**National Park Service**
**U.S. Department of the Interior**

**Natural Resource Stewardship and Science**

# Guadalupe Mountains National Park

## *Natural Resource Condition Assessment*

Natural Resource Report NPS/GUMO/NRR—2013/668

**ON THE COVER**
The desert environment of Guadalupe Mountains National Park, with El Capitan.
Photograph courtesy of Guadalupe Mountains National Park.

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Natural Resource Report NPS/GUMO/NRR—2013/668

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Chapter 4 of this report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information. The remainder of the report received informal peer review by park and network staff.



This report is available from the Chihuahuan Desert Inventory and Monitoring Network and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

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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 Guadalupe Mountains National Park (GUMO) 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 GUMO. The final project framework contains 16 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 GUMO resource managers and NPS Chihuahuan Desert Network staff.

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 a number of 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 9 of the 16 components (56%) due to these data gaps.

For those components with sufficient available data, the overall condition varied. Four components were determined to be of low concern: semidesert grasslands, birds, viewscape, and geological/paleontological resources. These components also showed a stable trend, with the exception of semidesert grasslands, which have improved in recent times. Sky islands (montane forests) and air quality were the only components of moderate concern, and they showed stable trends. Fire regime is of significant concern to park management, given the fuel buildup due to

past land management practices and weather conditions that often prohibit fuel-reducing prescribed burns. A parkwide trend was difficult to determine for this component, as condition may have improved in some areas but remains unchanged or has declined in others. However, NPS staff feel that the trend would best be described as declining. 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 GUMO. Those of primary concern include increased energy development (oil, gas, wind, and solar), a proposed desalination plant near the park, and the establishment of exotic species. Understanding these threats, and how they relate to the condition of these resources, can help the NPS prioritize management objectives and better focus conservation strategies to maintain the health and integrity of park ecosystems.

# Acknowledgments

We acknowledge Guadalupe Mountains National Park staff (present and past) for the technical expertise provided during scoping, through multiple stages of review, and via phone and email; specifically, Jonena Hearst, Janet Coles, Dennis Vasquez, John Montoya, and Fred Armstrong. Chihuahuan Desert Inventory and Monitoring Network staff, including Hildy Reiser, Missy Powell, and Kirsten Gallo offered logistical insight and critical review of interim documents. Ellen Porter of the NPS Air Resources Division and Mike George of the NPS Intermountain Region provided review of the air quality component. The NPS Dark Night Skies Team offered information and guidance on the preparation of the dark night skies component. Richard Gatewood and Colleen Filippone provided insight and review of the fire regime and hydrology assessments respectively. Este Muldavin supplied data, guidance, and review for the ecological community components. Dave Prival, Matt Goode, John Rotenberry, and Ken Halama provided reviews of the reptiles assessment. We also acknowledge Joel Brant, Mike Howard, Michael Powell, and Richard Worthington, who were willing to discuss specific resources and provide insight when asked. 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

BBS – Breeding Bird Survey

BLM – Bureau of Land Management

CFI - Composite Fire Return Interval

CHDN - Chihuahuan Desert Network

dB - Decibels

DEM – Digital Elevation Model

dNBR - Differenced Normalized Burn Ratio

EPA – Environmental Protection Agency

GIS – Geographic Information System

gpm - Gallons per minute

GUMO - Guadalupe Mountains National Park

I&M - Inventory and Monitoring

LiDAR - Light Detection and Ranging

MTBS - Monitoring Trends in Burn Severity

mya - Million years ago

NADP - National Atmospheric Deposition Program

NCDC - National Climatic Data Center

NLCD – National Land Cover Dataset

NPS - National Park Service

NPS ARD – National Park Service Air Resources Division

NRCA – Natural Resource Condition Assessment

NRCS - Natural Resources Conservation Service

NST - Night Sky Team

NVC – National Vegetation Classification

PAC – Protected Activity Center

PM – Particulate Matter

RMBO – Rocky Mountain Bird Observatory

RSS – Resource Stewardship Strategy

SMUMN GSS – Saint Mary's University of Minnesota, Geospatial Services

TCEQ – Texas Commission on Environmental Quality

TPWD – Texas Parks and Wildlife Department

TWDB - Texas Water Development Board

USFS – United States Forest Service

USFWS – United States Fish and Wildlife Service

USGS – United States Geological Survey

# Chapter 1 NRCA Background Information

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

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

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

***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*

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

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

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

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

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

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

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

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

Over the next several years, the NPS plans to fund a NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information on the NRCA program, visit http://nature.nps.gov/water/nrca/index.cfm

***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)***

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

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

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

# Chapter 2 Introduction and Resource Setting

## 2.1 Introduction

### *2.1.1 Enabling Legislation*

Guadalupe Mountains National Park (GUMO) was authorized by Congress on 15 October 1966 and formally established on 30 September 1972, "in order to preserve in public ownership an area possessing outstanding geological values together with scenic and other natural values of great significance" (Public Law 89-667) (NPS 2012a). In 1978, over half of the park was designated as wilderness area. Ten years later, in October of 1988, Congress expanded GUMO's boundary by approximately 4,100 ha (10,000 ac) to include dune areas on the western edge of the park (NPS 2012a).

### *2.1.2 Geographic Setting*

The park consists of nearly 35,000 ha (86,400 ac) just south of the New Mexico border in west Texas, with 19,000 ha (46,850 ac) of designated wilderness area (NPS 2009). GUMO is home to Guadalupe Peak (Photo 1), the highest point in Texas at 2,667 m (8,749 ft), and the western edge of "the world's most extensive and well-exposed fossil reef, including related shelf and basinal rocks which have achieved international designation as the world's best example of Middle Permian geology" (NPS 2009, p. 3).

**Photo 1.** A snow-covered Guadalupe Peak (NPS photo).

While the climate at GUMO is primarily typical of the Chihuahuan Desert, the northern portion is often cooler and moister due to its higher elevation (NPS 2012a). High temperatures in the summer around Pine Springs (where the Visitor Center is located) average 31°C (88°F), while winter temperatures average 5.5°C (42°F). However, temperatures often exceed 32°C (90°F) in the summer and below freezing temperatures are common during the winter months. At the park's higher elevations, temperatures average about 5.5°C (9.9°F) cooler, while the west side of the park (at a slightly lower elevation) is generally 5.5°C warmer than at Pine Springs (NPS 2012a). Average annual precipitation is 44.2 cm (17.4 in) at Pine Springs, 45.0 cm (17.7 in) in the north, and just 9.1 cm (3.6 in) on the west side. At lower elevations, the majority of precipitation falls during the summer, while higher elevations receive more precipitation in the winter. The Guadalupe Mountains are also known for their high winds, which regularly exceed 95 km/hour (60 mi/hour) (NPS 2012a). Table 1 summarizes average monthly temperature and precipitation for GUMO.

**Table 1.** Monthly climate summary (1981-2010) for GUMO (Station USW00023055, Pine Springs) (NCDC 2012).

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Temperature (°C) | | | | | | | | | | | | | |
| Max | 11.2 | 13.7 | 18.2 | 22.4 | 27.8 | 31.8 | 31.1 | 29.6 | 27.0 | 22.2 | 15.6 | 10.4 | 21.8 |
| Min | -0.4 | 1.4 | 4.3 | 8.9 | 13.8 | 17.9 | 17.8 | 18.1 | 14.7 | 10.3 | 4.0 | -0.4 | 9.2 |
| Average Precipitation (cm) | | | | | | | | | | | | | |
| Total | 1.5 | 0.8 | 1.1 | 1.4 | 2.7 | 3.7 | 5.7 | 5.7 | 5.3 | 3.0 | 1.2 | 1.7 | 33.9 |

#### *2.1.3 Visitation Statistics*

Since recordkeeping began in 1971, GUMO has received over 6.3 million visitors (NPS 2012b). Over the past decade, visitation has averaged around 178,360 recreational visitors annually with the majority of visits occurring in the spring and fall (NPS 2012b). An average of 17,000 to 18,000 people camp in the park each year. Popular activities include hiking, birdwatching, stargazing, visiting the Frijole Ranch History Museum, and viewing the fall colors in McKittrick Canyon (NPS 2012c).

### 2.2 Natural Resources

#### *2.2.1 Ecological Units and Watersheds*

The majority of GUMO is part of the Environmental Protection Agency's (EPA) Chihuahuan Deserts Level III Ecoregion. This ecoregion stretches from southeastern Arizona to the Edwards Plateau in south-central Texas. According to the EPA (2010, p. 5),

> the physiography is generally a continuation of basin and range terrain that is typical of the Mojave Basin and Range and the Central Basin and Range to the west and northwest… Vegetative cover is predominantly desert grassland and shrubland, except on the higher mountains where oak, juniper, and pinyon woodlands occur. The extent of desert shrubland is increasing across lowlands and mountain foothills due to the gradual desertification caused in part by historical grazing pressure.

The EPA divides Level III Ecoregions into smaller Level IV Ecoregions. The portion of the Chihuahuan Deserts ecoregion within GUMO includes two Level IV Ecoregions: the Chihuahuan Desert Grasslands and the Chihuahuan Basins and Playas (Figure 1) (EPA 2010).

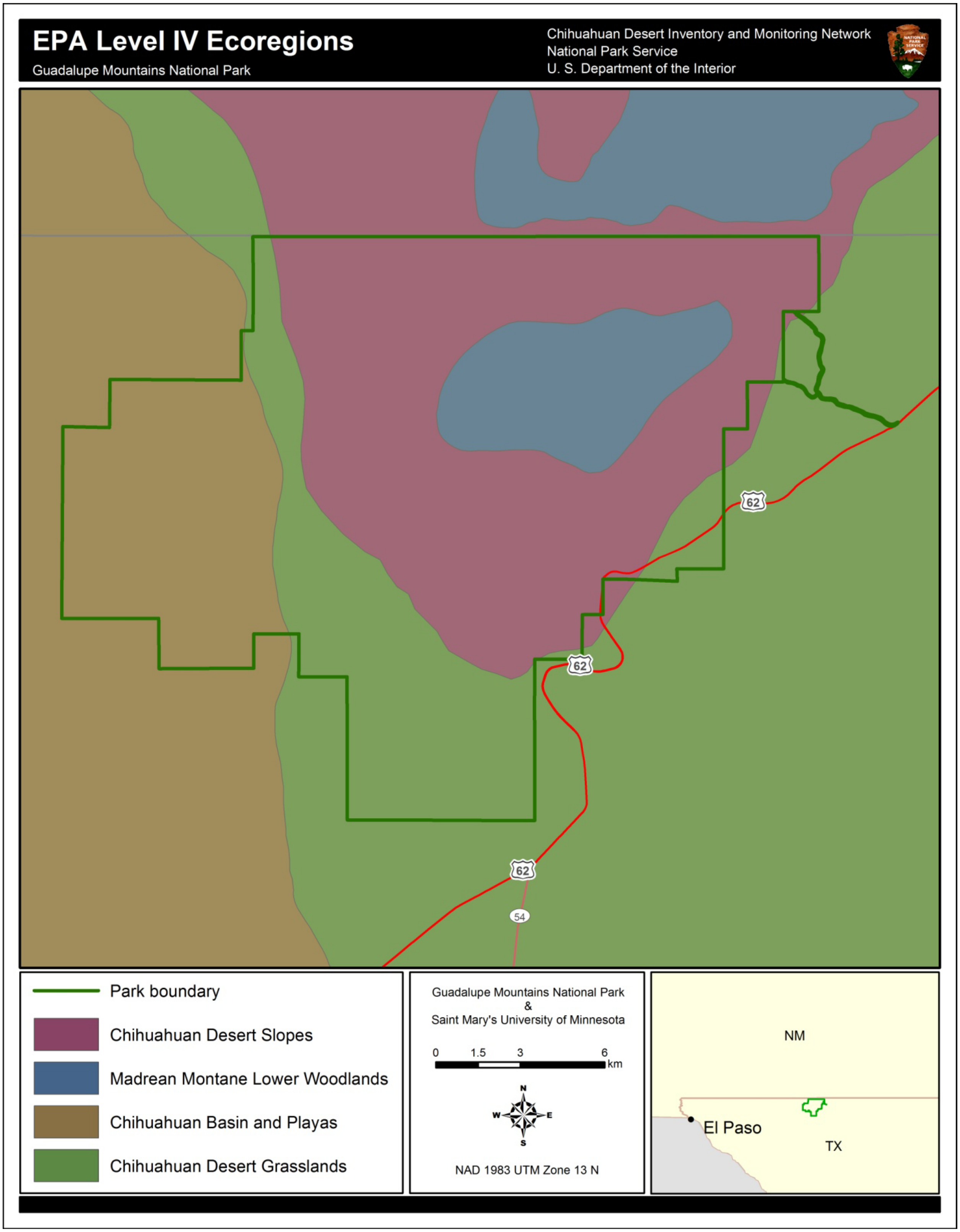


**Figure 1.** EPA Level IV ecoregions within GUMO (EPA 2011).

A small northern portion of the park belongs to the Arizona/New Mexico Mountains Level III Ecoregion, "distinguished from neighboring mountainous ecoregions by their lower elevations and an associated vegetation indicative of drier, warmer environments, which is due in part to the region's more southerly location" (EPA 2010, p. 5). Douglas-fir (*Pseudotsuga menziesii*) occurs occasionally at higher elevations, although these elevations typically are covered with ponderosa pine (*Pinus ponderosa*) at varying densities. Middle elevations generally support oak and pinyon-juniper woodlands while chaparral (shrubs and small trees) is prevalent at lower elevations. This ecoregion within the park is further divided into the Chihuahuan Desert Slopes and the Madrean Lower Montane Woodlands Level IV Ecoregions (EPA 2010, Figure 1).

**Photo 2.** Bone Spring (NPS photo).

Many of the park's water resources are seasonal; only one perennial stream (McKittrick) and 25 semipermanent springs occur within park boundaries (Kirsten Gallo, CHDN Program Coordinator, written communication, 22 February 2013). The park lies within three separate watersheds. The majority of GUMO drains to the west into the Salt Basin watershed, while northeastern portions of the park are in the Delaware and Upper Pecos-Black watersheds, draining eastward (Plate 1, USGS 1994).

#### *2.2.2 Resource Descriptions*

Due to its location at the "interface" of three biomes (Chihuahuan Desert, Rocky Mountains, and Great Plains), GUMO supports a number of diverse ecosystems (NPS 2009). While much of the park consists of desert scrub and semi-desert grassland, GUMO also contains canyon/riparian areas with deciduous woodlands and a montane or "sky island" forest in the north (Plate 2). The western portion of the park contains rare gypsum dunes that support a unique combination of plant and wildlife species (NPS 2009). Seven vegetation types have been identified within the park that correspond with the Brown-Lowe-Pase biome classification system (Brown 1994) for southwestern biotic communities. These vegetation types are shown in Figure 2.

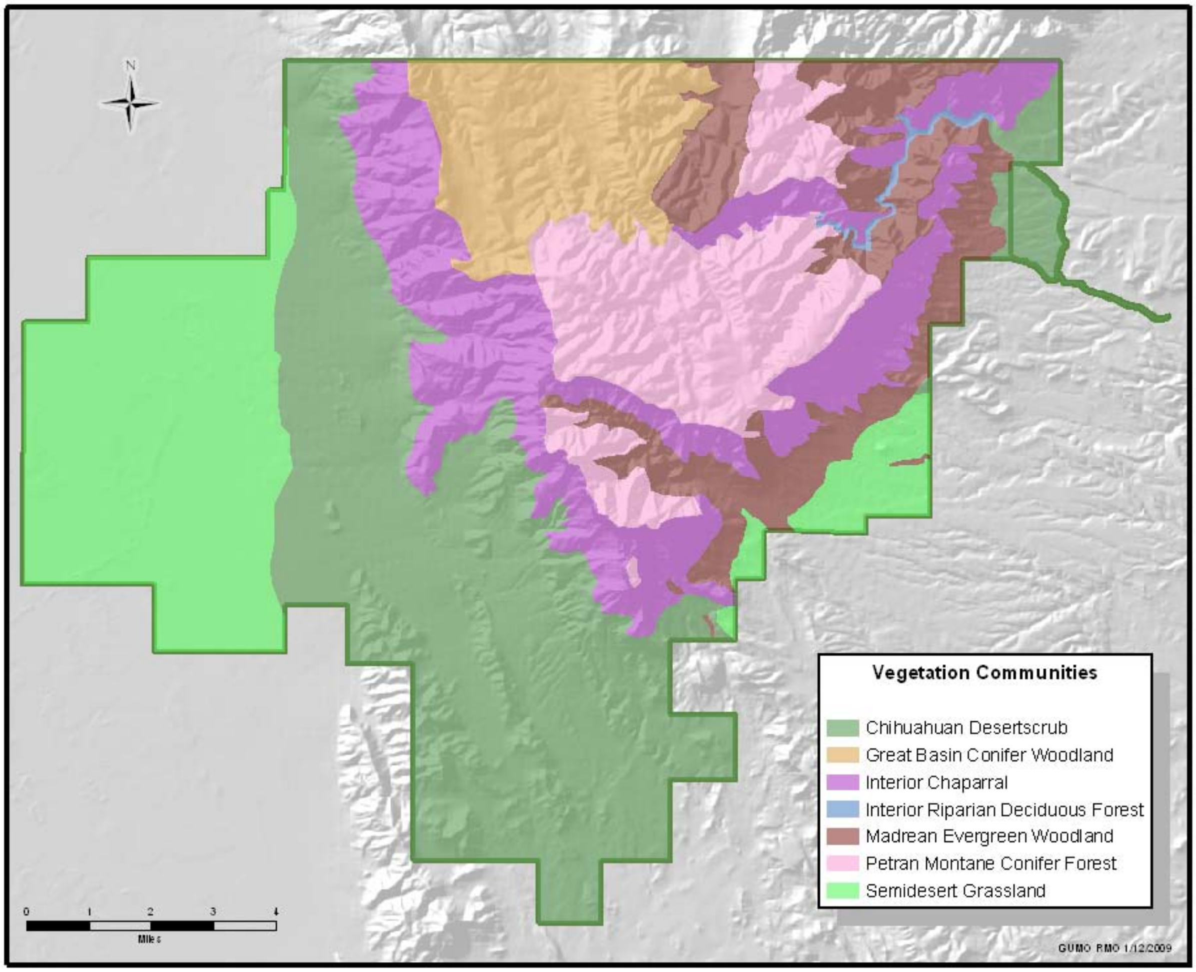


**Figure 2.** Vegetation types in GUMO, as classified and described by the Brown-Lowe-Pase biome classification system (NPS 2009).

Over 1,000 plant species have been documented in GUMO; 37 of these have been identified as species of special concern and 16 species are endemic to the Guadalupe Mountains (NPS 2012a). Unique taxa, such as the McKittrick pennyroyal (*Hedeoma apiculata*) and Guadalupe Mountains violet (*Viola guadalupensis*), are found on the park's limestone cliffs, in wooded canyons, and along streams (NPS 2012a).

The diverse habitats of GUMO are home to a surprising array of wildlife. Sixty species of mammals, over 260 bird species, and 55 reptile and amphibian species have been documented in the park (NPS 2009). Mammals observed in the park include mule deer (*Odocoileus hemionus*), javelina (*Tayassu tajacu*), coyote (*Canis latrans*), ringtail (*Bassariscus astutus*), and rabbits. Mountain lions (*Puma concolor*) and black bears

**Photo 3.** Black bear (NPS photo by Reine Wonite).

(*Ursus americanus*; Photo 3) are also occasionally spotted in the park.

Of the over 260 bird species observed in GUMO, 94 species are known to breed within the park (NPS 2012a). The organization Partners-In-Flight (PIF) has identified GUMO as an "Important Bird Area", supporting several species of concern such as the yellow-billed cuckoo (*Coccyzus americanus*), peregrine falcon (*Falco peregrinus*) and the Mexican spotted owl (*Strix occidentalis lucida*), which is federally listed as a threatened species (NPS 2012a).

Lizards and snakes are common in GUMO, including five species of rattlesnakes (NPS 2012a). Turtles and amphibians are present but are less common. Invertebrates such as grasshoppers, scorpions, and spiders are found throughout the park while butterflies occur in canyon areas (NPS 2012a).

According to NPS (2009), every geological formation in GUMO contains marine fossils, and fossils are visible along nearly every mile of the park's trails. An estimated 800-1,200 fossil species occur in the park, including 22 fossil type localities (the location where a fossil or rock type is first identified) (NPS 2009). Three locations in GUMO have been designated as global stratotype sections for the middle Permian Series (Roadian, Wordian, and Capitanian Stages), recognized as "having the world's best geological and paleontological record of any rock of its age" (KellerLynn 2008, NPS 2009, p. 33).

#### *2.2.3. Resource Issues Overview*

Due to its remote nature and often inhospitable climate, GUMO has largely escaped serious impact from human activities. While European settlement began in the mid-1800s, ranching and grazing did not intensify until the early 20$^{th}$ century (NPS 2012a). Grazing reduces the fine grass fuels required to carry fire, which has historically been an important natural disturbance process in GUMO (Sakulich and Taylor 2007, NPS 2009). As a result, fire frequency and extent decreased dramatically, particularly in the montane mixed conifer forests. This has greatly altered the region's natural fire regime and, in turn, forest structure (Sakulich and Taylor 2007). Fuel build-ups due to lack of fire can cause wildfires, when they do occur, to be more intense and therefore more dangerous than under the natural fire regime (Andersen 2003, Sakulich and Taylor 2007). Grazing also set back semidesert grassland vegetation, allowing desertscrub habitats to expand (Burgess and Klein 1978).

Exotic plants are an increasing threat to natural areas across the country. Many of these species have the ability to outcompete native plants and can alter ecological processes such as fire (Brooks and Pyke 2001, Reiser et al. 2012). In 2011, the CHDN surveyed 16.1 km (10.0 mi) along seven GUMO roads and trails for exotic plants (Reiser et al. 2012). In 2012, the CHDN's exotic plants field crew surveyed 16.75 km (10.4 mi) along twelve roads and trails in the park (NPS 2012d). Areas were divided into 50-m vector blocks and crews recorded the number of blocks in which exotic species were present. Sixteen exotics were observed in 2011 and 13 during the 2012 field season, including bermudagrass (*Cynodon dactylon*), Lehmann lovegrass (*Eragrostis lehmannia*), and common mullein (*Verbascum thapsus*). Overall, 42% of the blocks sampled contained exotic plants in 2011, but only 15% of blocks contained exotics in 2012 (NPS 2012d, Reiser et al. 2012). These differences are primarily due to the changes in areas surveyed. U.S. Highway 62/180, Dog Canyon and the New Corral Roads were not surveyed in the 2012 field season. Those three areas had high infestation rates, compared to the backcountry trails that were added in 2012 (CHDN 2012). Full species lists from the 2011 and 2012 surveys, with locations by species, are presented in Table 2 and Table 3. Table 4 is a list of all exotic plants (48 species) documented within GUMO since park establishment.

**Table 2.** Exotic species documented in GUMO by the CHDN in 2011 with the number of 50-meter vector blocks they were observed in at the seven locations surveyed (Reiser et al. 2012).

| Scientific name | Common name | US Hwy 62/180 | Employee Road | Pine Camp Loop | Dog Canyon Rd. | New Corral Rd. | Frijole Ranch Rd. | Tejas Trail | 2011 Total |
|---|---|---|---|---|---|---|---|---|---|
| *Apium graveolens* | wild celery | | 1 | | | | | | 1 |
| *Bromus catharticus* | rescuegrass | | | 2 | | | | | 2 |
| *Centaurea melitensis* | Maltese star-thistle | | 1 | | | | | | 1 |
| *Cynodon dactylon* | bermudagrass | 45 | 4 | | 19 | 2 | | | 70 |
| *Eragrostis cilianensis* | stinkgrass | 2 | | | 7 | | | 6 | 15 |
| *Eragrostis lehmanniana* | Lehmann lovegrass | 60 | 5 | | | 3 | | | 68 |
| *Erodium cicutarium* | redstem stork's bill | | | | 22 | | | 10 | 32 |
| *Marrubium vulgare* | horehound | 9 | 6 | | 26 | 5 | 1 | 12 | 59 |
| *Melilotus* spp. | sweetclover | 42 | 6 | | | | | | 48 |
| *Salsola kali* | Russian thistle | 2 | | | | 1 | | | 3 |
| *Setaria viridis* | green bristlegrass | 2 | | | | | | | 2 |
| *Sorghum halepense* | Johnsongrass | 50 | 2 | | | | | | 52 |
| *Taraxacum officinale* | common dandelion | | | | | | | 1 | 1 |
| *Tragopogon dubius* | yellow salsify | | | | | | | 4 | 4 |
| *Verbascum thapsus* | common mullein | 10 | | | 31 | | | 30 | 71 |
| *Xanthium spinosum* | spiny cocklebur | | | | 4 | | | 1 | 5 |

**Table 3.** Exotic species documented in GUMO by the CHDN in 2012 with the number of 50-meter vector blocks they were observed in at ten survey locations (NPS 2012d).

| Scientific name | Common name | El Capitan Trail | Employee Road | Frijole Trail | Guadalupe Peak Trail | Permian Reef Geology Trail | Pine Camp Loop | RV Camp Loop | Smith Spring Trail | Tejas Trail - VC | VC/ Campground Road | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bothriochloa ischaemum* | King Ranch bluestem | | 10 | | | | | 2 | | | 1 | 13 |
| *Centaurea melitensis* | Maltese star-thistle | | 1 | | | | | | | | | 1 |
| *Cynodon dactylon* | bermudagrass | | | | | | | 3 | 3 | | 1 | 7 |
| *Eragrostis cilianensis* | stinkgrass | | 3 | | | | | | | | | 3 |
| *Eragrostis lehmanniana* | Lehmann lovegrass | | 4 | 3 | 1 | 2 | 4 | 2 | | 1 | 3 | 20 |
| *Erodium cicutarium* | redstem stork's bill | | 2 | | | | | | | | | 2 |
| *Marrubium vulgare* | horehound | 1 | 2 | | | | | 3 | | | | 6 |
| *Melilotus officinalis* | yellow sweetclover | | 2 | | | | | | | | | 2 |
| *Salsola kali* | Russian thistle | 9 | 2 | 3 | | | | | | | 1 | 15 |
| *Salsola tragus* | prickly Russian thistle | 13 | 3 | 4 | | | | | | | 3 | 23 |
| *Sorghum halepense* | Johnsongrass | | 1 | | | | | | | | | 1 |
| *Tragopogon dubius* | yellow salsify | | 1 | | | | | | | | 2 | 3 |
| *Verbascum thapsus* | common mullein | | 1 | | | | | | | | | 1 |

**Table 4.** Exotic plant species documented in GUMO (NPS 2010, Reiser et al. 2012).

| Scientific name | Common name | Scientific name | Common name |
|---|---|---|---|
| *Amaranthus albus* | tumbleweed amaranth | *Poa annua* | annual bluegrass |
| *Ammi visnaga* | toothpick ammi | *Polypogon monspeliensis* | rabbitfoot polypogon |
| *Apium graveolens* | wild celery | *Polypogon viridis* | water bentgrass |
| *Avena fatua* | common oat | *Prunus armeniaca* | apricot |
| *Bothriochloa ischaemum* | King Ranch bluestem | | |
| *Bromus catharticus* | rescuegrass | *Rorippa nasturtium-aquaticum* | watercress |
| *Bromus japonicus* | Japanese brome | *Salsola collina* | spineless Russian thistle |
| | | *Salsola kali* | Russian thistle |
| *Bromus tectorum* | cheatgrass | *Salsola tragus* | prickly Russian thistle, tumbleweed |
| *Caesalpinia gilliesii* | bird-of-paradise flower | *Setaria viridis* | green bristlegrass |
| *Centaurea melitensis* | Malta starthistle | *Silene gallica* | forked catchfly |
| *Convolvulus arvensis* | field bindweed | *Sonchus asper* | spiny sow thistle |
| *Cynodon dactylon* | Bermudagrass | *Sonchus oleraceus* | common sow thistle |
| *Descurainia sophia* | flixweed tansymustard | *Sorghum halepense* | Johnson grass |
| *Echinochloa crusgalli* | barnyard grass | *Tamarix ramosissima* | salt cedar, tamarisk |
| *Eragrostis cilianensis* | stinkgrass | *Taraxacum officinale* | common dandelion |
| *Eragrostis lehmanniana* | Lehmann lovegrass | | |
| *Erodium cicutarium* | redstem stork's bill | *Tragopogon dubius* | salsify |
| *Marrubium vulgare* | common horehound | *Tragopogon porrifolius* | goat's beard |
| *Medicago lupulina* | black medick | *Tragus berteronianus* | spike burgrass |
| *Medicago sativa* | alfalfa | *Tribulus terrestris* | puncture vine |
| *Melilotus officinalis* | yellow sweetclover | *Triticum aestivum* | wheat |
| *Mentha spicata* | spearmint | *Ulmus pumila* | Chinese elm |
| *Peganum harmala* | African rue | *Verbascum thapsus* | common mullein |
| *Plantago lanceolata* | buckhorn plantain | *Xanthium spinosum* | spiny cocklebur |
| *Plantago major* | dooryard plantain | | |

To date, only two exotic mammal species have been documented in the park: feral hogs (*Sus scrofa*) and aoudad (*Ammotragus lervia*). Feral hogs, first documented in the park in 2009, can disturb and even destroy native vegetation with their rooting and wallowing, particularly in riparian areas (Fred Armstrong, former GUMO Chief or Resource Management, phone communication, 27 September 2011; Taylor 2012). An encroaching exotic species, the bullfrog (*Lithobates catesbeianus*), could have a serious impact if it becomes established in the park. This species can aggressively compete with and/or prey upon native amphibians and other wildlife (Rosen and Schwalbe 1995). Non-native rainbow trout (*Oncorhynchus mykiss*) were introduced to McKittrick Creek during the 1920s and are still found in the stream (Shepherd 2012); however, it is unclear if they have affected native fish populations or the stream ecosystem.

