six of the ten components due to these data gaps.

For those components with sufficient available data, the overall condition varied. Two components were determined to be in good condition: dark night skies and paleontological resources. However, both were at the edge of the good condition range, and any small decline in conditions could shift them into the moderate concern range. Of the components in good condition, a trend could not be

assigned for paleontological resources and dark night skies is considered stable. Two components (wetland and riparian communities and viewshed) were of moderate concern, with no trend assigned for wetland and riparian communities and a stable trend for viewshed. Detailed discussion of these designations is presented in Chapters 4 and 5 of this report.

Several park-wide threats and stressors influence the condition of priority resources in SAPU. Those of primary concern include invasive species, adjacent development, and climate change impacts (e.g., drought). Understanding these threats, and how they relate to the condition of park resources, can help the NPS prioritize management objectives and better focus their efforts to maintain the health and integrity of the park ecosystem, as well as its historically significant landscape.

Acknowledgments

We acknowledge Salinas Pueblo Missions National Monument and Southern Colorado Plateau Inventory and Monitoring Network staff for the technical expertise provided during scoping, through multiple stages of review, and via phone and email; specifically, Marc LeFrançois, Ron Fields, Jim DeCoster, Ellen Soles, Stacy Stumpf, and Megan Swan. Their logistical insight and critical review of interim documents was essential to this project's completion. Phyllis Pineda Bovin, Natural/Interdisciplinary Resource Specialist NPS Denver Service Center, and Jeff Albright, Natural Resource Condition Assessment Coordinator, provided program guidance. Thank you to all others who assisted the development of this document.

Acronyms and Abbreviations

ALR:Anthropogenic Light Ratio

ARD:Air Resources Division

CBC:Christmas Bird Count

dB:Decibels

DEM:Digital Elevation Model

dv:Deciviews

EPA:Environmental Protection Agency

Esri:Environmental Systems Research Institute

GIS:Geographic Information System

gpm:Gallons Per Minute

hz: Hertz

I&M:Inventory and Monitoring

IDA:International Dark-Sky Association

IDSP:International Dark Sky Park

IMBD:International Migratory Bird Day

NCEI:National Centers for Environmental Information

NCPN:Northern Colorado Plateau Network

NLCD:National Landcover Dataset

NPS:National Park Service

NRCA:Natural Resource Condition Assessment

NSNSD:Natural Sounds and Night Sky Division

NVC:National Vegetation Classification

NWI:National Wetlands Inventory

PIF:Partners in Flight

Acronyms and Abbreviations (continued)

PM:Particulate Matter

SAPU:Salinas Pueblo Missions National Monument

SCPN:Southern Colorado Plateau Network

SMUMN GSS: Saint Mary’s University of Minnesota – GeoSpatial Services

SQM:Sky Quality Meter

USFS:U.S. Forest Service

USFWS:U.S. Fish and Wildlife Service

USGS:United States Geological Survey

VCP:Variable Circular Plot

WCS:Weighted Condition Score

ZLM:Zenith Limiting Magnitude

1. NRCA Background Information

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

NRCAs Strive to Provide…

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

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

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

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

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

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

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

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

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

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

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

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

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

Important NRCA Success Factors

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

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

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

NRCA Reporting Products…

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

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

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

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

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

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

2. Introduction and Resource Setting

2.1 Introduction

2.1.1 Enabling Legislation

Salinas Pueblo Missions National Monument (SAPU) was initially established by President Taft as Gran Quivira National Monument in 1909 (NPS 1974). At the time, the monument included only the Gran Quivira Unit, and was intended to protect "one of the largest and most important of the early Spanish church ruins, commonly known as the Gran Quivira, together with numerous Indian pueblo ruins in its vicinity" (NPS 1974, p. 200). These ruins were recognized as "of great historical interest, and it appears that the public interest would be promoted by reserving these ruins with as much public land as may be necessary for the proper protection thereof" (NPS 1974, p. 201).

A 1929 photo of the newer church ruins (Iglesia San Buenaventura), looking south at Gran Quivira (NPS Archives photo).

In December of 1980, Gran Quivira was merged with two state monuments (Abó and Quarai) to form Salinas National Monument, "to set apart and preserve for the benefit and enjoyment of the American people the ruins of prehistoric Indian pueblos and associated seventeenth century Franciscan Spanish mission ruins" (NPS 1984, p. 7). The name was changed to Salinas Pueblo Missions National Monument in 1987 (NPS 1997a).

The reconstructed Missions at Quarai (left) and Abó (right) (NPS photos).

2.1.2 Geographic Setting

SAPU is located in central New Mexico and consists of three distinct units: Abó, Quarai, and Gran Quivira (Figure 1). The units are approximately 55–95 km (34–59 mi) southeast of Albuquerque in Torrance and Socorro Counties. The park boundary includes 433 ha (1,071 ac), 399 ha (985 ac) of which is in federal ownership (NPS 2015b). Gran Quivira is the largest unit at 247 ha (610 ac), followed by Abó at 113 ha (279 ac) and Quarai at 39 ha (96 ac) (NPS 2002b, 2014b). Abó and Quarai are on the edge of the Manzano Mountains, at elevations of about 1,860 m (6,090 ft) and 2,020 m (6,630 ft), respectively (KellerLynn 2018). Gran Quivira lies on Chupadera Mesa at elevations from 1,965 m (6,447 ft).

The park's geology is dominated by Permian sedimentary rocks, Tertiary igneous rocks (at Gran Quivira only), and unconsolidated Quaternary deposits, representing 299 million years of geologic time (KellerLynn 2018). The Permian rocks at Abó and Quarai include the distinct red sandstones of the Abo and Arroyo de Alamillo Formations, which were used to construct the pueblos and Mission churches. Recently, the first ever vertebrate fossil known from these rock formations was discovered at Abó (Lucas et al. 2018). At Gran Quivira, the gray limestone of the San Andres Formation was used for Mission and pueblo construction (NPS 2010, KellerLynn 2018). The limestone at Gran Quivira is susceptible to dissolution by percolating water, leading to the formation of karst features and possibly caves (KellerLynn 2018).

The climate at SAPU is continental and arid to semi-arid, with cool winters and warm, moist summers (Muldavin et al. 2012). Gran Quivira is slightly warmer than Abó and Quarai, with average high summer temperatures around 30–31°C (86–87°F) and average winter low temperatures around −5.5°C (22°F) (Table 1). Summer highs at Mountainair, closer to Abó and Quarai, average 29–30.5°C (85–87°F), with winter average lows around −6.0°C (21°F) (Table 2). Gran Quivira also receives slightly more annual precipitation on average (43.4 cm [17.1 in]) than Mountainair (38.3 cm [15.1 in]) (NCEI 2015a, b). The majority of annual precipitation in central New Mexico falls during the summer months, particularly July and August (Tables 1, 2).

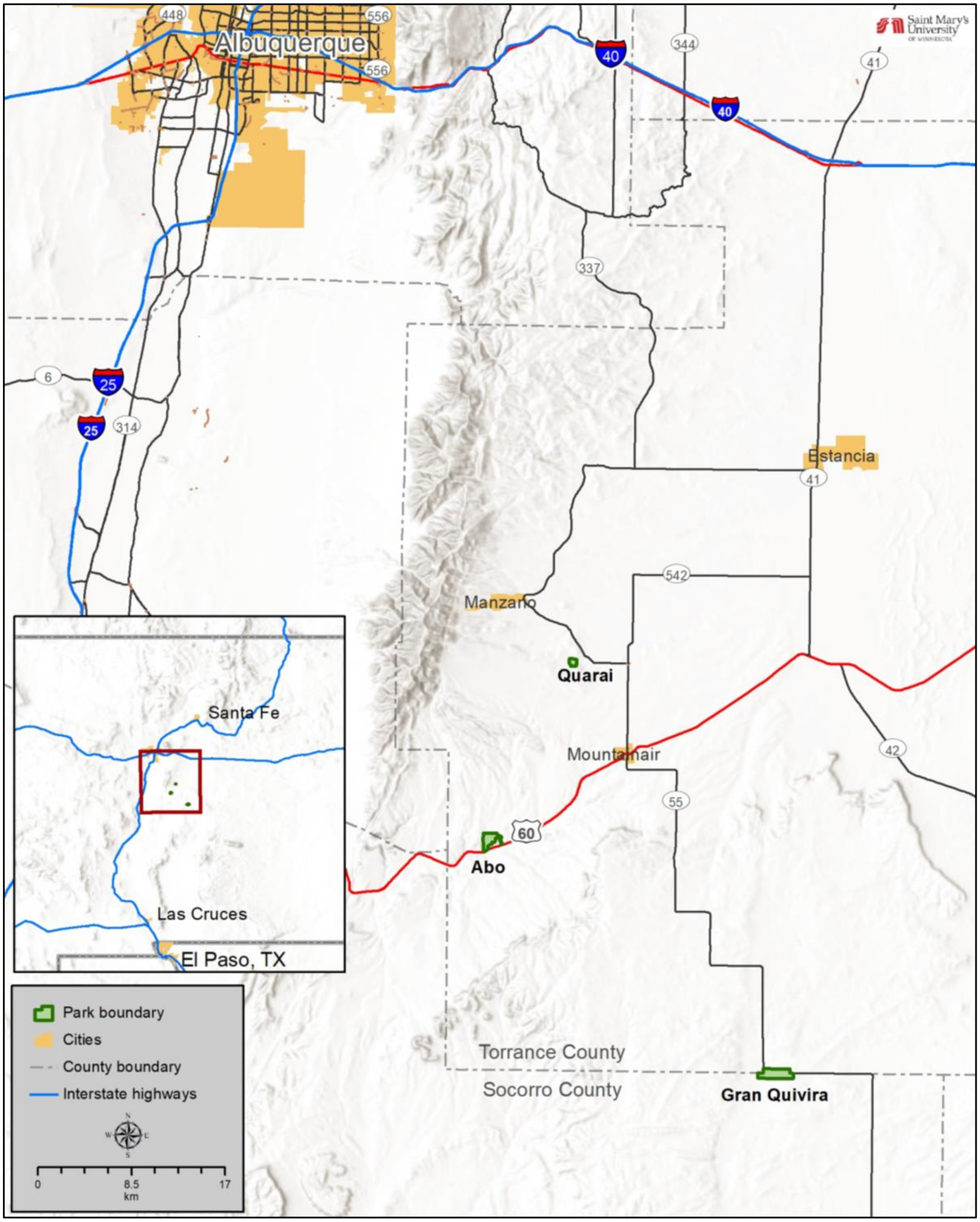


Figure 1. The location of SAPU's three units within New Mexico.

Table 1. 30-year climate normals (1981–2010) from Gran Quivira, NM (NCEI 2015a).

Month	Temperature in °C (°F)		Average precipitation in cm (in)
	Average daily min	Average daily max	
January	−5.5 (22.1)	9.0 (48.2)	1.7 (0.7)
February	−3.6 (25.5)	11.6 (52.9)	1.8 (0.7)
March	−1.3 (29.7)	15.6 (60.1)	1.8 (0.7)
April	2.0 (35.6)	20.4 (68.8)	2.0 (0.8)
May	7.2 (44.9)	25.6 (78.1)	2.3 (0.9)
June	11.7 (53.0)	30.4 (86.7)	3.0 (1.2)
July	13.5 (56.3)	30.8 (87.4)	7.3 (2.9)
August	12.9 (55.2)	29.3 (84.7)	9.3 (3.6)
September	9.4 (49.0)	26.3 (79.4)	5.5 (2.2)
October	4.1 (39.3)	20.6 (69.1)	4.4 (1.7)
November	−1.7 (28.9)	13.7 (56.6)	2.1 (0.8)
December	−5.3 (22.4)	8.9 (48.0)	2.3 (0.9)
Annual	**3.6 (38.5)**	**20.2 (68.3)**	**43.4 (17.1)**

Table 2. 30-year climate normals (1981–2010) from Mountainair, NM, approximately 11.5 km (7 mi) northeast of Abó and 10 km (6.2 mi) southeast of Quarai (NCEI 2015b).

Month	Temperature in °C (°F)		Average precipitation in cm (in)
	Average daily min	Average daily max	
January	−6.0 (21.2)	8.0 (46.4)	1.5 (0.6)
February	−4.2 (24.4)	10.8 (51.4)	1.5 (0.6)
March	−1.7 (29.0)	15.1 (59.1)	2.1 (0.8)
April	1.3 (34.3)	19.6 (67.3)	1.5 (0.6)
May	6.0 (42.8)	24.7 (76.5)	1.9 (0.8)
June	10.9 (51.6)	29.8 (85.7)	2.6 (1.0)
July	13.7 (56.7)	30.7 (87.2)	6.8 (2.7)
August	13.2 (55.8)	28.9 (84.1)	7.3 (2.9)
September	9.6 (49.2)	26.0 (78.8)	4.6 (1.8)
October	3.7 (38.6)	20.3 (68.5)	3.8 (1.5)
November	−2.1 (28.3)	13.3 (56.0)	1.9 (0.8)
December	−6.1 (21.1)	7.9 (46.2)	2.7 (1.1)
Annual	**3.2 (37.8)**	**19.6 (67.3)**	**38.3 (15.1)**

2.1.3 Visitation Statistics

On average, SAPU received just over 32,000 visitors per year between 2004 and 2018 (NPS 2019). Visitation peaked at nearly 38,000 in 2009, with its lowest level during this period occurring in 2013 with just under 25,000 visitors. Visitation is typically highest in the fall (October) and late spring (April–May) (NPS 2019). Each of the three park units has its own visitor center, along with central visitor center at park headquarters in Mountainair. Visitors can walk around the mission and pueblo ruins at all three units and guided tours are available with advanced notice (NPS 2018c). At Abó, visitors can also schedule a tour of the unit's Native American pictographs (Figure 2). Quarai offers excellent bird watching opportunities and the hilltop location of Gran Quivira provides visitors with spectacular views of the surrounding landscape (NPS 2018c).

Figure 2. Native American pictographs at Abó from the Pueblo IV period (1300–1600) (SMUMN GSS photos).

2.2 Natural Resources

2.2.1 Ecological Units and Watersheds

SAPU lies within the Environmental Protection Agency's (EPA) Southwestern Tablelands Level III Ecoregion. Today, much of the Southwestern Tablelands are in sub-humid grassland and semiarid range land (EPA 2013). The EPA divides Level III Ecoregions into smaller Level IV Ecoregions. The park falls in two Level IV Ecoregions: Quarai and Gran Quivira are in the Central New Mexico Plains and Abó is in the Pinyon-Juniper Woodlands and Savannas ecoregion (Figure 3). The primary natural vegetation of the Central New Mexico Plains was shortgrass steppe, although livestock grazing is currently the dominant land use (Griffith et al. 2006). The primary land use in the Pinyon-Juniper Woodlands and Savannas, with their thin soils, are wildlife habitat and rangeland.

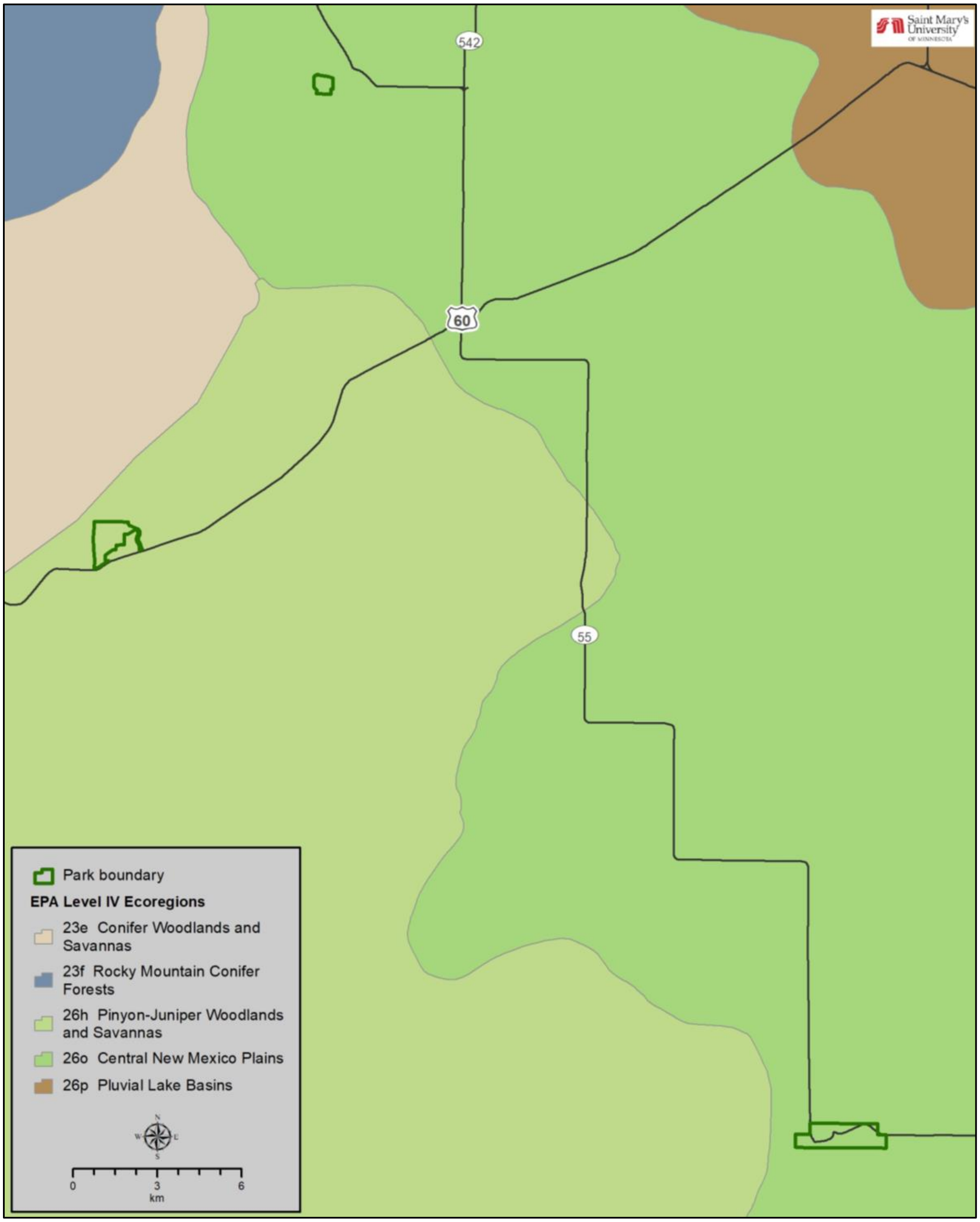


Figure 3. EPA Level IV Ecoregions of SAPU (EPA 2010).

The park's units fall within three different watersheds (Figure 4). Quarai is part of the Estancia Basin, Abó drains west into the Rio Grande-Albuquerque watershed, and Gran Quivira is within the Tularosa Valley watershed, draining to the south.

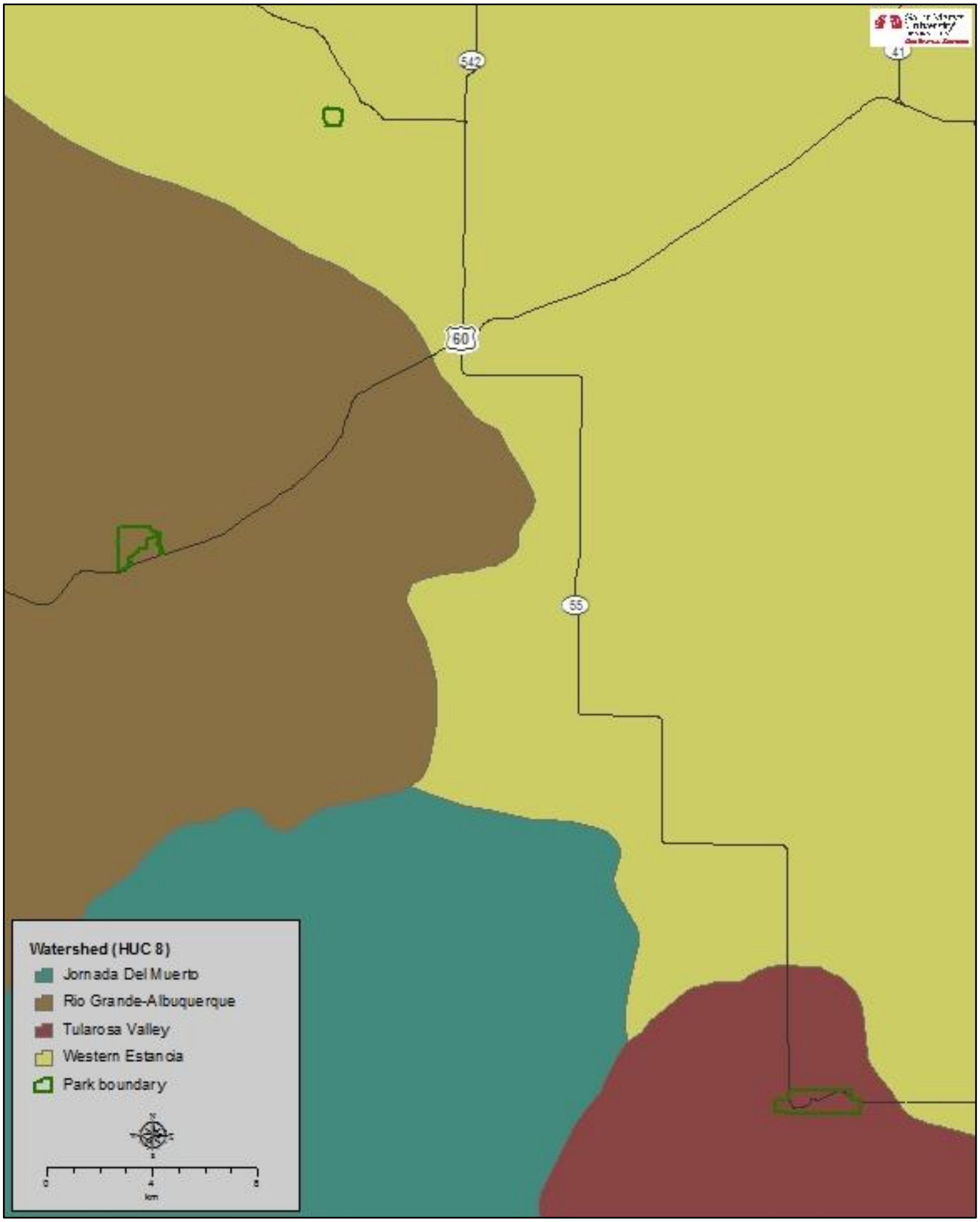


Figure 4. HUC 8 watersheds of SAPU (EPA 2010).

2.2.2 Resource Descriptions

The semi-arid landscape of SAPU supports primarily oneseed juniper (*Juniperus monosperma*)-dominated vegetation communities, ranging from open savannas to pinyon-juniper forests (Floyd-Hanna et al. 1994, Muldavin et al. 2012). Small riparian vegetation areas, with occasional cottonwoods (*Populus* spp.) and willows (*Salix* spp.), occur at Abó and Quarai, where small amounts of surface water persist throughout the year. According to NPSpecies, 191 plant species are confirmed present at SAPU, with an additional 63 considered unconfirmed but possibly present (NPS 2018a). However, 17 of the unconfirmed species were reported by Muldavin et al. (2012) during their vegetation mapping project and could likely be moved to the "present" category.

Forty-eight mammal species have been confirmed in the park, with 15 species classified as probably present and 20 more species unconfirmed (NPS 2018a). Small rodents are abundant while larger mammals including black bears (*Ursus americanus*), mountain lions (*Puma concolor*), and coyotes (*Canis latrans*) are rare (Bogan et al. 2007, NPS 2018a). Thirteen bat species are confirmed and an additional seven are probably present or unconfirmed.


The deer mouse (*Peromyscus maniculatus*, left) is one of the abundant small rodents at SAPU; the hoary bat *(Lasiurus cinereus*, right) is the most common bat species at the park (NPS photos).

Approximately 130 bird species are known from the park, with 12 species probably present and 15 species unconfirmed (NPS 2018a). About one-third of the species are considered migratory and just over one-third breed within the park. Thirteen of the present or probably present species are classified as priority species by Partners in Flight (Johnson et al. 2007). Common birds include the spotted towhee (*Pipilo maculatus*), violet-green swallow (*Tachycineta thalassina*), and juniper titmouse (*Baeolophus ridgwayi*) (Figure 5).

Figure 5. Common birds at SAPU include the violet-green swallow (young on a nest at Quarai, left) and the juniper titmouse (right) (NPS photos).

Seventeen reptile species have been documented at SAPU, and 14 additional species are probably present or unconfirmed (NPS 2018a). Collared lizards (*Crotaphytus collaris*, Figure 6), eastern fence lizards (*Sceloporus undulatus*), and tree lizards (*Urosaurus ornatus*) are common. Snakes, including the western diamondback rattlesnake (*Crotalus atrox*), and the prairie rattlesnake (*Crotalus viridis*) are also frequently encountered by visitors in the park, although to a lesser degree than lizards. The park also supports five amphibian species: four toads and one salamander (NPS 2018a). Information on the distribution of herpetofauna species by park unit can be found in Nowak et al. (2001). SAPU is home to numerous invertebrates as well, including desert tarantulas (*Aphonopelma chalcodes*), praying mantises (Family Mantidae), and dragonflies (Order Odonata) (NPS 2016c).

Figure 6. Collared lizards (left) are common at SAPU, and tarantulas (right) may be seen in the fall (NPS photos).

The remoteness of SAPU's units offers a relatively undisturbed viewshed and soundscape, as well as nearly pristine dark night skies. As of 2016, less than 3% of the land surrounding SAPU (within an 80 km [50 mi] buffer) is classified as "developed" (USGS 2019b, see Chapter 4.7). Visitors are able to experience a cultural landscape very similar to what existed during the Pueblo period (NPS 2014b). In 2016, the park was designated as an International Dark Sky Park (IDSP) by the International Dark-Sky Association (IDA) (IDA 2016).

Stars over the ruins at Gran Quivira (NPS photo by David Schneider).

2.2.3 Resource Issues Overview

Despite the distance and differences between SAPU's three units, there are some overarching issues that threaten nearly all of the park's resources. These include non-native species invasions, climate change, and landscape alterations due to historic land use.

Non-native Species

Non-native, invasive species pose one of the greatest threats to biodiversity and ecosystem integrity worldwide, with the potential to impact ecological community composition, structure, and function (Mooney et al. 2005, Beard and App 2013). These species can compete with native plants and animals and disrupt ecosystem processes such as nutrient cycling and disturbance regimes (e.g., fire, flooding). According to the NPS (2018a) and Korb (2011), 29 non-native plant species have been documented at SAPU. Seven of these species have been classified as noxious weeds by the state of New Mexico (Table 3). A 2009 park-wide non-native plant survey found that non-native plant cover was highest at Quarai (14.4%) and lowest at Gran Quivira (0.6%) (Korb 2011). The threats posed by non-native plants to specific communities at SAPU will be addressed in Chapter 4.

Table 3. Non-native plant species present at SAPU that are classified as noxious weeds in the state of New Mexico (NMDA 2016).

Scientific Name	Common Name	Class [1]
Elymus repens	quackgrass	B
Ailanthus altissima	tree of heaven	C
Bromus tectorum	cheatgrass	C
Carduus nutans	musk thistle	C
Elaeagnus angustifolia	Russian olive	C
Tamarix chinensis	saltcedar; tamarisk	C
Ulmus pumila	Siberian elm	C

[1] Class B – species found in portions of the state; in severe infestations, management should be designed to contain the infestation and stop any further spread.

Class C – species are wide-spread in the state; management decisions should be determined at the local level, based on feasibility of control and level of infestation.

Climate Change

Climate is a key driving factor in the ecological and physical processes influencing park ecosystems throughout the SCPN (Davey et al. 2006). As a result of global climate change, temperatures are projected to increase across the Southwest United States over the next century (Garfin et al. 2014). The mean annual temperature at SAPU has already increased significantly since 1950 (Figure 7) and could climb another 2°C (~4°F) by 2050 (Gonzalez 2014). Warmer air temperatures will increase evaporation rates and plant transpiration (i.e., plant water use), meaning that even if annual precipitation remains constant or slightly increases, overall conditions could still become drier in the future. According to the NPS (2014b), SAPU has already experienced an increase in drought conditions related to climate change. A decline in water availability, along with shifts in precipitation patterns due to climate change, will impact the structure and functioning of the park's ecosystems, including vegetation, wildlife, and physical resources (Betancourt et al. 1993, Istanbulluoglu and Bras 2006, NPS 2014b).

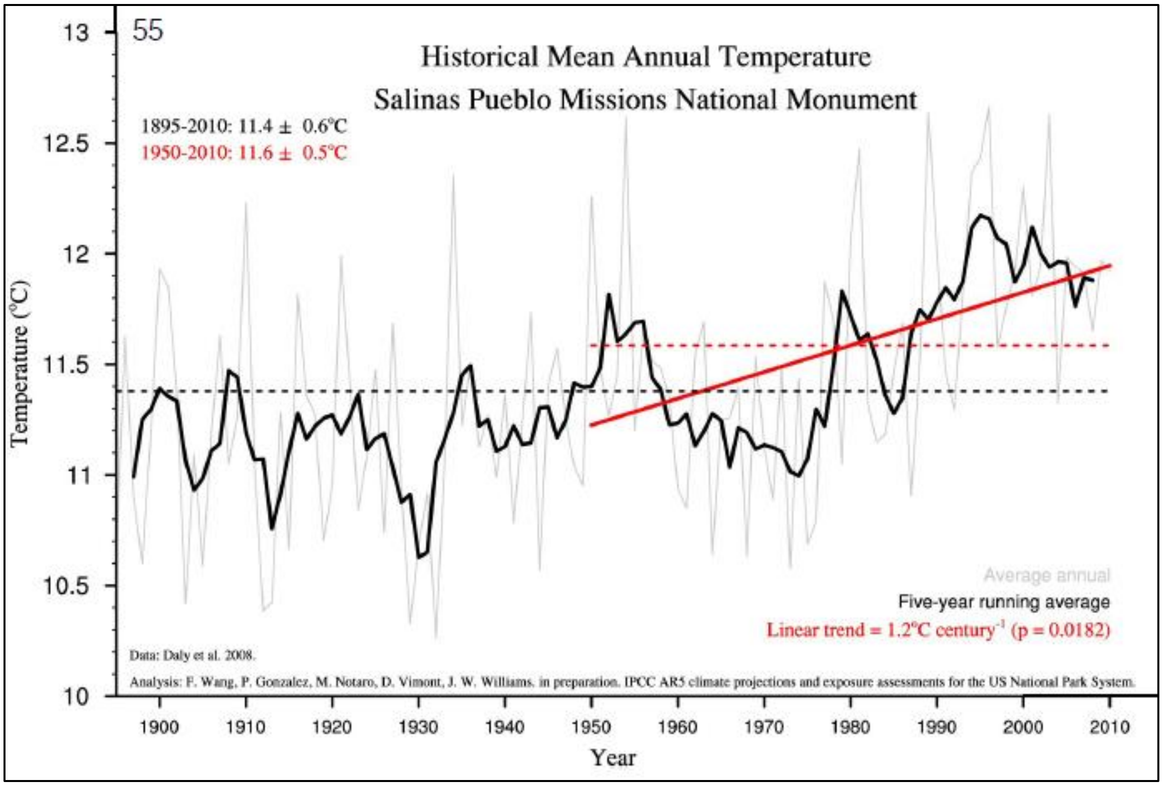


Figure 7. Change in mean annual temperature (°C) over time at SAPU (Gonzalez 2014). Dashed lines represent averages for the periods 1895–2010 (black) and 1950–2010 (red). Linear trend analysis (solid red line) shows the temperature increase is significant ($p = 0.0182$).

Landscape Alteration/Historic Land Use

The lands around SAPU have been utilized by human populations since Native Americans first built structures in the area, over 800 years prior to Spanish colonization around 1600 (NPS 2010). Early uses were limited to foraging for food, firewood, and shelter-building materials. Human use intensified during the late 1800s when large-scale ranching began and livestock herds were introduced to the landscape (NPS 2002a, 2010). Over time, grazing by these herds substantially altered the region's vegetation communities and some ecological processes (NPS 1997b, Gori and Bate 2007). Specific issues related to historic land use and alteration (e.g., juniper encroachment, soil erosion) will be discussed in Chapter 4.

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

The original SAPU general management plan (NPS 1984, p. 56) states

> *…the objectives for natural resource management are to protect and improve the condition of existing resources and where feasible to return the landscape to a condition and appearance which better reflects the historic environment. The latter must be undertaken only in coordination with the management of cultural resources and after sufficient research has been accomplished.*

SAPU's strategic plan (NPS 1997a, p. 6) includes two goals related to natural resources:

> *I.a. Natural and cultural resources and associated values are protected restored and maintained in good condition and managed within their broader ecosystem and cultural context.*
>
> *I.b. Salinas Pueblo Missions National Monument contributes to knowledge about natural and cultural resources and associated values; management decisions about resources and visitors are based on adequate scholarly and scientific information.*

The importance of SAPU's natural resources were recognized in one of the Foundation Document's significance statements (NPS 2014b, p. 7):

> *The cultural landscape surrounding Salinas Pueblo Missions National Monument continues to be representative of its prehistoric and historic settings and remains largely unchanged. This landscape that is the Salinas province includes natural resources such as water features, flora, fauna, and salt for which the monument was named, along with the abundance of naturally occurring construction materials that attracted and sustained inhabitants for centuries.*

2.3.2 Status of Supporting Science

The SCPN identifies key resources network-wide and for each of its parks that can be used to determine the overall health of the parks. These key resources are called Vital Signs. In 2008, the SCPN completed and released a Vital Signs Monitoring Plan (Thomas et al. 2006b); Table 4 shows the SCPN Vital Signs selected for monitoring in SAPU. In addition, specific divisions within the NPS (e.g., Air Resources Division, Geological Resources Division, Natural Sounds and Night Skies Division) assist with in-park monitoring.

Table 4. SCPN Vital Signs selected for monitoring in SAPU (Thomas et al. 2006b). **Category 1** represents Vital Signs for which the network will develop protocols and implement monitoring. **Category 2** represents Vital Signs that are monitored by the park, another NPS program, or by another federal or state agency using other funding. **Category 3** represents priority Vital Signs for which monitoring has been deferred. An "x" indicates that vital sign occurs in that category, and an en-dash indicates that it does not.

Category	SCPN Vital Sign	Category 1	Category 2	Category 3
Air and Climate	Ozone, wet and dry deposition, visibility and particulate matter	–	–	x
	Weather and climate	–	x	–
Riparian and Aquatic Ecosystems	Water quality	–	–	x
	Spring, seep, and tinaja ecosystems	x	–	–
	Channel morphology	x	–	–
	Hydrology: streamflow and depth to groundwater	x	–	–
	Riparian vegetation composition and structure	x	–	–
	Riparian bird communities	–	–	x
Upland Ecosystems	Soil stability and upland hydrologic function	–	–	x
	Vegetation composition and structure	–	–	x
	Upland bird communities	–	–	x
	Ground-dwelling arthropods	–	–	x
Landscape	Invasive exotic plants (early detection)	x	–	–
	Land use – land cover and landscape vegetation pattern	x	–	–
Wildland Values	Natural soundscape condition	–	–	x
	Night sky condition	–	–	x

3. Study Scoping and Design

This NRCA is a collaborative project between the NPS and SMUMN GSS. Project stakeholders include the SAPU resource management team, and SCPN Inventory and Monitoring Program staff. Before embarking on the project, it was necessary to identify the specific roles of the NPS and SMUMN GSS. Preliminary scoping meetings were held, and a task agreement and a scope of work document were created cooperatively between the NPS and SMUMN GSS.

3.1 Preliminary Scoping

A preliminary scoping meeting was held from 30 January–1 February 2018. At this meeting, SMUMN GSS, SCPN, and park staff confirmed that the purpose of the SAPU NRCA was to evaluate and report on current conditions, critical data and knowledge gaps, and selected existing and emerging resource condition influences of concern to SAPU managers. Certain constraints were placed on this NRCA, including the following:

- Condition assessments are conducted using existing data and information;
- Identification of data needs and gaps is driven by the project framework categories;
- The analysis of natural resource conditions includes a strong geospatial component;
- Resource focus and priorities are primarily driven by SAPU resource management;

This condition assessment provides a "snapshot-in-time" evaluation of the condition of a select set of park natural resources that were identified and agreed upon by the project team. Project findings will aid SAPU resource managers in the following objectives:

- Develop near-term management priorities (how to allocate limited staff and funding resources);
- Engage in watershed or landscape scale partnership and education efforts;
- Consider new park planning goals and take steps to further these;
- Report program performance (e.g., Department of Interior Strategic Plan "land health" goals, Government Performance and Results Act [GPRA]).

Specific project expectations and outcomes included the following:

- For key natural resource components, consolidate available data, reports, and spatial information from appropriate sources including SAPU resource staff, the NPS Integrated Resource Management Application (IRMA) website, Inventory and Monitoring Vital Signs, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project;
- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point;
- Clearly identify "management critical" data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process;

- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually;
- Utilize "gray literature" and reports from third party research to the extent practicable.

3.2 Study Design

3.2.1 Indicator Framework, Focal Study Resources and Indicators

Selection of Resources and Measures

As defined by SMUMN GSS in the NRCA process, a "framework" is developed for a park or preserve. This framework is a way of organizing, in a hierarchical fashion, bio-geophysical resource topics considered important in park management efforts. The primary features in the framework are key resource components, measures, stressors, and reference conditions.

"Components" in this process are defined as natural resources (e.g., birds), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current park management. Each key resource component has one or more "measures" that best define the current condition of a component being assessed in the NRCA. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of a component. In addition to measures, current condition of components may be influenced by certain "stressors," which are also considered during assessment. A "stressor" is defined as any physical, biological, or chemical agent that induces adverse changes within a component (EPA 2016a). These typically refer to anthropogenic factors that adversely affect natural ecosystems, but may also include natural processes or disturbances such as floods, fires, or predation.

During the SAPU NRCA scoping process, key resource components were identified by NPS staff and are represented as "components" in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the park, it includes resources and processes that are unique to the park in some way, or are of greatest concern or highest management priority in SAPU. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

Selection of Reference Conditions

A "reference condition" is a benchmark to which current values of a given component's measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., a bison herd of at least 200 individuals) (Stoddard et al. 2006).

Reference conditions in this project were identified during the scoping process using input from NPS resource staff. In some cases, reference conditions represent a historical reference before human activity and disturbance was a major driver of ecological populations and processes, such as "pre-fire suppression.” In other cases, peer-reviewed literature and ecological thresholds helped to define appropriate reference conditions.

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science’s “State of Our Nation’s Ecosystems 2008” (Heinz Center 2008). Key resources for the park were adapted from the SCPN Vital Signs monitoring plan (Thomas et al. 2006b) and the SAPU Foundation Document (NPS 2014b). This initial framework was presented to park resource staff to stimulate meaningful dialogue about key resources that should be assessed. Significant collaboration between SMUMN GSS analysts and NPS staff was needed to focus the scope of the NRCA project and finalize the framework of key resources to be assessed.

The NRCA framework was finalized and accepted by NPS staff at the end of February 2018. The framework contains a total of 10 components (Table 5) and was used to drive analysis in this NRCA. This framework outlines the components (resources), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each component for comparison to current conditions.

Table 5. Salinas Pueblo Missions National Monument natural resource condition assessment framework.

Category	Component	Measures (Significance Level)	Stressors	Reference Condition
Ecological Communities	Upland Woodland and Savanna Communities	Community extent, plant species richness, proportion of total cover of non-native plants and invasive plants, tree density, tree mortality	Climate change – drought, bark beetles, soil erosion, invasive/non-native plants, fire, historic land use (grazing, tree removals)	Ideal would be the condition at the time of historical significance (mid-1600s); best professional judgement will be used
	Wetland and Riparian Communities	Community extent, cottonwood community extent, plant species richness, proportion of total cover held by invasive plants and by non-native plants, tree regeneration	Climate change (surface and ground water availability – drought, reduction of water table), illegal diversions of water, pollution, erosion, non-native species, water quality impacts (pesticides)	Ideal would be the condition at the time of historical significance (mid-1600s); best professional judgement will be used
Wildlife	Birds	Species richness, species abundance, species distribution	Wind turbines, climate change, habitat loss/destruction outside of park, visitor use, invasive plant species could impact habitat, collision with power lines, disease	Unknown, best professional judgement will be used to assess condition and establish a baseline for future comparison
	Mammals	Species richness, species abundance, species distribution	Wind turbines (bats), non-native species, drought and climate change, hunting on adjacent lands, habitat loss and fragmentation, mining and energy development around parks, installation of power lines and associated impacts of those lines, disease	Ideal would be the condition at the time of historical significance (mid-1600s); best professional judgement will be used
Environmental Quality	Dark Night Skies	NPS NSNSD suite of measures	Wind farm lights and power line lights will be visible from GQ at night, developments adjacent to the park, increasing light trespass from Albuquerque, vehicle and train traffic, degradations to air quality, smoke from fires	Absence of anthropogenic light

Table 5 (continued). Salinas Pueblo Missions National Monument natural resource condition assessment framework.

Category	Component	Measures (Significance Level)	Stressors	Reference Condition
Environmental Quality (continued)	Soundscape and Acoustical Environment	Sound pressure levels, frequency, duration of sounds	Train noises and blasting at active gravel pits near Abo, car/truck/vehicle traffic, military overflights	Natural ambient sound level in the absence of human-caused noise
	Viewshed	Visibility, change in adjacent land use/cover, changes in viewshed within the park, changes in viewshed outside of the park	Wind farms, adjacent land development, power line lights, air quality/visibility changes, smoke from wildfires	NPS Air Resources Division standards for visibility; best professional judgement for other measures
Physical Characteristics	Cave and Karst Features of Gran Quivira	Magnitude of subsidence, frequency of viscous seepage events, number of blowhole locations within the park	Flooding, adjacent land developments and industrial projects, human damage to blowholes, earthquakes, lightning strikes, root and animal burrowing activity, loss of grass cover, loss of cryptobiotic soil	Unknown
	Paleontological Resources	Percentage of paleo sites in good/fair/poor condition, annual number of case incident reports related to geo/paleo sites, documentation of all paleo/geo sites in the park	Weathering and erosion, theft/damage (human and livestock trespass), burying of trackways, vibration (train, highways, rock mines)	Best professional judgement
	Hydrology	Ground water levels, frequency and duration of surface water presence, volume of discharge from springs, timing and amount of precipitation	Historic land use, channel instability, climate change, drought, non-native species, adjacent land use, flooding	30-year climate normal for precipitation; best professional judgement for remaining measures

3.2.2 General Approach and Methods

This study involved gathering and reviewing existing literature and data relevant to each of the key resource components included in the framework. No new data were collected for this study; however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations. After all data and literature relevant to the measures of each component were reviewed and considered, a qualitative statement of overall current condition was created and compared to the reference condition when possible.

Data Mining

The data mining process (acquiring as much relevant data about key resources as possible) began at the initial scoping meeting, at which time SAPU staff provided data and literature in multiple forms, including: NPS reports and monitoring plans, reports from various state and federal agencies, published and unpublished research documents, databases, tabular data, and charts. GIS data were provided by NPS staff. Additional data and literature were also acquired through online bibliographic literature searches and inquiries on various state and federal government websites. Data and literature acquired throughout the data mining process were inventoried and analyzed for thoroughness, relevancy, and quality regarding the resource components identified at the scoping meeting.

Data Development and Analysis

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available for the component and recommendations from NPS reviewers and sources of expertise including NPS staff from SAPU and the SCPN. Specific approaches to data development and analysis can be found within the respective component assessment sections located in Chapter 4 of this report.

Scoring Methods and Assigning Condition

Significance Level

A set of measures are useful in describing the condition of a particular component, but all measures may not be equally important. A "Significance Level" represents a numeric categorization (integer scale from 1–3) of the importance of each measure in assessing the component's condition; each Significance Level is defined in Table 6. This categorization allows measures that are more important for determining condition of a component (higher significance level) to be more heavily weighted in calculating an overall condition. If a measure is given a Significance Level of 1, it is thought to be of low importance when determining the overall condition of the component. For this reason, measures with a Significance Level of 1 are not discussed in detail in the Current Condition and Trends section of a component's chapter. Significance Levels were determined for each component measure in this assessment through discussions with park staff and/or outside resource experts.

Table 6. Scale for a measure's Significance Level in determining a components overall condition.

Significance Level (SL)	Description
1	Measure is of low importance in defining the condition of this component.
2	Measure is of moderate importance in defining the condition of this component.
3	Measure is of high importance in defining the condition of this component.

Condition Level

After each component assessment is completed (including any possible data analysis), SMUMN GSS analysts assign a Condition Level for each measure on a 0–3 integer scale (Table 7). This is based on all the available literature and data reviewed for the component, as well as communications with park and outside experts.

Table 7. Scale for Condition Level of individual measures.

Condition Level (CL)	Description
0	**GOOD CONDITION**. No net loss, degradation, negative change, or alteration.
1	Of **LOW** concern. Signs of limited and isolated degradation of the component.
2	Of **MODERATE** concern. Pronounced signs of widespread and uncontrolled degradation.
3	Of **SIGNIFICANT** concern. Nearing catastrophic, complete, and irreparable degradation of the component.

Weighted Condition Score

After the Significance Levels (SL) and Condition Levels (CL) are assigned, a Weighted Condition Score (WCS) is calculated via the following equation:

$$WCS = \frac{\sum_{i=1}^{\#\ of\ measures} SL_i * CL_i}{3 * \sum_{i=1}^{\#\ of\ measures} SL_i}$$

The resulting WCS value is placed into one of three possible categories: resource is in good condition (WCS = 0.0 – 0.33); condition warrants moderate concern (WCS = 0.34 − 0.66); and condition warrants significant concern (WCS = 0.67 to 1.00). Table 8 and Table 9 displays and describes the symbology used to represent a component's condition in this assessment. The colored circles represent the categorized WCS; red circles signify a significant concern, yellow circles a moderate concern, and green circles are in good condition. White circles are used to represent situations in which SMUMN GSS analysts and park staff felt there was currently insufficient data to make a statement about the condition of a component. The border of the circles represents SMUMN GSS's confidence in the assessment of current condition; bold borders indicate high confidence, normal borders indicate medium confidence, and a dashed-border indicates low confidence. The arrows inside the circles indicate the trend of the condition of a resource component, based on data and literature from the past 5–10 years, as well as expert opinion. An upward pointing arrow indicates the condition of the component has been improving in recent times. An arrow that points to the left and right indicates a stable condition or trend and an arrow pointing down indicates a decline in the condition of a component in recent times. These are only used when it is appropriate to comment on the trend of condition of a component. An empty circle with no arrow is reserved for situations in which the trend of the component's condition is currently unknown.

Table 8. Description of symbology used for individual component assessments.

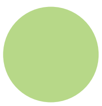
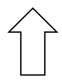
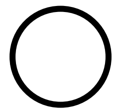
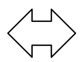
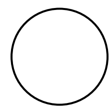
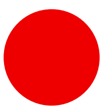
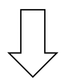
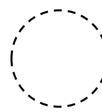
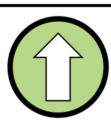
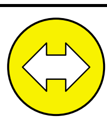
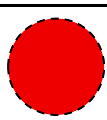
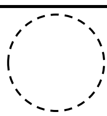
Condition Status		**Trend in Condition**		**Confidence in Assessment**	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern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

Table 9. Example indicator symbols and descriptions of how to interpret them in WCS tables.

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

Preparation and Review of Component Draft Assessments

The preparation of draft assessments for each component was a highly cooperative process among SMUMN GSS analysts, and SAPU and SCPN staff. Though SMUMN GSS analysts rely heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also plays a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step is especially important when data or literature are limited for a resource component.

The process of developing draft documents for each component began with a detailed phone or conference call with an individual or multiple individuals considered local experts on the resource components under examination. These conversations were a way for analysts to verify the most relevant data and literature sources that should be used and also to formulate ideas about current condition with respect to the NPS staff opinions. Upon completion, draft assessments were forwarded to component experts for initial review and comments.

Development and Review of Final Component Assessments

Following review of the component draft assessments, analysts used the review feedback from resource experts to compile the final component assessments. As a result of this process, and based on the recommendations and insights provided by SAPU resource staff and other experts, the final component assessments represent the most relevant and current data available for each component and the sentiments of park resource staff and resource experts.

Format of Component Assessment Documents

All resource component assessments are presented in a standard format. The format and structure of these assessments is described below.

Description

This section describes the relevance of the resource component to the park and the context within which it occurs in the park setting. For example, a component may represent a unique feature of the park, it may be a key process or resource in park ecology, or it may be a resource that is of high management priority in the park. Also emphasized are interrelationships that occur among the featured component and other resource components included in the NRCA.

Measures

Resource component measures were defined in the scoping process and refined through dialogue with resource experts. Those measures deemed most appropriate for assessing the current condition of a component are listed in this section, typically as bulleted items.

Reference Conditions/Values

This section explains the reference condition determined for each resource component as it is defined in the framework. Explanation is provided as to why specific reference conditions are appropriate or logical to use. Also included in this section is a discussion of any available data and literature that explain and elaborate on the designated reference conditions. If these conditions or values originated with the NPS experts or SMUMN GSS analysts, an explanation of how they were developed is provided.

Data and Methods

This section includes a discussion of the data sets used to evaluate the component and if or how these data sets were adjusted or processed as a lead-up to analysis. If adjustment or processing of data involved an extensive or highly technical process, these descriptions are included in an appendix for the reader or a GIS metadata file. Also discussed is how the data were evaluated and analyzed to determine current condition (and trend when appropriate).

Current Condition and Trend

This section presents and discusses in-depth key findings regarding the current condition of the resource component and trends (when available). The information is presented primarily with text but is often accompanied by detailed maps or plates that display different analyses, as well as graphs, charts, and/or tables that summarize relevant data or show interesting relationships. All relevant data and information for a component is presented and interpreted in this section.

Threats and Stressor Factors

This section provides a summary of the threats and stressors that may impact the resource and influence to varying degrees the current condition of a resource component. Relevant stressors were described in the scoping process and are outlined in the NRCA framework. However, these are elaborated on in this section to create a summary of threats and stressors based on a combination of available data and literature, and discussions with resource experts and NPS natural resources staff.

Data Needs/Gaps

This section outlines critical data needs or gaps for the resource component. Specifically, what is discussed is how these data needs/gaps, if addressed, would provide further insight in determining the current condition or trend of a given component in future assessments. In some cases, the data needs/gaps are significant enough to make it inappropriate or impossible to determine condition of the resource component. In these cases, stating the data needs/gaps is useful to natural resources staff seeking to prioritize monitoring or data gathering efforts.

Overall Condition

This section provides a qualitative summary statement of the current condition that was determined for the resource component using the WCS method. Condition is determined after thoughtful review of available literature, data, and any insights from NPS staff and experts, which are presented in the Current Condition and Trend section. The Overall Condition section summarizes the key findings and highlights the key elements used in determining and justifying the level of concern, if any, that analysts attribute to the condition of the resource component. Also included in this section are the graphics used to represent the component condition.

Sources of Expertise

This is a listing of the individuals (including their title and affiliation with offices or programs) who had a primary role in providing expertise, insight, and interpretation to determine current condition (and trend when appropriate) for each resource component. Sources are listed alphabetically by last name.

4. Natural Resource Conditions

This chapter presents the background, analysis, and condition summaries for the nine key resource components in the project framework. The following sections discuss the key resources and their measures, stressors, and reference conditions. The summary for each component is arranged around the following sections:

1. Description
2. Measures
3. Reference Condition
4. Data and Methods
5. Current Condition and Trend (including threats and stressor factors, data needs/gaps, and overall condition)
6. Sources of Expertise
7. Literature Cited

The order of components follows the project framework (Table 5):

Upland Woodland and Savanna Communities

Wetland and Riparian Communities

Birds

Mammals

Dark Night Skies

Soundscape and Acoustical Environment

Viewshed

Cave and Karst Features

Paleontological Resources

Hydrology

4.1 Upland Woodland and Savanna Communities

4.1.1 Description

The uplands of SAPU are largely covered by pinyon-juniper woodlands and savannas, dominated by oneseed juniper along with twoneedle pinyon (*Pinus edulis*) (Pache 1979, Floyd-Hanna et al. 1994, Muldavin et al. 2012). Pinyon-juniper vegetation covers around 40 million ha (100 million ac) across the Western U.S., providing valuable wildlife habitat and performing vital ecosystem services (Romme et al. 2008). The juniper woodland and savanna types at SAPU are characterized by relatively open tree canopies (10–60% cover) interspersed with grassy areas (Muldavin et al. 2012). Common understory grasses at SAPU include blue grama (*Bouteloua gracilis*), muhly grasses (*Muhlenbergia* spp.), and purple threeawn (*Aristida purpurea*) (Pache 1979, Muldavin et al. 2012). The various pinyon-juniper community types documented at SAPU during the most recent vegetation mapping effort are shown in Table 10.

Table 10. Upland woodland and savanna communities found at SAPU, along with common plant species (Muldavin et al. 2012).

Vegetation community	Plant species
Pinyon-Oneseed Juniper/Blue Grama Woodland	twoneedle pinyon, oneseed juniper, blue grama, curlyleaf muhly
Oneseed Juniper/Blue Grama-Galleta Woodland Savanna	oneseed juniper, blue grama, ring muhly (*Muhlenbergia torreyi*), purple threeawn
Oneseed Juniper/Black Grama Woodland Savanna	oneseed juniper, black grama (*Bouteloua eriopoda*)
Oneseed Juniper/Curlyleaf Muhly Woodland Savanna	oneseed juniper, curlyleaf muhly, grama grasses, purple threeawn
Oneseed Juniper/New Mexico Muhly-Black Grama Rockland Woodland	oneseed juniper, New Mexico muhly (*Muhlenbergia pauciflora*)
Oneseed Juniper/Ruderal Forbs Woodland	oneseed juniper, weedy forbs
Oneseed Juniper/Blue Grama-Alkali Sacaton Woodland Savanna	oneseed juniper, blue grama, alkali sacaton (*Sporobolus airoides*)
Oneseed Juniper/Little Bluestem Woodland Savanna	oneseed juniper, little bluestem (*Schizachyrium scoparium*), blue grama, sand dropseed (*Sporobolus cryptandrus*)
Oneseed Juniper/Fourwing Saltbush Woodland	oneseed juniper, fourwing saltbush (*Atriplex canescens*), blue grama
Oneseed Juniper/Sand Sagebrush Woodland	oneseed juniper, sand sagebrush (*Artemisia filifolia*), blue grama
Oneseed Juniper/Sparse Woodland	oneseed juniper, wavyleaf oak (*Quercus* x *undulata*), grama grasses, little bluestem
Oneseed Juniper/Blue Grama-Big Bluestem Woodland Savanna	oneseed juniper, blue grama, big bluestem (*Andropogon gerardii*), yuccas (*Yucca* spp.)

The woodlands of SAPU provided vital resources for the Pueblo and Spanish people that historically lived in the area. Foods harvested included pinyon nuts, juniper berries, cactus fruits, and acorns (NPS 2010). Junipers and pines also provided wood for building structures and for firewood. The majority of these native plant species are still present on the landscape today, and the current woodland vegetation provides important historical context and character for the monument's periods of significance (NPS 2010).

Pinyon-juniper woodlands on the hills surrounding the Abó ruins (NPS photo).

4.1.2 Measures

- Community extent (area)
- Plant species richness
- Proportion of total cover of non-native, invasive plants
- Tree density
- Tree mortality
- Herbaceous vs. shrub percent cover

4.1.3 Reference Condition/Values

The ideal reference condition for upland woodland and savanna communities would be the condition at the time the Pueblo people and Spanish missionaries lived in the SAPU area, around the early and mid-1600s. However, information from this time is limited and it may no longer be feasible to restore these conditions due to environmental and land use changes. For the purposes of this assessment, the best professional judgement of the project team will be used to assess condition when feasible. The data presented in this NRCA may serve as a reference condition or baseline for future assessments.

4.1.4 Data and Methods

The earliest known vegetation study for any of the SAPU units was a description and quantification of the plant communities at Gran Quivira by Pache (1979). Initial delineation was done using aerial photography, followed by field verification in December 1978 and May 1979. The report included a plant species list by community/habitat type and a rough vegetation map, along with the total area covered by each community (Pache 1979). In the early 1990s, Floyd-Hanna et al. (1994) conducted a similar vegetation study for the Abó and Quarai units of SAPU. Preliminary delineation was based on 1977 aerial photography, with field sampling completed in May, June, and October of 1993. A vegetation map and plant species list were created for each unit (Floyd-Hanna et al. 1994).

Korb (2011) conducted an exotic plant species inventory of all three SAPU units. Sampling was conducted from mid-June to mid-September of 2009. Variable-width transects were established within 125 randomly-selected grid cells, each approximately 2 ha (4.9 ac) in size and spread across the three units (36 at Abó, 12 at Quarai, 77 at Gran Quivira) (Figure 8). Ninety-nine of the grid cells were within pinyon-juniper woodlands or pinyon-juniper woodland and savanna communities (Korb 2011). Each exotic species along the transect was assigned a cover class (1 = less than 0.1% foliar cover, 2 = 0.1 to 1%, 3 = 1 to 5%, 4 = 5 to 10%, 5 = 10 to 25%, 6 = 25 to 50%, and 7 = 50 to 100%). Researchers also walked the perimeter and the remaining area in each grid cell to detect any additional exotic species that weren't found along the transect (Korb 2011).

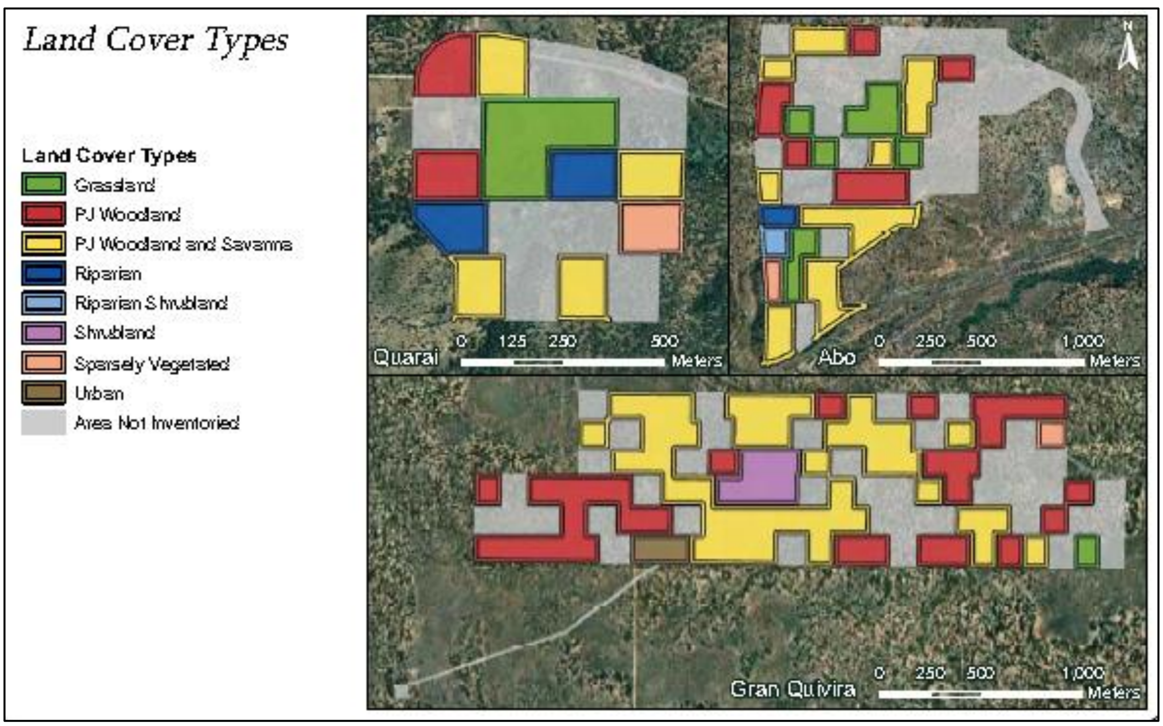


Figure 8. Grid cells sampled during the Korb (2011) exotic plant inventory by land cover type. Upland woodland and savanna cells are represented in red and yellow (reproduced from Korb 2011).

The U.S. Geological Survey (USGS)-NPS Vegetation Mapping Program, in cooperation with the SCPN and Natural Heritage New Mexico, completed a vegetation classification and mapping project for SAPU based on field sampling and aerial imagery interpretation (Muldavin et al. 2012). The project was initiated in 2003, with field surveys conducted between 2005 and 2009. A total of 288 sampling points across all three units were visited, 132 of which fell within upland woodland and savanna community types. Vegetation mapping was based on spring 2002 and 2003 aerial imagery of the park, as well as wider-scale statewide imagery from 2005 (Muldavin et al. 2012). Plant communities were classified into vegetation associations using the U.S. National Vegetation Classification (NVC).

4.1.5 Current Condition and Trend

Community Extent

In the late 1970s, Pache (1979) mapped 190.3 ha (470.3 ac) of juniper woodland at Gran Quivira. The woodlands were divided into two sub-groups based on soil characteristics: Subgroup A on moderately deep soils over limestone and Subgroup B with deeper soils and unstabilized surface sands (Figure 9, Figure 10). Subgroup A woodlands covered substantially more area with 169.1 ha (417.8 ac) than Subgroup B with 21.2 ha (52.5 ac) (Pache 1979).

Figure 9. Juniper woodlands within the Gran Quivira unit of SAPU, as mapped by Pache (1979).

Figure 10. 1979 photos of juniper woodland Subgroup A (left) and Subgroup B (right) at Gran Quivira (NPS photos).

Floyd-Hanna et al. (1994) identified a total of 128.3 ha (317.3 ac) of upland woodland and savanna within the current boundaries of SAPU's Abó and Quarai units (Table 11), the majority occurring within the Abó Unit. Three different woodland community types occurred at Abó and four community types at Quarai (Figure 11, Figure 12).

Table 11. The extent (area) of upland woodland and savanna vegetation communities in the Abó and Quarai units of SAPU, as mapped by Floyd-Hanna et al. (1994).

	Extent in ha (ac)	
Vegetation community	**Abó**	**Quarai**
Oneseed juniper/Blue grama-Douglas' ragwort	50.6 (125.1)	–
Oneseed juniper/ Douglas' ragwort-Alkali sacaton	19.9 (49.2)	–
Pinyon pine/Oneseed juniper	38.7 (95.7)	–
Oneseed juniper/Blue grama	–	5.8 (14.4)
Pinyon pine-Oneseed juniper/Fremont's berberis	–	10.9 (26.9)
Oneseed juniper/Woods' rose	–	2.0 (5.1)
Oneseed juniper/Fremont's berberis	–	0.4 (0.9)
Total	**109.2 (270.0)**	**19.1 (47.3)**

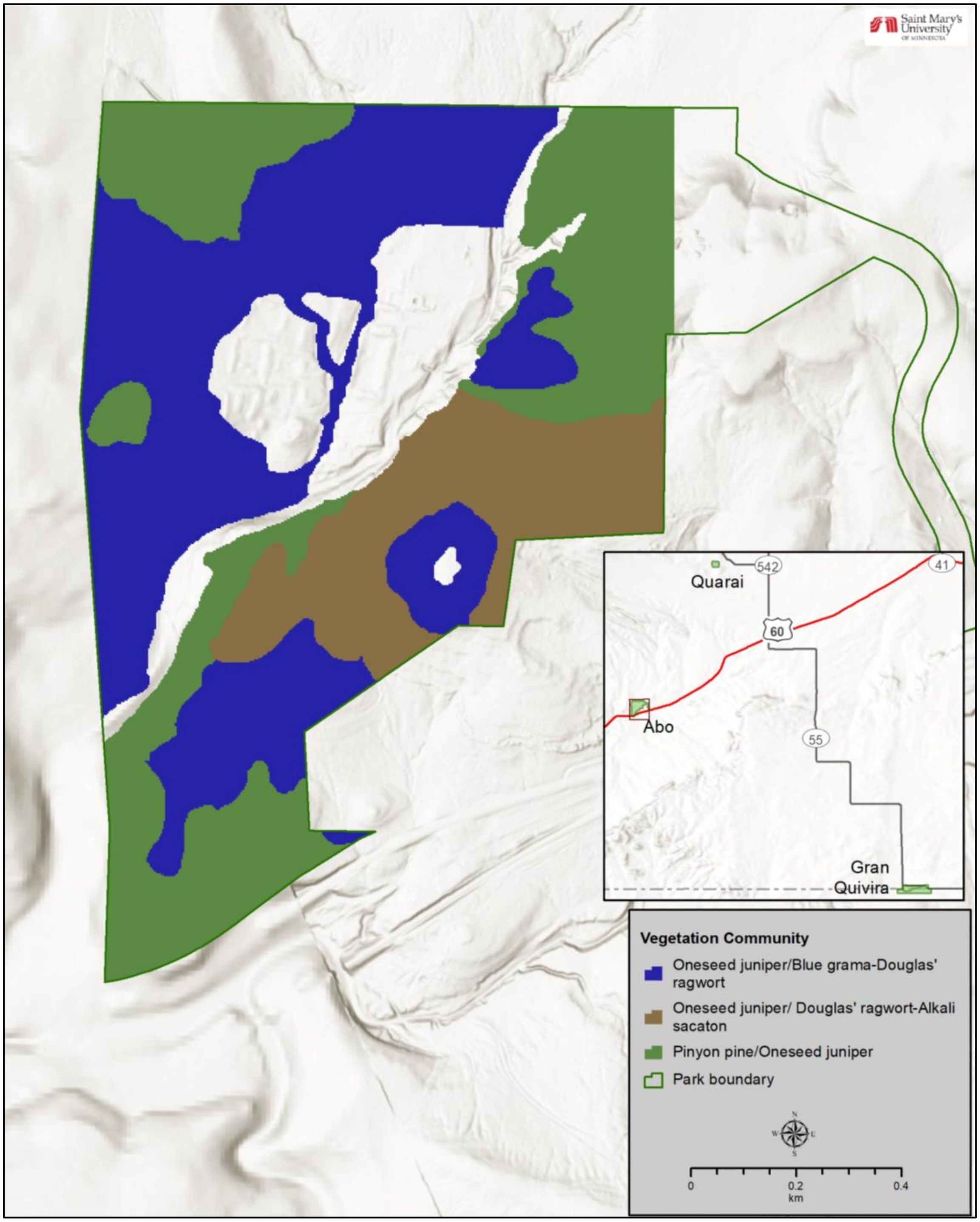


Figure 11. Upland woodland and savanna communities within the Abó unit of SAPU, as mapped by Floyd-Hanna et al. (1994).

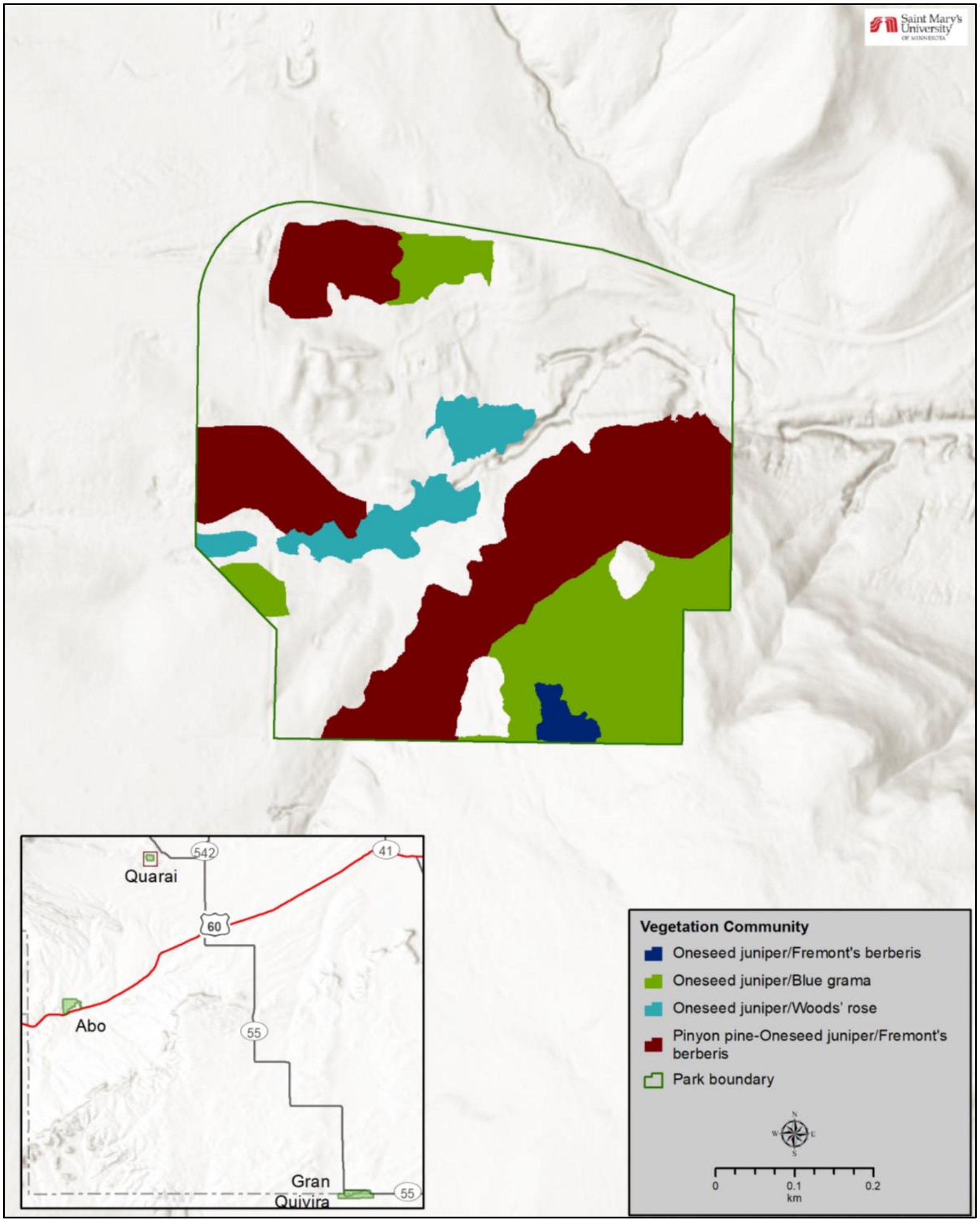


Figure 12. Upland woodland and savanna communities within the Quarai unit of SAPU, as mapped by Floyd-Hanna et al. (1994).

Muldavin et al. (2012) mapped a total of 302.5 ha (747.6 ac) of upland woodland and savanna vegetation across all three units of SAPU. These included 13 different vegetation types (Table 12), the most common of which were oneseed juniper/sparse woodland with 70.2 ha (173.4 ac), oneseed juniper/little bluestem woodland savanna with 70.0 ha (173.1 ac), and oneseed juniper/ blue grama-galleta woodland savanna with 60.3 (ha (149.1 ac). Upland woodland vegetation types were not universally distributed across all park units, as Quarai contained four woodland types, Abó seven woodland types, and Gran Quivira eight woodland types (Figure 13, Figure 14, Figure 15) (Muldavin et al. 2012). Four of the upland woodland/savanna vegetation communities occurred only at Gran Quivira (Table 12). Muldavin et al. (2012) identified more upland woodland/savanna at Gran Quivira than previous vegetation maps: 217.4 ha (537.2 ac) compared to 190.3 ha (470.2) reported by Pache (1979). They reported similar areas of woodlands/savannas at Quarai: 21.9 ha (54.1 ac) compared to 19.1 ha (47.2 ac) documented by Floyd-Hanna et al. (1994). At Abó, Muldavin et al. (2012) reported less area of woodlands/savannas when compared to the historic results of Floyd-Hanna et al. (1994): 63.1 ha (155.9 ac) compared to 109.2 ha (269.8 ac). The most notable change at Abó appeared to be in pinyon-juniper woodlands, which declined from nearly 39 ha (96 ac) in the early 1990s (Floyd-Hanna et al. 1994) to just 0.7 ha (1.7 ac) in the early to mid-2000s (Muldavin et al. 2012). However, this may be due to differences in classification and mapping methodologies rather than actual change over time.

Table 12. The extent (area) of upland woodland and savanna vegetation communities at SAPU, as mapped by Muldavin et al. (2012).

	Extent (area) in ha			
Vegetation community	**Abó**	**Quarai**	**GQ**	**Total (ac)**
Pinyon-Oneseed Juniper/Blue Grama Woodland	0.7	8.6	–	9.4 (23.1)
Oneseed Juniper/Blue Grama-Galleta Woodland Savanna	13.9	6.9	39.5	60.3 (149.1)
Oneseed Juniper/Black Grama Woodland Savanna	12.9	–	6.5	19.4 (48.0)
Oneseed Juniper/Curlyleaf Muhly Woodland Savanna	11.7	–	–	11.7 (29.0)
Oneseed Juniper/New Mexico Muhly-Black Grama Rockland Woodland	11.0	–	–	11.0 (27.1)
Oneseed Juniper/Blue Grama Treated Woodland	5.3	–	–	5.3 (13.0)
Oneseed Juniper/Ruderal Forbs Woodland	5.5	2.0	0.5	8.0 (19.8)
Oneseed Juniper/Blue Grama-Alkali Sacaton Woodland Savanna	2.1	–	–	2.1 (5.2)
Oneseed Juniper/Little Bluestem Woodland Savanna	–	–	70.0	70.0 (173.1)
Oneseed Juniper/Fourwing Saltbush Woodland	–	–	6.5	6.5 (16.0)
Oneseed Juniper/Sand Sagebrush Woodland	–	–	4.2	4.2 (10.5)
Oneseed Juniper/Sparse Woodland	–	4.4	65.8	70.2 (173.4)
Oneseed Juniper/Blue Grama-Big Bluestem Woodland Savanna	–	–	24.4	24.4 (60.3)
Total	**63.1**	**21.9**	**217.4**	**302.5 (747.6)**

Oneseed Juniper/Little Bluestem Woodland Savanna vegetation; this savanna association found in the Gran Quivira Unit has not been reported elsewhere in the Southwest (NPS photo).

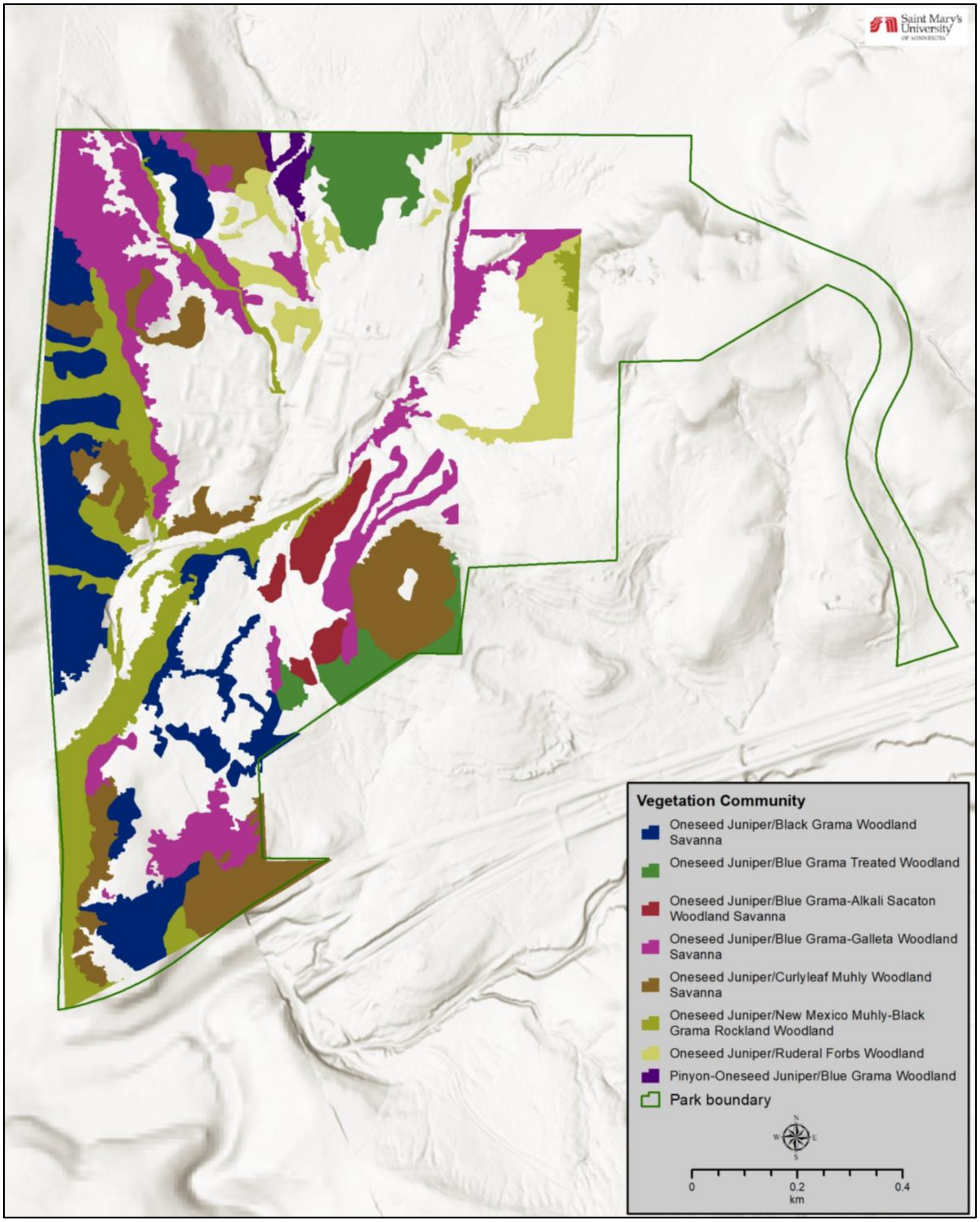


Figure 13. Upland woodland and savanna communities within the Abó unit of SAPU (Muldavin et al. 2012).

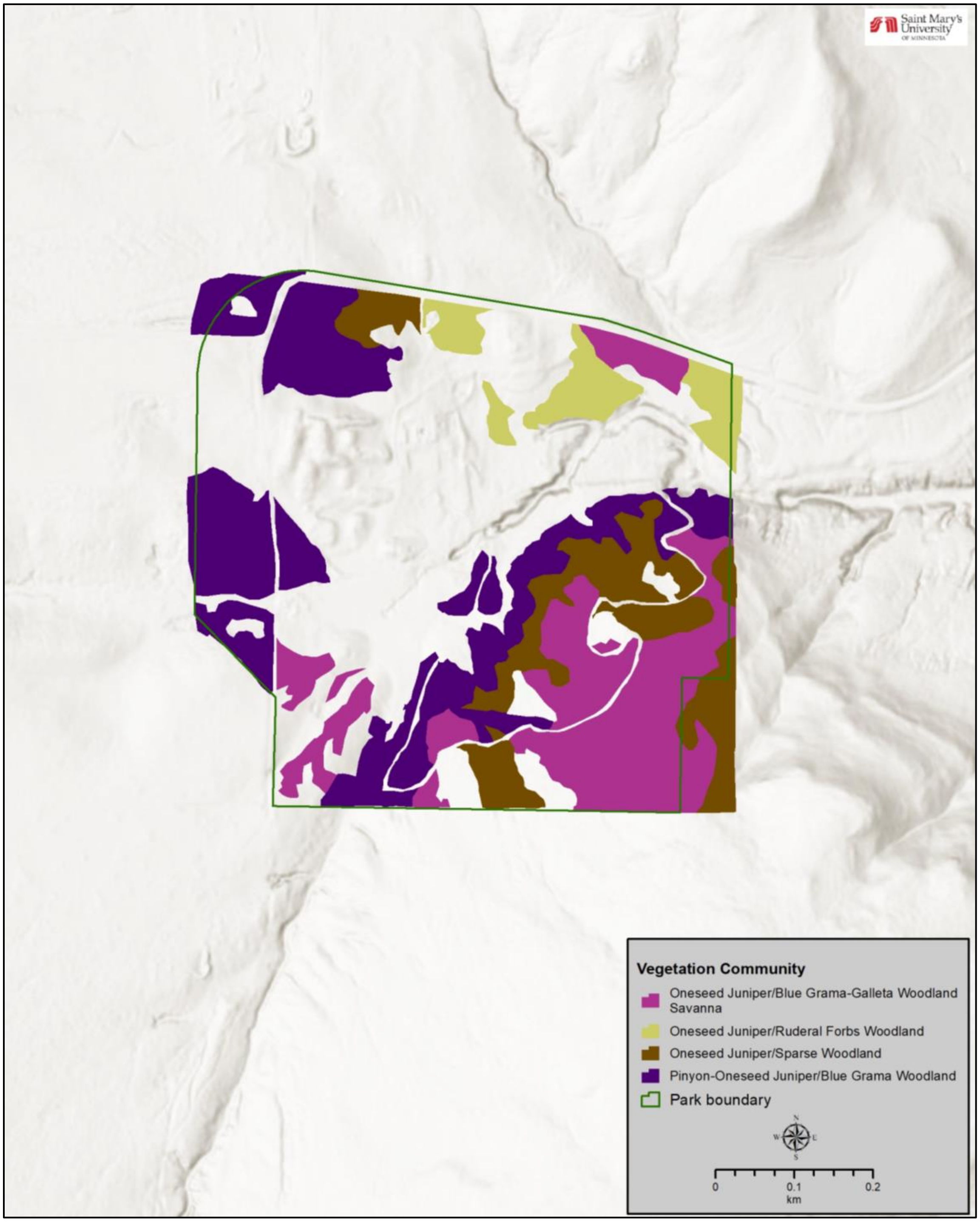


Figure 14. Upland woodland and savanna communities within the Quarai unit of SAPU (Muldavin et al. 2012).

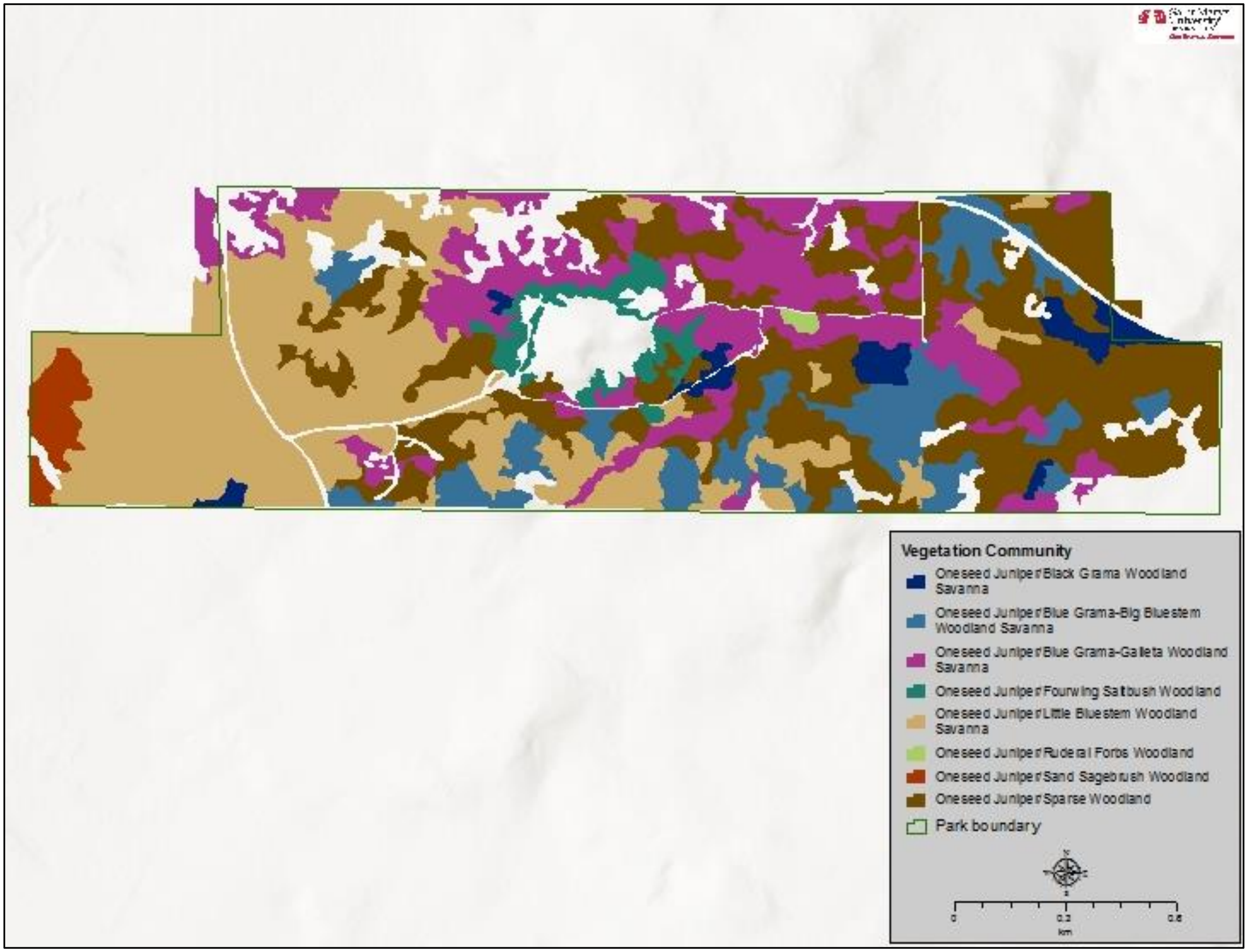


Figure 15. Upland woodland and savanna communities within the Gran Quivira unit of SAPU (Muldavin et al. 2012).

Plant Species Richness

A total of 149 plant species have been documented over time in SAPU's pinyon-juniper woodlands and savannas (Appendix A). Eighteen of the species (12%) are non-native. Surveys prior to 2000 documented 99 different plant species (Pache 1979, Floyd-Hanna et al. 1994). Pache (1979) observed 51 species at Gran Quivira, and Floyd-Hanna et al. (1994) identified at least 62 species in Abó and Quarai combined. During the most recent park-wide vegetation study, Muldavin et al. (2012) documented a total of 100 plant species across all three units. In an exotic plant inventory of SAPU, Korb (2011) found nine exotic species in upland woodlands and savannas at Quarai and Abó, and just one exotic species (*Marrubium vulgare*) in a Gran Quivira woodland.

Proportion of Total Cover of Non-native, Invasive Plants

Non-native invasive species pose one of the greatest threats to biodiversity and ecosystem integrity, as they can compete with native plants and disrupt ecosystem processes such as nutrient cycling and disturbance regimes (Mooney et al. 2005, Beard and App 2013). Data on non-native plant cover at SAPU is somewhat limited. Of the 35 upland woodland plots sampled by Muldavin et al. (2012) between 2005 and 2009, non-native species were found in just four plots. Only one plot exceeded 1% non-native cover, with a total of 42.55% (Table 13). This plot in a juniper/blue grama woodland at Quarai exhibited 41.5% cover of cheatgrass (*Bromus tectorum*) (Muldavin et al. 2012).

Table 13. Non-native plant species cover in upland woodland and savanna plots at SAPU (Muldavin et al. 2012).

Plot	Unit	Community type	% non-native cover
SAPU.0039	Quarai	Juniper/blue grama woodland	42.55
SAPU.0048	Abó	Juniper/blue grama woodland	0.50
SAPU.0089	Abó	Juniper/blue grama woodland	0.50
SAPU.0068	Quarai	Juniper/blue grama woodland	0.05
31 additional plots	–	–	0.00
Average	**–**	**–**	**1.25**

During a 2009 exotic plant inventory, Korb (2011) documented measurable non-native cover at eight of 99 upland woodland/savanna grid cells. Percent cover was very low, ranging from 0.05–0.5% (Table 14). For comparison, the mean exotic plant cover across all communities at SAPU was 2.5% (Korb 2011).

Table 14. Non-native plant species cover in pinyon-juniper woodland and savanna grid cells at SAPU (Korb 2011).

Grid cell	Unit	Community type	% non-native cover
3	Abó	Woodland and savanna	0.05
33	Abó	Woodland and savanna	0.05
59	Abó	Woodland and savanna	0.05
63	Abó	Woodland and savanna	0.05
71	Abó	Woodland and savanna	0.05
138	GQ	Woodland	0.50
183	Quarai	Woodland	0.05
201	Quarai	Woodland and savanna	0.10

Tree Density

Tree density in pinyon-juniper woodlands is influenced by environmental conditions (e.g., climate, soils, pests) and by land use (e.g., logging, grazing, fire) (Gori and Bate 2007). In the southwest, tree density is often higher on deeper mesic soils than on thin, dry soils (Gori and Bate 2007). Across much of the western U.S., researchers and land managers have noted increased tree and shrub density in numerous woodlands, savannas, and grasslands over the past century (Romme et al. 2008, SWCA Environmental Consultants 2016). It is unclear whether this is due to environmental changes, land use changes, or a combination of the two. Higher densities may increase the vulnerability of some tree species to drought stress and insect outbreaks (Gori and Bate 2007).

Information from relict sites and historical reconstructions in the southwest suggest that mean tree density for pinyon-juniper savannas prior to European settlement ranged from 22–122 trees/ha (8.9–49.4 trees/ac) while densities for persistent juniper woodlands was 948–3,989 trees/ha (384 to 1,614 trees/ac) (Table 15) (Gori and Bate 2007). Current tree densities at historical savanna/open woodland sites range from 175–1,154 trees/ha (71–467 trees/ac), an increase of up to 33 times over pre-settlement densities. Current densities in historical shrub and persistent woodlands was 325–2,120 trees/ha (132–858 trees/ac), a smaller increase of approximately three times over pre-settlement times (Gori and Bate 2007).

Table 15. Estimated stand densities for various pinyon-juniper woodland and savanna communities in New Mexico and Arizona (Gori and Bate 2007).

	Mean estimated density (trees per ha/ac)	
Community type	Historic	Current
Pinyon-juniper savanna	22–122 (8.9–49.4)	175–1,154 (71–467)
Pinyon-juniper grass open woodland	246 (99.7)	175–1,154 (71–467)
Pinyon-juniper shrub woodlands	215–740 (87–300)	325–2,120 (132–858)
Persistent pinyon-juniper woodland	948–3,989 (384–1,614)	325–2,120 (132–858)

No quantitative information is currently available regarding tree density in SAPU's upland woodlands and savannas. However, some insight into tree density may be gleaned from percent cover in the tree strata (canopy and subcanopy) of Muldavin et al. (2012) study plots. While tree density and percent cover are not comparable, low tree cover would likely mean that tree density is also low. Across all SAPU upland woodland and savanna plots, tree cover ranged from 0–69%, with the highest values in pinyon-juniper/grama woodlands (Table 16).

Table 16. Tree cover in upland woodland and savanna plots at SAPU (Muldavin et al. 2012).

Community type	Plot	Unit	Tree % cover
Juniper/blue grama woodland	SAPU.0018	Gran Quivira	29.0
	SAPU.0026	Gran Quivira	0.0
	SAPU.0033	Quarai	17.5
	SAPU.0035	Quarai	17.5
	SAPU.0039	Quarai	17.5
	SAPU.0043	Abó	20.0
	SAPU.0048	Abó	7.5
	SAPU.0068	Quarai	29.0
	SAPU.0072	Abó	10.5
	SAPU.0073	Abó	30.0
	SAPU.0089	Abó	10.0
	SAPU.0093	Abó	13.0
	Mean (all)	**–**	**16.8**
Juniper/curlyleaf muhly woodland	SAPU.0049	Abó	22.5
	SAPU.0070	Abó	31.5
	SAPU.0077	Abó	20.0
	SAPU.0081	Abó	20.0
	SAPU.0082	Abó	20.0
	SAPU.0083	Abó	47.0
	SAPU.0092	Abó	34.0
	Mean (all)	**–**	**27.9**
Juniper/black grama woodland	SAPU.0025	Gran Quivira	44.0
	SAPU.0078	Abó	20.0
	SAPU.0085	Abó	24.5
	SAPU.0086	Abó	32.5
	SAPU.0095	Abó	19.5
	Mean (all)	**–**	**28.1**
Juniper sparse woodland	SAPU.0024	Gran Quivira	17.5
	SAPU.0047	Abó	5.0

Table 16 (continued). Tree cover in upland woodland and savanna plots at SAPU (Muldavin et al. 2012).

Community type	Plot	Unit	Tree % cover
Juniper sparse woodland (continued)	SAPU.0069	Abó	25.0
	SAPU.0094	Abó	30.0
	Mean (all)	**–**	**19.4**
Juniper/little bluestem woodland	SAPU.0023	Gran Quivira	18.0
	SAPU.0027	Gran Quivira	41.5
	SAPU.0028	Gran Quivira	29.0
	Mean (all)	**–**	**29.5**
Juniper/oak woodland	SAPU.0022	Gran Quivira	32.0
	SAPU.0031	Quarai	69.0
	SAPU.0091	Abó	59.0
	Mean (all)	**–**	**64.0**
Juniper/oak woodland	SAPU.0076	Abó	37.0

Tree Mortality

While some tree mortality is natural in healthy woodlands, elevated mortality rates in a stand would be a cause for concern. In the western U.S., causes of tree mortality include drought stress, pests (e.g., insects, fungi), and fires (Gori and Bate 2007, NMSFD 2017). There are no data regarding tree mortality specifically for SAPU's park units. However, a long-term regional drought from 1996–2003 contributed to high pinyon mortality and some juniper mortality in many areas of New Mexico, which likely impacted park woodlands (Gori and Bate 2007). Park staff have noted that most large pinyons at Gran Quivira have been killed off but some smaller trees remain (Marc LeFrançois, SAPU Chief of Facility and Resource Management, personal communication, 1 February 2018). Around 2012–2014, a severe outbreak of pinyon ips beetles occurred in the Manzano Mountains, which are just northwest of the park's Abó and Quarai units (NMSFD 2014). These bark beetles caused extensive pinyon mortality in New Mexico for several years, but the outbreak was declining by 2015 (NMSFD 2016).

Herbaceous vs. Shrub Percent Cover

The shrub and herbaceous cover in woodlands and savannas varies by community type and land use history. In addition to increased tree density, researchers have noted a decline in herbaceous cover in open woodlands and savannas in the Western U.S., likely related to historic grazing and fire suppression (Asner et al. 2004, Bundshuh 2007). A loss of herbaceous ground cover can accelerate soil erosion (Davenport et al. 1998, Gori and Bate 2007).

Across all plots sampled by Muldavin et al. (2012), herbaceous cover averaged 25.7%, while shrub cover averaged 1.8% (Table 17). Herbaceous cover was highest in juniper/blue grama woodlands, with two plots having over 75% cover. This was the only upland woodland community where herbaceous cover exceeded 50%. Shrub cover was highest in the one juniper/oak woodland plot and generally lowest in juniper/black grama woodland and juniper sparse woodland. Shrub cover was higher than herbaceous cover in just two plots (SAPU0022, SAPU0076) (Muldavin et al. 2012).

Table 17. Shrub and herbaceous cover in upland woodland and savanna plots at SAPU (Muldavin et al. 2012).

Community type	Plot	Unit	Shrub % cover	Herbaceous % cover
Juniper/blue grama woodland	SAPU.0018	Gran Quivira	1.1	18.9
	SAPU.0026	Gran Quivira	2.6	39.4
	SAPU.0033	Quarai	3.7	85.0
	SAPU.0035	Quarai	1.7	42.9
	SAPU.0039	Quarai	5.6	75.7
	SAPU.0043	Abó	1.0	24.5
	SAPU.0048	Abó	1.6	31.6
	SAPU.0068	Quarai	1.0	24.1
	SAPU.0072	Abó	3.0	49.6
	SAPU.0073	Abó	0.6	16.7
	SAPU.0089	Abó	0.6	53.1
	SAPU.0093	Abó	3.1	45.1
	Mean (all)	**–**	**2.1**	**42.2**
Juniper/curlyleaf muhly woodland	SAPU.0049	Abó	3.1	16.5
	SAPU.0070	Abó	0.0	15.0
	SAPU.0077	Abó	1.0	21.5
	SAPU.0081	Abó	0.2	21.1
	SAPU.0082	Abó	0.5	38.8
	SAPU.0083	Abó	0.6	22.0
	SAPU.0092	Abó	2.5	8.2
	Mean (all)	**–**	**1.1**	**20.4**
Juniper/black grama woodland	SAPU.0025	Gran Quivira	0.6	34.1
	SAPU.0078	Abó	1.0	17.1
	SAPU.0085	Abó	<0.1	13.1
	SAPU.0086	Abó	<0.1	29.0
	SAPU.0095	Abó	0.0	10.0
	Mean (all)	**–**	**0.3**	**20.7**
Juniper sparse woodland	SAPU.0024	Gran Quivira	0.7	2.8
	SAPU.0047	Abó	0.1	0.2
	SAPU.0069	Abó	0.0	3.1
	SAPU.0094	Abó	<0.1	8.6
	Mean (all)	**–**	**0.2**	**3.7**

[1] Plots where shrub cover exceeds herbaceous cover.

Table 17 (continued). Shrub and herbaceous cover in upland woodland and savanna plots at SAPU (Muldavin et al. 2012).

Community type	Plot	Unit	Shrub % cover	Herbaceous % cover
Juniper/little bluestem woodland	SAPU.0023	Gran Quivira	3.6	32.7
	SAPU.0027	Gran Quivira	0.2	26.1
	SAPU.0028	Gran Quivira	2.7	46.7
	Mean (all)	**–**	**2.2**	**35.2**
Juniper/oak woodland	SAPU.0022	Gran Quivira	18.2 (1)	11.6 (1)
Pinyon-juniper/grama woodland	SAPU.0031	Quarai	1.2	2.6
	SAPU.0091	Abó	0.6	11.1
	Mean (all)	**–**	**0.9**	**6.9**
Pinyon-juniper sparse woodland	SAPU.0076	Abó	1.2 (1)	0.3 (1)
Average (all plots and units)	**–**	**–**	**1.8**	**25.7**

[1] Plots where shrub cover exceeds herbaceous cover.

Threats and Stressor Factors

Threats to SAPU's upland woodlands and savannas include soil erosion, invasive plants, drought, pests (e.g., bark beetles), historic land uses, fire, and climate change. Historic land uses that are still impacting SAPU's vegetation communities include grazing and tree removal. Domestic livestock have been present in New Mexico since the early 1600s, with a ranching boom beginning in the mid to late 1800s (Gori and Bate 2007). Intensive historic grazing reduced herbaceous understory vegetation and promoted the growth of less palatable woody species (Bundshuh 2007, Gori and Bate 2007). Pache (1979, p. 12) noted "large areas of bare ground" in Gran Quivira juniper woodlands that were thought to be the result of over-grazing. This loss of ground cover, along with soil compaction from grazing animals, has increased soil erosion at many sites in New Mexico, including Abó (Bundshuh 2007, Gori and Bate 2007). The soils at SAPU's units, and in most southwestern pinyon-juniper woodlands, are relatively unstable and naturally vulnerable to wind and water erosion when exposed (Pache 1979, NPS 1984, Gori and Bate 2007). Severe erosion can alter soil physical properties and nutrient distribution to a point that herbaceous vegetation recovery is impeded (Gori and Bate 2007).

During the period of significance for SAPU, trees were harvested for firewood and some construction (NPS 2010). With European settlement and the expansion of grazing, trees were also taken for fence posts and woodlands were cleared for pastures (Floyd-Hanna et al. 1994). One method of land clearing that was used in the Abó area in the 20^{th} century, called "chaining", used a heavy chain dragged between two bulldozers to tear trees from the ground (FAO 1988, Bundshuh 2007). As the chain dragged across the land surface, it also disturbed shrubs, herbaceous plants, and even soils (SUWA 2019). Muldavin et al. (2012) identified 5.3 ha (13.o ac) of "treated woodland" at Abó where junipers had been mechanically removed, most likely by chaining.

Historically, fire often played an important role in pinyon-juniper woodlands of the southwest, particularly in the more open, savanna-like communities (Gori and Bate 2007, Muldavin et al. 2012). For nearly a century, fires have been suppressed on western public lands as a threat to human populations and developments (Bundshuh 2007, SWCA Environmental Consultants 2016). This has contributed to an increase in tree density in some locations, which can contribute to reduced cover of herbaceous understory plants, increasing the risk of erosion. In addition, increased density likely makes trees more vulnerable to drought stress and insect outbreaks (Gori and Bate 2007). Additionally, the buildup of fuel in these denser stands may cause fires to be more severe if they do occur (Gruell 1999, Allen 2001).

The most prevalent insect pest in New Mexico’s pinyon-juniper woodlands is the pinyon ips beetle (*Ips confusus*) (Gori and Bate 2007). These bark beetles occur at low levels naturally, but damaging outbreaks can occur under drought conditions (Allen 2007, Gori and Bate 2007). The adult beetles tunnel under the bark of pinyon pines, causing dieback and potentially mortality (Cranshaw and Leatherman 2013). Pinyon ips beetles reached outbreak levels in New Mexico between 2010 and 2015 due to dry conditions, particularly in the Manzano and Sandia Mountains, not far from SAPU (Figure 16) (NMSFD 2014, 2016). The outbreak peaked in 2013, when 28,045 ha (69,300 ac) of pinyon damage was documented across the state (NMSFD 2014). After multiple years of adequate precipitation, the outbreak had begun subsiding by 2017, when less than 40 ac (100 ac) of damage was noted statewide (NMSFD 2017). Pinyon needle scale (*Matsucoccus acalyptus*), a native sap-sucking insect, can also damage pinyon pines but rarely causes mortality in isolation (NMSFD 2017).

Figure 16. Pinyon mortality (brown trees towards center) due to pinyon ips beetles in the Sandia Mountains of New Mexico, north of SAPU (NMSFD photo by Tom Zegler).

As mentioned previously, 18 non-native invasive plant species have been documented in SAPU's upland woodlands (Korb 2011). Invasive plants compete with native species for limited resources and may alter natural fire regimes (Mooney et al. 2005, Gori and Bate 2007). Some non-native plants were likely introduced or spread by livestock (NPS 2010), and further invasion is promoted by human disturbances (e.g., road, trail, and facility construction) (Floyd-Hanna et al. 1994, Korb 2011). Species of particular concern found in SAPU's upland woodlands include tamarisk (*Tamarix* spp.), Siberian elm (*Ulmus pumila*), and cheatgrass (Korb 2011, Muldavin et al. 2012). Efforts to remove and control invasive woody species have occurred at both Abó and Quarai (Bogan et al. 2000, LeFrançois 2017c).

Climate change has already contributed to warmer temperatures in the Southwest, a trend that is expected to continue over the next century (Garfin et al. 2014). The region is also projected to become drier with more sustained droughts due to shifting precipitation patterns and increased evapotranspiration (Seager et al. 2007, Garfin et al. 2014). Extended droughts have long been known to stress trees in the western U.S., sometimes contributing to mortality (Betancourt et al. 1993). Droughts in New Mexico during the 1950s and early 2000s are known to have triggered significant pinyon pine die-offs (Betancourt et al. 1993, Breshears et al. 2005). According to Allen et al. (2010), episodes of tree mortality linked to drought and heat have increased in recent decades, and are expected to continue to increase in the future. Mortality linked to drought includes not only cases of water and heat stress, but also insect outbreaks and severe wildfires driven by warmer, drier conditions (NPS 2014b). Given that pinyon pine is already limited to the higher elevation, cooler and moister microclimates of SAPU (Pache 1979, Floyd-Hanna et al. 1994), it is possible that the changing climate may make the park units unsuitable for the species and it may be extirpated.

<u>Data Needs/Gaps</u>

With the exception of community extent, data are very limited for the measures selected for this component. To better understand the condition of SAPU's upland woodlands and savannas, additional studies of tree density, tree mortality, herbaceous vs. shrub cover, and species richness at finer spatial scales are needed. In addition, regular monitoring for non-native plant species would be helpful in detecting any new infestations and controlling current problem species. Muldavin et al. (2012) noted that park staff conducted vegetation management on trees and shrubs (e.g., mechanical removal, fire) at Quarai after the completion of the vegetation map, and that the map could be updated using GIS software to reflect these and any other ongoing changes. The park's Foundation Document (NPS 2014b) noted the need for a combined plan for vegetation, invasive species, and fire management, including a management program for hazardous trees in visitor use areas.

In general, there is an inadequate understanding of the historical variability within pinyon-juniper ecosystems and of the current ecological processes that shape them (Gori and Bate 2007, Romme et al. 2008). While increased tree density in woodlands, savannas, and shrublands is well-documented in some regions (Romme et al. 2008), the extent and impact of tree density increases at SAPU is unclear. Grazing, fire suppression, and climate shifts have likely all contributed to changes in tree density, but to what degree and how these factors interact is unknown. One researcher (Sallach 1986) hypothesized that the increased density in parts of New Mexico may represent natural recovery of woodlands after centuries of prehistoric and historic human disturbance (e.g., wood-cutting and pasture clearing). Additional examples of uncertainties include successional dynamics in pinyon-juniper savannas and factors that favor pinyon and juniper seedling germination and establishment (Gori and Bate 2007).

<u>Overall Condition</u>

Community Extent

The project team assigned this measure a *Significance Level* of 3. During the most recent vegetation mapping project, Muldavin et al. (2012) identified slightly more upland woodland at Gran Quivira than Pache (1979), and a similar extent at Quarai but less upland woodland at Abó than Floyd-Hanna et al. (1994). Differences in the vegetation maps suggest that there may have been a decline in the extent of pinyon-juniper woodlands at Abó between studies. However, it is unclear whether the apparent decline represents actual change over time or is due to differences in classification and mapping methodologies between studies. At this time, a *Condition Level* of 1 has been assigned, as the concern for overall upland woodland and savanna extent is low.

Plant Species Richness

This measure was also assigned a *Significance Level* of 3. A total of 149 plant species have been documented over time in SAPU's upland woodlands and savannas, 18 of which are non-native (Appendix A). The number of species detected by surveys prior to 2000 (Pache 1979, Floyd-Hanna et al. 1994) is nearly identical to the number recorded more recently by Muldavin et al. (2012). As a result, this measure is currently of low concern (*Condition Level* = 1).

Proportion of Total Cover of Non-native, Invasive Plants

A *Significance Level* of 3 was assigned for this measure. Muldavin et al. (2012) documented non-native plants in four of 35 upland woodland sampling plots, with cover exceeding 1% in just one plot. Korb (2011) found measurable non-native plant cover in eight of 99 upland woodland/savanna grid cells, but none exceeded 0.5%. Therefore, a *Condition Level* of 1 was assigned, indicating low concern at this time.

Tree Density

A *Significance Level* of 2 was assigned for the tree density measure. Since no actual data regarding tree density are available for SAPU, a *Condition Level* could not be assigned for this measure.

Tree Mortality

This measure was assigned a *Significance Level* of 3. As with the previous measure, no tree mortality information specifically from SAPU's upland woodlands and savannas is available. Therefore, a *Condition Level* could not be assigned for this measure.

Herbaceous vs. Shrub Percent Cover

A *Significance Level* of 3 was also assigned for this final measure. In Muldavin et al. (2012) sampling plots, herbaceous cover averaged 25.7% while shrub cover averaged just 1.8%. Shrub cover exceeded herbaceous cover in only two plots. However, because this is the only data available for shrub and herbaceous cover at this time, a *Condition Level* has not been assigned.

Weighted Condition Score

A *Weighted Condition Score* was not calculated for SAPU's upland woodlands and savannas due to a lack of data or limited information for three of the six selected measures (Table 18). The condition and trend for this component are unknown at this time.

Table 18. Current condition of Upland Woodland and Savanna Communities at SAPU.

Measures	Significance Level	Condition Level	WCS = N/A
Community Extent	2	1	–
Plant Species Richness	3	1	–
Non-native, Invasive Plant Cover	3	1	–
Tree Density	2	n/a	–
Tree Mortality	3	n/a	–
Herbaceous vs. Shrub Cover	3	n/a	–
Overall	**–**	**–**	

4.1.6 Sources of Expertise

- Jim DeCoster, SCPN Plant Ecologist
- Megan Swan, SCPN Botanist

4.2 Wetland and Riparian Communities

4.2.1 Description

Wetland and riparian communities in the arid southwest are uncommon and typically small, but support a relatively high diversity of plant and animal life (Springer et al. 2006a, SWCA Environmental Consultants 2016). At SAPU, wetlands and riparian areas are found only in the Abó and Quarai units (Muldavin et al. 2012). These wetlands, streams, and riparian areas are primarily spring-fed, and provide a critical water source for local wildlife (Springer et al. 2006a, Muldavin et al. 2012). The reliable water at these springs and streams also attracted early Native American and European settlers to the area (NPS 2002a, b).

The Abó and Quarai units contain approximately 5.8 km (3.6 mi) of perennial and intermittent streams/arroyos (Figure 17) (NPS 2014b). Riparian tree and shrub species, such as cottonwoods and willows, are found along these streams (Floyd-Hanna et al. 1994). Large cottonwoods are so distinctive within the regional landscape that they are now considered key contributors to the two units' cultural landscapes (NPS 2002a, b). Wetland plants including horsetails (*Equisetum* spp.), bulrushes (*Schoenoplectus* spp.), and cattails (*Typha* spp.) occur where water pools (Figure 18). The wetland and riparian community types found at SAPU, along with common plant species in each, are presented in Table 19.

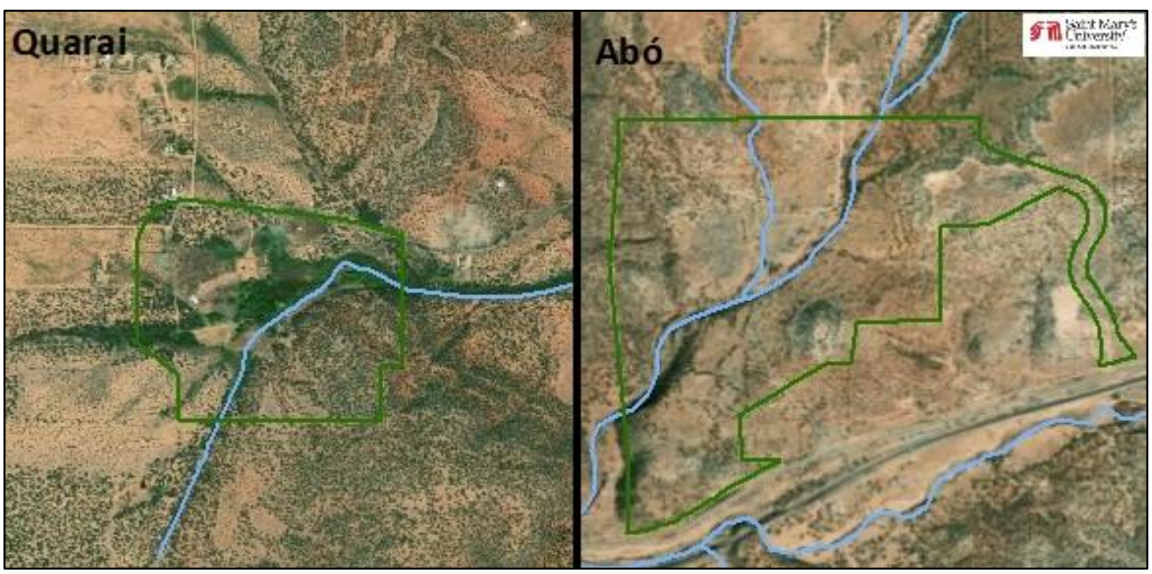


Figure 17. Streams (blue lines) in the Quarai and Abó units of SAPU.

Figure 18. A wetland area at Quarai, March 2010 (NPS photo from Muldavin et al. 2012).

Table 19. Wetland and riparian communities found at SAPU, along with common plant species (Muldavin et al. 2012).

Vegetation community	**Plant species**
Cottonwood/Goodding's Willow/Mixed Shrub Riparian Woodland	eastern cottonwood (*Populus deltoides*), narrowleaf cottonwood (*Populus angustifolia*), Goodding's willow (*Salix gooddingii*), narrowleaf willow (*S. exigua*), golden currant (*Ribes aureum*), Wood's rose (*Rosa woodsii*), chokecherry (*Prunus virginiana*)
Goodding's Willow-Coyote Willow Riparian Woodland	Goodding's willow, narrowleaf (coyote) willow, Baltic rush (*Juncus balticus*), smooth horsetail (*Equisetum laevigatum*), common threesquare (*Schoenoplectus pungens* var. *longispicatus*), cattails (*Typha* spp.)
Coyote Willow Riparian Shrubland	narrowleaf (coyote) willow, Wood's rose
Chokecherry-Woodrose Riparian Shrubland	chokecherry, Wood's rose, currants (*Ribes* spp.), pineywoods geranium (*Geranium caespitosum*)
Cattail and Horsetail Emergent Wetland	smooth horsetail, sedges (*Carex* spp.), spikerush (*Eleocharis* sp.), cutleaf waterparsnip (*Berula erecta*), cattails
Rabbitbrush Dry Wash Shrubland	rubber rabbitbrush (*Ericameria nauseosa*)

4.2.2 Measures

- Community extent (area)
- Cottonwood community extent
- Plant species richness
- Proportion of total cover of non-native, invasive plants
- Tree regeneration

4.2.3 Reference Condition/Values

As with the upland forest and woodland communities component, the ideal reference condition for wetland and riparian communities would be the condition at the time the Pueblo people and Spanish missionaries lived in the SAPU area (early and mid-1600s). However, information from this time is limited and it may no longer be feasible to restore these conditions due to environmental and land use changes. For the purposes of this NRCA, best professional judgement will be used to assess condition; the data presented here may serve as a reference condition or baseline for future assessments.

4.2.4 Data and Methods

Several of the sources utilized for the upland forest and woodland communities component were also used for this component. These include Floyd-Hanna et al. (1994), Korb (2011), and Muldavin et al. (2012). Twenty-five of Muldavin et al.'s (2012) sampling plots fell within wetland and riparian community types. Summaries of these shared data sources can be found in the Data and Methods section of Chapter 4.1.

In 2005, Springer et al. (2006a) inventoried 75 springs in SCPN and Northern Colorado Plateau Network (NCPN) parks. These included Abó Spring and Quarai Spring at SAPU, which were visited in mid-May. Site inventories documented environmental and climate conditions, vegetation, invertebrates, water quantity (if measurements were possible), and water quality (Springer et al. 2006a).

Data on the location and extent of wetlands can often be obtained from the National Wetland Inventory (NWI), a database maintained by the U.S. Fish and Wildlife Service (USFWS). However, NWI data for the region surrounding SAPU was out of date and of low quality. SMUMN GSS, in cooperation with the New Mexico Environment Department, is currently completing an update of the NWI data for this area of the state using aerial imagery interpretation, based on imagery obtained in 2016. An experienced SMUMN GSS wetland interpreter prioritized the mapping of wetlands within SAPU's units as part of this update, so that they could be incorporated into the NRCA. However, it should be noted that field verification of NWI data is typically limited and, therefore, the mapping is often not as precise as on-the-ground mapping and sampling.

4.2.5 Current Condition and Trend

Community Extent

Floyd-Hanna et al. (1994) mapped a total of 9.8 ha (24.3 ac) of wetland and riparian area within the current boundaries of SAPU's Abó and Quarai units (Table 20). The riparian extent at Abó was slightly smaller than at Quarai and consisted of just one vegetation community type (Figure 19); two riparian vegetation types were found at Quarai (Figure 20). The riparian border (weedy) community at Quarai consisted of recently disturbed sites near waterways where weeds such as burningbush (*Kochia scoparia*) were found (Floyd-Hanna et al. 1994).

Table 20. The extent (area) of wetland and riparian communities within the Abó and Quarai units of SAPU, as mapped by Floyd-Hanna et al. (1994).

	Extent (area) in ha (ac)	
Vegetation community	**Abó**	**Quarai**
Lanceleaf cottonwood series	4.5 (11.1)	–
Fremont's cottonwood series	–	2.0 (5.1)
Riparian border (weedy)	–	3.3 (8.1)
Total	**4.5 (11.1)**	**5.3 (13.2)**

Muldavin et al. (2012) mapped a total of 7.1 ha (17.6 ac) of wetland and riparian vegetation at SAPU (Table 21). This included 2.7 ha (6.7 ac) at Abó and 4.4 ha (10.9 ac) at Quarai (Figure 21, Figure 22). These totals were lower than the wetland/riparian extent mapped by Floyd-Hanna et al. (1994), who identified 9.8 ha (24.3 ac) total, 4.5 ha (11.1 ac) at Abó and 5.3 ha (13.2 ac) at Quarai. It is uncertain whether this represents actual change over time or if it is due to differences in classification and mapping methodologies. The most extensive wetland community type was Quarai's Chokecherry-Woodrose Riparian Shrubland, followed by the Cottonwood/Goodding's Willow/Mixed Shrub Riparian Woodland, which was found at both units. No wetlands or riparian communities occur at the Gran Quivira unit.

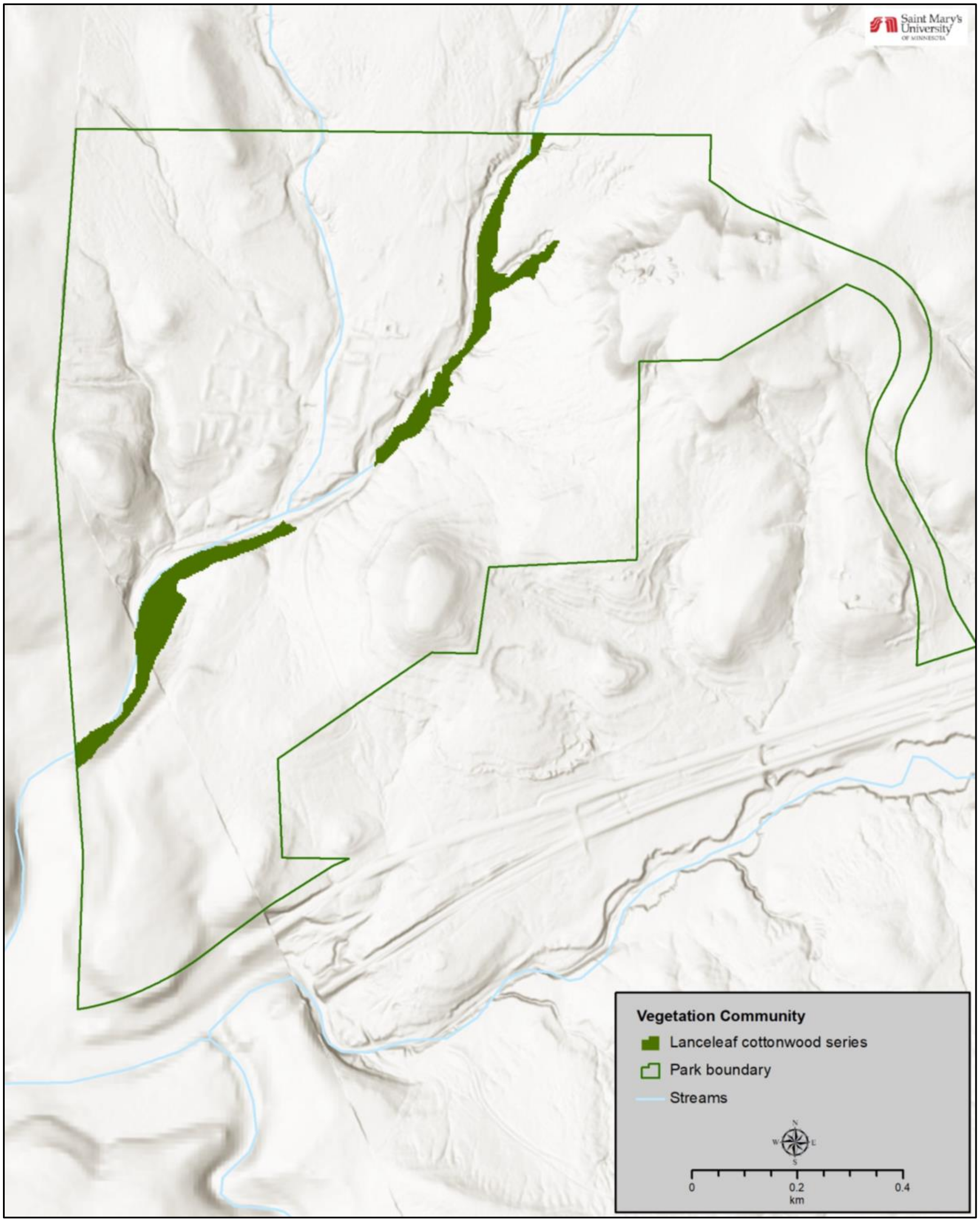


Figure 19. Wetland and riparian vegetation within the Abó unit of SAPU, as mapped by Floyd-Hanna et al. (1994).

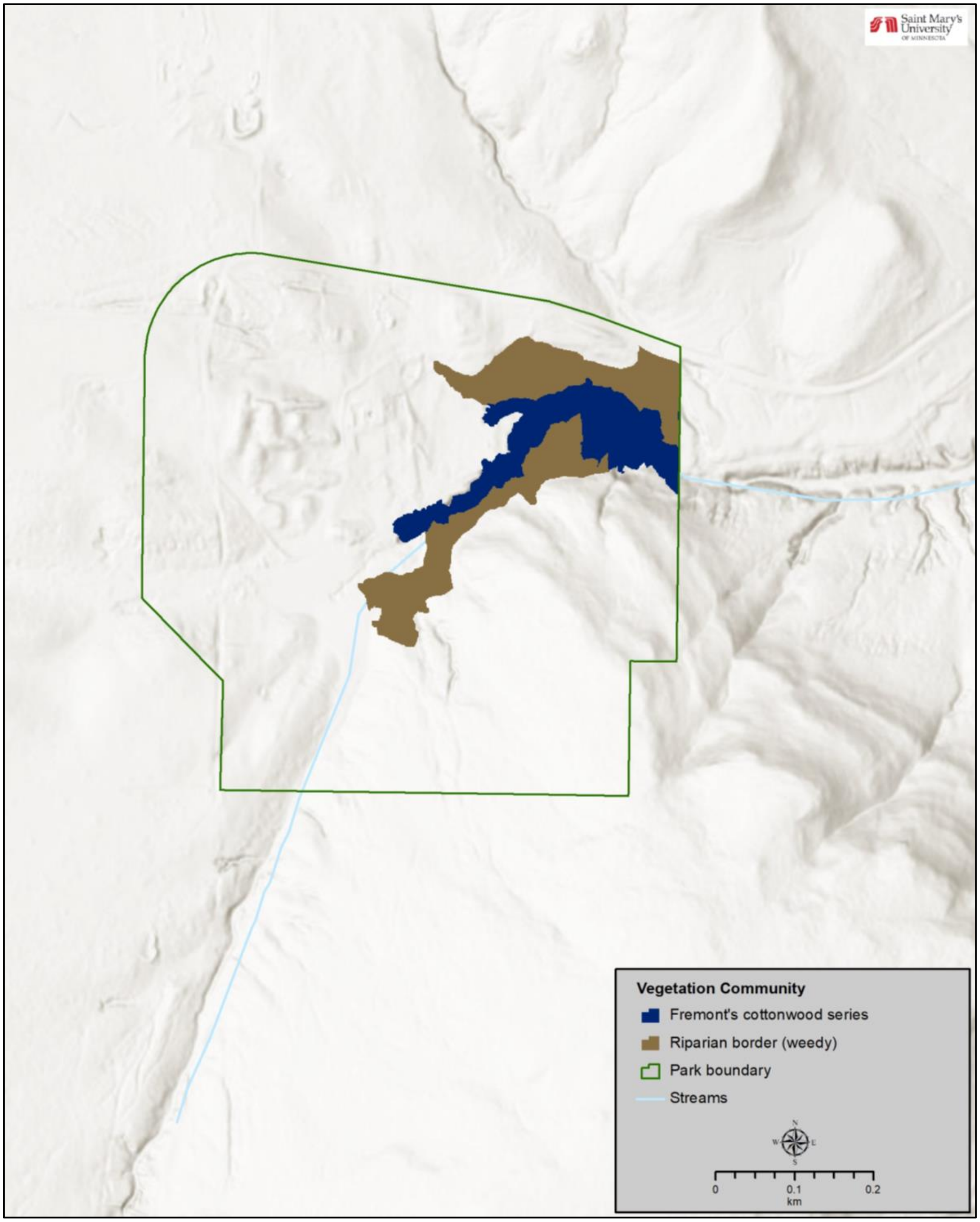


Figure 20. Wetland and riparian vegetation within the Quarai unit of SAPU, as mapped by Floyd-Hanna et al. (1994).

Table 21. The extent (area) of wetland and riparian vegetation communities at SAPU, as mapped by Muldavin et al. (2012).

Vegetation community	Abó (ha/ac)	Quarai (ha/ac)	Area in ha (ac)
Cottonwood/Goodding's Willow/Mixed Shrub Riparian Woodland	0.9 (2.2)	0.8 (2.0)	1.7 (4.2)
Goodding's Willow-Coyote Willow Riparian Woodland	0.8 (2.0)	0.5 (1.2)	1.3 (3.2)
Coyote Willow Riparian Shrubland	0.09 (0.2)	0.05 (0.1)	0.1 (0.3)
Chokecherry-Woodrose Riparian Shrubland	–	2.4 (5.9)	2.4 (5.9)
Cattail and Horsetail Emergent Wetland	0.5 (1.2)	0.7 (1.7)	1.2 (2.9)
Rabbitbrush Dry Wash Shrubland [1]	0.4 (1.0)	–	0.4 (1.0)
Total	**2.7 (6.7)**	**4.4 (10.9)**	**7.1 (17.6)**

[1] Due to the small size of this community, it does not appear on the SAPU vegetation map.

A cottonwood riparian woodland at Abó (NPS photo).

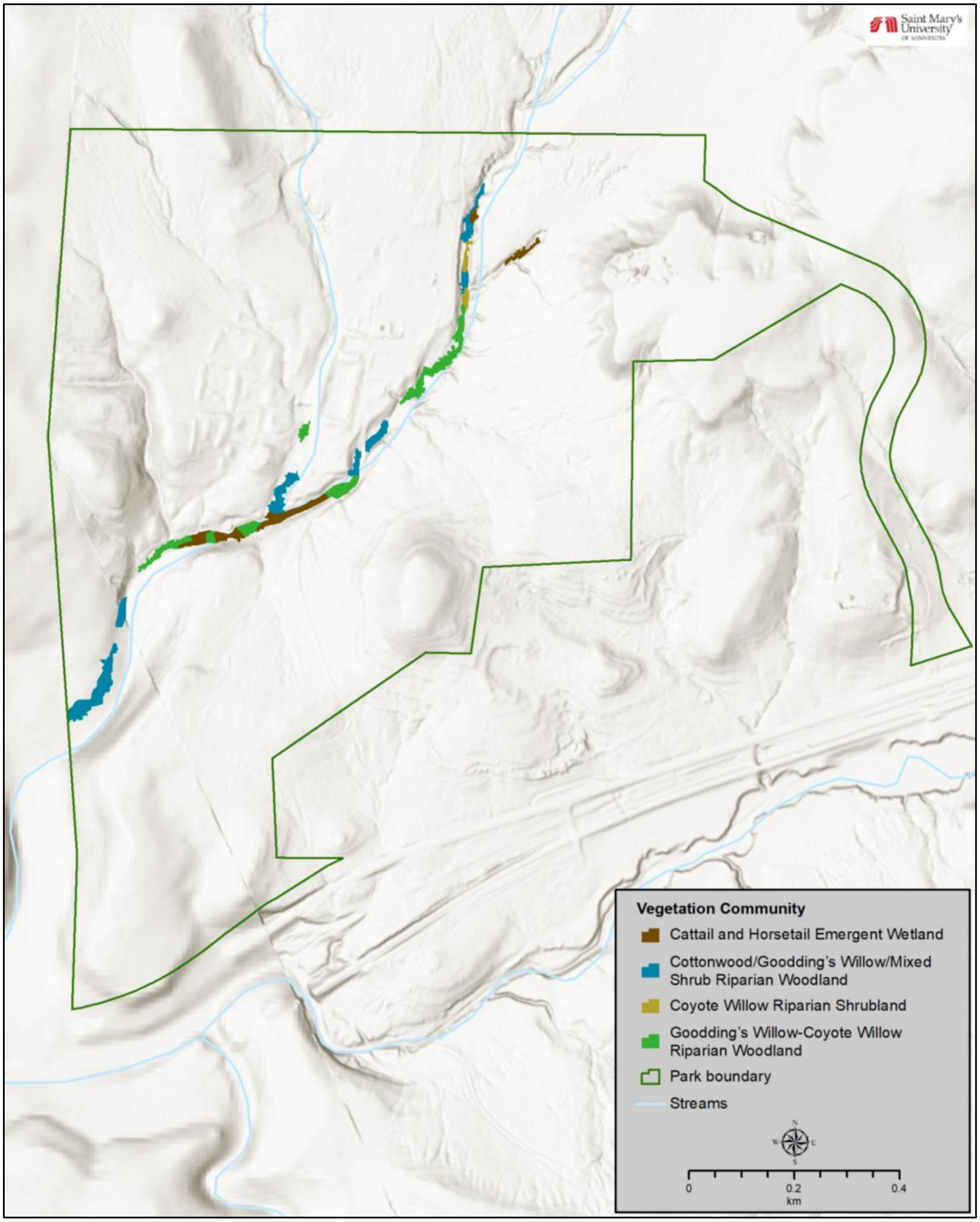


Figure 21. Wetland and riparian communities within the Abó unit of SAPU (Muldavin et al. 2012).

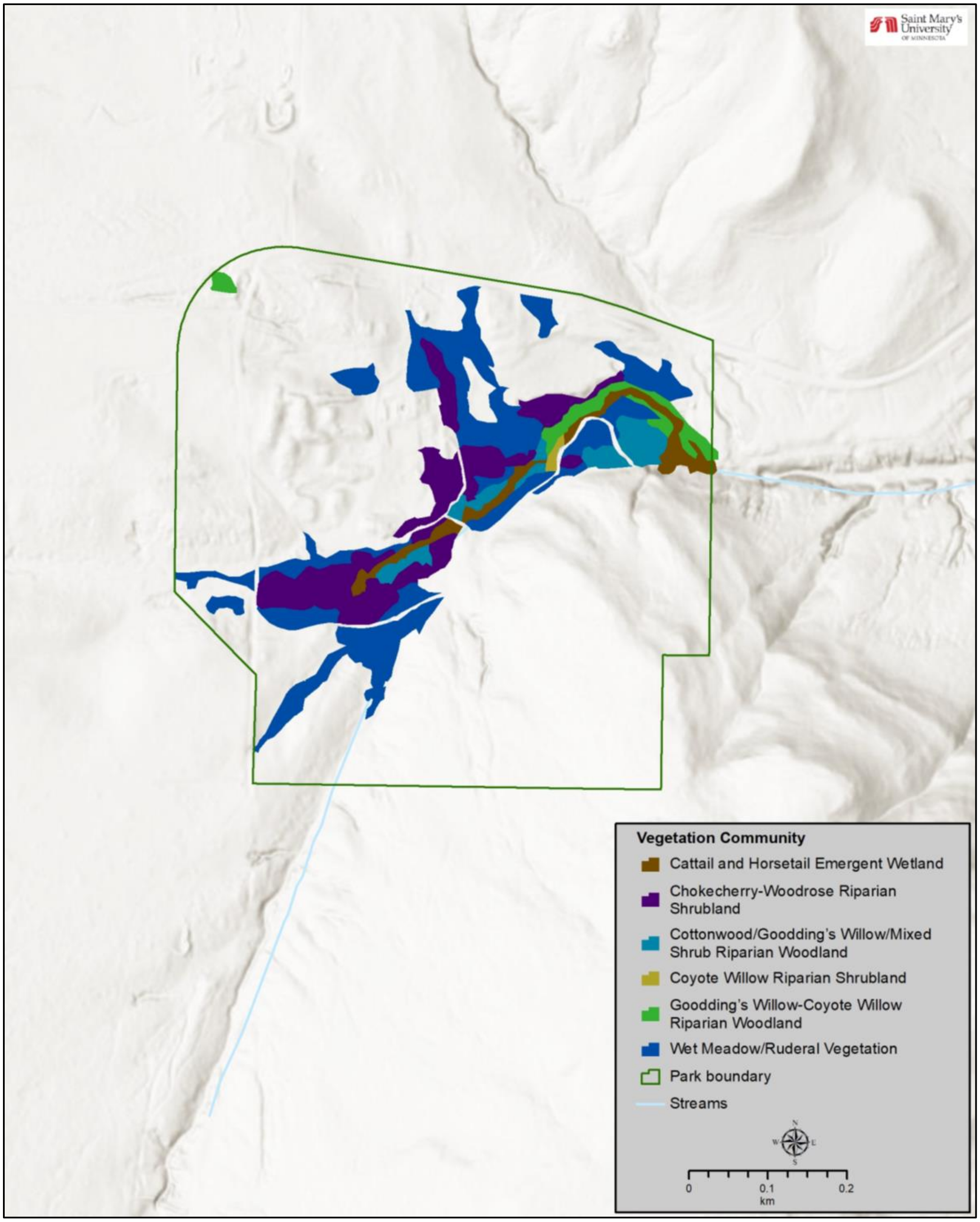


Figure 22. Wetland and riparian communities within the Quarai unit of SAPU (Muldavin et al. 2012).