Climate change is a significant concern within the CHDN. Potential effects of climate change in the region include higher temperatures, more frequent extreme events, and shifts in the amount and seasonality of precipitation (NAST 2001, as cited by Davey et al. 2007). Warmer temperatures could accelerate the evapotranspiration process, resulting in less available moisture in an already arid environment. These climate changes could also influence plant distributions, landscape connectivity (which would affect wildlife movements), insect and disease outbreaks, and disturbance regimes (e.g, fire, flooding, erosion) (Davey et al. 2007).

## 2.3 Resource Stewardship

### *2.3.1 Management Directives and Planning Guidance*

According to the GUMO Resource Stewardship Strategy (RSS), the current purposes of the park are:

- To preserve an area possessing outstanding, globally unique geological features together with scenic, natural, and cultural values of great significance;

- To manage a designated wilderness area where the earth and its community of life are untrammeled, and where humans are visitors who do not remain;

- To provide opportunities for visitors to understand, enjoy, appreciate, and experience the unique nature of the park;

- To provide educational and research opportunities that enhance stewardship and wider understanding of resources (NPS 2009).

### *2.3.2 Status of Supporting Science*

The CHDN selects 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 2010, the CHDN completed and released a Vital Signs monitoring plan (NPS 2010). Table 5 shows the network Vital Signs selected for monitoring in GUMO.

**Table 5.** CHDN Vital Signs selected for monitoring in GUMO (NPS 2010). Bold indicates Vital Signs being monitored by a network park, another NPS program, or another federal or state agency, using other funding. The network will collaborate with or supplement these efforts. Italics indicate Vital Signs which the network is currently monitoring or will implement monitoring protocols for using funding from the Vital Signs or water quality monitoring programs, or in concert with other networks. Monitoring of remaining Vital Signs cannot be implemented at this time due to limited staff and funding.

| Category | CHDN Vital Signs |
|---|---|
| Air and Climate | **Ozone**, **wet and dry deposition**, **visibility and particulate matter**, **and basic meteorology** |
| Geology & Soils | Dune formation and stability, dune morphology, *soil hydrologic function, biological soil crusts, and soil erosion (wind and water)* |
| Water | *Groundwater quantity, surface water dynamics*, *persistence of springs, surface water quality, and aquatic invertebrates* |
| Biological Integrity | *Invasive/non-native plants, plant community composition, bird communities,* and heteromyid rodent communities |
| Landscapes | *Land cover, land-use changes* |

While this NRCA was underway, the CHDN was completing a park-wide vegetation classification and mapping project at GUMO (Muldavin et al., *in prep.*). This study provided valuable data regarding the extent and composition of the park's various ecological communities. The Muldavin et al. (*in prep.*) project divided the park into many small vegetation types or mapping units; the NRCA, in contrast, focuses on broader ecological communities of interest to park management. Table 6 shows which of the mapping units utilized by Muldavin et al. (*in prep.*) were included within each community discussed in this NRCA.

**Table 6.** Vegetation mapping units (as defined by Muldavin et al., *in prep.*) included for each ecological community addressed in this NRCA (Plate 2).

| Ecological Community in NRCA | Mapping unit (Muldavin et al., *in prep.*) |
|---|---|
| Dune Communities | **Gypsum Chihuahuan Semidesert Grassland** - Gypsum Dune Semidesert Grassland, Gypsum Flat Dropseed Grassland<br>**Gypsum Desertscrub -** Gypsum Flat Desertscrub, Frosted Mint Gypsum Dune Desertscrub, Fourwing Saltbush Gypsum Desertscrub<br>**Chihuahuan Desertscrub -** Honey Mesquite-Broom Dalea Coppice Dune |
| Sky Island/ Montane Forest | **Madrean Upper Montane Conifer-Oak Forest & Woodland -** Mixed Conifer Woodland Savanna, Mixed Conifer -Gambel Oak Forest, Mixed Conifer -Bigtooth Maple-Knowlton's Hophornbeam Forest, Mixed Conifer Maple and Chinkapin Oak Forest<br>**Madrean Lower Montane Pine-Oak Forest & Woodland -** Madrean Ponderosa Pine Woodland Savanna, Madrean Ponderosa Pine -Gambel Oak Forest, Madrean Ponderosa Pine Bigtooth Maple and Chinkapin Oak Forest<br>**Madrean Upper Montane Broadleaf Forest & Woodland -** Madrean Bigtooth Maple -Oak Woodland<br>**Madrean Pinyon-Juniper Woodland -** Madrean Pinyon-Alligator Juniper Woodland, Madrean Pinyon-Alligator Juniper Woodland Savanna, Madrean Pinyon and Juniper-Wavyleaf Oak-Mountain Mahogany Woodland |
| Riparian/Canyon | **Madrean Encinal Group (upland) -** Madrean Gray Oak-Alligator Juniper Woodland, Madrean Gray Oak-Alligator Juniper Savanna<br>**Warm Semidesert Shrub & Herb Wash-Arroyo -** Apache Plume Dry Wash Riparian Shrubland, Desert Willow Dry Wash Riparian Shrubland, Chihuahuan Desert Scrub Dry Wash Riparian Shrubland<br>**Sonoran-Chihuahuan Lowland Riparian Forest -** Mixed Riparian Woodland, Madrean Evergreen Riparian Dry Wash Woodland and Shrubland<br>**Riparian/Wetland -** Herbaceous Wetland |
| Semidesert Grasslands | **Southwest Foothill-Mesa Grasslands -** Needlegrass Foothill Grassland, Finestem Needlegrass Foothill Grassland, Grama Foothill Grassland, Grama Grasslands with Pinchot Juniper<br>**Chihuahuan Semidesert Grasslands -** Curlyleaf Muhly Semidesert Grassland, Green Sotol-Sacahuista Semidesert Grassland, Grama Upper Bajada-Foothill Semidesert Grassland, Black Grama Yucca-Mixed Grassland |
| Desertscrub | **Chihuahuan Desertscrub -** Mariola-Goldeneye Desertscrub, Ocotillo-Cactus Desertscrub, Viscid Acacia Desertscrub, Catclaw Mimosa Desertscrub, Fourwing Saltbush Desertscrub, Creosotebush Desertscrub, Creostoebush Desertscrub with Honey Mesquite |

**Photo 4.** Prickly pear in a GUMO desertscrub community (photo by Kathy Kilkus, SMUMN GSS, 2012).

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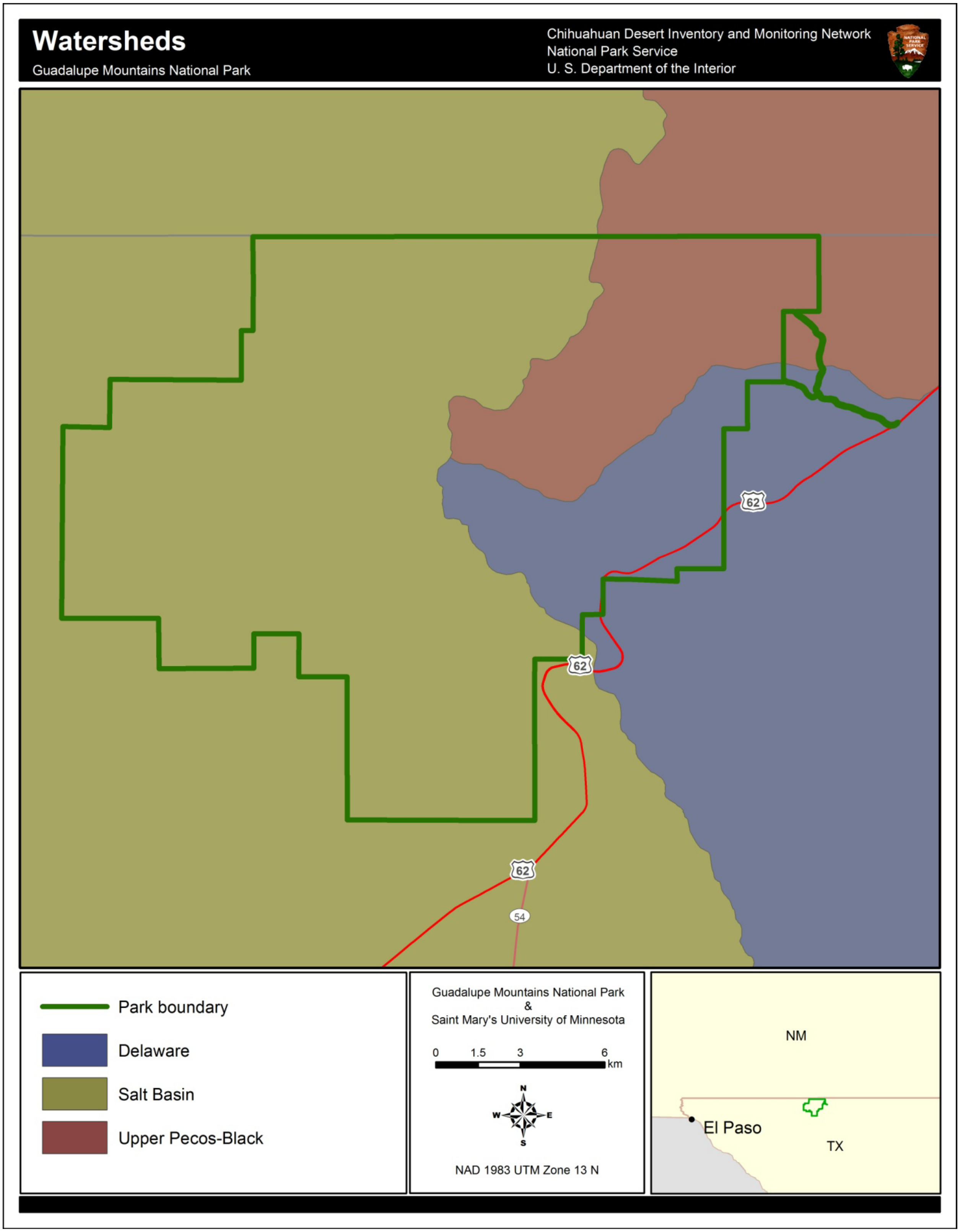


**Plate 1.** Watersheds within GUMO (USGS 1994).

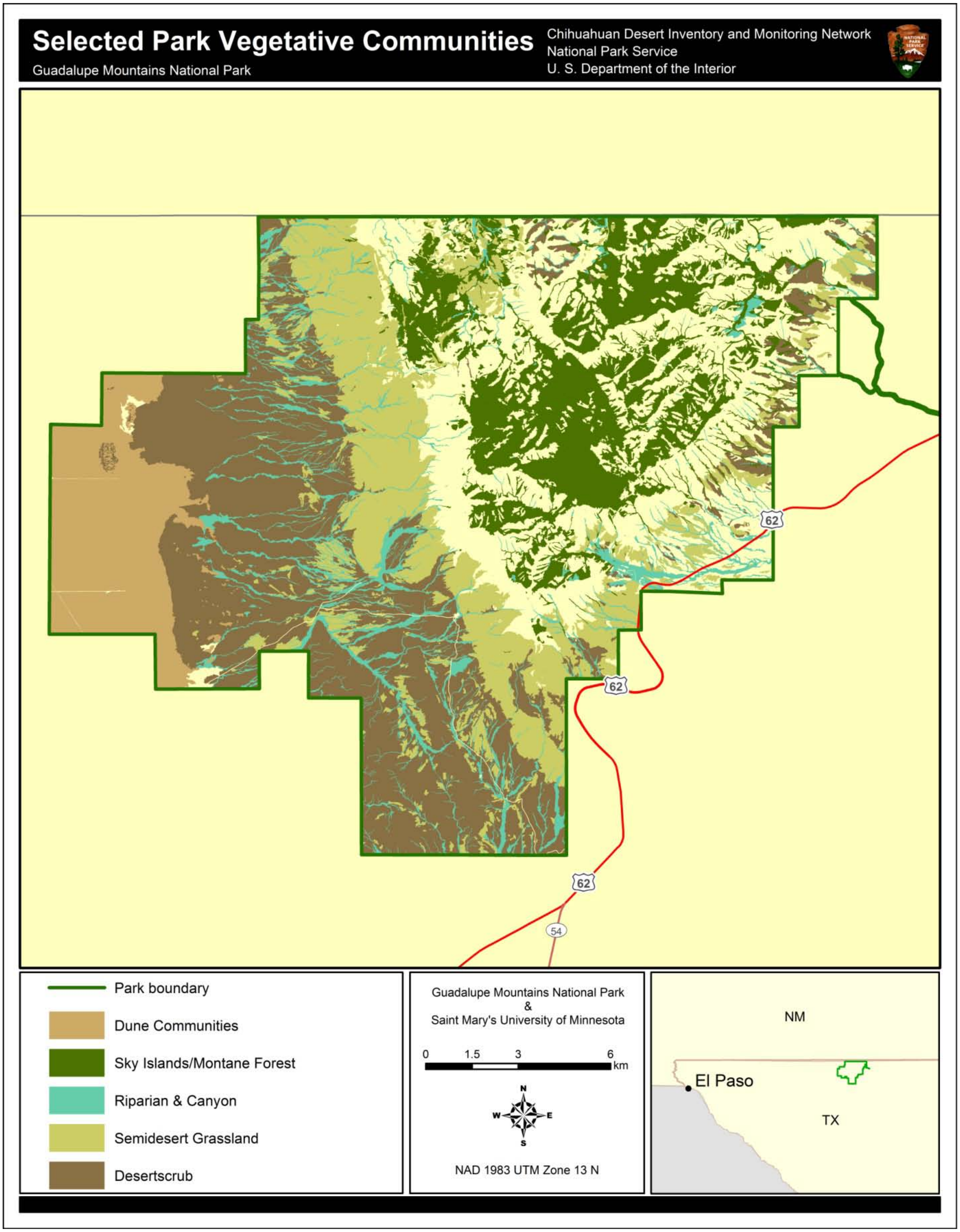


**Plate 2.** The distribution of park vegetation communities selected for assessment in this NRCA project (Muldavin et al., *in prep.*).

# Chapter 3 Study Scoping and Design

This NRCA is a collaborative project between the NPS and Saint Mary's University of Minnesota Geospatial Services (SMUMN GSS). Project stakeholders include the GUMO resource management team and CHDN 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 on 24-25 January 2012. At this meeting, SMUMN GSS and NPS staff confirmed that the purpose of the GUMO 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 GUMO 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 GUMO 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 GUMO 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: GUMO resource staff, the NPS Integrated Resource Management Application (IRMA) website, Inventory and Monitoring Vital Signs program, 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, plant communities), 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 agent that imposes adverse changes upon a component. 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 (adapted from GLEI 2010).

During the GUMO 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 GUMO. 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) (adapted from 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 GUMO Resource Stewardship Strategy (RSS) (NPS 2009). 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 in February 2012 following acceptance from NPS resource staff. It contains a total of 16 components (Table 7) 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 7.** Guadalupe Mountains National Park natural resource condition assessment framework.

## Guadalupe Mountains National Park
### Natural Resource Condition Assessment Framework

| | Component | Measures | Stressors | Reference Condition |
|---|---|---|---|---|
| **Ecosystem Extent and Function** | | | | |
| *Disturbance Regimes* | | | | |
| | Fire Regime | Frequency, severity, fuel loading and distribution, location, intensity | Current climate and weather patterns, past grazing practices, historic fire suppression | Pre-European settlement |
| **Biotic Composition** | | | | |
| *Ecological Communities* | | | | |
| | Dune Communities | Small mammal species richness and diversity, plant species richness and extent of the vegetation community, changes in dune morphology, movement, and mass using LiDAR, biological soil crust resilience and resistance | Increased visitor use, external minerals development, shallow water aquifer withdrawl, off-road vehicle use, Desalinization plant | Current condition of dune community (early 21st century) |
| | Sky Islands (Montane Forest) | Change in vegetation community extent, change in plant species richness, change in incidence of forest diseases and pests, age class structure | Exotic species, drought and extreme fire, historic land practices (grazing and browsing), air pollutants, climate change, | Pre-European settlement |
| | Riparian and Canyon Communities | Change in vegetation community extent, change in plant species richness, aquatic macroinvertebrate diversity | Wildfire, exotic plants and animals, visitor use, climate change reducing available moisture, flash floods | Community extent: no change from current condition. Species richness: Gehlbach's 1950s and 1960s surveys. Macroinvertebrate diversity: Green's (1993) survey of McKittrick Creek |
| | Semidesert Grasslands | Change in vegetation community extent, change in plant species richness, winter grassland bird diversity, | Woody species encroachment, fires outside the natural regime, exotic plants, human ground disturbing activities. | No degradation beyond early 21st century condition |
| | Desertscrub | Change in vegetation community extent, change in plant species richness, heteromyid diversity | Invasion of non-native grasses, potential threats from cactus poaching (currently minimal), drought (for heteromyids) | No degradation beyond early 21st century condition |
| *Birds* | | | | |
| | Birds | Species richness, breeding bird diversity, Mexican Spotted Owl occupancy, population trends of species of concern | Land cover change and habitat fragmentation, energy development, (wind, oil, and gas), catastrophic fire (particularly for canyon and cavity nesting species) | Newman's (1975) survey results, 1972-1974 |
| *Herptiles* | | | | |
| | Reptiles | Species diversity, distribution | Poaching, habitat change (vegetation), change in visitor use patterns | Bailey (1905) |
| *Mammals* | | | | |
| | Mountain Lion | Population trends | Predator control practices outside of the park, competition between non-native aoudad and mule deer (mountain lion's primary prey) | Genoways et al. (1979) |
| **Environmental Quality** | | | | |
| | Air Quality | Sulfate deposition, nitrogen deposition, ozone, PM 2.5, visibility | Oil and gas development, proposed desalinization plant, smog and pollution from industrial and vehicle sources, dust from unpaved roads and other sources | NPS ARD air quality index values |
| | Water Quality | Total dissolved solids (TDS), chloride, sulfate, dissolved oxygen, coliform bacteria, aquatic macroinvertebrates, stream and spring flow rates | Proposed desalinization plant adjacent to the park; groundwater withdrawals | TCEQ water quality criterion for surface waters; maintain "ecologically unique river and stream segment" designations |
| | Soundscape | Percent of time human caused sounds audible per day (back and front country, daytime and nighttime), sound level as expressed by hourly decibel level (back and front country, daytime and nighttime) | Local development, aircraft noise, highway traffic, human noises | As outlined in park's RSS for backcountry and frontcountry, daytime and nighttime |

**Table 7.** Guadalupe Mountains National Park natural resource condition assessment framework. (continued)

**Guadalupe Mountains National Park**
**Natural Resource Condition Assessment Framework**

| Component | Measures | Stressors | Reference Condition |
|---|---|---|---|
| **Environmental Quality** | | | |
| Viewscape | Change in land use cover type inside the park (internal viewscape), change in land use cover type outside the park (external viewscape) | Energy development (wind, solar), traffic and road use, air pollution reducing visibility | No significant change, as measured by GIS and aerial photography |
| Dark Night Skies | A suite of measures, as identified by the NPS Night Sky Team (e.g., V-Magnitude) | Development - proposed desalinization plant, lights from energy development, local rest area, and park infrastructure; light domes from El Paso, Dell City, Carlsbad | Absence of anthropogenic light |
| **Physical Characteristics** | | | |
| *Geologic and Hydrologic* | | | |
| Hydrology | Stream and spring flow rates, shallow groundwater aquifer flow rate and direction, depth to groundwater, groundwater water quality | Proposed desalinization plant, groundwater withdrawals, irrigation, increased development surrounding park, growth of El Paso and other cities (increased water demand) | Maintenance of the existing shallow ground water table (as of 2012) and no further degradation to ground water quality |
| Geological and Paleonotolgical Resources | Change in specimen abundance at paleo localities (based on actual loss score), annual number of case incident reports related to geologic/paleo sites, documentation of all paleo/geologic sites in the park | Theft and vandalism, impacts from visitor use, impacts from trail maintenance and development, inappropriate sampling techniques | Change in specimen abundance: actual loss score of 20 for each locality. Number of case incident reports: no annual increase over a 5-year period. Site documentation: no reference condition |

### *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 GUMO 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 also provided by NPS staff. Additional data and literature were 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, as well as recommendations from NPS reviewers and sources of expertise including NPS staff from GUMO and the CHDN. 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 8. 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. Significance Levels were determined for each component measure in this assessment through discussions with park staff and/or outside resource experts.

**Table 8**. 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 9). This is based on all the available literature and data reviewed for the component, as well as communications with park and outside experts.

**Table 9.** Scale for Condition Level of individual measures.

| Condition Level (CL) | Description |
|---|---|
| 0 | Of **NO** concern. 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 **HIGH** 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: condition of low concern (WCS = 0.0 – 0.33); condition of moderate concern (WCS = 0.34 - 0.66); and condition of significant concern (WCS = 0.67 to 1.00). Figure 3 displays all of the potential graphics 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 a condition of low concern. Gray circles are used to represent situations in which SMUMN GSS analysts and park staff felt there were currently insufficient data to make a statement about the condition of a component. For example, condition is not assessed when no recent data or information are available, as the purpose of an NRCA is to provide a "snapshot-in-time" of current resource conditions. 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. A right-pointing arrow 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. A gray, triple-pointed arrow is reserved for situations in which the trend of the component's condition is currently unknown.

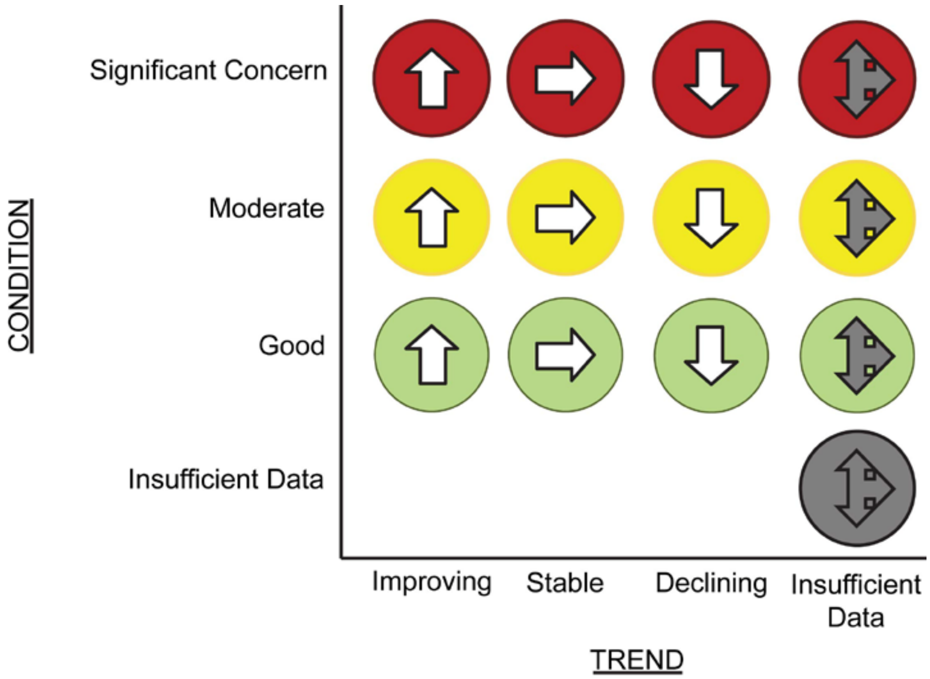


**Figure 3**. Symbols used for individual component assessments with condition or concern designations along the vertical axis and trend designations along the horizontal.

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 GUMO and CHDN 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 e-mail conversation 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 GUMO 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 outside 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. 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.

*Literature Cited*
This is a list of formal citations for literature or datasets used in the analysis and assessment of condition for the resource component. Note, citations used in appendices and plates referenced in each section (component) of Chapter 4 are listed in that component's "Literature Cited" section.

***Literature Cited***

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Stoddard. J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. J. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16(4):1267-1276.

# Chapter 4 Natural Resource Conditions

This chapter presents the background, analysis, and condition summaries for the 16 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 7):

4.1 Fire Regime
4.2 Dune Communities
4.3 Sky Islands (Montane Forest)
4.4 Riparian and Canyon Communities
4.5 Semidesert Grasslands
4.6 Desertscrub
4.7 Birds
4.8 Reptiles
4.9 Mountain Lion
4.10 Air Quality
4.11 Water Quality
4.12 Soundscape
4.13 Viewscape
4.14 Dark Night Skies
4.15 Hydrology
4.16 Geological and Paleontological Resources

## 4.1 Fire Regime

***Description***

Fire is a significant natural process in GUMO and was historically an important source of disturbance in mixed conifer forests throughout the southwestern U.S. (Sakulich and Taylor 2007, NPS 2009). Fire strongly influences the park's vegetation communities and ecosystem processes, which in turn impacts wildlife habitat (NPS 2009). It can accelerate nutrient cycling, control insects and plant diseases, and increase plant and habitat diversity by creating a variety of successional stages in the environment. These contributions lead to a more resilient (e.g., disaster-resistant) ecosystem (NPS 2009; Richard Gatewood, NPS Fire Ecologist, written communication, 29 October 2012). The term "fire regime" refers to several characteristics of fire occurrence in an area, including frequency, severity, and seasonality.

Prior to European settlement, evidence suggests that low-intensity ground fires were common in the Guadalupe Mountains' conifer forests (Ahlstrand and Cline 1978, Stubbs 1998). With the introduction of grazing in the 1920s, which reduced the fine grass fuels necessary to carry low intensity fires, fire frequency and extent decreased dramatically in these forests and in other ecosystems within the park (Ahlstrand 1982, Sakulich and Taylor 2007). This, combined with a federal policy of fire suppression, has greatly altered natural fire regimes and, therefore, forest structure over the past century (Sakulich and Taylor 2007). Conifer stands are now much denser because young trees are no longer thinned by low intensity fires (Fulé et al. 1997, 2003; Sakulich and Taylor 2007). As a result of this increase in woody fuels, fires are often more intense, burning larger areas with higher severity (Allen et al. 2002, Andersen 2003, Sakulich and Taylor 2007).

Fire season in GUMO generally runs from March to November, peaking in May and June, although fires have occurred during every month of the year due to the park's arid climate (NPS 2005). Lightning is the primary natural cause of fires in the park, particularly during the rainy season (July-October); however, fires spread slowly at this time due to higher humidity and green vegetation (NPS 2005). Earlier in the season, fires have the potential to move very quickly (30 m/min) and grow rapidly (200 ha/hr). Such extreme behavior is typically due to high winds, hot temperatures, and very low humidity (NPS 2005). The NPS has found that most suppression efforts are ineffective at these times, until there is a change in the weather.

**Photo 5.** Smoke from the El Capitan fire in May 2012 (NPS photo by Christie La Paz).

Federal fire management policies have evolved over the past several decades, and fire is now recognized as "a critical natural process" that should be reintroduced into ecosystems where it occurred historically (Glickman and Babbitt 1995, p. iii). This policy also acknowledges that fuel accumulation over time can lead to fire hazards, and recommends the use of prescribed fire as one tool to reduce or prevent these high fuel loads (Brooks and Pyke 2001). GUMO staff have been conducting prescribed burns in the park since 1976, and wildfires are allowed to burn in the majority of the park, unless conditions are hazardous for people or natural and cultural resources (NPS 2005). A key goal of the prescribed fire program is to reduce fuel buildup so that wildland fire can resume its natural place within the GUMO ecosystem (NPS 2005).

Within the montane forests of the Guadalupe Mountains, topography (e.g., slope angle, aspect, and elevation) can contribute to variation in fire regimes through its impact on fuels (i.e., vegetation type and density). For example, differences in snowpack duration and temperature between slope aspects favors long-needled pines on warmer south-facing slopes, and short-needled firs on cooler, moister north-facing slopes (Sakulich and Taylor 2007). Higher elevations also favor these short-needled species. Low density beds of litter from long needle pines generally support higher intensity and faster spreading fires than dense beds of short fir needles (Rothermel 1983 and Fonda et al. 1998, as cited in Sakulich and Taylor 2007). Snow also melts off south-facing slopes earlier in the year, leaving fuels dry enough to burn for a longer period than on north-facing slopes, increasing the probability of fire ignition and spread (Agee 1993, as cited in Sakulich and Taylor 2007). Lastly, fine fuel production (i.e., needles) is higher in pine stands than in fir, meaning fuels will build up faster and allow fires to burn again sooner on south-facing slopes (Stohlgren 1988, as cited in Sakulich and Taylor 2007). Descriptions of the fuel models (developed to help predict fire behavior) for different vegetation communities in GUMO are found in Table 10 and Table 11.