Recent NWI mapping by SMUMN GSS wetland interpreters identified 4.4 ha (10.9 ac) of wetlands at SAPU (Table 22). The NWI classifies wetlands by vegetation/substrate type (e.g., scrub-shrub, streambed, rock bottom) and by water regime (e.g., saturated, intermittently exposed, intermittently flooded). Non-vegetated wetlands (e.g., open water, streambed) were more extensive than vegetated wetlands, which were dominated by emergent/herbaceous vegetation (PEM1B) (Figure 23). The most prevalent water regime was intermittently flooded (J), which means "the substrate is usually exposed, but surface water is present for variable periods without detectable seasonal periodicity. Weeks, months, or even years may intervene between periods of inundation" (Cowardin et al. 1979, p. 40). It should be noted that NWI mapping includes open water and non-vegetated streambed wetlands, while previous sources in this section focused exclusively on vegetated wetland extent.

Table 22. Extent of wetlands and riparian communities at SAPU according to NWI mapping (SMUMN GSS, unpublished data). P = palustrine, R3 = riverine upper perennial, R4 = riverine intermittent. EM1 = persistent emergent (herbaceous) vegetation, SS = scrub-shrub, UB = unconsolidated bottom (open water), RB = rock bottom, SB1 = streambed (bedrock), SB3 = streambed (cobble-gravel), SB7 = streambed (vegetated). B = saturated, C = seasonally flooded, F = semipermanently flooded, G = intermittently exposed, J = intermittently flooded.

Category	Wetland Code	Area in ha (ac)
Vegetated	PEM1B	1.46 (3.60)
	PSS1B	0.05 (0.12)
	R3SB7F	0.24 (0.59)
	R4SB7J	0.27 (0.67)
	Total Vegetated	**2.02 (4.98)**
Non-vegetated	PUBF	0.02 (0.05)
	R3RBG	0.05 (0.12)
	R3UBF	0.20 (0.49)
	R4SB1J	1.01 (2.50)
	R4SB3J	1.04 (2.57)
	R4SBC	0.05 (0.12)
	Total Non-vegetated	**2.37 (5.87)**
Total (all)	**–**	**4.39 (10.85)**

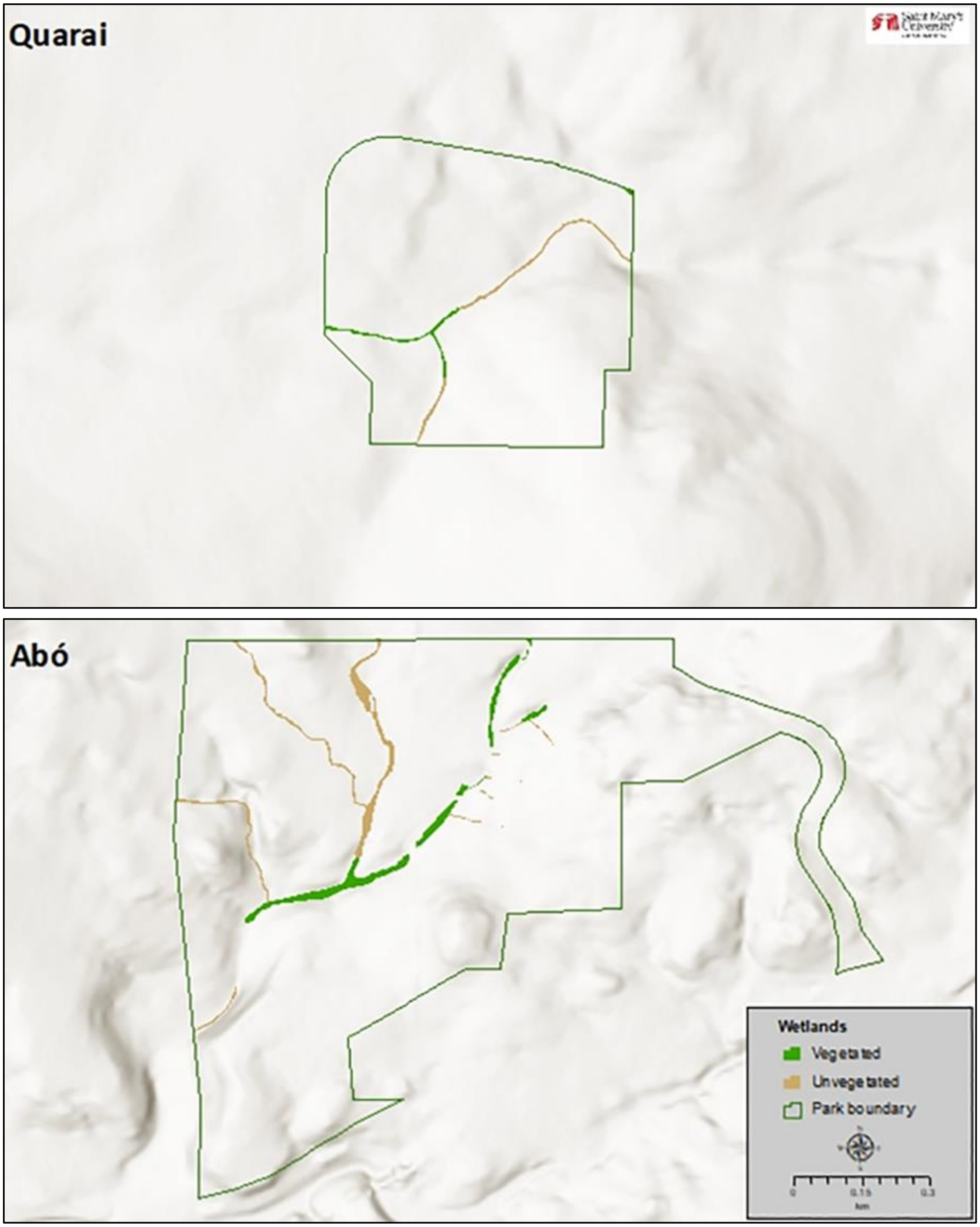


Figure 23. Wetlands within Quarai and Abó, according to NWI mapping by SMUMN GSS (based on aerial imagery interpretation).

<u>Cottonwood Community Extent</u>

All 4.5 ha (11.1 ac) of riparian area at Abó identified by Floyd-Hanna et al. (1994) were classified as a cottonwood community. At Quarai, 2.0 ha (5.1 ac) of cottonwood community were mapped.

More recently, Muldavin et al. (2012) identified just 1.7 ha (4.2 ac) of cottonwood communities at SAPU, 0.9 ha (2.2 ac) at Abó (Figure 24) and 0.8 ha (2.0 ac) at Quarai (Figure 25). As with the previous measure, some of the discrepancy may be due to differences in classification and mapping methodologies rather than actual change over time.

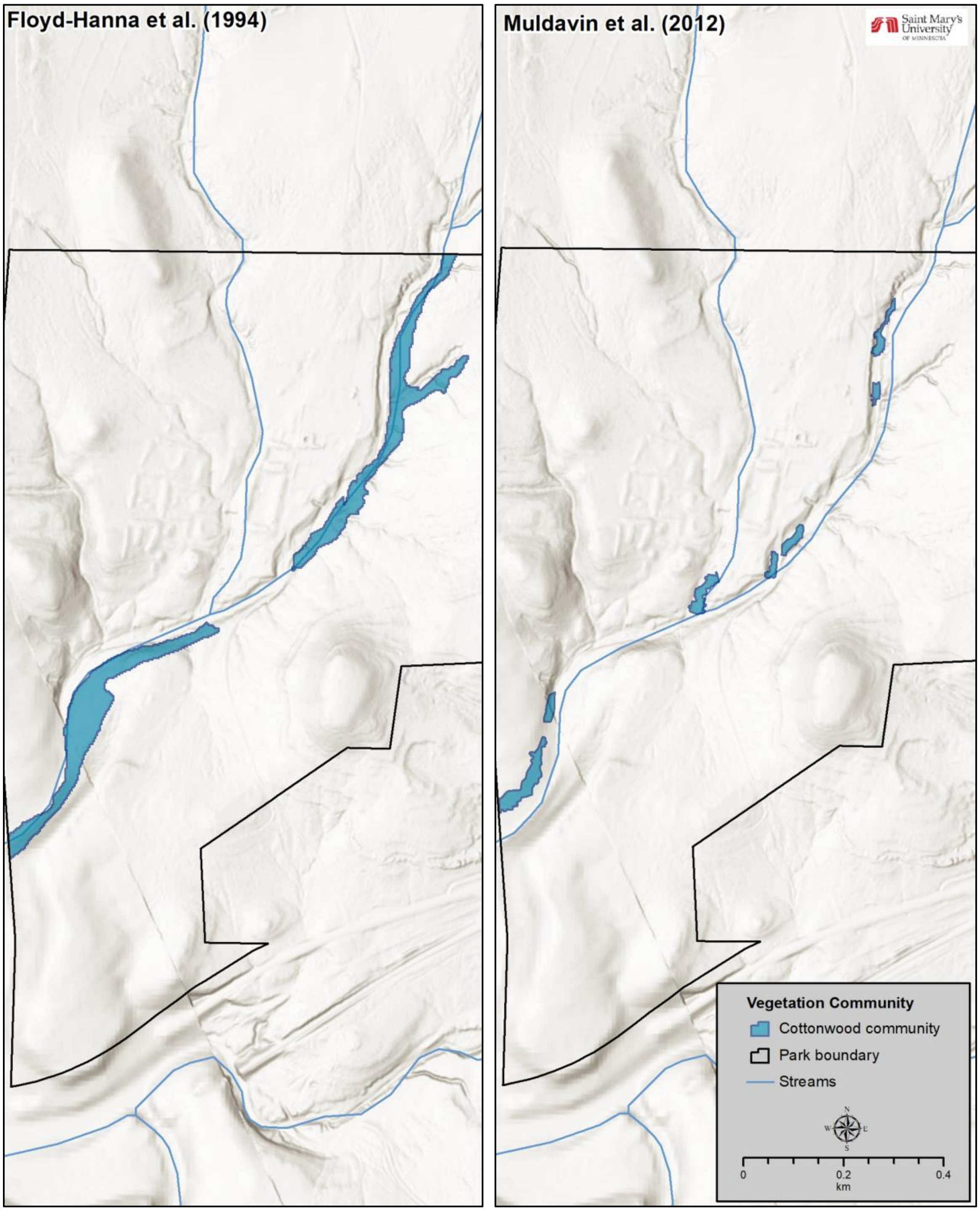


Figure 24. Cottonwood community extent at Abó, as mapped by Floyd-Hanna et al. (1994) (left) and Muldavin et al. (2012) (right).

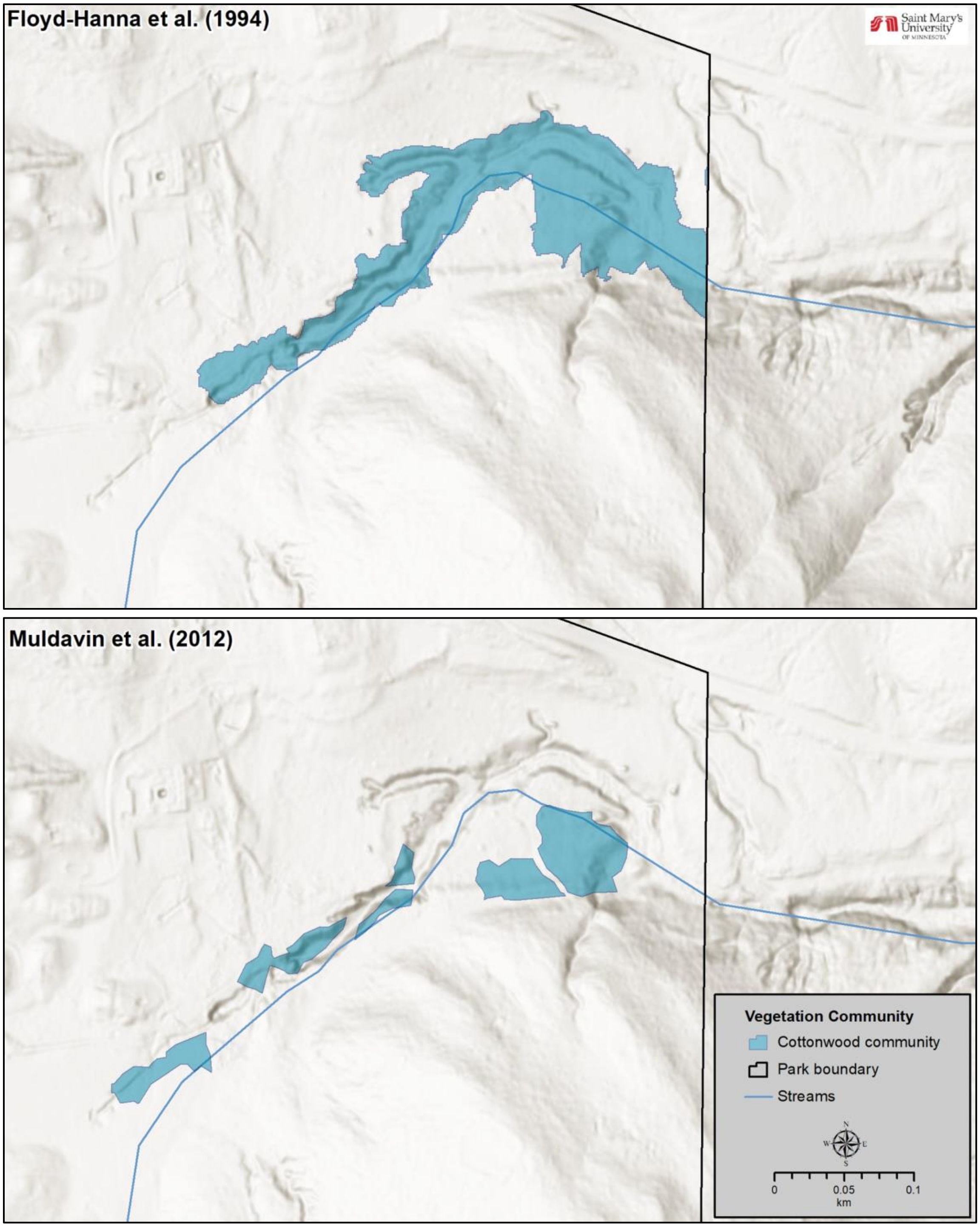


Figure 25. Cottonwood community extent at Quarai, as mapped by Floyd-Hanna et al. (1994) (top) and Muldavin et al. (2012) (bottom).

Plant Species Richness

A total of 99 plant species have been documented in SAPU's wetland and riparian communities (Appendix B). Twenty-three of these species (~23%) are non-native. Floyd-Hanna et al. (1994) identified at least 59 species at the Abó and Quarai units. The most recent park-wide vegetation study, Muldavin et al. (2012) documented a total of 60 plant species in wetland and riparian communities across the two units. In an exotic plant inventory of SAPU, Korb (2011) found 10 exotic species in riparian areas at Abó and nine exotic species at Quarai.

Wetland plants around a pool at Quarai, August 2011 (NPS photo by Ellen Soles).

Proportion of Total Cover of Non-native, Invasive Plants

As mentioned previously, invasive species pose a significant threat to biodiversity and ecosystem integrity (Mooney et al. 2005, Beard and App 2013). Non-native cover was found in five of the 24 wetland and riparian plots sampled by Muldavin et al. (2012) between 2005 and 2009, and ranged from 0.05% to 62.5%. The highest non-native plant cover was found in a Goodding's Willow Riparian Woodland at Abó, with 62.5% cover of tall fescue (*Schedonorus arundinaceus*) (Table 23).

Korb (2011) documented measurable non-native plant cover in all four of the riparian grid cells surveyed at Abó and Quarai, with ranges from 0.05–38.6% (Table 24). The most prevalent species was field bindweed (*Convolvulus arvensis*), which averaged 15% cover across all riparian grid cells (Korb 2011).

Table 23. Non-native plant species cover in wetland and riparian plots at SAPU (Muldavin et al. 2012).

Plot	Unit	Community type	% non-native cover
SAPU.0087	Abó	Goodding's Willow Riparian Woodland	62.50
SAPU.0044	Abó	Goodding's Willow-Coyote Willow Riparian Woodland	20.71
SAPU.0041	Quarai	Cattail and Horsetail Emergent Wetland	10.05
SAPU.0038	Quarai	Cottonwood/Goodding's Willow/Mixed Shrub Riparian Woodland	7.50
SAPU.0037	Quarai	Cottonwood/Goodding's Willow/Mixed Shrub Riparian Woodland	0.05
19 additional plots	–	–	0.00
Average	**–**	**–**	**4.20**

Table 24. Non-native plant species cover in riparian and riparian shrubland grid cells at SAPU (Korb 2011).

Grid cell	Unit	Community type	% non-native cover
50	Abó	Riparian	13.15
53	Abó	Riparian shrubland	0.05
191	Quarai	Riparian	0.65
197	Quarai	Riparian	38.60

During SCPN spring inventories at SAPU, plant species were assigned a "cover range" rather than an exact value (Springer et al. 2006b). Non-native species cover ranged from 3–30% at Abó Spring and from 2–20% at Quarai Spring (Table 25).

Table 25. Non-native plant species cover ranges at SAPU springs, documented during inventories by the SCPN (Springer et al. 2006b).

Spring	% non-native cover
Abó Spring	3–30%
Quarai Spring	2–20%

<u>Tree Regeneration</u>

Studies of tree recruitment, such as the composition and density of the seedling and sapling layers, can provide insight into the future character of the forest (McWilliams et al. 2015). Shifts in the composition of seedlings/saplings may indicate an eventual change in the composition of the forest as a whole, which can impact forest dynamics and wildlife habitat (McWilliams et al. 2015). At this time, no data could be found regarding tree regeneration in SAPU's wetland and riparian communities.

Threats and Stressor Factors

Threats to SAPU's wetland and riparian communities identified by the project team include climate change, non-native plants, erosion, water quality degradation, and illegal water diversions. Water quality parameters such as pH, turbidity, and nutrient levels can impact the composition and abundance of aquatic and wetland vegetation (Carter 1996). Pesticides, fertilizers, and excessive sediment in runoff from adjacent land uses may also harm wetland and riparian vegetation communities (EPA 2005, Mahaney et al. 2005).

As described in Chapter 4.1, the southwestern U.S. is projected to become warmer and drier with more sustained droughts as a result of climate change (Seager et al. 2007, Garfin et al. 2014). According to SAPU's Foundation Document (NPS 2014b), the park has already experienced an increase in drought conditions linked to climate change. The increased temperatures associated with global warming will likely contribute to higher evaporation rates and faster transpiration by plants, meaning surface waters and shallow groundwater associated with springs and ephemeral streams could be lost to the atmosphere faster. This decline in water availability, along with shifts in precipitation patterns, may alter the structure and functioning (e.g., nutrient cycling, hydrologic processes) of riparian ecosystems and impact the park's plant and wildlife communities (Thomas et al. 2006b, NPS 2014b). Water-stressed trees, in particular, are often more vulnerable to pests, pathogens, and anthropogenic stressors. In addition, droughts can reduce vegetation cover and increase wildfire risk, which then potentially increases runoff and erosion (Istanbulluoglu and Bras 2006, Ravi et al. 2010).

Drier conditions associated with climate change could also lead to increased groundwater pumping for irrigation in arid regions, which would likely cause the groundwater table to drop (Taylor et al. 2012). This concern will be discussed further in Chapter 4.10. Water shortages are likely to trigger more water use conflicts and disputes (Kaufman 2018), possibly including illegal water diversions upstream of SAPU's units, which could reduce the quantity of water reaching the park's riparian areas.

Heavy rainfall and floods can cause large-scale erosion and excessive sedimentation in the park's riparian areas (NPS 1974, Thomas et al. 2006b, Muldavin et al. 2012). The soils at SAPU are relatively unstable and vulnerable to such water erosion during precipitation events (NPS 1984). Soil that runs off may settle and contribute to sedimentation within the park's arroyos and riparian areas, or it may be swept further downstream and out of the park. The stream channel at Abó in particular is subject to flash flooding during summer thunderstorms, with Muldavin et al. (2012) noting entrenchment in some areas as much as 5–10 m (16–33 ft) deep. Wetland vegetation along the stream channel at Quarai is also vulnerable to scouring during high-intensity flooding (Soles, written communication, 12 June 2019).

Invasive, non-native plants may impact wetland and riparian communities in a number of ways. They can displace native plants which, in turn, can alter ecosystem functions such as water and nutrient cycling (Westbrooks 1998). In the Southwest, non-native shrubs have displaced and impeded regeneration of cottonwoods and willows in riparian areas (Korb 2011, NPS 2014b). At SAPU, tamarisk and Russian olive (*Elaeagnus angustifolia*) have invaded arroyo bottoms and spring beds at Abó and Quarai (Floyd-Hanna et al. 1994, Bundshuh 2007, NPS 2014b). However, park managers have worked to remove these two invasive shrubs, with treatments on up to 6.9 ha (17 ac) of park land, and their current presence is minimal (NPS 2002a, 2005; LeFrançois, personal communication, 30 January 2018).

Data Needs/Gaps

In general, more data are needed related to the park's riparian woodlands, shrublands and wetlands (Muldavin et al. 2012). For example, information is needed regarding tree regeneration in these communities, particularly for riparian species such as cottonwoods and willows. A comprehensive plant survey of park wetlands and riparian areas would help to better understand species diversity, distribution, and abundance. Some of these data needs may be addressed by the SCPN's new riparian monitoring program, which will include a sampling site at Quarai (DeCoster, email communication, 12 April 2019). Monitoring visits will include a "plant walk" of the entire sampling reach, in order to document as many species as possible (Perkins et al. 2018).

As with upland forests, an update of the park's vegetation map to reflect management actions and the development of a combined plan for vegetation, invasive species, and fire management would be helpful for park managers (Muldavin et al. 2012, NPS 2014b).

Overall Condition

Community Extent

The project team assigned this measure a *Significance Level* of 3. Floyd-Hanna et al. (1994) mapped 9.8 ha (24.3 ac) of wetland and riparian area at SAPU during the early 1990s. More recently, Muldavin et al. (2012) identified a total of 6.7 ha (16.6 ac) of wetland and riparian vegetation. As mentioned previously, it is uncertain whether this difference represents actual change over time or if it is due to differences in classification and mapping methodologies. NWI mapping of SAPU by SMUMN GSS (based on aerial imagery interpretation) identified 4.4 ha (10.9 ac) of wetlands at SAPU, 2.02 ha (4.98 ac) of which were vegetated and 2.37 ha (5.87 ac) were non-vegetated. Because it appears that SAPU's wetland extent may be declining, this measure is assigned a *Condition Level* of 2.

Cottonwood Community Extent

This measure was assigned a *Significance Level* of 2. Floyd-Hanna et al. (1994) identified 6.5 ha (16.2 ac) of cottonwood community at SAPU's Abó and Quarai units. Nearly two decades later, Muldavin et al. (2012) mapped just 1.7 ha (4.2 ac) of cottonwood communities at SAPU. As with the previous measure, some of the discrepancy may be due to differences in classification and mapping methodologies rather than actual change over time. However, given the already limited extent of cottonwood communities, this possible decline is a cause for moderate concern (*Condition Level* = 2).

Plant Species Richness

A *Significance Level* of 3 was assigned for the plant species richness measure. The number of species detected in the earliest known survey of SAPU's wetland and riparian communities (Floyd-Hanna et al. 1994) is nearly identical to the number recorded more recently by Muldavin et al. (2012). As a result, this measure is currently of low concern (*Condition Level* = 1).

Proportion of Total Cover of Non-native, Invasive Plants

This measure was also assigned a *Significance Level* of 3. Non-native species cover was higher in SAPU's wetland and riparian communities than in upland forests. Korb (2011) documented non-native cover as high as 38.6% in one riparian grid cell, while Muldavin et al. (2012) recorded 62.5% non-native cover in a riparian woodland plot. Currently, this measure is of moderate concern (*Condition Level* = 2).

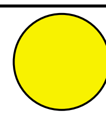
Tree Regeneration

A *Significance Level* of 3 was assigned for this final measure. No data related to tree regeneration could be found for the park's wetland and riparian communities. As a result, a *Condition Level* could not be assigned.

Weighted Condition Score

The *Weighted Condition Score* for SAPU's wetland and riparian communities is 0.58, indicating moderate concern (Table 26). While some data suggest the extent of wetlands at SAPU are declining, this cannot be stated with any certainty. Therefore, a trend has not been assigned.

Table 26. Current condition of Wetland and Riparian Communities at SAPU.

Measures	**Significance Level**	**Condition Level**	**WCS = 0.58**
Community Extent	3	2	–
Cottonwood Community Extent	2	2	–
Plant Species Richness	3	1	–
Cover of Non-native, Invasive Plants	3	2	–
Tree Regeneration	3	n/a	–
Overall	**–**	**–**	

4.2.6 Sources of Expertise

- Jim DeCoster, SCPN Plant Ecologist
- Ellen Soles, Northern Arizona University and NPS Senior Research Specialist

4.3 Birds

4.3.1 Description

Bird populations often serve as excellent indicators of an ecosystem's health (Morrison 1986, Hutto 1998, NABCI 2009). Birds are typically highly visible components of ecosystems, and bird communities often reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010). Resident birds provide insight into the current status of the habitats they frequent, while migratory birds serve as excellent ecological indictors because a disturbance adversely affecting any of the habitats used by these species (e.g., stopover, wintering, or breeding habitats) can cause declines in populations and a decrease in species' reproductive success (Hilty and Merenlender 2000, Zöckler 2005).

In total, SAPU has more than 140 species of birds that are either confirmed as present or are listed as probable species (NPS 2018a). SAPU is located near a crossover site for species migrating along the Central Flyway as they move from the Rocky Mountains towards the Gulf of Mexico and the eastern Mexican coast (Figure 26); it is likely that several migratory species cross through the park on their way to and from breeding grounds in northern North America.

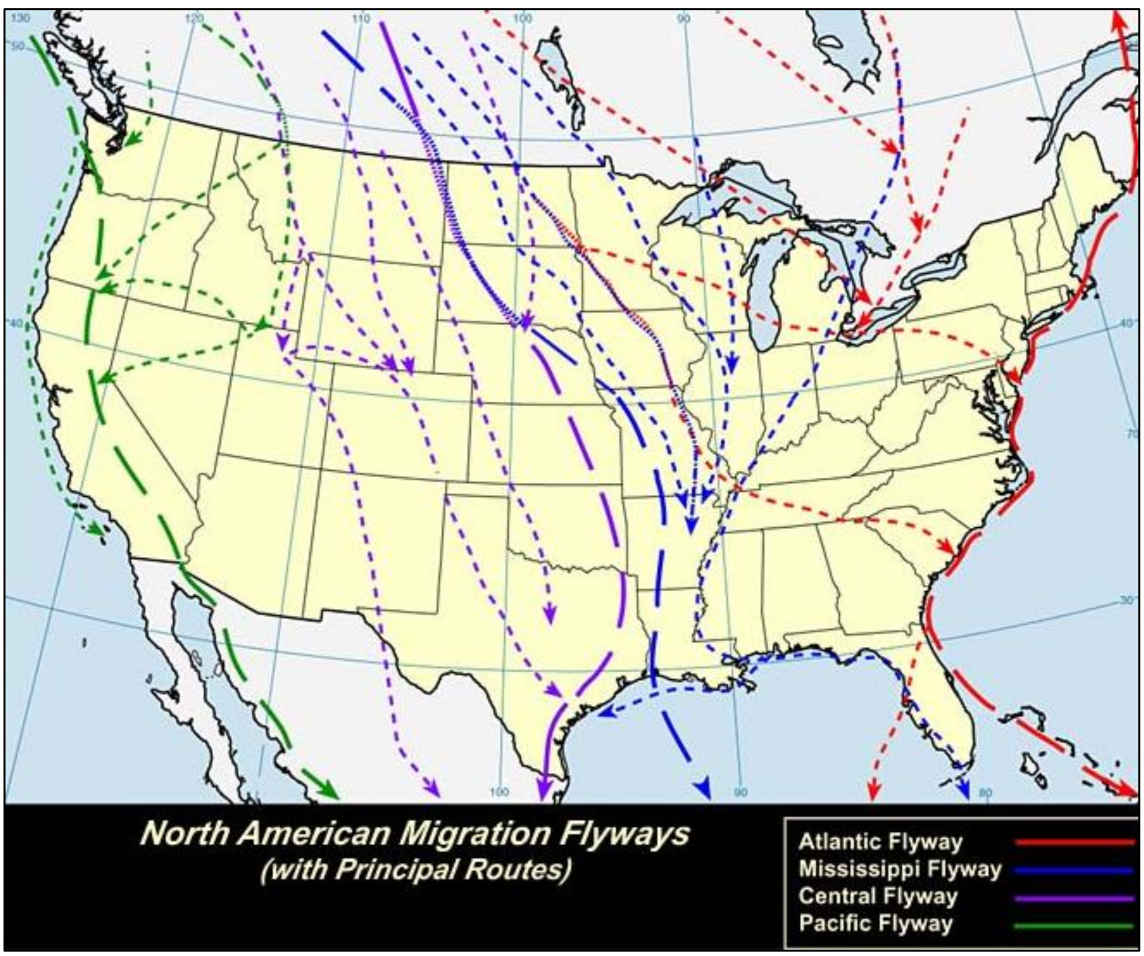


Figure 26. Major North American migratory flyways. SAPU is located near a crossover site as species move from the Rocky Mountains towards the Gulf of Mexico (NPS 2016a).

Long-distance migratory species are highly informative indicator species, as their overall health depends on several different ecosystems. Global Christmas Bird Count (CBC) and Breeding Bird Survey data indicate significant declines in migratory bird numbers in recent years (Peterjohn and Sauer 1999, Vickery and Herkert 2001, Niven et al. 2009). Monitoring of long distance migratory species populations as they pass through or overwinter in SAPU may help managers to develop a better understanding of the overall health of not only the SAPU ecosystem, but also the other ecosystems that these bird species rely on.

4.3.2 Measures

- Species richness
- Species abundance
- Species distribution

4.3.3 Reference Condition/Values

Due to a lack of historic surveys or inventories in the park, an appropriate reference condition does not exist for this component at this time. While the ideal reference condition for this resource would be the bird community composition of the monument at the time of Pueblo residence (approximately 1620–1670), those data do not exist. For this assessment, the best professional judgement of the identified subject matter experts and NPS staff was used to assess current condition. Future assessments of condition may be able to utilize this summary as a baseline for comparison.

4.3.4 Data and Methods

The NPS Certified Bird Species List (NPS 2018a) for SAPU was used for this assessment, as this list represents all of the confirmed bird species present in the park. The list is populated by the various bird inventories and surveys that occur in the park's area, and in the case of parks with limited bird work, will likely resemble the overall species list of the primary bird inventory effort for the park.

From 1978–1979, Scott (1979) attempted to inventory the vertebrate species of Gran Quivira National Monument (which was later incorporated into SAPU). Scott (1979) visited the monument on four occasions (1–4 November 1978, 30 January–2 February 1979, 8–10 May 1979, and 14–16 September 1979). Two permanent transects, each 1,100 m (3,609 ft) in length, were established in Gran Quivira, with one in the north portion of the monument (Torrance County) and one in the south (Socorro County); both transects ran west to east. Each transect was surveyed by one individual, with all birds seen or heard within 20 m (65 ft) of the transect being recorded. Any bird observed flying overhead was identified as a flyover, and birds observed off transect were recorded as off-transect observations. Some of the common and Latin names in Scott (1979) were outdated and needed to be adjusted to reflect the currently accepted taxonomic naming standards. These instances included:

- Observations of marsh hawks were treated as observations of norther harriers (*Circus cyaneus*);
- Records of "roadrunner" were treated as records of the greater roadrunner (*Geococcyx californianus*), which is the common name of the only roadrunner species in the area;

- Observations for common flicker were renamed to northern flicker (*Colaptes auratus*), as genetic analysis has classified flicker species (red-shafted, yellow-shafted, common) as one species (Sibley and Ahlquist 1983);
- The American white-necked raven was the formerly accepted common name of the Chihuahuan Raven (*Corvus cryptoleucus*) and all records of this species were adjusted to the currently accepted common and Latin names of the species;
- The plain titmouse was treated as the juniper titmouse (*Baeolophus ridgwayi*). The plain titmouse was split into two distinct species: the oak titmouse (*Baeolophus inornatus*) and the juniper titmouse (AOU 1997). The juniper titmouse is the species that occurs in the SAPU region;
- The records of "common bushtit" were adjusted to have a common name of "bushtit" (*Psaltriparus minimus*);
- Similarly, records of "mockingbird" were adjusted to northern mockingbird (*Mimus polyglottos*), and "robin" were adjusted to American robin (*Turdus migratorius*);
- Likely a simple spelling error in the source document, "western tanger" was treated as a record of western tanager (*Piranga ludoviciana*);
- Rufous-sided towhee observations were treated as observations of the spotted towhee (*Pipilo maculatus*) to reflect current taxonomic classification;
- Records of brown towhee were treated as *Pipilo fuscus*; this species is commonly referred to as both brown towhee and canyon towhee, the majority of current literature in the park uses canyon towhee;
- Dark-eyed junco and gray-headed junco observations were treated as one species (*Junco hyemalis*) (Sibley and Ahlquist 1983).

These adjustments were made to update the data to the currently accepted taxonomic standards, and to eliminate duplicate or historic references that were erroneous. After the adjustments were made, the data were analyzed and organized for an accurate assessment of the survey's results.

During the 2002 breeding season, Schwarz (2002) completed a breeding bird survey at Gran Quivira. This survey was the result of one independent researcher, and was provided to the NPS as an unpublished internal document. The transect followed a 3.2 km (2 mi) loop transect, with 11 point count stations along the route. Point counts were spaced no closer than 0.32 km (0.2 mi), and birds seen or heard were counted at each point for 10 minutes.

Johnson et al. (2007) represents the efforts of the SCPN to inventory all avian species that occur throughout the NPS units of the network. The inventory focused specifically on surveying breeding birds, but also featured non-breeding surveys to capture the resident and overwintering species. The small size of SAPU restricted the survey types to being either non-randomly selected transects or area searches rather than the larger scale variable circular plot (VCP) sampling efforts used elsewhere in the network. The non-random transects featured six to seven point count stations each that were spaced a minimum of 250 m (850 ft) apart, and had a minimum buffer between habitat types of 200 m (656 ft). Area searches involved researchers systematically covering as much of the park as possible and recording all individual birds detected and the time of detection (Johnson et al. 2007).

Transects were established by Johnson et al. (2007) in Abó and Gran Quivira, with a total of 26 point count stations along the routes. One transect with seven stations was created in the riparian area of Abó, while three transects were created in the pinyon juniper habitats (Figure 27); two transects were in Gran Quivira (six points each), and one was in Abó (seven points). The small size of Quarai prevented the establishment of transects, and researchers instead used area searches to survey the entire unit. Field work was conducted from 2001–2003. Point count surveys were completed in 2001, with all points being surveyed four times throughout the season. Additionally, incidental observations and area searches were also performed four times during the breeding season of 2001. No point counts were completed in 2002; instead, three visits were dedicated to area searches of Quarai and Abó during the breeding season. Four non-breeding surveys were completed, and were spaced out during the winter months of 2001–2003.

The International Migratory Bird Day (IMBD) is an annual event that takes place on the second Saturday in May each year. Hart R. Schwarz, a former employee of Cibola National Forest, has organized or led a bird count in Quarai on IMBD since 1998; the count has been conducted every year (current through 2017) (NPS unpublished data). Survey effort and results of the counts have been highly variable, often depending upon the number of volunteers, weather, and timing of breeding and migration.

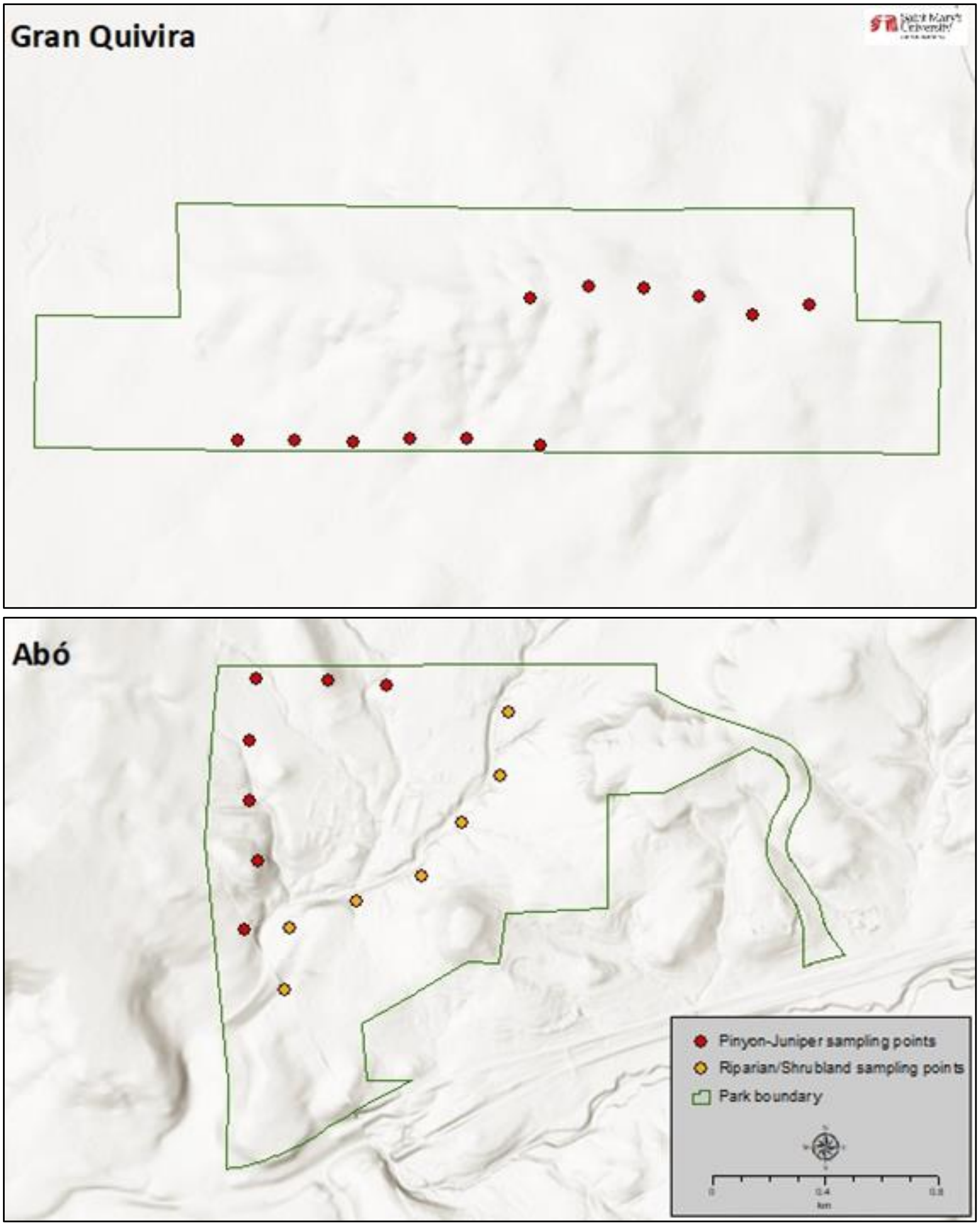


Figure 27. Point count locations along four transects in SAPU. Gran Quivira featured 12 point counts along two transects, both in the pinyon-juniper habitat, while the Abó unit had transects located in both riparian/shrubland and pinyon juniper habitats (Johnson et al. 2007).

4.3.5 Current Condition and Trend

Species Richness

The species richness measure refers to the total number of species present in a given study, survey, or other monitoring effort. This definition is in line with the traditional definition in published literature, and with the definition used by Johnson et al. (2007), which is the only NPS-led avian survey in the park. It is important to note that a higher species richness estimate does not always correlate to a healthier population. This is particularly true in developed landscapes, as the fragmentation of these areas may encourage generalist bird species or guilds to move in, which would increase the species richness estimate, but would lower the overall condition of the measure.

The differing methodologies and timing make trends and patterns observed in each study difficult to compare, and the results are best analyzed individually. This assessment presents the results of each study, but does not compare the species richness values between any studies.

NPS Certified Species List (NPS 2018a)

The NPS Certified Bird Species List contains 132 species that are confirmed in the park (Appendix C). This list also identifies 12 species that may be present in the area but have not been confirmed within the park's boundaries. These species were identified as "Probably Present" by NPS (2018a) and included species such as the sharp-shinned hawk (*Accipiter striatus*), red-breasted nuthatch (*Sitta canadensis*), and the downy woodpecker (*Picoides pubescens*). An additional 15 species were identified as unconfirmed species in the park, including the black-chinned sparrow (*Spizella atrogularis*), hairy woodpecker (*Picoides villosus*), and golden eagle (*Aquila chrysaetos*). The designation of "unconfirmed" indicates that the species has been attributed to the park, but little or no evidence to support its presence exists.

Unlike annual bird surveys, NPS (2018a) is not well suited for an analysis of annual species richness, as no data are collected yearly. The NPS Certified Species List documents the presence (or historic presence) of the identified species and serves as a useful point of comparison to determine which species have been documented in the park.

Scott (1979)

During four separate avian surveys at Gran Quivira spanning 1978–1979, Scott (1979) identified 49 species (Appendix C). Along the two permanent transects, species richness values ranged from eight species (Jan–Feb 1979) to 13 (November 1978, May 1979), with 25 total species observed. Opportunistic observations of species outside of the established transects during Scott (1979) had species richness estimates ranging from six (Jan–Feb 1979) to 21 (September 1979). Thirty-seven species were observed off-transect in total, with 25 of these species observed exclusively off-transect during the life of the study.

Schwarz (2002)

During 2002 surveys along a 3.2 km (2 mi) loop transect in Gran Quivira, Schwarz (2002) detected 19 species (Appendix C). The author indicated that, while the number of bird species was lower than anticipated, the results largely conformed with expectations based on results from other locations of similar habitat type, and the fact that a major drought was occurring in the region. A blue grosbeak

(*Passerina caerulea*) was observed during the survey, which was somewhat unexpected based on the habitat requirements of the species not correlating with what was available in Gran Quivira. Schwarz (2002) also noted that a gray flycatcher was observed, which is a Partners in Flight (PIF) Priority Species for the area.

Johnson et al. (2007)

Johnson et al. (2007) detected 75 avian species during baseline point count and area search efforts from 2001–2003. Point count efforts across Gran Quivira and Abó resulted in the identification of 37 species, while area searches of all units of SAPU identified 73 species (Appendix D). When including non-breeding winter surveys, the number of species detected in the park increased to 83. These winter efforts detected 25 species in the park; nine of the 25 species that were detected in the winter months are species that are not expected to breed in the area, and instead use the park for overwintering purposes only (Johnson et al. 2007).

Johnson et al. (2007) detected one species that is identified as a Species of Conservation Concern by the USFWS (USFWS 2002): the black-throated gray warbler (*Setophaga nigrescens*). In addition to the black-throated gray warbler, five other species were documented by Johnson et al. (2007) that are identified as Species of Conservation Concern by PIF (Table 27).

Table 27. Priority species (as identified by Partners in Flight) that are likely to occur in the SAPU region and the habitat they are associated with. Table reproduced from Johnson et al. (2007).

Priority Species	Priority Habitat	Detected in Johnson et al. (2007)
Bendire's thrasher [1]	**shrubland/grassland**	**–**
black-chinned sparrow	shrubland/grassland	–
black-throated gray warbler	pinyon-juniper	X
gray flycatcher	pinyon-juniper	X
gray vireo [1]	**pinyon-juniper**	**–**
Hammond's flycatcher	riparian	–
loggerhead shrike	shrubland/grassland	–
MacGillivray's warbler	riparian	X
red-naped sapsucker	riparian	X
sage thrasher	shrubland/grassland	–
Scott's oriole	pinyon-juniper	X
summer tanager	riparian	–
Virginia's warbler [1]	**montane shrubland**	**X**

[1] Target species for the Nature Conservancy, also shown in bold text.

Jackknife estimates of species richness performed by Johnson et al. (2007) indicated that nearly 80% of all expected species in SAPU were documented by the point count surveys (Table 28). The jackknife calculations only used data produced by the Johnson et al. (2007) point count surveys, and did not include species detected during area searches or incidental observations.

Table 28. Observed number of species, first order jackknife estimates of the total number of species, and the percent of species observed during Johnson et al. (2007).

Habitat	n	# of observed species	Jackknife estimate	% increase of estimate from observed	% species observed
All Habitats	26	37	47.6	20.2	79.8

International Migratory Bird Day Surveys (1998–2017)

Counts such as the IMBD (or other index counts, e.g., breeding bird surveys, Christmas Bird Counts) are neither censuses nor density estimates (Link and Sauer 1998). The overall usefulness of index count data is often limited by possible biases of count locations and the number of observers, and it is often not advisable to estimate overall population sizes from these data alone (Link and Sauer 1998). These biases may influence how many individuals or species are observed in a given year, and may potentially explain the annual variation observed in species each year. Results of the IMBD counts should be interpreted with a degree of caution.

One-day surveys that coincide with IMBD in Mid-May have occurred annually in the park since 1998 (data from 2018, 2019 were not available at the time of publication). These annual surveys represent the longest continual avian dataset in SAPU. For the duration of the surveys, 117 species were documented by volunteers (NPS unpublished data). The highest species richness estimate came in 2000 when 67 species were documented, and the lowest species richness estimate was in 2015 when 29 species were documented. The average species richness estimate for the duration of the IMBD surveys was 50.3 species/year (Figure 28). The number of observers per year were not provided by the organizer(s) of the annual count, and it is not possible to analyze potential trends between species richness and observer effort/year.

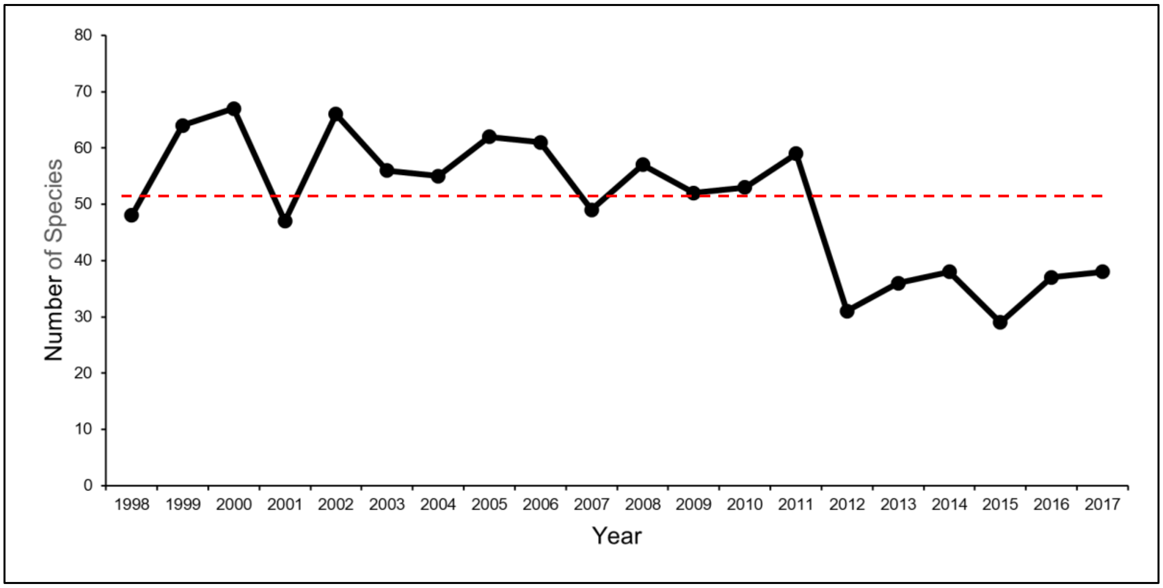


Figure 28. Number of species observed in SAPU during one-day IMBD surveys in mid-May from 1998 to 2017 (NPS unpublished data). The red dotted line indicates the average number of species observed per year (50.3 species).

<u>Species Abundance</u>

Species abundance refers to how many individuals are documented in a given survey/monitoring period. It needs to be noted, however, that all species have different detection probabilities, and measures of abundance reported here should be considered “naïve” estimates, as they do not account for these variable detection probabilities.

Scott (1979)

Scott (1979) documented avian detections that occurred directly on transect (two transects in total), and documented the number of detections that were the result of birds flying over the transect during the survey; a north transect and south transect were surveyed during the effort. Visits to the park between the fall of 1978 and late summer 1979 resulted in 606 total bird detections (Scott 1979).

Along the north transect, the number of birds detected directly on-transect ranged from 13 (Jan–Feb 1979) to 36 (November 1978); the average number of birds detected on-transect was 23.25 (Figure 29). Flyover detections ranged from zero (September 1979) to 63 (November 1978), and the average number of birds detected as flyovers was 21 (Figure 29). The total number of detections at the north transect (flyover and direct) from November 1978 to September 1979 was 177.

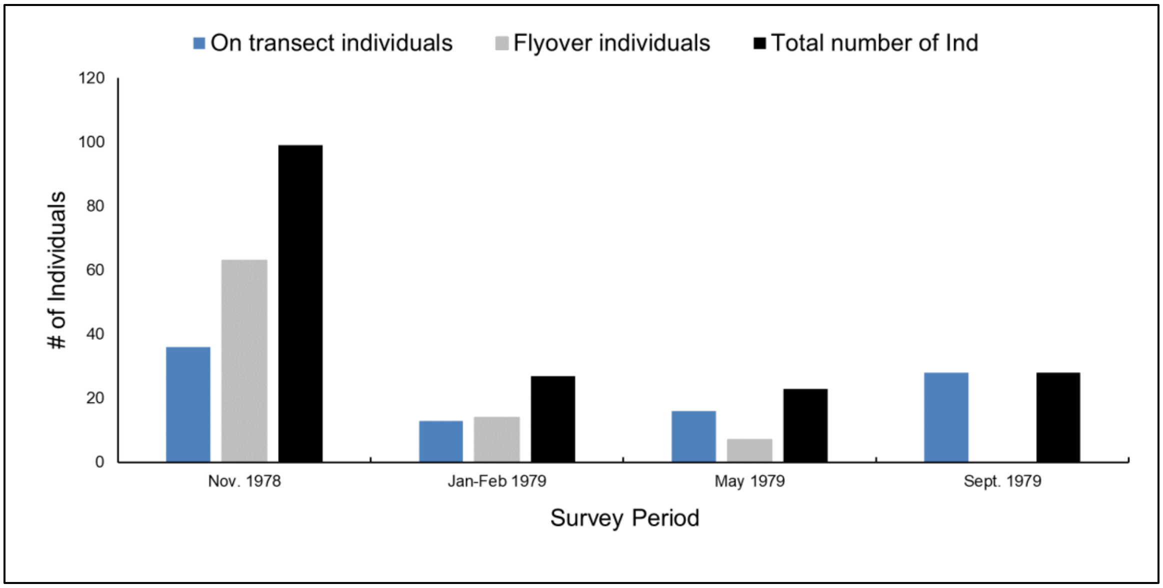


Figure 29. The number of individuals detected on-transect, as flyovers, and in total during surveys of the north transect established by Scott (1979).

The southern transect sampled by Scott (1979) had a higher number of detections, with the number of birds detected directly on transect ranging from 10 (May 1979) to 119 (Jan–Feb 1979) (Figure 30). The average number of detections directly on-transect was 61.25. Flyover detections at the south transect ranged from 11 (September 1979) to 138 (November 1978), with the average number of birds detected being 46.

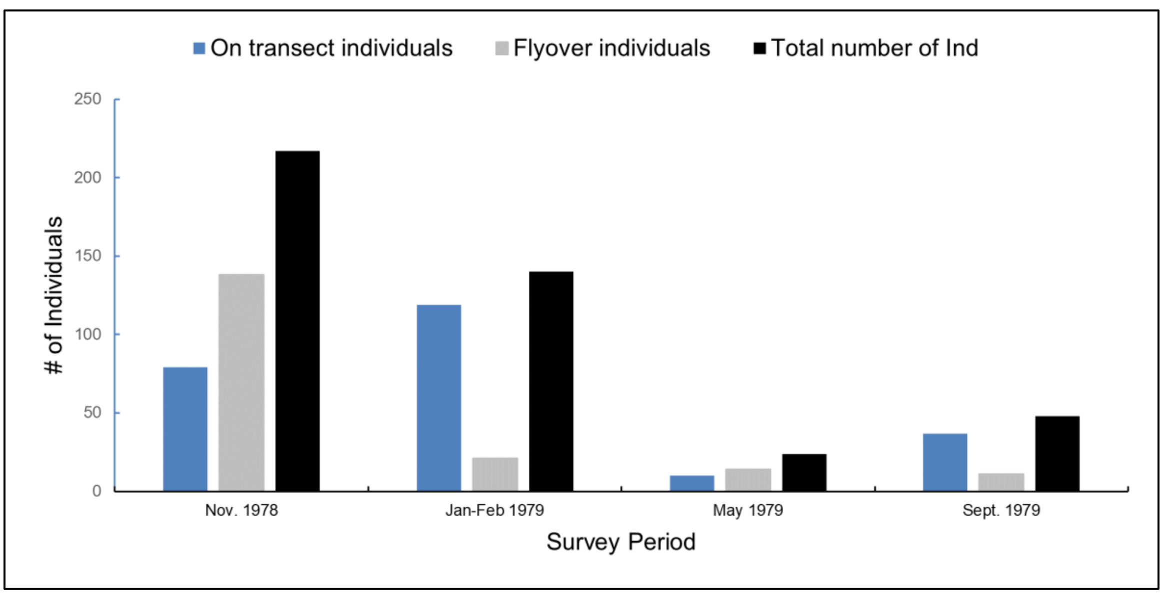


Figure 30. The number of individuals detected on-transect, as flyovers, and in total during surveys of the south transect established by Scott (1979).

The most commonly detected species during Scott (1979) included the western bluebird (*Sialia mexicana*), American robin, and the dark-eyed junco, which were found in high numbers on both transects during the November 1978 and Jan–Feb 1979 surveys. The chipping sparrow (*Spizella passerina*), spotted towhee, and Bewick's wren (*Thryomanes bewickii*) appeared in modest numbers in the park during the May and September surveys (Scott 1979).

Schwarz (2002)

A single-day survey of Gran Quivira in May 2002 resulted in the detection of 76 individuals (Schwarz 2002). Surveys were conducted along a 3.2 km (2 mi) loop transect, with 11 point count stations along the loop. The Bewick's wren was most commonly detected during the survey, being detected 10 times at seven locations (Table 29). Mourning doves (*Zenaida macroura*) and ash-throated flycatchers (*Myiarchus cinerascens*) were both detected eight times, with the mourning dove being detected at five locations, and the ash-throated flycatcher being detected at six. Schwarz (2002) hypothesized that the relatively low bird numbers may be attributed to ongoing drought in the area, and also indicated that some species, such as the chipping sparrow, may have been undercounted due to their singing and overall activity not beginning until after the survey completed.

Table 29. Number of detections for each species observed during Scott (1979). Detections are reported based on the survey station where they were observed.

Species	Survey Station											Total Detections
	1	2	3	4	5	6	7	8	9	10	11	
ash-throated flycatcher	–	1	–	–	2	1	2	1	1	–	–	**8**
Bewick's wren	1	1	2	–	2	–	2	1	–	–	1	**10**
blue grosbeak	–	1	–	–	–	–	–	–	–	–	–	**1**
brown-headed cowbird	1	–	–	–	–	–	–	–	–	–	2	**3**
bushtit	2	–	–	–	–	–	–	–	–	–	–	**2**
canyon towhee	–	2	–	–	–	–	–	–	–	–	2	**4**
chipping sparrow	3	–	1	–	–	1	–	–	–	–	–	**5**
common nighthawk	–	–	–	–	1	–	–	–	–	–	–	**1**
common raven	–	–	–	2	–	–	–	1	–	1	–	**4**
gray flycatcher	–	–	–	–	–	–	–	1	–	–	–	**1**
house finch	2	–	–	–	–	–	–	–	–	1	3	**6**
juniper titmouse	1	–	–	–	–	3	–	–	1	–	–	**5**
mourning dove	–	2	–	1	2	–	–	–	–	2	1	**8**
pinyon jay	–	–	–	–	–	–	–	1	–	–	–	**1**
rock wren	–	2	–	–	–	–	–	–	–	–	1	**3**
Say's phoebe	–	1	–	–	–	–	–	–	–	–	–	**1**
spotted towhee	2	1	2	–	–	–	–	1	–	–	–	**6**
turkey vulture	–	–	–	–	1	–	1	–	–	–	–	**2**
western scrub-jay	–	–	1	–	3	–	–	–	–	1	–	**5**

Johnson et al. (2007)

Johnson et al. (2007) detected 2,217 birds of 75 species during point count and area search efforts in SAPU between 2001 and 2003. Point count efforts detected 776 individuals across both the Gran Quivira and Abó units; no point count surveys were conducted at Quarai. The most frequently detected species during point count efforts were the juniper titmouse (*Baeolophus ridgwayi*; 88 detections, 11% of all detections), Ash-throated flycatcher (79 detections, 10% of all detections), and the spotted towhee (58 detections, 7.5% of all detections) (Table 30).

Table 30. Bird abundance by species in all habitat types based on VCP point counts at SAPU in 2001. Table modified from Johnson et al. (2007).

	All Habitats (n=26)	
Common Name	**# Detections**	**Avg./pt. ct. station**
juniper titmouse	88	3.4
ash-throated flycatcher	79	3.0
spotted towhee	58	2.2
pinyon jay	56	2.1
Bewick’s wren	55	2.1
chipping sparrow	55	2.1
cliff swallow	55	2.1
mourning dove	43	1.6
black-headed grosbeak	32	1.2
rock wren	31	1.2
Cassin’s kingbird	26	1.0
house finch	24	0.9
western scrub jay	21	0.8
lark sparrow	18	0.7
bushtit	17	0.6
lesser goldfinch	16	0.6
common raven	15	0.6
Say’s phoebe	11	0.4
brown-headed cowbird	10	0.4
black-chinned hummingbird	8	0.3
common nighthawk	8	0.3
canyon towhee	7	0.3
turkey vulture	7	0.3
western bluebird	7	0.3
American robin	5	0.2
black phoebe	3	0.1

Table 30 (continued). Bird abundance by species in all habitat types based on VCP point counts at SAPU in 2001. Table modified from Johnson et al. (2007).

	All Habitats (n=26)	
Common Name	**# Detections**	**Avg./pt. ct. station**
ladder-backed woodpecker	3	0.1
unknown species	3	0.1
western meadowlark	3	0.1
Bullock's oriole	2	0.1
unknown woodpecker	2	0.1
American crow	1	0.0
black-throated sparrow	1	0.0
blue-gray gnatcatcher	1	0.0
Cooper's hawk	1	0.0
Gambel's quail	1	0.0
gray flycatcher	1	0.0
northern rough-winged swallow	1	0.0
violet-green swallow	1	0.0

Area searches completed by Johnson et al. (2007) detected 1,441 individuals of 73 species. The increase in both species richness and abundance when compared to point count efforts is likely due to the fact that area searches were performed in all units of SAPU (Quarai included), when point counts only included two units (Gran Quivira, Abó). The most frequently detected species during area search and efforts were the band-tailed pigeon (*Patagioenas fasciata*; 146 detections, 10% of all detections), house finch (*Haemorhous mexicanus*; 102 detections, 7% of all detections), and the violet-green swallow (78 detections, 5% of all detections) (Table 31).

Table 31. List of species and the number of detections recorded for all habitats during area searches and incidental observations in SAPU from 2001 to 2002. Table reproduced from Table 32 in Johnson et al. (2007).

Species	Total Detections
band-tailed pigeon	146
house finch	102
violet-green swallow	78
black-headed grosbeak	73
spotted towhee	65
lesser goldfinch	64
juniper titmouse	53

Table 31 (continued). List of species and the number of detections recorded for all habitats during area searches and incidental observations in SAPU from 2001 to 2002. Table reproduced from Table 32 in Johnson et al. (2007).

Species	Total Detections
northern mockingbird	52
mourning dove	50
blue grosbeak	37
yellow-breasted chat	37
ash-throated flycatcher	36
cliff swallow	35
western scrub jay	35
western wood-pewee	35
black-chinned hummingbird	33
brown-headed cowbird	32
barn swallow	30
bushtit	27
rock wren	26
Bullock's oriole	24
western bluebird	24
Bewick's wren	19
Cassin's kingbird	18
lark sparrow	17
Say's phoebe	17
western tanager	17
Wilson's warbler	17
chipping sparrow	16
MacGillivray's warbler	15
phainopepla	14
canyon towhee	13
warbling vireo	13
American robin	12
common raven	12
ladder-backed woodpecker	12
red-winged blackbird	11
Virginia's warbler	9
white-crowned sparrow	9
black phoebe	8
Cooper's hawk	7

Table 31 (continued). List of species and the number of detections recorded for all habitats during area searches and incidental observations in SAPU from 2001 to 2002. Table reproduced from Table 32 in Johnson et al. (2007).

Species	Total Detections
turkey vulture	7
Gambel's quail	6
great horned owl	6
yellow-rumped warbler	6
American kestrel	5
house wren	5
northern flicker	5
western meadowlark	5
black-throated gray warbler	4
pinyon jay	4
plumbeous vireo	4
broad-tailed hummingbird	3
common nighthawk	3
white-breasted nuthatch	3
American crow	2
blue-gray gnatcatcher	2
Brewer's blackbird	2
gray catbird	2
mallard	2
scarlet tanager	2
Scott's oriole	2
American coot	1
common poorwill	1
gray flycatcher	1
lazuli bunting	1
Lincoln's sparrow	1
mountain bluebird	1
mountain chickadee	1
red-naped sapsucker	1
red-tailed hawk	1
scaled quail	1
yellow warbler	1
Total number of detections	**1441**
Total number of species	**38**

International Migratory Bird Day Surveys (1998–2017)

IMBD survey efforts in SAPU have resulted in the detection of 3,227 birds since 1998 (Appendix F). The average number of detections from 1998–2017 was 177 detections/year, and the annual number of detections has ranged from 73 (2014) to 271 (2005) (Figure 31). The violet-green swallow had the highest number of detections from 1998–2017 (358, 25% of all detections), as well as the highest average number of detections (20.28/year) (Figure 31). Other species with high numbers of detections from 1998–2017 included the yellow-rumped warbler (*Setophaga coronata*, 146, 10% of all detections), mourning dove (128, 9% of all detections), and house finch (118, 8% of all detections).

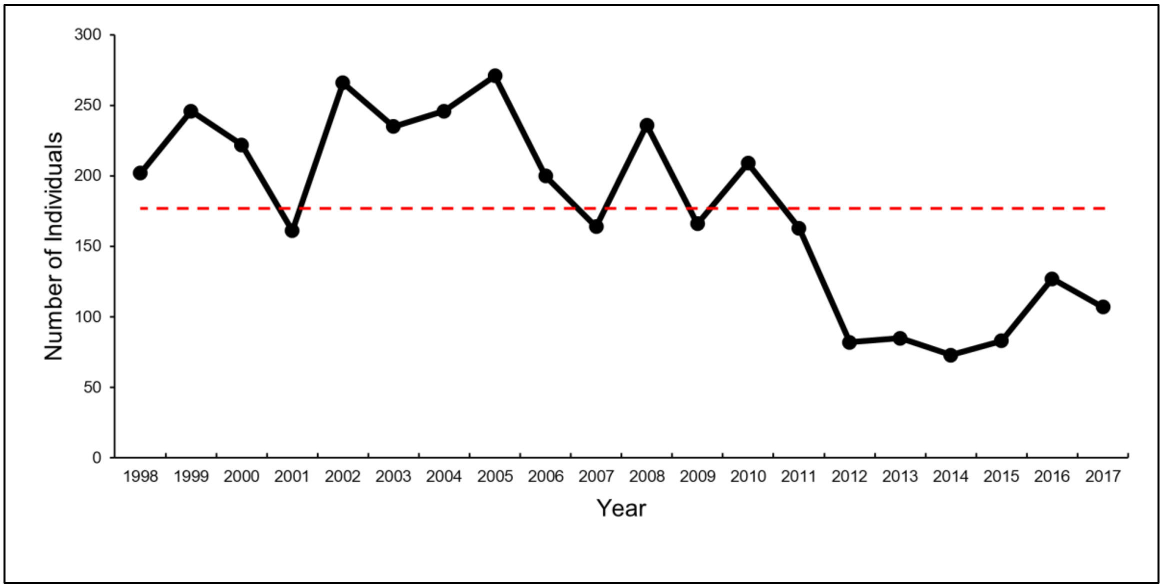


Figure 31. Number of individuals detected in SAPU during one-day IMBD surveys in mid-May from 1998 to 2017 (NPS unpublished data). The red dotted line indicates the average number of detections per year (177 detections).