**Table 10.** Fuel models and fire behavior notes for vegetation types in GUMO (from NPS 2005). Fuel models are based on Anderson (1982) and described in the following table (Table 11).

| Vegetation Type | Fuel Models | Fire Behavior Notes |
|---|---|---|
| Chihuahuan Desertscrub | Potential 4 | Lack of contiguous fuel. |
| Semi-desert Grassland | Lightly loaded 2 | With normal precipitation & low wind speeds, fire creeps through cured grass; summer green up hinders spread. Intense behavior is possible during high wind periods after curing due to dryness. |
| Interior Chaparral | 6 | With normal precipitation, fires creep through deep duff layers under the shrub canopy & spread to other pockets of brush through herbaceous fuels. Steep slopes & high winds can foster dangerous fast-moving fires. With prolonged drought when live fuel moistures drop below 80%, extreme behavior possible, with all foliage readily burning & shrub “crown” fires occurring when aided by wind or steep slope. |
| Madrean Evergreen Woodland | 2/6 | Model 2 - Fire spreads though either curing or dead fine herbaceous fuels. Herbaceous layer plus litter & dead-down wood stems contribute to fire intensity. Model 6 - Fires carry through shrub layer, but require moderate winds. |
| Great Basin Conifer Woodland | 2/6 | Same as above |
| Petran Montane Conifer Forest | 8/10 | “Normal” fires are slow burning with low flame lengths, and they stay on the ground near single ignited trees. After dry periods, 1000-hr TLFM fuels can dry to 12% moisture. Fires torch individual trees, spread on the ground & in understory vegetation, and can involve more trees. Continued drought can bring extreme fire behavior, with 1000-hr fuels drying to 10%. Single thunderstorms can start multiple ignitions. High intensity fires spread in surface fuels, and when wind is a factor, crowning is common & long-range spotting possible. Duff & litter are consumed to expose mineral soil. |
| Interior Deciduous Forest and Woodland | 5/11 or 6/11 if more decadent | Generally very little fire activity in riparian zone due to high moisture levels. |

**Table 11.** Fuel model descriptions from Anderson (1982).

| Fuel Model | Description |
|---|---|
| 2 | Fire spread is primarily through the fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, in addition to litter and dead-down stemwood from the open shrub or timber overstory, contributes to the fire intensity. |
| 4 | Fires intensity and fast-spreading fires involve the foliage and live and dead fine woody material in the crowns of a nearly continuous secondary overstory. Besides flammable foliage, dead woody material in the stands significantly contributes to the fire intensity. A deep litter layer may also hamper suppression efforts. |
| 5 | Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs and the grasses or forbs in the understory. The fires are generally not very intense because surface fuel loads are light, the shrubs are young with little dead material, and the foliage contains little volatile material. |
| 6 | Fires carry through the shrub layer where the foliage is more flammable than fuel model 5, but this requires moderate winds, greater than 8 mi/h (13 km/h) at midflame height. Fire will drop to the ground at low wind speeds or at openings in the stand. |
| 8 | Slow-burning ground fires with low flame lengths are generally the case, although the fire may encounter an occasional “jackpot” or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose fire hazards. |
| 10 | The fires burn in the surface and ground fuels with greater fire intensity than the other timber litter models. Crowning out, spotting, and torching of individual trees are more frequent in this fuel situation, leading to potential fire control difficulties. |
| 11 | Logging slash group - Fires are fairly active; the spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. |

### *Measures*

- Frequency
- Severity
- Fuel loading and distribution
- Location
- Intensity

### *Reference Conditions/Values*

The reference condition for fire regime is pre-European settlement. Some of the above measures have been determined for this reference period in the park's coniferous forests by Taylor and Sakulich (2006). Historic fire parameters are often determined through examination of fire-scars on trees and stumps and by charcoal research. Unfortunately, in grassland and scrub ecosystems where fuels are typically consumed by fires, very little fire scar data exists to determine these parameters. In these cases, estimates from scientific literature were used.

### *Data and Methods*

The fire history geodatabase (NPS 2010) maintained by GUMO staff contains information for all the fires that have occurred in the park from 1960 to 2010, including location, size, and cause (natural or human). Burn severity data for five park fires were obtained through the Monitoring Trends in Burn Severity (MTBS) project website (MTBS 2012b). Information on the historic or "natural" fire regime was found in scientific literature, including Sakulich and Taylor (2007), Ahlstrand and Cline (1978), and sources reviewed in the GUMO fire management plan (NPS 2005). Sakulich and Taylor (2007) used fire scars from trees and stand structure data to characterize the historic fire regime in GUMO's mixed conifer forest. Additional information regarding fire return interval (i.e., frequency), fuel loading, and severity, was obtained from the LANDFIRE website (http://www.landfire.gov/). LANDFIRE is an interagency mapping program that produces vegetation and fire-related spatial data layers (at a 30-m pixel resolution) for the entire country.

### *Current Condition and Trend*

<u>Frequency</u>

Historically, low-intensity fires were quite frequent in the montane forests of GUMO (Ahlstrand and Cline 1978, Sakulich and Taylor 2007). The earliest research into past fire frequency in the park's conifer forests was conducted by Ahlstrand (1979, 1981 as cited in NPS 2005; Ahlstrand and Cline 1978). Ahlstrand examined fire scars from 49 southwestern white pines (*Pinus strobiformis*) and found that fires occurred in his study area during 71 of the years between 1496 and 1980, a 484-year period (Ahlstrand 1981, as cited in NPS 2005). The vast majority of these fires (63 of the 71) occurred prior to 1850. Ahlstrand (1981, as cited in NPS 2005) estimated a mean fire return interval of 4.7 years for the period 1554-1842, and suggested that a 5-15 year return interval would open up the thickets of Douglas-fir and other conifers that have developed due to grazing and fire suppression. The mean interval between "large fires" for the period 1696-

1922 was 17.4 years; until the 20th century, the longest interval between large fires was 30 years (Ahlstrand 1981, as cited in NPS 2005).

Sakulich and Taylor (2007) expanded upon Ahlstrand's work, studying 854 fire scars from southwestern white and ponderosa pines (*Pinus ponderosa*) in GUMO. They calculated a mean composite fire return interval (CFI) of 4 years for their study area. Widespread fires were less frequent; burns that affected at least 10% of their samples showed a CFI of 9.2 years, while fires affecting 25% of samples had a CFI of 16.3 years (Sakulich and Taylor 2007). Fire frequency also varied greatly over time. During the pre-European settlement period (1700-1879), the CFI was 2.7 years. After settlement (1880-1922), the CFI increased significantly to 8.4 years ($p<0.05$) (Sakulich and Taylor 2007). Only two fire scar samples occurred after 1922, which was not a large enough sample size to calculate a CFI for this most recent period. From 1922 until the Frijole fire in 1990, no large, high-intensity fires occurred in the park (NPS 2005).

Historic fire frequency in the park's other ecosystems has not been studied but may be estimated from research in similar ecosystems within the region. For example, little is known about the fire ecology of oak woodlands like those in McKittrick Canyon, but Abbott (1998, as cited in NPS 2005) estimated a fire return interval of 10-30 years for oak woodlands in southeastern Arizona, based on frequency estimates from neighboring coniferous forests. Southwestern shrubland vegetation generally "experiences stand-replacing fires at intervals measured in decades" (NPS 2005, p. 16, citing Wright 1990 and Paysen et al. 2000). The importance of fire in southwestern semi-desert grasslands is somewhat unclear. Early researchers estimated that burning every 10-15 years (Ahlstrand 1982) or every 10-30 years (Leopold 1924, as cited in Ishaque 1996) would maintain grassland biodiversity and control shrub/scrub invasion. A fire ecology study in a New Mexico grassland found that semidesert perennial grasses (particularly black grama [*Bouteloua eriopoda*]) required 6-8 years after a fire to return to pre-burn cover levels (Cornelius 1988). These findings suggest that a fire return interval less than 10 years would likely harm a semidesert grassland rather than help it. The interagency LANDFIRE program utilized a vegetation and disturbance dynamics model VDDT (Vegetation Dynamics Development Tool) to generate a nationwide mean fire return interval GIS data layer (under a presumed historic regime) (LANDFIRE 2012). Due to its broad scale, this information is not as accurate as on-the-ground research, but can provide some insight into fire frequency where studies have not been conducted (e.g., GUMO's desertscrub or grasslands). The mean fire return interval data for GUMO is shown in Plate 3.

According to the park's fire history geodatabase (NPS 2010), 115 known fires have occurred within GUMO boundaries since the park's establishment in 1972. Over 70% of these fires were lightning-caused, and 10 were prescribed or research burns. However, only 58 fires burned more than 0.1 acre and only 50 burned more than 0.5 acre (NPS 2010). The total number of fires within park boundaries per year (1972-2010) is shown in Figure 4, while Figure 5 shows the number of fires over 0.1 acre per year.

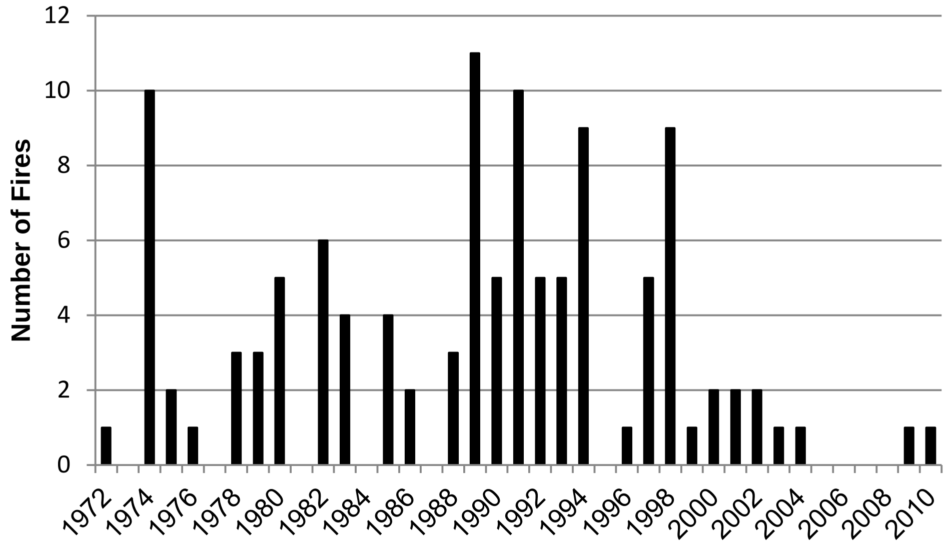


**Figure 4.** Number of fires within GUMO boundaries by year, 1972-2010 (NPS 2010).

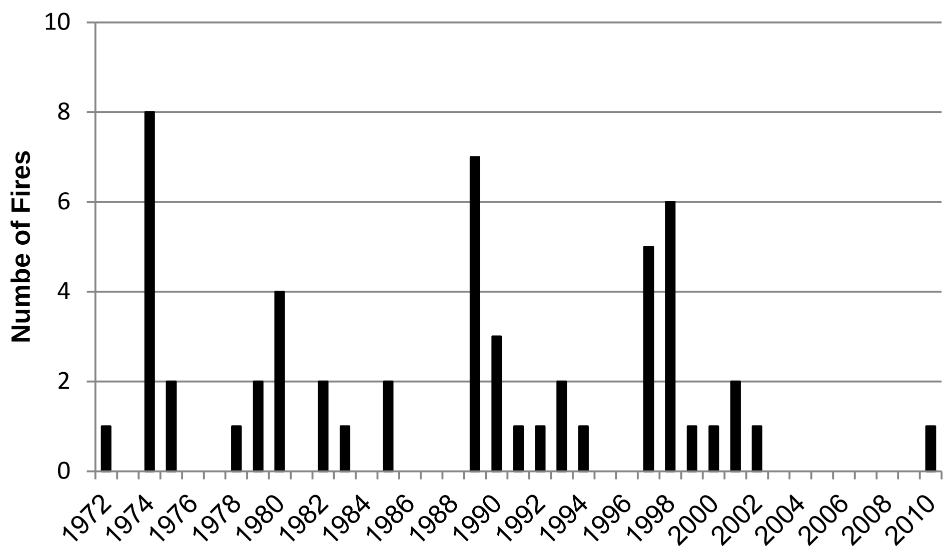


**Figure 5.** Number of fires >0.1 acres within GUMO boundaries by year, 1972-2010 (NPS 2010).

<u>Severity</u>

Fire (or burn) severity is a term used to describe the physical and chemical changes to the soil, the conversion of vegetation and fuels to inorganic carbon, and structural or compositional transformations that create new microclimates and species assemblages (Key and Benson 2006). Severity can be measured by amount of organic matter loss both above and below the surface of the ground after a fire (Keeley 2008). To estimate the severity of historic fires, researchers sometimes use forest age structure. High severity fires are usually stand-replacing, resulting in a forest that is relatively even-aged; forests that experience low severity fires, in contrast, are usually multi-aged (Agee 1993, as cited in Sakulich and Taylor 2007). Sakulich and Taylor (2007) found that conifer stands in GUMO are multi-aged, suggesting that historic fires in the park were primarily of low to moderate severity. This evidence is supported by the fact that most fire scars were found on the thinner-barked southwestern white pine but typically not on ponderosa pine and Douglas-fir, which have thicker, more fire resistant bark (Ahlstrand and Cline 1978, Sakulich and Taylor 2007). However, an increase in tree density due to grazing and fire suppression has created a forest that is "prone to high severity fire, as evidenced by two stand-replacing wildlfires in GUMO in the 1990s" (Sakulich and Taylor 2007, p. 62).

A more recently developed method for measuring burn severity is to compare Landsat imagery prior to and after a fire to determine a Differenced Normalized Burn Ratio (dNBR). The dNBR data, which represent continuous values, are separated into six categories. MTBS (2012b) classifies the six severity categories as unburned to low, low, moderate, high, increased greenness, and no data. According to MTBS (2012a), an analyst evaluates the dNBR data range and determines where significant thresholds exist to discriminate between severity categories. In Sorbel and Allen (2005), the accuracy of the dNBR method was tested by sampling Composite Burn Index (CBI) plots established on the ground in recently burned areas. CBI methods involve scoring burn severity based on 22 variables including soil cover/color change, duff and litter consumption, percent of colonizers, percent of altered foliage, and percent of canopy mortality (Sorbel and Allen 2005). A comparison of CBI scores and dNBRs for the same areas shows that dNBR can be "a suitable measure and predictor of burn severity" (Sorbel and Allen 2005, p. 9). However, this comparison study occured in Alaska, and similar comparisons have not been conducted in GUMO. Richard Gatewood, NPS Fire Ecologist, believes that the dNBR may underestimate the severity of some fires in the GUMO region (written communication, April 2013). Sampling of CBI plots in burned areas of the park would be necessary to verify dNBR accuracy or to adjust dNBR calculations to better reflect true severity. MTBS (2012b) provided burn severity data in which acreage of severity categories were derived for five fires within GUMO (Table 12). A spatial representation of MTBS data for the Marcus Fire is presented in Plate 4, as an example.

**Table 12.** Area of four different burn severity categories for five fires in GUMO (MTBS 2012b). According to MTBS data, none of the fires reached above the moderate severity level. The locations of these fires, most of which burned some additional area outside of park boundaries, are shown on Plate 7.

| Fire | Severity Level (acres) | | | |
|---|---|---|---|---|
| | **Increased Greenness** | **Unburned to Low** | **Low** | **Moderate** |
| Big Canyon - 1989 | --- | 30.5 | 734.1 | 556.3 |
| Camp - 1989 | --- | 31.6 | 383.4 | 113.2 |
| Pine - 1993 | --- | 9.7 | 677.8 | 1,721.5 |
| Marcus - 1994 | --- | 58.8 | 1,761.2 | 891.4 |
| Cutoff - 2010 | 6.9* | 3,385.7 | 4,842.3 | --- |
| Total | 6.9 | 3,516.3 | 8,398.8 | 3,282.4 |

* According to MTBS data, all of the area that experienced increased greenness was in New Mexico and therefore not within GUMO boundaries.

The LANDFIRE program has also generated nationwide fire severity GIS data using the vegetation and disturbance dynamics model VDDT. This includes a "percent of replacement-severity fires" layer (under the presumed historic fire regime); replacement severity is defined as "greater than 75 percent average top-kill within a typical fire perimeter for a given vegetation type" (LANDFIRE 2012). This modeled severity data is presented in Plate 5.

Fuel Loading and Distribution

Fuel loading and distribution strongly influence the frequency, intensity, and severity of fires. When fuels build up due to a reduction in fire frequency, as has been the case in GUMO, fire intensity and severity generally increase when fires do occur. Fuel distribution also influences a fire's ability to carry or spread across the landscape.

Ahlstrand and Cline (1979) gathered some data on fuel loading from mixed conifer and deciduous woodland plots in the park in the late 1970s. Woody fuels averaged 7.8 tons/ac in mixed conifer plots and 3.4 tons/ac in deciduous woodland plots (Ahlstrand and Cline 1979). Dried litter and duff samples averaged 20.1 and 16.9 tons/ac for mixed conifer and deciduous woodland plots, respectively. Samples from plots in other vegetation types in this montane study area averaged 6.6 tons/ac of woody fuels and 11.8 tons/ac of dried litter and duff (Ahlstrand and Cline 1979). Fuel loading data have been gathered at fire effects monitoring plots within two park ecosystems (Rocky Mountain conifer forests and semi desert grasslands) since the late 1990s (NPS 2005), but these data have not been analyzed or published.

The LANDFIRE program has created a nationwide Fuel Loading Model (FLM) surface fuel classification system. This GIS data layer can be used by land managers in fire behavior and effects software programs (LANDFIRE 2012). As mentioned previously, this modeled data (Plate 6) is not as accurate as on-the-ground research due to its broad scale, but it can provide some information on fuel loading in areas of the park where it has not been monitored or studied.

Threats and Stressor Factors

The greatest threats to fire regime are current climate and weather patterns, past grazing practices, and historic fire suppression. Grazing by sheep and goats began in the park's montane forests in the early 1920s and continued until park establishment in 1972 (Sakulich and Taylor 2007). As mentioned previously, livestock grazing reduces herbaceous cover, which provides the fine fuels and continuity necessary to carry fire (Ahlstrand 1982, Sakulich and Taylor 2007). As a result, fires became less frequent throughout the area that is now GUMO. Young trees and shrubs that were previously thinned by burning now survived to significantly increase forest and shrubland density, causing "dramatic changes" in community structure and composition, particularly in montane forests (Sakulich and Taylor 2007, p. 62). This increase in tree and shrub cover also increased shading and resource competition among plant species; as a result, the fine fuels necessary to carry low intensity surface fires have not yet recovered, despite the cessation of grazing with park establishment (Gatewood, written communication, 29 October 2012). When fires did occur, this buildup of woody fuel often increased the burn's severity and the mortality of vegetation. Smaller trees and other thick understory vegetation can serve as "ladder fuels", which allow the fire to spread into the tree canopy (Andersen 2003).

Fuel buildup in the park was further exacerbated by a federal policy of fire suppression, which took effect as soon as the NPS took ownership in 1972. While NPS policy changed during the 1980s to allow wildland fire use and prescribed burning, fuel buildup was so severe at GUMO that wildland fires often still needed to be suppressed for human and/or park resource safety, particularly given the frequent extreme weather conditions (e.g., winds, heat, low humidity) (Fred Armstrong, former GUMO Chief of Resource Management, e-mail communication, 12 September 2012). Although prescribed burns and some wildland fire use over the past several decades have slightly reduced hazardous fuel loads, much work remains before the park can return to a natural fire regime.

Weather conditions at GUMO often make it difficult for park management to conduct prescribed burns for fuel reduction and other vegetation management purposes (Armstrong, e-mail communication, 12 September 2012). The region around the park is known for its high winds, which regularly exceed 95 km/hour (60 mi/hour) for days at a time (NPS 2005, 2008). Wind-driven fires are fast-moving and can generate spot fires ahead of the main burn (NPS 2005). During the peak fire season, humidity generally ranges from 10-25%, meaning fuels are relatively dry and flammable. In addition, the park only receives approximately 34 cm (13.4 in) of precipitation a year (NCDC 2012). These weather factors make prescribed burning and even wildland fire use at GUMO unsafe for much of the year.

<u>Data Needs/Gaps</u>

Several research needs are discussed in the park's fire management plan (NPS 2005). One of these is regarding the long-term impacts of fuel reduction methods on forest structure. Fuel reduction, whether mechanical or through low intensity prescribed fire, provides the short-term benefit of decreasing the potential for severe fires. While low intensity fires are effective in reducing accumulated dead and downed fuels, their impact on living trees (especially smaller sizes where mortality is desirable) is not well understood (NPS 2005). If low intensity prescribed fires are not achieving the desired mortality and reduction in fuels, alternative and/or additional methods may be necessary.

A better understanding is also needed of fire's natural role in park plant communities other than the montane forests (e.g., grass and shrublands, riparian/canyon woodlands), and what role fire can or should play in current vegetation management in these areas (NPS 2005). According to NPS (2005, p. 70), "If the goal is to shift vegetation structure and composition back to pre-ranching conditions, where fire return intervals where conceivably shorter, shrub density lower and grass cover greater, treatments other than prescribed fire may be required." These could include mechanical or chemical treatments, where appropriate (i.e., not restricted by Wilderness regulations); any treatment method should be assessed for efficacy and feasibility and tested in a small area before being applied over a large area (NPS 2005). Since little is known about the natural fire regime in desert grasslands and shrublands (e.g., frequency, timing, etc.), monitoring the effects of prescribed burning in these communities will be important to determine appropriate return intervals (Cornelius 1988, NPS 2005). Research into the potential for exotic plant species invasion following fire disturbance would also be of value.

<u>Overall Condition</u>

*Frequency*

The project team assigned this measure a *Significance Level* of 3. Analysis of fire scar data showed that low intensity fires were fairly frequent in GUMO prior to settlement and grazing (Ahlstrand 1981, Sakulich and Taylor 2007). Grazing led to reduction in fine fuels which, combined with later fire suppression efforts, caused fires to become much less frequent over the past century. This change in frequency influences plant community structure and, in some cases, community composition, as well as the severity and intensity of fires when they do occur. Therefore, this measure is of significant concern (*Condition Level* = 3).

*Severity*
The severity measure was also assigned a *Significance Level* of 3. Historic evidence suggests that the majority of fires in the GUMO area were low severity (Sakulich and Taylor 2007). Present-day fires appear to be more severe, likely due to fuel buildup. According to MTBS data for four fires between 1989 and 1994, nearly as many acres burned at moderate severity as at low severity. NPS staff are concerned that fires of moderate severity (or higher) could potentially cause vegetation type conversions (i.e., forest to grassland or scrub) (Coles and Gatewood, written communications, April 2013). The *Condition Level* for this measure is a 3, indicating high concern.

*Fuel Loading and Distribution*
The *Significance Level* of this measure is a 3. Fuels built up in many areas of the park when fire frequency decreased after the 1920s. While the NPS has been gathering fuel loading data in GUMO for several years, this information has not yet been published. However, based on observations by park staff, this measure was assigned a *Condition Level* of 2.

*Location*
This measure was assigned a *Significance Level* of 1. The locations of known fires from 1971 to 2010 are represented in Plate 7. This map shows that large portions of the park, including many areas thought to have shorter fire return intervals (<15 yrs), have not burned in over 35 years. Very few locations have burned more than once during this time period, as would likely have occurred under the historic fire regime. Therefore, the location measure was assigned a *Condition Level* of 2, or moderate concern.

*Intensity*
The intensity measure received a *Significance Level* of 1. Intensity is the energy or magnitude of heat produced by a fire (Key and Benson 2006, Keeley 2008). It can be an indicator to fire managers of the potential effects of fire on soil and vegetation (i.e., fire severity) during prescribed burns. Sakulich and Taylor (2007) used the size of a surviving tree when it was first scarred by fire to estimate historic fire intensity in GUMO. If tree diameter is small at the time of scarring, fires were low intensity because they damaged the cambium without killing the tree (Agee 1993, as cited in Sakulich and Taylor 2007). Sakulich and Taylor (2007) found that trees in GUMO were relatively small when first scarred (mean diameter = 10.1 cm), suggesting that historic fires were low in intensity. While no similar intensity estimates have been taken in recent decades, the severe damage to vegetation caused by several large fires (e.g., Frijole and Pine) suggests that these were higher in intensity than what historically occurred. The current buildup of fuels in many areas of the park increases the risk of high intensity fires. As a result, this measure is of moderate concern (*Condition Level* = 2).

*Weighted Condition Score*
The *Weighted Condition Score* for GUMO fire regime is 0.879, indicating high concern. Park-wide trend in condition is difficult to determine. In some areas where wildfires, prescribed burns, or mechanical fuel treatments have occurred in the past 20 years, conditions may have improved. However, conditions in areas that have not experienced fire in nearly 100 years are likely stable (but at a high concern level) or declining. If generalized across the park, NPS staff feel that the trend would best be described as declining.

## Fire Regime

| Measures | SL | CL |
|---|---|---|
| • Frequency | 3 | 3 |
| • Severity | 3 | 3 |
| • Fuel loading & distribution | 3 | 2 |
| • Location | 1 | 2 |
| • Intensity | 1 | 3 |

**WCS = 0.879**

***Sources of Expertise***

Richard Gatewood, Fire Ecologist, Chihuahuan Desert and Southern Plains Networks

John Montoya, Fire Management Officer, GUMO and Carlsbad Caverns National Park

Fred Armstrong, former GUMO Chief of Resource Management, currently Chief of Resource Management and Research at Zion National Park

Janet Coles, GUMO Chief of Resource Management

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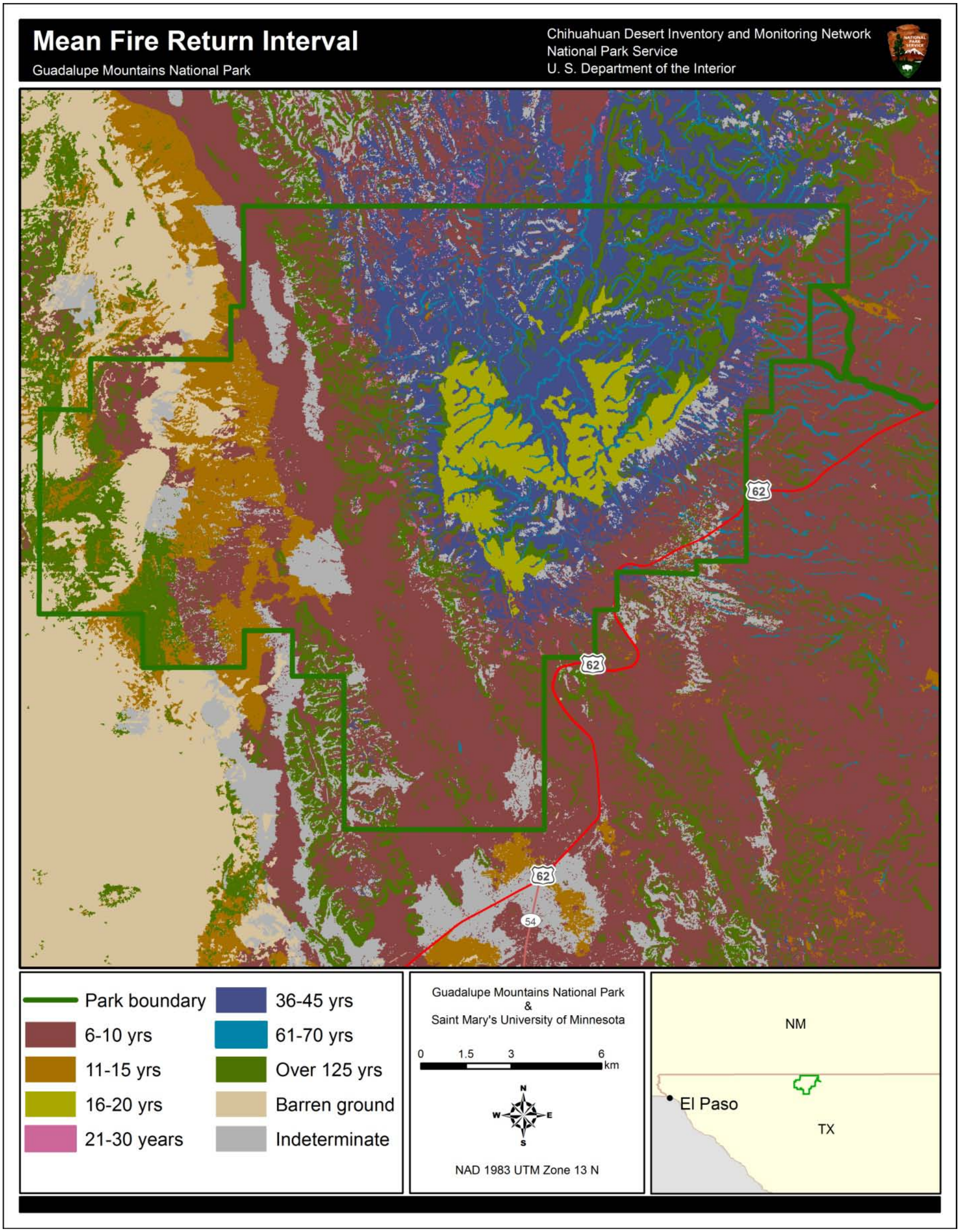



**Plate 3.** Mean fire return interval data, under the presumed historical fire regime, for GUMO from LANDFIRE (2011).

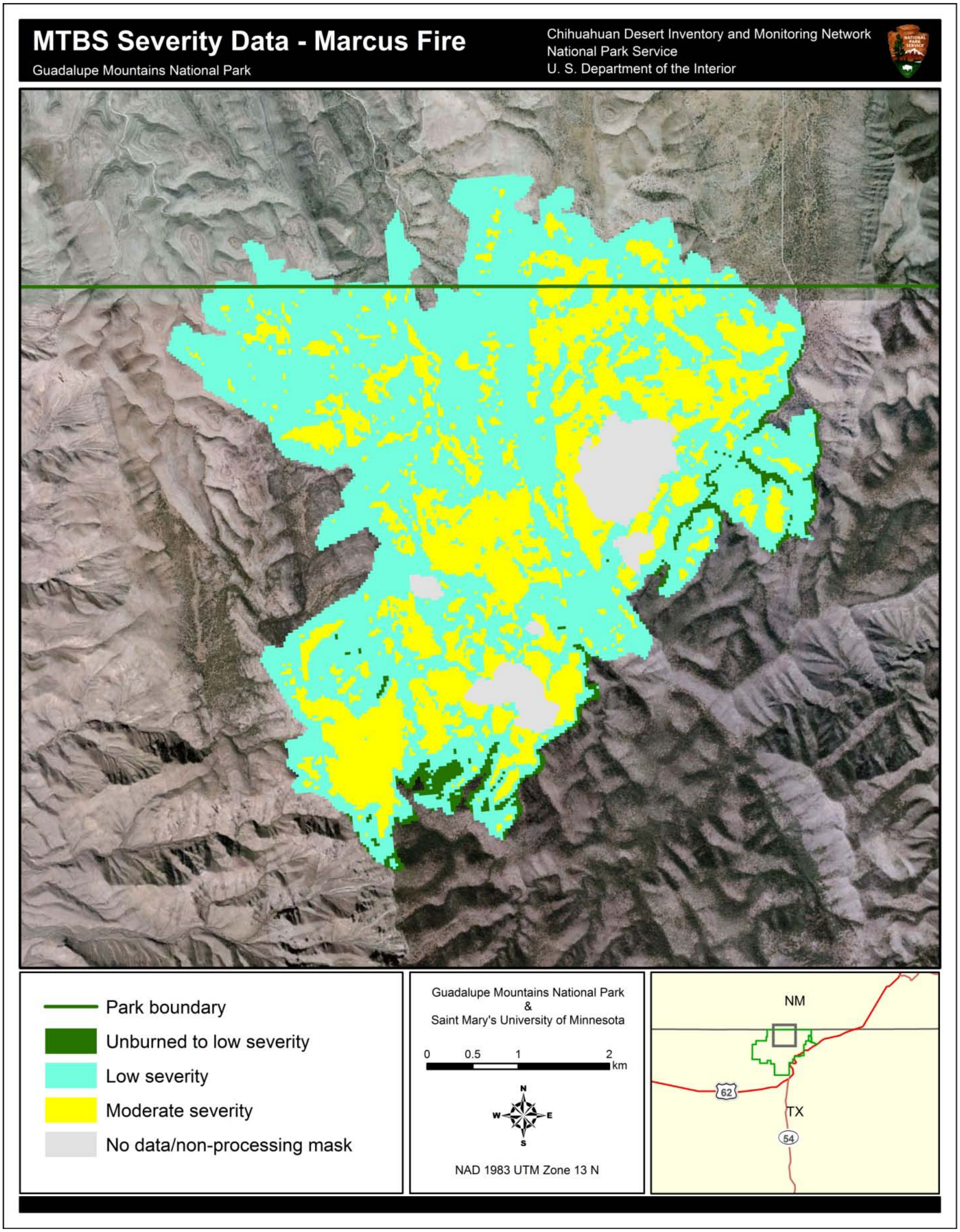



**Plate 4.** MTBS fire severity data for the 1994 Marcus Fire in northern GUMO (data obtained through MTBS 2012b).

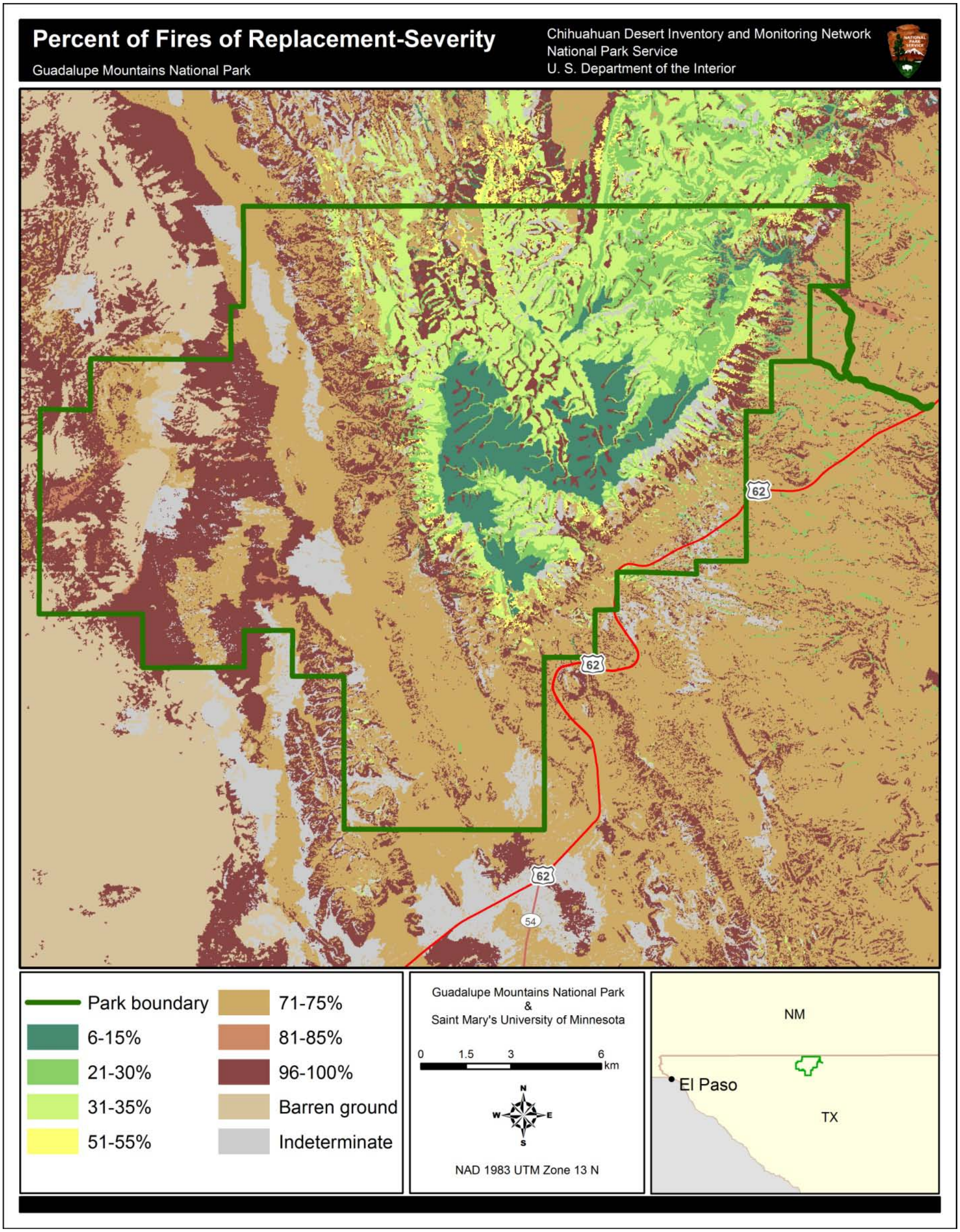



**Plate 5.** Percent of replacement-severity fires data from LANDFIRE (2010a).

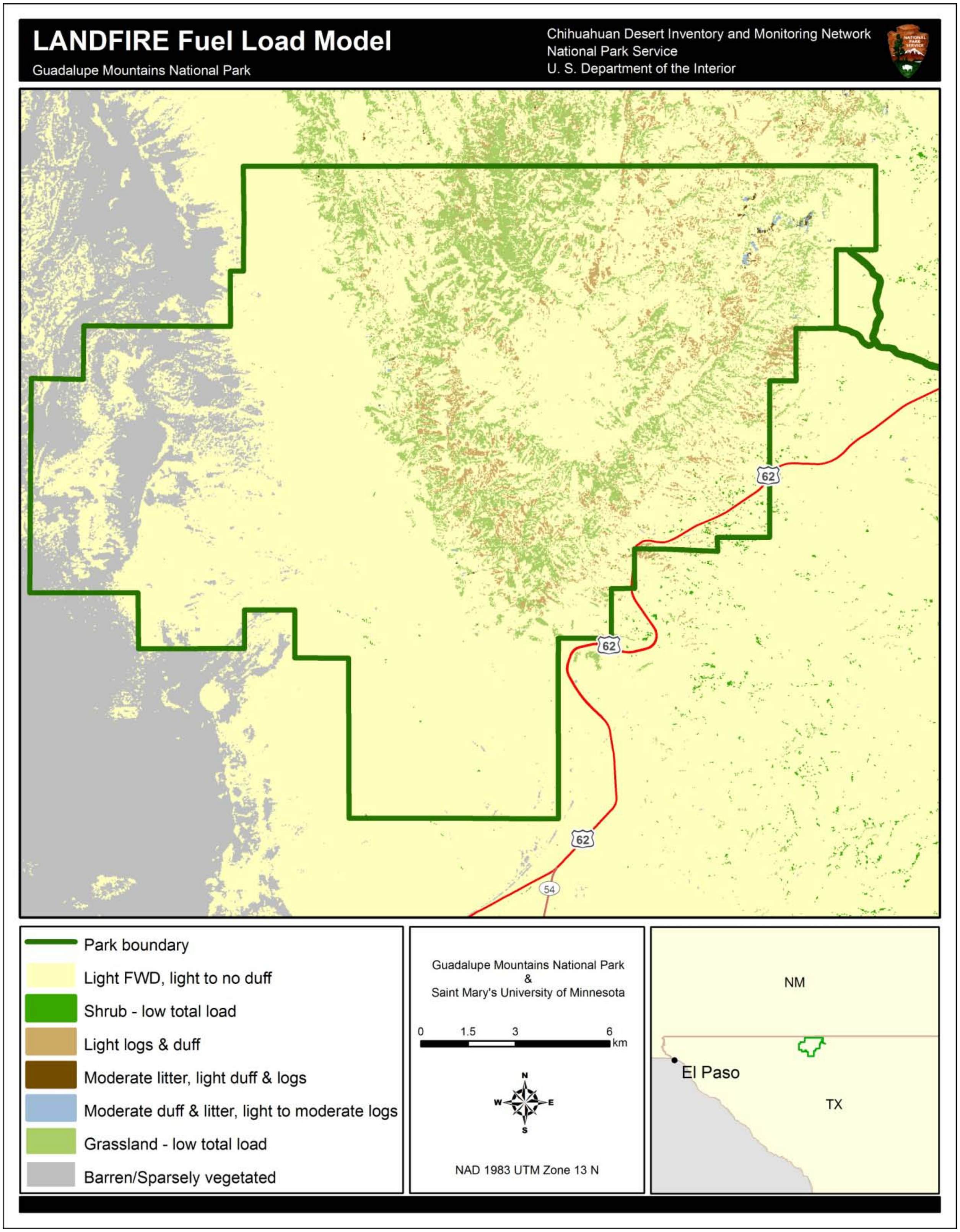



**Plate 6.** Fuel load modeling GIS data for GUMO from LANDFIRE (2010b) (FWD = fine woody debris).

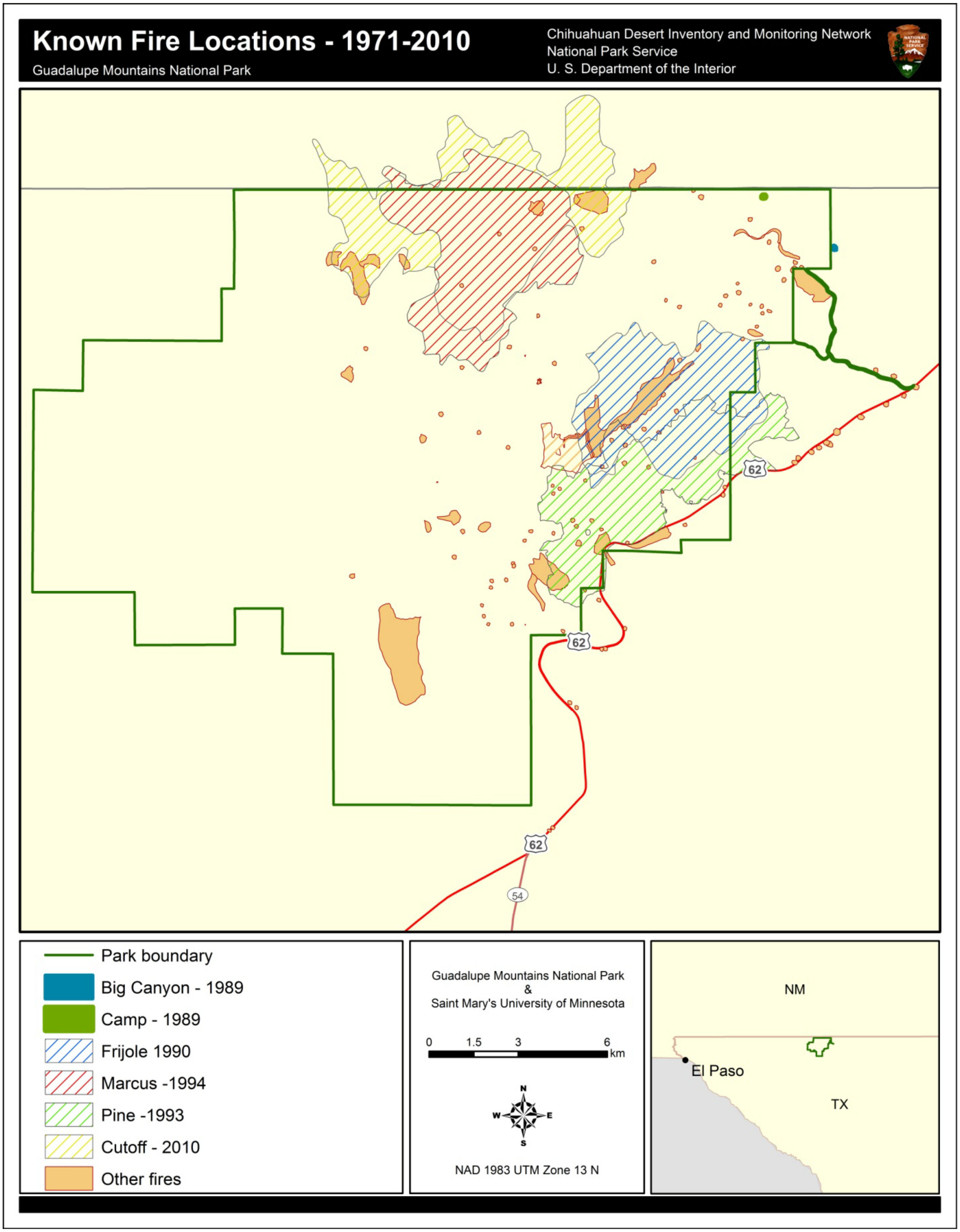



**Plate 7.** Known locations of fires in GUMO (1971-2010) (NPS 2010). Large fires, several of which are shown in the legend, are represented with cross-hatching so that smaller fires in the same area are visible. Fires that were evaluated by the MTBS program are also shown in the legend.

## 4.2 Dune Communities

### *Description*

One of the most distinctive landscapes within GUMO is the gypsum dune field near the western edge of the park (Photo 6). These dunes are one of only two gypsum dune formations in the United States (Weeks et al. 2008). During the development of the park's RSS, the gypsum dunes were recognized as a fundamental scenic resource (NPS 2009). The white gypsum dunes, which rise up to 30 m (98 ft) and cover approximately 2,080 ha (5,150 ac), contain both active (constantly shifting) and stabilized dunes with higher vegetative cover. The active dunes occupy just over 440 ha (1,094 ac) (Jonena Hearst, GUMO geologist, e-mail communication, 5 October 2012). North of the gypsum dunes lies a slightly smaller area of red quartzose dunes (approximately 1,640 ha [4,056 ac] within the park) (Plate 8). These dunes are more vegetated and lack actively shifting areas, suggesting they are older than the gypsum dunes (Brant 2005, citing Wilkins and Currey 1999). Due to differences in age and substrate, the gypsum and quartzose dunes support slightly different plant and animal communities. The quartzose dunes are dominated by the short shrubs honey mesquite (*Prosopis glandulosa*) and fourwing saltbush (*Atriplex canescens*) with soaptree yucca (*Yucca elata*) and sparse grasses (Northington and Burgess 1979a). The more sparse vegetation of the gypsum dunes includes hairy crinklemat (*Tiquilia hispidissima*), gypsum grama (*Bouteloua breviseta*), and frosted or rosemary mint (*Poliomintha incana*). Many areas lacking vascular vegetation are instead covered by a biological soil crust composed of cyanobacteria, lichens, and other microorganisms (Northington and Burgess 1979a, NPS 2009).

**Photo 6.** Gypsum dunes (photo by Kathy Kilkus, SMUMN GSS 2012).

The dune area of GUMO is located within a salt basin that collects runoff and sediment from surrounding mountain ranges (Brant 2005). The basin has experienced repeated flooding and drying over time. During dry periods, the fine sediment deposited from runoff is blown eastward toward the Guadalupe Mountains. The red and white dunes formed where the wind dropped this sediment (Brant 2005, citing Wilkins and Currey 1999).

**Photo 7.** Gypsum dunes in the foreground with red quartzose dunes behind (photo by Andy Nadeau, SMUMN GSS 2012).

While the harsh dune community environment is inhospitable for most mammals, small rodents such as kangaroo rats (*Dipodomys* spp.) are relatively common here (Scudday 1977). Rodents and other small mammals can serve as biological indicators of habitat conditions in an area due to their close ecological relationships with the flora of an ecosystem, and because they are often common prey for carnivores (August et al. 1979, Cornely 1979). August et al. (1979, p. 333) hypothesized that small mammal population structure and function would be affected by human use, making these populations, "important in the determination of the effects of human use upon a given area." Small mammals are also easily trappable and "relative density comparisons among sites are feasible with limited investment" (Rowe 2004, p. 3). Since these mammal species have been surveyed over several decades in GUMO's dune communities and could provide insight into the community's recovery from prior human use (e.g., grazing), they will be included as a measure in this assessment.

### *Measures*

- Change in vegetation community extent
- Change in plant species richness
- Small mammal diversity
- Changes in dune morphology, movement, and mass using LiDAR
- Biological soil crust resilience and resistance

### *Reference Conditions/Values*

Very little historical information is available on the dune communities of GUMO. The earliest record of the gypsum dunes is from Havard (1885), who traveled through southern and western Texas and reported on the vegetation and natural features he observed. Havard (1885, p. 497) wrote: “Between Crow Spring and Guadalupe Peak, is a range of white sandhills whose shifting, glistening surface is delicately undulated by the wind.” Since they were not protected from grazing and other human uses until the early 1990s, their current condition may be better than it has been since European settlement (Hearst, pers. comm. 2012). Therefore, the current condition (early 21st century) will serve as reference condition for this component.

### *Data and Methods*

The vegetation of GUMO’s dune communities was first described by Burgess and Klein (1978) in an unpublished report on the vegetation of the northern salt basin for the Texas Parks and Wildlife Department (TPWD). At this time the dunes were not yet part of the park. They sampled vegetation along transects throughout the salt basin, including both the quartzose and gypsum dunes. Around the same time, Northington and Burgess (1979b) presented a list of rare and unique plant species found in the park’s dune communities. In 1984, Worthington and Reid (1985) studied the dune habitat vegetation in more depth, focusing on the active gypsum dunes. They created a plant species list, collected lichens, and performed quantitative vegetation sampling using the point-quarter method. A park-wide vegetation classification and mapping project was recently completed by Muldavin et al. (*in prep.*). This provides current information on the extent and species richness of GUMO’s plant communities.

Small mammals were first studied specifically in the dune areas of GUMO in the late 1970s. As part of a TPWD study of the Northern Salt Basin Natural Area (which included salt flats and associated dune areas in Hudspeth County), Scudday (1977) sampled vertebrates in the salt flats and the dune communities that are now within GUMO. The report includes a list of small mammals from the area and notes on abundance. In the early 1980s, West (1985) returned to observe vertebrates in this area, focusing on the gypsum dunes. The species reported were observed only, and no capturing or collecting occurred.

Stangl (1992) surveyed the mammals of the dune communities in the early 1990s when the area was part of The Nature Conservancy’s Gypsum Dunes Preserve. Stangl (1992) observed and collected mammals in the area.

In the early 2000s, Brant (2005) and Brant and Jones (2005) studied the mammals of the dune communities, with a focus on small rodents. Brant (2005) divided the dune communities into four habitat types (gypsum dunes, quartzose dunes, intergrade dunes, and cover sands) and categorized the rodent composition of each habitat.

### *Current Condition and Trend*

<u>Change in Vegetation Community Extent</u>

No information is available regarding the historic extent of the dune community. When the first vegetation survey of the park was conducted in the 1970s (Glass et al. 1974), the dunes were not yet part of the park and were therefore not included in the survey and mapping effort.

A park-wide vegetation mapping effort was recently completed at GUMO (Muldavin et al., *in prep.*). Six mapping classification units are considered dune community vegetation (Table 13). These six units together cover nearly 4,900 ha (12,108 ac) or 14% of the park (Plate 9). Five units occur on gypsum soils (white dunes), covering approximately 3,020 ha (7,463 ac), while the one unit that occurs on quartzose (red) dunes (Honey Mesquite-Broom Dalea Coppice Dune) covers 1,878 ha (4,641 ac) (Table 13, Muldavin et al., *in prep.*).

**Table 13.** Extent of dune community vegetation mapping units in GUMO (Muldavin et al., *in prep.*).

| Mapping Unit | | Hectares |
|---|---|---|
| **Gypsum Chihuahuan Semidesert Grassland** | | |
| Gypsum Dune Semidesert Grassland | | 192.0 |
| Gypsum Flat Dropseed Grassland | | 279.3 |
| **Gypsum Desertscrub** | | |
| Gypsum Flat Desertscrub | | 804.7 |
| Frosted Mint Gypsum Dune Desertscrub | | 505.0 |
| Fourwing Saltbush Gypsum Desertscrub | | 1,238.6 |
| **Chihuahuan Desertscrub** | | |
| Honey Mesquite-Broom Dalea Coppice Dune | | 1,878.3 |
| | **Total** | 4,897.9 |

Change in Plant Species Richness

While several studies have described the species composition of the dunes and generated plant lists, none have focused specifically on species richness. Burgess and Klein's (1978) survey of northern salt basin vegetation included several stands on gypsum and quartzose substrates. Their report documented 34 plant species occurring on quartzose and 25 species on gypsum substrates. In a more thorough survey that focused specifically on the dune community, Worthington and Reid (1985) identified 58 plant species in gypsum habitats (dunes/interdunes, flats, and stabilized ridges) and 13 on quartzose sand. More survey locations and effort were focused on gypsum habitats and may explain the difference in species number between quartzose and gypsum substrates. Worthington and Reid (1985) also identified six lichen species on stabilized gypsum ridges. A full plant and lichen species list from these historic studies, with habitat type and general abundance, is included in Appendix A.

Muldavin et al. (*in prep.*) did not focus on the dune communities, but some species richness information can be extracted from their data. In the vegetation classes that could be considered dune communities, Muldavin et al. (*in prep.*) documented just over 85 plant species from 22 families. The most common families were Poaceae and Asteraceae. The majority of species identified in historic studies (Appendix A) were also found by Muldavin et al. (*in prep.*). Any differences could be due to different sampling locations rather than actual change in species composition.

Small Mammal Diversity

Approximately 20-25 total mammal species have been observed in GUMO's dune habitats. Small mammals (for the purpose of this document, those less than 10 kg [22 lbs]) documented or expected to occur in the park's dune communities are presented in Table 14. Notes from several surveys regarding abundance or distribution are also included.

**Table 14.** Small mammals of the dune communities within GUMO.

| Common name | Scientific name | Scudday (1977) | West (1985) | Stangl (1992) | Brant (2005) |
|---|---|---|---|---|---|
| desert cottontail | *Sylvilagus audubonii* | one of the most visible mammals of the area | more frequent in the Red Dunes | found evidence this species was abundant | not captured, but seen all over the park |
| black-tailed jackrabbit | *Lepus californicus* | one of the most visible mammals of the area | seen frequently throughout the gypsum dunes | apparently abundant; likely common in dune area | not captured, but frequently seen in all dune habitats |
| spotted ground squirrel | *Spermophilus spilosoma* | one of the most visible mammals of the area | seen around Dell City and the highway, but not in dunes area | prefers sandy soils; common in dune area | not seen, likely due to season of sampling |
| yellow-faced pocket gopher | *Pappogeomys castanops* | single capture | mounds observed, but few appeared fresh | captured 5 gophers; mounds were common in sandy flats | found in cover sands and intergrade dunes |
| Merriam's pocket mouse | *Perognathus merriami* | | | | found in vegetated gypsum dunes |
| Chihuahuan Desert pocket mouse | *Chaetodipus eremicus* | appears to have very high population densities | likely observed, but not captured to confirm identification | not encountered but likely occurs | $2^{nd}$ most captured in every dune category |
| Merriam's kangaroo rat | *Dipodomys merriami* | appears to have very high population densities | "more prevalent in the Red Dunes area than elsewhere" | collected in creosote habitat; less common in fixed dunes | most abundant in every category except gypsum dunes - preference for cover sands area |
| Ord's kangaroo rat | *Dipodomys ordii* | appears to have very high population densities | widespread throughout the dunes, but seemed more common in non-gypsum areas | most abundant small mammal of the sand flats | most abundant on gypsum dunes, absent from cover sands |
| banner-tailed kangaroo rat | *Dipodomys spectabilis* | | | found in nearby creosote flats, likely uses dune areas occasionally | not captured, but "highly likely" that it occurs in dune complex |
| western harvest mouse | *Reithrodontomys megalotis* | single specimen from an area of tall grass & yuccas at the southern edge of the gypsum dunes | | not encountered but likely occurs | not encountered, most common in grassy areas (Genoways et al. 1979) |
| cactus mouse | *Peromyscus eremicus* | | | | collected in active gypsum dunes - first record of species in dunes complex |
| white-footed mouse[1] | *Peromyscus leucopus* | | | not encountered but likely occurs | not captured; one specimen known from sandy area of park (Genoways et al. 1979) |

| Common name | Scientific name | Scudday (1977) | West (1985) | Stangl (1992) | Brant (2005) |
|---|---|---|---|---|---|
| deer mouse[1] | *Peromyscus maniculatus* | present | | not encountered but likely occurs | not captured |
| northern grasshopper mouse | *Onychomys leucogaster* | single mouse captured in a stabilized quartz sand area | | | suggests that Scudday's (1977) specimen may have been misidentified; could be *O. arenicola* |
| Mearn's grasshopper mouse | *Onychomys arenicola* | | | two specimens taken from sandy flats adjacent to the dunes | collected on intergrade dunes and edge of gypsum dunes |
| hispid cotton rat | *Sigmodon hispidus* | | | not encountered but likely occurs | not captured |
| eastern white-throated woodrat | *Neotoma albigula* | | | two captures in sand flats were "unexpected", as typical habitat is rocky hills | not captured; "could be expanding its range into the sand dunes" |
| southern plains woodrat | *Neotoma micropus* | | | not common, but "stabilized dunes seem to provide ideal habitat for this species" | captured in cover sands and quartz dunes |
| American badger | *Taxidea taxus* | widespread evidence of burrowing | diggings noted frequently; tracks seen on dunes occasionally | | not captured, but burrowing activity in cover sands and intergrade dunes |
| striped skunk | *Mephitis mephitis* | present | | | not captured; commonly seen along highway south of dune area |

[1]According to Cornely et al. (1981, p. 27), "Specimens of both *P. leucopus* and *P.maniculatus* were taken on the gypsum soils near Lewis Well near the western boundary of the park."