Overall, fewer birds have been detected during recent IMBD surveys, with a particular decline noted between the 2010 survey and the 2012 survey. While the number of detections has increased since the lowest point in 2014, they are still less than half the levels observed from 2002–2010 (Figure 31). These trends have not been studied in detail, and could be the result of sampling effort, timing, weather, or other factors. Additional analysis is needed.

The violet-green swallow was the most frequently detected species during the IMBD surveys, with a total of 358 detections from 1998–2017 (Table 32), and was detected an average of 20.3/year. Other frequently detected species during IMBD work included the yellow-rumped warbler (146 detections), mourning dove (128 detections), house finch (118 detections), and the chipping sparrow (112 detections) (Table 32).

Table 32. The five most frequently detected species during the annual, one-day IMBD survey in SAPU from 1998–2017 (NPS unpublished data).

Year	Mourning Dove	Violet-green Swallow	Yellow-rumped Warbler	Chipping Sparrow	House Finch
1998	7	30	24	5	7
1999	12	25	13	12	6
2000	8	25	3	1	6
2001	6	25	2	4	8
2002	10	30	10	5	20
2003	8	30	6	15	12
2004	12	40	4	2	12
2005	8	35	5	7	10
2006	10	20	1	4	8
2007	8	16	1	–	6
2008	5	25	15	30	7
2009	8	25	2	12	6
2010	6	12	50	10	2
2011	7	15	6	2	5
2012	6	3	–	–	1
2013	4	–	3	3	–
2014	3	2	1	–	2
2015	1	2	3	3	–
2016	9	–	–	–	1
2017	3	5	–	–	1
Total	**128**	**358**	**146**	**112**	**118**

Species Distribution

Of the major bird surveys that have taken place in SAPU, only Johnson et al. (2007) investigated the distribution of birds by habitat type. Project goals outlined by Johnson et al. (2007) included documenting bird species distribution in habitats that were either under sampled or not sampled historically, as well as identifying important habitats that birds may utilize for breeding or overwintering. The transects and survey points of Johnson et al. (2007) were distributed across the pinyon-juniper habitat types of Abó and Gran Quivira, and the riparian/shrublands of Abó. Quarai is home to springs and perennial water sources and has a more complex and diverse vegetation community than the other two units; this unit was sampled via area searches which did not allow for an analysis of distribution, as habitat types were not documented for detections.

Point count efforts in SAPU in 2001 resulted in the detection of 37 species across Abó and Gran Quivira, with 31 species (83.8%) being detected in the pinyon-juniper habitats of both units, and 28 (75.7%) species in the riparian/shrubland habitats of Abó (Table 33). Twenty-two species (59.5%)

were documented in both of the surveyed habitat types in the park, while nine species were detected only in the pinyon-juniper habitats, and six species were detected only in the riparian/shrubland habitats (Johnson et al. 2007).

Table 33. Species richness and distribution across two priority habitat types in SAPU as sampled by Johnson et al. (2007).

Habitat Type	n	Species Richness/Habitat (Species Distribution)	Percent Total
Pinyon Juniper	19	31	83.80%
Riparian/Shrubland	7	28	75.70%
All Habitats	26	37	–

Threats and Stressor Factors

NPS staff identified several threats to SAPU's bird communities, including wind turbines, climate change, habitat loss and destruction outside of park, visitor use, invasive plant species, and collisions with power lines and other structures. Recent efforts to develop alternative energy sources have resulted in more wind farm development across the planet (de Lucas et al. 2008). Collisions with wind turbines are likely more frequent among raptors and Neotropical migrants. However, the exact effects that these wind farms have on birds are still poorly understood. Some studies have found that wind farms are responsible for no more mortalities than other human-made structures (e.g., buildings, communication towers) (Osborn et al. 2000), while other studies have found that turbines are responsible for unusually high numbers of bird mortalities (Smallwood and Thelander 2007).

A more understood threat to bird species are collisions with human-made structures. Bird collisions with buildings, power lines, communication towers, and windows may result in between 97–976 million bird deaths across the globe (USFWS 2002). While there are relatively few buildings and towers in the immediate SAPU area, structures are indeed present and birds that migrate to/from the park may encounter such obstacles during migration periods. Additionally, the construction and installation of power lines likely introduces more perching locations for foraging raptors, which could have an impact on ground nesting species in SAPU (LeFrançois, pers. communication, 2018).

Climate change is one of the major forces affecting bird communities across the globe; this threat is becoming better understood as research and data continue to become available. Changes in the temperature and precipitation norms in the park could have both direct and indirect effects on the bird community of SAPU. An example of a direct impact to the bird community in the park includes potential shifts in the timing of spring plant phenology, while indirect impacts resulting from shifts in temperature and precipitation could include effects on the frequency, extent, and severity of insect outbreaks.

Another climate-related threat facing breeding bird populations is the shifting of species' reproductive phenology. Several bird species depend on temperature ranges or weather cycles to cue their breeding. As global temperatures change, some bird species have adjusted by moving their home range north (Hitch and Leberg 2007). Other species have adjusted their migratory period and have begun returning to their breeding grounds earlier in the spring; American robins in the Colorado Rocky Mountains are now returning to their breeding grounds 14 days earlier compared to 1981 (NABCI 2009). A concern is that this shift in migration may be out of sync with food availability and could ultimately lead to lowered reproductive success and population declines (Jones and Cresswell 2010).

Migratory bird species face deteriorating habitat conditions along their migratory routes and on wintering grounds. Most of the birds that breed in the U.S. winter in the Neotropics (MacArthur 1959); deforestation in these wintering grounds has occurred at an annual rate up to 3.5% (Lanly 1982). While forest and habitat degradation does occur in the United States, it does not approach the level of degradation seen in the tropics (WRI 1989). Furthermore, Robbins et al. (1989) supported the suggestion that deforestation in the tropics has a more direct impact on Neotropical migrant populations than deforestation and habitat loss in the U.S.

As urban areas continue to develop and grow, modern alterations to the landscape often foster competition between native and non-native bird species. Human-made structures may fragment a landscape and reduce the continuity of a landscape, and often as these changes occur, non-native bird species are able to inhabit the areas. Marzluff (2001, pp. 26–28) states that, "The most consistent effects of increasing settlement were increases in non-native species of birds, increases in birds that use buildings as nest sites (e.g., swallows and swifts), increases in nest predators and nest parasites (brown-headed cowbird [*Molothrus ater*]), and decreases in interior- and ground-nesting species."

Data Needs/Gaps

Johnson et al. (2007) represents the most rigorous and scientifically repeatable bird survey and inventory to occur within the park. However, the data are now nearly 20 years old and are not suitable for an assessment of current condition. The continuation, or reestablishment of these point counts and area searches would prove useful for managers to analyze departures from the baseline established in 2001, and long-term monitoring would allow for potential trend analysis.

Continuation of the annual IMBD monitoring is recommended. While the data set is not the most robust or statistically comparable source, it does provide highly useful snapshots of the avian community for one day over a relatively long period. Standardization of monitoring techniques and methodology would allow for more repeatable and comparable survey efforts, as well as the reporting of annual observer effort.

Various avian surveys and inventories in SAPU have documented several species of conservation concern. Globally, populations of species of conservation concern are monitored by various agencies. However, specific monitoring of these species' abundance in the park would help managers to understand how many species and individuals are present in the park, and would also provide approximate estimates of what seasons the species are present in SAPU. The perennial water sources and associated habitats in SAPU represent a vital bird habitat for both migratory and resident species. Monitoring the health of the bird populations in these areas would provide managers with insights into the health of many bird communities, and the overall health of the priority habitats in the park.

Overall Condition

Species Richness

The SAPU project team assigned the species richness measure a *Significance Level* of 3 during project scoping. Species richness values obtained from the various bird surveys completed historically in SAPU indicate that species richness estimates are likely close to what should be expected based on the size and location of the park. This is supported by the jackknife estimates of species richness performed by Johnson et al. (2007) that indicated nearly 80% of all expected species in SAPU were documented by point count surveys. The jackknife calculations only used data produced by the Johnson et al. (2007) point count surveys, and did not include species detected during area searches or incidental observations.

The permanent water sources and associated vegetation communities in SAPU likely serve as a critical habitat for many avian species. Several species of conservation concern have been documented in the park, and additional monitoring could identify even more species of concern that utilize the priority habitats of SAPU. Records of the southwestern willow flycatcher (*Empidonax trailii extimus*), a federally endangered species exist in the park, although there are only isolated documentations of this species occurring in the park; it is likely this species is a vagrant in the area. The Mexican spotted owl (*Strix occidentalis lucida*), listed federally as threatened, exists in the vicinity of the park.

However, the data sources available at the time of publication are now outdated by nearly 20 years and are not appropriate to use for an assessment of current condition. While the IMBD data are more current, they represent the results of a single-day survey in one unit and do not accurately capture the true status of the entire bird community in SAPU. Further, the data may be influenced by observer effort, timing/weather, and the overall area sampled. The sources summarized in this document provide a useful baseline for future assessments of condition in SAPU. While there does not appear to be reason for significant concern for the park’s avian community, an assessment of condition cannot be made at this time. Because of this, no *Condition Level* was assigned to this measure.

Species Abundance

The species abundance measure was assigned a *Significance Level* of 3 during project scoping. Schwarz (2002) sampled the breeding population of birds in SAPU during a one-day survey in 2002 and, despite occurring during an ongoing drought, identified 76 individuals from 19 species; the Bewick’s wren, mourning dove, and ash-throated flycatcher were the most frequently detected species. Abundance estimates from the most recent NPS-led point count surveys between 2001 and 2003 detected 2,217 birds of 75 species (Johnson et al. 2007). The most frequently detected species during point counts included the juniper titmouse, ash-throated flycatcher, and the spotted towhee. Area searches of the park detected band-tailed pigeons, house finches, and violet-green swallows in high frequencies. IMBD survey efforts (one day each year from 1998–2017) in SAPU have resulted in the detection of 3,227 birds since 1998, with an average of 177 detections/year. Species detected most frequently during IMBD efforts included the violet-green swallow, yellow-rumped warbler, mourning dove, and house finch.

Similar to the species richness measure, the data that are available for this measure are either outdated (Scott 1979, Schwarz 2002, Johnson et al 2007), or sample only a small period and group of birds (IMBD data). The sources summarized in this measure can provide future researchers with a useful point of comparison and may allow for future assessments of condition in SAPU. An assessment of condition cannot be made at this time, and no *Condition Level* was assigned to this measure.

Species Distribution

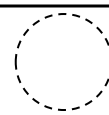
A *Significance Level* of 3 was assigned to the species distribution measure. Only Johnson et al. (2007) documented species distribution across priority habitat types in SAPU. With sampling distributed across the pinyon/juniper habitat and the riparian tracts of the park, Johnson et al. (2007) found that more species were detected in the pinyon juniper habitats (31 species) than the riparian areas (28 species); it should be noted that more point counts were located in pinyon-juniper habitats than riparian areas, which may account for the varying number of detections by habitat. Twenty-two species were found in both habitat types, while nine species were exclusively found in the pinyon-juniper habitat, and six species were found only in riparian areas.

As discussed previously in this chapter, SAPU is home to several vegetation types and unique habitats that are likely highly important for avian species. Many of these areas are under sampled by historic avian research in the park. Without the reestablishment of monitoring efforts in the park, an accurate assessment of current condition for species distribution is not possible at this time. A *Condition Level* was not assigned to this measure.

Weighted Condition Score

A *Weighted Condition Score* could not be calculated for SAPU's bird community due to a lack of contemporary data and limited information for the selected measures (Table 34). The condition and trend for this component are unknown at this time

Table 34. Current condition of Birds at SAPU.

Measures	Significance Level	Condition Level	WCS = N/A
Species Richness	3	n/a	–
Species Abundance	3	n/a	–
Species Distribution	3	n/a	–
Overall	**–**	**–**	

4.3.6 Sources of Expertise

- Marc LeFrançois, SAPU Chief of Facility and Resource Management

4.4 Mammals

4.4.1 Description

Mammals are critical components of many ecosystems, as they include both predator and prey species and perform or influence numerous ecological functions (e.g., nutrient cycling, seed distribution, vegetation productivity and succession) (Boddicker et al. 2002, Sinclair 2003). Small mammals in particular can be useful in detecting environmental changes; because they are typically in the middle of the food chain, these species rely upon lower trophic levels for food (plants, invertebrates) and are impacted by higher-level species through predation and competition (Hope et al. 2017).

The majority of wildlife habitat at SAPU is semi-arid, where environmental conditions can be harsh and resources (e.g., water, food) may be ephemeral (Stapp 2010). Such conditions can often limit wildlife diversity and abundance. However, the riparian and wetland areas of the Abó and Quarai units offer valuable resources and habitat for local mammal populations. For example, the stands of fruiting shrubs near Quarai's riparian area (e.g., chokecherries, currants) are known to attract larger mammals such as black bears (NPS 2014b).

The badger (left, NPS photo by A. Summerlin) and desert cottontail (right, USFWS photo by G. Stoltz) are just two of the mammals that occur at SAPU.

4.4.2 Measures

- Species richness
- Species abundance
- Species distribution

4.4.3 Reference Condition/Values

As with the vegetation community components, the ideal reference condition for mammals would be the condition during the period of historical significance (early and mid-1600s). However, information from this time is limited and it may no longer be a feasible target due to environmental changes. As a result, best professional judgement will be used to assess condition for this component. The data presented here may serve as a reference condition or baseline for future assessments.

4.4.4 Data and Methods

In the late 1970s, staff from the USFWS's Albuquerque Field Station conducted survey of the vertebrates at Gran Quivira (Scott 1979). During four multi-day field trips between November 1978 and September 1979, researchers sampled two permanent transects for birds and mammals, and laid additional traplines for mammals through habitats not covered by the two permanent transects. Small mammals were primarily surveyed using three types of traps at 75 trapping stations spaced 15 m (49 ft) apart along the permanent transects (Scott 1979). Larger mammals were surveyed by directly observing animals or detecting animal signs (e.g., tracks, scat) during other sampling activities. Scott (1979) also searched park files for records of faunal observations kept by park staff over the years.

From 2001–2003, the USGS Arid Lands Field Station cooperated with the NPS to conduct mammalian inventories at five SCPN parks, including SAPU (Bogan et al. 2007). The main objective was to document the occurrence of mammal species at each park, with a secondary goal of describing the abundance and distribution of species of special conservation concern. All fieldwork was conducted between May and September, with inventory methods including traplines, mistnetting, acoustic surveys, spotlighting, and track/scat surveys (Bogan et al. 2007). Other mammals, particularly larger species, were documented opportunistically during survey activities. Study sites included all major habitat types within each park (Figure 32). Bats were sampled using both mistnets and acoustic surveys; mistnets were deployed across or around water bodies for several hours following sunset. Additional details regarding trapping methods can be found in Bogan et al. (2007).

In addition to published scientific surveys, SAPU staff have documented several additional mammal species using wildlife trail cameras. These cameras were deployed at Gran Quivira and Abó in the fall of 2011 (NPS 2011a).

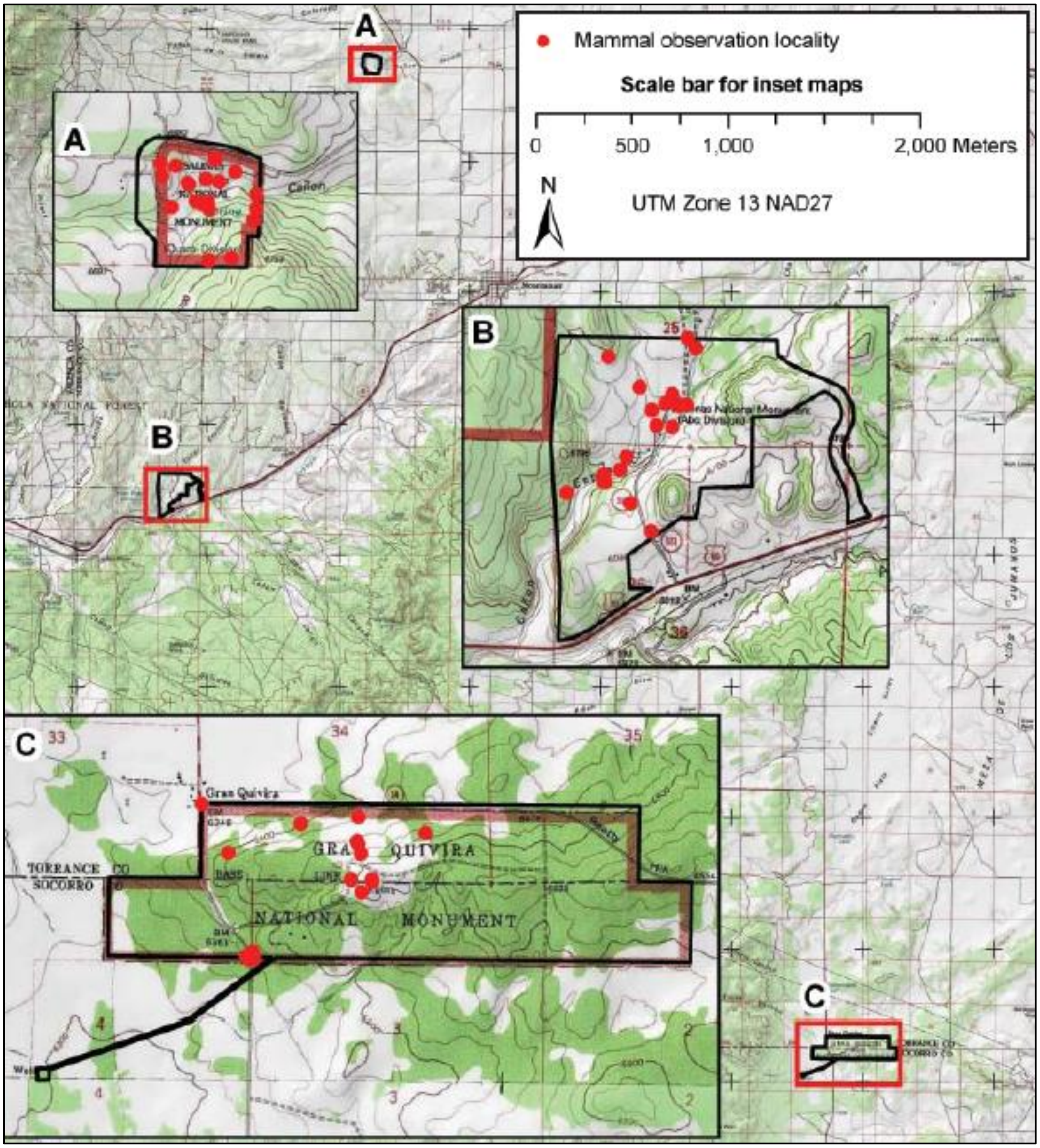


Figure 32. Mammalian study sites at SAPU utilized by Bogan et al. (2007) (reproduced from Bogan et al. 2007).

4.4.5 Current Condition and Trend

<u>Species Richness</u>

According to NPSpecies (NPS 2018a), 45 mammal species have been confirmed as present at SAPU, with an additional 14 species considered "probably present" (Appendix G). "Probably present" status indicates species that may be present in the area but have not been confirmed within the park's boundaries. Species confirmed as present include 12 bats, seven carnivores, two ungulates, and numerous small mammals (e.g., rodents, rabbits). Only one non-native mammal species, the house mouse (*Mus musculus*), has been recorded (NPS 2018a).

Historically, Scott (1979) documented 18 mammal species at Gran Quivira alone (Table 35). Researchers noted five additional species that were “probably present at some times” (Scott 1979, p. 30). No bat species were recorded, as no efforts were made to survey bats. More recently, Bogan et al. (2007) detected 37 mammal species overall, but predicted there were an additional 10–15 species likely present that may have gone undetected due to low abundances or lack of appropriate trapping methods. Despite being the smallest unit, the highest number of mammal species were detected at Quarai, with 23 (Table 35). Gran Quivira, which does not have a permanent water source, showed the lowest species richness at 17 (Bogan et al. 2007)(Figure 33).

In addition to these published surveys, several mammal species were documented by wildlife cameras at Abó and Gran Quivira in November 2011. Two of these species had not previously been confirmed at SAPU: elk (*Cervus elaphus*) at Gran Quivira, and bobcat (*Lynx rufus*) at Abó (NPS 2011a). According to park staff, bobcats are seen fairly frequently at Gran Quivira, and black bears have been seen at all three units (LeFrançois, written communication, September 2019). While the bobcat and black bear are on the park’s NPSpecies list as “probably present”, elk are not currently on the NPSpecies list (NPS 2018a) but are definitely present at all three units of the park (LeFrançois, written communication, March 2020).

Table 35. Mammal species documented at SAPU by Scott (1979, Gran Quivira only) and Bogan et al. (2007).

Order	Scientific name	Common name	Scott (1979)	Bogan (2007)		
				Abo	Quarai	GQ
Chiroptera	*Antrozous pallidus*	pallid bat	–	–	X	–
	Corynorhinus townsendii	Townsend's big-eared bat	–	X	X	–
	Eptesicus fuscus	big brown bat	–	–	X	–
	Lasionycteris noctivagans	silver-haired bat	–	X	X	–
	Lasiurus cinereus	hoary bat	–	X	X	–
	Myotis californicus	California myotis	–	–	X	–
	Myotis ciliolabrum	small-footed myotis	–	X	X	–
	Myotis thysanodes	fringed myotis	–	X	X	–
	Myotis volans	long-legged myotis	–	X	X	–
	Myotis yumanensis	Yuma myotis	–	X	X	–
	Pipistrellus hesperus	western pipistrelle	–	X	–	–
	Tadarida brasiliensis	Brazilian free-tailed bat	–	X	–	–
Lagomorpha	*Lepus californicus*	black-tailed jack rabbit	X	–	–	X
	Sylvilagus audubonii	desert cottontail	X	–	–	X
Rodentia	*Dipodomys ordii*	Ord's kangaroo rat	X	–	–	X
	Erethizon dorsatus	common porcupine	X	–	X	–
	Geomys bursarius	plains pocket gopher	X	–	–	–
	Microtus mexicanus (mogollensis)	Mexican vole	–	–	X	–
	Mus musculus [1]	house mouse	–	–	X	–
	Neotoma albigula	white-throated woodrat	X	X	X	X
	Neotoma micropus	southern plains woodrat	X	–	–	–
	Onychomys leucogaster	northern grasshopper mouse	X	X	–	X
	Otospermophilus variegatus	rock squirrel	X	–	–	X
	Perognathus flavescens	plains pocket mouse	X	X	–	X

[1] Non-native species.

Table 35 (continued). Mammal species documented at SAPU by Scott (1979, Gran Quivira only) and Bogan et al. (2007).

Order	Scientific name	Common name	Scott (1979)	Bogan (2007)		
Rodentia (continued)	*Perognathus flavus*	silky pocket mouse	X	X	–	X
	Peromyscus boylii	brush deermouse	–	X	X	X
	Peromyscus eremicus	cactus deermouse	–	–	–	X
	Peromyscus leucopus	white-footed deermouse	X	X	X	X
	Peromyscus maniculatus	deer mouse	X	–	X	X
	Peromyscus truei	pinyon deermouse	X	X	–	X
	Reithrodontomys megalotis	western harvest mouse	X	X	X	X
	Sigmodon hispidus	hispid cotton rat	–	X	X	–
	Tamias minimus	least chipmunk	–	–	X	–
	Thomomys bottae	Botta's pocket gopher	–	–	X	–
Carnivora	*Canis latrans*	coyote	X	X	X	X
	Mustela frenata	long-tailed weasel	–	X	–	–
	Puma concolor	mountain lion	–	–	X	–
	Taxidea taxus	American badger	X	–	–	–
	Vulpes	red fox	–	–	–	X
Artiodactyla	*Odocoileus hemionus*	mule deer	X	X	–	X
Totals	–	–	**18**	**21**	**23**	**17**

[1] Non-native species.

Figure 33. The white-throated woodrat (*Neotoma albigula*) (left, USGS photo by K. Geluso) and the coyote (right, NPS photo by S. King) are two of the mammals that were found in all three SAPU units.

<u>Species Abundance</u>

Scott (1979) reported the number of small mammals caught during transect trapping at Gran Quivira in 1978–79. On permanent transects, the pinyon deermouse (*Peromyscus truei*) was the most abundant species by far, comprising over half of all captures (Table 36). The next most abundant species were Ord's kangaroo rat (*Dipodomys ordii*) and the deer mouse (*Peromyscus maniculatus*). The two most abundant species on other traplines in different habitats were the same, with the white-footed deermouse (*Peromyscus leucopus*) replacing the deer mouse as third most abundant (Table 37).

Table 36. Results of small mammal trapping along permanent transects at Gran Quivira, 1978–1979 (Scott 1979).

		# of captures		
Scientific name	**Common name**	**Nov 1978**	**May 1979**	**Sept 1979**
Peromyscus truei	pinyon deermouse	133	65	64
Dipodomys ordii	Ord's kangaroo rat	17	21	12
Peromyscus maniculatus	deer mouse	36	4	3
Onychomys leucogaster	northern grasshopper mouse	15	–	10
Peromyscus leucopus	white-footed deermouse	2	4	2
Perognathus flavus	silky pocket mouse	–	4	3
Reithrodontomys megalotis	western harvest mouse	–	7	–
Neotoma albigula	white-throated woodrat	1	–	3
Perognathus flavescens	plains pocket mouse	–	–	2
Otospermophilus variegatus	rock squirrel	–	2	–

Table 37. Results of small mammal trapping along other traplines in different habitats at Gran Quivira, Sept 1979 (Scott 1979).

Scientific name	Common name	# of captures
Peromyscus truei	pinyon deermouse	8
Dipodomys ordii	Ord's kangaroo rat	7
Peromyscus leucopus	white-footed deermouse	7
Neotoma micropus	southern plains woodrat	2
Reithrodontomys megalotis	western harvest mouse	2

During mammal surveys of all three SAPU units, Bogan et al. (2007) found that the white-footed deermouse was most abundant, with a relative abundance of 17.6% (Table 38). The only other species with a relative abundance above 10% was the brush deermouse (*Peromyscus boylii*), at 13.2%. Eight different species were represented by only one individual (Bogan et al. 2007).

Table 38. Results of mammal surveys (trapping, observations, etc.) at SAPU, 2001–2003 (Bogan et al. 2007).

Order	Scientific name	Common name	# of captures/ observations	Relative abundance (%)
Chiroptera	*Lasiurus cinereus*	hoary bat	21	6.2
	Lasionycteris noctivagans	silver-haired bat	10	2.9
	Myotis volans	long-legged myotis	7	2.1
	Corynorhinus townsendii	Townsend's big-eared bat	5	1.5
	Myotis thysanodes	fringed myotis	5	1.5
	Antrozous pallidus	pallid bat	3	0.9
	Myotis ciliolabrum	small-footed myotis	3	0.9
	Myotis yumanensis	Yuma myotis	3	0.9
	Tadarida brasiliensis	Brazilian free-tailed bat	3	0.9
	Eptesicus fuscus	big brown bat	2	0.6
	Myotis sp.	unknown myotis	1	0.3
	Myotis californicus	California myotis	1	0.3
	Pipistrellus hesperus	western pipistrelle	1	0.3
Lagomorpha	*Sylvilagus audubonii*	desert cottontail	2	0.6
	Sylvilagus sp.	unknown cottontail	1	0.3
	Lepus californicus	black-tailed jack rabbit	1	0.3
Rodentia	*Peromyscus leucopus*	white-footed deermouse	60	17.6
	Peromyscus boylii	brush deermouse	45	13.2
	Neotoma albigula	white-throated woodrat	28	8.2
	Peromyscus truei	pinyon deermouse	22	6.5
	Peromyscus maniculatus	deer mouse	17	5.0
	Dipodomys ordii	Ord's kangaroo rat	15	4.4
	Microtus mexicanus (mogollensis)	Mexican vole	14	4.1
	Onychomys leucogaster	northern grasshopper mouse	12	3.5

[1] Non-native species.

Table 38 (continued). Results of mammal surveys (trapping, observations, etc.) at SAPU, 2001–2003 (Bogan et al. 2007).

Order	Scientific name	Common name	# of captures/ observations	Relative abundance (%)
Rodentia (continued)	*Sigmodon hispidus*	hispid cotton rat	12	3.5
	Perognathus flavus	silky pocket mouse	9	2.6
	Reithrodontomys megalotis	western harvest mouse	7	2.1
	Perognathus flavescens	plains pocket mouse	5	1.5
	Otospermophilus variegatus	rock squirrel	2	0.6
	Erethizon dorsatus	common porcupine	2	0.6
	Thomomys bottae	Botta's pocket gopher	2	0.6
	Peromyscus eremicus	cactus deermouse	1	0.3
	Mus musculus [1]	house mouse	1	0.3
	Tamias minimus	least chipmunk	1	0.3
	Microtus sp.	unknown vole	1	0.3
Carnivora	*Canis latrans*	coyote	6	1.8
	Puma concolor	mountain lion	3	0.9
	Mustela frenata	long-tailed weasel	1	0.3
	Vulpes	red fox	1	0.3
Artiodactyla	*Odocoileus hemionus*	mule deer	3	0.9

[1] Non-native species.

Species Distribution

Five of the mammal species documented by Bogan et al. (2007) were found at all three units of SAPU: four small rodents and the coyote (see Table 35). Eighteen species were found in only one of the three units; nine were limited to Quarai (Figure 34), six to Gran Quivira, and three to Abó. Six of the species found at only one unit were bats and three were carnivores (Bogan et al. 2007). Mountain lion (Puma concolor) sign has been observed by SAPU staff at all the units of the park, and porcupine have had direct observations at Gran Quivira (LeFrançois, written communication, March 2020). Additionally, park staff have reported coatimundi (*Nasua narica*) sign at Gran Quivira, although these reports have not been verified.


Figure 34. The mountain lion (*Puma concolor*, left) and common porcupine (*Erethizon dorsatus*, right) were only observed at Quarai during the Bogan et al. (2007) inventory (NPS photos).

Threats and Stressor Factors

Threats to SAPU's mammals include habitat loss/fragmentation, drought and climate change, surrounding developments, non-native species, disease, and hunting on adjacent lands. Habitat loss and fragmentation are frequently caused by development or other human activities, which will be discussed below. Drought and extreme weather events can also contribute to habitat loss and degradation (Opdam and Wascher 2004, USFS 2017).

As mentioned in previous chapters, the southwestern U.S. is projected to become warmer and drier with more sustained droughts as a result of climate change (Seager et al. 2007, Garfin et al. 2014). Droughts reduce water availability and even food resources (e.g., plants, seeds) for mammals. Rodent populations, for example, are generally lower during drought periods (Bogan et al. 2007). Warmer, drier conditions have also been associated with declines in bat reproduction (Adams 2010) and mule deer survival (Lawrence et al. 2004).

The surrounding developments of most concern for the SAPU region are mining and energy development (e.g., wind turbines, power lines) and the associated disturbances, such as access road construction and other general construction activity (Lovich and Ennen 2011, Arnett and Baerwald 2013, BLM 2013). Wind energy development has been expanding in New Mexico and the potential for utility-scale solar development is high (Lovich and Ennen 2011, NMEMNRD 2018). The disturbance from these developments often causes habitat loss and fragmentation. Human activity along access roads and on construction sites can also disrupt animal activities, such as feeding, migration, and reproduction (Lovich and Ennen 2011, BLM 2013). In addition, active wind turbines are known to cause bat mortalities, particularly among migratory tree-roosting species (Arnett and Baerwald 2013, BLM 2013). Bat species found at SAPU that could be particularly vulnerable to wind turbine fatality include the hoary bat (*Lasiurus cinereus*) and silver-haired bat *(Lasionycteris noctivagans*) (Arnett and Baerwald 2013).

Diseases that threaten park mammals include rabies and plague (*Yersinia pestis*), both of which can also infect humans and domesticated animals. Rabies is a viral infection of a mammal's central nervous system that is nearly always fatal (Cornell Wildlife Health Lab 2018). The virus is primarily transmitted through the bite of an infected animal. In the U.S., the majority of cases are in skunks (Family Mephitidae), raccoons (*Procyon lotor*), foxes (Family Canidae), coyotes, and bats. Symptoms in wildlife include excessive aggression, salivation, loss of balance/coordination, lethargy, and mild paralysis (Cornell Wildlife Health Lab 2018). There were 15 confirmed animal rabies cases in New Mexico in 2018 and 13 confirmed animal cases in 2017, but none in the counties surrounding SAPU (NMDH 2019b).

Plague is caused by a bacterium that is typically transmitted through flea bites, although carnivores may become infected by consuming prey with the disease (Abbott and Rocke 2012). The plague bacterium occurs naturally in rodent populations, particularly in the southwestern U.S., but is also carried by many other mammal species. However, not all species are susceptible to the disease; some are just "carriers". Mammals found in the SAPU area that are considered susceptible to plague include rock squirrels (*Otospermophilus variegatus*), chipmunks (*Tamias minimus*), woodrats (*Neotoma* spp.), deer mice (*Peromyscus* spp.), voles (*Microtus* spp.), rabbits (Family Leporidae), and felids (Abbott and Rocke 2012). Twenty-eight animal plague cases were confirmed in New Mexico in 2017 and 34 cases in 2016, including two dogs and a cat in Torrance County (NMDH 2019a). In 2017, a dead rock squirrel found at Quarai tested positive for plague, and an insecticide was applied to rodent burrows and soil to kill any infected fleas (LeFrançois 2017b).

Non-native animal species may interfere with native park mammals in several ways. First, non-native feral animals such as cats and dogs may carry and spread diseases to wildlife (Suzan and Ceballos 2005, Young et al. 2011). Non-native species may also compete with, harass, or prey upon native mammals (Young et al. 2011, Loss et al. 2012). Free-ranging cats alone have been estimated to kill 6.3–22.3 billion mammals across the U.S. annually (Loss et al. 2012).

The mammals of SAPU that can be legally hunted and/or trapped in New Mexico include mule deer (*Odocoileus hemionus*), mountain lions, black bears, foxes, weasels (*Mustela frenata*), coyotes, skunks, porcupines (*Erethizon dorsatus*), and rabbits. Deer, elk, and bear hunting seasons in the SAPU area are in the fall (Sept.-Oct. or Nov.), with an additional deer archery season in early January (NMDGF 2019). The trapping season for protected furbearers (e.g., badger, weasel, fox, bobcat) runs from November to mid-March; coyote and skunk are “unprotected furbearers” and can be harvested year-round with no bag limit (NMDGF 2019).

<u>Data Needs/Gaps</u>

Bogan et al. (2007) reported there were an additional 10–15 expected mammal species at SAPU that they were unable to document. Further inventory efforts to confirm the presence of these species and to detect any changes in species richness or abundance would help to understand park mammal populations. Research into how park mammals are impacted by environmental change and/or human activity could help managers better understand park wildlife.

<u>Overall Condition</u>

Species Richness

The project team assigned this measure a *Significance Level* of 3. According to NPS (2018a), 45 mammal species are present at SAPU, with 14 species considered “probably present”. Thirty-seven of these species were documented by Bogan et al. (2007) during a 2001–2003 inventory. However, no efforts have been made since the early 2000s to confirm that mammalian species richness is similar today. As a result, a *Condition Level* cannot be assigned at this time.

Species Abundance

The abundance measure was also assigned a *Significance Level* of 3. Data regarding mammal species abundance is limited to the 2001–2003 inventory (Bogan et al. 2007) and the late 1970s survey at Gran Quivira (Scott 1979). As with the previous measure, because no more recent information is available, a *Condition Level* cannot be assigned.

Species Distribution

A *Significance Level* of 3 was assigned for this final measure. Data regarding mammal species distribution at SAPU is also limited. Of the 37 mammal species documented by Bogan et al. (2007), five were found at all three units and 18 were found at only one unit. However, this study is nearly two decades old and no more recent information is available. Therefore, a *Condition Level* has not been assigned.

Weighted Condition Score

A *Weighted Condition Score* was not calculated for SAPU’s mammals, as condition could not be assigned to any of the measures due to lack of recent information/data (Table 39). The condition and trend of the park’s mammals is currently unknown.

Table 39. Current condition of Mammals at SAPU.

Measures	Significance Level	Condition Level	WCS = N/A
Species Richness	3	n/a	–
Species Abundance	3	n/a	–
Species Distribution	3	n/a	–
Overall	**–**	**–**	

4.4.6 Sources of Expertise

- Marc LeFrançois, SAPU Chief of Facility and Resource Management

4.5 Dark Night Skies

4.5.1 Description

A natural lightscape is a place or environment characterized by the natural rhythm of the sun and moon cycles, clean air, and of dark nights unperturbed by artificial light (NPS NSNSD 2015). The NPS directs each of its units to preserve, to the greatest extent possible, these natural lightscapes (NPS 2006b). Natural cycles of dark and light periods during the course of a day affect the evolution of species and other natural resource processes such as plant phenology (NPS 2006b, NPS NSNSD 2015). Several species require darkness to hunt, hide their location, navigate, or reproduce (NPS NSNSD 2015). In addition to the ecological importance of dark night skies, park visitors expect skies to be free of light pollution and allow for star observation.

SAPU is located in central New Mexico, approximately 55–95 km (34–59 mi) southeast of Albuquerque, depending on the unit. All three units are somewhat remote; Mountainair, with a population around 900, is the nearest town for Abó (14.5 km [9 mi]) and Gran Quivira (30.6 km [19 mi]). Quarai is approximately 9 km (5.6 mi) from Mountainair and 7 km (4.3 mi) from Manzano, a town of fewer than 100 people (Figure 35). On clear nights, the Milky Way can be seen from the park year-round. The park is typically only open for day use, closing at 5:00 p.m., except for several special night sky events/programs held throughout the year (NPS 2016b). In 2016, SAPU was designated as an International Dark Sky Park (IDSP) by the International Dark-Sky Association (IDA) (IDA 2016). To maintain IDSP status, the park is required to host at least four dark sky events each year; SAPU staff typically hold six events per year (LeFrançois, written communication, September 2019).

The night sky over the ruins at Gran Quivira (NPS photo by David Schneider)

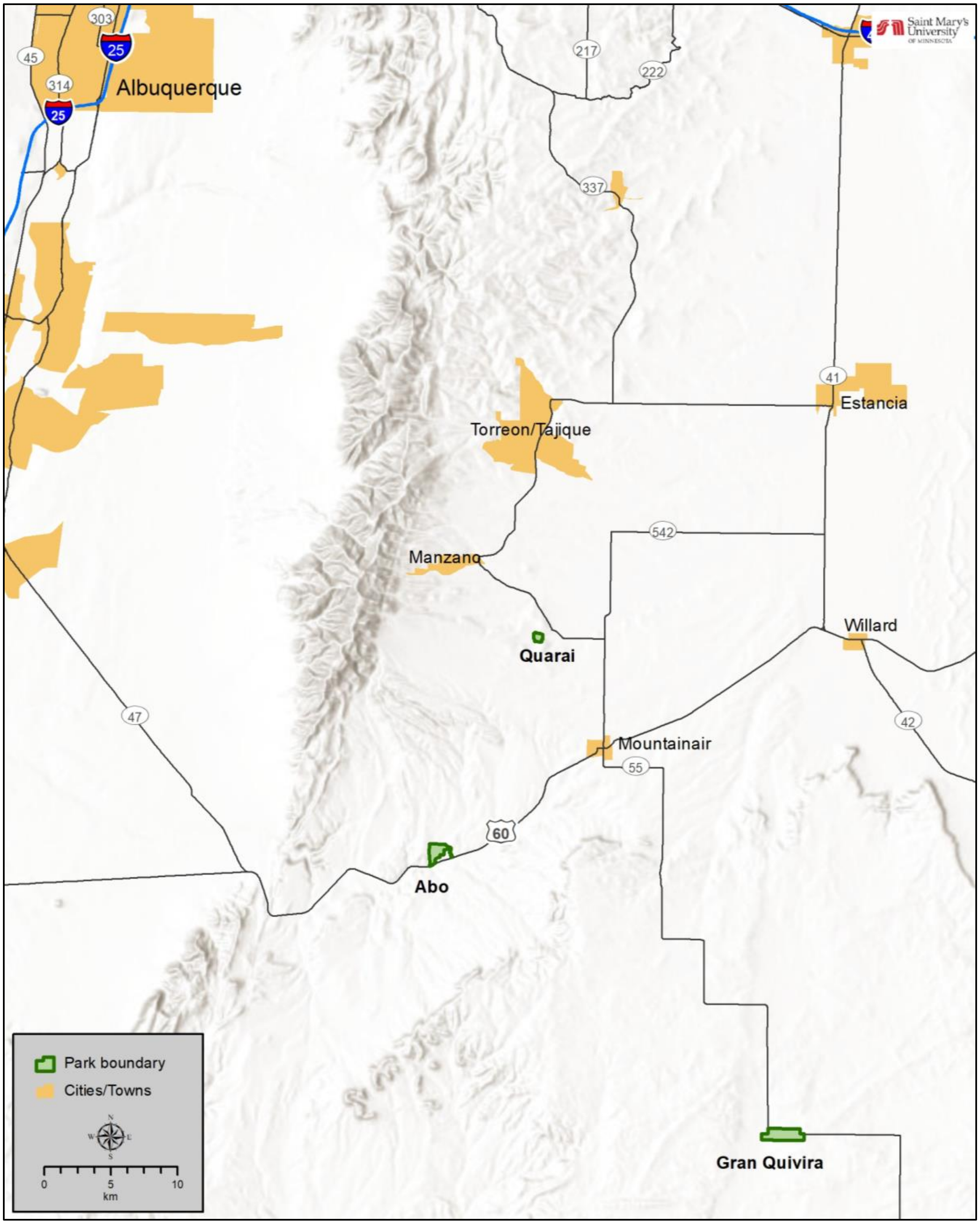


Figure 35. The locations of cities/towns in the vicinity of SAPU that may contribute to anthropogenic light pollution.

A dark night sky is important to the NPS for a variety of reasons. First, the preservation of natural lightscapes (the intensity and distribution of light on the landscape at night) will keep the nocturnal photic environment within the range of natural variability. Excursions outside this natural range may result in a modification to natural ecosystem function, especially to systems involving the behavior and survival of nocturnal animals (NPS NSNSD 2015). The natural night sky is therefore one of the physical resources under which natural ecosystems have evolved. Second, the “scenery” of national park areas does not just include the daytime hours (NPS NSNSD 2015). Third, the history and culture of many civilizations are steeped in interpretations of night sky observations, whether for scientific, religious, or time-keeping purposes (NPS NSNSD 2015). As such, the natural night sky may be a very important cultural resource, especially in areas where evidence of aboriginal cultures is present. Fourth, the recreational value of dark night skies is important to campers and backpackers, allowing the experience of having a campfire or “sleeping under the stars” (NPS NSNSD 2015). And lastly, night sky quality is an important wilderness value, contributing to the ability to experience a feeling of solitude in a landscape free from signs of human occupation and technology (NPS NSNSD 2015).

4.5.2 Measures

The dark night sky at SAPU was assessed using the suite of measures that the NPS Natural Sounds and Night Sky Division (NSNSD) uses to define the night sky conditions in a park unit. Selection of the standard NSNSD measures ensures that this assessment aligns with NSNSD standards. The suite of measures that the NSNSD typically uses to define the condition of dark night skies include:

- Sky luminance over the hemisphere in high resolution (thousands of measurements comprise a data set), reported in photometric luminance units (V magnitudes per square arc second [mag/arcsec^2] or milli-candela per square meter [mCd/m^2]) or relative to natural conditions, often shown as a sky brightness contour map of the entire sky. V magnitude (mags) is a broadband photometric term in astronomy, meaning the total flux from a source striking a detector after passing through a “Johnson-Cousins V” filter. It is similar to the “CIE photopic” broadband function for wavelengths of light to which the human eye is sensitive (Bessell 1990);
- Integrated measures of anthropogenic sky glow from selected areas of sky that may be attributed to individual cities or towns (known as city light domes), reported in milli-Lux of hemispheric illuminance or vertical illuminance;
- Integration of the entire sky illuminance measures, reported either in milli-Lux of total hemispheric (or horizontal) illuminance, milli-Lux of anthropogenic hemispheric (or horizontal) illuminance, V-magnitudes of the integrated hemisphere, or ratio of anthropogenic illuminance to natural illuminance;
- Vertical illuminance from individual (or groups of) outdoor lighting fixtures at a given observing location, in milli-Lux;
- Visual observations by a human observer, such as Bortle Class and visual or zenith limiting magnitude (VLM or ZLM);
- Integrated synthesized measure of the luminance of the sky within 50 degrees of the Zenith, as reported by the Unihedron Sky Quality Meter (SQM), in mag/arcsec^2.

When data are not available for a park, the NPS NSNSD recommends the use of the anthropogenic light ratio (ALR) as a measure of the quality of the photic environment and lightscape within a park (Moore et al. 2013). The ALR measures the average anthropogenic sky luminance as a ratio of natural conditions. This measure is easily modeled using GIS and provides a robust and descriptive metric (Moore et al. 2013).

4.5.3 Reference Condition/Values

NPS staff identified the absence of anthropogenic light as the preferred reference condition. This condition can be defined as the absence of artificial light in terms of sky luminance and illuminance at the observer's location from anthropogenic sources as follows:

> *No portion of the sky background brightness exceeds natural levels by more than 200 percent, and the sky brightness at the Zenith does not exceed natural Zenith sky brightness by more than 10 percent. The ratio of anthropogenic hemispheric illuminance to natural hemispheric illuminance from the entire night sky does not exceed 20 percent. The observed light from a single visible anthropogenic source (light trespass) is not observed as brighter than the planet Venus (0.1 milli-Lux) when viewed from within any area of the park designated the naturally dark zone* (Dan Duriscoe, NPS NSNSD, pers. comm., 2011).

Achieving this reference condition for preserving natural night skies is well summarized in the NPS Management Policies (NPS 2006b, p. 7) in section 4.10 as follows:

> *The Service will preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light.*

Implementing this directive in SAPU requires that facilities within the park meet outdoor lighting standards that provide for the maximum amount of environmental protection while meeting human needs for safety, security, and convenience. This means that outdoor lights within the park:

- produce zero light trespass beyond the boundary of their intended use;
- be of an intensity that meets the minimum requirement for the task, but does not excessively exceed that requirement;
- be of a color that is toward the yellow or orange end of the spectrum to minimize sky glow;
- be controlled intelligently, preventing unnecessary dusk to dawn bright illumination of areas.

The IDSP silver-tier guidelines can provide some reference for night skies at the park. To achieve silver-tier status, a park's night skies should have a limiting magnitude of 6.0–6.7, an SQM of 21.74–21.00, and a Bortle Sky Class of 3–5 (IDA 2015, NPS 2016b).

4.5.4 Data and Methods

The NPS NSNSD has not conducted a field visit to SAPU as of this writing, but park staff collected night sky data using a Unihedron SQM and an SQM-L (narrower field of vision) in April 2016 (NPS 2016b). Measurements were taken at four locations within each of the three units for a total of 12 sites. At each location, three readings were taken with the SQM and three with the SQM-L between 9:00 and 9:45 p.m. The median values for each location and instrument were averaged to find a representative SQM for each unit. These values were then averaged to gain one overall SQM value for SAPU as a whole (NPS 2016b). In April 2018, two follow-up SQM measurements were taken at Gran Quivira (NPS 2018b). In addition, The Lake County Astronomical Society (LCAS) of Illinois has been stargazing at SAPU since 1986. Between 29 April and 2 May 2011, LCAS member John Smith recorded SQM, VLM, and Bortle Class measurements at Gran Quivira.

The Milky Way, viewed from Gran Quivira (NPS photo by Jack Kramer).

The NPS NSNSD has developed a geographic information system (GIS) model derived from data from the 2001 World Atlas of Night Sky Brightness (Cinzano et al. 2001), which depicts *zenith* sky brightness (the brightness of the sky directly above the observer) (Moore et al. 2013). A neighborhood analysis is then applied to the World Atlas to determine the anthropogenic sky brightness over the *entire* sky. Anthropogenic light up to 200 km (124 mi) from parks can have an impact on a park's night sky quality. Finally, the modeled anthropogenic light over the entire sky is presented as a ratio (ALR) over the natural sky brightness (Dursicoe 2016). The modelled ALR data for SAPU are included in this NRCA to offer further insight into night sky condition.

4.5.5 Current Condition and Trend

<u>Background for NPS Night Sky Division's Suite of Measures</u>

Anthropogenic light in the night environment can be very significant, especially on moonless nights. Unshielded lamps mounted on tall poles have the greatest potential to cause light pollution, since light directly emitted by the lamp has the potential to follow an unobstructed path into the sky or the distant landscape. This type of light spill has been called glare, intrusive light, or light trespass (Narisada and Schreuder 2004). The dark-adapted human eye will see these individual light sources as extremely bright points in a natural environment. These sources also have the potential to illuminate the landscape, especially vertical surfaces aligned perpendicular to them, often to a level that approaches or surpasses moonlight. The brightness of such objects may be measured as the amount of light per unit area striking a "detector" or a measuring device, or entering the observer's pupil. This type of measure is called illuminance (Ryer 1997).

Illuminance is measured in lux (metric) or foot-candles (English), and is usually defined as luminous flux per unit area of a flat surface (1 lux = 1 lumen/m^2). However, different surface geometries may be employed, such as a cylindrical surface or a hemispheric surface. Integrated illuminance of a hemisphere (summed flux per unit area from all angles above the horizon) is a useful, unbiased metric for determining the brightness of the entire night sky. Horizontal and vertical illuminance are also used; horizontal illuminance weights areas near the Zenith much greater than areas near the horizon, while vertical illuminance preferentially weights areas near the horizon, and an azimuth of orientation must be specified (Ryer 1997).

Direct vertical illuminance from a nearby anthropogenic source will vary considerably with the location of the observer since this value varies as the inverse of the square of the distance from light source to observer (Ryer 1997). Therefore, measures of light trespass are usually made in sensitive areas (such as public campgrounds).

Anthropogenic light which results in an upward component will be visible to an observer as "sky glow". This is because the atmosphere effectively scatters light passing through it. The sky is blue in daytime because of Rayleigh scattering by air molecules, which is more effective for light of shorter wavelengths. For this reason, bluish light from outdoor fixtures will produce more sky glow than reddish light. Larger particles in the atmosphere (aerosols and water vapor droplets) cause Mie scattering and absorption of light, which is not as wavelength-dependent and is more directional. When the air is full of larger particles, this process gives clouds their white appearance and produces a whitish glow around bright objects (e.g., the sun and moon). The pattern of sky glow as seen by a distant observer will appear as a dome of light of decreasing intensity from the center of the city on the horizon. As the observer moves closer to the source, the dome gets larger until the entire sky appears to be luminous (Garstang 1989).

Light propagated at an angle near the horizon will be effectively scattered and the sky glow produced will be highly visible to an observer located in the direction of propagation. Predictions of the apparent light dome produced by a sky glow model demonstrate this (Luginbuhl et al. 2009). Light reflected off surfaces (e.g., a concrete road or parking area) becomes visible light pollution when it is scattered by the atmosphere above it, even if the light fixture has a "full cutoff" design and is not visible as glare or light trespass to a distant observer. For this reason, the intensity and color of outdoor lights must be carefully considered, especially if light-colored surfaces are present near the light source.

Light domes from many cities, as they appear from a location within Joshua Tree National Park, are shown in Figure 36 and Figure 37, as a grayscale and in false color. This graphic demonstrates that the core of the light dome may be tens or hundreds of times brighter than the extremities. A logarithmic scale for sky luminance and false color are commonly used to display monochromatic images or data with a very large dynamic range, and are used extensively in reports of sky brightness by the NSNSD.

Figure 36. Grayscale representation of sky luminance from a location in Joshua Tree National Park (Figure provided by Dan Duriscoe, NPS NSNSD).

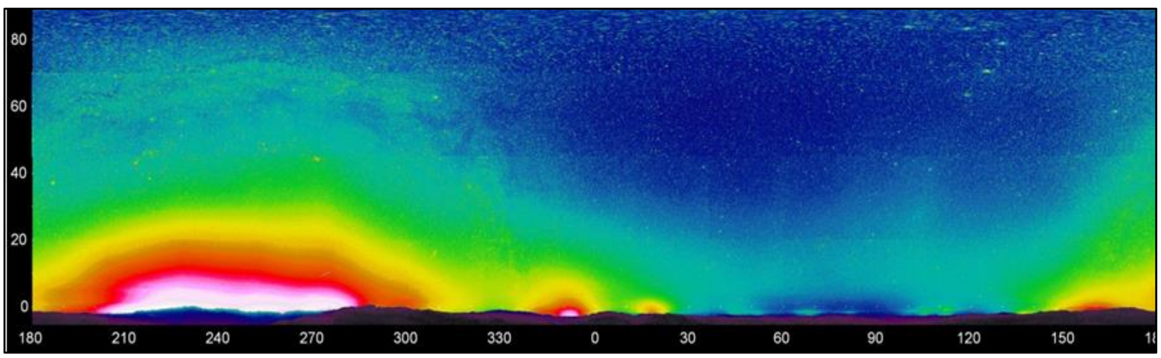


Figure 37. False color representation of Figure 36 after a logarithmic stretch of pixel values (Figure provided by Dan Duriscoe, NPS NSNSD).

The brightness (or luminance) of the sky in the region of the light domes may be measured as the number of photons per second reaching the observer for a given viewing angle, or area of the sky (such as a square degree, square arc minute, or square arc second). The NSNSD utilizes a digital camera with a large, dynamic range, monochromatic charge-coupled device (CCD) detector and an extensive system of data collection, calibration, and analysis procedures (Duriscoe et al. 2007). This system allows for the accurate measurement of both luminance and illuminance, since it is calibrated on standard stars that appear in the same images as the data and the image scale in arc seconds per pixel is accurately known. Sky luminance is reported in astronomical units of V-magnitudes per square arc second, and in engineering units of milli-candela per square meter. High resolution imagery of the entire night sky reveals details of individual light domes that may be attributed to anthropogenic light from distant cities or nearby individual sources. These data sets may be used for both resource condition assessment and long-term monitoring.

Figure 36 and Figure 37 contain information on natural sources of light in the night sky as well as anthropogenic sources. The appearance of the natural night sky may be modeled and predicted in terms of sky luminance and illuminance over the hemisphere, given the location, date, time, and the relative brightness of the natural airglow (the so-called “permanent aurora” which varies in intensity over time) (Roach and Gordon 1973). The NSNSD has constructed such a model, and uses it in analysis of data sets to remove the natural components. This results in a more accurate measure of anthropogenic sky glow (Figure 38). Figure 37 represents “total sky brightness” while Figure 38 displays “anthropogenic sky glow” or “net light pollution.” This is an important distinction, especially in areas where anthropogenic sky glow is of relatively low intensity.

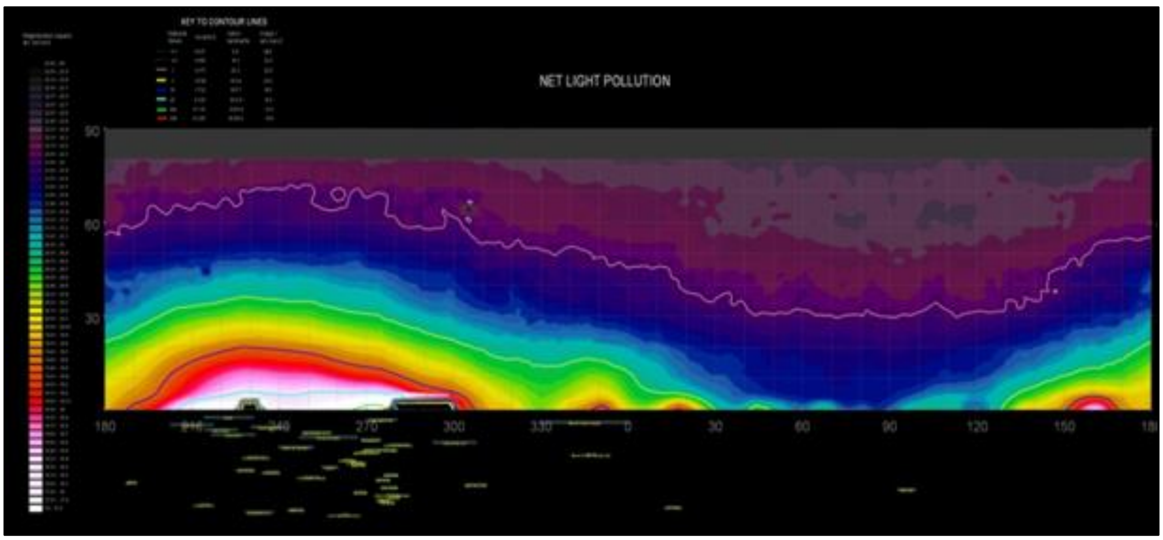


Figure 38. Contour map of anthropogenic sky glow at a location in Joshua Tree National Park, analogous to Figure 37 with natural sources of light subtracted (Figure provided by Dan Duriscoe, NPS NSNSD).

The accurate measurement of both anthropogenic light in the night sky and the accurate prediction of the brightness and distribution of natural sources of light allows for the use of a very intuitive metric of the resource condition—a ratio of anthropogenic to natural light, the ALR identified previously (Moore et al. 2013). Both luminance and illuminance for the entire sky or a given area of the sky may be described in this manner (Hollan 2010). This so-called “light pollution ratio” is unitless and is always referenced to the brightness of a natural moonless sky under average atmospheric conditions, or, in the case of the NSNSD data, the atmospheric conditions determined from each individual data set. The ALR is derived from ground–based measurements when available, or from a GIS model (calibrated to ground-based measurements in the park) when field based data are measures are not available (Moore et al. 2013).

A quick and moderately accurate method of quantifying sky brightness near the Zenith is the use of a Unihedron SQM. The Unihedron SQM is a single-channeled hand-held photometric device. A single number in magnitudes per square arc second is read from the front of the device after its photodiode and associated electronics are pointed at the Zenith and the processor completes its integration of photon detection. Because the meter is relatively inexpensive and easy to use, a database of measures has grown since its introduction (see http://unihedron.com/projects/darksky/database/index.php). The NSNSD produces values from each data set as both a synthesized value derived from the high-resolution images and by hand held measures with a Unihedron SQM. The performance of the SQM has been tested and reviewed by Cinzano et al. (2001). While fairly accurate and easy to use, the value it produces is biased toward the Zenith. Therefore, the robustness of data collected in this manner is limited to areas with relatively bright sky glow near the Zenith, corresponding to severely light polluted areas. While not included in the reference condition, an SQM value of about 21.85 would be considered “pristine”, providing the Milky Way is not overhead and/or the natural airglow is not unusually bright when the reading is taken (Moore et al. 2013).

Visual observations are important in defining sky quality, especially in defining the aesthetic character of night sky features. A published attempt at a semi-quantitative method of visual observations is described in the Bortle Dark Sky Scale (Bortle 2001). Observations of several features of the night sky and anthropogenic sky glow are synthesized into a 1–9 integer interval scale, where class 1 represents a “pristine sky” filled with easily observable features and class 9 represents an “inner city sky” where anthropogenic sky glow obliterates all the features except a few bright stars. Bortle Class 1 and 2 skies possess virtually no observable anthropogenic sky glow (Bortle 2001).

Another visual method for assessing sky quality is the visual or zenith limiting magnitude (VLM or ZLM), which is the apparent brightness or magnitude of the faintest star observable to the unaided human eye, which usually occurs near the Zenith. This method involves many factors, the most important of which is variability from observer to observer. A ZLM of 7.0–7.2 is usually considered “pristine” or representing what should be observed under natural conditions; observation of ZLM is one of the factors included in the Bortle Dark Sky Scale. The ZLM or VLM are often referenced in literature on the quality of the night sky, and is the basis for the international “Globe at Night” citizen-scientist program (see http://www.globeatnight.org/index.html). The NSNSD has experimented with the use of this observation in predicting sky quality, and has found that it is a much coarser measure and prone to much greater error than accurate photometric measures over the entire sky. For these reasons, it is not included in the reference conditions section.

NPS Night Sky Division Suite of Measures

Several of the NSNSD’s suite of measures have been recorded at SAPU. In late April/early May of 2011, a qualified astronomer with LCAS recorded several night sky quality measurements at Gran Quivira (NPS 2016b). Median SQM and SQM-L measurements ranged from 21.50–21.73 and VLM measurements were 6.38–6.49. Smith rated the skies as a Bortle class of 2 (NPS 2016b).

SQM readings taken by park staff in April 2016 are presented in Table 40. As mentioned previously, an SQM value of about 21.85 would be considered “pristine”; the lower the SQM value, the more degraded the sky is by light pollution. Mean SQM values for SAPU were 21.41 for Quarai and 21.51 for Abó and Gran Quivira (NPS 2016b). The lowest or most degraded measurements (<21.3) were recorded at the Quarai visitor center parking lot. Higher values (>21.56) were noted at the Abó church, the Quarai church and the Gran Quivira visitor center parking lot (Table 40). In April 2018, two SQM readings were taken at Gran Quivira, yielding values of 21.43 and 21.47 (NPS 2018b). These 2016 and 2018 measurements are consistent with the park’s IDSP silver-tier status.

Table 40. Night sky brightness measurements (magnitudes/square arc second) from SAPU's three units, 4–6 April 2016 (NPS 2016b). VC = visitor center.

Unit	Site	SQM readings			SQM-L readings		
		#1	**#2**	**#3**	**#1**	**#2**	**#3**
Abó (mean = 21.51)	VC parking lot	21.46	21.49	21.53	21.35	21.35	21.36
	Loop trail (near departure to petroglyph site)	21.55	21.55	21.54	21.38	21.36	21.34
	Loop trail (northernmost location)	21.46	21.45	21.43	21.38	21.36	21.32
	Church	21.57	21.51	21.56	21.44	21.45	21.43
Quarai (mean = 21.41)	VC parking lot	21.34	21.29	21.29	21.24	21.18	21.23
	Loop trail (at bridge intersection)	21.45	21.48	21.49	21.23	21.22	21.21
	Spanish corral trail (at bench)	21.35	21.28	21.25	21.23	21.19	21.17
	Church	21.57	21.57	21.60	21.39	21.38	21.40
Gran Quivira (mean = 21.51)	VC parking lot	21.57	21.53	21.56	21.45	21.44	21.42
	Mound 7	21.47	21.47	21.47	21.41	21.39	21.38
	Church	21.49	21.49	21.49	21.44	21.43	21.43
	Employee housing area	21.53	21.53	21.54	21.44	21.43	21.44

The NSNSD used GIS-modeling to show ALR values for the vicinity around SAPU (Figure 39). A condition level can be assigned to the modeled ALR data, based on a threshold applied spatially to the park (Moore et al. 2013). This threshold is dependent on whether the park is considered to be urban or non-urban. The distinction between urban (Level 2) and non-urban (Level 1) parks is based on the relative proximity of the park (and its borders) to Urban Areas as defined by the 2010 U.S. Census. For parks managed as wilderness, the designated condition is based on ALR level that exists in more than 90% of the wilderness area (Moore et al. 2013). As all of SAPU's units are well outside of urban areas, the park is classified as a non-urban (Level 1) park.

In interpreting the results of the model, for both urban and non-urban parks, the condition (green, amber, red) corresponds to the ALR level that represents the median condition (in at least half the park's area) for the park's landscape (Moore et al. 2013). This median condition reflects the probable night sky quality that park visitors will experience at any location within the park. It is also probable that the majority of wildlife and habitats within the park exist under this quality of night sky (Moore et al. 2013). The NPS NSNSD recommendations for ALR condition are given in Table 41. The median ALR values are approximately 0.58 for Quarai, 0.37 for Abó, and 0.11 for Gran Quivira (Figure 39). This would put Quarai and Abó in the moderate condition category and Gran Quivira in the good condition category (Moore et al. 2013). If weighted for the total percentage of park area (Gran Quivira is largest, Quarai is smallest), the ALR for SAPU as a whole falls below 0.33, which means the park would be considered in good condition overall.

The night sky and ruins at Gran Quivira (NPS photo by Jose R. Sandoval).