**Photo 8.** Kangaroo rat (NPS photo by Patrick Myers) and spotted ground squirrels (NPS photo).

From October 2003 to February 2004, Brant (2005) conducted a survey of small mammals in GUMO's dunes in an effort to characterize the rodent communities inhabiting these sand dune habitats. This survey divided the dune communities into four categories based on sand composition and vegetation. The first two categories were the quartzose (red) dunes and the gypsum (white) dunes. A third category, where the quartzose and gypsum dunes meet and both sand types occur, was called the intergrade dunes. The final category, called the "cover sands," consists of the area around the dunes where a thin layer of sand is present but vegetation is typically thicker than on the actual dunes (Brant 2005). Brant (2005) found that rodent diversity was higher in dune areas than in the surrounding cover sands and that rodent communities differed between the gypsum and quartzose dunes. The cover sands at GUMO supported just three rodent species, while the quartzose and intergrade dunes supported four species, and the gypsum dunes hosted six different species (Table 15). Merriam's kangaroo rat (*Dipodomys merriami*) was the most abundant species in all dune categories except the gypsum dunes, where Ord's kangaroo rat (*Dipodomys ordii*) was most abundant (Figure 6, Brant 2005).

**Table 15.** Rodent species diversity indices (with 95% confidence intervals) and individual species abundance by dune habitat type in GUMO (Brant 2005).

| | **Quartzose dunes** | **Gypsum dunes** | **Intergrade dunes** | **Cover sands** | **Total** |
|---|---|---|---|---|---|
| Total species | 4 | 6 | 4 | 3 | 7 |
| Total individuals | 42 | 30 | 23 | 49 | 144 |
| Most abundant | *D. merriami* (50%) | *D. ordii* (37%) | *D. merriami* (74%) | *D. merriami* (57%) | *D. merriami* (52%) |
| Margalef's richness | 1.848 (1.232-1.848) | 3.385 (2.031-3.385) | 2.203 (1.469-2.203) | 1.183 (0.592-1.183) | 2.784 (1.856-2.784) |
| Simpson's evenness | 0.637 (0.529-0.905) | 0.652 (0.497-0.872) | 0.615 (0.439-0.914) | 0.555 (0.465-0.914) | 0.373 (0.337-0.554) |
| Shannon diversity | 0.459 (0.352-0.519) | 0.659 (0.496-0.715) | 0.467 (0.291-0.546) | 0.283 (0.193-0.351) | 0.545 (0.437-0.562) |
| Merriam's kangaroo rat | Very abundant | Abundant | Very abundant | Very abundant | |
| Ord's kangaroo rat | Abundant | Very abundant | Common | --- | |
| Chihuahuan Desert pocket mouse | Abundant | Abundant | Abundant | Very abundant | |
| Merriam's pocket mouse | --- | Common | --- | --- | |
| cactus mouse | --- | Common | --- | --- | |
| Mearn's grasshopper mouse | --- | Rare | Rare | --- | |
| southern plains woodrat | Rare | --- | --- | Rare | |

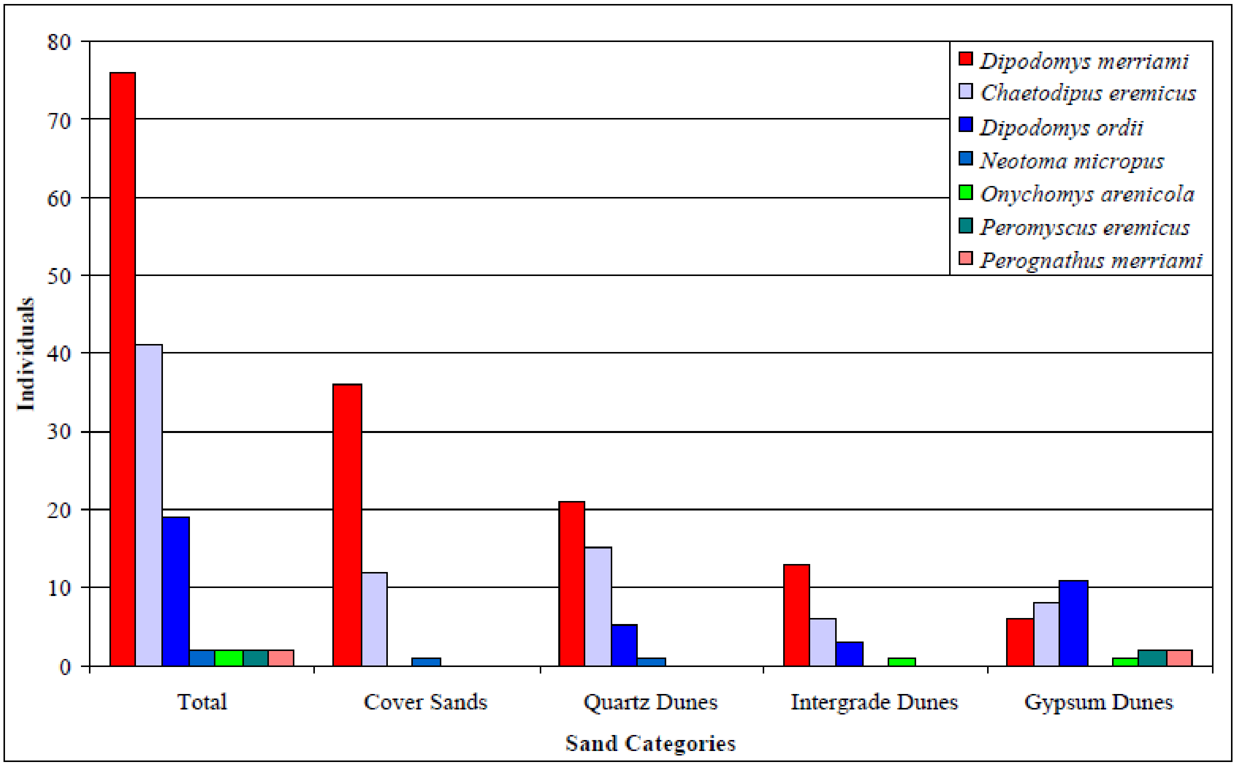



**Figure 6.** The abundance of rodent species by dune habitat within GUMO (Brant 2005).

<u>Changes in Dune Morphology, Movement, and Mass Using LiDAR</u>

Changes in dune morphology could be caused by drought, variations in wind (velocity and direction), or human disturbance. In addition to indicating dune condition, the monitoring of dune movement and morphology can also suggest near-surface moisture conditions (Weeks et al. 2008). The CHDN has recognized the importance of the geomorphic processes of dune formation, stability, and reactivation and has designated them as Vital Signs with high priority for monitoring (Weeks et al. 2008). Potential metrics that could be monitored using satellite imagery such as LiDAR (Light Detection and Ranging) include changes in size, shape, and position for both individual dunes and the dune fields as a whole.

As of 2008, the dunes had an "active front" approximately 15 m (50 ft) high and were advancing to the northeast (Weeks et al. 2008). To date, no data has been gathered for this measure using LiDAR. The CHDN I&M Program has tested the use of LiDAR for monitoring dune dynamics at White Sands National Monument (Kocurek et al. 2012); the lessons learned from this effort can be applied to future dune monitoring at GUMO (Weeks et al. 2008).

<u>Biological Soil Crust Resilience and Resistance</u>

Biological soil crusts are common "in the alkaline environment where gypsum sand dunes have become stabilized" and are a vital part of this arid ecosystem (NPS 2009, p. 32). The organisms in this soil crust have the capacity to capture and store water, and can convert atmospheric nitrogen to a form that is usable by plants (Rosentreter et al. 2007, NPS 2009). These crusts are extremely fragile and are easily damaged by human activities such as hiking and off-road vehicle use, as well as by livestock grazing (Belnap and Eldridge 2001). This disturbance can increase erosion, which causes further damage; when surrounding biological soil crusts are covered by wind- or water-borne sediment, they are unable to photosynthesize and may die (Belnap and Eldridge 2001, NPS 2009). In the absence of further disturbance, a thin layer of biological soil crust may return to a disturbed area in 5 years, although extensive damage may require 50 years or more for recovery. GUMO staff have observed "natural healing of park soil crusts disturbed by vehicles or livestock within a 10-15 year period" (NPS 2009, p. 32). However, the distribution, composition, and resiliency of biological soil crusts in the park have not been fully mapped or studied. Therefore, very little is known about their current condition.

Threats and Stressor Factors

Threats and stressors to the park's dune communities include increased visitor use, illegal off-road vehicle use, regional development, shallow water aquifer withdrawal, and a proposed desalination plant. Visitor use and off-road vehicles are a threat to the fragile biological soil crusts that stabilize much of the dune community. These uses could also trample sensitive vegetation and disturb wildlife.

Regional development is a threat partly due to potential water withdrawals. Shallow groundwater is critical for maintaining the dune formations and the community as a whole. A potential threat from the proposed desalination plant just outside the park's western boundary is the disposal of brine, a concentrated byproduct of the desalination process. A private landowner in the area has proposed pumping the brine into a playa basin on salt flats on his property just 8 km (5 mi) west of the park, which will serve as an "evaporation pond" (Mrkvicka 2004; Janet Coles, GUMO Chief of Resource Management, written communication, November 2012). Evaporation ponds allow the remaining water to evaporate out of the brine while salts evaporate on the bottom and can later be disposed of at a landfill (Younos 2005). However, the current desalination plant proposal does not include plans for removal of the solid salt wastes (Hearst, written communication, April 2013). The brine byproduct may also contain small amounts of chemicals used in the pre- and post-treatment processes (Table 16). If any brine leaks from the evaporation playa or the pipes transporting it, the brine and chemicals could leach into the groundwater (Younos 2005). Dried waste products (i.e., pollutant-carrying dust) may threaten the dune community's biological soil crusts and other organisms if they are blown from the evaporation basin into the park (Coles, written communication, November 2012).

**Table 16.** Chemicals used in the desalination process that may be present in the brine byproduct (Younos 2005).

| Pre-treatment chemicals | Chemicals for cleaning desalination equipment |
|---|---|
| NaOCl or chlorine - prevents biological growth | Enzymes - break down bacterial slimes |
| $FeCl_3$ or $AlCl_3$ - removes suspended sediment | Detergents and surfactants - dissolve organic material |
| $H_2SO_4$ or HCl - adjusts pH | Biocides - kill bacteria |
| $NaHSO_3$ - neutralizes chlorine | chelators - remove scale buildup |
| | Acids - dissolve inorganic substances |
| | Caustics - dissolve organic substances & silica |

Data Needs/Gaps

The dune community has received less attention than many other ecosystems in GUMO because it was not part of the park until 1987. The park has not developed a monitoring plan for the dune area. Weeks et al. (2008) identified the following list of research needs, to be pursued as resources become available:

- Acquire high-resolution mapping (e.g., LiDAR) of the dunes and surrounding source areas to evaluate dune dynamics (repeat every 5-10 years);
- Develop a ground water monitoring program through the use of shallow piezometers;
- Determine natural range of variability of dune movement and determine dune mobility index.

Additional needs include an inventory and mapping of biological soil crusts (extent, variety, and resilience) (NPS 2009), research on the status of rare plants such as gypsum scalebroom (*Lepidospartum burgessii*), and the potential effects of climate change on the dune communities. Drought, which could intensify with global climate change, appears to be causing a decline in gypsum scalebroom populations (Mike Howard, BLM Botanist, written communication, November 2012) and could contribute to decreased stability or resilience in dune communities overall. Various methods for monitoring biological soil crusts are discussed in Belnap and Eldridge (2001) and Rosentreter et al. (2007). Further research into the potential impacts of the proposed desalination plant (particularly discharged brine fluids) on the dune community may also be warranted (e.g., could the solid wastes remaining after evaporation blow into the park and impact dune vegetation, particularly biological soil crusts?). In 2012, New Mexico State University researchers began a soil faunal inventory of GUMO's dune communities (Hildy Reiser, CHDN Science Advisor, e-mail communication, 25 February 2013). The results from this research, when available, will contribute to the park's knowledge of the dune communities and their condition.

<u>Overall Condition</u>

*Change in Vegetation Community Extent*
The project team assigned this measure a *Significance Level* of 3. Given the lack of historic information to serve as a reference condition, a current *Condition Level* could not be determined. The information presented in this assessment can serve as a reference condition for future assessments.

*Change in Plant Species Richness*
This measure was assigned a *Significance Level* of 3. A comparison of historic (pre-1990) plant species lists to recent findings by Muldavin et al. (*in prep.*) suggests that species richness has changed little over the past several decades. As a result, this measure is of low concern (*Condition Level* = 1).

*Small Mammal Diversity*
This measure was assigned a *Significance Level* of 2. The species composition of the dunes' small mammal community appears to have changed little over time (refer to Table 14). The most abundant species also appear to have remained the same over time. Therefore, the *Condition Level* for this measure is a 0, indicating no current concern.

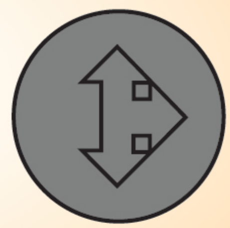
*Changes in Dune Morphology, Movement, and Mass Using LiDAR*
The project team assigned this measure a *Significance Level* of 3. However, no data has been gathered for these metrics and a *Condition Level* cannot be assigned at this time.

*Biological Soil Crust Resilience and Resistance*
The biological soil crust measure was assigned a *Significance Level* of 3. These soil crusts are a vital part of the dune ecosystem, but no data is available regarding their extent or resiliency in the park. Therefore, the current condition of biological soil crusts is unknown and a *Condition Level* could not be assigned.

*Weighted Condition Score*
A *Weighted Condition Score* was not calculated for GUMO's dune communities, as *Condition Levels* could not be assigned for the majority of the component's measures. The overall condition is therefore considered unknown.

## Dune Communities

| Measures | SL | CL |
|---|---|---|
| Change in community extent | 3 | n/a |
| Change in plant species richness | 3 | 1 |
| Small mammal diversity | 2 | 0 |
| Changes in dune morphology, movement, and mass | 3 | n/a |
| Biological soil crusts | 3 | n/a |



WCS = N/A

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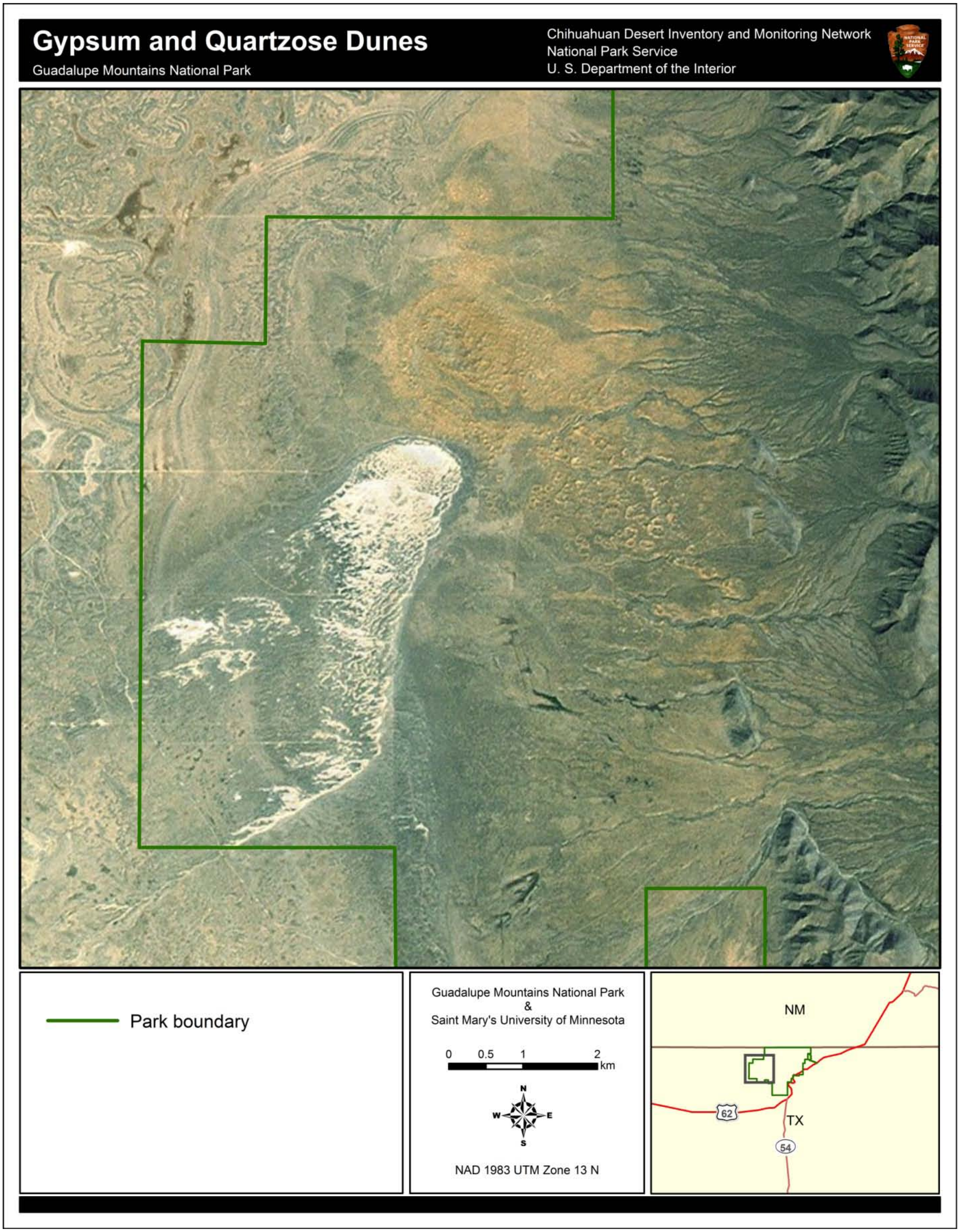


**Plate 8.** The gypsum (white) and quartzose (red) dunes to the north are visible in this aerial photo of the park (scale 1:65,000).

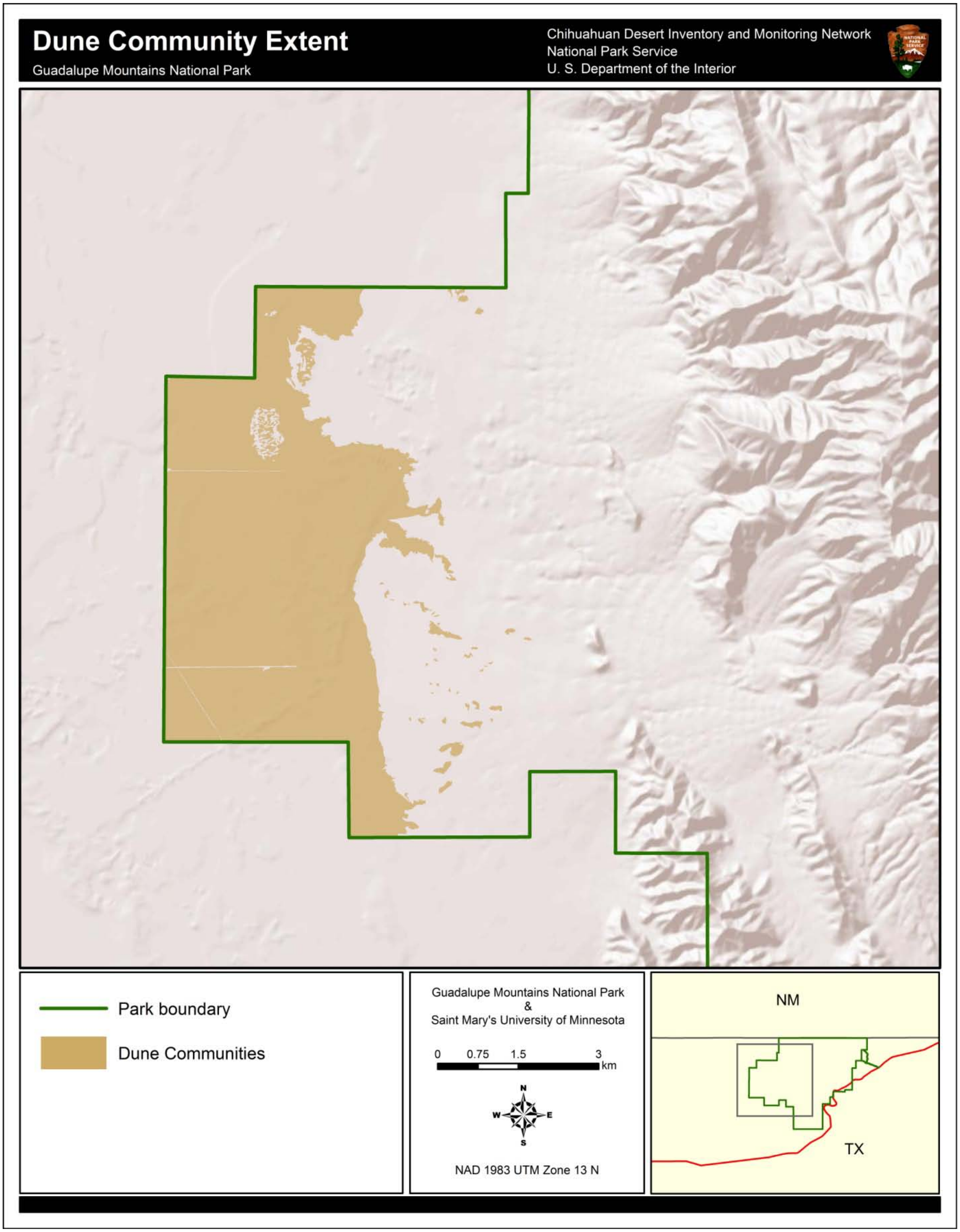


**Plate 9.** Current extent of dune community vegetation within GUMO (Muldavin et al., *in prep.*)

### 4.3 Sky Islands (Montane Forest)

***Description***

Montane coniferous forests are limited to higher elevations in the northern part of GUMO (Photo 9). These forests are surrounded by typical Chihuahuan Desert vegetation and isolated from similar stands in nearby mountain ranges (Potter and Robinson 1968); as a result, these outliers are sometimes called "sky islands." They support a variety of wildlife including black bear (*Ursus americanus*), mountain lion (*Puma concolor*), mule deer (*Odocoileus hemionus*), gray fox (*Urocyon cinereoargenteus*), and a small introduced population of elk (*Cervus canadensis*) (NPS 2012a).

**Photo 9.** Montane forest in the Bowl of GUMO (NPS photo by William Leggett).

Montane forests within the park vary in species composition depending on elevation, topography, and soil moisture (Sakulich and Taylor 2007). The most dominant tree species are ponderosa pine, Douglas-fir (*Pseudotsuga menzeisii*), and southwestern white pine. Other common species include alligator juniper (*Juniperus deppeana*) and pinyon pine (*Pinus edulis*), with Gambel oak (*Quercus gambelii*) occurring in more open areas (Northington and Burgess 1979, Sakulich and Taylor 2007). Common understory species are the shrubs (or small trees) hophornbeam (*Ostrya knowltonii*), bigtooth maple (*Acer grandidentatum*), and serviceberry (*Amelanchier utahensis*), and the graminoids blue grama (*Bouteloua gracilis*), pinyon ricegrass (*Piptochaetium fimbriatum*), and sedges (*Carex* spp.) (Potter and Robinson 1968, Sakulich and Taylor 2007). In more mesic microclimates, wildflowers such as Indian paintbrush (*Castilleja* spp.), phlox (*Phlox* spp.), and gilia (Polemoniaceae) are also common. A small remnant aspen (*Populus tremuloides*) grove can be found near the top of South McKittrick Canyon, approximately 2.7 km (1.7 mi) east of Bush Mountain (Potter and Robinson 1968, NPS 2012b). During a brief survey of this stand in 1984, it contained an estimated 75 mature aspens and 35 young trees (most less than 2 m tall) (Jones and Kinney 1984).

### *Measures*

- Change in vegetation community extent
- Change in plant species richness
- Change in incidence of forest disease and pests
- Age class structure

### *Reference Conditions/Values*

The ideal reference condition for this component is pre-European settlement condition. The earliest available observation of montane forests in the GUMO region comes from Havard (1885), who reported on the vegetation of southern and western Texas. Havard (1885, p. 486) described the Guadalupe Mountains as "well timbered on their broad summit" with pine, oak, and juniper.

> The species of Pine are: Yellow Pine *(Pinus ponderosa*), the prevalent and most valuable large tree, 30 to 50 feet high and with trunks 1 to 2 feet in diameter, extending from the summit to the base of the mountain; Flexible Pine* *(Pinus flexilis*), smaller than the last, with trunk seldom exceeding 1 foot in diameter, and hardly found below the summit; Nut Pine (*Pinus edulis*), a low, twisted tree straggling on the slopes… The only Fir seen here, or anywhere in Western Texas, is the *Pseudotsuga* (*Abies*) *douglasii*, a fine tree, next in prevalence and size to the Yellow Pine." (Havard 1885, p. 486)
>
> *The subspecies of "flexible pine" identified by Havard has since been reclassified as southwestern white pine.

Havard (1885, p. 486) also recorded alligator juniper (the "principal and characteristic" juniper of the mountains) and Gambel oak ("a small shrub or gnarled tree 20 feet high") in the Guadalupe Mountain forests.

Forest structure reference conditions for the pre-grazing and pre-fire suppression period (around 1922) were reconstructed by Taylor and Sakulich (2006) using standard dendroecological methods.

### *Data and Methods*

In the late 1960s, Potter and Robinson (1968) conducted a study of montane forest vegetation in an area that is now part of GUMO. The study area was roughly bounded by Blue Ridge, Bush, and Pine Top Mountains and the eastern escarpment, including the area known as "the Bowl" (Plate 10). They gathered information on tree species composition and importance (canopy and sapling), age structure, and understory vegetation.

From 1972-73, Glass et al. (1974) conducted an inventory of GUMO vegetation types to identify and map key wildlife browse areas in the park. Forty-nine transects were sampled and the park was divided into four ranges to evaluate browse conditions: the upper range (above 2,286 m), Dog Canyon (north sector of the park below 2,134 m), the eastern escarpment, and the west side range. The montane forests fell within the upper range (dominated by coniferous forest) and Dog

Canyon (mostly pinyon-juniper and mountain shrub) (Glass et al. 1974). As part of a later elk population dynamic study in the 1990s (Carpenter 1993), the vegetation map created by Glass et al. (1974) was digitized into GIS format (ArcInfo).

As part of a study of fire ecology in GUMO, Ahlstrand (1979) gathered data on species composition and density by size class of conifer stands in the Bowl. Taylor and Sakulich (2006, Sakulich and Taylor 2007) studied fire regimes and forest change over time in GUMO's coniferous forest. In order to characterize historic and current fire regimes, they collected data on stand age structure, density, and species composition. A recent vegetation classification and mapping project (Muldavin et al., *in prep*) provided current information on the extent and species richness of GUMO's plant communities.

### *Current Condition and Trend*

Change in Vegetation Community Extent

When Glass et al. (1974) surveyed the park's vegetation in 1972-1973, they identified 3,263 ha (8,063 ac) of coniferous forest and 1,046 ha (2,585 ac) of pinyon-juniper woodland for a total montane forest area of 4,309 ha (10,648 ac) (Plate 11). The recent vegetation classification project identified 11 different montane forest mapping units, along with three shrubland mapping units that will succeed to montane forest in the absence of disturbance (Muldavin et al., *in prep.*). The 11 forest units comprise 5,408 ha (13,363 ac) or approximately 15.5% of the park (Table 17, Plate 12). While the two mapping projects are not directly comparable due to methodology differences, the results suggest an approximate 20% increase in montane forest area. The three shrubland units cover an additional 7,600 ha (approximately 22% of the park) (Table 18, Plate 12; Muldavin et al., *in prep.*).

**Table 17.** Extent of sky island/montane forest vegetation mapping units in GUMO (Muldavin et al., *in prep.*).

| Mapping Unit | Hectares |
|---|---|
| **Madrean Upper Montane Conifer-Oak Forest & Woodland** | |
| Mixed Conifer Woodland Savanna | 93.2 |
| Mixed Conifer -Gambel Oak Forest | 1,297.2 |
| Mixed Conifer -Bigtooth Maple-Knowlton's Hophornbeam Forest | 273.9 |
| Mixed Conifer Maple and Chinkapin Oak Forest | 619.3 |
| **Madrean Lower Montane Pine-Oak Forest & Woodland** | |
| Madrean Ponderosa Pine Woodland Savanna | 52.1 |
| Madrean Ponderosa Pine -Gambel Oak Forest | 111.5 |
| Madrean Ponderosa Pine-Wavyleaf Oak Forest | 488.5 |
| Madrean Ponderosa Pine Bigtooth Maple and Chinkapin Oak Forest | 15.2 |
| **Madrean Upper Montane Broadleaf Forest & Woodland** | |
| Madrean Bigtooth Maple -Oak Woodland | 483.6 |
| **Madrean Pinyon-Juniper Woodland** | |
| Madrean Pinyon-Alligator Juniper Woodland | 125.6 |
| Madrean Pinyon-Alligator Juniper Woodland savanna | 256.1 |
| Madrean Pinyon and Juniper-Wavyleaf Oak-Mountain Mahogany Woodland | 1,592.2 |
| **Total** | 5,408.4 |

**Table 18.** Extent of shrubland vegetation mapping units in GUMO that will succeed to montane forest in the absence of disturbance (Muldavin et al., *in prep.*).

| Mapping Unit | Hectares |
|---|---|
| **Southern Rocky Mountain Gambel Oak-Mixed (Mesic) Montane Shrubland** | |
| Gambel Oak-New Mexico Locust Shrubland | 273.2 |
| **Madrean Cercocarpus-Mixed Foothill Shrubland** | |
| Pinchot Juniper-Oak Shrubland | 1,031.7 |
| Oak-Mountain Mahogany Shrubland | 6,303.7 |
| **Total** | 7,608.6 |

**Photo 10.** Ponderosa pine in GUMO (NPS photo by William Legget).

Change in Plant Species Richness

When Potter and Robinson (1968) studied the forests of GUMO, they identified five major species in the mature tree canopy (listed in order of importance): ponderosa and southwestern white pine (Photo 10), Gambel oak, Douglas-fir, and alligator juniper. These trees were also present in the sapling/shrub layer along with gray oak, skunkbush sumac (*Rhus trilobata*), hophornbeam, and goldeneye (*Viguiera* sp.) (Potter and Robinson 1968). Sakulich and Taylor (2007) also sampled the forests of GUMO and found the same major species, with the addition of pinyon pine and bigtooth maple in some stands.

During the recent vegetation mapping and classification project, Muldavin et al. (*in prep.*) documented approximately 340 total plant species from 72 families in montane forest vegetation units (as defined by the National Vegetation Classification [NVC] standard) (Table 19). They confirmed the presence of the previously identified major species (Potter and Robinson 1968, Sakulich and Taylor 2007), suggesting that species richness has changed little over time.

**Table 19.** Total plant species richness for the sky island/montane forest community and by National Vegetation Classification (NVC) unit (Muldavin et al., *in prep.*).

| NVC Unit | Number of Species |
|---|---|
| **Sky Islands (Montane Forest)** | **340** |
| Madrean Juniper Savanna & Woodland Group | 138 |
| Madrean Lower Montane Pine - Oak Forest & Woodland Group | 130 |
| Madrean Pinyon - Juniper Woodland Group | 131 |
| Madrean Upper Montane Conifer - Oak Forest & Woodland Group | 284 |
| Southern Rocky Mountain Ponderosa Pine Savanna Group | 12 |

Change in Incidence of Forest Disease and Pests

According to NPS (2012b, p. 166), “Light infestations of Douglas-fir beetle, budworm, and western pine beetle are present in the park, especially at higher elevations, where populations cyclically wax and wane.” These infestations are a natural process in the montane forest and, in some ways, benefit the ecosystem. For example, dead standing trees provide habitat for cavity-nesting birds and decaying logs return nutrients to the soil (NPS 2004). In 2004, bark beetle damage was observed on ponderosa pines and Douglas-firs in the Dog Canyon and McKittrick Ridge areas of GUMO (NPS 2004). This outbreak, the worst in the southwest in nearly 50 years, involved several species of beetle and was brought on by extended drought conditions (NPS 2004). Drought and other stressors, such as disturbance or mistletoe infection, can make conifers more susceptible to insect damage. However, there is some concern that infestation rates may be unnaturally intensified by past human activities such as ranching, which has increased tree density and competition for limited water resources (NPS 2004). While removing infected trees or applying pesticides may help limit the damage, this is not a viable option in GUMO due to the fact that most of the forested area is designated as wilderness area (2004). Prescribed fire may help to thin conifer stands and increase their resistance to insect and disease outbreaks.

No quantitative data are available regarding the current or historic incidence of disease and pests in the park's montane forests. Given that forest density is currently much greater than historic levels and the state of Texas recently experienced a prolonged drought, the park's montane forests are likely more vulnerable to pests and disease now than they were prior to European settlement (Coles, written communication, November 2012).

Age Class Structure

While Potter and Robinson (1968) did not specifically study the age class structure of GUMO's montane forests, they did collect some size class density data (Table 20).

**Table 20.** Densities (trees per acre) by size class of tree species in the Bowl of GUMO (Potter and Robinson 1968). Class A includes seedlings less than 3 ft. (~1 m) tall, B includes seedlings over 3 ft. tall but less than 1 in. in diameter. Numbers represent diameter at breast height (DBH) to the nearest inch. Beyond size class 13, all tree densities were <5 trees per acre. Note that 1 inch = 2.54 cm.

| | Size Class | | | | |
|---|---|---|---|---|---|
| **Species** | **A** | **B** | **1"** | **5"** | **10"** |
| Douglas-fir | 850 | 371 | 50-55 | <5 | <5 |
| southwestern white pine | 250-255 | 110 | 30-35 | 5 | <5 |
| ponderosa pine | 270-275 | 285-290 | 260-265 | 30-35 | <5* |

* While all densities were less than 5 trees/acre in this size class, ponderosa pine had a slightly higher density than the other two species.

Ahlstrand (1979) also sampled the density of various size classes in the Bowl (Table 21). Similar to Potter and Robinson (1968), Ahlstrand (1979) found that small Douglas-firs were much denser than any other species sampled, although the difference was even greater.

**Table 21.** Densities (trees per acre) by size class of tree species in the Bowl (Ahlstrand 1979).

| | Diameter at Breast Height (DBH) in cm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **<5** | | **5-10** | **10-20** | **20-30** | **30-40** | **40-50** | **>50** |
| **Species** | **<1 m tall** | **> 1 m tall** | | | | | | |
| Douglas-fir | 3,411 | 525 | 14 | 9 | 12 | 3 | 6 | 4 |
| southwestern pine | 332 | 166 | 14 | 19 | 18 | 18 | 4 | 2 |
| ponderosa pine | 303 | 453 | 184 | 82 | 9 | 4 | 4 | 2 |
| alligator juniper | 14 | 12 | 1 | 6 | 2 | 3 | 7 | -- |
| Total | 4,060 | 1,156 | 224 | 116 | 41 | 29 | 21 | 8 |

Taylor and Sakulich (2006, and Sakulich and Taylor 2007) gathered data specifically on age class structure in GUMO's montane forests. They found that the park's mixed conifer forests were typically multi-aged. When divided into 20-year age classes, forest plots averaged 5.3 age-classes, with 48% of plots comprised of six or more age-classes and 57% of plots containing trees over 160 years old (Sakulich and Taylor 2007). Plots in the southwestern pine/Douglas-fir group (PIST-PSME) supported the highest number of age-classes with an average of 6.0. The average number of age classes in both the Douglas-fir/oak/mixed conifer (PSME-QUGA-MC) and the Douglas-fir (PSME) groups was 5.6, while the pinyon pine/alligator juniper group (PIED-JUDE) and the alligator juniper/ponderosa pine/Douglas-fir group (JUDE-PIPO-PSME) averaged 5.2 and 4.3 respectively (Sakulich and Taylor 2007).

Using standard dendroecological methods, Taylor and Sakulich (2006) were able to reconstruct forest structure conditions at the time just before grazing and fire suppression began (around 1922). Age class structure (based on densities) for five common tree species during the reference period and at the time of Taylor and Sakulich's (2006) sampling are shown in Figure 7. These results indicate that there are currently more trees in the middle age classes (40-80 years) and relatively fewer in the youngest class (20 years) than during the reference period.

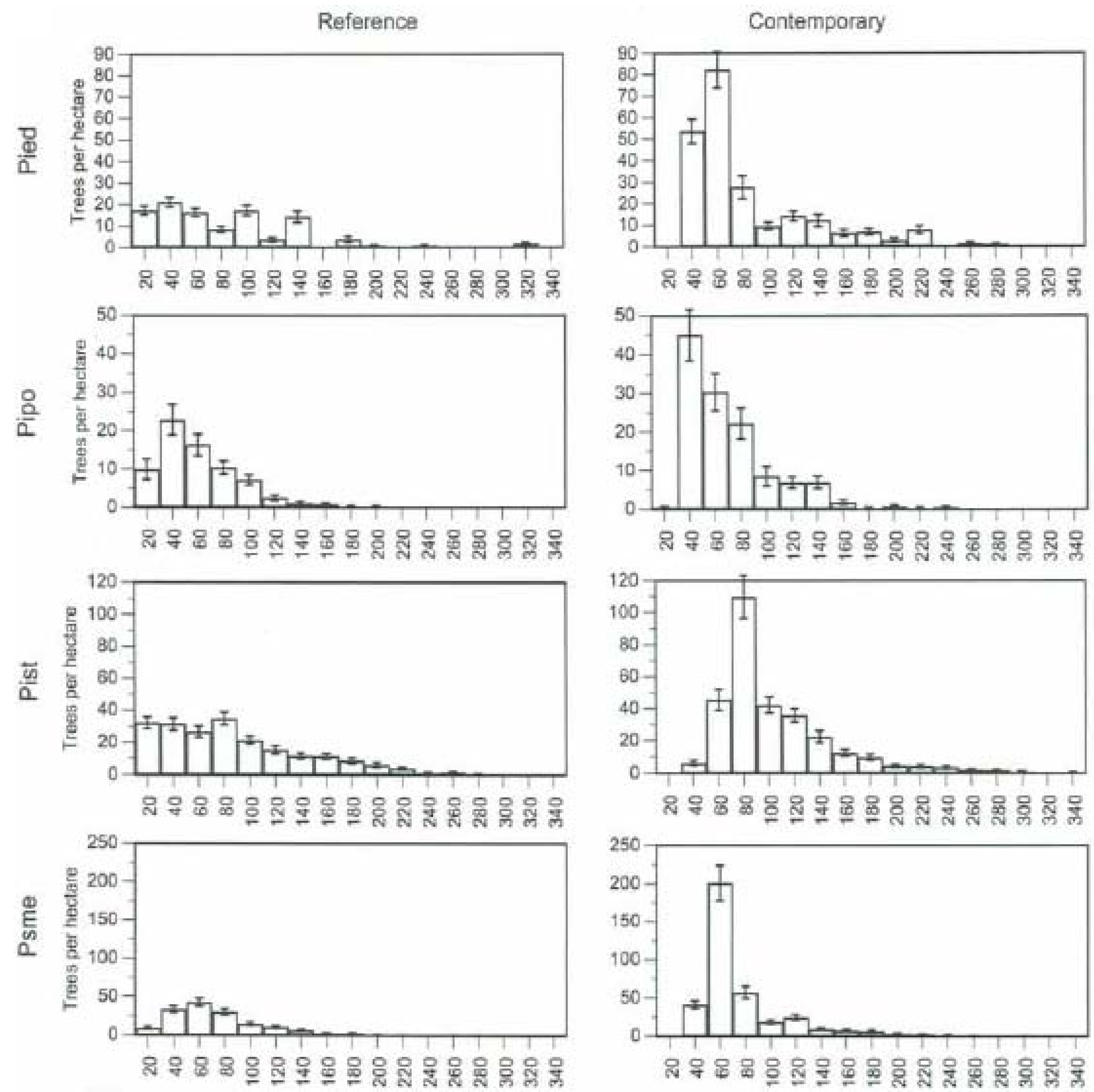


**Figure 7.** Reference period and contemporary age class distribution (densities) in GUMO's montane forest (Taylor and Sakulich 2006). The individual tree species represented are pinyon pine (PIED), ponderosa pine (PIPO), southwestern white pine (PIST), and Douglas-fir (PSME). Note that the vertical scales vary between graphs/species.

Threats and Stressor Factors

Threats and stressors to GUMO's montane forests include wildfire, drought, exotic species, historic land use/management (e.g., grazing, fire suppression), air pollutants, and climate change. Livestock grazing in the 20th century resulted in a composition shift in the park's sky island forests; grass cover declined while shrub and small tree density increased dramatically (Sakulich and Taylor 2007). The loss of fine fuels nearly eliminated the occurrence of low-intensity fires that naturally thinned the brushy layer in these forests. This, combined with a federal policy of fire suppression until the late 1900s, has led to dense growth of conifer seedlings and saplings in the park's sky island forests (Potter and Robinson 1968, Sakulich and Taylor 2007). This growth provides "enough fuel to any future fire to destroy all living vegetation in the area" (Potter and Robinson 1968, p. 47), as was demonstrated by two "stand-replacing" wildfires in GUMO during the 1990s (Sakulich and Taylor 2007, p. 1). Drought can also cause tree mortality and dry conditions that could favor or intensify wildfires (NPS 2005). The increase in tree density over the past century has likely intensified competition for water, increasing the forest's susceptibility to drought-related mortality (Taylor and Sakulich 2006).

Climate change has been identified by the CHDN as a significant concern to natural resources throughout the network (Davey et al. 2007). Montane habitats, such as the sky islands in GUMO, are of particular concern as temperatures are expected to warm and these habitats are already at the southern edge of their current range. Warmer temperatures may contribute to earlier snow melt, potentially increasing the fire season, as fuels will dry and become combustible earlier in the year (Sakulich and Taylor 2007). Changes in the amount and seasonality of precipitation could also increase the frequency of drought and impact fire regime. Finally, climate change can affect insect and disease outbreaks as well as the forest's susceptibility to these attacks (Davey et al. 2007).

Several species found in GUMO's montane forests may be impacted by air pollution. For example, ponderosa pine, trembling aspen, and skunkbush sumac are known to be sensitive to ozone (NPS 2006). Lastly, the invasion of exotic plant species (e.g., common mullein [*Verbascum thapsus*], Lehmann lovegrass [*Eragrostis lehmanniana*]) threatens to displace native plants and alter ecological processes such as fire and nutrient cycling (Reiser et al. 2012).

Data Needs/Gaps

The montane forests of GUMO have been studied more than any other community in the park. However, little is known about several threats to this forest community. For example, no quantitative data could be found on the incidence of disease or pests in the park, only that outbreaks do occur. Little is also known about the potential impacts of climate change on sky islands and on the wildlife that rely on them.

Researchers also have an opportunity to study the impact of repeated burning on the park's montane forests. A large area in the north area of the park that burned during the Marcus fire of 1994 burned again in 2010 during the Cutoff fire. Both of these were natural, lightning-caused fires (NPS 2010). The occurrence of two fires within 20 years may have a significant effect on stand structure and composition in a forest that went so many years without burning.

Overall Condition

*Change in Vegetation Community Extent*

The project team assigned this measure a *Significance Level* of 3. While historic vegetation mapping results (Glass et al. 1974) are not directly comparable to recent efforts (Muldavin et al., *in prep.*), results suggest that montane forest area has increased over the past 30 years. Therefore, the *Condition Level* for this measure is 0, indicating no concern at this time.

*Change in Plant Species Richness*

This measure was also assigned a *Significance Level* of 3. Nearly all the plant species documented historically in the park's montane forest were identified in Muldavin et al.'s (*in prep.*) forest sampling plots. This suggests that species richness has changed very little over time. As a result, this measure was assigned a *Condition Level* of 0 or no concern.

*Change in Incidence of Forest Disease and Pests*
The project team assigned this measure a *Significance Level* of 2. Since no current or historic data are available regarding the incidence of pests and disease, a *Condition Level* could not be assigned for this measure.

*Age Class Structure*
The age class structure measure was assigned a *Significance Level* of 3. The majority of montane forest stands in the park are multi-aged. However, Taylor and Sakulich (2006) showed that the age class structure of these stands has changed since the pre-grazing period, with the densities of multiple age classes increasing dramatically (see Figure 7). Therefore, the *Condition Level* for this measure is a 3, of high concern.

*Weighted Condition Score*
The *Weighted Condition Score* for GUMO's sky islands is 0.333, which falls on the line between low and moderate concern. Given the strong connection between montane forest condition and fire regime, and the fact that a single high severity fire could quickly and seriously alter forest condition, this component is considered of moderate concern. In recent years, the condition of these forests appears to be stable.

**Sky Islands/Montane Forest**

| Measures | SL | CL |
|---|---|---|
| • Change in community extent | 3 | 0 |
| • Change in plant species richness | 3 | 0 |
| • Incidence of disease/pests | 2 | n/a |
| • Forest age class structure | 3 | 3 |

**WCS = 0.333**

***Sources of Expertise***
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Janet Coles, GUMO Chief of Resource Management

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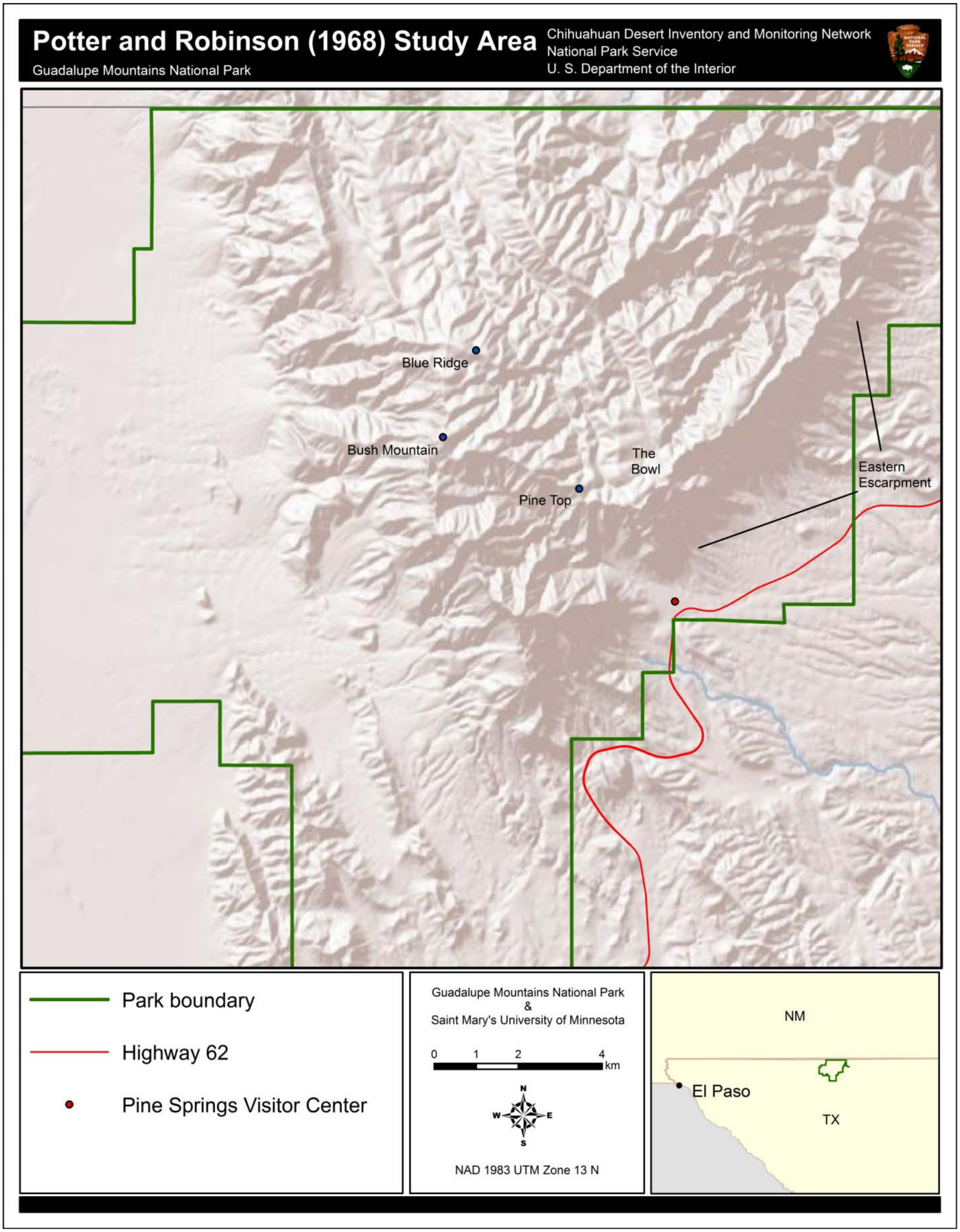



**Plate 10.** General location of Potter and Robinson's (1968) montane forest study area within the current park boundary.

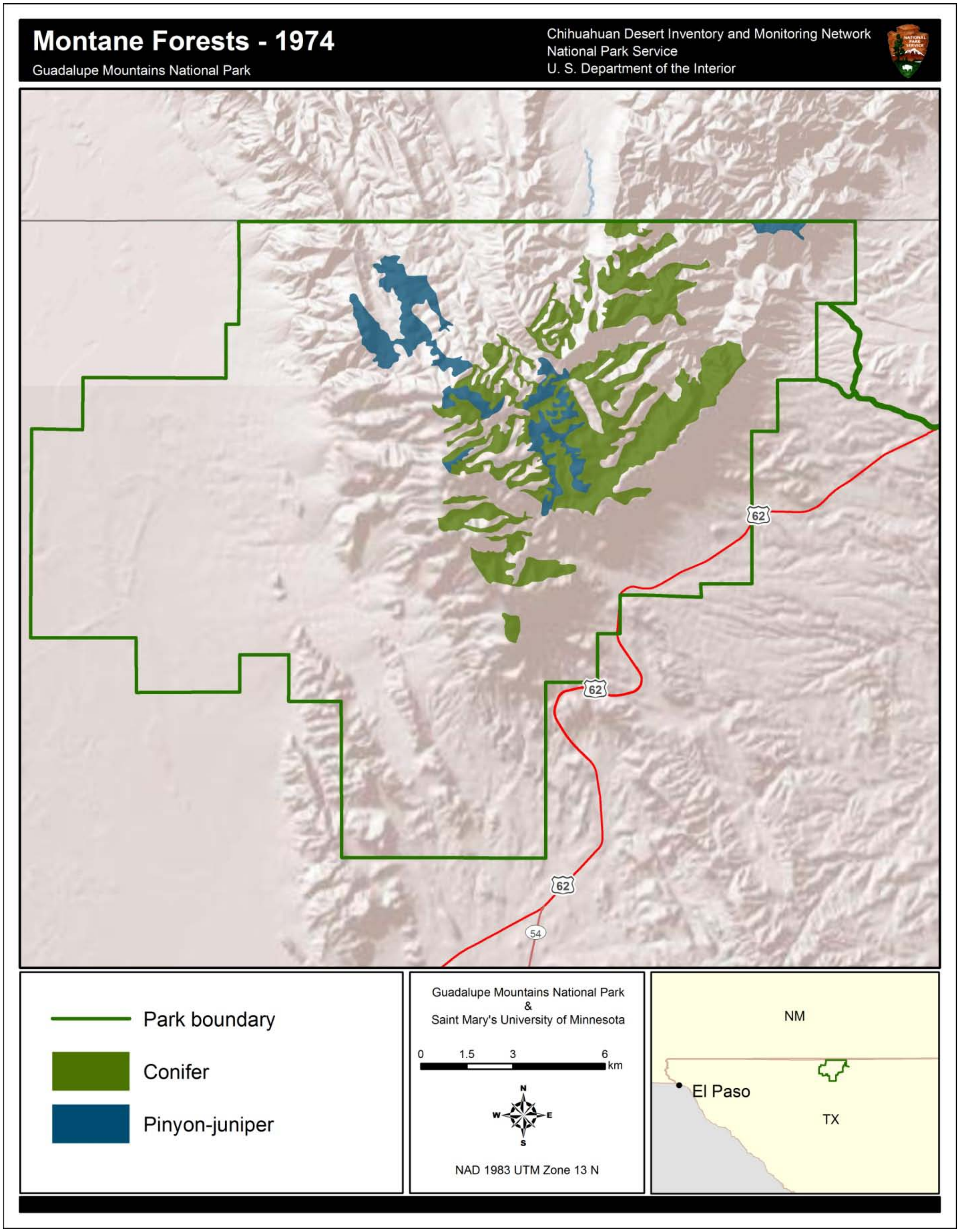



**Plate 11.** Extent of montane forests (conifer and pinyon-juniper) within GUMO in 1974 (Glass et al. 1974).

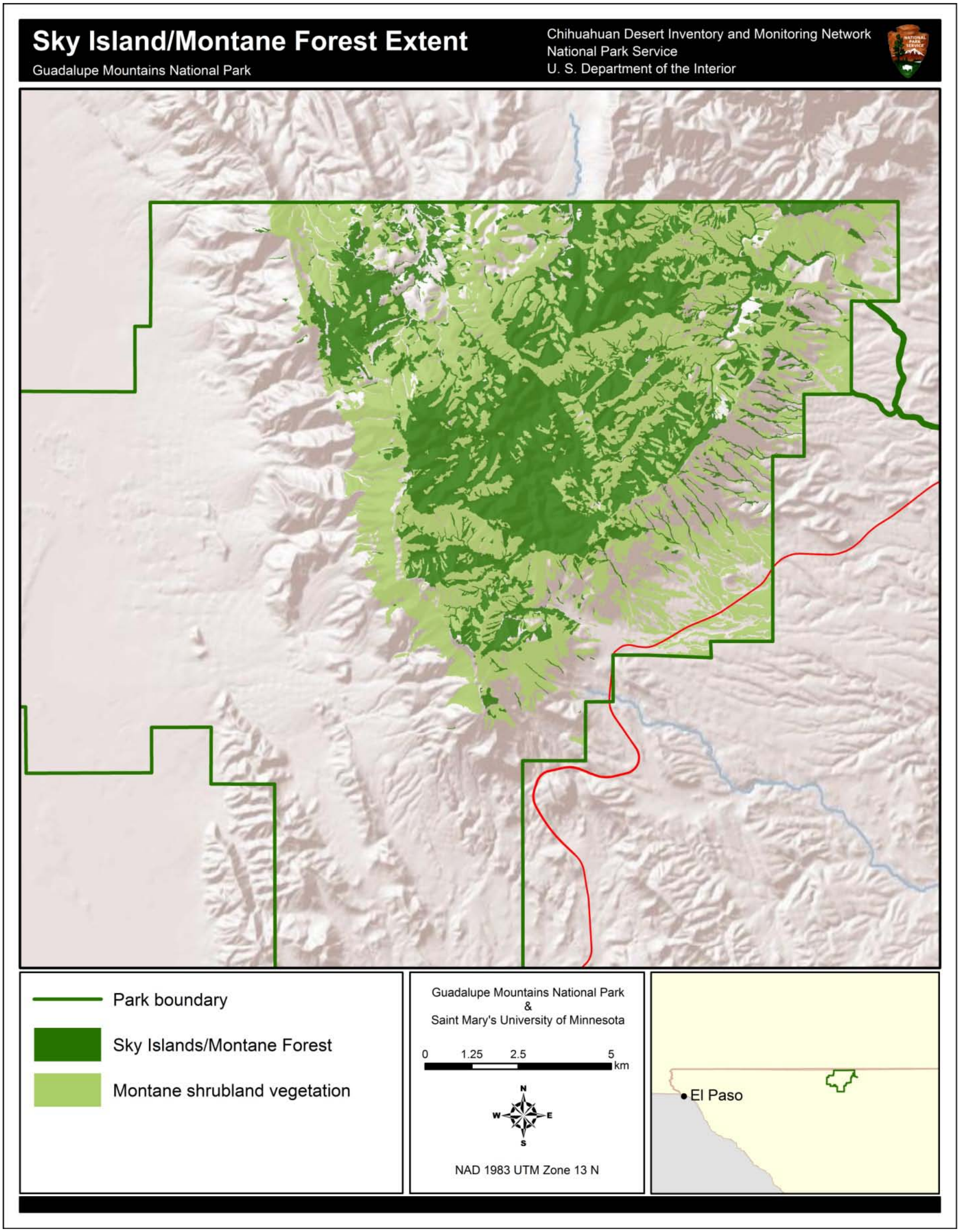



**Plate 12.** Current extent of sky island/montane forest vegetation within GUMO, and extent of shrubland vegetation that will likely succeed to montane forest in the absence of disturbance (Muldavin et al., *in prep.*)

## 4.4 Riparian and Canyon Communities

### *Description*

Riparian and canyon areas support vegetation communities that are very different compared to the rest of GUMO, due to higher moisture levels and/or cooler conditions. This is particularly evident in McKittrick Canyon, the park's largest riparian area (Photo 11). Riparian areas comprise a very small percentage of the park, but are incredibly important ecologically. These areas perform several significant functions, including providing a water supply, maintaining water quality, providing habitat for flora and fauna, and maintaining the park's biodiversity (Weeks et al. 2008). The park's riparian areas and canyons support many rare and endemic plant species (Northington and Burgess 1979), along with wildlife such as mule deer, nocturnal mammals, migratory birds, and even the Rio Grande leopard frog (*Rana berlandieri*) (NPS 2012).

**Photo 11.** Vegetation along the McKittrick Canyon trail (NPS photo).

Riparian and canyon areas support hardwood woodlands with gray and chinkapin oak (*Quercus grisea* and *Q. muehlenbergii*), bigtooth maple, Texas madrone (*Arbutus xalapensis*), and alligator juniper (Gehlbach 1967, Ferris 2006). Common understory species include green sotol (*Dasylirion leiophyllum*) and a variety of grasses, while creeks are often lined with Jamaican sawgrass (*Cladium mariscus* spp. *jamaicense*) (Gehlbach 1967, Weeks et al. 2008).