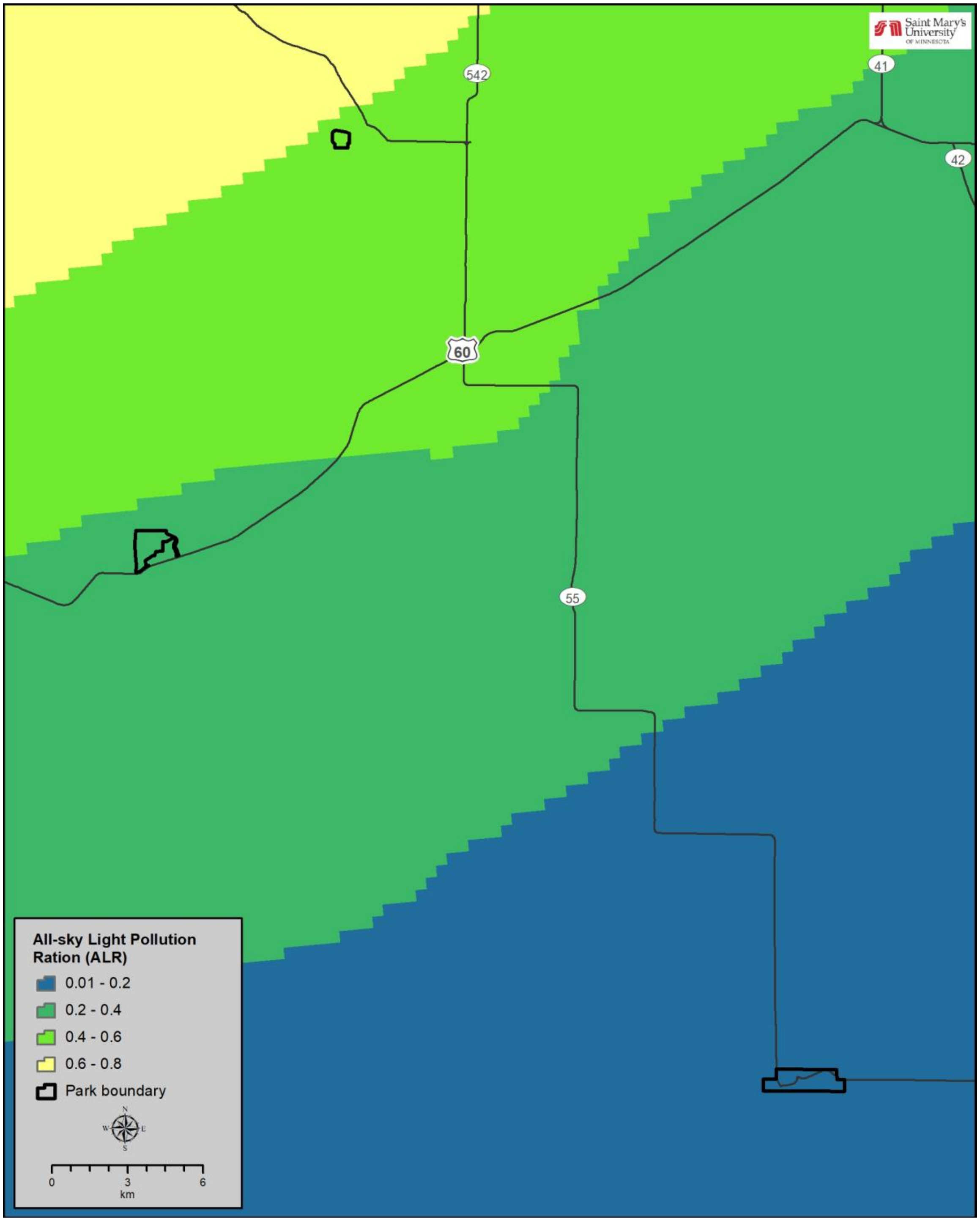


Figure 39. Modeled all-sky average sky brightness (ALR) in and around the three units of SAPU. Data provided by NPS NSNSD.

Table 41. NPS NSNSD recommendations for condition levels for modeled ALR values (Moore et al. 2013).

Classification	Good Condition (Green)	Moderate Condition (Amber)	Poor Condition (Red)
Non-urban (Level 1) parks	< 0.33	0.33–2.00	> 2.00
Urban (Level 2) parks	< 2.00	2.00–18.00	> 18.00

Threats and Stressor Factors

Threats to SAPU's night skies include wind turbine and power line lights, adjacent developments, vehicle traffic, air quality degradation, and increasing light trespass from Albuquerque. As a primarily day-use park, very little light pollution is produced by park infrastructure. As of March 2016, there were just 19 lights spread across SAPU's three units (NPS 2016b). All outdoor lights are dark sky compliant fixtures and are motion sensor-activated. Rural residences near the park units (e.g., ranches) may have outdoor lighting that is visible within the park; these fixtures may not be night sky-friendly.

Wind turbines include a red flashing light for the safety of aircraft flying at night (Windpower Engineering 2011). There is a 100 MW utility-scale wind farm with 40 turbines on High Lonesome Mesa, which is visible from Gran Quivira (Figure 40) (NextEra Energy 2018). Power lines also have lights for aircraft safety that may detract from night sky views. Additional sources of anthropogenic light near the park units include vehicle traffic (e.g., cars and trucks on Highway 60, trains on the tracks near Abó) and light trespass/sky glow from Albuquerque, approximately 55 km (44 mi) northwest of Quarai (LeFrançois, personal communication, 30 January 2018).

Air quality and transparency conditions (e.g., haze, smoke) can impair dark night sky visibility. Air polluting compounds scatter light, making nearby light pollution sources seem brighter (Moore 2001). Smoke from wildfires has this effect and can also obscure the view of stars in the night sky. Visibility and air pollution impacts will be discussed further in Chapter 4.7.

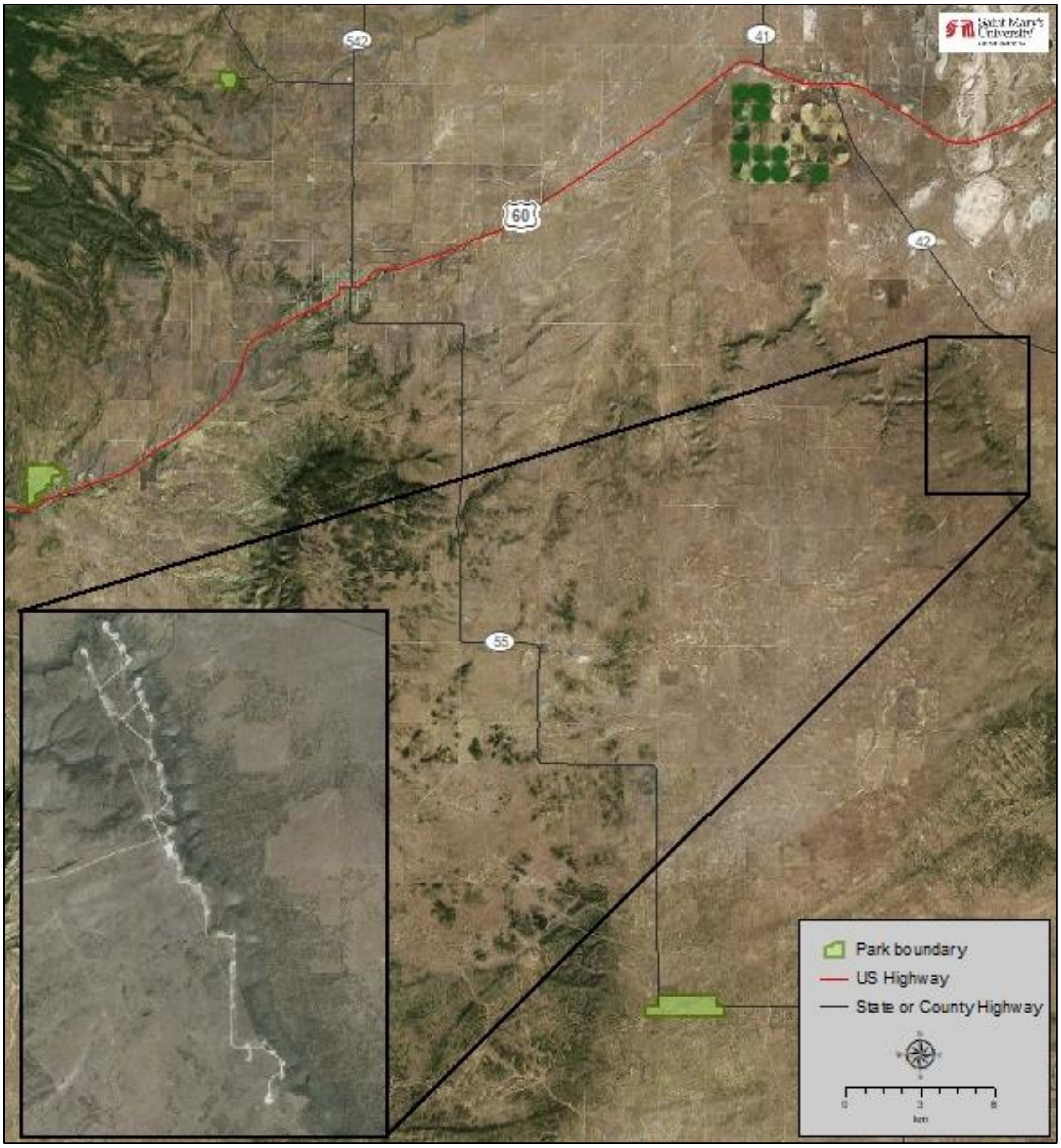


Figure 40. The location of the High Lonesome Mesa wind farm (black box) relative to SAPU's units. The small white circles in the inset map (lower left) represent individual turbine locations.

Data Needs/Gaps

While park staff have collected SQM measurements at all three SAPU units, the NPS NSNSD has never visited SAPU to collect a more comprehensive suite of data. The night sky condition data collected by the NPS NSNSD would offer additional insight more conducive to developing desired conditions or making management decisions. Along with periodic park monitoring visits, the NPS NSNSD could assess and track external light source impacts to SAPU.

Overall Condition

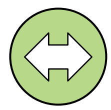
NSNSD Suite of Measures

A *Significance Level* of 3 was selected for this measure. NSNSD metrics recorded at SAPU's units (SQM, VLM) meet the IDSP's silver-tier guidelines (NPS 2016b, 2018b). Modelled ALR estimates for SAPU range from moderate condition at Abó and Quarai to good condition at Gran Quivira, with a park-wide median value in the good condition range. As a result, this measure is assigned a *Condition Level* of 1 for low concern.

Weighted Condition Score

The *Weighted Condition Score* for SAPU's dark night skies is 0.33, indicating good condition (Table 42). Conditions appear stable currently, but are under constant threat from increasing development in the region.

Table 42. Current condition of Dark Night Skies at SAPU.

Measures	Significance Level	Condition Level	WCS = 0.33
NSNSD Suite of Measures	3	1	

4.5.6 Sources of Expertise

National Park Service Night Sky Division members Dan Duriscoe and Jeremy White were instrumental in putting together much of the background narrative for this component. Sharolyn Anderson, also of the NPS NSNSD, provided the modeled ALR data used in this assessment.

4.6 Soundscape and Acoustic Environment

4.6.1 Description

The acoustic environment consists of all physical sound sources, including natural sounds (wind, water, wildlife), cultural and historic sounds (battle reenactments, tribal ceremonies, mission bells), and non-natural human-caused sounds (NPS 2018e). A "soundscape" is the human perception of those physical sound sources, which can contribute to a sense of place that differentiates an area from other places. Noise refers to sound which is unwanted, either because of its effects on humans and wildlife, or its interference with the perception or detection of other sounds (NPS 2018e). The natural and historical soundscape are critical to park ecosystem integrity and visitor experience (NPS 2018d). NPS Management Policies (4.9, 5.3.1.7) require the NPS to preserve the park's soundscape and to prevent or minimize noise that impacts park resources or values (NPS 2006b).

Visitors to national parks often indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. In a 1998 survey of the American public, 72% of respondents identified opportunities to experience natural quiet and the sounds of nature as an important reason for having national parks (Haas and Wakefield 1998). Additionally, 91% of NPS visitors consider enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald et al. 1995). At SAPU, visitors value the largely unchanged cultural landscape with its natural sounds, which offer a sense of remoteness and hardship that existed during the Pueblo period (NPS 2014b). Despite this desire for quiet environments, anthropogenic noise continues to intrude upon natural areas and has become a source of concern in national parks (Lynch et al. 2011).

Noise not only affects visitor experience, it can also alter the behavior of wildlife. Studies have shown that wildlife can be adversely affected by sounds that intrude on their habitats (Lynch et al. 2011, Shannon et al. 2016). While the severity of the impacts varies depending on the species being studied and other conditions, research strongly supports the fact that wildlife can suffer adverse behavioral and physiological changes from intrusive sounds (noise) and other human disturbances. Documented responses of wildlife to noise include increased heart rate, startle responses, flight, and disruption of behavior (Lynch et al. 2011, Shannon et al. 2016). Even low levels of noise can interfere with ecological processes in surprising and complex ways (Shannon et al. 2016). Repeated noise can cause chronic stress to animals, possibly affecting their energy use, reproductive success, and long-term survival (Radle 2007).

4.6.2 Measures

- Sound pressure levels
- Frequency of sounds
- Duration of sounds

4.6.3 Reference Condition/Values

Soundscape reference conditions should address the effects of noise on human health and physiology, the effects of noise on wildlife, the effects of noise on the quality of the visitor experience, and finally, how noise impacts the acoustic environment itself. NPS policy states that the natural ambient sound level is the baseline (reference condition) and standard against which current conditions in a soundscape are to be measured and evaluated (NPS 2006b). The NPS defines natural ambient sound level as the environment of sound that would exist in the absence of human-caused noise (NPS 2006). An additional reference point is not to exceed 52 dBA, which is the level that interferes with speech and would interrupt interpretive programs (EPA 1974).

4.6.4 Data and Methods

<u>Sound Science</u>

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 sound level or loudness (amplitude) (NPS 2018e). Frequency, measured in hertz (hz), describes the cycles per second of a sound wave. Humans with normal hearing can perceive sounds between 20 hz and 20,000 hz. A sound’s frequency can influence the distance from which a sound can be heard, with low frequency sounds (<500 hz) travelling farther than higher frequency sounds (>2,000 Hz) (NPS 2018e). High frequency sounds include birds chirping and jets in flight while low frequency sounds include thunder and idling trucks (IMH 2016). Most human-caused noise falls in the 20–1,250 hz range (Nelson 2015).

The level or loudness (amplitude) of a sound is described in decibels (dB). The decibel scale is logarithmic, meaning that every 10 dB increase in sound pressure level (SPL) represents a tenfold increase in sound energy (NPS 2018e). This also means that small variations in sound pressure level can have significant effects on the acoustic environment. Sound pressure level is commonly summarized in terms of dBA (A-weighted decibels) (NPS 2018e). Table 43 provides examples of A-weighted sound levels measured in national parks.

Table 43. Examples of sound levels measured in national parks (NPS 2018e).

Park Sound Sources	Sound level (dBA)
Volcano crater (Haleakala National Park)	10
Leaves rustling (Canyonlands National Park)	20
Crickets at 5m (16 ft) (Zion National Park)	40
Conversational speech at 5m (16 ft) (Whitman Mission National Historic Site)	60
Cruiser motorcycle at 15m (49 ft) (Blueridge Parkway)	80
Thunder (Arches National Park)	100
Military jet at 100m (328 ft) above ground (Yukon-Charley Rivers National Preserve)	120
Cannon fire at 150 m (492 ft) (Vicksburg National Military Park)	126

The NPS Natural Sounds and Night Skies Division (NSNSD) assesses a park’s acoustic environment by measuring or estimating human sound impact on natural sound conditions (NPS 2014a). In the absence of on-the-ground acoustic data collected at parks, the NSNSD uses a geospatial sound model to estimate how much human-generated sounds raise ambient sound levels. Sound levels across the continental U.S. have been modeled using extrapolation from actual acoustical measurements at 190 sites, combined with additional variables such as climate, landcover, wind speed, and proximity to noise sources (e.g., transportation, industry, other development) (Mennitt et al. 2014, NPS 2014a). The estimated impacts reflect midsummer, daytime conditions. The geospatial model can generate park-specific maps, showing how impacts vary across the landscape or different park units (NPS 2014a). Since no on-site acoustic monitoring has been conducted at SAPU, the NSNSD modeled data will be used to assess condition in this NRCA. Additional details regarding the modeling methodology can be found in Mennitt et al. (2014).

4.6.5 Current Condition and Trend

Sound Pressure Levels

According to NSNSD estimates, natural ambient sound levels at SAPU range from 25.0–26.1 dBA (NPS 2014a). As of 2014, existing sound levels varied from 28.5 dBA at Abó to 34.7 dBA at Quarai and Gran Quivira (Table 44, Figure 41). The impact levels, which reflect the difference between existing and natural levels, ranged from 3.4–8.9 dBA (Figure 42) (NPS 2014a). Impact was lowest in the most remote, northwest corner of Abó, and highest along the road near the entrance in the northwest corner of Quarai (Figure 43). At Gran Quivira, impact was also highest along State Highway 55 near the park entrance. Across the park units as a whole, the mean estimated impact level is 4.9 dBA, meaning that the "listening area" for wildlife and visitors is reduced by approximately 68% (NPS 2014a). For example, if a visitor could hear a bird calling within an area of 10 square meters (108 sq. ft.) under natural ambient sound levels, the visitor would only be able to hear the bird calling within 3.2 square meters (34.4 sq. ft.) if sound levels increase by 4.9 dBA.

Table 44. Median sound pressure level estimate ranges (dBA) for SAPU's units (NPS 2014a). Impact levels reflect the difference between existing and natural sound levels.

Unit	Natural sound levels	Existing sound levels	Impact levels
Abó	25.0–25.8	28.5–32.5	3.4–7.1
Quarai	25.7–26.0	31.1–34.7	5.1–8.9
Gran Quivira	25.7–26.1	29.8–34.7	3.9–8.8

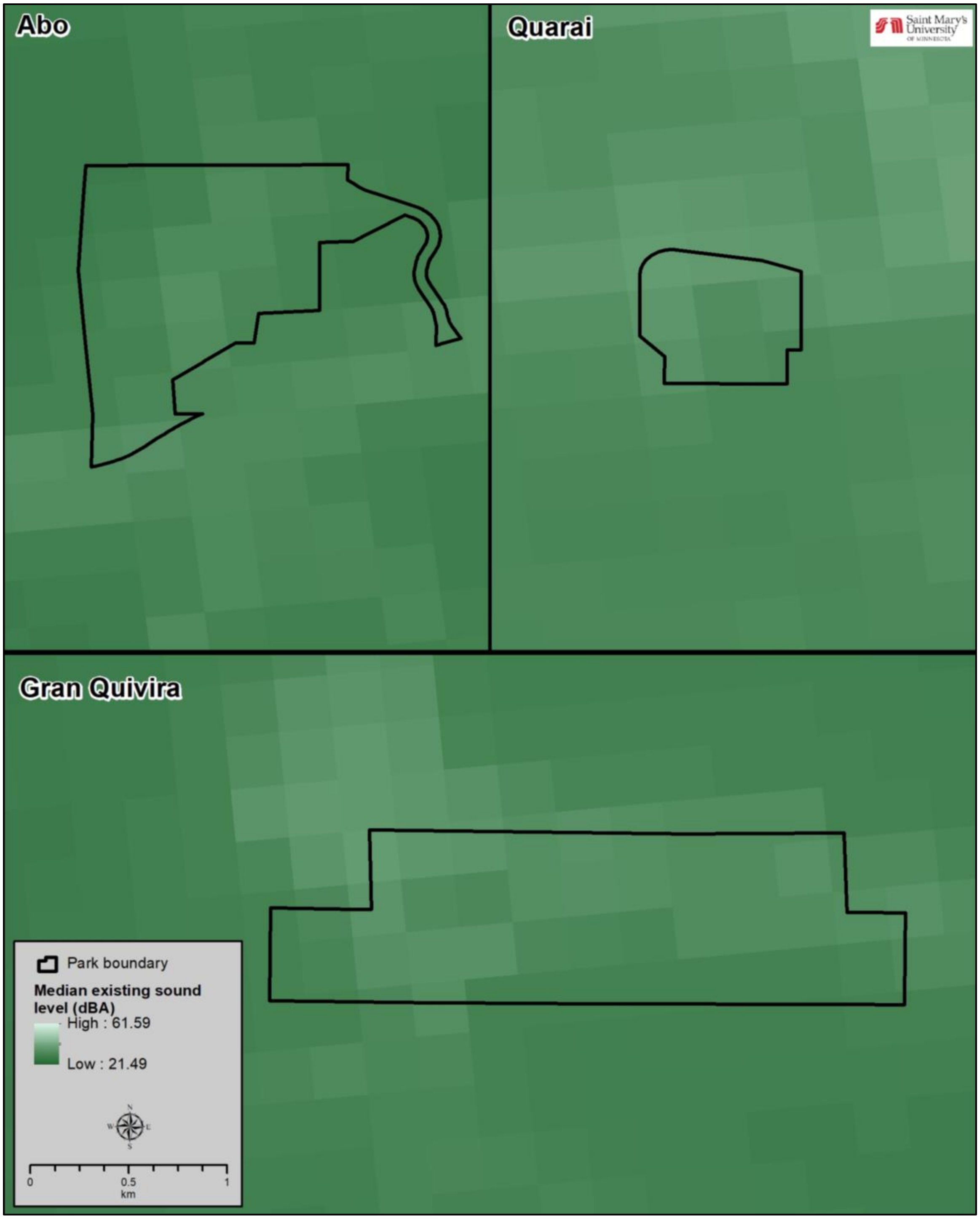


Figure 41. Median (L_{50}) existing sound levels (dBA) at the three SAPU units (NPS NSNSD 2014).

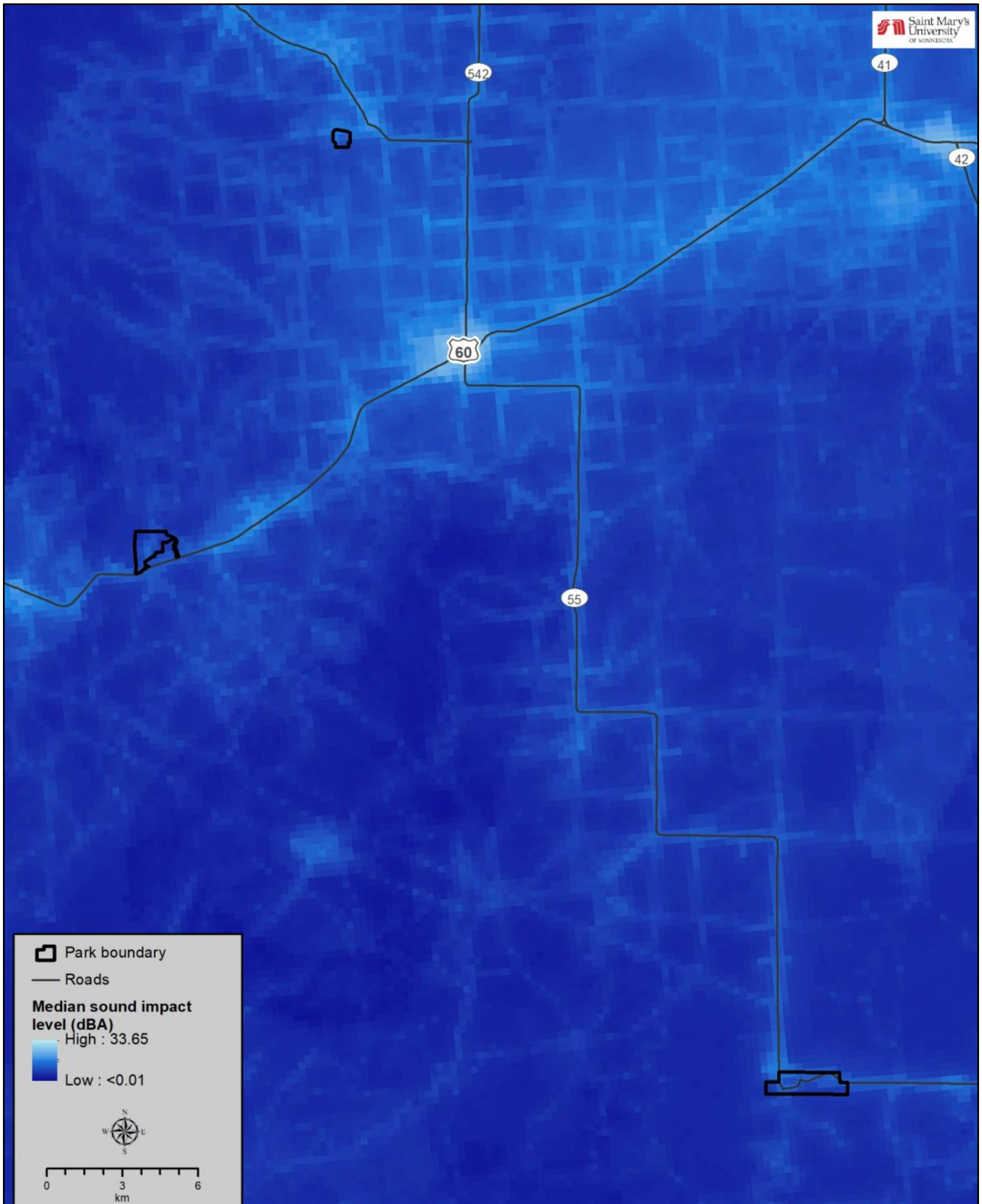


Figure 42. Median (L_{50}) sound impact levels (dBA) in the SAPU region (NPS NSNSD 2014). Sound impact levels reflect the difference between existing and natural ambient sound levels.

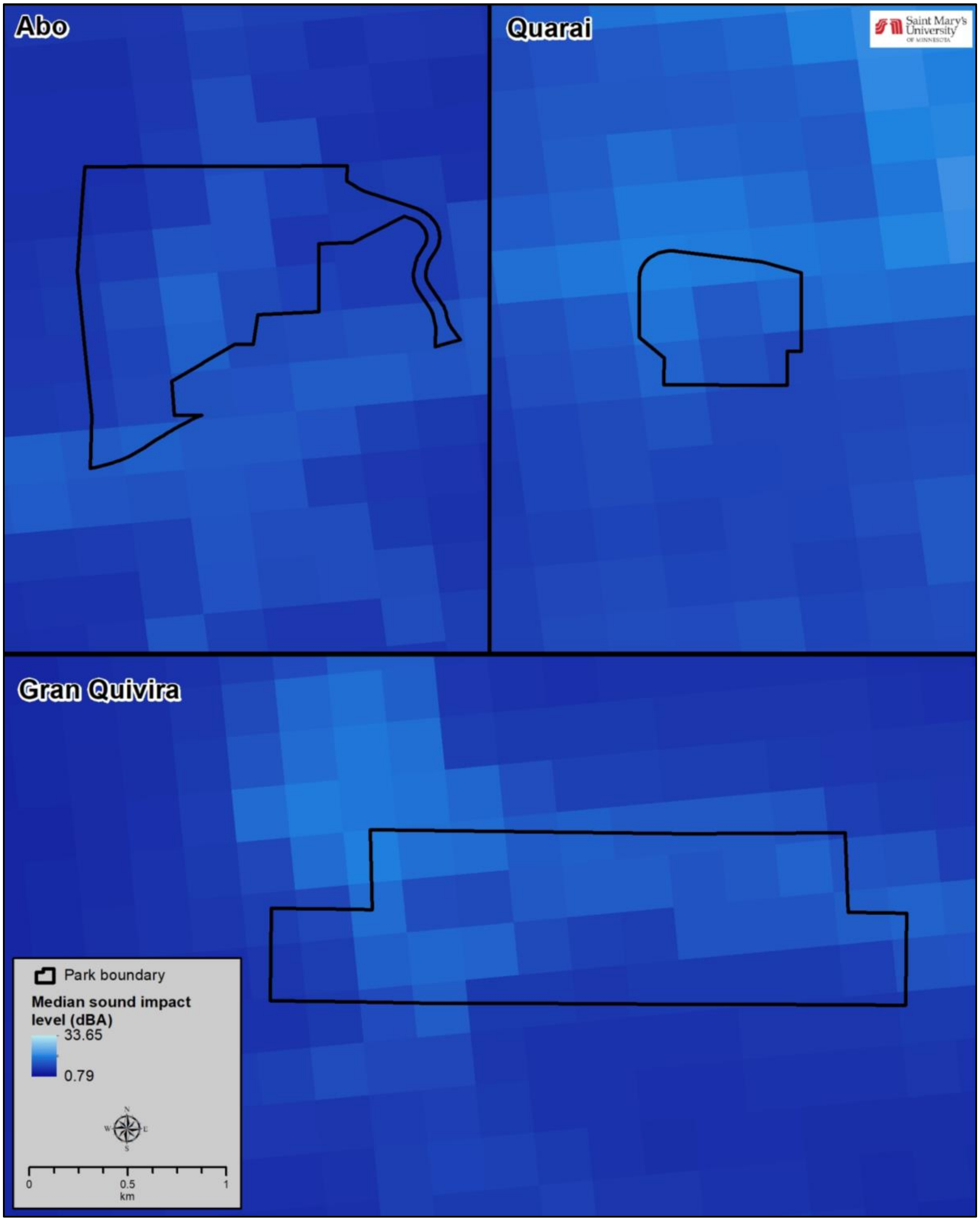


Figure 43. Median (L_{50}) sound impact levels (dBA) at the three SAPU units (NPS NSNSD 2014).

Frequency of Sounds

As mentioned previously, a sound's frequency can influence how it is perceived, as low frequency sounds can travel farther than higher frequency sounds. Also, sounds with overlapping frequencies (e.g., wind, vehicle and aircraft noise) are more likely to mask or block each other out than sounds with very different frequencies (e.g., bird song and vehicle noise) (Nelson 2015). At this time there are no data available regarding the frequency of sounds audible at SAPU.

<u>Duration of Sounds</u>

The duration of a sound (i.e., how long it lasts) can also influence how visitors and wildlife react to that sound. For example, short-duration sounds like a quickly passing car or a slamming door may be perceived as less disturbing than longer-lasting sounds, such as a hovering helicopter or construction equipment. Duration may be measured as the amount/percent of time a sound is audible or that it exceeds a certain sound level. As with the previous measure, there are no data available on the duration of sounds at SAPU at this time.

<u>Threats and Stressor Factors</u>

Threats to the soundscape at SAPU include vehicle traffic noise, train noise and gravel pit operations near Abó, and military aircraft overflights from White Sands Missile Range. Highways run near or along the boundaries of Gran Quivira and Abó, and a local road parallels the northern boundary of Quarai (Figure 44). Nationwide, road traffic has tripled since 1970 (Mennitt et al. 2014). In New Mexico alone, vehicle miles traveled increased 55% from 1990–2003, and is projected to increase by an additional 35% by 2030 (TRIP 2016). Vehicle noise can have far-reaching impacts, as sound from a loud truck or motorcycle can be heard up to 10 km (6.2 mi) away in the absence of intervening terrain (Mennitt et al. 2014). Train noise can also be heard at Abó, as a railroad runs just south of the unit (Figure 44 and Figure 45). The rail line was recently expanded to include a second track, potentially doubling the rail traffic (NPS 2014b, KellerLynn 2018). In addition, there is an active gravel pit near Abó where rock blasting sometimes occurs (NPS 2014b; LeFrançois, personal communication, 30 January 2018).

White Sands Missile Range is approximately 51 km (32 mi) south of Gran Quivira and 68 km (42 mi) south of Abó (Figure 44). The Range's Stallion Army Airfield is 65–72 km (40–45 mi) from the two units. In addition, Holloman Air Force Base is 158 km (98 mi) south of Gran Quivira. While military aircraft overflights related to these facilities are not common, low-flying aircraft do occasionally travel through the region and can be heard from park units (NPS 2014b, KellerLynn 2018). A single aircraft may be audible up to 40 km (25 mi) from its flight path (Mennitt et al. 2014). The sound from an F-16 military jet flying at 152 m (500 ft) above ground can be as high as 104 dB (USAF 2015).

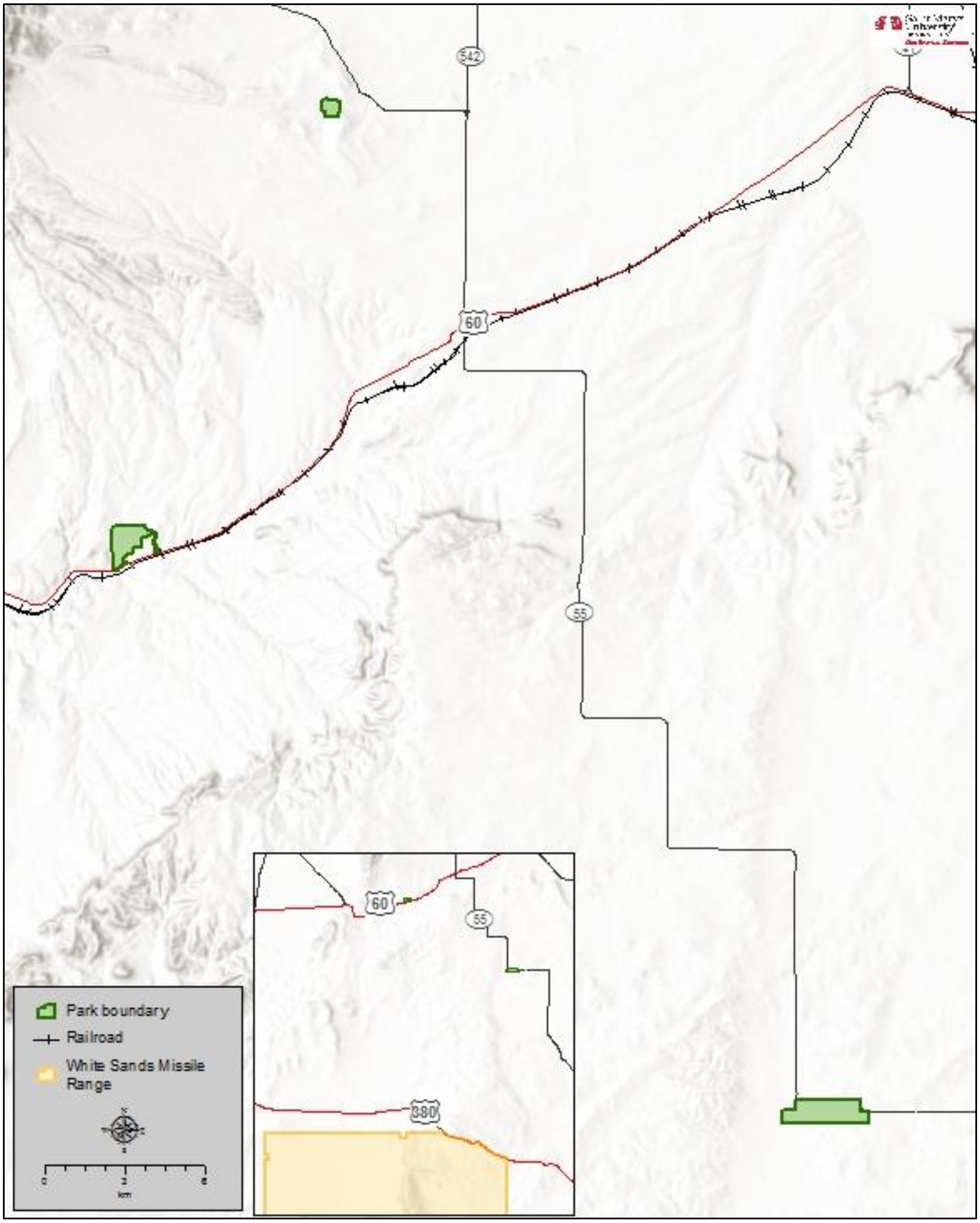


Figure 44. Potential sources of transportation-related noise near SAPU, including the White Sands Missile Range.

Figure 45. A train crossing a bridge over the Abó arroyo just south of the park (NPS photo).

Data Needs/Gaps

The SAPU Foundation Document (NPS 2014b) identified the need to coordinate with the NSNSD to conduct baseline acoustic monitoring at the park's units to help inform management of the park soundscape. Repeat acoustic monitoring every 3–5 years could then detect any changes of concern. The modeling approach used by the NSNSD to create sound level estimate maps could also be applied to other sound metrics, such as the percent time that noise is audible and the duration of noise-free intervals (Mennitt et al. 2014).

Overall Condition

Sound Pressure Levels

The project team assigned this measure a *Significance Level* of 3. The mean estimated impact level (difference between existing and natural ambient levels) for SAPU as a whole is 4.9 dBA (NPS 2014a). Existing sound levels ranged from 28.5 dBA at Abó to 34.7 dBA at Quarai and Gran Quivira, which are well below the 52 dBA level that would interfere with interpretive programs. At this time, sound levels are assigned a *Condition Level* of 2, indicating moderate concern.

Frequency of Sounds

This measure was also assigned a *Significance Level* of 3. Since no data are available regarding the frequency of sounds audible at SAPU, the current condition is unknown (*Condition Level* = n/a).

Duration of Sounds

A *Significance Level* of 3 was assigned for this measure as well. As with the frequency measure, there are currently no data regarding the duration of sounds experienced at SAPU. As a result, a *Condition Level* could not be assigned.

Weighted Condition Score

A *Weighted Condition Score* has not been calculated for SAPU's soundscape due to a lack of data for two of the three selected measures (Table 45). The condition is unknown at this time; a declining trend is likely, given the increase in vehicle and train traffic, but there are currently no data to support such a conclusion.

Table 45. Current condition of Soundscape & Acoustic Environment at SAPU.

Measures	Significance Level	Condition Level	WCS = N/A
Sound Pressure Levels	3	2	–
Frequency of Sounds	3	n/a	–
Duration of Sounds	3	n/a	–
Overall	**–**	**–**	

4.6.6 Sources of Expertise

- Marc LeFrançois, SAPU Chief of Facility and Resource Management

4.7 Viewshed

4.7.1 Description

A viewshed is the area that is visible from a particular location or set of locations, which can be mapped using GIS analysis tools. Two datasets are required to calculate a viewshed using GIS: a digital elevation model (DEM) and point or polyline data defining points in which a person would be viewing a landscape. With the defined data, GIS software determines visibility to and from a particular cell or set of cells in a DEM resulting in a viewshed layer. This viewshed layer is a raster that defines the visible area on the landscape from the point or set of points contained within an outline of a polygon. Viewshed analysis can help document changes over time in the view an observer might see (e.g., natural vs. developed landscapes). Combining viewshed layers with layers that identify undesirable features on the landscape (e.g., development, disturbance) can also highlight areas that have been negatively impacted visually within the viewshed.

Many studies indicate that people prefer natural views over developed landscapes (Ulrich 1983, Sheppard 2001, Han 2010). The NPS Organic Act (16 U.S.C. l) implies the need to protect the views from National Parks and Monuments. At SAPU, the surrounding natural and cultural landscape "continues to be representative of its prehistoric and historic settings and remains largely unchanged" (NPS 2014b, p. 7). The park's management objectives specifically include providing for "the restoration and maintenance of the integrity of the historic scene at each site" and managing natural resources "to preserve the natural and historic scene and to complement the park's cultural resources" (NPS 1984, p. 109).

View from the Convento ruins at Gran Quivira looking southwest (SMUMN GSS photo).

On a clear day, visitors to Gran Quivira can see up to 160 km (100 mi) away and as many as seven mountain ranges (NPS 2014b). Due to its ridgetop location, the 360 degree panoramic views of the natural landscape contribute substantially to the site's historic integrity (NPS 2010). While the views from Quarai and Abó are not as extensive because of the surrounding hillsides and pinyon-juniper woodlands, Manzano Peak is visible and dominates the visible landscape at these units (NPS 2002a, b).

4.7.2 Measures

- Visibility
- Change in adjacent land use/cover
- Changes in viewshed within the park
- Changes in viewshed outside of the park

4.7.3 Reference Condition/Values

As with previous components, pre-settlement conditions would be the ideal reference condition for viewshed, but this is not currently a realistic goal. Given the absence of baseline/reference data for viewsheds and land use/cover, the best professional judgement of the NRCA project team will be used to assess the condition of those measures.

Visibility conditions are assessed in terms of a Haze Index, a measure of visibility (termed deciviews [dv]) that is derived from calculated light extinction and represents the minimal perceptible change in visibility to the human eye (NPS 2013). Conditions measured near 0 dv are clear and provide excellent visibility, and as dv measurements increase, visibility conditions become hazier (NPS 2013). The NPS Air Resources Division (ARD) assesses visibility condition status based on the deviation of the estimated current visibility on mid-range days from estimated natural visibility on mid-range days (i.e., those estimated for a given area in the absence of human- caused visibility impairment, EPA-454/B003- 005) (NPS 2015c). The NPS ARD chose reference condition ranges to reflect the variation in visibility conditions across the monitoring network. Visibility on mid-range days is defined as the mean of the visibility observations falling within the 40th and 60th percentiles (NPS 2015c). A visibility condition estimate of <2 dv above estimated natural conditions indicates a *Good Condition*, estimates ranging from 2–8 dv above natural conditions indicate *Moderate Concern*, and estimates >8 dv above natural conditions indicate *Significant Concern* (NPS 2015c).

Visibility trends are computed from the Haze Index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the Clean Air Act and Regional Haze Rule, which include improving visibility on the haziest days and allowing no deterioration on the clearest days (NPS 2015c). Although this legislation provides special protection for NPS areas designated as Class I, the NPS applies these standard visibility metrics to all units of the NPS. If the Haze Index trend on the 20% clearest days is deteriorating, the overall visibility trend is reported as deteriorating. Otherwise, the Haze Index trend on the 20% haziest days is reported as the overall visibility trend (NPS 2015c).

4.7.4 Data and Methods

In order to assess the condition of the park's viewshed (both internal and external), a GIS analysis was conducted using Environmental Systems Research Institute's (Esri) Spatial Analyst Viewshed2 tool. This involved selecting observation points within the park and running the Viewshed2 tool to determine the area that can be seen from those points (Esri 2019). This tool requires two data inputs, a DEM and point or polyline data defining points from which a person would be observing the landscape.

Visitors frequently get their first impression of SAPU from the units' parking areas. For this reason, one observation point was placed at or near each parking area. One additional point was selected for each unit, in order to represent a different perspective than what is visible from the parking area. For Gran Quivira and Abó, points at higher elevations with more of a "scenic view" of the missions' ruins were selected. At Quarai, where there is less elevation change and more tall vegetation near the historic mission, a point along the interpretive trail on the opposite side from the parking area was chosen. For each location, a point shapefile was created to represent the approximate location (Figure 46). An 80 km (50 mi) buffer around the park boundary was selected for analysis.

The second input for the Viewshed2 tool, the DEM, was obtained from the USGS's National Map website (https://viewer.nationalmap.gov/basic/). This elevation surface had a resolution of approximately 10 m (32.8 ft). In order to replicate as accurately as possible the view as seen by a person standing at these points, a 1.7 m (5.5 ft) observer offset was applied to each observation point shapefile to account for average human height (CDC 2017). This analysis resulted in a theoretical surface layer that represents the visible area or viewshed from selected points without correcting for visibility factors (e.g., vegetation, smoke, humidity, or heat shimmer) (Figure 47). The size/extent of the viewshed from each observation point and each unit (two observation points combined) is shown in Table 46. For purposes of the analysis in this report, the internal viewshed is defined as those areas within the park boundary that are visible from any of the observation points and the external viewshed includes those areas outside the park boundary that are visible from any of the selected observation points.

The landcover change dataset used in the change analysis was obtained from the U.S. Geological Survey (USGS). The USGS, in cooperation with the Multi-Resolution Land Characteristics (MRLC) Consortium, produces the National Land Cover Dataset (NLCD). The landcover is classified as: open water, developed-open space, developed-low intensity, developed-medium intensity, developed-high intensity, barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, pasture/hay, cultivated crops, woody wetlands, or herbaceous wetlands (descriptions of these cover types can be found at https://www.mrlc.gov/data/legends/national-land-cover-database-2011-nlcd2011-legend). The 2011 NLCD raster dataset (USGS 2014) is the most recent land cover product for the United States that details change in cover types over time. It identifies areas where landcover has changed from 2001–2011and the type of landcover change (e.g., shrub/scrub to grassland/herbaceous or developed, open space to developed, low intensity), providing a 10-year record of change occurring in and around the park. While a 2016 NLCD update was released in May 2019 and shows land cover as of 2016, it does not specifically identify the previous and current land cover types in areas where change has occurred. Thus, the NLCD 2001–2011 landcover change classifications were used to assess changes in the park's internal and external viewscapes for this NRCA.

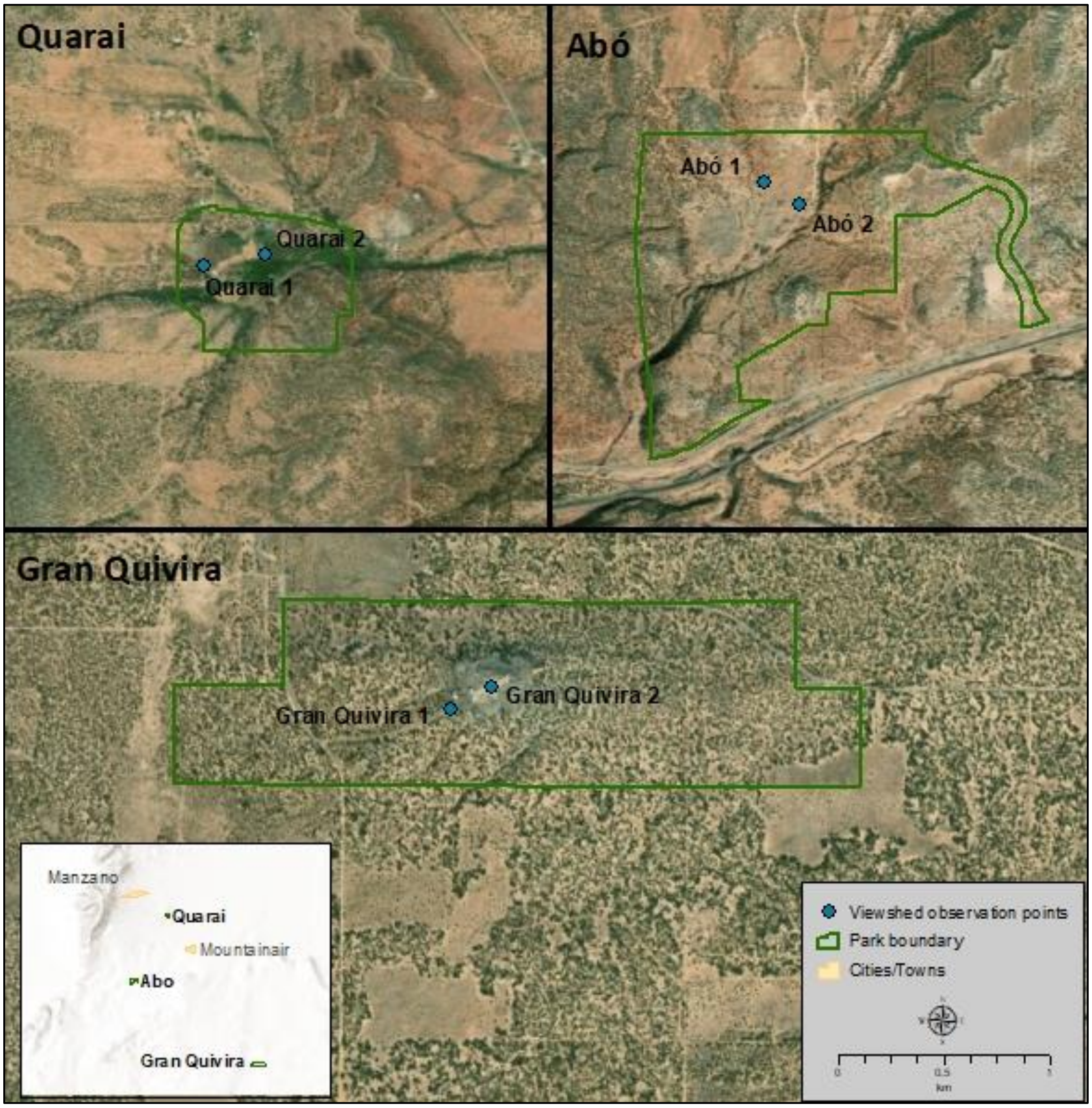


Figure 46. The six observation points used in the SAPU viewshed analysis.

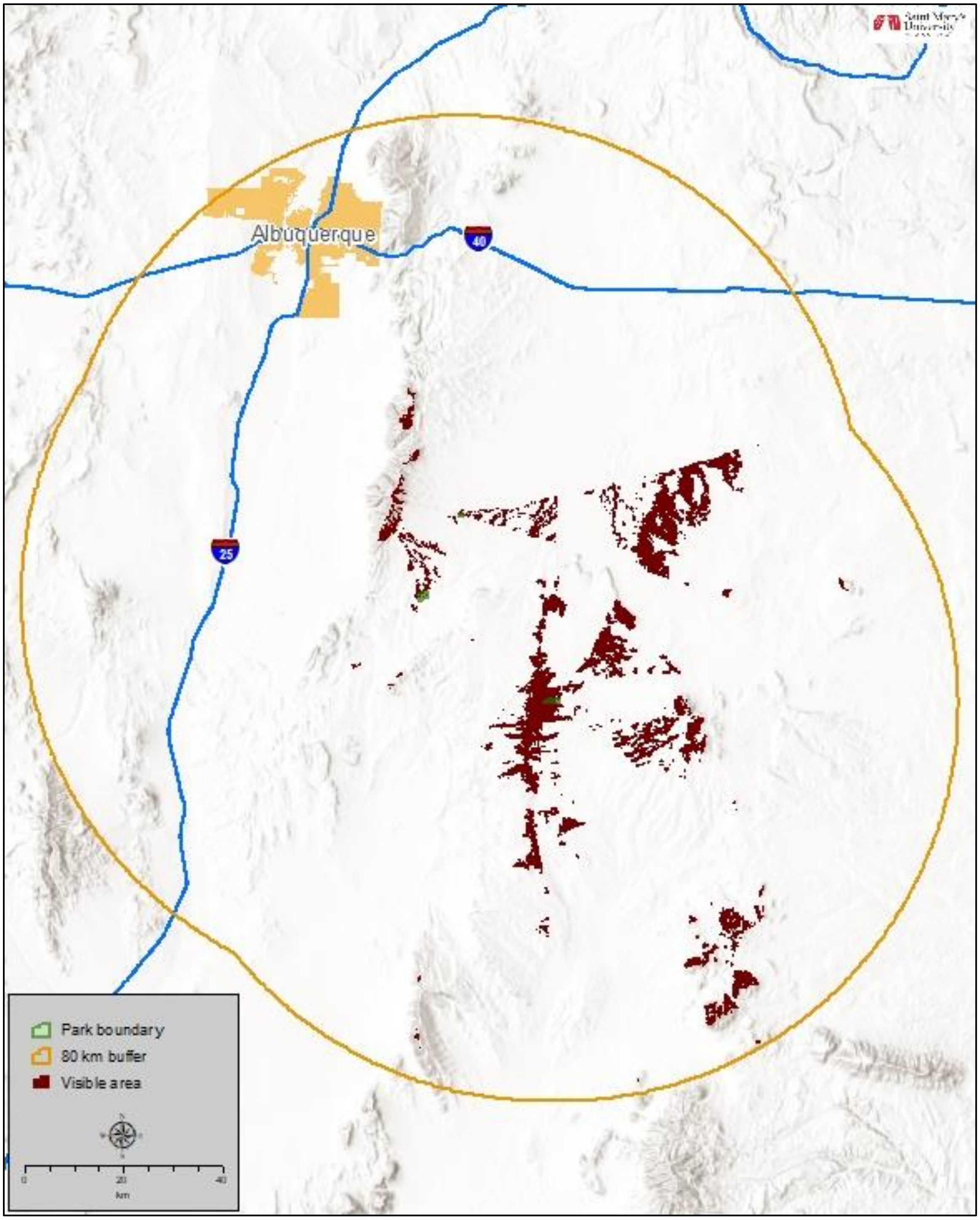


Figure 47. The overall viewshed output for SAPU. The areas in dark red represent the features within an 80 km buffer that are visible from one or more of the six observation points at the park units.

Table 46. The visible area (viewshed) extent for each unit and observation point.

Unit/Observation point	Visible area in ha (ac)
Gran Quivira	20,894 (51,630)
Gran Quivira 1 (parking area)	10,698 (26,435)
Gran Quivira 2 (top of ruins)	20,832 (51,477)
Abó	2,172 (5,369)
Abó 1 (trail north of mission)	1,701 (4,203)
Abó 2 (parking area)	1,727 (4,267)
Quarai	15,548 (38,420)
Quarai 1 (parking area)	11,009 (27,204)
Quarai 2 (trail south of mission)	14,026 (34,659)
Visible from all three units	81 (199)

Although visibility is not actively monitored within park boundaries, data collected at several regional monitoring stations can be used to estimate visibility conditions at SAPU. NPS ARD provides estimates of visibility and other air quality parameters that are based on interpolations of data from all air quality monitoring stations operated by NPS, EPA, various states, and other entities, averaged over the most recent 5 years (2011–2015). Estimates and conditions data for SAPU were obtained from the NPS Air Quality by park data products page (http://www.nature.nps.gov/air/data/products/parks/index.cfm).

For visibility trend analysis, monitoring data from an Interagency Monitoring of Protected Visual Environments Program (IMPROVE) station is required. An IMPROVE monitoring site considered representative of a Class II park has to be between within ± 30.48 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) (NPS 2015c). The IMPROVE visibility monitor at White Mountain near Ruidoso, NM is approximately 105 km (65 mi) southeast of Gran Quivira and is considered representative for the park.

The U.S. Forest Service (USFS) Air Resource Management Division has developed a visibility "conversion calculator" that will convert a haze index (dv) value to a standard visual range in miles. This calculator was used to determine the standard visual range for SAPU's visibility assessment (USFS 2019).

4.7.5 Current Condition and Trend

Visibility

Air pollution, especially particulate matter (PM), influences a visitor's ability to view scenic vistas and landscapes at parks (NPS 2007). Particulate matter is a complex mixture of extremely small particles and liquid droplets that become suspended in the atmosphere. Fine PM is a major cause of reduced visibility (haze) in many national parks and wilderness areas (EPA 2012). PM can either absorb or scatter light, causing the clarity, color, and distance seen by humans to decrease, especially during humid conditions when additional moisture is present in the air. Fine PM can either be directly emitted from sources (e.g., forest fires) or they can form when gas emissions from power plants, industry, and/or vehicles react in the air (EPA 2016b).

Five-year estimated averages of visibility on mid-range days minus natural condition visibility on mid-range days are used to estimate condition for visibility. The 2011–2015 estimated visibility on mid-range days for SAPU was 4.9 dv above estimated natural conditions (NPS 2015a). This estimate falls into the *Moderate Concern* category based on NPS criteria for air quality assessment, and translates to a standard visual range of approximately 240 km (149 mi) (USFS 2019).

Comparing the most recent mid-range estimate to previous NPS ARD estimates of visibility suggests that conditions have been relatively stable at SAPU. The 2005–2009 estimated visibility was also 4.9 dv above estimated natural conditions, and all estimates since 2009 have fallen between 4.7 dv and 5.0 dv (Figure 48) (NPS 2015a). Based on monitoring data from the nearby WHIT1 station, conditions also appear to be relatively stable over time on the 20% haziest and 20% clearest days (Figure 49) (NPS 2015a).

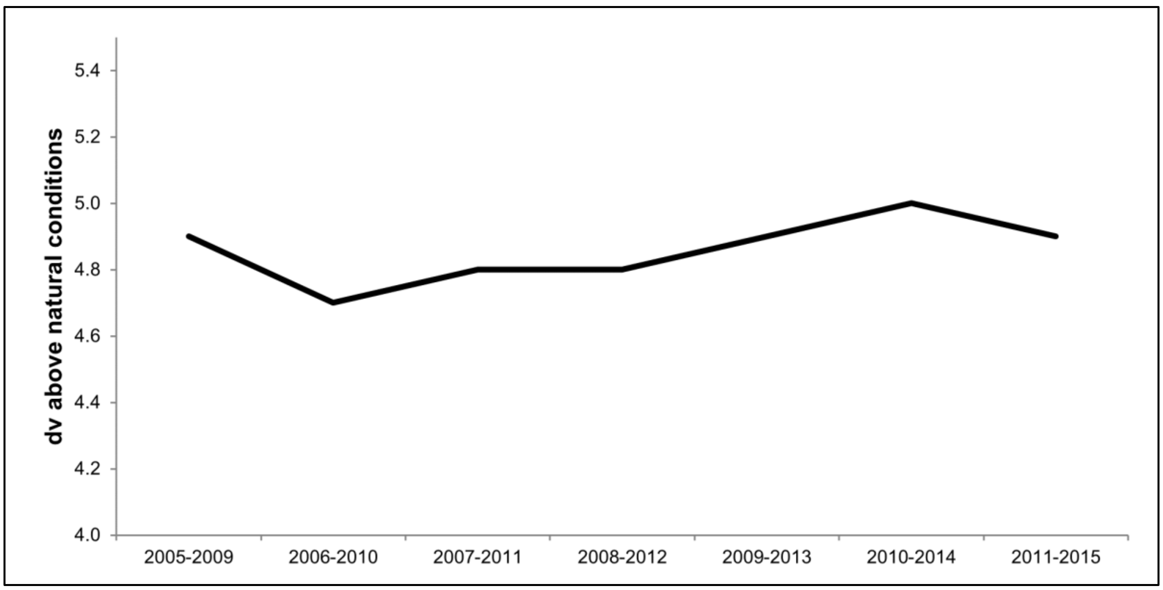


Figure 48. Estimated 5-year averages of visibility (dv above natural conditions) on mid-range days at SAPU (NPS 2015a). Measurements of 2–8 dv above natural conditions indicate *Moderate Concern.*

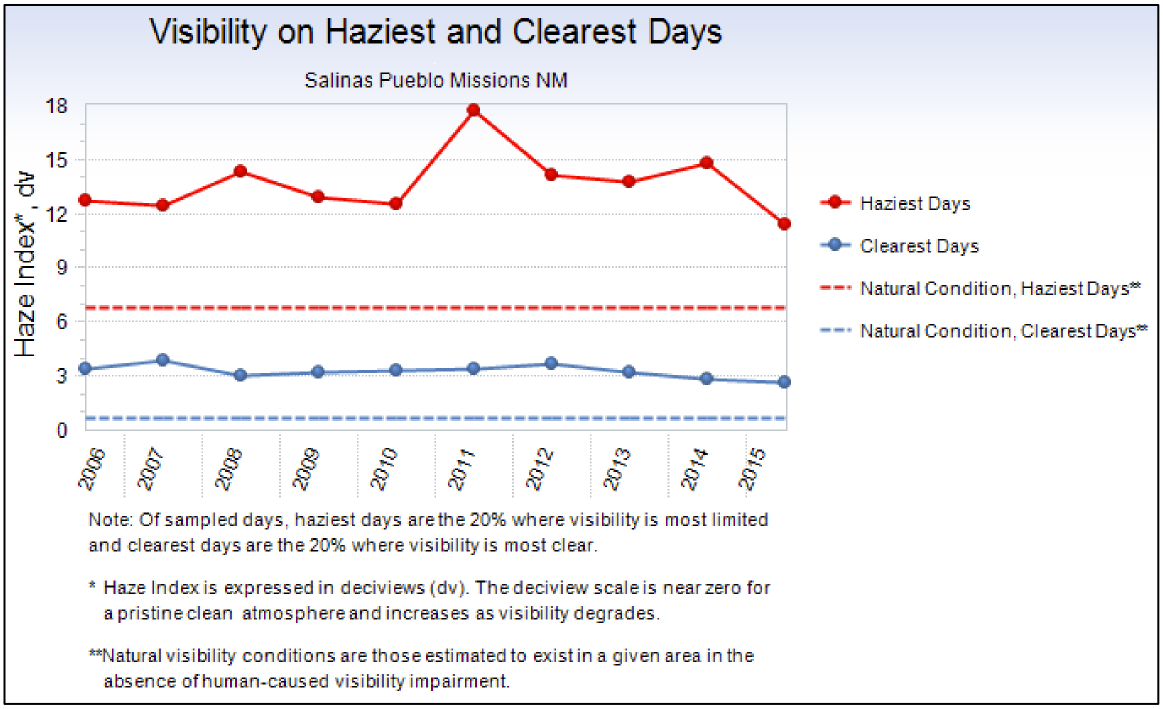


Figure 49. Long-term trends in visibility in the SAPU region, based on measurements from the WHIT1 monitoring station near Ruidoso, NM (reproduced from NPS 2015a).

Change in Adjacent Land Use/Cover

Between 2001 and 2011, very little land cover change occurred within the entire 80 km (50 mi) buffer around SAPU's three units (USGS 2014). Just over 98% of the area was classified as "no change", and only 0.3% of the area changed from natural vegetation types (e.g., evergreen forest, shrub/scrub) to agricultural or developed cover types. Within the areas *visible* from SAPU's selected observation points, 97.4% experienced no change, and no areas changed from vegetated to developed (Table 47, Figure 50). Less than 0.01% transitioned from natural vegetation to agricultural use (pasture/hay). Within natural vegetation classes, more land changed from forested vegetation types to shrubby or herbaceous types (697 ha [1,722 ac]) than from herbaceous or shrubby to forested types (31 ha [76 ac]) (USGS 2014). This may result in a slightly more open appearance on the visible landscape. Much of this change seems concentrated in the Manzano Mountains west of Quarai (Figure 51).

Table 47. Extent of changes in land cover within the SAPU viewshed, 2001–2011 (USGS 2014).

	Area	
Land Cover, 2001–2011	**Hectares**	**Acres**
No change	33,049.62	81,667.26
Open water to emergent herbaceous wetlands	2.16	5.34
Deciduous forest to evergreen forest	3.33	8.23
Deciduous forest to mixed forest	9.54	23.57

Table 47 (continued). Extent of changes in land cover within the SAPU viewshed, 2001–2011 (USGS 2014).

Land Cover, 2001–2011	Area	
	Hectares	**Acres**
Deciduous forest to shrub/scrub	60.21	148.78
Deciduous forest to grassland/herbaceous	61.65	152.34
Evergreen forest to deciduous forest	3.33	8.23
Evergreen forest to mixed forest	3.33	8.23
Evergreen forest to shrub/scrub	150.3	371.40
Evergreen forest to grassland/herbaceous	417.96	1032.80
Evergreen forest to pasture/hay	1.26	3.11
Mixed forest to shrub/scrub	2.25	5.56
Mixed forest to grassland/herbaceous	3.06	7.56
Shrub/scrub to open water	13.59	33.58
Shrub/scrub to deciduous forest	4.59	11.34
Shrub/scrub to evergreen forest	18.63	46.04
Shrub/scrub to mixed forest	1.98	4.89
Shrub/scrub to grassland/herbaceous	56.25	139.00
Shrub/scrub to pasture/hay	0.18	0.44
Shrub/scrub to emergent herbaceous wetland	1.71	4.23
Grassland/herbaceous to deciduous forest	4.05	10.01
Grassland/herbaceous to evergreen forest	1.44	3.56
Grassland/herbaceous to shrub/scrub	49.14	121.43
Emergent herbaceous wetland to grassland/herbaceous	4.86	12.01
Total forest to shrub/scrub, grassland, or pasture	**696.69**	**1,721.56**
Total shrub/scrub or grassland to forest	**30.69**	**75.84**

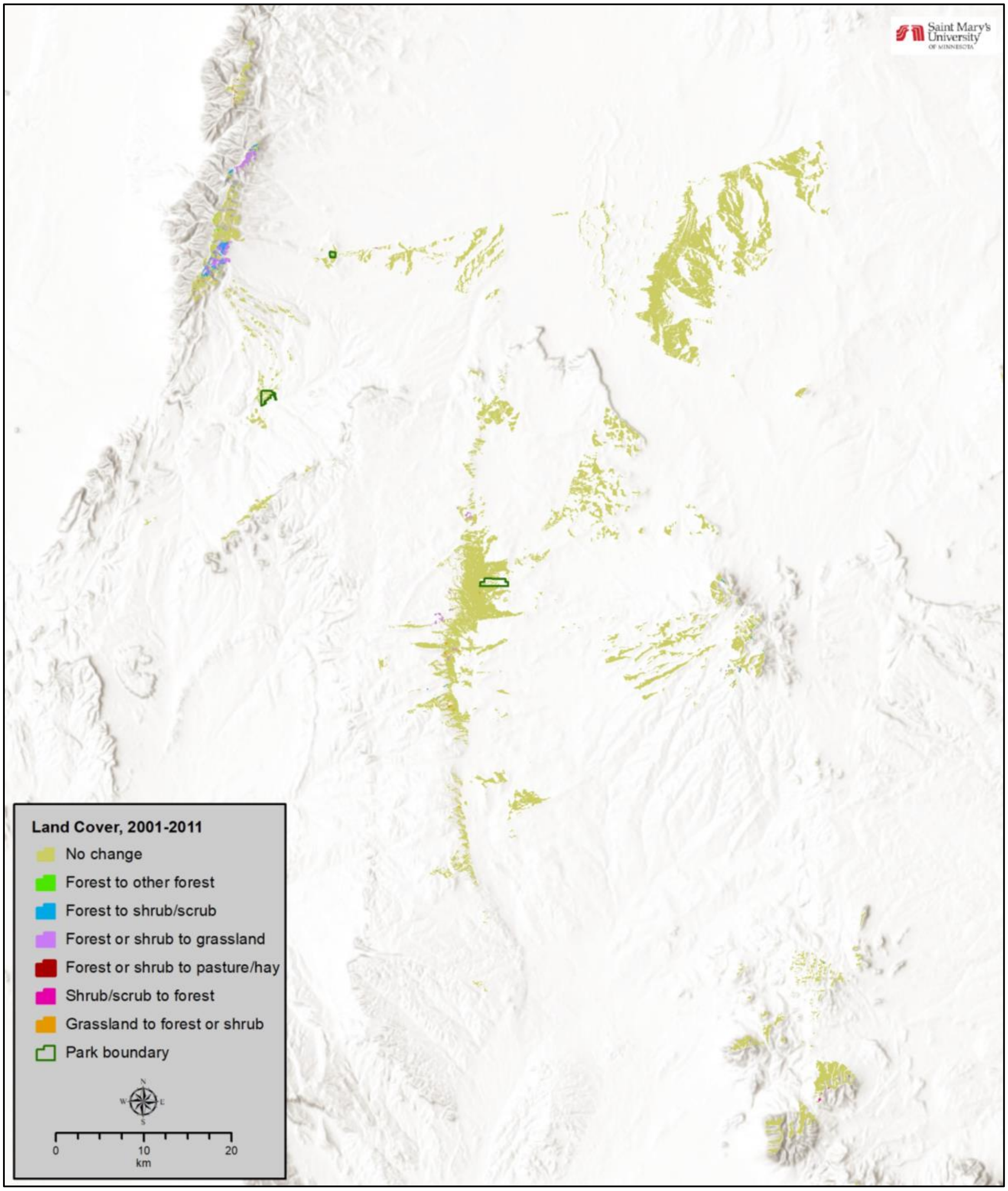


Figure 50. Distribution of land cover change throughout the SAPU viewshed (USGS 2014).

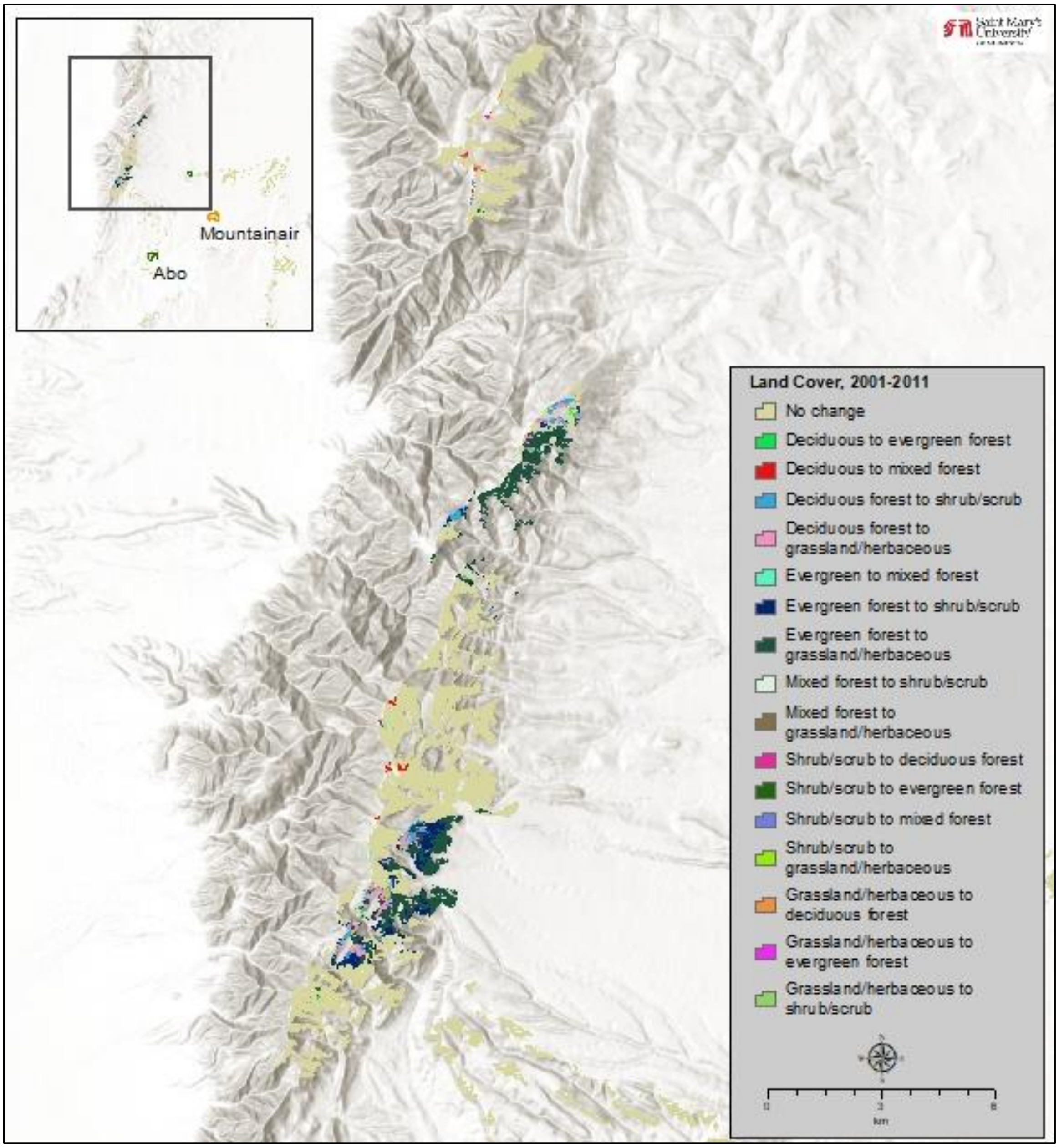


Figure 51. Land cover change in the visible portion of the Manzano Mountains, west of Quarai and north of Abó (USGS 2014).

According to the recently-released 2016 NLCD (USGS 2019b), the vast majority of land surrounding SAPU is still vegetated. The most common land cover types within an 80 km (50 mi) buffer around SAPU's units are shrub/scrub (62%), herbaceous/grassland (24%), and evergreen forest (9%) (Figure 52, Table 48). However, land cover within the areas that are *visible* from the selected viewshed observation points are slightly different. They are dominated by herbaceous/grassland (44%), shrub/scrub (34%), and evergreen forest (20%). Only 0.5% of visible area is classified as developed (USGS 2019b).

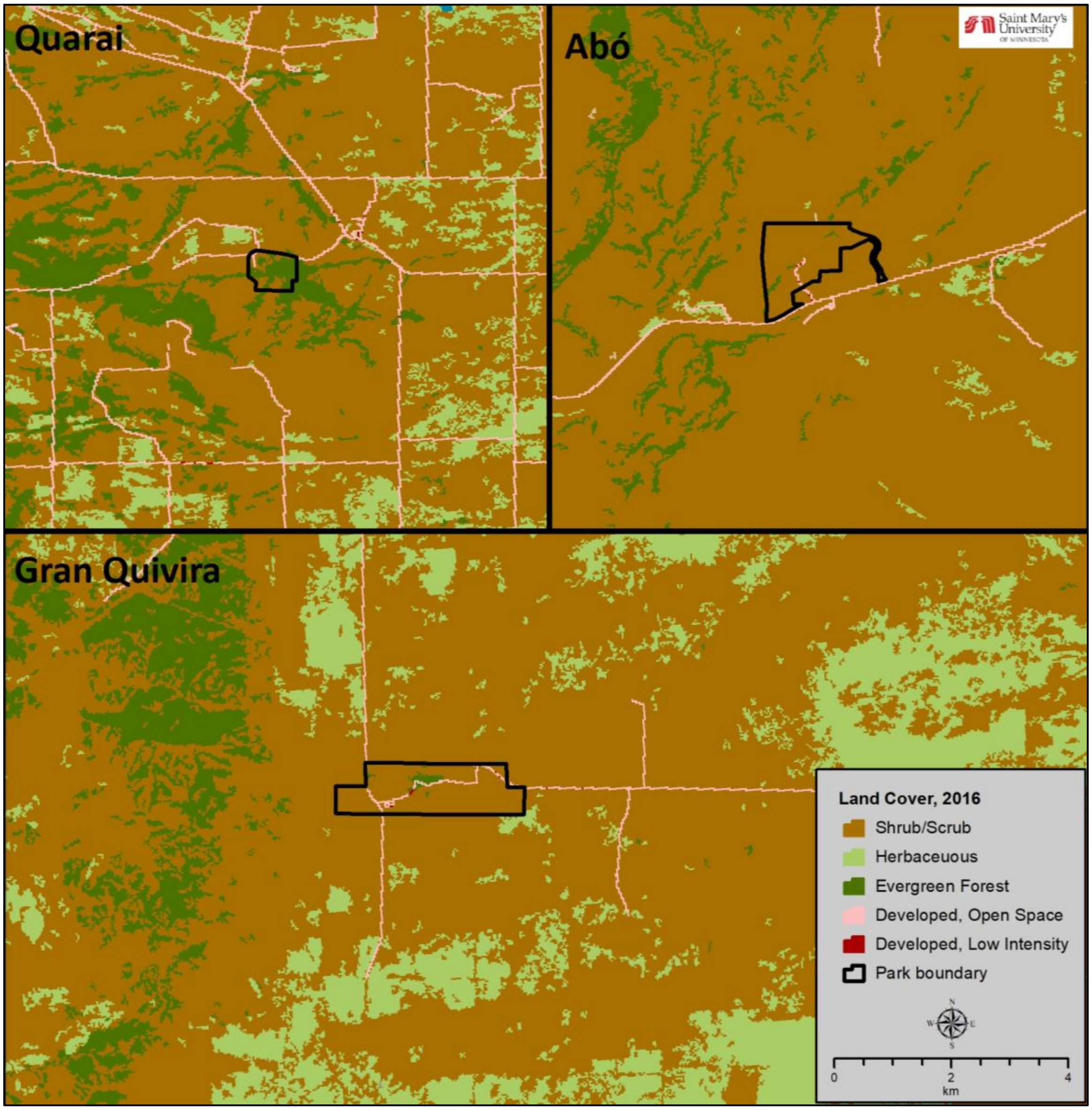


Figure 52. Land cover in and around SAPU's three units, as of 2016 (USGS 2019b).

Table 48. Land cover in the region surrounding SAPU, 2016 (USGS 2019b).

Land Cover	Area within 80 km buffer (ha/ac)	Area visible from SAPU (ha/ac)
Shrub/Scrub	1,751,245.5 (4,327,421.9)	11,477.5 (28,361.5)
Herbaceous	687,008.4 (1,697,634.7)	14,928.8 (36,889.9)
Evergreen Forest	244,071.7 (603,114.3)	6,660.7 (16,458.9)
Developed, Open Space	37,449.8 (92,540.5)	171.8 (424.5)
Developed, Low Intensity	24,508.9 (60,562.8)	5.9 (14.6)
Hay/Pasture	21,046.8 (52,007.8)	–
Cultivated Crops	19,089.5 (47,171.2)	–

Table 48 (continued). Land cover in the region surrounding SAPU, 2016 (USGS 2019b).

Land Cover	Area within 80 km buffer (ha/ac)	Area visible from SAPU (ha/ac)
Developed, Medium Intensity	13,209.1 (32,640.4)	3.5 (8.6)
Emergent Herbaceous Wetlands	12,074.9 (29,837.7)	25.8 (63.8)
Woody Wetlands	7,846.3 (19,388.6)	–
Barren Land	4,582.2 (11,322.9)	14.0 (34.6)
Deciduous Forest	3,133.7 (7,743.5)	452.6 (1,118.4)
Developed, High Intensity	2,971.2 (7,342.0)	0.5 (1.2)
Open water	1,399.2 (3,457.5)	–
Mixed Forest	680.9 (1,682.5)	141.2 (348.9)

Change in Viewshed within the Park (Internal)

The internal viewshed area from all observation points covers 187.5 ha (463.2 ac) (Figure 53). According to the NLCD (USGS 2014), no change in landcover occurred in the Gran Quivira and Abó units between 2001 and 2011. The only landcover change within Quarai during this period was between natural vegetation types; one area northeast of the mission transitioned from shrub/scrub and grassland/herbaceous to evergreen forest, while an area southeast of the mission changed from evergreen forest to shrub/scrub (Figure 54). Each area is between 1–2 ha (2.5–5 ac) and together they comprise about 8% of the unit's total area.

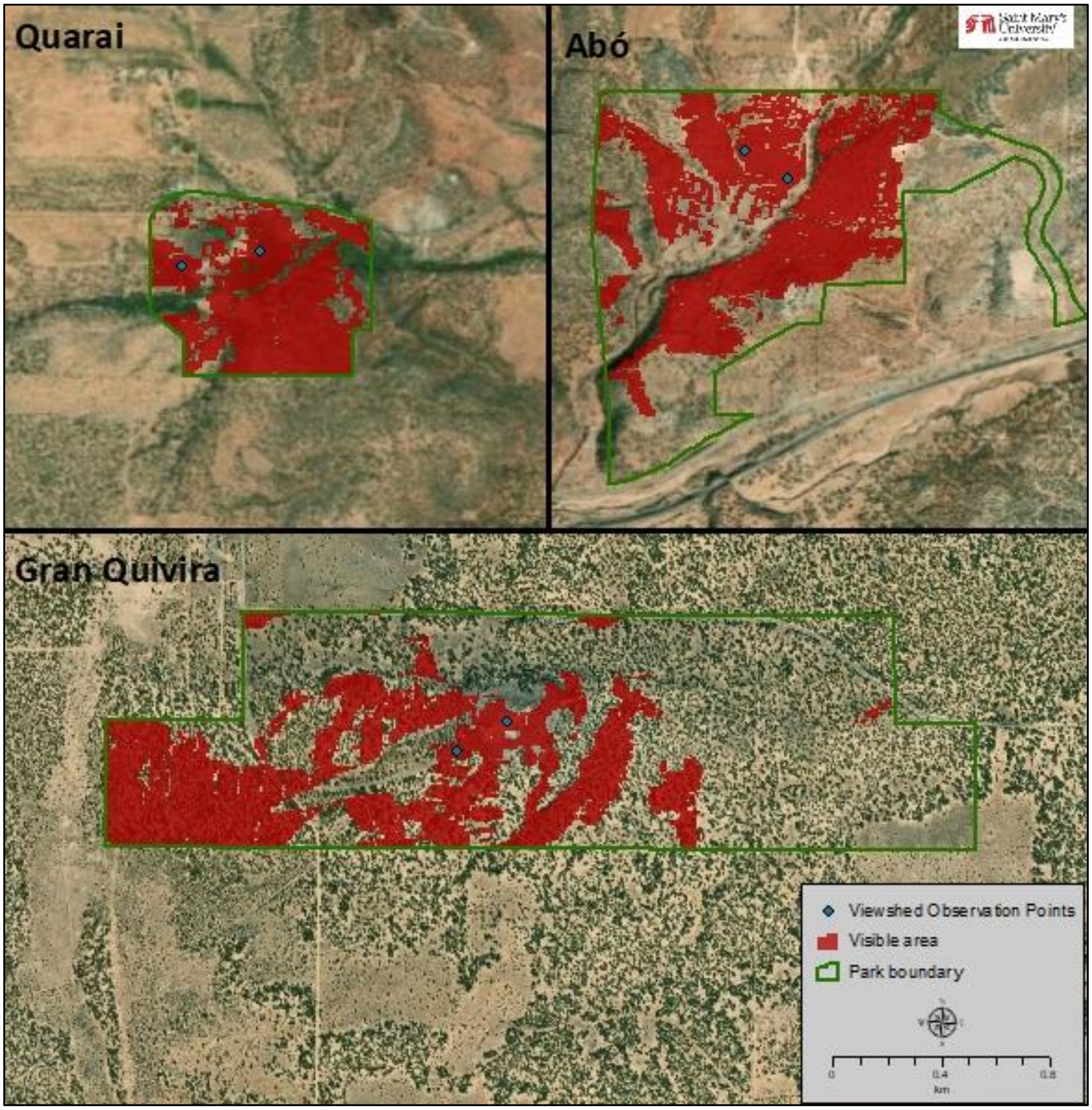


Figure 53. The internal viewshed at each SAPU unit from the selected observation points.

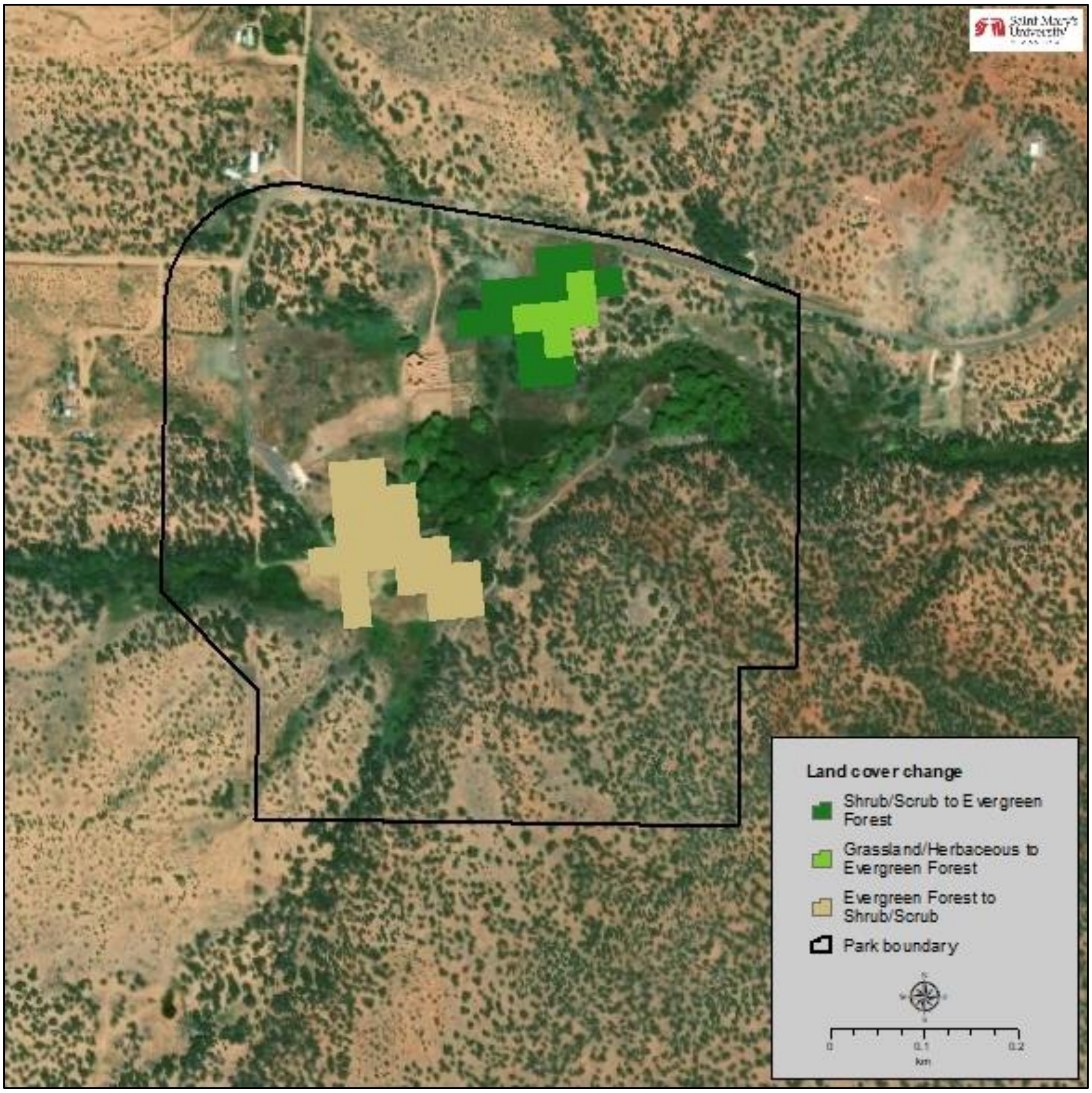


Figure 54. Change in land cover within Quarai boundaries, 2001–2011 (USGS 2014).

Since 2011, some invasive tree removal and juniper thinning has occurred along the arroyos at Abó and Quarai (LeFrançois 2017c). Some thinning was also conducted around culturally significant trees (e.g., apples and cottonwoods) in the two units in an effort to preserve these components of the historic landscape (LeFrançois 2017a). These efforts may have made the landscape appear more open but would not have substantially impacted the internal viewshed.

Change in Viewshed Outside the Park

The external viewshed area from all observation points covers 59,806 ha (147,783 ac) (see Figure 47). 35% of this area is visible from the Gran Quivira points, 26% from the Quarai points, and 4% from Abó (Figure 55). A small area (81 ha [199 ac]) in and east of the Manzano Mountains is visible from all three units, with some spots (23 ha [57 ac]) visible from all six observation points (Figure 56). As discussed previously, very little change in land cover occurred within the SAPU viewshed between 2001 and 2011 (see Table 47, Figure 50). The most notable alteration would be the addition of wind turbines northeast of the park, which will be discussed in the “Threats and Stressor Factors” section.

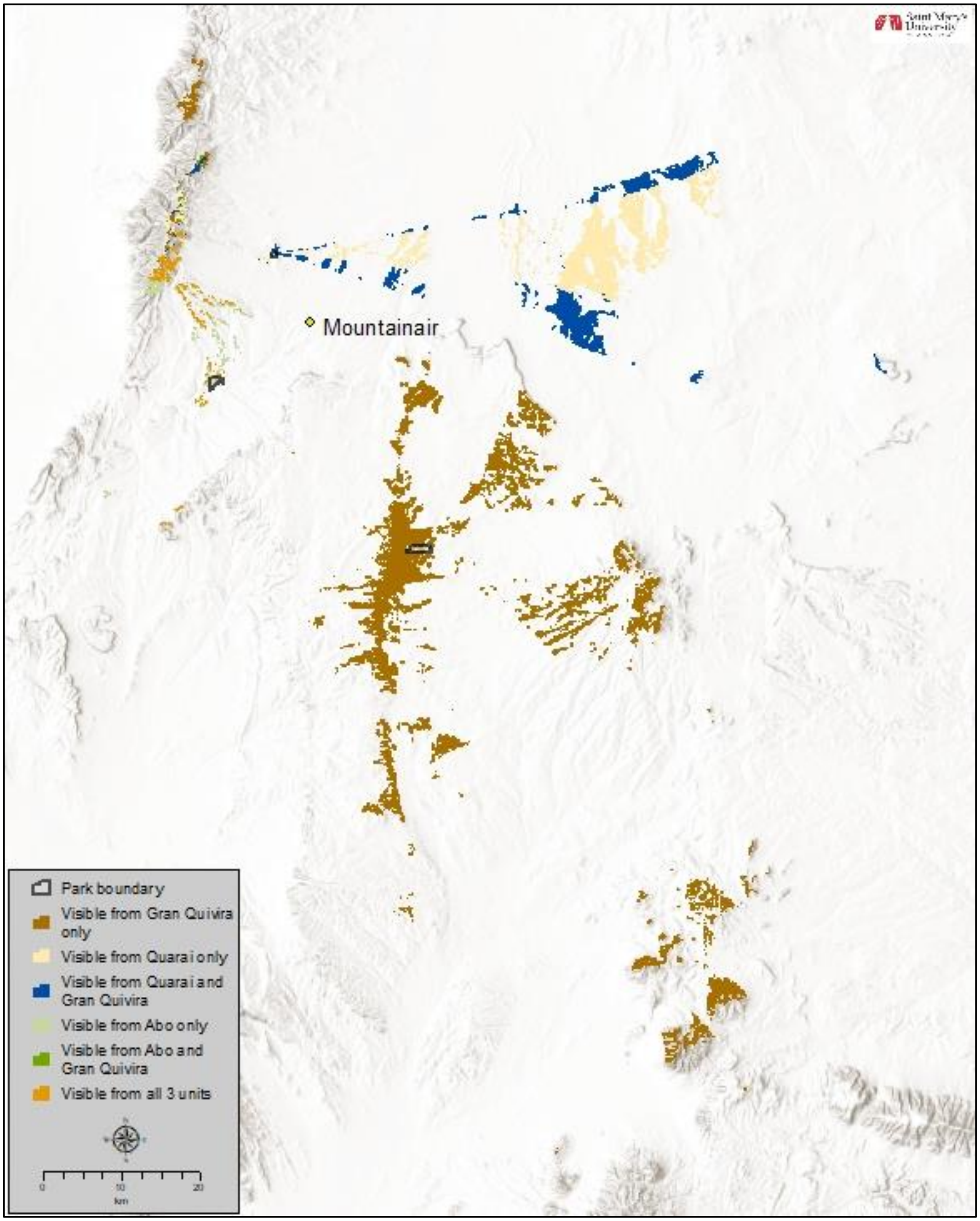


Figure 55. Portions of the viewshed visible from multiple park units or from a single unit.

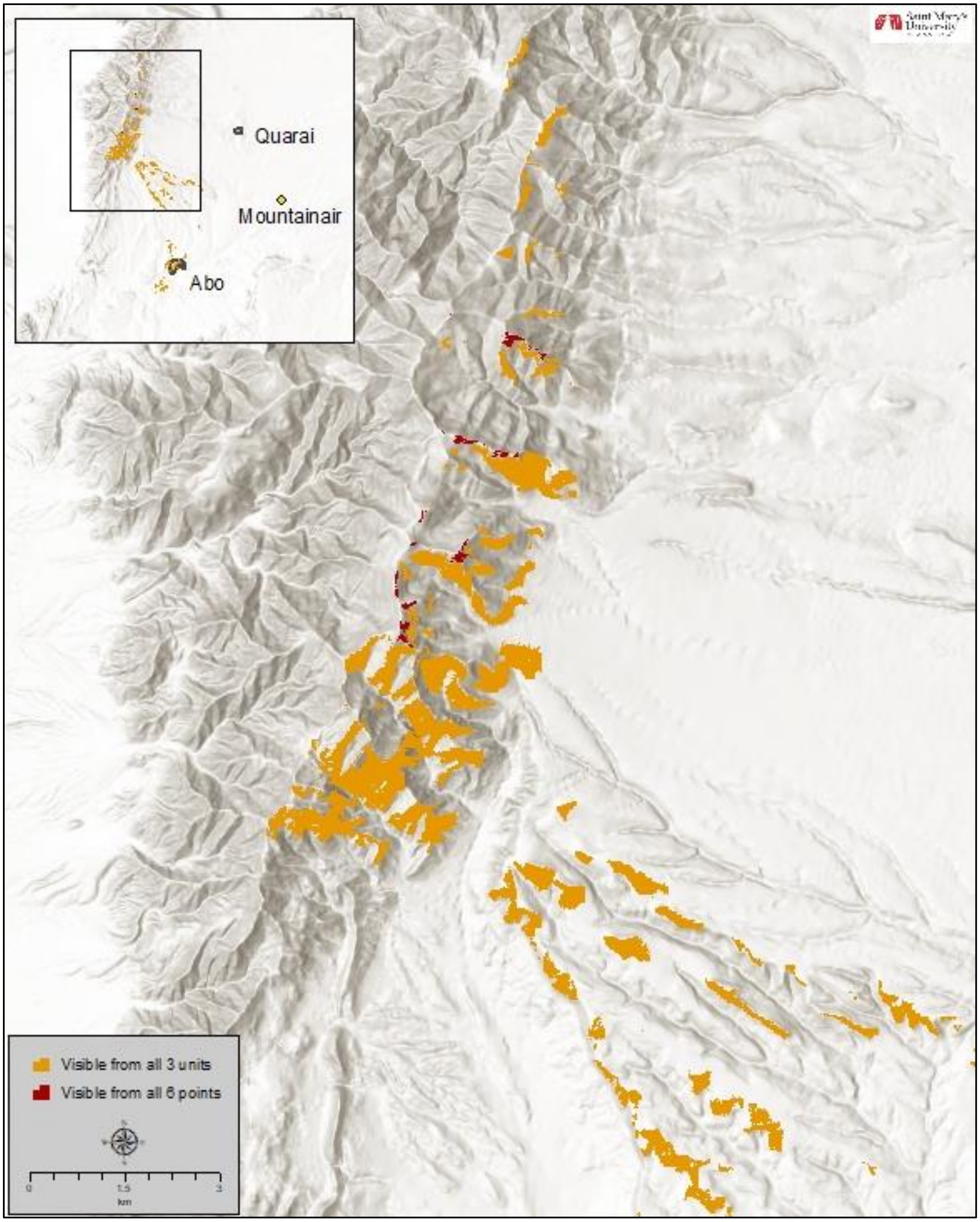


Figure 56. Areas in the Manzano Mountains visible from all three units and from all six observation points.

View to the northwest from the Pueblo ruins at Gran Quivira, with the Manzano Mountains in the far distance (SMUMN GSS photo).

Threats and Stressor Factors

Threats to the park's viewshed are primarily from adjacent land development, including wind farms, electrical transmission lines, gravel mines, and other industrial activity (NPS 2014b). Smoke from wildfires may also impact the viewshed by impairing visibility.

Wind energy development poses a threat to the external viewscape of the park. Wind energy is a cost-effective and environmentally attractive form of energy that is growing in New Mexico (NMEMNRD 2018), and projects are often located on ridges or mesa tops to take full advantage of the wind (BLM 2013). Industrial wind turbines are typically at least 100 m (328 ft) tall (Rosenbloom 2005), making them visible from more locations and very notable on the landscape. A 100 MW utility-scale wind farm with 40 2.5-megawatt Clipper turbines was commissioned on High Lonesome Mesa in 2009, and is visible from Gran Quivira (Figure 57) (NPS 2010). More recently, the 298 MW El Cabo wind farm with 142 turbines began operating in Torrance County near Encino, just over 50 km (~32 mi) west of Quarai and northwest of Gran Quivira (Robinson-Avila 2018). The turbine blades at El Cabo reach 137 m (450 ft) into the air and are visible from Quarai. It has been estimated that as many as 500 new wind turbines will be installed near SAPU in the near future, as well as large solar energy fields, associated transmission lines, and a CO_2 pipeline (KellerLynn 2018). Figure 57 shows the areas surrounding SAPU where wind turbines or any other 100-m-tall structures would be visible from one or more of the selected observation points.

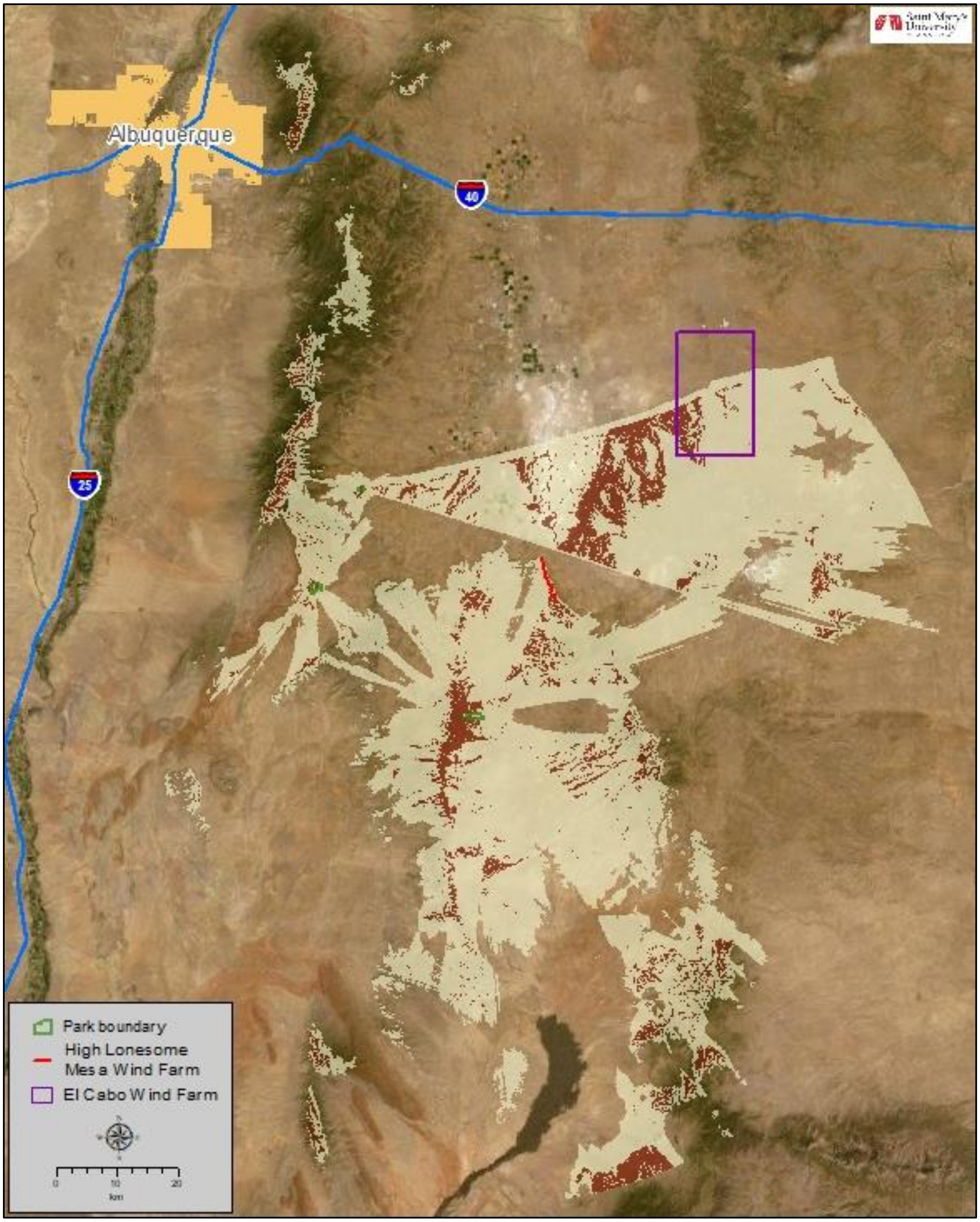


Figure 57. Tan shading represents areas beyond the standard, ground-level viewshed (red-brown shading) where 100-meter (328 ft) tall structures (e.g., wind turbines) would be visible from a SAPU observation point. The red line towards the center of the map represents the High Lonesome Mesa wind farm and the purple box shows the approximate location of the El Cabo wind farm.

Power transmission lines are also a threat to the viewshed at SAPU. Transmission lines are over 30 m (100 ft) tall, which makes it difficult for visitors to overlook their presence among the natural viewscape. Currently, a transmission line located northwest of Abó is very noticeable when viewing the mission ruins from the unit's entrance road and parking area (Figure 58). In addition to the power lines themselves, vegetation is regularly cleared along the rights-of-way for maintenance purposes, which creates a very visible contrast on the landscape (BLM 2013). Similar clearing occurs along railroads and pipelines.

Figure 58. A transmission line is clearly visible on the landscape (red arrows) when viewing the Abó mission ruins from the entrance road and parking area (SMUMN GSS photo).

Wildfires produce air pollutants, including PM, that often impair visibility and can travel long distances (Wise 2008, Georgiou 2018). For example, smoke from the 2018 California wildfires created hazy conditions as far east as Philadelphia, Pennsylvania (Georgiou 2018). In August of 2019, smoke from fires in Arizona spread across central New Mexico into Oklahoma (Gabbert 2019) (Figure 59). Additional sources of PM that could impact visibility around SAPU include vehicle emissions and blasting at a gravel mine next to Abó, which produces dust.

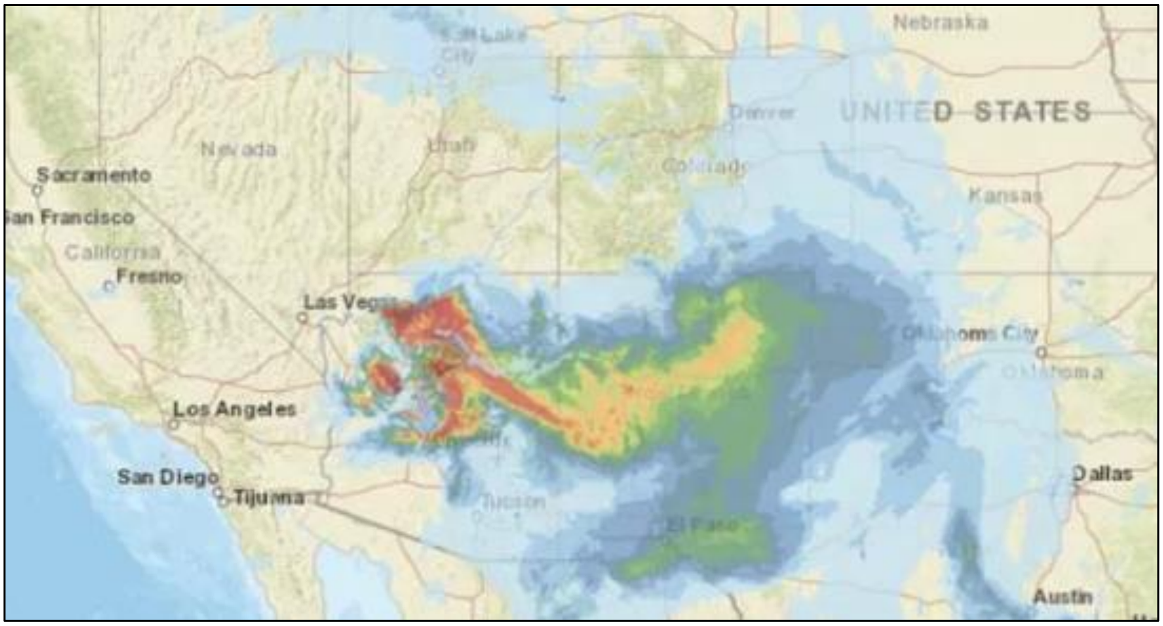


Figure 59. The forecast for wildfire smoke distribution on 22 August 2019 (from wildfiretoday.com archives).

Data Needs/Gaps

Some of the development projects near SAPU have been initiated without park staff ever being aware of the proposals or having an opportunity to comment on potential impacts (NPS 2014b). The park needs a convenient way to learn about such development projects, so they have an opportunity to provide input that may minimize impacts to park resources. It may be beneficial to establish photo monitoring points at each unit, where repeat photography every 2–3 years could be used to document any changes in the surrounding viewshed.

Overall Condition

Visibility

The project team assigned visibility a *Significance Level* of 3. The 2011–2015 estimated visibility on mid-range days for SAPU was 4.9 dv above estimated natural conditions, which falls into the *Moderate Concern* category based on NPS criteria for air quality assessment. Visibility conditions have been relatively stable at SAPU over the past decade. As a result, this measure is assigned a *Condition Level* of 2.

Change in Adjacent Land Use/Cover

This measure was also assigned a *Significance Level* of 3. Very little land cover change occurred in the region surrounding SAPU from 2001–2011 (USGS 2014). Within the areas visible from SAPU's selected observation points, 97.4% experienced no change, and no areas changed from vegetated to developed (see Table 47). Therefore, this measure is assigned a *Condition Level* of 1, indicating low concern.

Changes in Viewshed within the Park

A *Significance Level* of 2 was assigned for this measure. According to the NLCD (USGS 2014), no change in landcover occurred in the Gran Quivira and Abó units between 2001 and 2011, and the only landcover change within Quarai during this period was between natural vegetation types (Figure 54). As a result, a *Condition Level* of 0 (no concern) is assigned.

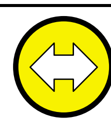
Changes in Viewshed Outside the Park

This final measure was assigned a *Significance Level* of 3. Very little land cover change has occurred in the region surrounding SAPU in recent decades, and from 2001–2011, no areas visible from the selected observation points transitioned from natural vegetation to developed areas (USGS 2014). However, the addition of wind turbines northeast of the park has impacted a portion of the Gran Quivira viewshed. Currently, these changes are of low concern (*Condition Level* = 1), but it is likely this concern will grow as the region faces growing energy development pressures.

Weighted Condition Score

The *Weighted Condition Score* for SAPU's viewshed is 0.36, indicating moderate concern (Table 49). The overall trend is stable, given that air quality-related visibility conditions are relatively unchanged over the past decade and little to no land cover change is occurring in visible areas both inside and outside park boundaries.

Table 49. Current condition of Viewshed at SAPU.

Measures	**Significance Level**	**Condition Level**	**WCS = 0.36**
Visibility	3	2	–
Change in Adjacent Land Use/Cover	3	1	–
Changes in Viewshed within the Park	2	0	–
Changes in Viewshed Outside the Park	3	1	–
Overall	**–**	**–**	

4.7.6 Sources of Expertise

- Marc LeFrançois, SAPU Chief of Facility and Resource Management

4.8 Cave and Karst Features (Gran Quivira)

4.8.1 Description

Gran Quivira lies on the rolling topography of the Chupadera Mesa (NPS 1974, KellerLynn 2018). This rolling nature, dotted with depressions and sinkholes, is characteristic of karst areas, where certain rock layers are dissolved by water, causing the layers above to sink or subside (KellerLynn 2018). Karst is any series of distinctive surface or subterranean features/conditions developed by the solution of carbonate and other rocks, which often cause problems for building or infrastructure engineering due to the potential for subsidence (Davies 1984, Weary and Doctor 2014). Karst features include caves, sinkholes, underground drainage channels, and any type of subterranean cavity or void (KellerLynn 2018). These features can range in size from tiny voids to large caverns; when subsidence occurs, it typically appears on the surface as a steep-sided depression up to 6 m (20 ft) deep (Davies 1984). On the Chupadera Mesa, sinkholes range in size from a few square meters to several hectares (Bates et al. 1947).

Much of SAPU is underlain by various karst terrain (Figure 60), but cave and karst features are most prominent at Gran Quivira (Land et al. 2013, KellerLynn 2018). Karst features here occur where gypsum and limestone in the underlying San Andres Limestone formation have been dissolved by water, including groundwater flow (Bates et al. 1947, KellerLynn 2018). Cave and karst geology were defined as an important park resource in SAPU's Foundation Document (NPS 2014b). The existence of cave and karst features at Gran Quivira was first noted in 1932 when a visiting engineer was investigating an excavated shaft. During his investigation, the engineer observed "some very interesting cave formations, appearing to me to be identical with the gypsum formation at Carlsbad", and natural openings in the ground where the air flow coming out "has been strong enough to raise a hat from the ground" (Attwell 1932). More recently, park staff noticed unusual cracks in the Gran Quivira ruins that appeared to be a result of subsidence, raising the possibility of a cave or other void beneath the Mound 7 Pueblo ruins (NPS 2006a). No known entrance or opening to this cave exists, but a "blowhole" (i.e., ground opening where air rushes out) existed just west of Mound 7 until the 1980s, when a pipe that was inserted into the otherwise sealed blowhole was inadvertently struck by a lawnmower and effectively "plugged" the opening (NPS 2006a).

Several other "blowholes" occur at Gran Quivira, including a cavern opening that has been documented along the park road (Figure 61). There are also several pits on the Gran Quivira site that were excavated by treasure hunters, and there is good evidence to show that the reason these hunters dug into undisturbed bedrock is because blowholes were present in these locations (LeFrançois, written communication, March 2020). The air flow at these blowholes is a result of changes in barometric pressure, and occurs at caverns of all sizes (Attwell 1932). Blowholes or air-breathing crevices may have had some cultural significance to Native American peoples, as many prehistoric village locations in the southwest are closer to these features than to a water source (Schley 1963).

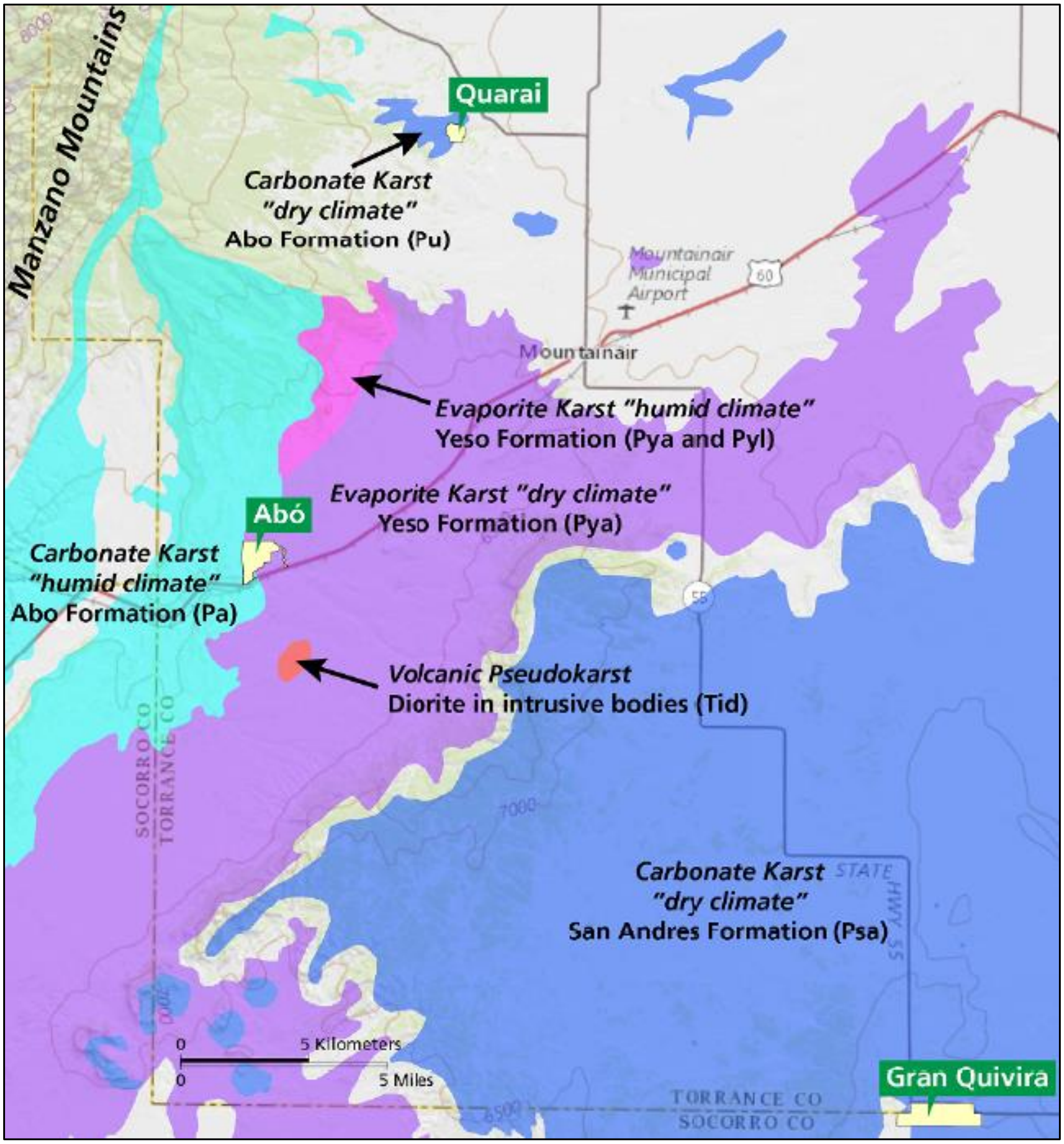


Figure 60. Map of karst areas and types in the SAPU region (reproduced from KellerLynn 2018).

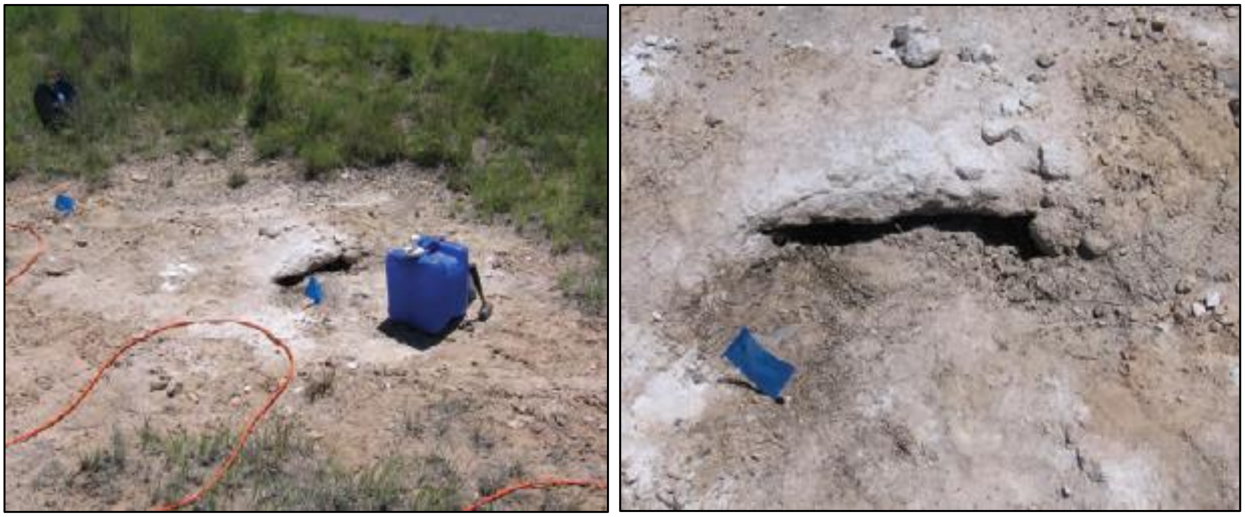


Figure 61. Photos of a small gypsum cavern opening along the Gran Quivira Road, June 2005 (USGS photos).

NPS management policies state that, "The Service will manage karst terrain to maintain the inherent integrity of its water quality, spring flow, drainage patterns, and caves", including protection from human developments and/or mitigation of development impacts (NPS 2006b, p. 54). In addition, the Federal Cave Resources Protection Act of 1988 (16 USC §§ 4301– 4309) requires the identification of "significant caves" in NPS areas, the restriction/regulation of use as needed to protect cave resources, and the inclusion of significant caves in land management planning.

4.8.2 Measures

- Magnitude of subsidence
- Frequency of viscous seepage events
- Number of blowhole locations within park boundaries

4.8.3 Reference Condition/Values

The geologic processes that create cave and karst features are natural and normal for the types of rock that occur at Gran Quivira. However, the rates and magnitudes of change within these processes are highly variable; some geological changes are slow and gradual, while others are sudden and dramatic. As a result, the NRCA project team felt it would not be appropriate to choose reference conditions for the selected measures. Best professional judgement will be used to assess condition if enough information is available.

4.8.4 Data and Methods

Study of SAPU's cave and karst features have been limited to date. A 1930s report by an engineer investigating "treasure hunter" excavations is the earliest known published documentation of cave and karst features at Gran Quivira (Attwell 1932, Vivian 1964).

The park's Geologic Resource Evaluation Scoping Summary (NPS 2006a) and Geologic Resources Inventory Report (KellerLynn 2018) summarize several issues and threats related to SAPU's cave and karst features, including the unknown viscous substance that seeps from structures/rocks at Gran Quivira. In June 2005, Ball et al. (2006) used surface-geophysical techniques (electromagnetic and resistivity methods) to characterize the near surface geology of areas of interest within the Gran Quivira unit (Figure 62). The objective was to identify potential subsurface voids (e.g., caves) and test various methods for detecting them. While this study confirmed the existence of one blowhole within the unit, it did not otherwise address the measures selected for this assessment.

Figure 62. Field crew conducting near-surface geological research at Gran Quivira, as described in Ball et al. (2006) (USGS photos).

4.8.5 Current Condition and Trend

<u>Magnitude of Subsidence</u>

Subsidence is any sinking of the Earth's surface due to geologic or human-related causes. Cracks in some of the ruins at Gran Quivira, particularly on Mound 7, are thought to be the result of differences in subsidence (e.g., some areas are sinking faster than others, creating an undulating surface) (NPS 2006a). In some rooms, cracks were tight at the bottom with gaps at the top, while in the next room, cracks were tight at the top with gaps at the bottom (LeFrançois, written communication, 23 September 2019). However, measurements or any other documentation of this subsidence is not publicly available at this time.

<u>Frequency of Viscous Seepage Events</u>

Observers have noted a dark-colored unknown low-viscosity substance seeping from San Andres Formation rocks at Gran Quivira, including those used in the construction of the Mission church and convento (NPS 2006a, KellerLynn 2018). A 2003 analysis of the substance, at the request of SAPU's Chief of Resource Management, identified it as an organic hydrocarbon. At the time, it was thought that the substance was artificial, likely a mastic resin from Spain that had been brought to the missions (NPS 2006a). However, this was based on an assumption that the substance was limited to isolated areas within the mission complex; it was later realized that there are extensive amounts of the substance, widespread throughout the Gran Quivira site. Subsequent analysis by a University of Arizona lab recognized it as a natural hydrocarbon (LeFrançois, written communication, 23

September 2019). While some observers have reported a “petroleum-like odor” upon cracking open stones at Gran Quivira (NPS 2006a), the unknown substance itself does not have a distinctive smell and is not flammable (LeFrançois, verbal communication, 30 January 2018). The substance is negatively affecting the rocks of the structures from which it seeps, because it seems to make the stone surface and mortar more vulnerable to flaking or crumbling (i.e., “spalling”) (Figure 63). At this time, the origin of the substance and the cause of seepage is unknown (KellerLynn 2018). It seems more likely to emerge after rain or snowfall (LeFrançois, verbal communication, 30 January 2018). However, the frequency of these seepage events has not been officially documented.

Figure 63. Evidence of past seepage events can be seen in the darker, oily of appearance of rocks in the Gran Quivira church walls (left, red arrows). Rocks that experience seepage appear more likely to flake or crumble, as seen on the right (GSS photos).

Number of Blowhole Locations within Park Boundaries

The earliest mention of blowholes at Gran Quivira comes from the Attwell (1932) report on treasure hunting activity at the monument. Attwell (1932) reports that “there are four natural openings at the Mission where the air whistles out of the ground” but does not provide location information; the blowhole near Mound 7 previously described in this component was likely one of these openings. Current park staff hope to find the exact location and dimensions of the original blowhole and reopen it to restore airflow into the cavern below (NPS 2006a). Ball et al. (2006) documented one blowhole, with an opening about 20 x 10 cm (7.9 x 3.9 in), along the shoulder of Gran Quivira’s main road.

One additional blowhole near the main ruins is known to park staff because it is also a snake den (LeFrançois, written communication, 23 September 2019).

Threats and Stressor Factors

Threats to Gran Quivira's cave and karst features include human damage to blowholes, lightning strikes, earthquakes, vibrations from adjacent land development and industrial projects, bioturbation (i.e., plant root and animal burrowing activity), flooding, and loss of vegetative cover or cryptobiotic soils. Humans may damage blowholes by trying to fill or cover them, dropping trash in them, or by trying to widen/expand them.

Bioturbation, including plant root and animal burrowing activity can disturb cave and karst features directly (e.g., intercepting subsurface voids) or indirectly by altering water infiltration. Plant root tips can seek out existing rock and soil cracks or voids and expand them, potentially opening new pathways for water infiltration (MacDonald 1990). Animal burrows also create openings in the soil where new water flows can contribute to gullying or piping (subsurface soil erosion). These changes in water infiltration and flow could create additional karst features or erode/collapse existing cave and karst features.

The vibrations from earthquakes or development/industrial projects may fracture the rock surrounding cave and karst features, eventually leading to full or partial collapse (Papadopoulou-Vrynioti et al. 2013, Gutierrez et al. 2014). Small earthquakes with a magnitude above 1.3 are common in New Mexico, with rare earthquakes greater than 5.0 in magnitude (KellerLynn 2018). A swarm of approximately 150 earthquakes occurred in the Willard-Mountainair region in 1997–1998 and were felt at all three SAPU units; the strongest earthquake, with a magnitude of 3.8, was detected on 4 January 1998 (KellerLynn 2018). Vibrations from human activities in the SAPU region, such as road construction, vehicle and railroad traffic, military overflights, or blasting at quarries could also fracture rocks (King et al. 1985, KellerLynn 2018).

The energy from a lightning strike can cause rock to fracture and even collapse (Wilson 2003). Air and moisture in rock cavities/cracks or moisture on the surface is superheated by the lightning's energy and expands, causing expansion of the cracks or splintering/explosion of the rock (Wilson 2003, Knight 2016). Lightning-induced fractures or explosions could alter the park's cave and karst features. New Mexico experiences a high number of lightning events, especially from June to August (NWS 2019). During a 14-hour period in July 2015, the northern two-thirds of the state experienced 20,000 lightning strikes (Reed Jr. 2015).

Any natural process or human activity that alters soils or surface water infiltration has the potential to impact cave and karst features (James 1993, Parise and Pascali 2003, North et al. 2009). The loss of vegetation or cryptobiotic crusts that maintain soil stability can accelerate soil erosion; during rainfall/flash flooding events, the eroding sediment may run into and fill karst features (Drew and Hotzl 1999, Parise and Pascali 2003). The filling/plugging of karst openings may cause surface water pooling or flooding and could reduce groundwater recharge (James 1993). Other changes in land use may increase surface runoff, causing it to find new flow paths, which could initiate new karst feature formation or re-open historic karst features (Drew and Hotzl 1999).

Data Needs/Gaps

Documentation is needed for the magnitude of subsidence and frequency of viscous seepage events at Gran Quivira. Additional analysis is needed to clearly determine the chemical composition and source of the viscous substance that seeps from Gran Quivira's rocks (NPS 2006a, KellerLynn 2018). A ground survey of the site should be conducted to officially document the number of blowholes as well as their locations, although locations should not be made public. Documenting these measures as soon as possible is important so that any changes of concern can be detected. Further exploration with surface-geophysical techniques and ground-truthing of potential voids detected would assist in identifying and delineating any cave features at Gran Quivira (Ball et al. 2006, NPS 2014b).

Overall Condition

Magnitude of Subsidence

This measure was assigned a *Significance Level* of 3 by the NRCA project team. Subsidence at Gran Quivira, likely related to the presence of karst features, is thought to be the cause of cracks in ruins on site. However, the magnitude of this subsidence has not yet been documented; a *Condition Level* cannot be assigned at this time.

Frequency of Viscous Seepage Events

A *Significance Level* of 2 was assigned for this measure. The viscous hydrocarbon detected on Gran Quivira rocks threatens the ruins, as the surfaces covered with the substance appear more vulnerable to flaking or crumbling. While NPS staff have observed this substance many times, the frequency of seepage events has not been recorded. As a result, a *Condition Level* could not be assigned for this measure.

Number of Blowhole Locations within Park Boundaries

The final measure was assigned a *Significance Level* of 3. In the 1930s, four known blowholes were reported at Gran Quivira. More recent reports have described individual blowholes, but a unit-wide survey to locate and count blowholes has not been conducted. As with the previous measures, a *Condition Level* could not be assigned.

Weighted Condition Score

A *Weighted Condition Score* was not calculated for cave and karst features due to a lack of information and data (Table 50). The current condition and trend for this component are unknown.

Table 50. Current condition of Cave and Karst Features at SAPU.

Measures	Significance Level	Condition Level	WCS = N/A
Magnitude of Subsidence	3	n/a	–
Frequency of Viscous Seepage Events	2	n/a	–
Number of Blowhole Locations	3	n/a	–
Overall	**–**	**–**	

4.8.6 Sources of Expertise

- Marc LeFrançois, SAPU Chief of Facility and Resource Management

4.9 Paleontological Resources

4.9.1 Description

Paleontological resources (i.e., fossils) include any remains of past life in a geologic setting (Tweet et al. 2009). They are considered non-renewable resources with high scientific, educational, and interpretive value. Fossils can be divided into two main types: body fossils, which are the physical remains of an organism (bones, shells, vegetation), and trace fossils, which are evidence of an organism's activity (footprints, burrows, etc.) (Tweet et al. 2009). The NPS also classifies fossils into three context categories: in situ (in place where it was found), in museum collections, or in cultural resource contexts (e.g., building stones, archeological tools). The Paleontological Resource Preservation Act (PRPA) (P.L. 111-11) of 2009 mandates the NPS to enhance paleontological resources stewardship, and calls for "the management and protection of paleontological resources using scientific principles and expertise", and the development of plans "for inventory, monitoring, and the scientific and educational use of paleontological resources" (Tweet et al. 2009, p. 10).

The paleontological resources of an area depend on the type and age of rocks exposed. At SAPU, the geology is primarily Permian sedimentary rocks from about 270–300 million years ago (mya) and younger Quaternary alluvium (Tweet et al. 2009). The Permian rocks contain plant fossils, trace fossils, and marine microfossils (e.g., gastropods). A mammoth skeleton was found during road construction in Quaternary deposits near Quarai in 1939 (Tweet et al. 2009, Fields 2020). In 2016, the first vertebrate body fossil from the Permian Yeso Group's Arroyo de Alamillo Formation was discovered at Abó (Thorpe et al. 2017, Lucas et al. 2018). It was a partial skeleton of a small varanopid reptile called a eupelycosaur (Figure 64). The skeleton is the youngest varanopid found in New Mexico and the largest tetrapod known from the lower Yeso Group, suggesting it was likely a top predator in the community (Lucas et al. 2018). The fossil was found in two pieces of sandstone rock and includes 18 caudal vertebrae, a partial pelvis, both legs and most of the hind feet bones (Figure 65).

Figure 64. The varanopid fossil in situ at Abó (i.e., in the original place it was found) (NPS photo by Emily Thorpe).

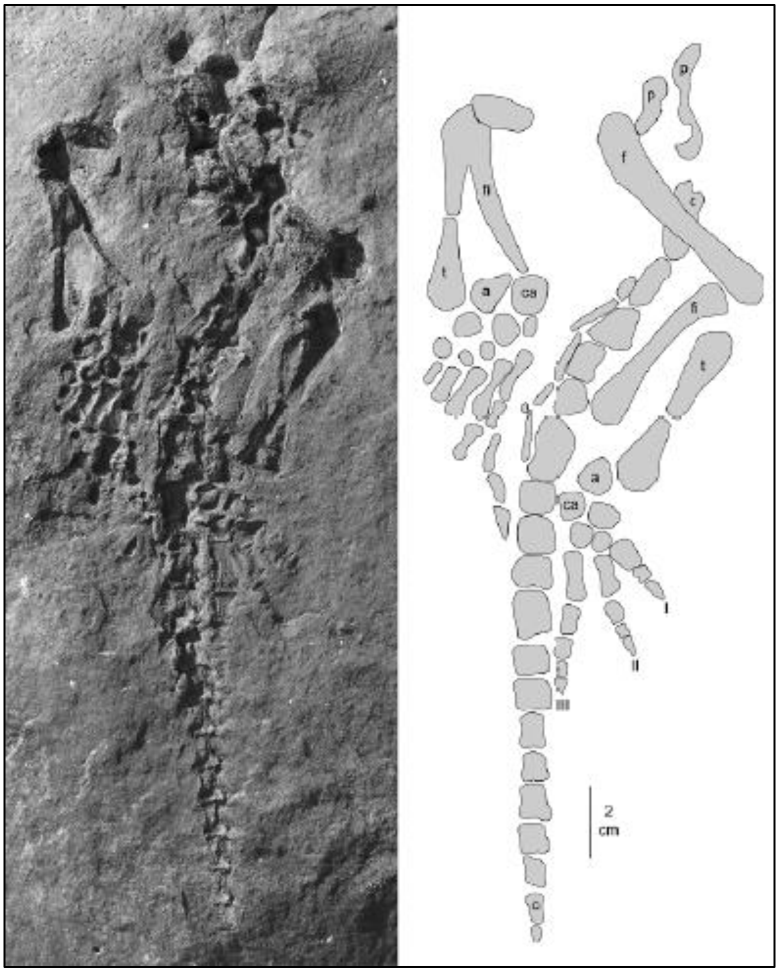


Figure 65. A stereophotograph and bone map drawing of the incomplete skeleton of a varanopid eupelycosaur from the lower Permian Arroyo de Alamillo Formation at Abó (NPS photo by Jack Woods). Abbreviations in the bone map include: a = astragalus (foot), c = caudal vertebra (tail), ca = calcaneum (foot/heel), f = femur, fi = fibula, p = pelvis, t = tibia, digits (toes) I-V are numbered.

4.9.2 Measures

- Percentage of paleontological sites in good/fair/poor condition
- Annual number of case incident reports related to paleontological sites
- Documentation of all paleontological sites in the park

4.9.3 Reference Condition/Values

Paleontological resources are to be preserved in their natural current state, with rare exceptions when collection/removal is necessary to protect a particular item or feature (LeFrançois, personal communication, 30 January 2018). Ideally, none of the park's paleontological sites would be in poor condition, there would be no case incident reports related to paleontological sites, and all paleontological sites in the park would be fully documented. However, these conditions are difficult to achieve, as natural processes beyond human control can easily expose, modify, cover, or destroy paleontological features. As a result, best professional judgement will be used to assess this component's condition at this time.

4.9.4 Data and Methods

Tweet et al. (2009) prepared a summary of paleontological resources in SCPN parks, as well as known inventory and monitoring activities. The authors conducted an intensive literature search, including unpublished materials from park files, field notes, museum archives, and even local newspapers. Additional information was obtained through interviews with park staff, geologists from other government agencies, university researchers, and local amateur paleontologists (Tweet et al. 2009).

A paleontological resources inventory report for the park was published in 2017, based on 2016 field surveys of all three units by Geoscientists-in-the-Parks intern Emily Thorpe (Thorpe et al. 2017). Each time a paleontological resource was found, the location was recorded and a "Paleontological Locality Form" was completed, including information about site access, lithology, resource sensitivity, and fossil condition. This was the first known paleontological research conducted within park boundaries (Thorpe et al. 2017). Specific fossil locations were not published, as these resources are considered sensitive. A geological resources inventory report for SAPU, which addressed paleontological resources within a geological context, was then published in 2018 (KellerLynn 2018).

4.9.5 Current Condition and Trend

<u>Percentage of Paleontological Sites in Good/Fair/Poor Condition</u>
During 2016 field surveys, Emily Thorpe conducted qualitative condition assessments of all known SAPU paleontological sites. It is important to keep in mind that the condition of paleontological sites are largely influenced by natural processes beyond the control of park managers. Based on park records, 5% of sites are in excellent condition, 50% are in good condition, and 45% are in poor condition (LeFrançois, written communication, November 2019).

<u>Annual Number of Case Incident Reports Related to Paleontological/Geological Sites</u>
NPS personnel are required to report any incidents involving a paleontological resource on NPS lands (e.g., human damage, destruction, or unauthorized removal). To date at SAPU, there have been no case incidents related to paleontological sites (LeFrançois, written communication, November 2019).

<u>Documentation of All Paleontological Sites in the Park</u>
Thorpe et al. (2017) conducted a comprehensive field inventory of all three SAPU units to document paleontological resources in 2016. In 2019, NPS and cooperating researchers re-located and investigated the site near Quarai where mammoth remains were found in 1939; some additional testing is likely to occur at this site in the near future (Fields 2020). At this time, the documentation of paleontological sites at SAPU is relatively complete, with the exception of any resources that may have been exposed within the past 2–3 years.

Threats and Stressor Factors

Many of SAPU's paleontological resources are protected by their inaccessibility (NPS 2014b). Park trails and visitor activities are primarily concentrated in the historic mission and pueblo areas, which are not near paleontological sites. However, threats to the park's paleontological resources include weathering and erosion, sedimentation, and theft or damage from human-related activity (including vibrations and livestock trespass) (NPS 2014b, KellerLynn 2018). The factors and processes that impact paleontological resources are broadly summarized in Figure 66.