Aquatic macroinvertebrates are often used as indicators of water quality and overall watershed health (EPA 2011). Some species are tolerant of pollution or poor water quality, while others are highly sensitive to it. The presence or absence of tolerant and intolerant species can therefore be an indication of a water body's condition and water quality (EPA 2011). Species diversity can also be an indicator of habitat health, as a diverse habitat with more ecological "niches" can generally support more species. For these reasons, aquatic macroinvertebrate diversity is included as a measure for the riparian/canyon community.

#### *Measures*

- Change in vegetation community extent
- Change in plant species richness
- Aquatic macroinvertebrate diversity

#### *Reference Conditions/Values*

The earliest reference to this region's riparian and canyon vegetation comes from Havard (1885). During a survey of western and southern Texas, Havard (1885) observed gray oak, chinkapin oak, velvet ash (*Fraxinus velutina*, typically near water), bigtooth maple, and Texas mulberry (*Morus microphylla*). Characteristic shrubs or bushy plants included common hoptree (*Ptelea trifoliata*), cliff fendlerbush (*Fendlera rupicola*), and creeping barberry (*Mahonia repens*). Havard (1885) also mentions large cottonwoods (*Populus deltoides*), chinkapin oak, and cattail (*Typha latifolia*) in the "Five Springs" valley (the area around Frijole, Manzanita, Smith, Juniper, and Choza springs).

Different reference conditions will be used for this component's three measures. The reference condition for community extent will be no change from the current extent of riparian and canyon vegetation. For species richness, some historic information is available from canyon vegetation surveys completed by Gehlbach (1965, 1967) in the 1950s and 1960s. Regarding aquatic macroinvertebrate diversity, Green (1993) provides a thorough data set and will serve as reference condition for McKittrick Creek. Due to limited data, no reference condition could be established for aquatic macroinvertebrates in the park's springs; however, the information presented here from four park springs (Maher 2009) could serve as a baseline for future assessments.

#### *Data and Methods*

The study of canyon communities in what is now GUMO began in the late 1950s (Gehlbach 1965, 1967). Dr. Frederick Gehlbach of Baylor University surveyed the flora of McKittrick, Bear, and Pine Spring Canyons, along with several canyons in New Mexico (Gehlbach 1967). Another study focused on vegetation along the McKittrick Canyon trail, in comparison to Boot Canyon trail in Big Bend National Park (Gehlbach 1965). Northington and Burgess (1979) documented the rare and endemic plant species within the riparian/canyon areas of the park. More recent (although less detailed) descriptions of GUMO riparian areas are given in Ferris (2006) and Weeks et al. (2008). Walsh and Worthington (1996) conducted a biotic

**Photo 12.** Manzanita Spring (NPS photo).

assessment of Manzanita Spring (Photo 12), including both flora and fauna. Andersen (2003) studied and compared the flora and fauna of Choza, Smith, and Juniper Springs. A recent vegetation classification and mapping project (Muldavin et al., *in prep.*) provided current information on the extent and species richness of GUMO's plant communities.

The most thorough study of aquatic macroinvertebrates was conducted in McKittrick Creek by Green (1993). Sampling occurred over 2 years at 12 sites on North, South, and Lower McKittrick Creek. Earlier studies of macroinvertebrates include Lind (1979) and Meyerhoff and Lind (1987). Walsh and Worthington's (1996) assessment at Manzanita Spring also included some aquatic macroinvertebrate sampling. Maher (2009) sampled macroinvertebrates in springs across west Texas, including Choza, Guadalupe, Upper Pine, and Smith Springs at GUMO. Sampling occurred between 2004 and 2006.

### *Current Condition and Trend*

<u>Change in Vegetation Community Extent</u>

During Glass et al.'s (1974) inventory and mapping effort in the early 1970s, only one of their vegetation categories (hardwood) could clearly be classified as a riparian or canyon community. This vegetation, which likely included riparian and non-riparian hardwoods, was mapped only in the McKittrick Canyon area, covering just 132.7 ha (327.9 ac) of the park (Plate 13).

Muldavin et al. (*in prep.*) identified eight vegetation mapping units that are characteristic of riparian and/or canyon areas. The Madrean Encinal Group occurs in upland canyons, typically not in riparian areas (Esteban Muldavin, Natural Heritage Division Director, written communication, 1 August 2012). Many of the riparian mapping units are likely dry for long periods of time (e.g., "dry washes"), but temporary or seasonal moisture increases allow these areas to support riparian vegetation. Relatively shallow bedrock underlying streambeds also keeps the water table relatively high (Coles, written communication, November 2012). Overall, riparian/canyon vegetation covers 2,375 ha (5,868.8 ac), or just 7% of the park (Table 22, Plate 14; Muldavin et al., *in prep.*).

**Table 22.** Extent of riparian/canyon vegetation mapping units in GUMO (Muldavin et al., *in prep.*).

| Mapping Unit | Hectares |
|---|---|
| **Madrean Encinal Group (upland)** | |
| Madrean Gray Oak-Alligator Juniper Woodland | 202.1 |
| Madrean Gray Oak-Alligator Juniper Savanna | 94.0 |
| **Warm Semidesert Shrub & Herb Wash-Arroyo** | |
| Apache Plume Dry Wash Riparian Shrubland | 466.8 |
| Desert Willow Dry Wash Riparian Shrubland | 237.0 |
| Chihuahuan Desert Scrub Dry Wash Riparian Shrubland | 1,241.9 |
| **Sonoran-Chihuahuan Lowland Riparian Forest** | |
| Mixed Riparian Woodland | 5.9 |
| Madrean Evergreen Riparian Dry Wash Woodland and Shrubland | 127.3 |
| **Riparian/Wetland** | |
| Herbaceous Wetland | 0.2 |
| **Total** | 2,375.2 |

<u>Change in Plant Species Richness</u>

The plant species in GUMO's riparian/canyon communities have not been comprehensively surveyed. A total of 48 plant and three algae species were noted by Gehlbach (1965, 1967) and

Lind (1979) in McKittrick Canyon during the 1960s and 1970s (Appendix B). However, Gehlbach (1965, 1967) focused on the most dominant species and did not publish a full species list. Northington and Burgess (1979) generated a list of rare or unique plants found in the park, including 34 documented in McKittrick Canyon or other canyon habitats (Appendix B). Andersen (2003) and Walsh and Worthington (1996) conducted comprehensive floral surveys of their study springs, and Ferris (2006) documented plant species at Choza and Smith Springs. Species richness at these springs varied from 68 at Juniper Spring (which was impacted by a major wildfire in 1993) to 164 at Manzanita Spring (Appendix B).

During a recent vegetation mapping and classification project, Muldavin et al. (*in prep.*) documented approximately 230 plant species from 66 families in three riparian/canyon NVC vegetation units. The Madrean Encinal Group, a canyon vegetation type, was most diverse with nearly 200 species (Muldavin et al., *in prep.*). Most of the species identified by Gehlbach (1965, 1967) were also documented by Muldavin et al. (*in prep.*); some species that were not found in Muldavin et al.'s (*in prep.*) riparian/canyon NVC units were present in montane forest units, suggesting differences in classification methods rather than actual change. Very few of the rare or unique species found by Northington and Burgess (1979) in McKittrick Canyon during the 1970s (Appendix B) were documented by Muldavin et al. (*in prep.*). This could be a function of their rarity rather than loss of species, as Muldavin et al.'s (*in prep.*) study was a sampling effort rather than a comprehensive plant survey.

<u>Aquatic Macroinvertebrate Diversity</u>
Diversity is a metric that incorporates both species richness and species abundance through the mathematical calculation of an index (e.g., Shannon-Wiener Index, Simpson Index). While aquatic macroinvertebrate species richness has been studied in GUMO water bodies, very little abundance data is available (see Lind 1979). Therefore, diversity indices could not be calculated for this assessment. The available species richness research will be presented here, as it provides some insight into diversity.

Several macroinvertebrate sampling efforts have been conducted in McKittrick Creek, the park's largest perennial stream. These results are presented in Appendix B. The most comprehensive study (Green 1993) documented 84 taxa in the stream, including approximately 20 taxa from the orders Ephemeroptera and Trichoptera, which are known to be pollution-sensitive. However, taxa from the order Plecoptera, also known to be pollution-sensitive, were not found in the creek. An analysis of macroinvertebrate taxa lists from McKittrick Creek (Lind 1979, Meyerhoff and Lind 1987, Green 1993) using Texas Commission on Environmental Quality (TCEQ) pollution tolerance values (TCEQ 2007) suggests that in the past, approximately 30% of taxa were categorized as "intolerant" (Appendix B; Gallo, written communication, April 2013). Only 11% of taxa were considered "tolerant", while the remaining macroinvertebrates were somewhere in between. This suggests that while McKittrick Creek is not pristine, it is also not a substantial cause for concern (Gallo, written communication, April 2013). For a more detailed description of this analysis, see Appendix B.

Maher (2009) sampled four springs (Choza, Guadalupe, Upper Pine, and Smith) as part of a larger study of west Texas springs. Aquatic macroinvertebrate richness in the GUMO springs ranged from 26 to 35 taxa with an average of 28.75 (Table 23). In comparison, macroinvertebrate richness across all sampled west Texas springs ranged from 1 to 46 taxa with an average of 22.6

(Maher 2009). Notable findings within the park included a previously undescribed Trichopteran taxa (*Marilia* sp.) at Guadalupe Spring and a "never before seen" Trichopteran (*Lepistoma* sp.) from Upper Pine Spring (Maher 2009, p. 23).

**Table 23.** Aquatic macroinvertebrate taxa richness (aggregated at the family level) and total macroinvertebrates at four springs in GUMO (N = number of samples) (Maher 2009).

| Site | N | Total taxa (families) | Total macroinvertebrates |
|---|---|---|---|
| Choza | 4 | 35 | 534 |
| Guadalupe | 4 | 27 | 403 |
| Smith | 4 | 27 | 656 |
| Upper Pine | 5 | 26 | 1,944 |

Threats and Stressor Factors

Threats to the park's riparian/canyon communities include wildfire, exotic animals and plants, flash floods, inappropriate visitor use, and climate change. Changes to the park's fire regime over the past century have led to fuel build ups in many riparian areas that increase burn severity when fires do occur (see Chapter 4.1). An example of this is the crown fire that killed all the trees and destroyed the protective woodland canopy around Juniper Spring in 1993 (Andersen 2003). Ten years after the fire, the site supported shrubby vegetation and few riparian-specific species (Andersen 2003). The lack of a tree canopy can alter the microclimate typical of a riparian area and the wildlife species the area can support.

Exotic animals, such as feral hogs (*Sus scrofa*) and bullfrogs (*Lithobates catesbeianus*), also threaten riparian communities. Rooting and wallowing by feral hogs, which were first documented in the park in 2009, disturbs and can destroy native vegetation, particularly in wet areas (Fred Armstrong, former GUMO Chief or Resource Management, phone communication, 27 September 2011; Taylor 2012). Feral hogs seem to be attracted to canyons and riparian areas as a water source and by acorn mast in the winter (Armstrong, phone communication, 27 September 2011). Bullfrogs, though not currently present in the park, are encroaching and would aggressively compete with and/or prey upon native amphibians and other wildlife (Rosen and Schwalbe 1995). Exotic plants can compete with and displace native riparian plant species as well. Several exotic species have been documented at Choza Spring, including common mullein, horehound (*Marrubium vulgare*), and Maltese star-thistle (*Centaurea melitensis*) (Ferris 2006). Bermudagrass (*Cynodon dactylon*) has been noted at several springs, including Manzanita and Frijole Ranch (NPS 2000, Reiser et al. 2012). Lehmann lovegrass was also recently detected at Frijole Ranch Spring (Reiser et al. 2012).

Predicted climate change, particularly increased temperature (which can accelerate evaporation), could reduce the amount of available moisture in riparian/canyon environments (Schindler 1997). This would likely shift plant composition in favor of species that can tolerate drier conditions and may favor exotic plants over natives (Meyer and Pulliam 1991, as cited in Weeks et al. 2008). Flash floods, which could also increase with climate change, can uproot or otherwise disturb riparian vegetation, leaving bare areas that could be colonized by exotic plants.

Data Needs/Gaps

According to Weeks et al. (2008, p. 62), "Other than a cursory understanding of the presence of plant species, the riparian zones in the park are unstudied. More importantly, it is not known how healthy these areas are and if they are functioning properly, thus providing maximum ecological protection to the park's water resources." Weeks et al. (2008) recommends the use of a broad riparian assessment tool, such as the Bureau of Land Management's (BLM) Assessing Proper Functioning Condition (BLM 1995), which takes into account the "functionality" of 17 hydrologic, vegetation, and stream geomorphology characteristics. This screening tool could be repeated approximately every 5 years to help managers identify areas that are functioning well and those that need further attention (Weeks et al. 2008).

Perhaps one of the greatest needs is an updated macroinvertebrate sampling of McKittrick Creek. Green's (1993) data are now 20 years old. Floods have occurred during this time and likely altered aquatic habitats, which could influence the macroinvertebrate community. New sampling could include the calculation of a Benthic Index of Biotic Integrity (BIBI), a rapid bioassessment tool developed by the TCEQ to evaluate the biological integrity of macroinvertebrate communities (TCEQ 2007). Future sampling efforts should also attempt to include species abundance data, so that diversity indices can be calculated.

Little seems to be known about the natural role of fire in the park's riparian/canyon communities. According to Gehlbach (1965, p. 4), "evidence from burned stumps and logs, coupled with present dominance of grasses, indicates fire as an important factor" in the ecosystem. A better understanding of the natural fire regime (e.g., frequency, severity, etc.) would help managers to return and/or maintain this important natural process on the landscape. Researchers also have an opportunity to study the recovery of riparian vegetation after a severe fire at Juniper Spring, which burned in 1993. An exotic plant survey of all the park's riparian areas would help managers understand the current extent and impacts of these species on riparian communities. Current exotic plant monitoring in the park by the CHDN does not cover riparian areas. However, the CHDN spring monitoring program will continue to provide some information on exotic species at selected park springs. A more thorough plant survey in McKittrick Canyon for species identified as rare and unique in the 1970s (Northington and Burgess 1979) would help managers determine their current status and provide insight into potential changes in plant species richness.

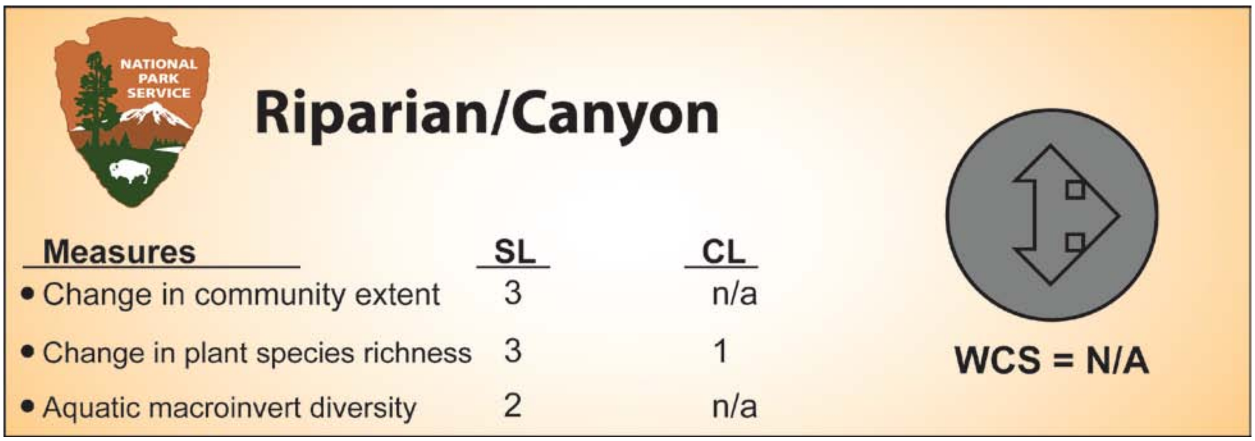
<u>Overall Condition</u>

*Change in Vegetation Community Extent*
The project team assigned this measure a *Significance Level* of 3. No historic data are available regarding the extent of riparian/canyon vegetation communities throughout the park. As a result, a *Condition Level* was not assigned for this measure. For future assessments, the information presented in this assessment (from Muldavin et al., *in prep.*) can be used as a reference condition.

*Change in Plant Species Richness*
The plant species richness measure was also assigned a *Significance Level* of 3. While many of the species documented historically in riparian/canyon habitats were found by Muldavin et al. (*in prep.*), most of the rare or unique species were not documented. It is unclear if this is due to a change in species richness or is simply a function of these species' rarity and Muldavin et al.'s (*in prep.*) study approach (sampling vs. a comprehensive survey). The *Condition Level* for this measure is a 1, indicating low concern.

*Aquatic Macroinvertebrate Diversity*
This measure was assigned a *Significance Level* of 3. While available data indicate that aquatic macroinvertebrate richness is relatively high in McKittrick Creek given its size, these data are nearly 20 years old. Diversity indices could not be calculated, as only a very limited amount of abundance data is available. In addition, some of the park's springs have never been surveyed for aquatic macroinvertebrates. Due to the lack of current data, a *Condition Level* could not be assigned for this measure at this time.

*Weighted Condition Score*
A *Weighted Condition Score* was not calculated for GUMO's riparian/canyon community as *Condition Levels* could not be assigned for two of the three measures because of data gaps.

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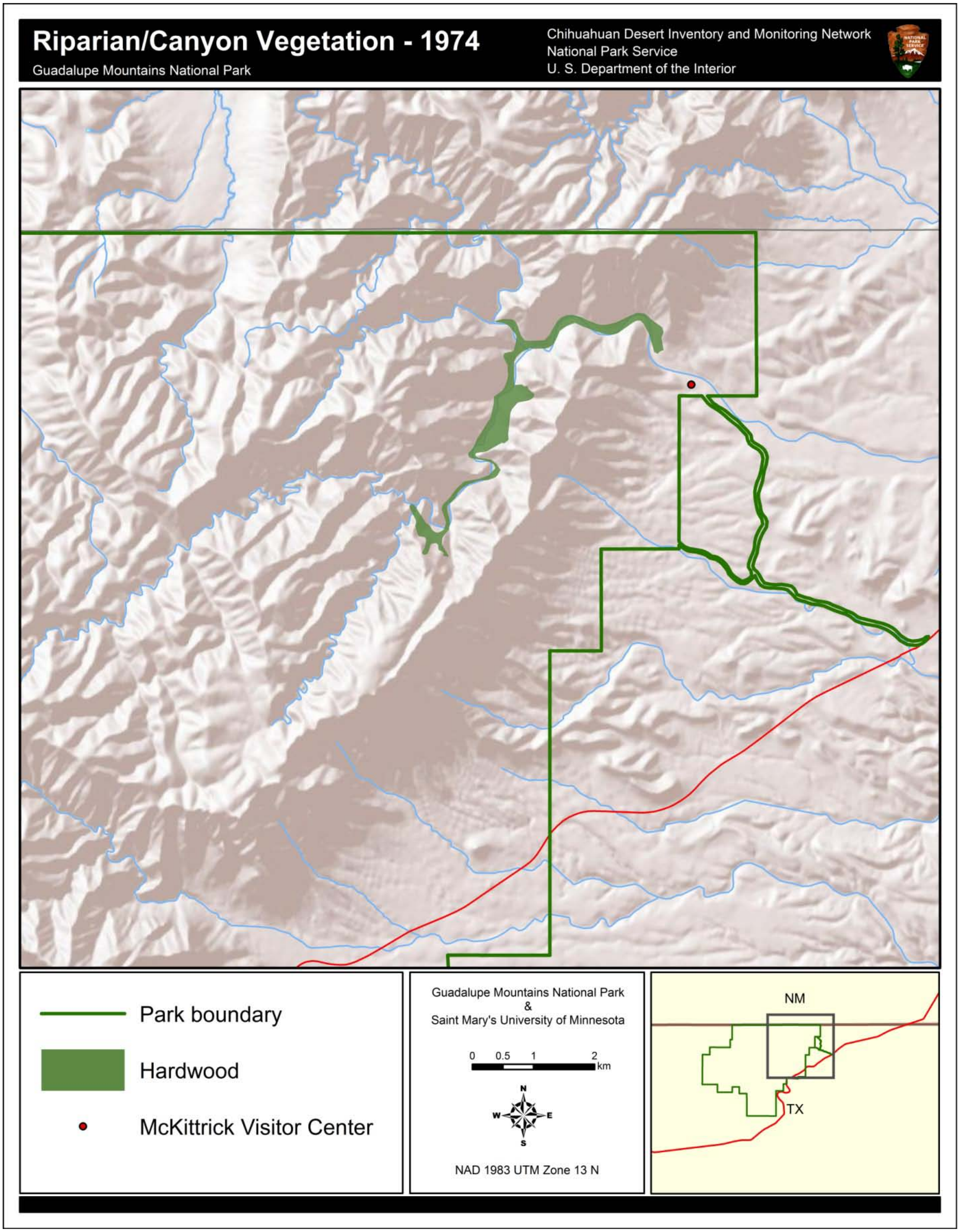


**Plate 13.** Riparian/Canyon (hardwood) vegetation mapped by Glass et al. (1974).

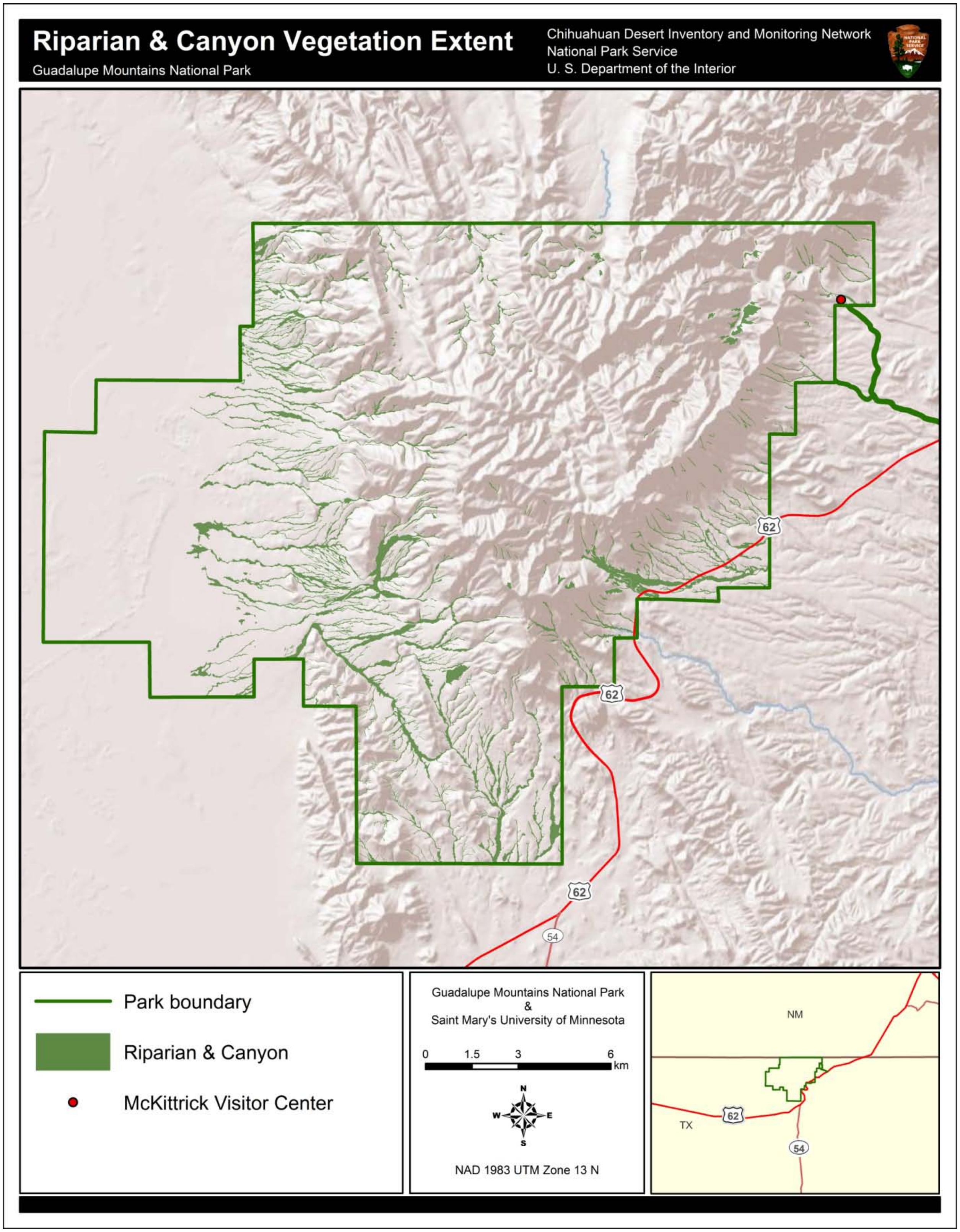


**Plate 14.** Current extent of riparian and canyon vegetation within GUMO (Muldavin et al., *in prep.*)

## 4.5 Semidesert Grassland

***Description***

Semidesert grasslands are found interspersed with desertscrub vegetation at lower elevations within GUMO. Examples can be found on the western escarpment, extending down to alluvial fans at the base of the mountains (Northington and Burgess 1979). Historically, grasses likely covered greater areas in this region and throughout the Chihuahuan Desert; however, the introduction of livestock grazing in the early 1900s appears to have triggered a shift from semidesert grassland vegetation to desertscrub (Burgess and Klein 1978). While the degree to which this occurred within the current park boundary has not been quantified, GUMO lands were grazed by a variety of livestock (e.g., cattle, horse, sheep and goats) between the 1880s and 1988 (Coles, written communication, January 2013).

**Photo 13.** Semidesert grassland in GUMO (photo by Andy Nadeau, SMUMN GSS, 2012).

The dominant grasses in GUMO's grasslands include black grama, blue grama, blue threeawn (*Aristida purpurea*), sideoats grama (*Bouteloua curtipendula*), curlyleaf muhly (*Muhlenbergia setifolia*), and hairy grama (*Bouteloua hirsuta*) (Muldavin et al., *in prep*.). Typically, these grasslands also have a strong component of shrubs, subshrubs, and succulents such as green sotol, resinbush (*Viguiera stenoloba*), white ratany (*Krameria grayi*), soaptree yucca, Torrey's yucca (*Yucca torreyi*), Texas sacahuista (*Nolina texana*), and tulip pricklypear (*Opuntia phaeacantha*) (Northington and Burgess 1979, Muldavin et al., *in prep.*). The forb component of grasslands can be exceptionally diverse, with more than 150 species documented in these communities by Muldavin et al. (*in prep.*). Additional grassland species found within the park are listed below in Table 24.

**Table 24.** Additional plant species of GUMO's semidesert grasslands (Muldavin et al., *in prep.*).

| Common name | Scientific name | Common name | Scientific name |
|---|---|---|---|
| **Grasses** | | bush muhly | *Muhlenbergia porteri* |
| poverty threeawn | *Aristida divaricata* | slim tridens | *Tridens muticus* |
| bristly wolfstail | *Lycurus setosus* | **Shrubs** | |
| plains lovegrass | *Eragrostis intermedia* | mariola | *Parthenium incanum* |
| Warnock's grama | *Bouteloua warnockii* | plumed crinklemat | *Tiquilia greggii* |
| New Mexico needlegrass | *Hesperostipa neomexicana* | fourwing saltbush | *Atriplex canescens* |
| sand dropseed | *Sporobolus cryptandrus* | ocotillo | *Fouquieria splendens* |
| burrograss | *Scleropogon brevifolius* | cactus apple | *Opuntia engelmannii* |

### *Measures*

- Change in vegetation community extent
- Change in plant species richness
- Winter grassland bird diversity

### *Reference Conditions/Values*

While the condition of the semidesert grasslands prior to European settlement may be the ideal reference condition for this component, no information is available from this time period. Therefore, the reference condition for this assessment will be no degradation from current (early $21^{st}$ century) condition. The park's semidesert grasslands have actually been recovering and expanding since livestock grazing ceased with the establishment of the park (NPS 2012), and grasslands may currently be in better condition than they have been in over a century.

### *Data and Methods*

Glass et al. (1974) conducted the first vegetation mapping effort in GUMO during the early 1970s. Burgess and Klein (1978) and Northington and Burgess (1979) produced descriptions of the park's various plant communities, including semidesert grasslands. A park-wide vegetation classification and mapping project was recently completed by Muldavin et al. (*in prep.*). This provides current information on the extent and species richness of GUMO's plant communities.

Bird populations can serve as excellent indicators of an ecosystem's health (NABCI 2009), as they often reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010). Birds, including those typical of grasslands, have been studied in the park since the mid-1970s. However, Bryan (2007) is the only survey to focus on winter grassland birds. White (2011) and White and Valentine-Darby (2012) also sampled birds in grassland habitats, but not during the winter season.

### *Current Condition and Trend*

<u>Change in Vegetation Community Extent</u>

When Glass et al. (1974) mapped the park's vegetation in the early 1970s, only 120 ha (296 ac) of grassland habitat were identified (Plate 15). However, this mapping did not include the grassland habitat found near the western edge of GUMO, which was not added to the park until the late 1980s. In the recent park-wide vegetation classification and mapping project (Muldavin et al., *in prep.*), eight grassland vegetation mapping units were identified. These mapping units covered a combined 6,047 ha (14,942 ac), or approximately 17% of the park (Table 25, Plate 16; Muldavin et al., *in prep.*).