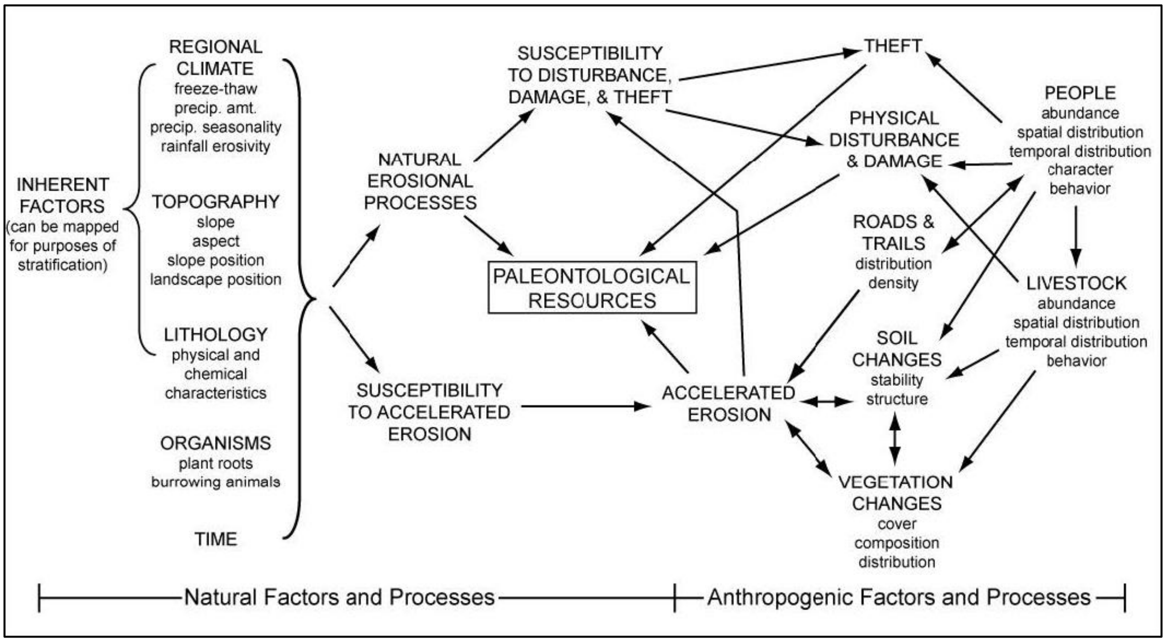


Figure 66. Conceptual diagram illustrating various environmental and anthropogenic factors and processes that might affect the stability of in situ paleontological resources. The graphic is an NPS diagram reproduced from Santucci et al. (2009).

Fossils are considered non-renewable resources that are regularly lost to erosion and other destructive chemical and physical processes. Many of these processes are natural and beyond the control of land managers (Santucci et al. 2009). Wind and water erosion can lead to both the exposure of new fossil resources and the loss of existing fossil resources to natural deterioration. Fossils may also be buried in sediment that has been eroded upstream and washed into park units. However, human activities that accelerate erosion (e.g., land use changes, improper recreation) often amplify the threat to paleontological resources. Livestock from adjacent lands occasionally get on to park lands and can damage fossils directly through trampling or indirectly through increased erosion due to soil disturbance. Incidents of outright theft of paleontological resources from public lands can increase when demand escalates on commercial fossil markets (Santucci et al. 2009).

Changes to the timing, frequency, and duration of precipitation events associated with climate change has the potential to influence the erosional and weathering rates of geological formations containing paleontological resources at the park (Wei et al. 2009). Climate change and extreme weather events can also lead to changes in other erosional factors such as freeze-thaw events and wind erosion.

Changes in climate could contribute to loss of vegetation, opening up new areas to wind and water erosion (Wei et al. 2009), potentially exposing more paleontological sites.

As with cave and karst features, vibrations from earthquakes or development/industrial projects may fracture the rock surrounding paleontological resources or even the fossils themselves (NPS 2008). Human activities in the SAPU region that may cause vibrations include quarrying at the gravel pit west of Abó, transportation sources (e.g., trucks, trains), and road or energy infrastructure construction (SWCA Environmental Consultants 2016).

Data Needs/Gaps

Thorpe et al. (2017) recommended annual monitoring of all known fossil localities to track condition and potentially detect any newly exposed resources. This will be particularly important for sites located in drainages and near trails, where the threats of erosion and/or theft are higher. In addition to regular monitoring, park staff can observe exposed cliffs, stream banks, and other erosional bedrock areas where fossils may occur while in the field conducting their usual duties (Tweet et al. 2009). The recent discovery of the varanopid body fossil at Abó suggests that more vertebrate fossils may be found in the Yeso Group in the region (Lucas et al. 2018).

Overall Condition

Percentage of Paleontological Sites in Good/Fair/Poor Condition

The NRCA team assigned this measure a *Significance Level* of 3. According to 2016 field assessments, 5% of the park's paleontological sites are in excellent condition, 50% are in good condition, and 45% are in poor condition (LeFrançois, written communication, November 2019). Because nearly half of park sites are considered in poor condition, this measure is assigned a *Condition Level* of 2 for moderate concern. However, as mentioned previously, it is important to remember that paleontological site conditions are largely influenced by natural processes and are often beyond the control of park managers.

Annual Number of Case Incident Reports Related to Paleontological/Geological Sites

This measure was also assigned a *Significance Level* of 3. To date, there have been no case incidents related to paleontological sites at SAPU. Therefore, a *Condition Level* of 0, indicating no concern, is assigned for this measure.

Documentation of All Paleontological Locations in the Park

A *Significance Level* of 3 was assigned for this final measure. Given the recent paleontological inventory of all three park units by Thorpe et al. (2017), this measure is assigned a *Condition Level* of 1, indicating low concern.

Weighted Condition Score

The *Weighted Condition Score* for SAPU's paleontological resources is 0.33, which is at the edge of the good condition range (Table 51). A trend could not be assigned, as all information regarding the condition of the park's paleontological resources is relatively recent (i.e., since 2016).

Table 51. Current condition of Paleontological Resources at SAPU.

Measures	Significance Level	Condition Level	WCS = 0.33
Paleontological Sites in Good/Fair/Poor Condition	3	2	–
Annual Number of Case Incident Reports	3	0	–
Documentation of Paleo/Geological Sampling Locations	3	1	–
Overall	**–**	**–**	

4.9.6 Sources of Expertise

- Marc LeFrançois, SAPU Chief of Facility and Resource Management

4.10 Hydrology

4.10.1 Description

Water resources have been critical to the natural and cultural history of SAPU and the surrounding region (NPS 1997b). Springs and streams in arid regions provide habitat and a consistent water source for wildlife and were a key attraction for Native American populations and European settlers (NPS 1997b, Springer et al. 2006a). At SAPU, springs and surface waters are found only at Abó and Quarai; Gran Quivira is on a hilltop, where nearly all precipitation runs off or swiftly percolates into the ground to recharge groundwater (NPS 1997b). The surface waters of Abó and Quarai (e.g., streams and pools) come from snowmelt and precipitation, either directly through runoff or from springs fed by these sources (Thomas et al. 2006a). While most of the springs in the Manzano Mountains and foothills above Abó and Quarai are intermittent, both park units have semi-permanent springs with historically dependable flows (NPS 1997b). These springs typically emerge from the Abó or Yeso rock formations, where impervious rock layers block further downward infiltration and water instead flows to the surface as a spring (NPS 1997b, Thomas et al. 2006a).

Approximately 3 km (1.9 mi) of intermittent streams occur within the Abó and Quarai units combined, most of which flow only after summer storms or during spring snowmelt (NPS 1997b, Thomas et al. 2006a). In many places, these streams have formed arroyos, a type of steep-sided gully common in the Southwest. At Abó, the largest arroyo is part of the Cañon Espinoso, a 52 km^2 (20.1 mi^2) watershed originating in the Manzano Mountains (NPS 1997b). This drainage is subject to flash flooding due to its bedrock streambed and upstream shallow soils that allow little precipitation infiltration. A slightly smaller drainage to the east is more vegetated and supports two permanent pools (Thomas et al. 2006a). After leaving the Abó unit, the Cañon Espinoso stream enters Abó Arroyo, which runs west and connects to the Rio Grande drainage (NPS 1997b). The Abó unit also contains a perennial spring, known as the Abó or Sisneros Spring, but it falls within a private inholding and is not managed by the NPS (NPS 1997b, Thomas et al. 2006a).

The main drainage at Quarai is part of the upper watershed of Cañon Sapato, a primarily intermittent stream running into the Estancia Valley (NPS 1997b). However, the springs within the Quarai unit produce enough reliable flow to support several temporary pools (Figure 67) and a vegetated wetland/riparian zone for approximately 0.5 km (0.3 mi) downstream (NPS 1997b, Thomas et al. 2006a; Soles, pers. comm, June 2019). Wetlands have formed in areas where an arroyo has cut down to impermeable rock or clay layers and formed pools where sediment can settle, allowing for the establishment of wetland plants (NPS 1997b). Historically, the stream flow at Quarai also supported an acequia (irrigation ditch) for irrigation of nearby agricultural lands. The acequia connects to the drainage approximately 30.5 m (100 ft) upstream of the current park boundary and operated until 1972 (NPS 1997b).

Figure 67. A spring pool at Quarai (NPS photo by Ellen Soles, May 2012).

Surface and groundwater dynamics and the moisture gradients they create influence plant and soil organism diversity, as well as ecological processes; as a result, an understanding of surface and groundwater hydrology is key to understanding wetland and riparian ecosystems (Zhang et al. 2002, Moeslund et al. 2013, Perkins et al. 2018). Shallow groundwater tables at Abó and Quarai are a key source of moisture for riparian vegetation, particularly cottonwoods, and deeper groundwater from wells drilled into the Abó and Yeso rock formations supply drinking water for visitors and staff at all three park units (NPS 1997b, Thomas et al. 2006a). Depths to water-bearing rock layers in wells near Abó and Quarai are generally shallower than in those farther south and east, towards Gran Quivira. As a result, wells in the vicinity of Abó and Quarai do not need to be drilled as deep (typically 8–60 m [25–200 ft]) as wells around Gran Quivira (120–275 m [400–900 ft]). For example, the well that provides water for Quarai is 28 m (92 ft) deep, while the well at Gran Quivira is 197 m (646 ft) deep (Thomas et al. 2006a).

4.10.2 Measures

- Groundwater levels
- Frequency and duration of surface water presence
- Volume of spring discharge
- Timing and amount of precipitation

4.10.3 Reference Condition/Values

Reference conditions for this component vary among the different measures. For timing and amount of precipitation, 30-year climate normals (1980–2010) for the area will be used as a reference. For spring discharge, park managers would like to see perennial (year-round) flow continue. The reference condition for the remaining measures would be conditions during the period of historical significance (early and mid-1600s), but little to no information is available from this time. The data presented in this NRCA for these measures may serve as a point of comparison or baseline for future assessments.

4.10.4 Data and Methods

Because there are no major streams within SAPU units, no permanent stream gages or monitoring stations have been maintained in the area by federal or state agencies (NPS 1997b). Historic data are scant, although some anecdotal observations are available. The park's Water Resources Management Plan (NPS 1997b) incorporates much of this scattered and anecdotal information.

As described in Chapter 4.2, Springer et al. (2006a, 2006b) conducted a springs inventory of SCPN and NCPN parks in 2005 which included Abó and Quarai Springs (Figure 68). Discharge was measured when possible, with various methods depending on site conditions. The authors noted that the winter preceding this inventory was one of the wettest on record, which may have influenced the recent recharge and runoff feeding the sampled springs (Springer et al. 2006a).

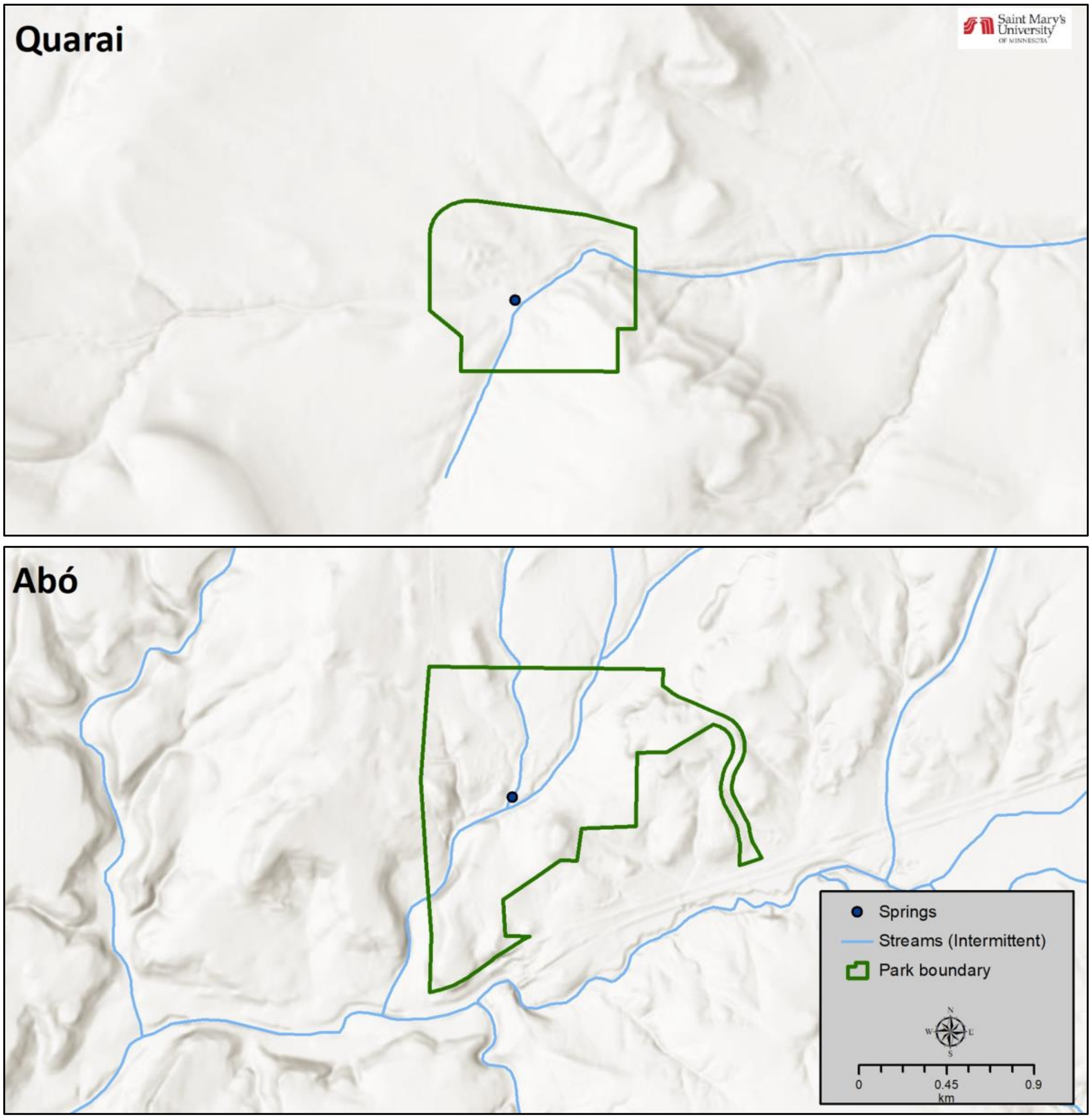


Figure 68. Locations of permanent springs at Abó and Quarai surveyed by NPS I&M networks. The Abó Spring is on a private inholding within the park unit.

In 2010, the SCPN initiated hydrologic monitoring at Quarai, at and downstream of the spring in Cañon Sapato (Soles and Monroe 2012). The objectives are to document the timing, magnitude, and duration of surface water flow events, and changes in shallow ground water levels. Two piezometers were installed to measure shallow groundwater levels, with an additional piezometer modified to detect surface flows (Soles and Monroe 2012). The piezometers are located at the Quarai Spring (QUA01b), just upstream of the pedestrian bridge (QUA01RSG), and downstream of the bedrock ledges (QUA01c) (Figure 69). A pressure transducer inside each piezometer records water levels every 15 minutes (Soles and Monroe 2015). A steel pipe installed at the upstream end of the spring pool (QUA01a) enables manual measurements to the pool surface under some conditions. SCPN staff visit the site periodically to collect data and take photos of the channel and the spring pool just upstream of the pedestrian bridge. Monitoring results through October 2014 were published in Soles and Monroe (2012, 2015). Continuous data since this time remain provisional and are unavailable for publication (Ellen Soles, Northern Arizona University and NPS Senior Research Specialist, email communication, 10 May 2019).

Figure 69. Hydrologic monitoring locations utilized by the SCPN at Quarai.

Precipitation data for the two weather stations closest to SAPU's units were downloaded from the National Centers for Environmental Information's (NCEI) climate data online database (https://www.ncdc.noaa.gov/cdo-web/). These included 30-year normals and monthly precipitation for each of the past 10 years (2009–2018). The station closest to Abó and Quarai is in Mountainair, NM, approximately 11.5 km (7 mi) northeast of Abó and 10 km (6.2 mi) southeast of Quarai; the Gran Quivira station is located within the SAPU unit (Figure 70). Recent annual precipitation records for the Gran Quivira and Mountainair weather stations are somewhat incomplete. Over the past decade, 9 out of 10 years for Mountainair and 8 out of 10 years for Gran Quivira are missing precipitation data for at least one month. For this assessment, annual precipitation measurements from 2005–2019 will be used to evaluate current condition, as this period offers 7–8 years for each station where records are complete or only one month outside the rainiest period is missing.

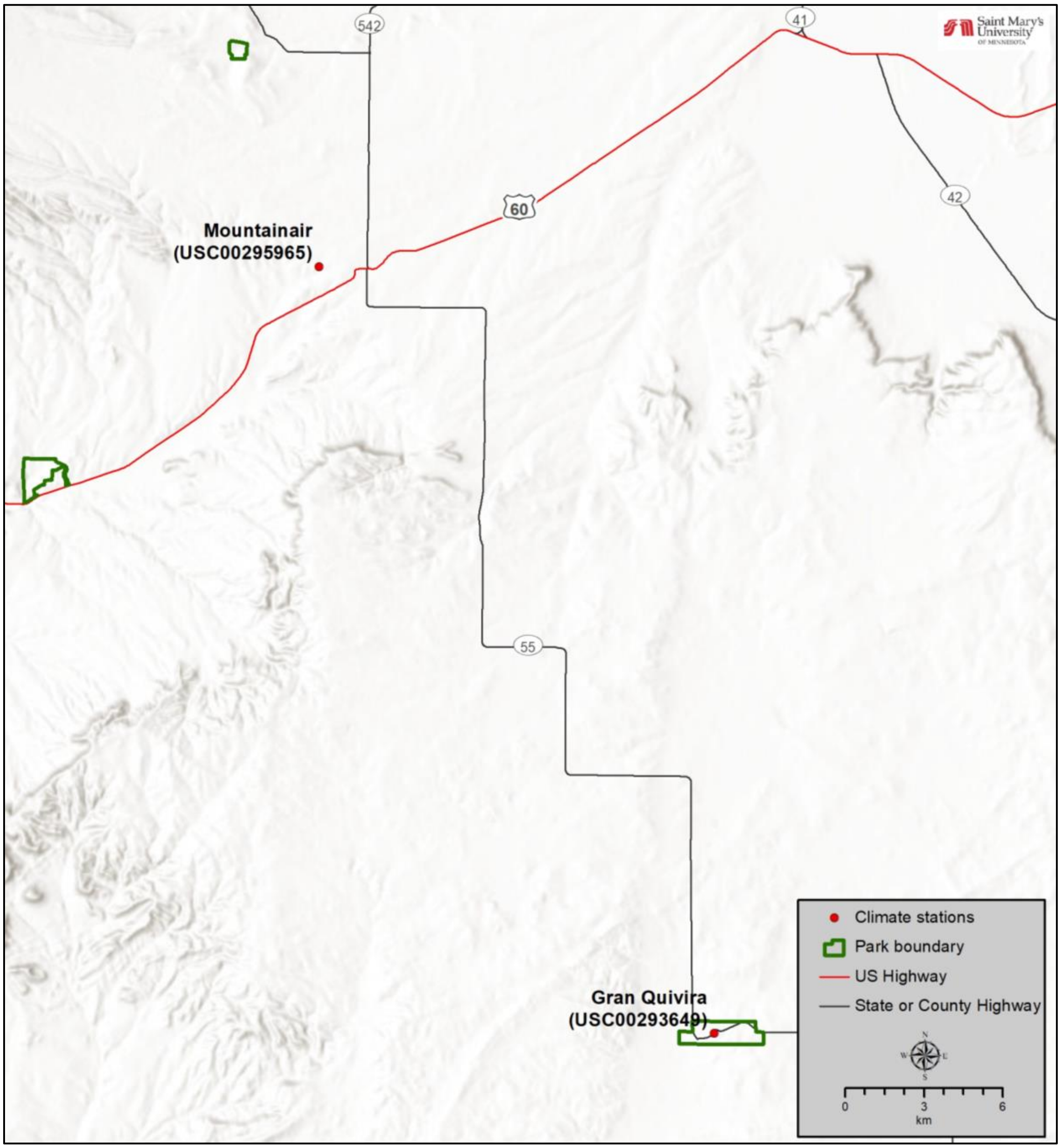


Figure 70. Locations of climate stations relative to SAPU's units.

4.10.5 Current Condition and Trend

Groundwater Levels

As mentioned previously, the groundwater table is generally higher (i.e., shallower or closer to the surface) around Abó and Quarai than it is at Gran Quivira. As of 1995, groundwater levels throughout the region were considered stable (Wilkins and Garcia 1995). More recent regional measurements (since 2010) have been varied; groundwater levels in some wells in the Estancia Basin have dropped, while others have risen or remained stable (Chace and Roberts 2017). At this time, the wells that provide water for SAPU's three units are not regularly monitored.

When the Gran Quivira well was drilled in 1959, the water level was approximately 186.5 m (612 ft) deep. According to SAPU's 1997 Water Resources Management Report, the Gran Quivira well was still maintaining this same water table depth (NPS 1997b). In 2006, the NPS reported that the depth to water was around 188 m (616.8 ft) at Gran Quivira (Thomas et al. 2006a).

Only one report could be found for depth to groundwater at the Abó well. In 2006, Thomas et al. (2006a) noted that groundwater was present at 9 m (29.5 ft). A historic report for a well drilled for the railroad at the nearby town of Abó in 1907 indicates that water in the 117-m (384-ft) deep well rose to within 7.6 m (25 ft) of the surface (NPS 1997b).

A State Engineer's Office well record from 1969 indicated that the depth to water at the Quarai well was 4.9 m (16 ft) (NPS 2011b). From 1973–2005, the USGS took occasional depth measurements at the well (Table 52). Over this period, groundwater levels ranged from 6.38–7.50 m (20.92–24.60 ft) with an average depth of 6.93 m (22.73 ft). However, the two greatest depths to groundwater occurred in the last two years for which measurements are available (2004, 2005).

Table 52. Depth to water at the Quarai well, as measured by the USGS (2019a). All measurements were taken in January or February, with the exception of 2004, which was taken in April.

Year	Depth to water in m (ft)
1973	6.38 (20.92)
1976	6.93 (22.75)
1977	7.14 (23.44)
1979	7.11 (23.34)
1980	7.10 (23.28)
1981	6.72 (22.06)
1985	7.18 (23.55)
1990	6.42 (21.05)
1995	6.38 (20.93)
2000	6.85 (22.47)
2004	7.43 (24.39)
2005	7.50 (24.60)

Two of the SCPN piezometers in Cañon Sapato (QUA01b, QUA01c) measure shallow alluvial groundwater levels, shown as water elevation in Figure 71. Shallow groundwater in Cañon Sapato fluctuated seasonally, rising in winter and spring and then dropping during the summer and fall (Soles and Monroe 2015). The yearly high and low groundwater levels at QUA01b, the upstream spring pool, were lower in 2013 and 2014 than in 2011 (Figure 71). Unpublished data show that yearly highs and lows at QUA01b declined even further in 2015, 2016, and 2017 (Soles 2018). Around August–September of 2017, groundwater levels dropped below the bottom of the 1.8-m (6 ft) deep monitoring well and were unmeasurable for the remainder of the year (Soles 2018). However, it is unclear whether this was a significant change/trend or part of a natural cycle.

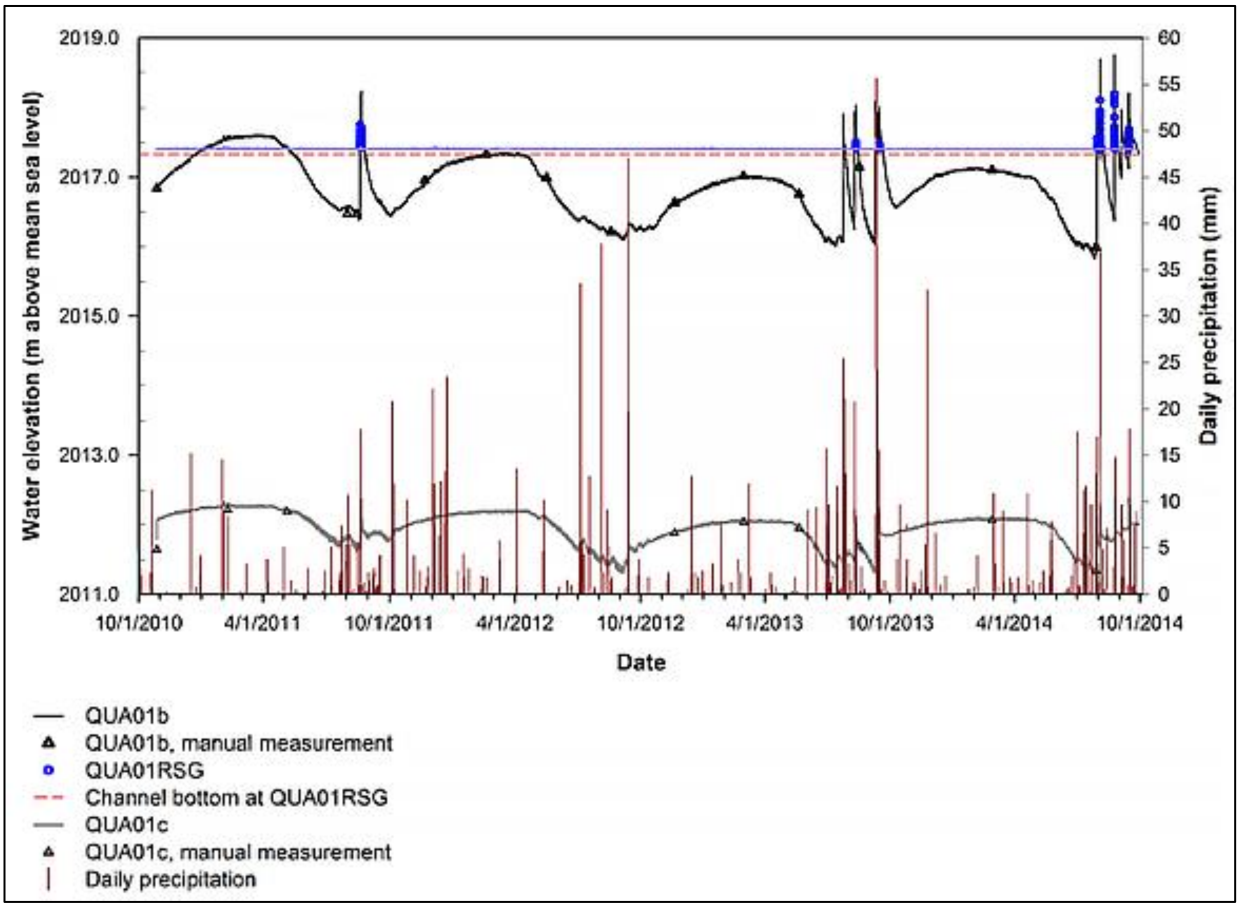


Figure 71. Water levels in the piezometers at QUA01b, QUA01c, and QUA01RSG, October 2010 through September 2014, in Cañon Sapato at Quarai (reproduced from Soles and Monroe 2015). Note that QUA01c is further downstream at a lower elevation than QUA01b and QUA01RSG (see Figure 69). Red vertical lines indicate daily precipitation.

Frequency and Duration of Surface Water Presence

At Abó and Quarai, anecdotal evidence indicates that sporadic areas of perennial surface flow have been historically present in Cañon Espinoso and Cañon Sapato downstream of the springs in each drainage. During 1996 field visits to both units, a state aquatic biologist found aquatic organisms (e.g., macroinvertebrates, small fish, aquatic plants) that could not survive without a permanent water source (NPS 1997b). However, little or no actual data are available regarding the frequency and duration of surface flow or presence in the arroyos outside the spring pools. In the SAPU area, it is common for surface streamflow in arroyos to seep into alluvial fill and essentially flow underground (i.e., "underflow) and then reappear at the surface further downstream (NPS 1997b). For example, while the springs in Cañon Sapato support lush wetlands within Quarai, the stream disappears underground downstream of the village of Punta de Agua just east of the park unit.

Surface water pools amid rock ledges in Cañon Espinoso at Abó (NPS photo).

In Cañon Sapato at Quarai, surface water begins with a spring-fed pool that originates approximately 30 m (98 ft) upstream of the pedestrian bridge along an interpretive trail (Soles and Monroe 2015). There are at least three additional pools downstream of the bridge within park boundaries (Soles and Monroe 2012). The SCPN monitoring program has documented when surface flow occurs between these pools with a recording stage gauge (RSG) installed inside the piezometer at QUA01RSG (Soles and Monroe 2012, 2015). From October 2010 through September 2011, surface flows occurred on only two occasions: on 21 August for 3 hours and on 23 August for 3 hours (Table 53) (Soles and Monroe 2012). Park staff reported that surface flows did not reach the downstream park boundary on either of these occasions. From August 2011 through July 2013, no surface flows were detected

(Soles and Monroe 2015). The next surface flows occurred briefly in August 2013 and following very heavy rainfall (more than 5 cm [2 in] in a day) on 11 September 2013. Surface flows occurred three times in August and September of 2014, with two large floods on 4 August and 25 August (Soles and Monroe 2015). From October 2014 through October 2017, surface flow occurred only once on 21 October 2015 (Soles 2018). In Figure 71 above, blue circles indicate periods of surface flow while the blue line for QUA01RSG designates periods of no flow. Measurements were recorded every 15 minutes, and each circle represents a measurement of flow (i.e., more circles indicate longer periods of flow).

Table 53. Summary of surface flow frequency between two pools in Cañon Sapato at Quarai, 2011–2017 (Soles and Monroe 2012, 2015, Soles 2018).

Year	# of Surface Flow Events	Timing
2011	2	21 August and 23 August
2012	0	–
2013	2	mid-August, 11 September
2014	3	4 August, 25 August, mid-September
2015	1	21 October
2016	0	–
2017	0	–

<u>Volume of Spring Discharge</u>

Anecdotal reports from local residents suggest that spring flow at Abó and Quarai are reliable year-round, but scientific measurements of spring discharge at SAPU are very limited. In a 1996 interview, local residents with a long history at Abó stated that while the spring there still produces a steady flow, it probably “does not flow as much as before” (NPS 1997b, p. 17, quoting Sisneros 1996).

At Quarai, long-time local residents report that spring flow is dependable and, as of 1996, had never dried up, even during the 1950s droughts (NPS 1997b). According to one local resident, state technicians visited the site many years ago and pumped water from the pond below the main spring at a rate of 1.3 liters/second (20 gallons per minute [gpm]), and the pond “continued to stay full” (NPS 1997b, p. 28, quoting T. Gonzales, 1996 interview). The same resident noted that a volunteer set up a temporary flume below the main spring sometime during the 1960s and recorded discharge as high as 5.36 liters/second (85 gpm) during high flow periods. In late 2017, the pool below this spring dried up, indicating that spring discharge at that time was not enough to maintain permanent surface water (Soles, pers. comm, June 2019). Additional residents of the area report that landowners in the areas southwest of Quarai were allowed to build berms on USFS land to divert natural water flow to their property. These diversions had serious impacts on communities like Punta de Agua and La Cienega who historically depended on natural runoff to sustain the acequias. The springs along, although strong, are not enough to sustain acequias and ponds (LeFrançois, written communication, March 2020).

During SCPN inventories in mid-May of 2005, discharge was measured 12 m (30 ft) downstream of the Abo Spring (Springer et al. 2006b). The measurements were made using a weir and, as mentioned previously, followed a winter that was one of the wettest on record. Total discharge was 0.3 liters/second (4.8 gpm). Discharge could not be measured at Quarai Spring at this time, as there was no location near the spring orifice(s) where water could be collected (Springer et al. 2006b). Approximations of combined flow for Quarai's springs were calculated in 1997, based on precipitation amounts and the estimated amount of infiltration multiplied by the watershed area (NPS 1997b). These calculations estimated that the average flow from Quarai's springs was 1.8 liters/second (28 gpm). Daily flows would naturally vary from this average, depending on weather conditions (NPS 1997b).

Timing and Amount of Precipitation

Spring and stream flow in the SAPU vicinity, as well as groundwater recharge, is largely influenced by precipitation falling within the watershed. In this area, a majority of precipitation falls between July and September, when evaporation rates are high (NPS 1997b, NCEI 2015a, 2015b). The most recent 30-year (1981–2010) annual precipitation normal for the Mountainair station was 38.3 cm (15.1 in) (NCEI 2015b) and the 30-year normal for the Gran Quivira weather station was higher at 43.4 cm (17.1 in) (NCEI 2015a).

From 2005–2018 (excluding six years with more than one month of missing data), annual precipitation at the Mountainair station ranged from 18.4–39.6 cm (67.2–15.6 in) with a mean of 31.3 cm (12.3 in) (NCEI 2018b). This mean is 7.0 cm (2.8 in) below the station's 30-year precipitation normal. During this period, only 1 year fell above the 30-year normal (2005), and 2 years (2007, 2016) were well below normal (Figure 72). However, even these low values may be within the range of natural variation for the area, as the record low for the station is 17.3 cm (6.8 in) of precipitation in 1934 (NPS 1997b).

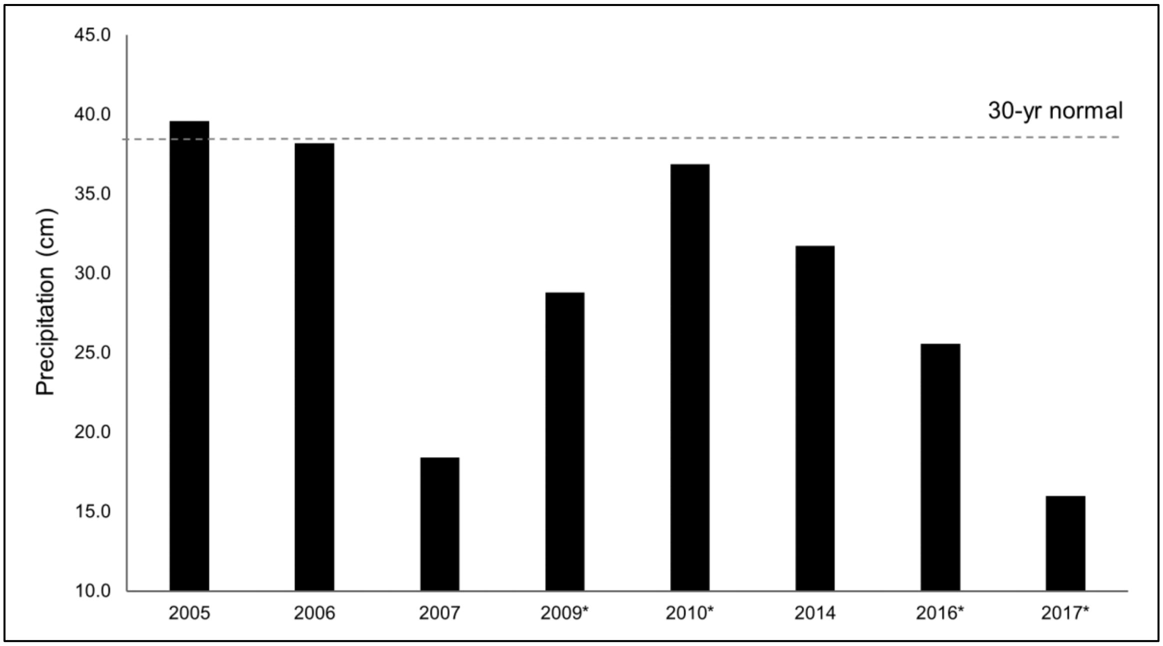


Figure 72. Total annual precipitation at the Mountainair, NM weather station, 2005–2017, compared to the 30-year normal (1981–2010, dashed line) (NCEI 2015b, 2018b). Note that six years, including 2018, are excluded due to more than 1 month of missing data. Years with asterisks had one month of data missing (outside the rainiest part of the year, July–Sept).

The wettest month on average at the Mountainair station from 2005–2018 was July, with a mean of 6.6 cm (2.6 in) (NCEI 2018b). The wettest month under the 30-year normals was August with 7.3 cm (2.9 in) (NCEI 2015b). All months except January and May received less precipitation on average from 2005–2018 than during the 30-year normal period (Figure 73). Monthly precipitation totals for all years during this period are provided in Appendix H.

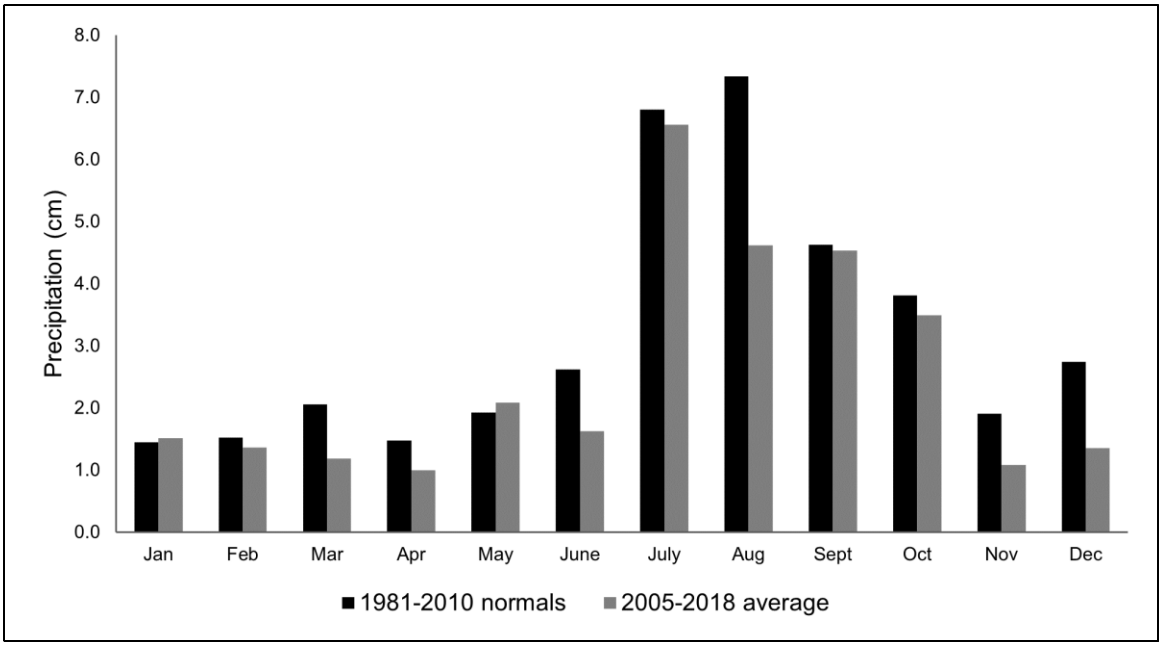


Figure 73. A comparison of monthly precipitation normals (1981–2010) for the Mountainair weather station to monthly averages for the period 2005–2018 (NCEI 2015b, 2018b).

At the Gran Quivira station, annual precipitation from 2005–2018 (excluding five years with more than one month of missing data) ranged from 20.7–59.4 cm (8.1–23.4 in) with a mean of 40.1 cm (15.8 in) (NCEI 2018a). This mean is 3.3 cm (1.3 in) below the 30-year normal; the minimum of 20.7 cm is also below the lowest value for the 1962–1994 period of record of 25.0 cm (9.9 in) from 1989 (NPS 1997b). As with Mountainair, only 1 year (2006) fell above the 30-year normal, and 2017 was well below normal (although December was missing for that year) (Figure 74).

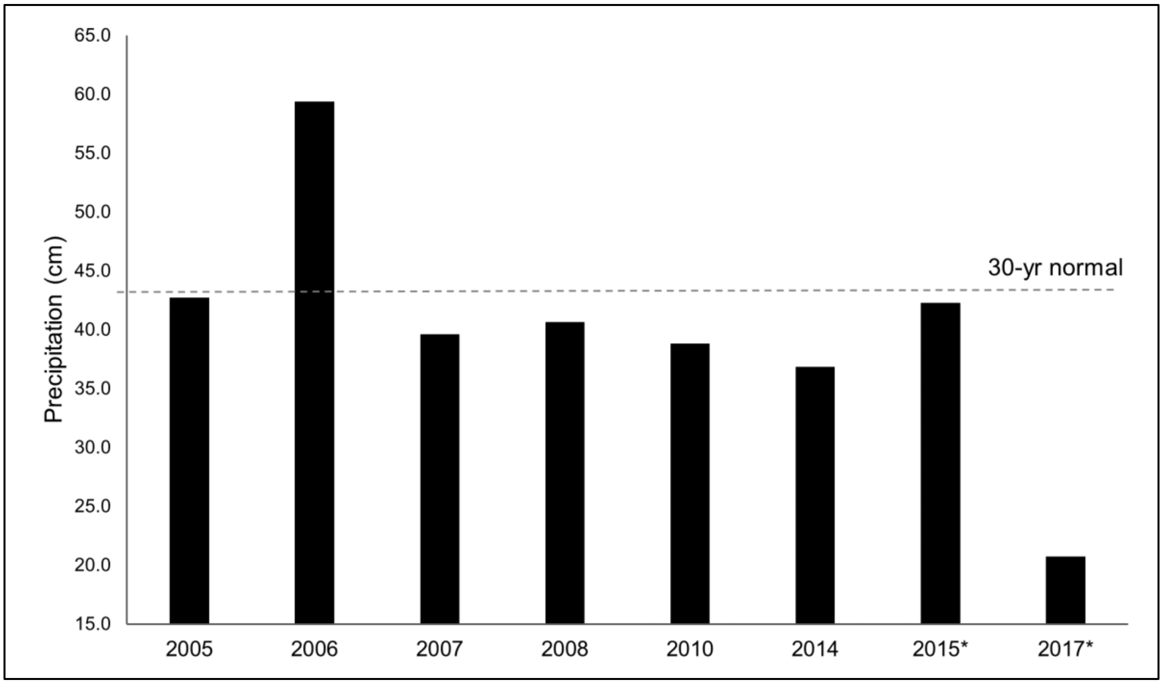


Figure 74. Total annual precipitation at the Gran Quivira, NM weather station, 2005–2017, compared to the 30-year normal (1981–2010, dashed line) (NCEI 2015a, 2018a). Note that five years, including 2018, are excluded due to more than 1 month of missing data. Years with asterisks had one month of data missing (outside the rainiest part of the year, July–Sept).

In terms of monthly precipitation, the wettest month on average from 2005–2018 was July, with a mean of 7.7 cm (3.0 in), followed closely by August with a mean of 7.5 cm (2.9 in) (NCEI 2018a). This differed from the 30-year normal, when August was the wettest month, with 9.3 cm (3.6 in) of precipitation. All except 2 months of the year (May and July) received less precipitation on average from 2005–2018 than during the 30-year normal period (Figure 75).

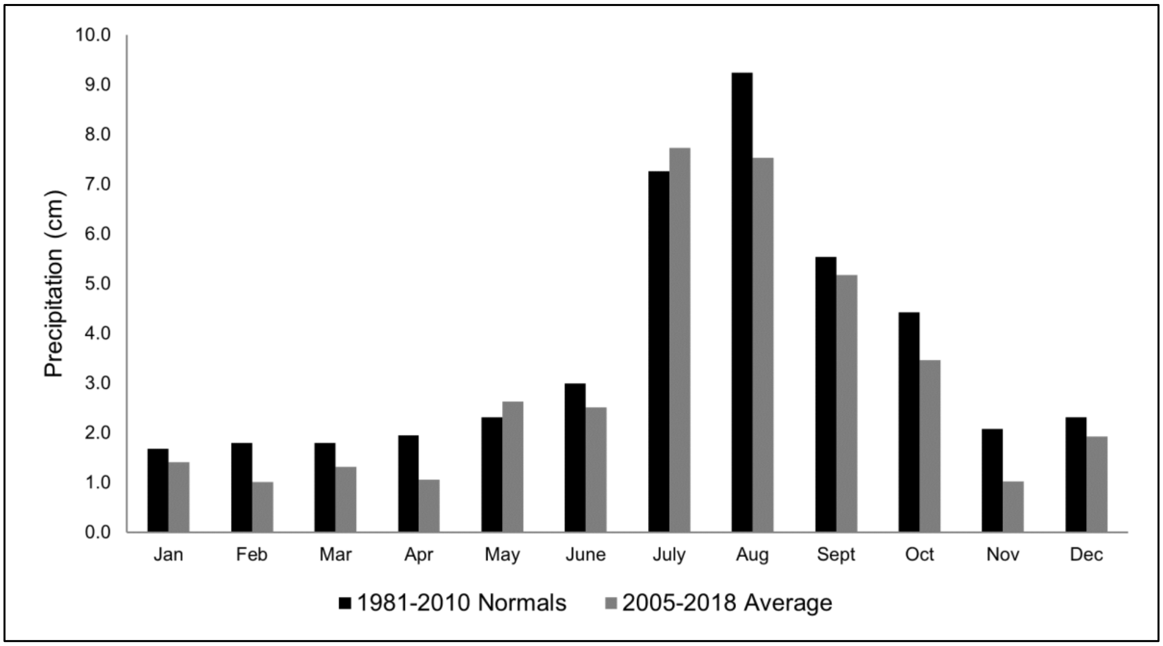


Figure 75. A comparison of monthly precipitation normals (1981–2010) for the Gran Quivira weather station to monthly averages for the period 2005–2018 (NCEI 2015a, 2018a).

Threats and Stressor Factors

Threats to the park's hydrology include invasive plant species, historic and adjacent land use (e.g., agriculture), channel instability, and climate change, especially droughts. Some invasive plants use more water than native species and can reduce spring flow or even cause springs to dry up (Westbrooks 1998). While such invasive species have been controlled and largely eliminated by park managers at this time (NPS 2002a, 2005), there is always a risk of re-infestation that may negatively impact water availability.

Historic grazing, farming, and logging have caused substantial land cover changes both within and upstream of current SAPU boundaries (NPS 1997b, Thomas et al. 2006a, NPS 2014b). The loss of vegetative ground cover due to overgrazing destabilized soils, contributing to increased erosion and gullying during storms. Also, soil compaction from grazing animals reduces infiltration, increasing stormwater runoff (NPS 1997b). The resulting increases in volume and power of storm flows can deepen and/or widen stream channels or arroyos. Overgrazing has also encouraged the encroachment of pinyon-juniper woodlands, which use more water and allow less infiltration than the historic herbaceous vegetation (NPS 1997b, Gori and Bate 2007, Roundy et al. 2014). This change, along with a decline in infiltration due to soil compaction, has likely reduced the amount of groundwater recharge, which ultimately feeds the park's springs (Thurow and Hester 1997, Huang et al. 2006, Acharya et al. 2018). While the cessation of grazing allows vegetation to recover somewhat, the impacts of the land cover changes on hydrology may continue for decades without management intervention (NPS 1997b). Topographic mapping of the arroyo channel at Quarai by SCPN (Soles and Monroe 2012, 2015) showed that headcutting in the Cañon Sapato channel, upstream of two pools, proceeded and steepened between 2010 and 2014, indicating channel instability (Figure 76).

This could be related to historic overgrazing and other land use changes upstream of the park that have altered vegetation and/or soils (NPS 1997b, Maloney et al. 2008).

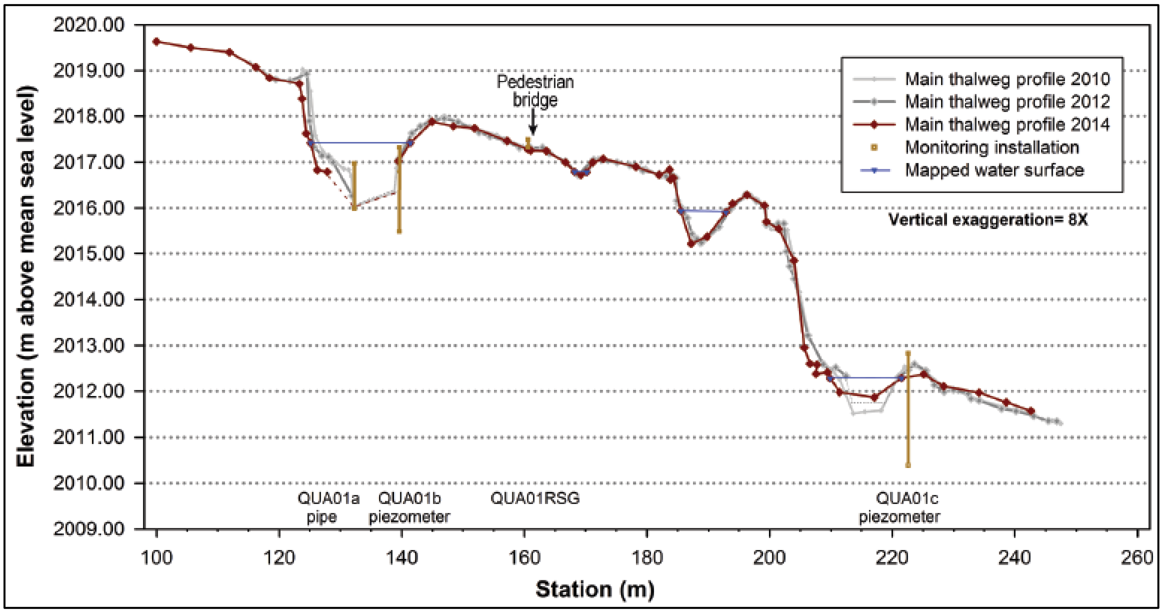


Figure 76. Changes in the channel profile of the surveyed reach in Cañon Sapato at Quarai between 2010 and 2014 (reproduced from Soles and Monroe 2015). Locations where the red line (2014) is to the left of or below the gray lines (2010, 2012) show where the channel has receded or steepened.

Evidence of bank erosion observed when looking upstream from the main pool at Quarai (NPS photo by Ellen Soles, July 2014).

Diversions of natural runoff in the Quarai area have dramatically impacted the sustainability of acequias and ponds in the area. Local residents have expressed interest in rehabilitating the acequia that operated between Quarai and the nearby village of Punta de Agua until 1972, a diversion of water that would likely eliminate some wetlands downstream in Cañon Sapato (NPS 1997b). The acequia provided water for bean agriculture and domestic use, but the water was no longer needed when a deeper town well was drilled in the early 1970s (NPS 1997b). The acequia has historical and interpretive value, and park managers are open to discussing the possibility of its re-opening (NPS 1997b). Since the diversion point would be near the downstream SAPU boundary, the most likely impacts may be to wetlands outside the park.

The Southwest is projected to become drier with more sustained droughts as a result of climate change, and SAPU has already experienced an increase in drought conditions (Seager et al. 2007, Garfin et al. 2014, NPS 2014b). The increased temperatures associated with global warming will contribute to higher evaporation rates and faster transpiration by plants, meaning surface waters associated with springs and ephemeral streams could be lost to the atmosphere faster. These drier conditions could reduce the volume of spring discharge and the frequency and duration of surface water presence. Climate changes could also increase the frequency of high-intensity wildfires, which increase runoff and reduce infiltration during precipitation events (Ebel and Moody 2013, Garfin et al. 2014). Although storm events are projected to be less frequent, their intensity or magnitude may increase (Easterling et al. 2000). When these more intense storms do occur, runoff and flooding will be more extreme (Istanbulluoglu and Bras 2006) and erosion of channel/arroyo banks could also intensify, potentially altering flow regimes.

Drier conditions associated with climate change could also lead to increased groundwater pumping for irrigation and human use, which would likely cause groundwater tables to drop (Taylor et al. 2012). In the northern portion of the Estancia Basin, north of SAPU, groundwater withdrawals for irrigation and municipal use were already exceeding recharge in the 1990s, and groundwater levels were declining yearly (Wilkins and Garcia 1995, NPS 1997b). While groundwater table declines had not yet been detected in the southern Estancia Basin closer to SAPU, they are likely to occur with increasing development and continued climate changes.

Data Needs/Gaps

Additional, longer-term, and consistent data are needed for all the selected hydrology measures. The hydrological monitoring at Quarai (Soles and Monroe 2015) will continue as part of the SCPN's new riparian monitoring protocol (Perkins et al. 2018), which will help to assess some of these data needs at one of the park's units. If groundwater levels are a serious concern, depth measurements should be taken at least quarterly at each of the park units' water supply wells. More frequent measurements (e.g., monthly) could help identify seasonal fluctuations in the groundwater table. Spring discharge at Abó could also be sampled annually or quarterly to better understand the spring's hydrology and to detect any changes of concern. The Cañon Espinoso could be surveyed to identify and map any additional springs or seeps with frequent or intermittent discharge. As time allows, park staff could visit Abó after precipitation events to make observations regarding the frequency and duration of surface water flows.

Overall Condition

Groundwater Levels

A *Significance Level* of 3 was assigned for this measure by the project team. Measurements of groundwater levels in the park units' wells are extremely limited, particularly at Abó and Gran Quivira. Data from the SCPN monitoring of shallow groundwater at Quarai suggest these levels are dropping (Soles 2018), but continued monitoring is needed to better understand any trends. As a result, a *Condition Level* could not be assigned for the measure at this time.

Frequency and Duration of Surface Water Presence

This measure was also assigned a *Significance Level* of 3. Surface water is present in pools below the springs at Abó and Quarai nearly year-round, but little is known about surface water presence and flow in the other arroyos. Recent observations suggest that the duration of surface water presence at Quarai may be declining (Soles, pers. comm, June 2019), but additional observations are needed for verification. As SCPN hydrologic monitoring continues at Quarai, a better understanding of this measure will emerge. Currently, a *Condition Level* cannot be assigned.

Volume of Spring Discharge

The spring discharge measure was assigned a *Significance Level* of 3. Actual data regarding discharge at the park's springs is very limited, although anecdotal observations indicated flow was historically persistent year-round. However, there is not enough recent information to assign a *Condition Level* at this time.

Timing and Amount of Precipitation

A *Significance Level* of 2 was assigned for this final measure. Since 2005, annual precipitation at the Gran Quivira and Mountainair weather stations have fallen below the 30-year normal (1980–2010) in most years (NCEI 2015a, b, 2018a, b). Average monthly precipitation from 2005–2018 was also below 30-year normals for nearly all months at both stations, with the exception of May (Figure 75, Figure 73). While continued monitoring is needed to verify a declining trend, these changes in precipitation patterns are currently of moderate concern (*Condition Level* = 2).

Weighted Condition Score

A *Weighted Condition Score* was not calculated for this component, as *Condition Levels* could not be assigned for three of the four measures due to limited data availability (Table 54). There are some indications of cause for concern regarding hydrology (e.g., dropping shallow groundwater levels and pool drying at Quarai), but more information is needed to assess condition with any confidence. The current condition and trend of the park's hydrology is unknown.

Table 54. Current condition of Hydrology at SAPU.

Measures	Significance Level	Condition Level	WCS = N/A
Groundwater Levels	3	n/a	–
Frequency & Duration of Surface Water Presence	3	n/a	–
Spring Discharge	3	n/a	–
Timing & Amount of Precipitation	2	2	–
Overall	**–**	**–**	

4.10.6 Sources of Expertise

- Ellen Soles, NAU and NPS Senior Research Specialist
- Stacy Stumpf, NPS Aquatic Ecologist

5. Discussion

Chapter 5 provides an opportunity to summarize assessment findings and discuss the overarching themes or common threads that have emerged for the featured components. The data gaps and needs identified for each component are summarized and the role these play in the designation of current condition is discussed. Also addressed is how condition analysis relates to the overall natural resource management issues of the park.

5.1 Component Data Gaps

The identification of key data and information gaps is an important objective of NRCAs. Data gaps or needs are those pieces of information that are currently unavailable, but are needed to help inform the status or overall condition of a key resource component in the park. Data gaps exist for most key resource components assessed in this NRCA. Table 55 provides a detailed list of the key data gaps by component. Each data gap or need is discussed in further detail in the individual component assessments (Chapter 4).

Table 55. Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Upland Woodland and Savanna Communities	• Additional studies of tree density, tree mortality, herbaceous vs. shrub cover, and species richness at finer spatial scales. • A combined plan for vegetation, invasive species, and fire management, including a management program for hazardous trees in visitor use areas. • Regular monitoring for non-native plant species to detect new infestations and control current problem species.
Wetland and Riparian Communities	• Information regarding tree regeneration, particularly for riparian species such as cottonwoods and willows. • A comprehensive plant survey of park wetlands and riparian areas would help to better understand species diversity, distribution, and abundance
Birds	• Re-establishment of point counts and area searches as conducted by Johnson et al. (2007). • Continuation of the annual IMBD monitoring at Quarai with standardization of monitoring techniques. • Monitoring abundance of avian species of conservation concern, and health of bird communities around the park's perennial water sources.
Mammals	• Further inventory efforts to confirm the presence of "expected" species and to detect any changes in species richness or abundance. • Research into how park mammals are impacted by environmental change and/or human activity.
Dark Night Skies	• A visit by the NPS NSNSD to collect a comprehensive suite of data. • Periodic park monitoring to assess and track external light source impacts.
Soundscape and Acoustical Environment	• Coordinate with the NSNSD to conduct baseline acoustic monitoring at all park units; repeat acoustic monitoring every 3–5 years to detect any changes of concern.

Table 55 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Viewshed	• A convenient way for park staff to learn about nearby development projects, so they have an opportunity to provide input that may minimize impacts to park resources. • Establish photo monitoring points at each unit, where repeat photography every 2–3 years could be used to document any changes in the surrounding viewshed.
Cave and Karst Features	• Documentation of the magnitude of subsidence and frequency of viscous seepage events at Gran Quivira. • Additional analysis to clearly determine the chemical composition and source of the viscous substance that seeps from Gran Quivira's rocks. • Ground survey to officially document the number of blowholes and their locations. • Further exploration with surface-geophysical techniques and ground-truthing of potential voids to assist in identifying and delineating any cave features.
Paleontological Resources	• Annual monitoring of all known fossil localities to track condition and potentially detect any newly exposed resources, particularly sites where the threats of erosion and/or theft are higher (e.g., in drainages and near trails). • Opportunistic observations by staff of exposed cliffs, stream banks, and other erosional bedrock areas where fossils may occur while in the field conducting their usual duties.
Hydrology	• Additional, longer-term, and consistent data for all the selected measures. • Depth to groundwater measurements at each units' water supply wells at least quarterly; more frequent measurements could help identify seasonal fluctuations in the groundwater table. • Annual or quarterly sampling of spring discharge at Abó, and a survey of Cañon Espinoso to identify and map any additional springs or seeps. • Visits to Abó after precipitation events to make observations regarding the frequency and duration of surface water flows.

Some of the park's data needs will be addressed by recently initiated SCPN monitoring, particularly in SAPU's wetland and riparian areas. Resources not currently included in monitoring programs that would particularly benefit from additional research include woodlands, birds, mammals, and cave and karst features. Many components would benefit from research into how environmental factors or various threats, particularly climate change, are influencing park resources.

5.2 Component Condition Designations

Table 56 displays the conditions assigned to each resource component presented in Chapter 4 (definitions of condition graphics and examples of how symbols are applied are located in Table 56 and Table 56). It is important to remember that the graphics represented are simple symbols for the overall condition and trend assigned to each component. Because the assigned condition of a component (as represented by the symbols in Table 56) is based on a number of factors and an assessment of multiple literature and data sources, it is strongly recommended that the reader refer back to each specific component assessment in Chapter 4 for a detailed explanation and justification of the assigned condition. Condition designations for some components are supported by existing datasets and monitoring information and/or the expertise of NPS staff, while other components lack historic data, a clear understanding of reference conditions (i.e., what is considered desirable or natural), or even current information.

For featured components with available data and fewer data gaps, assigned conditions varied. Two components were considered to be in good condition: dark night skies and paleontological resources. Two additional components (wetland and riparian communities and viewshed) were of moderate concern. Condition could not be assigned for six of the ten components (Table 56). Trends could only be assigned for two components (dark night skies and viewshed), and in both cases, the resources were considered stable. Tables 57 and 58 display and describe the symbology used in Table 56.

Table 56. Summary of current condition and condition trend for featured NRCA components.

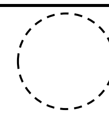
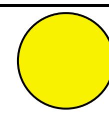
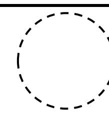
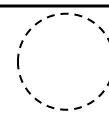
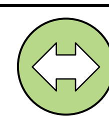
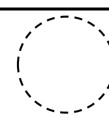
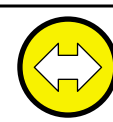
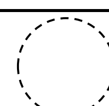
Category	Component	WCS	Condition
Biotic Composition *Ecological Communities*	Upland Woodland and Savanna Communities	N/A	
	Wetland and Riparian Communities	0.58	
Biotic Composition *Wildlife*	Birds	N/A	
	Mammals	N/A	
Environmental Quality	Dark Night Skies	0.33	
	Soundscape and Acoustical Environment	N/A	
	Viewshed	0.36	
Physical Characteristics	Cave and Karst Features (Gran Quivira only)	N/A	

Table 56 (continued). Summary of current condition and condition trend for featured NRCA components.

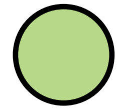
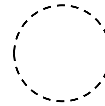
Category	Component	WCS	Condition
Physical Characteristics (continued)	Paleontological Resources	0.33	
	Hydrology	N/A	

Table 57. Description of symbology used for individual component assessments.

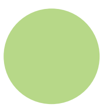
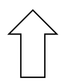
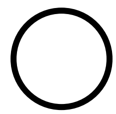
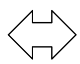
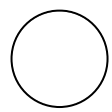
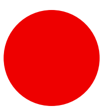
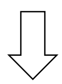
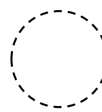
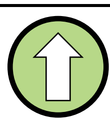
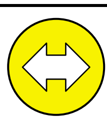
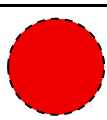
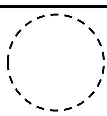
Condition Status		Trend in Condition		Confidence in Assessment	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition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

Table 58. Example indicator symbols and descriptions of how to interpret them in WCS tables.

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

5.3 Park-wide Condition Observations

Despite the distance and differences between the three units of SAPU, many of the resources discussed in this report are interrelated and share similar management concerns (e.g., data gaps, threats from outside the park).

5.3.1 Vegetation Communities

The native vegetation communities of SAPU are vital resources for the park, providing habitat for wildlife and performing critical ecological functions. A condition could not be assigned for the park's upland woodland and savanna communities, which comprise large portions of the park's units, due to a lack of data. However, woodlands across the Southwest are increasingly stressed by drought, insect and disease outbreaks, and extreme wildfires (Allen 2007, NMSFD 2017); this should be considered a cause for concern at SAPU.

The park's wetland and riparian communities are of moderate concern, as evidence suggests these areas within SAPU are declining in extent (Floyd-Hanna et al. 1994, Muldavin et al. 2012). Non-native species cover was also higher in SAPU's wetland and riparian communities than in its upland woodlands (Korb 2011). The warmer and drier conditions expected with climate change pose a particular threat to water availability in these invaluable habitats (Garfin et al. 2014).

5.3.2 Other Biotics

Wildlife featured as NRCA components were birds and mammals. The current condition of birds at SAPU is unknown due to a lack of contemporary park-wide data. Avian studies conducted at all park units are nearly 20 years old (Johnson et al. 2007), and although IMDB data have been collected every year since 1998, those surveys occur only at Quarai and are just one day per year. The perennial water sources and associated habitats in SAPU are important for both migratory and resident species, and further study of the park's bird populations would provide managers with insights not only into the health of wildlife communities, but also the overall health of these critical habitats in the park.

The condition of the park's mammals is also unknown due to data gaps. No scientific surveys of mammals have been conducted at SAPU since 2003 (Bogan et al. 2007). Further survey efforts and research into how park mammals are impacted by environmental change and/or human activity could help managers better understand park wildlife.

5.3.3 Environmental Quality

Environmental quality is not only important for maintaining healthy functioning ecosystems, but also for maximizing visitor experience at parks. The elements of environmental quality included in this NRCA were dark night skies, soundscape, and viewshed. A condition could not be assigned for soundscape because no on-site acoustic monitoring has been conducted at SAPU. While intrusive noise is not currently a major concern for SAPU managers, the park does face some threats from increasing traffic (highways and trains) and military overflights from White Sands Missile Range (Mennitt et al. 2014, TRIP 2016).

Due in large part to the remoteness of the park's units, dark night skies are considered to be in good condition. On clear nights, the Milky Way can be seen from the park year-round. Modelled ALR estimates for SAPU from the NPS NSNSD range from moderate condition at Abó and Quarai to good condition at Gran Quivira (Figure 39), but the park-wide median value falls in the good condition range.

Viewshed is a valuable resource at SAPU, as the surrounding natural and cultural landscape "continues to be representative of its prehistoric and historic settings and remains largely unchanged" (NPS 2014b, p. 7). The park's viewshed is currently of moderate concern. No substantial changes have occurred within park boundaries to influence the views, and from 2001–2011, no areas visible from the observation points selected for this analysis transitioned from natural vegetation to developed areas (USGS 2014). However, the addition of wind turbines northeast of the park has impacted a portion of the Gran Quivira viewshed, and visibility in the region is considered of moderate concern according to NPS ARD standards (NPS 2015a).

5.3.4 Physical Characteristics

Physical characteristics of SAPU considered in this NRCA were cave and karst features, paleontological resources, and hydrology. Condition could only be assigned for paleontological resources, which are considered in good condition. During a comprehensive 2016 field survey of all three park units, the first vertebrate body fossil from the Permian Yeso Group's Arroyo de Alamillo Formation was discovered at Abó (Thorpe et al. 2017). This finding suggests that more vertebrate fossils may be found in the Yeso Group in or near the park, and known fossil localities should be monitored annually to potentially detect any newly exposed resources.

Little is known about SAPU's cave and karst features, which are most prominent at Gran Quivira. The existence of cave and karst features at Gran Quivira, including "blowholes", was first noted in the 1930s (Attwell 1932), but were not scientifically investigated until the 2000s (Ball et al. 2006). Park managers are concerned about the impacts of subsidence and viscous seepage events on historic ruins, but no documentation or analysis regarding the magnitude of subsidence or the frequency of viscous seepage events currently exists.

The park's hydrology supports surface water features that are critical for vegetation and wildlife in the arid environment of New Mexico. Until recently, very little consistent hydrological data (e.g., spring discharge, stream flow) was available for SAPU's surface and groundwater resources. As a result, a condition could not be assigned at this time, but recent monitoring by the SCPN suggests that shallow groundwater levels and the duration of surface water presence may be declining (Soles 2018, pers. comm, June 2019).

5.3.5 Park-wide Threats and Stressors

Several threats and stressors influence the condition of multiple resources at SAPU. These include invasive species, adjacent development, and climate change impacts (e.g., drought). The surrounding developments of most concern for the SAPU region are mining, energy development, and the associated disturbances (e.g., access roads and other general construction) (Lovich and Ennen 2011, Arnett and Baerwald 2013). In New Mexico and across the Southwest, wind energy development has been expanding and the potential for utility-scale solar development is high (Lovich and Ennen 2011, NMEMNRD 2018). Adjacent development can directly impact environmental quality, including the condition of the park's dark night skies, viewshed, and soundscape (NPS 2014b). Development also causes habitat loss and fragmentation, which often harms wildlife populations, and may promote the introduction of invasive species (Lovich and Ennen 2011).

Invasive species compete with native species for limited resources and may alter ecosystem processes, such as water and nutrient cycling and natural fire regimes (Westbrooks 1998, Mooney et al. 2005). In wetland and riparian communities in the Southwest, for example, non-native shrubs have displaced and impeded regeneration of cottonwoods and willows in riparian areas (Korb 2011, NPS 2014b). According to a 2009 park-wide survey, non-native plant cover was highest at Quarai (14.4%) and lowest at Gran Quivira (0.6%) (Korb 2011). For wildlife, invasive species, including feral animals, can prey upon or carry and spread diseases to native species (Suzan and Ceballos 2005, Young et al. 2011, Loss et al. 2012).

As discussed in Chapters 2 and 4, the Southwest is projected to become warmer and drier with more sustained droughts as a result of climate change (Seager et al. 2007, Garfin et al. 2014). The increased temperatures will likely contribute to higher evaporation rates and faster transpiration by plants, meaning surface waters and shallow groundwater associated with springs and ephemeral streams could be lost to the atmosphere faster. This decline in water availability, along with shifts in precipitation patterns, may alter the structure and functioning (e.g., nutrient cycling, hydrologic processes) of park ecosystems and impact plant and wildlife communities (Thomas et al. 2006b, NPS 2014b). Water-stressed trees, in particular, are often more vulnerable to pests, pathogens, and anthropogenic stressors (NPS 2014b, NMSFD 2016). The loss of water-dependent ecosystems in the park, especially in regard to the park's tree and shrub communities, would drastically affect the wildlife communities that depend upon them.

5.3.6 Overall Conclusions

Although SAPU's three units are relatively small and disconnected, the park supports a range of valuable natural resources, from riparian habitats and migratory birds to stunning night skies and largely undisturbed scenic vistas. This assessment serves as a review and summary of available data and literature for featured natural resources in the park. The information presented here may serve as a baseline against which any changes in condition of components in the future may be compared. Current condition could not be determined for a majority of components due to data gaps; for resources where condition could be assessed, two were in good condition and two were of moderate concern. Understanding the condition of these resources can help managers prioritize management objectives and better focus conservation strategies to maintain the health and integrity of these ecosystems.

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Appendix A. Plant species documented in upland woodland and savanna communities

Table A-1. Plant species documented in upland woodland and savanna communities at SAPU over time. Note that Korb (2011) focused exclusively on non-native species. An “x” indicates that species was observed during that sampling effort.

Scientific name	Common name	Pache (1979)	Floyd-Hanna et al. (1994) [1]	Korb (2011)	Muldavin et al. (2012)
Abronia sp.	sand verbena sp.	x	–	–	–
Achnatherum hymenoides	Indian ricegrass	x	x	–	–
Amaranthus retroflexus	red-root amaranth	–	–	–	x
Andropogon gerardii	big bluestem	x	–	–	–
Andropogon gerardii ssp. *hallii*	sand bluestem	x	–	–	x
Aristida sp.	threeawn sp.	x	–	–	–
Aristida purpurea	purple threeawn	–	x	–	x
Aristida purpurea var. *purpurea*	purple threeawn	–	–	–	x
Artemisia campestris ssp. *caudata*	field sagewort	–	x	–	x
Artemisia carruthii	Carruth’s sagewort	–	x	–	x
Artemisia dracunculus	tarragon	–	x	–	x
Artemisia filifolia	sand sagebrush	x	–	–	x
Artemisia frigida	prairie sagewort	–	–	–	x
Artemisia tridentata	big sagebrush	x	–	–	–
Aster sp.	aster sp.	x	–	–	–
Astragalus brandegeei	Brandegee’s milkvetch	–	–	–	x
Astragalus lentiginosus var. *diphysus*	freckled milkvetch	–	–	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in woodland and savanna by Pache (1979) or Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994) or were included in their juniper woodland community descriptions.

[2] Nonnative species.

Table A-1 (continued). Plant species documented in upland woodland and savanna communities at SAPU over time. Note that Korb (2011) focused exclusively on non-native species. An “x” indicates that species was observed during that sampling effort.

Scientific name	Common name	Pache (1979)	Floyd-Hanna et al. (1994) [1]	Korb (2011)	Muldavin et al. (2012)
Atriplex canescens	fourwing saltbush	x	x	–	–
Berberis fremontii	Fremont’s berberis	–	x	–	–
Bouteloua curtipendula	sideoats grama	–	–	–	x
Bouteloua eriopoda	black grama	x	–	–	x
Bouteloua gracilis	blue grama	x	x	–	x
Bouteloua hirsuta	hairy grama	x	–	–	x
Bromus tectorum [2]	cheatgrass	–	x	x	x
Bromus japonicus [2]	Japanese brome	–	–	x	–
Carduus nutans [2]	nodding plumeless thistle	–	–	x	–
Castilleja integra	wholeleaf Indian paintbrush	x	x	–	–
Chamaesaracha coronopus (*C. arida*)	greenleaf five eyes	–	–	–	x
Cheilanthes feei	slender lipfern	–	–	–	x
Cirsium ochrocentrum	yellowspine thistle	–	–	–	x
Convolvulus arvensis [2]	field bindweed	–	x	x	–
Cordylanthus wrightii	Wright’s bird’s beak	–	x	–	x
Corydalis aurea	golden corydalis	x	–	–	–
Cylindropuntia imbricata	tree cholla	x	–	–	x
Cyperus schweinitzii	Schweinitz’s flatsedge	–	–	–	x
Dalea candida	white prairie clover	–	–	–	x
Dalea compacta var. *compacta*	compact prairie clover	x	–	–	–
Dalea formosa	featherplume	–	x	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in woodland and savanna by Pache (1979) or Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994) or were included in their juniper woodland community descriptions.

[2] Nonnative species.

Table A-1 (continued). Plant species documented in upland woodland and savanna communities at SAPU over time. Note that Korb (2011) focused exclusively on non-native species. An "x" indicates that species was observed during that sampling effort.

Scientific name	Common name	Pache (1979)	Floyd-Hanna et al. (1994) [1]	Korb (2011)	Muldavin et al. (2012)
Dalea lanata	woolly prairie clover	–	–	–	x
Dalea nana	dwarf prairie clover	–	–	–	x
Dasyochloa pulchella	low woollygrass	–	–	–	x
Descurainia sp. [2]	tansy mustard sp.	–	–	–	x
Dimorphocarpa wislizeni	touristplant; spectaclepod	–	–	–	x
Draba reptans	Carolina draba	–	–	–	x
Echinocereus fendleri ssp. *fendleri*	pinkflower hedgehog cactus	–	–	–	x
Echinocereus triglochidiatus	kingcup cactus	–	–	–	x
Elymus elymoides	western bottle-brush grass	x	–	–	x
Ephedra torreyana	Torrey's jointfir	–	–	–	x
Ericameria nauseosa	rubber rabbitbrush	x	–	–	–
Erigeron divergens	spreading fleabane	–	x	–	x
Eriogonum alatum	winged buckwheat	–	x	–	–
Eriogonum annuum	annual buckwheat	x	–	–	–
Eriogonum hieraciifolium	hawkweed buckwheat	–	–	–	x
Erodium cicutarium [2]	redstem stork's bill	–	x	x	–
Erysimum capitatum	sand dune wallflower	x	–	–	x
Escobaria vivipara	spinystar	–	x	–	x
Euphorbia davidii	David's spurge	–	–	–	x
Euphorbia (*Chamaesyce*) *fendleri*	Fendler's sandmat	–	–	–	x
Fallugia paradoxa	Apache plume	–	x	–	–

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in woodland and savanna by Pache (1979) or Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994) or were included in their juniper woodland community descriptions.

[2] Nonnative species.

Table A-1 (continued). Plant species documented in upland woodland and savanna communities at SAPU over time. Note that Korb (2011) focused exclusively on non-native species. An "x" indicates that species was observed during that sampling effort.

Scientific name	Common name	Pache (1979)	Floyd-Hanna et al. (1994) [1]	Korb (2011)	Muldavin et al. (2012)
Gaillardia pulchella	Indian blanket	x	–	–	–
Gaura coccinea	scarlet beeblossom	x	x	–	–
Glandularia bipinnatifida	Dakota mock vervain	–	–	–	x
Grusonia clavata	club cholla	–	–	–	x
Gutierrezia sarothrae	broom snakeweed	–	x	–	x
Heliomeris multiflora	showy goldeneye	–	–	–	x
Hesperidanthus linearifolius	slimleaf plainsmustard	–	–	–	x
Hesperostipa comata	needle and thread	x	–	–	–
Hesperostipa neomexicana	New Mexico needlegrass	x	–	–	–
Heterotheca villosa	hairy false goldenaster	–	x	–	x
Hilaria jamesii	James' galleta	–	x	–	x
Houstonia rubra	red bluet	–	–	–	x
Ipomopsis aggregata	scarlet gilia	–	–	–	x
Ipomopsis longiflora	flaxflowered ipomopsis	–	x	–	x
Ipomopsis multiflora	manyflowered ipomopsis	–	x	–	x
Juniperus monosperma	oneseed juniper	x	x	–	x
Kochia scoparia [2]	burningbush; fireweed	–	–	x	x
Koeleria macrantha	junegrass	–	x	–	x
Krascheninnikovia lanata	winterfat	–	x	–	x
Lepidium alyssoides	mesa pepperwort	–	–	–	x
Linum puberulum	plains flax	–	x	–	x
Lithospermum multiflorum	manyflowered stoneseed	x	–	–	–

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in woodland and savanna by Pache (1979) or Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994) or were included in their juniper woodland community descriptions.

[2] Nonnative species.

Table A-1 (continued). Plant species documented in upland woodland and savanna communities at SAPU over time. Note that Korb (2011) focused exclusively on non-native species. An “x” indicates that species was observed during that sampling effort.

Scientific name	Common name	Pache (1979)	Floyd-Hanna et al. (1994) [1]	Korb (2011)	Muldavin et al. (2012)
Lorandersonia pulchella	southwestern rabbitbrush	–	–	–	x
Lupinus sp.	lupine sp.	–	x	–	–
Lupinus kingii	King’s lupine	–	–	–	x
Lycium sp.	wolfberry sp.	x	–	–	–
Lycium pallidum	pale wolfberry	–	x	–	x
Malva neglecta [2]	common mallow	–	x	x	–
Marrubium vulgare [2]	horehound	–	x	x	–
Medicago lupulina [2]	black medick	–	x	x	–
Melampodium leucanthum	plains blackfoot	–	x	–	x
Melilotus officinalis [2]	yellow sweetclover	–	x	x	–
Menodora scabra	rough menodora	–	–	–	x
Mirabilis multiflora	Colorado four o’clock	x	x	–	x
Mirabilis oxybaphoides	smooth spreading four-o’clock	–	–	–	x
Monarda punctata	spotted beebalm	x	–	–	–
Muhlenbergia alopecuroides	bristly wolfstail	–	–	–	x
Muhlenbergia (*Schedonnardus*) *paniculata*	tumblegrass	–	–	–	x
Muhlenbergia pauciflora	New Mexico muhly	x	–	–	x
Muhlenbergia phleoides	common wolfstail	x	–	–	–
Muhlenbergia pungens	sandhill muhly	–	–	–	x
Muhlenbergia setifolia	curlyleaf muhly	–	–	–	x
Muhlenbergia torreyi	ring muhly	x	–	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in woodland and savanna by Pache (1979) or Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994) or were included in their juniper woodland community descriptions.

[2] Nonnative species.

Table A-1 (continued). Plant species documented in upland woodland and savanna communities at SAPU over time. Note that Korb (2011) focused exclusively on non-native species. An "x" indicates that species was observed during that sampling effort.

Scientific name	Common name	Pache (1979)	Floyd-Hanna et al. (1994) [1]	Korb (2011)	Muldavin et al. (2012)
Oenothera albicaulis	whitest evening primrose	x	x	–	–
Oenothera curtiflora	velvetweed	–	–	–	x
Oenothera hartwegii	Hartweg's sundrops	x	–	–	–
Opuntia phaeacantha	tulip pricklypear	–	–	–	x
Opuntia polyacantha	plains pricklypear	–	x	–	x
Opuntia polyacantha var. *erinacea*	grizzlybear pricklypear	x	–	–	–
Pascopyrum smithii	western wheatgrass	–	x	–	–
Pectis angustifolia	lemonscent	–	–	–	x
Penstemon barbatus	beardlip penstemon	–	x	–	–
Penstemon virgatus	upright blue beardtongue	–	x	–	x
Phacelia arizonica	Arizona phacelia	x	–	–	–
Phoradendron juniperinum	juniper mistletoe	x	x	–	–
Physalis hederifolia	ivyleaf groundcherry	x	–	–	–
Physaria (*Lesquerella*) *fendleri*	Fendler bladderpod	x	x	–	x
Physaria intermedia	Santa Fe bladderpod	x	–	–	–
Pinus edulis	twoneedle pinyon	x	x	–	x
Pinus ponderosa	ponderosa pine	–	x	–	–
Piptatherum micranthum	littleseed ricegrass	–	–	–	x
Poa fendleriana	muttongrass	–	x	–	x
Polygala alba	white milkwort	–	x	–	x
Portulaca oleracea [2]	little hogweed	–	–	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in woodland and savanna by Pache (1979) or Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994) or were included in their juniper woodland community descriptions.

[2] Nonnative species.

Table A-1 (continued). Plant species documented in upland woodland and savanna communities at SAPU over time. Note that Korb (2011) focused exclusively on non-native species. An "x" indicates that species was observed during that sampling effort.

Scientific name	Common name	Pache (1979)	Floyd-Hanna et al. (1994) [1]	Korb (2011)	Muldavin et al. (2012)
Psilostrophe tagetina	wooly paperflower	x	–	–	–
Quercus emoryi	Emory's oak	x	–	–	–
Quercus x undulata (*pauciloba*)	wavyleaf oak	–	x	–	x
Ratibida tagetes	green prairie coneflower	–	–	–	x
Rhus aromatica (*trilobata*)	skunkbush sumac	x	x	–	x
Rumex crispus [2]	curly dock	–	x	x	–
Salsola tragus [2]	prickly Russian thistle	–	x	x	x
Schizachyrium scoparium	little bluestem	x	–	–	x
Senecio sp.	groundsel sp.	x	x	–	–
Senecio flaccidus var. *flaccidus*	threadleaf ragwort	–	–	–	x
Sisymbrium spp. [2]	hedgemustard	–	x	–	x
Solanum elaeagnifolium	silverleaf nightshade	–	x	–	x
Solanum jamesii	wild potato	–	–	–	x
Sphaeralcea coccinea	scarlet globemallow	–	x	–	x
Sporobolus airoides	alkali sacaton	–	–	–	x
Sporobolus cryptandrus	sand dropseed	x	x	–	x
Sporobolus giganteus	giant dropseed	x	–	–	–
Stephanomeria pauciflora	brownplume wirelettuce	–	–	–	x
Tamarix sp. [2]	tamarisk sp.	–	x	x	–
Taraxacum officinale	common dandelion	–	–	x	–
Thelesperma megapotamicum	Hopi tea greenthread	–	x	–	x
Tragopogon dubius [2]	yellow salsify	–	x	x	–

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in woodland and savanna by Pache (1979) or Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994) or were included in their juniper woodland community descriptions.

[2] Nonnative species.

Table A-1 (continued). Plant species documented in upland woodland and savanna communities at SAPU over time. Note that Korb (2011) focused exclusively on non-native species. An "x" indicates that species was observed during that sampling effort.

Scientific name	Common name	Pache (1979)	Floyd-Hanna et al. (1994) [1]	Korb (2011)	Muldavin et al. (2012)
Townsendia annua	annual Townsend daisy	–	–	–	x
Ulmus pumila [2]	Siberian elm	–	–	x	–
Verbesina encelioides	golden crownbeard	–	x	–	x
Xanthisma gracile	slender goldenweed	x	–	–	–
Yucca baccata	datil/banana yucca	x	–	–	x
Yucca elata	soaptree yucca	x	x	–	x
Yucca glauca	soapweed yucca	–	x	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in woodland and savanna by Pache (1979) or Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994) or were included in their juniper woodland community descriptions.

[2] Nonnative species.

Appendix B. Plant species documented in wetland and riparian communities

Table B-1. Plant species documented in wetland and riparian communities at SAPU over time. An “x” indicates that species was observed during that sampling effort.

Scientific name	Common name	Floyd-Hanna et al. (1994) [1]	Springer et al. (2006a)	Korb (2011)	Muldavin et al. (2012)
Achillea millefolium	common yarrow	x	x	–	–
Anemopsis californica	yerba mansa	x	x	–	–
Artemisia campestris	field sagewort	x	–	–	x
Artemisia campestris ssp. *caudata*	field sagewort	–	–	–	x
Artemisia carruthii	Carruth’s sagewort	x	x	–	–
Artemisia dracunculus	tarragon	–	–	–	x
Artemisia ludoviciana	white sagebrush	–	–	–	x
Asclepias subverticillata	horsetail milkweed	–	–	–	x
Berberis (Mahonia) haematocarpa	red barberry	–	–	–	x
Berula erecta	cutleaf waterparsnip	–	–	–	x
Bromus catharticus [2]	rescuegrass	x	–	x	x
Bromus japonicus [2]	Japanese brome	–	–	–	x
Bromus tectorum [2]	cheatgrass	x	x	x	x
Carex sp.	sedges	x	–	–	–
Carex douglasii	Douglas sedge	–	x	–	–
Carex pellita (lanuginosa)	woolly sedge	x	–	–	x
Carex praegracilis	clustered field sedge	–	–	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in wetlands or riparian communities by Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994), as well as species that are classified as wetland plants (OBL, FACW) by the USDA PLANTS database.

[2] Nonnative species.

Table B-1 (continued). Plant species documented in wetland and riparian communities at SAPU over time. An “x” indicates that species was observed during that sampling effort.

Scientific name	Common name	Floyd-Hanna et al. (1994) [1]	Springer et al. (2006a)	Korb (2011)	Muldavin et al. (2012)
Cirsium neomexicanum	New Mexico thistle	–	–	–	x
Convolvulus arvensis [2]	field bindweed	x	–	x	x
Conyza canadensis	Canadian horseweed	–	–	–	x
Cucurbita foetidissima	Missouri gourd	x	–	–	x
Dactylis glomerata [2]	orchardgrass	–	x	–	x
Descurainia pinnata ssp. *halictorum*	western tansy mustard	–	x	–	–
Distichlis spicata	saltgrass	x	x	–	–
Elaeagnus angustifolia [2]	Russian olive	x	–	–	x
Eleocharis macrostachya	pale spikerush	x	–	–	–
Eleocharis palustris	common spikerush	x	–	–	–
Eleocharis rostellata	beaked spikerush	–	–	–	x
Equisetum laevigatum	smooth horsetail	x	x	–	x
Ericameria nauseosa	rubber rabbitbrush	x	–	–	x
Erigeron divergens	spreading fleabane	x	x	–	–
Erodium cicutarium [2]	redstem stork’s bill	x	x	x	x
Fallugia paradoxa	Apache plume	x	–	–	x
Gaura coccinea	scarlet beeblossom	x	–	–	x
Geranium caespitosum	pineywoods geranium	x	x	–	x
Glycyrrhiza lepidota	American licorice	x	–	–	x
Grindelia squarrosa	curlycup gumweed	–	–	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in wetlands or riparian communities by Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994), as well as species that are classified as wetland plants (OBL, FACW) by the USDA PLANTS database.

[2] Nonnative species.

Table B-1 (continued). Plant species documented in wetland and riparian communities at SAPU over time. An “x” indicates that species was observed during that sampling effort.

Scientific name	Common name	Floyd-Hanna et al. (1994) [1]	Springer et al. (2006a)	Korb (2011)	Muldavin et al. (2012)
Gutierrezia sarothrae	broom snakeweed	x	–	–	x
Hordeum jubatum	foxtail barley	x	x	–	–
Juncus balticus (arcticus)	Baltic rush	x	x	–	x
Juncus ensifolius	swordleaf rush	x	–	–	–
Juniperus monosperma	oneseed juniper	x	x	–	x
Kochia scoparia [2]	burningbush; fireweed	–	–	x	–
Lactuca serriola [2]	prickly lettuce	–	–	–	x
Lappula occidentalis	flatspine stickseed	x	x	–	–
Marrubium vulgare [2]	horehound	x	–	x	–
Melilotus officinalis [2]	yellow sweetclover	x	x	x	x
Mimulus glabratus	roundleaf monkeyflower	x	–	–	–
Muhlenbergia asperifolia	scratchgrass	–	–	–	x
Nasturtium officinale [2]	watercress	–	x	–	–
Oenothera curtiflora	velvetweed	–	–	–	x
Parthenocissus vitacea	woodbine	–	x	–	x
Pascopyrum smithii	western wheatgrass	x	x	–	x
Plantago major [2]	common plantain	x	x	–	–
Poa pratensis [2]	Kentucky bluegrass	–	x	x	–
Populus x *acuminata*	lanceleaf cottonwood	x	–	–	x
Populus angustifolia	narrowleaf cottonwood	–	–	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in wetlands or riparian communities by Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994), as well as species that are classified as wetland plants (OBL, FACW) by the USDA PLANTS database.

[2] Nonnative species.

Table B-1 (continued). Plant species documented in wetland and riparian communities at SAPU over time. An “x” indicates that species was observed during that sampling effort.

Scientific name	Common name	Floyd-Hanna et al. (1994) [1]	Springer et al. (2006a)	Korb (2011)	Muldavin et al. (2012)
Populus deltoides	eastern cottonwood	–	–	–	x
Populus deltoides ssp. wislizeni	Rio Grande cottonwood	–	–	–	x
Populus fremontii	Fremont’s cottonwood	x	x	–	–
Prunus virginiana	chokecherry	x	x	–	x
Ranunculus cymbalaria	alkali buttercup	x	–	–	–
Ranunculus macounii	Macoun’s buttercup	x	–	–	–
Ratibida tagetes	green prairie coneflower	–	–	–	x
Rhus aromatica (trilobata)	skunkbush sumac	x	–	–	–
Ribes aureum	golden currant	x	x	–	x
Ribes cereum	wax currant	x	x	–	–
Rosa woodsii	Wood’s rose	x	x	–	x
Rumex crispus [2]	curly dock	x	x	x	x
Salix amygdaloides	peach-leaf willow	–	–	–	x
Salix eriocephala	Missouri River willow	–	x	–	–
Salix exigua	narrowleaf willow	–	–	–	x
Salix gooddingii	Goodding’s willow	–	–	–	x
Salix lasiandra	Pacific willow	x	–	–	–
Salix lutea	yellow willow	x	x	–	–
Schedonorus arundinaceus [2]	tall fescue	–	–	–	x
Schedonorus pratensis [2]	meadow fescue	–	x	–	–
Schoenoplectus americanus	chairmaker’s bulrush	x	x	–	–

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in wetlands or riparian communities by Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994), as well as species that are classified as wetland plants (OBL, FACW) by the USDA PLANTS database.

[2] Nonnative species.

Table B-1 (continued). Plant species documented in wetland and riparian communities at SAPU over time. An “x” indicates that species was observed during that sampling effort.

Scientific name	Common name	Floyd-Hanna et al. (1994) [1]	Springer et al. (2006a)	Korb (2011)	Muldavin et al. (2012)
Schoenoplectus tabernaemontani	softstem bulrush	x	–	–	–
Schoenoplectus pungens var. *longispicatus*	common threesquare	–	x	–	–
Sisymbrium altissimum [2]	tall tumblemustard	x	–	x	–
Solanum elaeagnifolium	silverleaf nightshade	x	–	–	x
Solanum jamesii	wild potato	–	–	–	x
Sonchus asper [2]	spiny sowthistle	–	x	–	–
Sphaeralcea sp.	globemallow sp.	x	x	–	–
Sporobolus airoides	alkali sacaton	–	x	–	x
Symphyotrichum spp.	aster sp.	x	–	–	x
Tamarix sp. [2]	tamarisk sp.	–	–	x	–
Tamarix chinensis [2]	five-stamen tamarisk	x	–	–	x
Taraxacum officinale	common dandelion	–	x	x	–
Thelesperma megapotamicum	Hopi tea greenthread	x	–	–	x
Toxicodendron sp.	poison ivy	x	–	–	–
Tragopogon dubius [2]	yellow salsify	x	–	x	–
Tragopogon pratensis [2]	meadow salsify	–	–	–	x
Tribulus terrestris [2]	puncturevine	–	–	–	x
Typha sp.	cattails	–	x	–	–
Typha domingensis	southern cattail	–	–	–	x
Typha latifolia	broadleaf cattail	x	–	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in wetlands or riparian communities by Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994), as well as species that are classified as wetland plants (OBL, FACW) by the USDA PLANTS database.

[2] Nonnative species.

Table B-1 (continued). Plant species documented in wetland and riparian communities at SAPU over time. An “x” indicates that species was observed during that sampling effort.

Scientific name	Common name	Floyd-Hanna et al. (1994) [1]	Springer et al. (2006a)	Korb (2011)	Muldavin et al. (2012)
Ulmus pumila [2]	Siberian elm	–	x	–	–
Verbena sp.	vervain sp.	x	–	–	–
Veronica anagallis-aquatica	water speedwell	x	x	–	–
Xanthium strumarium	rough cocklebur	x	–	–	x

[1] Floyd-Hanna et al. (1994) did not document habitat for all species; this column includes species listed as occurring in wetlands or riparian communities by Muldavin et al. (2012) that were documented by Floyd-Hanna et al. (1994), as well as species that are classified as wetland plants (OBL, FACW) by the USDA PLANTS database.

[2] Nonnative species.

Appendix C. Bird species that have been documented in SAPU during various bird inventories and surveys

Table C-1. Bird species that have been documented in SAPU during various bird inventories and surveys. “X” indicates a species that has been confirmed, “P” indicates a species that is probably present, and “U” indicates a species that is unconfirmed in the park.

Common Name	NPS (2018a)	Scott (1979)	Schwartz (2002)	Johnson et al. (2007)	IMB Day (thru ‘17)
American bushtit	X	X	X	X	X
American coot	X	–	–	X	–
American crow	X	–	–	X	X
American goldfinch	X	–	–	–	X
American kestrel	X	X	–	X	X
American redstart	X	–	–	–	X
American robin	X	X	–	X	X
American white pelican	X	–	–	–	–
ash-throated flycatcher	X	X	X	X	X
band-tailed pigeon	X	–	–	X	X
barn swallow	X	–	–	X	X
belted kingfisher	X	–	–	–	–
Bendire’s thrasher	X	–	–	–	–
Bewick’s wren	X	X	X	X	X
black phoebe	X	–	–	X	X
black-and-white warbler	X	–	–	–	X
black-chinned hummingbird	X	X	–	X	X
black-chinned sparrow	U	–	–	–	X
black-headed grosbeak	X	X	–	X	X
black-throated gray warbler	X	–	–	X	X
black-throated sparrow	X	–	–	–	X
blue goose	X	–	–	–	–
blue grosbeak	X	–	X	X	X
blue-gray gnatcatcher	X	–	–	X	X
blue-winged warbler	X	–	–	–	X
Brewer’s blackbird	X	–	–	X	–
Brewer’s sparrow	X	–	–	–	X
broad-tailed hummingbird	X	X	–	X	X
brown-headed cowbird	X	–	X	X	X

Table C-1 (continued). Bird species that have been documented in SAPU during various bird inventories and surveys. "X" indicates a species that has been confirmed, "P" indicates a species that is probably present, and "U" indicates a species that is unconfirmed in the park.

Common Name	NPS (2018a)	Scott (1979)	Schwartz (2002)	Johnson et al. (2007)	IMB Day (thru '17)
brown thrasher	–	–	–	–	X
Bullock's oriole	X	–	–	X	X
canyon towhee	X	X	X	X	X
canyon wren	X	–	–	–	–
Cassin's finch	P	–	–	–	–
Cassin's kingbird	X	X	–	X	X
Cassin's vireo	X	–	–	–	–
cedar waxwing	P	–	–	–	X
chestnut-sided warbler	X	–	–	–	X
Chihuahuan raven	–	X	–	–	X
chipping sparrow	X	X	X	X	X
cinnamon teal	X	–	–	–	–
Clark's nutcracker	X	–	–	–	–
cliff swallow	X	–	–	X	X
common nighthawk	X	–	X	X	–
common poorwill	X	–	–	X	–
common raven	X	X	X	X	X
common yellowthroat	X	–	–	–	X
Cooper's hawk	X	–	–	X	X
crissal thrasher	U	–	–	–	–
curve-billed thrasher	X	–	–	–	–
dark-eyed junco	X	X	–	–	X
dickcissel	X	–	–	–	–
downy woodpecker	–	–	–	–	X
dusky flycatcher	X	–	–	–	X
eastern bluebird	X	–	–	–	–
Eurasian collared-dove	–	–	–	–	X
European starling	P	–	–	–	X
evening grosbeak	P	–	–	–	–
Gambel's quail	X	–	–	X	–
golden eagle	U	–	–	–	–
golden-crowned kinglet	X	–	–	–	–
golden-crowned sparrow	X	–	–	–	X

Table C-1 (continued). Bird species that have been documented in SAPU during various bird inventories and surveys. “X” indicates a species that has been confirmed, “P” indicates a species that is probably present, and “U” indicates a species that is unconfirmed in the park.

Common Name	NPS (2018a)	Scott (1979)	Schwartz (2002)	Johnson et al. (2007)	IMB Day (thru ‘17)
Grace’s warbler	U	–	–	–	–
gray catbird	X	–	–	X	X
gray flycatcher	X	–	X	X	X
gray vireo	P	–	–	–	–
great grey shrike (northern shrike)	X	–	–	–	–
great horned owl	X	X	–	X	X
greater roadrunner	P	X	–	–	X
green-tailed towhee	X	X	–	–	X
green heron	–	–	–	–	X
hairy woodpecker	U	X	–	–	X
Hammond’s flycatcher	X	–	–	–	–
hepatic tanager	X	–	–	–	–
hermit thrush	X	–	–	–	X
hooded oriole	U	–	–	–	–
hooded warbler	X	–	–	–	X
horned lark	P	–	–	–	–
house finch	X	X	X	X	X
house sparrow	P	–	–	–	–
house wren	X	X	–	X	X
indigo bunting	X	–	–	–	X
juniper titmouse	X	X	X	X	X
killdeer	X	–	–	–	X
ladder-backed woodpecker	X	X	–	X	X
lark bunting	P	–	–	–	–
lark sparrow	X	X	–	X	X
lazuli bunting	X	–	–	X	X
lesser goldfinch	X	X	–	X	X
Lewis’ woodpecker	X	–	–	–	X
Lincoln’s sparrow	X	–	–	X	X
loggerhead shrike	P	–	–	–	–
MacGillivray’s warbler	X	–	–	X	X
mallard	X	–	–	X	X
merlin	U	–	–	–	–

Table C-1 (continued). Bird species that have been documented in SAPU during various bird inventories and surveys. “X” indicates a species that has been confirmed, “P” indicates a species that is probably present, and “U” indicates a species that is unconfirmed in the park.

Common Name	NPS (2018a)	Scott (1979)	Schwartz (2002)	Johnson et al. (2007)	IMB Day (thru ‘17)
mountain bluebird	X	X	–	X	X
mountain chickadee	X	X	–	X	X
mountain pygmy owl (northern pygmy-owl)	U	–	–	–	–
mourning dove	X	X	X	X	X
northern flicker	X	X	–	X	X
northern goshawk	U	–	–	–	–
northern harrier	U	X	–	–	–
northern mockingbird	X	X	–	X	X
northern parula	X	–	–	–	X
northern rough-winged swallow	X	–	–	–	X
northern waterthrush	X	–	–	–	X
olive-sided flycatcher	X	X	–	–	X
orange-crowned warbler	X	–	–	–	X
peregrine falcon	–	–	–	–	X
phainopepla	X	–	–	X	–
pine siskin	X	–	–	–	X
pinyon jay	X	X	X	X	X
plumbeous vireo	X	–	–	X	X
pyrrhuloxia	X	–	–	–	–
red crossbill	X	–	–	–	–
red-breasted nuthatch	–	–	–	–	X
red-naped sapsucker	X	–	–	X	X
red-tailed hawk	X	X	–	X	X
red-winged blackbird	X	–	–	X	X
rock pigeon	–	–	–	–	X
rock wren	X	–	X	X	X
rose-breasted grosbeak	U	–	–	–	X
ruby-crowned kinglet	X	X	–	–	X
rufous hummingbird	U	–	–	–	–
sage thrasher	P	–	–	–	–
sandhill crane	X	–	–	–	–
Say’s phoebe	X	X	X	X	X

Table C-1 (continued). Bird species that have been documented in SAPU during various bird inventories and surveys. "X" indicates a species that has been confirmed, "P" indicates a species that is probably present, and "U" indicates a species that is unconfirmed in the park.

Common Name	NPS (2018a)	Scott (1979)	Schwartz (2002)	Johnson et al. (2007)	IMB Day (thru '17)
scaled quail	X	–	–	X	–
scarlet tanager	X	–	–	X	–
Scott's oriole	X	–	–	X	X
sharp-shinned hawk	–	X	–	–	X
song sparrow	X	–	–	–	X
spotted sandpiper	X	–	–	–	X
spotted towhee	X	X	X	X	X
Steller's jay	X	–	–	–	–
summer tanager	X	–	–	–	X
Swainson's hawk	U	–	–	–	X
Tennessee warbler	X	–	–	–	–
Townsend's solitaire	X	X	–	–	X
Townsend's warbler	X	–	–	–	–
tree swallow	X	X	–	–	–
turkey vulture	X	X	X	X	X
vesper sparrow	X	X	–	–	X
violet-green swallow	X	–	–	X	X
virginia rail	X	–	–	–	X
Virginia's warbler	X	X	–	X	X
warbling vireo	X	–	–	X	X
western bluebird	X	X	–	X	X
western kingbird	P	X	–	–	X
western meadowlark	X	X	–	X	X
western screech owl	U	–	–	–	–
western scrub jay	X	X	X	X	X
western tanager	X	X	–	X	X
western wood pewee	X	X	–	X	X
white-breasted nuthatch	X	–	–	X	X
white-crowned sparrow	X	–	–	X	X
white-throated sparrow	X	–	–	–	X
white-throated swift	X	–	–	–	X
white-winged dove	X	–	–	–	X
wild turkey	X	–	–	–	–

Table C-1 (continued). Bird species that have been documented in SAPU during various bird inventories and surveys. "X" indicates a species that has been confirmed, "P" indicates a species that is probably present, and "U" indicates a species that is unconfirmed in the park.

Common Name	NPS (2018a)	Scott (1979)	Schwartz (2002)	Johnson et al. (2007)	IMB Day (thru '17)
Williamson's sapsucker	U	–	–	–	–
willow flycatcher	X	–	–	–	X
Wilson's warbler	X	X	–	X	X
wood duck	X	–	–	–	–
yellow warbler	X	–	–	X	X
yellow-bellied sapsucker	X	–	–	–	–
yellow-breasted chat	X	–	–	X	X
yellow-rumped warbler	X	–	–	X	X
Confirmed Species	**132**	**49**	**19**	**73**	**116**
Probably Present Species	**12**	**0**	**0**	**0**	**0**
Unconfirmed Species	**15**	**0**	**0**	**0**	**0**
Species not on NPSpecies that were observed	**–**	**1**	**0**	**0**	**8**

Appendix D. Species documented during various survey methodologies between 2001 and 2003

Table D-1. Species documented during various survey methodologies between 2001 and 2003 by Johnson et al. (2007). “X” indicates a species that has been confirmed.

Species	Point Counts	Area Searches /Incidentals	Winter Area Search
American coot	–	X	–
American crow	X	X	X
American goldfinch	–	–	X
American kestrel	–	X	X
American robin	X	X	X
ash-throated flycatcher	X	X	–
band-tailed pigeon	–	X	–
barn swallow	–	X	–
Bewick’s wren	X	X	X
black phoebe	X	X	–
black-chinned hummingbird	X	X	–
black-headed grosbeak	X	X	–
black-throated sparrow	X	–	–
black-throated gray warbler	–	X	–
blue-gray gnatcatcher	X	X	–
blue grosbeak	–	X	–
Brewer’s blackbird	–	X	–
broad-tailed hummingbird	–	X	–
brown-headed cowbird	X	X	–
Bullock’s oriole	X	X	–
bushtit	X	X	–
canyon towhee	X	X	–
Cassin’s kingbird	X	X	–
chipping sparrow	X	X	–
cliff swallow	X	X	–
common nighthawk	X	X	–
common poorwill	–	X	–
common raven	X	X	X
Cooper’s hawk	X	X	X
dark-eyed junco	–	–	X
Gambel’s quail	X	X	–

Table D-1 (continued). Species documented during various survey methodologies between 2001 and 2003 by Johnson et al. (2007). "X" indicates a species that has been confirmed.

Species	Point Counts	Area Searches /Incidentals	Winter Area Search
gray catbird	–	X	–
gray flycatcher	X	X	–
great horned owl	–	X	–
house finch	X	X	X
house wren	–	X	–
juniper titmouse	X	X	X
ladder-backed woodpecker	X	X	X
lark sparrow	X	X	–
lazuli bunting	–	X	–
lesser goldfinch	X	X	–
Lincoln's sparrow	–	X	–
MacGillivray's warbler	–	X	–
mallard	–	X	–
mountain bluebird	–	X	X
mountain chickadee	–	X	–
mourning dove	X	X	–
northern flicker	–	X	X
northern harrier	–	–	X
northern mockingbird	–	X	–
northern rough-winged swallow	X	–	–
phainopepla	–	X	–
pine siskin	–	–	X
pinyon jay	X	X	X
plumbeous vireo	–	X	–
red crossbill	–	–	X
red-naped sapsucker	–	X	–
red-tailed hawk	–	X	–
red-winged blackbird	–	X	–
rock wren	X	X	–
Say's phoebe	X	X	–
scaled quail	–	X	–
scarlet tanager	–	X	–
Scott's oriole	–	X	–
song sparrow	–	–	X

Table D-1 (continued). Species documented during various survey methodologies between 2001 and 2003 by Johnson et al. (2007). “X” indicates a species that has been confirmed.

Species	Point Counts	Area Searches /Incidentals	Winter Area Search
spotted towhee	X	X	X
Townsend’s solitaire	–	–	X
turkey vulture	X	X	–
violet-green swallow	X	X	–
Virginia’s warbler	–	X	–
warbling vireo	–	X	–
western bluebird	X	X	X
western meadowlark	X	X	–
western scrub jay	X	X	X
western tanager	–	X	–
western wood-pewee	–	X	–
white-breasted nuthatch	–	X	X
white-crowned sparrow	–	X	X
white-throated sparrow	–	–	X
Wilson’s warbler	–	X	–
yellow warbler	–	X	–
yellow-breasted chat	–	X	–
yellow-rumped warbler	–	X	–

Appendix E. Bird abundance by species across habitats, based on variable circular plot point counts

Table E-1. Bird abundance by species across habitats, based on variable circular plot point counts, SAPU, 2001 (Table 28, Johnson et al 2007).

	Pinyon Juniper (n=19)		Riparian/Shrubland (n=7)		All Habitats (n=26)	
Common Name	**# Detections**	**Avg./pt. ct. station**	**# Detections**	**Avg./pt. ct. station**	**# Detections**	**Avg./pt. ct. station**
American crow	–	–	1	0.1	1	0.0
American robin	5	0.3	–	–	5	0.2
ash-throated flycatcher	57	3.0	22	3.1	79	3.0
Bewick's wren	55	2.9	–	–	55	2.1
black phoebe	–	–	3	0.4	3	0.1
black-chinned hummingbird	4	0.2	4	0.6	8	0.3
black-headed grosbeak	8	0.4	24	3.4	32	1.2
black-throated sparrow	1	0.1	–	–	1	0.0
blue-gray gnatcatcher	–	–	1	0.1	1	0.0
brown-headed cowbird	3	0.2	7	1.0	10	0.4
Bullock's oriole	–	–	2	0.3	2	0.1
bushtit	14	0.7	3	0.4	17	0.6
canyon towhee	–	–	7	1.0	7	0.3
Cassin's kingbird	13	0.7	13	1.9	26	1.0
chipping sparrow	46	2.4	9	1.3	55	2.1
cliff swallow	26	1.4	29	4.1	55	2.1
common nighthawk	7	0.4	1	0.1	8	0.3
common raven	12	0.6	3	0.4	15	0.6
Cooper's hawk	1	0.1	–	–	1	0.0
Gambel's quail	1	0.1	–	–	1	0.0

Table E-1 (continued). Bird abundance by species across habitats, based on variable circular plot point counts, SAPU, 2001 (Table 28, Johnson et al 2007).

Common Name	Pinyon Juniper (n=19)		Riparian/Shrubland (n=7)		All Habitats (n=26)	
	# Detections	Avg./pt. ct. station	# Detections	Avg./pt. ct. station	# Detections	Avg./pt. ct. station
gray flycatcher	1	0.1	–	–	1	0.0
house finch	13	0.7	11	1.6	24	0.9
juniper titmouse	84	4.4	4	0.6	88	3.4
ladder-backed woodpecker	2	0.1	1	0.1	3	0.1
lark sparrow	11	0.6	7	1.0	18	0.7
lesser goldfinch	4	0.2	12	1.7	16	0.6
mourning dove	32	1.7	11	1.6	43	1.6
northern rough-winged swallow	–	–	1	0.1	1	0.0
pinyon jay	11	0.6	45	6.4	56	2.1
rock wren	12	0.6	19	2.7	31	1.2
Say's phoebe	4	0.2	7	1.0	11	0.4
spotted towhee	51	2.7	7	1.0	58	2.2
turkey vulture	7	0.4	–	–	7	0.3
unknown species	3	0.2	–	–	3	0.1
unknown woodpecker	1	0.1	1	0.1	2	0.1
violet-green swallow	1	0.1	–	–	1	0.0
western bluebird	5	0.3	2	0.3	7	0.3
western meadowlark	3	0.2	–	–	3	0.1
western scrub jay	20	1.1	1	0.1	21	0.8
Total # Detections/Habitat (relative Abundance)	**518**	**–**	**258**	**–**	**776**	**–**
Percent of Total	**66.80%**	**–**	**33.20%**	**–**	**–**	**–**

Table E-1 (continued). Bird abundance by species across habitats, based on variable circular plot point counts, SAPU, 2001 (Table 28, Johnson et al 2007).

Common Name	Pinyon Juniper (n=19)		Riparian/Shrubland (n=7)		All Habitats (n=26)	
	# Detections	Avg./pt. ct. station	# Detections	Avg./pt. ct. station	# Detections	Avg./pt. ct. station
Average # detections/pt.ct. station	27	–	37	–	–	–
Species Richness/habitat (species distribution)	31	–	28	–	37	–
Percent Total	83.80%	–	75.70%	–	–	–

Appendix F. Number of detections for each species encountered during annual, one-day surveys of SAPU on International Migratory Bird Day from 1998–2017

Table F-1. Number of detections for each species encountered during annual, one-day surveys of SAPU on International Migratory Bird Day from 1998–2017 (NPS unpublished data).

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
American crow	1	–	1	–	–	–	2	1	1	1	2	2	1	2	1	2	–	–	–	–	**17**
American goldfinch	2	2	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	**6**
American kestrel	2	2	2	1	1	1	1	2	2	2	–	–	1	–	–	–	–	–	–	–	**17**
American redstart	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	**2**
American robin	8	4	8	1	–	2	–	1	2	–	1	–	3	3	–	2	3	–	–	6	**38**
ash-throated flycatcher	2	4	3	4	4	1	2	4	3	3	1	2	–	1	–	–	1	–	2	–	**35**
band-tailed pigeon	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
barn swallow	6	6	6	1	4	4	4	8	15	6	5	1	2	3	7	3	6	4	6	5	**87**
Bewick’s wren	3	4	2	1	2	4	3	2	2	3	2	6	3	2	–	–	1	3	–	2	**40**
black phoebe	–	1	1	–	–	1	–	1	3	–	2	1	–	1	–	–	–	–	2	–	**11**
black-and-white warbler	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	**2**
black-chinned hummingbird	5	3	1	2	1	–	5	4	2	1	2	2	3	4	1	–	2	4	4	4	**38**
black-chinned sparrow	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
black-headed grosbeak	5	6	2	4	4	5	4	8	10	10	11	12	4	6	8	7	4	15	13	14	**110**
black-throated gray warbler	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
black-throated sparrow	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	**1**
blue grosbeak	–	1	–	4	4	3	4	2	3	2	–	1	–	2	1	–	–	–	1	1	**27**
blue-gray gnatcatcher	–	1	–	2	2	2	–	–	–	–	2	–	–	1	–	–	–	–	1	–	**10**
blue-winged warbler	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
Brewer’s sparrow	–	–	4	–	7	4	–	–	1	–	1	1	–	–	–	–	–	–	–	–	**18**
broad-tailed hummingbird	5	2	1	2	4	2	2	3	1	2	1	1	2	1	–	3	1	–	–	2	**33**

Table F-1 (continued). Number of detections for each species encountered during annual, one-day surveys of SAPU on International Migratory Bird Day from 1998–2017 (NPS unpublished data).

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
brown thrasher	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	**1**
brown-headed cowbird	2	2	4	4	1	1	3	3	6	4	3	2	4	1	3	–	–	–	–	8	**43**
Bullock's oriole	1	3	2	5	2	2	3	7	4	3	4	4	5	2	–	3	–	1	–	–	**50**
bushtit	–	–	2	1	1	6	1	5	2	5	–	–	4	2	2	–	–	–	4	–	**31**
canyon towhee	1	2	–	1	2	1	3	4	2	2	2	2	1	2	2	2	1	1	1	1	**30**
Cassin's kingbird	–	1	–	–	–	–	–	2	–	–	–	–	–	–	–	1	–	–	–	–	**4**
cedar waxwing	–	–	–	–	–	–	40	6	–	20	–	–	–	–	–	–	–	–	–	3	**66**
chestnut-sided warbler	–	–	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	**2**
Chihuahuan raven	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	**1**
chipping sparrow	5	12	1	4	5	15	2	7	4	–	30	12	10	2	–	3	–	3	–	–	**112**
cliff swallow	–	5	1	1	6	4	2	–	1	1	–	–	–	–	–	–	–	–	–	–	**21**
common raven	2	3	4	2	2	4	2	4	2	3	3	5	2	3	3	2	2	4	12	2	**48**
common yellowthroat	–	4	1	–	4	3	3	1	3	1	3	1	1	1	–	–	–	1	–	–	**26**
Cooper's hawk	–	1	1	1	3	1	2	–	1	–	1	1	–	1	2	–	–	–	1	1	**15**
dark-eyed junco	–	–	–	–	1	1	–	–	–	–	5	–	2	–	–	–	–	–	–	–	**9**
downy woodpecker	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	**1**
dusky flycatcher	–	3	3	–	7	–	1	2	1	–	4	–	4	2	–	–	–	–	–	–	**27**
empidonax (sp.)	1	–	–	–	–	2	–	–	–	–	–	–	–	–	–	1	–	1	3	1	**4**
Eurasian collared-dove	–	–	–	–	–	–	–	2	1	1	2	2	5	3	4	–	4	–	3	2	**24**
European starling	–	–	–	–	–	–	–	2	–	–	5	–	–	–	–	–	–	–	–	1	**7**
golden-crowned sparrow	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
gray catbird	–	–	–	–	–	–	–	1	–	–	–	–	2	–	–	–	–	–	–	–	**3**
gray flycatcher	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**2**
great horned owl	2	2	2	1	2	1	2	2	1	2	–	2	1	1	2	1	2	2	–	–	**26**
greater roadrunner	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	**1**

Table F-1 (continued). Number of detections for each species encountered during annual, one-day surveys of SAPU on International Migratory Bird Day from 1998–2017 (NPS unpublished data).

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
green heron	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	**1**
green-tailed towhee	–	3	1	–	2	2	2	–	3	–	3	–	–	2	–	4	–	–	–	–	**22**
hairy woodpecker	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	1	1	**2**
hermit thrush	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	**2**
hooded warbler	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
house finch	7	6	6	8	20	12	12	10	8	6	7	6	2	5	1	–	2	–	1	1	**118**
house wren	2	1	3	–	8	8	2	6	3	–	5	4	2	3	–	1	–	–	1	–	**48**
indigo bunting	–	–	–	–	–	1	–	1	–	1	–	–	–	–	–	–	–	–	–	–	**3**
juniper titmouse	3	3	3	2	3	1	4	3	3	2	1	4	1	3	–	2	–	–	–	3	**38**
killdeer	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
ladder-backed woodpecker	2	2	2	2	1	1	4	2	2	1	2	1	4	1	1	1	–	–	–	1	**29**
lark sparrow	–	5	1	–	2	2	1	5	4	–	3	3	7	2	–	–	1	–	–	–	**36**
lazuli bunting	–	–	1	1	–	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	**4**
lesser goldfinch	1	–	–	–	2	1	1	–	–	1	–	–	–	–	3	–	–	–	–	–	**9**
Lewis’s woodpecker	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
lincoln’s sparrow	–	–	2	–	1	–	–	2	–	1	–	–	–	1	–	–	–	–	–	–	**7**
MacGillivray’s warbler	2	1	4	–	7	6	3	5	4	3	3	2	1	3	2	2	1	2	–	2	**49**
mallard	2	2	1	2	–	2	2	–	–	1	–	1	–	1	3	1	2	2	2	–	**20**
mountain bluebird	2	1	–	2	1	2	–	2	–	–	–	–	2	–	–	1	–	–	–	–	**13**
mountain chickadee	–	–	2	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	1	**4**
mourning dove	7	12	8	6	10	8	12	8	10	8	5	8	6	7	6	4	3	1	9	3	**128**
northern flicker	4	6	5	2	–	–	–	2	3	–	–	1	1	1	–	–	1	–	1	1	**26**
northern mockingbird	4	2	5	4	15	3	1	3	4	–	–	1	1	2	–	2	–	–	2	1	**47**
northern parula warbler	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	**1**
northern rough-winged swallow	–	1	1	–	1	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	**5**

Table F-1 (continued). Number of detections for each species encountered during annual, one-day surveys of SAPU on International Migratory Bird Day from 1998–2017 (NPS unpublished data).

Species	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Total**
northern waterthrush	–	–	1	–	1	1	–	1	–	–	–	–	1	1	–	–	–	–	–	–	**6**
olive-sided flycatcher	1	2	2	2	1	–	–	1	–	1	–	1	–	–	–	–	–	–	4	–	**11**
orange-crowned warbler	–	2	5	–	5	6	4	2	2	1	3	1	1	3	1	–	1	–	1	–	**37**
peregrine falcon	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	**1**
pine siskin	–	12	2	–	1	–	–	12	3	–	10	–	9	2	–	–	–	15	–	–	**51**
pinyon jay	–	5	6	2	1	4	2	–	5	3	–	3	4	2	–	2	–	–	–	–	**39**
plumbeous vireo	2	1	1	–	3	3	1	1	–	–	2	–	1	4	1	1	2	–	2	1	**23**
red-breasted nuthatch	–	–	–	–	–	–	–	3	–	–	–	1	–	–	–	1	–	–	–	–	**5**
red-naped sapsucker	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	**1**
red-tailed hawk	–	2	2	–	–	–	–	1	2	–	–	–	1	–	–	1	1	1	–	–	**10**
red-winged blackbird	–	4	–	–	2	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	**8**
rock pigeon	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	**1**
rock wren	3	3	2	2	–	–	2	2	2	2	1	–	1	2	–	1	–	–	–	–	**23**
rose-breasted grosbeak	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	**1**
ruby-crowned kinglet	1	–	1	1	1	1	–	–	1	–	–	–	–	–	–	–	–	–	2	–	**6**
Say's phoebe	1	2	3	3	3	5	4	3	2	2	–	1	1	2	2	1	4	1	2	2	**39**
Scott's oriole	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	**2**
sharp-shinned hawk	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	**2**
song sparrow	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
spotted sandpiper	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
spotted towhee	10	8	8	10	3	8	6	10	4	8	4	6	8	4	6	4	3	2	8	6	**110**
summer tanager	–	–	1	–	2	–	–	1	1	–	3	–	–	–	–	–	1	–	–	–	**9**
Swainson's hawk	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	1	**1**
Townsend's solitaire	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	**2**
turkey vulture	2	2	2	4	4	5	2	4	3	2	1	5	2	2	2	2	2	1	2	3	**46**

Table F-1 (continued). Number of detections for each species encountered during annual, one-day surveys of SAPU on International Migratory Bird Day from 1998–2017 (NPS unpublished data).

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
vesper sparrow	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
violet-green swallow	30	25	25	25	30	30	40	35	20	16	25	25	12	15	3	–	2	2	–	5	**358**
Virginia rail	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
Virginia’s warbler	2	2	1	1	–	4	2	2	1	1	2	1	4	1	–	–	1	–	–	–	**25**
warbling vireo	–	–	3	1	3	–	2	4	4	1	1	1	1	1	–	–	2	–	2	3	**24**
western bluebird	2	4	2	3	–	–	–	–	–	2	2	–	–	4	1	6	2	1	5	4	**28**
western kingbird	–	–	–	–	–	–	–	–	1	–	–	2	1	1	–	–	–	–	–	1	**5**
western meadowlark	2	3	–	2	2	–	2	2	2	2	2	–	–	–	–	–	–	–	–	–	**19**
western scrub-jay	3	4	5	5	4	7	5	5	5	3	5	5	4	4	2	4	3	3	6	5	**73**
western tanager	3	1	6	4	3	5	4	6	1	3	4	1	1	2	–	2	–	1	5	2	**46**
western wood-pewee	–	1	5	7	3	2	2	8	3	4	2	3	1	4	1	–	–	–	1	1	**46**
white-breasted nuthatch	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
white-crowned sparrow	7	8	6	6	8	12	10	5	6	4	4	1	–	2	1	–	–	–	–	–	**80**
white-throated sparrow	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–	**1**
white-throated swift	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
white-winged dove	–	–	–	–	–	–	1	–	–	–	1	–	–	–	1	–	–	–	1	2	**3**
willow flycatcher	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**
Wilson’s warbler	10	12	15	–	15	3	6	10	3	2	10	1	5	12	–	2	1	2	9	–	**107**
yellow warbler	4	2	4	3	3	7	3	4	1	–	6	3	5	4	–	–	1	1	1	–	**50**
yellow-breasted chat	4	4	8	7	8	4	6	10	6	8	6	8	6	5	8	6	5	4	5	4	**109**
yellow-rumped warbler	24	13	3	2	10	6	4	5	1	1	15	2	50	6	–	3	1	3	–	–	**146**
Number of individuals	**202**	**246**	**222**	**161**	**266**	**235**	**246**	**271**	**200**	**164**	**236**	**166**	**209**	**163**	**82**	**85**	**73**	5	17	14	**3227**
Number of species	**48**	**64**	**67**	**47**	**66**	**56**	**55**	**62**	**61**	**49**	**57**	**52**	**53**	**59**	**31**	**36**	**38**	26	26	26	**117**

Appendix G. Mammal species considered present or probably present at SAPU

Table G-1. Mammal species considered present or probably present at SAPU (NPS 2018a).

Order	Scientific name	Common name	Occurrence
Chiroptera	*Antrozous pallidus*	pallid bat	present
	Corynorhinus townsendii	Townsend's big-eared bat	present
	Eptesicus fuscus	big brown bat	present
	Euderma maculatum	spotted bat	probably present
	Lasionycteris noctivagans	silver-haired bat	present
	Lasiurus borealis	eastern red bat	probably present
	Lasiurus cinereus	hoary bat	present
	Myotis californicus	California myotis	present
	Myotis ciliolabrum	small-footed myotis	present
	Myotis lucifugus	little brown bat	probably present
	Myotis thysanodes	fringed myotis	present
	Myotis volans	long-legged myotis	present
	Myotis yumanensis	Yuma myotis	present
	Nyctinomops macrotis	big free-tailed bat	probably present
	Pipistrellus hesperus	western pipistrelle	present
	Tadarida brasiliensis	Brazilian free-tailed bat	present
Lagomorpha	*Lepus californicus*	black-tailed jack rabbit	present
	Sylvilagus audubonii	desert cottontail	present
	Sylvilagus floridanus	eastern cottontail	probably present
Rodentia	*Ammospermophilus interpres*	Texas antelope squirrel	probably present
	Dipodomys ordii	Ord's kangaroo rat	present
	Dipodomys spectabilis	banner-tailed kangaroo rat	present
	Erethizon dorsatus	common porcupine	present
	Geomys bursarius	plains pocket gopher	present
	Microtus longicaudus	long-tailed vole	present
	Microtus mexicanus (mogollensis)	Mexican vole	present
	Mus musculus [1]	house mouse	present
	Neotoma albigula	white-throated woodrat	present
	Neotoma mexicana	Mexican woodrat	present
	Neotoma micropus	southern plains woodrat	present
	Onychomys leucogaster	northern grasshopper mouse	present
	Otospermophilus variegatus	rock squirrel	present

[1] Non-native species.

Table G-1. Mammal species considered present or probably present at SAPU (NPS 2018a).

Order	Scientific name	Common name	Occurrence
Rodentia (continued)	*Perognathus flavescens*	plains pocket mouse	present
	Perognathus flavus	silky pocket mouse	present
	Peromyscus boylii	brush deermouse	present
	Peromyscus eremicus	cactus deermouse	present
	Peromyscus leucopus	white-footed deermouse	present
	Peromyscus maniculatus	deer mouse	present
	Peromyscus nasutus	northern rock deermouse	probably present
	Peromyscus truei	pinyon deermouse	present
	Reithrodontomys megalotis	western harvest mouse	present
	Sigmodon hispidus	hispid cotton rat	present
	Tamias minimus	least chipmunk	present
	Thomomys bottae	Botta's pocket gopher	present
Soricomorpha	*Notiosorex crawfordi*	gray shrew, desert shrew	probably present
Carnivora	*Bassariscus astutus*	ringtail	probably present
	Canis latrans	coyote	present
	Lynx rufus	bobcat	probably present
	Mephitis mephitis	striped skunk	present
	Mustela frenata	long-tailed weasel	present
	Puma concolor	mountain lion	present
	Spilogale gracilis	western spotted skunk	probably present
	Taxidea taxus	American badger	present
	Urocyon cinereoargenteus	gray fox	present
	Ursus americanus	black bear	probably present
	Vulpes macrotis	kit fox	probably present
	Vulpes vulpes	red fox	present
Artiodactyla	*Odocoileus hemionus*	mule deer	present
	Antilocapra americana	pronghorn	probably present

[1] Non-native species.

Appendix H. Monthly precipitation at weather stations near SAPU, compared to 30-year normal for each station

Table H-1. Monthly precipitation (cm) at Mountainair Station, compared to 30-year normal (NCEI 2015a, b, 2018b, a). An en-dash (–) indicates missing data.

Year	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total [1]
2005	3.73	6.73	3.28	2.92	1.68	0.71	3.15	3.94	10.01	3.35	0.00	0.08	39.57
2006	0.00	0.00	0.81	0.00	0.00	5.54	9.55	6.22	6.55	5.79	0.36	3.38	38.20
2007	1.37	1.68	1.02	0.86	4.29	0.66	2.39	1.30	1.45	0.94	0.28	2.16	18.39
2008	0.41	0.86	0.00	–	1.45	0.25	9.30	11.84	1.27	5.26	–	1.80	(32.44)
2009	0.53	0.20	0.10	0.81	3.07	2.36	7.11	3.35	5.94	3.96	1.32	–	(28.78)
2010	3.68	3.05	4.62	2.06	0.38	0.84	10.01	3.43	2.62	3.76	–	2.44	(36.88)
2011	0.00	–	0.00	–	0.00	0.00	–	–	–	–	–	–	–
2012	–	–	–	–	0.25	0.00	3.76	–	–	–	–	–	–
2013	–	–	0.08	–	–	0.69	5.41	4.06	6.32	–	1.85	0.10	(18.52)
2014	0.00	0.58	0.84	1.35	0.89	0.13	13.64	3.56	5.87	1.78	1.83	1.27	31.72
2015	5.61	1.12	3.30	0.00	10.39	3.58	7.09	3.53	2.13	–	–	–	(36.75)
2016	1.52	0.05	0.00	1.52	–	2.54	3.18	8.97	1.35	2.18	3.30	0.94	(25.55)
2017	1.17	0.18	0.18	0.48	0.51	1.37	3.94	3.33	4.83	–	0.00	0.00	(15.98)
2018	0.15	0.53	–	0.00	–	4.06	6.81	1.88	6.10	4.37	0.76	–	(24.66)
2005–18 av.	1.52	1.36	1.19	1.00	2.08	1.62	6.56	4.62	4.54	3.49	1.08	1.35	–
30-yr normal	**1.45**	**1.52**	**2.06**	**1.47**	**1.93**	**2.62**	**6.81**	**7.36**	**4.62**	**3.81**	**1.91**	**2.74**	**38.28**

[1] Values in parentheses are incomplete totals, due to missing months of data for those years. If more than 5 months were missing, totals were not calculated.

Table H-2. Monthly precipitation (cm) at Gran Quivira Station, compared to 30-year normal (NCEI 2015a, b, 2018b, a). An en-dash (–) indicates missing data.

Year	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total [1]
2005	3.05	5.82	3.78	1.37	1.35	0.69	2.79	8.71	11.43	3.73	0.00	0.00	42.72
2006	0.00	0.00	0.43	0.25	0.25	5.11	12.45	24.23	6.78	7.29	0.79	1.80	59.39
2007	2.44	1.07	2.44	1.27	6.35	2.41	11.71	5.66	3.10	0.03	0.53	2.59	39.60
2008	0.81	0.86	0.71	0.15	1.32	0.46	12.42	11.51	2.49	7.82	0.61	1.17	40.64
2009	0.28	0.23	0.89	1.02	1.24	3.99	–	2.21	5.51	6.48	1.47	2.03	(25.35)
2010	2.84	2.49	2.57	2.01	2.57	0.18	14.48	6.17	2.06	2.36	0.00	1.12	38.84
2011	–	0.00	0.05	0.03	–	–	4.62	3.35	2.29	1.50	0.33	–	(12.17)
2012	0.00	0.71	0.38	0.48	1.52	0.76	9.58	2.46	–	0.13	0.36	–	(16.38)
2013	–	–	0.61	0.05	0.05	0.23	6.60	10.57	11.07	–	0.84	0.53	(30.56)
2014	0.00	0.03	1.57	2.03	2.79	0.33	8.86	9.09	7.01	2.08	2.18	0.84	(36.83)
2015	3.51	0.10	0.74	0.79	11.23	8.56	4.24	3.25	1.85	–	0.81	7.21	(42.29)
2016	1.52	0.03	0.05	3.20	4.42	6.55	–	7.06	4.04	3.05	4.90	–	(34.82)
2017	1.02	0.81	2.87	1.14	0.69	1.27	2.46	3.43	5.33	1.55	0.15	–	(20.73)
2018	–	–	–	–	0.38	1.78	2.54	7.75	4.37	5.59	1.30	–	(23.70)
2005–18 av.	1.41	1.01	1.31	1.06	2.63	2.51	7.73	7.53	5.18	3.47	1.02	1.92	–
30-yr normal	**1.68**	**1.80**	**1.80**	**1.96**	**2.31**	**3.00**	**7.26**	**9.25**	**5.54**	**4.42**	**2.08**	**2.31**	**43.41**

[1] Values in parentheses are incomplete totals, due to missing months of data for those years.

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