**Table 25.** Extent of semidesert grassland vegetation mapping units in GUMO (Muldavin et al., *in prep.*).

| Mapping Unit | | Hectares |
|---|---|---|
| **Southwest Foothill-Mesa Grasslands** | | |
| Needlegrass Foothill Grassland | | 82.2 |
| Finestem Needlegrass Foothill Grassland | | 45.0 |
| Grama Foothill Grassland | | 260.4 |
| Grama Grasslands with Pinchot Juniper | | 147.7 |
| **Chihuahuan Semidesert Grasslands** | | |
| Curlyleaf Muhly Semidesert Grassland | | 898.7 |
| Green Sotol-Sacahuista Semidesert Grassland | | 578.5 |
| Grama Upper Bajada-Foothill Semidesert Grassland | | 4,018.4 |
| Black Grama Yucca-Mixed Grassland | | 16.1 |
| | **Total** | 6,047.0 |

Change in Plant Species Richness

Several sources have described the plant species found in GUMO's semidesert grassland community, but no historic studies addressed total species richness. Muldavin et al. (*in prep.*) documented all plant species found in semidesert grassland plots during the recent vegetation classification and mapping project. The study identified approximately 340 different species from 58 families (Table 26). Of the various grassland units found in the park (as defined by the NVC standard), the Chihuahuan Semi-Desert Foothill Grassland Group was the most diverse with just over 300 different species (Muldavin et al., *in prep.*). Three of the species listed as occurring in park grasslands by historic sources (Burgess and Klein 1978, Northington and Burgess 1979) were not documented in Muldavin et al.'s (*in prep.*) grassland study plots: Wooton's threeawn (*Aristida pansa*), mourning lovegrass (*Eragrostis lugens*), and burrograss (*Scleropogon brevifolius*). However, two of these species (Wooton's threeawn and burrograss) were documented in the park's desertscrub communities. The absence of some historically documented grassland species in Muldavin et al.'s (*in prep.*) plots may be due to differences in community classification methods or sampling locations rather than actual change in species richness.

**Table 26.** Total plant species richness for the semidesert grassland community and by NVC unit (Muldavin et al., *in prep.*).

| NVC Unit | Number of Species |
|---|---|
| **Semidesert Grassland (total)** | **340** |
| Chihuahuan Sandy Plains Semi-Desert Grassland & Steppe Group | 120 |
| Chihuahuan Semi-Desert Foothill Grassland Group | 304 |
| Chihuahuan Semi-Desert Grassland & Steppe Group | 160 |
| Chihuahuan Semi-Desert Lowland Grassland Group | 60 |
| Great Plains Shortgrass Prairie Group | 75 |
| Southwest Plains-Mesa Grassland | 51 |

Winter Grassland Bird Diversity

Grassland bird species are among North America's most threatened bird communities; grassland birds have experienced "steeper, more consistent, and more geographically widespread declines than any other behavioral or ecological guild" (Knopf 1994, p. 251). NABCI (2009) indicates that grassland birds have been rapidly declining over the past 50 years, and that 55% of grassland species are showing significant population declines. Furthermore, 48% of North American grassland-breeding bird species are of conservation concern. In addition, the western Great Plains have the most extensive and intact native grasslands remaining in North America, and support the most important breeding areas for the greatest number of grassland bird species. Over 90% of grassland-breeding birds species are migratory, and the greatest number of migratory grassland species in the western Great Plains over-winter in the Chihuahuan Desert of northern Mexico and the southwestern United States (Panjabi et al. 2007).

Bird research in the park has been focused primarily on riparian and canyon habitats, and only Bryan (2007) focused surveys on winter grassland bird diversity. The methodology and results of this report are discussed in Chapter 4.7 of this document. Bryan (2007) observed 496 individual birds of 39 different species. The Rocky Mountain Bird Observatory (White 2011, White and Valentine-Darby 2012) also sampled birds in the grassland habitat of GUMO, although these studies did not take place during the winter. As a comparison of the two sampling seasons (winter vs. summer/breeding), White (2011) observed 363 individuals of 34 species during the 2010 breeding season, and White and Valentine-Darby (2012) documented 717 individuals from 68 species in 2011 (see Chapter 4.7 and Appendix D). A comparison of the species observed during both the breeding and winter grassland surveys is provided in Appendix C. Because no reference condition exists for the winter grassland bird diversity component, future analyses could use the species diversity estimate from Bryan (2007) as a baseline for comparison.

**Photo 14.** The scaled quail (*Callipepla squamata*), a grassland bird of conservation concern documented in GUMO (NPS photo by Robert Shantz).

Threats and Stressor Factors

Threats to the park's grasslands include woody species encroachment, exotic plant invasion, fires outside the natural regime, and human ground-disturbing activities. Over the past century, extensive grazing and fire suppression have allowed shrubs to invade desert grasslands across the southwest (Humphrey 1953, 1974, as cited by Ahlstrand 1979; Wright and Bailey 1982). While grazing has ceased inside GUMO and grasslands are beginning to recover (NPS 2012a), it is a slow process and woody species such as juniper and catclaw acacia (*Acacia greggii*) are still invading some areas. Prescribed burning could inhibit this woody invasion and stimulate the return of native grasses. However, if fire occurs too frequently, it can promote the invasion of exotic grasses, which can further alter natural fire regimes (Brooks and Pyke 2001). Research from a New Mexico semidesert grassland suggests that some native perennial grasses require 6-8 years to fully recover from a fire (Cornelius 1988). Therefore, a fire frequency of more than once every 10 years may harm semidesert grasslands more than it helps.

Exotic plant species are a threat to semidesert grasslands, as they can displace native species and impact ecological processes such as soil-water dynamics, fire regimes, and nutrient cycling (NPS

2010). Particular species of concern include Russian thistle (*Salsola kali*), Johnson grass (*Sorghum halapense*), and Lehmann lovegrass. These three exotic species are all present in GUMO and are increasing along roadsides adjacent to the park (Coles, written communication, January 2013). Lehmann lovegrass is known for its "unusual ability to invade existing stands of native perennial grasses and shrubs, and, in the process, replace most of the native perennial grasses" (Cable 1971, p. 18). Ground-disturbing activities, such as maintenance or construction, increase the likelihood that these species will invade and become established.

<u>Data Needs/Gaps</u>
Semidesert grasslands in GUMO were severely impacted by livestock grazing prior to the park's establishment. Researchers are unsure how grasslands will respond to the elimination of this grazing (Burgess and Klein 1978). For example, it is unknown how long it will take for grass cover to increase enough to carry a fire, which would likely further aid in grassland recovery. It is also unclear how climate change, with its potential for more frequent or extreme droughts, could affect grassland recovery. Some research, based on prehistoric plant fossils and paleoclimate, suggests that the balance between grassland and desertscrub may be influenced by the seasonality of precipitation (Holmgren et al. 2006). Additional research into the natural role of fire within the park's grasslands and its potential as a current management tool would be beneficial.

The establishment of an annual winter grassland bird survey is necessary to assess the current condition of this resource in GUMO. Long-term trend data will be needed for this measure in order to accurately assess and identify trends in abundance and species diversity. Current bird monitoring efforts occur in the park (e.g., Breeding Bird Surveys, Christmas Bird Counts, CHDN monitoring), but none of these surveys are specific to the grassland habitat in the winter months. While the continuation of the White (2011) and White and Valentine-Darby (2012) grassland surveys will help to understand the breeding bird composition of the grassland habitats in the park, they will not help to understand the winter bird diversity of this habitat.

<u>Overall Condition</u>

*Change in Vegetation Community Extent*
This measure was assigned a *Significance Level* of 3. Historic vegetation mapping (Glass et al. 1974) did not cover the entire current area of the park and is therefore not directly comparable to more recent mapping efforts (Muldavin et al., *in prep.*). Recent mapping results, along with park staff observations strongly suggest that semidesert grassland cover is increasing in GUMO. However, grasslands have likely not recovered to their extent prior to livestock grazing and are therefore still of low concern (*Condition Level* = 1).

*Change in Plant Species Richness*
The project team assigned this measure a *Significance Level* of 3. While some historically documented grassland species were not found in Muldavin et al.'s (*in prep.*) grassland plots, species richness appears to have remained largely the same since the park's establishment. Therefore, the *Condition Level* for this measure is a 1, indicating low concern.

*Winter Grassland Bird Diversity*

The grassland bird measure was given a *Significance Level* of 2. Bryan (2007) represents the only winter grassland bird survey and no measurements of diversity were reported (only species richness and composition). White (2011) mentions plans to continue bird monitoring in the grassland habitats of GUMO, but the surveys proposed will not be completed during the winter months. Because of the data gaps for this measure, a *Condition Level* was not assigned.

*Weighted Condition Score*
The *Weighted Condition Score* for semidesert grassland in GUMO is 0.333. This indicates low concern, but is right on the edge of the moderate concern range. The condition of the semidesert grasslands has been improving since grazing ceased with park establishment in the 1970s.

**Semidesert Grassland**

| Measures | SL | CL |
|---|---|---|
| • Change in community extent | 3 | 1 |
| • Change in plant species richness | 3 | 1 |
| • Winter grassland bird diversity | 2 | n/a |

**WCS = 0.333**

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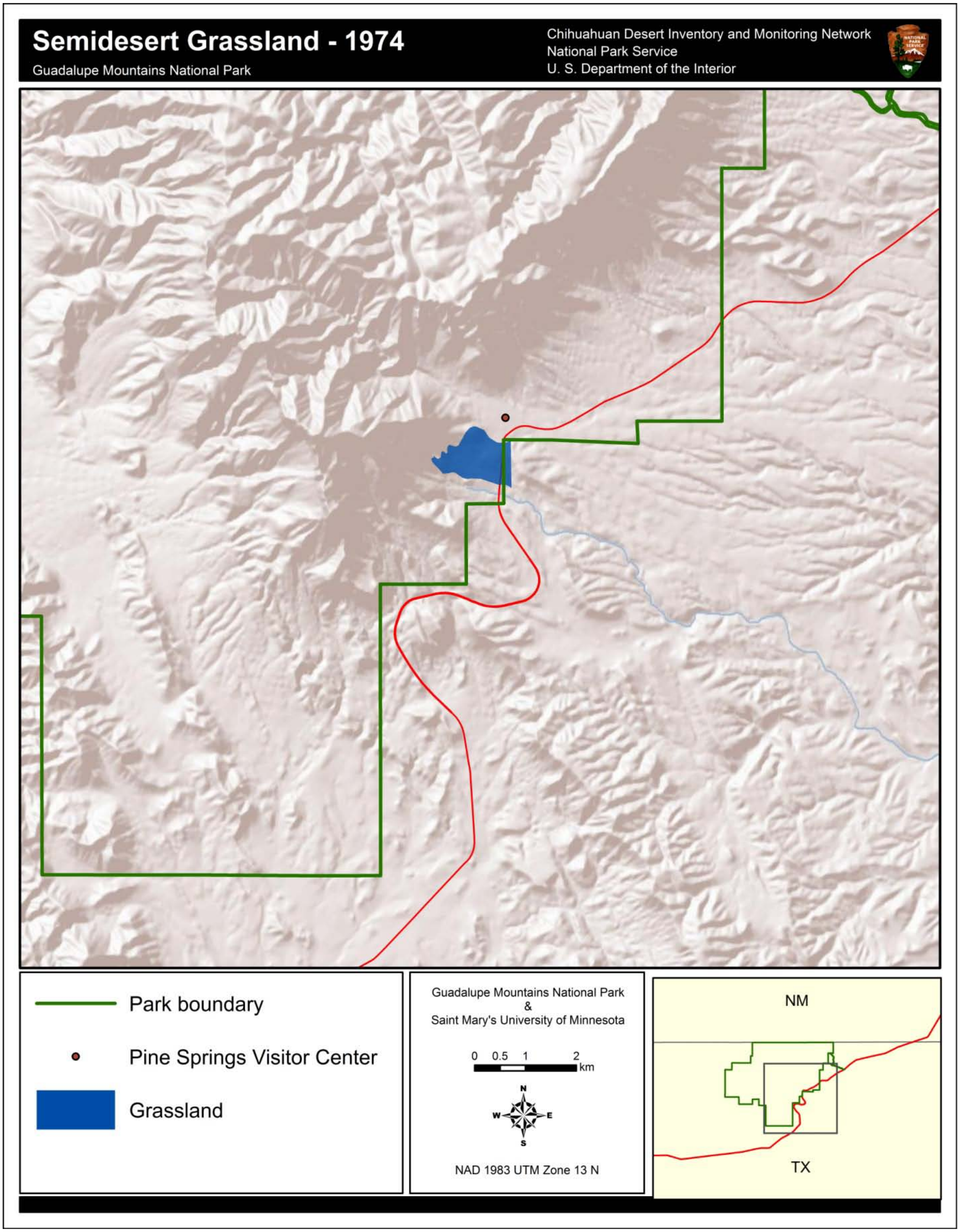



**Plate 15.** Semidesert grassland within GUMO in 1974 (Glass et al. 1974).

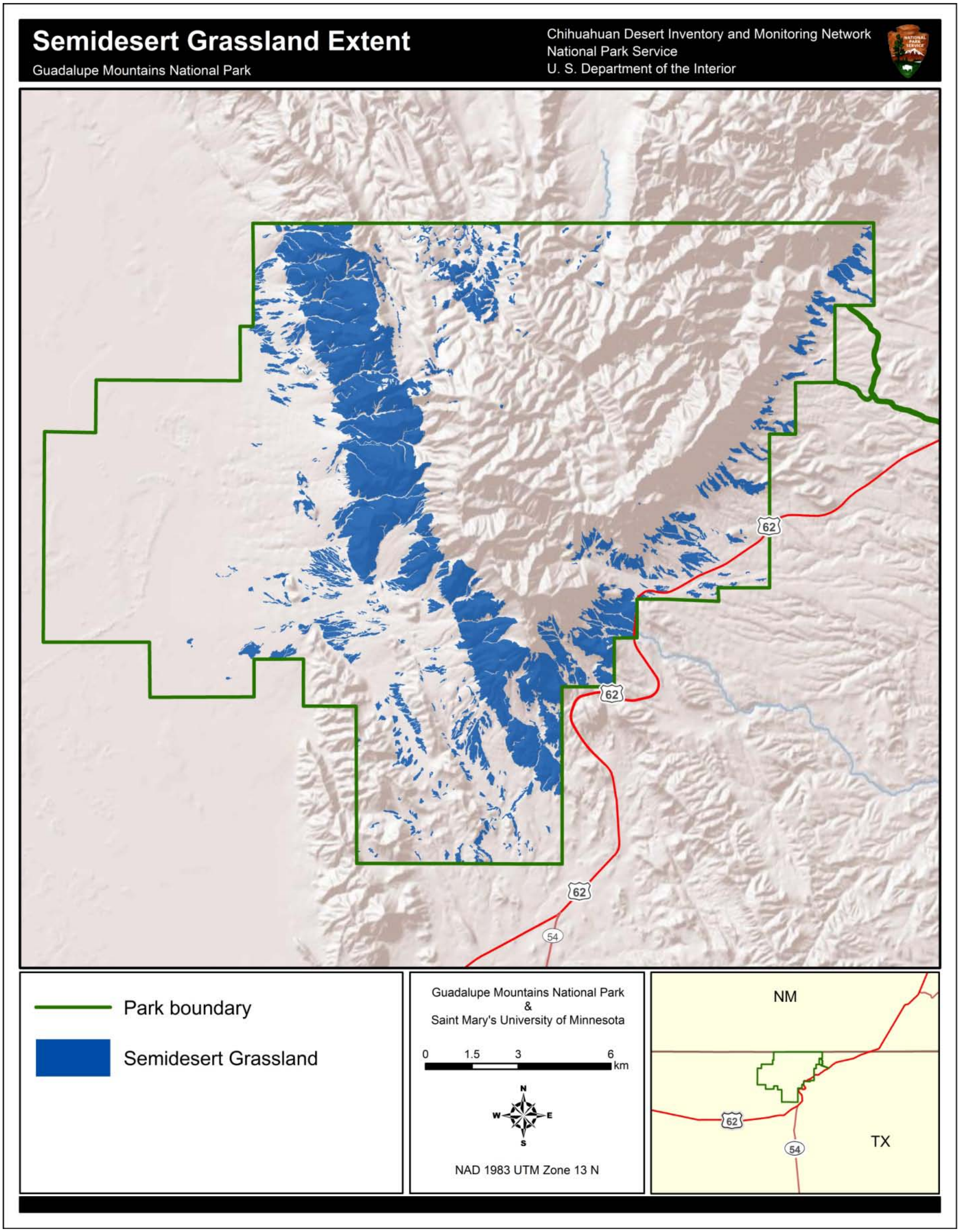



**Plate 16.** Current extent of semidesert grassland vegetation within GUMO (Muldavin et al., *in prep.*)

### 4.6 Desertscrub

***Description***

Desertscrub vegetation is common in the areas below the eastern and western escarpments within GUMO. Much of this desert is dominated by microphyllous (small-leaved) shrubs including creosotebush (*Larrea tridentata*), honey mesquite, tarbush (*Flourensia cernua*), viscid acacia (*Acacia neovernicosa*), and fourwing saltbush (Northington and Burgess 1979). Other species indicative of the Chihuahuan desertscrub community are lechuguilla (*Agave lechuguilla*), ocotillo (*Fouquieria splendens*), resinbush, and whitethorn acacia (*Acacia constricta*) (Gehlbach 1998). Herbaceous species often associated with these shrubs include black grama, alkali sacaton (*Sporobolus airoides*), low woolygrass (*Dasyochloa pulchella*), and prickly pear cacti (*Opuntia* spp.) (Northington and Burgess 1979).

**Photo 15.** Desertscrub vegetation in GUMO (Photo by Kathy Kilkus, SMUMN GSS, 2012).

Deserts are generally considered inhospitable environments for most plants and animals. In the GUMO region, desertscrub environments typically have saline or alkaline soils, wide diurnal temperature ranges, and a high evapotranspiration rate (Griffith and Omernik 2009). The limited precipitation falls primarily between July and September, and is sparse for the remainder of the year. However, GUMO is part of the Chihuahuan Desert, which has been recognized as one of the most biologically diverse desert ecoregions in the world (WWF et al. 2000). Mammals such as coyotes, mule deer, and javelina utilize desert habitats primarily at night when temperatures are cooler. Reptiles and invertebrates are common, including the western diamondback rattlesnake (*Crotalus atrox*), many lizard species, scorpions, and tarantulas (Theraphosidae) (NPS 2012). Small mammals such as heteromyids (nocturnal burrowing rodents) are also common. These rodent species can serve as biological indicators of habitat conditions in an area due to their close ecological relationships with the flora of an ecosystem, and because they are often common prey for carnivores (August et al. 1979, Cornely 1979, Whitford and Bestelmeyer 2006). Heteromyid rodents impact desert systems through burrowing, herbivory, and granivory, activities which redistribute limited resources or influence plant community development (Guo et al. 1995, Whitford and Bestelmeyer 2006). Therefore, heteromyid diversity is included as a measure for this component.

### *Measures*

- Change in vegetation community extent
- Change in plant species richness
- Heteromyid diversity

### *Reference Conditions/Values*

While pre-European settlement condition may be the ideal reference condition for this component, no information is available from this time period. Therefore, the reference condition for this assessment will be no degradation from current (early 21$^{st}$ century) condition.

### *Data and Methods*

The vegetation of GUMO was first surveyed and mapped by Glass et al. (1974). Several vegetation types that could be classified as desertscrub were identified, such as creosotebush, four-wing saltbush, and mesquite. Northington and Burgess (1979) prepared one of the earliest descriptions of GUMO's vegetation, including desertscrub. A recent vegetation classification and mapping project (Muldavin et al., *in prep.*) provided current information on the extent and species richness of GUMO's plant communities.

GUMO's small mammals have been surveyed and studied by several researchers. Genoways et al. (1979) performed a comprehensive mammal survey from 1973-75. In the mid-1970s, August et al. (1979) and O'Connell (1979) studied the ecology of selected rodent species. In 2004, Rowe (2004) returned to three sites sampled by Genoways et al. (1979) to explore changes in small mammal diversity.

### *Current Condition and Trend*

Change in Vegetation Community Extent

During the early 1970s, Glass et al. (1974) identified 7,451.5 ha (18,413 ac) of vegetation that could be classified as desertscrub. At the time, this accounted for approximately 24% of the total park area (Plate 18). The areas of individual desertscrub vegetation types are shown in Table 27.

**Table 27.** Area covered by desertscrub vegetation types in the early 1970s (Glass et al. 1974).

| Vegetation type | Area (ha) |
|---|---|
| Creosotebush | 6,770.4 |
| Four-wing saltbush | 415.6 |
| Mesquite | 265.5 |
| **Total** | 7,451.5 |

The recent vegetation classification and mapping project (Muldavin et al., *in prep.*) identified seven desertscrub mapping units. These units combined covered over 7,900 ha (19,521 ac), or nearly 23% of the park (Table 28, Plate 19; Muldavin et al., *in prep.*). Creosotebush Desertscrub covered the greatest area of any individual mapping unit, followed by Mariola-Goldeneye Desertscrub.

**Table 28.** Extent of desertscrub vegetation mapping units in GUMO (Muldavin et al., *in prep.*).

| Mapping Unit | Hectares |
|---|---|
| **Chihuahuan Desertscrub** | |
| Mariola-Goldeneye Desertscrub | 1,967.3 |
| Ocotillo-Cactus Desertscrub | 325.7 |
| Viscid Acacia Desertscrub | 321.1 |
| Catclaw Mimosa Desertscrub | 636.8 |
| Fourwing Saltbush Desertscrub | 880.5 |
| Creosotebush Desertscrub | 2,312.3 |
| Creosotebush Desertscrub with Honey Mesquite | 1,464.7 |
| **Total** | 7,908.4 |

Change in Plant Species Richness

While multiple sources describe the plant species found in the desertscrub community and even identify some indicator species, none focused on overall species richness until the recently completed vegetation classification and mapping project (Muldavin et al., *in prep.*). Muldavin et al. (*in prep.*) documented 245 plant species from 52 families in desertscrub NVC units. The most common families were the Asteraceae, Poaceae, and Cactaceae.

Heteromyid Diversity

Heteromyids were first studied in GUMO in the mid 1970s. At this time, six species were identified in the desertscrub portions of the park (Genoways et al. 1979, O'Connell 1979; Table 29). When Rowe (2004) resurveyed two desertscrub sites sampled by Genoways et al. (1979), only two of these heteromyid species were captured (Table 29). However, this could be due to the temporal and spatial limitations of the study rather than actual change. Rowe (2004) only set traps at two desertscrub sites on two nights in March, while Genoways et al. (1979) sampled many more sites during all seasons over three years. However, the absence of the rock pocket mouse (*Chaetodipus intermedius*), which was abundant during 1970s sampling, indicates that further sampling and study is warranted (Rowe 2004).

**Table 29.** Heteromyid rodent species captured in GUMO desertscrub in the 1970s (Genoways et al. 1979; densities from August et al. 1979) and in 2004 (Rowe 2004).

| **Scientific name** | **Common name** | **1970s Locations** | | | | | **2004 Locations** | |
|---|---|---|---|---|---|---|---|---|
| | | Western park | Est. density (per hectare) | Patterson Hills | Williams Ranch House | Notes | Patterson Hills | Williams Ranch House |
| *Dipodomys merriami* | Merriam's kangaroo rat | x | 16.0 | x | x | widely distributed in park; well-adapted to desert habitats | x | x |
| *Dipodomys ordii* | Ord's kangaroo rat | x | 2.5 | | | associated with "deeper sandy areas" in western part of park | | |
| *Dipodomys spectabilis* | banner-tailed kangaroo rat | x | 3.7 | | | limited to the western and southwestern boundaries of park | | |
| *Perognathus flavus* | silky pocket mouse | x | -- | x | | grassland and desert habitats; largest sample at Williams Ranch Road entrance | | |
| *Chaetodipus intermedius* | rock pocket mouse | x | 4.9 | | x | grassland and desert habitats; most abundant on desert bajadas | | |
| *Chaetodipus penicillatus* | desert pocket mouse | x | 11.1 | | x | grassland and desert habitats; most abundant species at Williams Ranch Road entrance | x | x |

Threats and Stressor Factors

Threats and stressors to GUMO's desertscrub community are currently limited. The primary threat is invasion by exotic grasses such as Lehmann lovegrass. These species could increase fine fuel biomass and continuity, elevating the risk of fire and burn intensity in the region, which could severely impact fire-intolerant desert communities (Brooks and Pyke 2001). More frequent fires would in turn benefit these invasive exotic grasses over native species (Brooks and Pyke 2001). Cactus poaching is also a potential threat, although this is currently limited by gated access to the park's largest desertscrub areas (Armstrong, interview, 24 January 2012). Drought can significantly impact heteromyid populations, as it often reduces resource availability (Richard Worthington, UTEP Herbarium Curator, written communication, 8 November 2012).

Data Needs/Gaps

The greatest unknown regarding the desertscrub community is how the vegetation will respond to the cessation of grazing. Desertscrub vegetation was likely less extensive in the past, but grazing reduced competition from grass and allowed desertscrub to expand into semidesert grasslands (Burgess and Klein 1978). If grasses are able to recover without this grazing pressure, they could start competing with desertscrub and reduce its extent. It is also unknown how this change would affect wildlife that currently utilizes desertscrub habitats (O'Connell 1979). However, grazing may have impacted the soil (e.g., erosion, compaction) enough to make it difficult for grasslands to return (York and Dick-Peddie 1969, as cited in Burgess and Klein 1978).

A more thorough study of the heteromyid community is needed for comparison to 1970s research to determine if this rodent community has changed over time. Rowe (2004) gathered some recent data, but sampling was limited in both time and location. More sites should be sampled over a greater period of time, including different seasons, to gain a more accurate picture of heteromyid diversity in the park's desertscrub community.

Overall Condition

*Change in Vegetation Community Extent*

The project team assigned this measure a *Significance Level* of 3. While historic vegetation mapping results (Glass et al. 1974) are not directly comparable to recent efforts (Muldavin et al., *in prep.*) due to differences in classifications and a change in park boundaries, available data suggest that desertscrub cover has not changed greatly over the past 30 years. As a result, this measure is currently of no concern (*Condition Level* = 0).

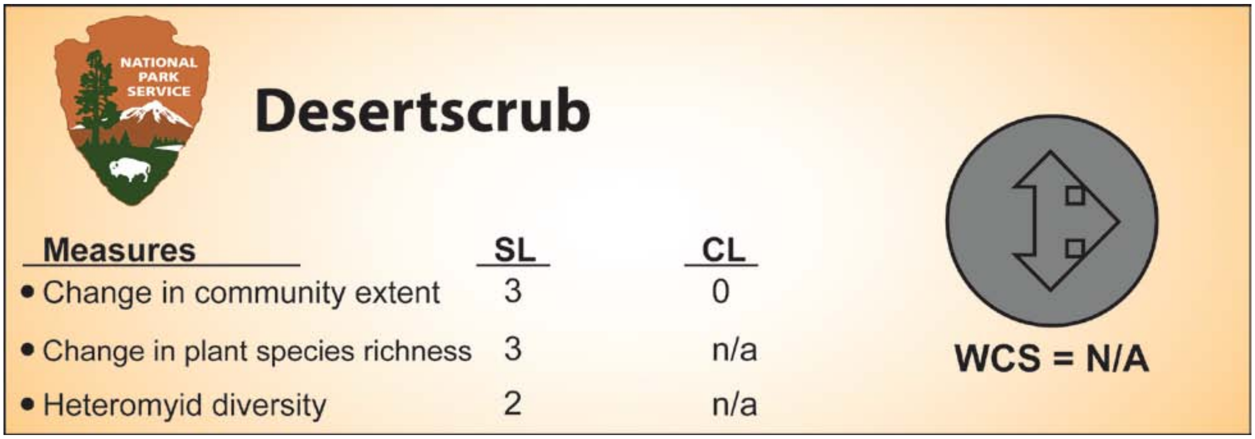
*Change in Species Richness*

This measure was assigned a *Significance Level* of 3. While Muldavin et al. (*in prep.*) provides information on current species richness in the desertscrub community, there are no historic data for comparison. Therefore, *Condition Level* could not be determined.

*Heteromyid Diversity*

The heteromyid diversity measure was assigned a *Significance Level* of 2. Heteromyids were studied in the park by several researchers during the 1970s, but since then were only surveyed briefly in 2004. Due to a lack of more recent information, a *Condition Level* cannot be assigned.

*Weighted Condition Score*
A *Weighted Condition Score* was not calculated for GUMO's desertscrub, since two of the three measures were not assigned *Condition Levels*. Therefore, the overall condition of desertscub in the park is unknown.

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Richard Worthington, Herbarium Curator, University of Texas – El Paso

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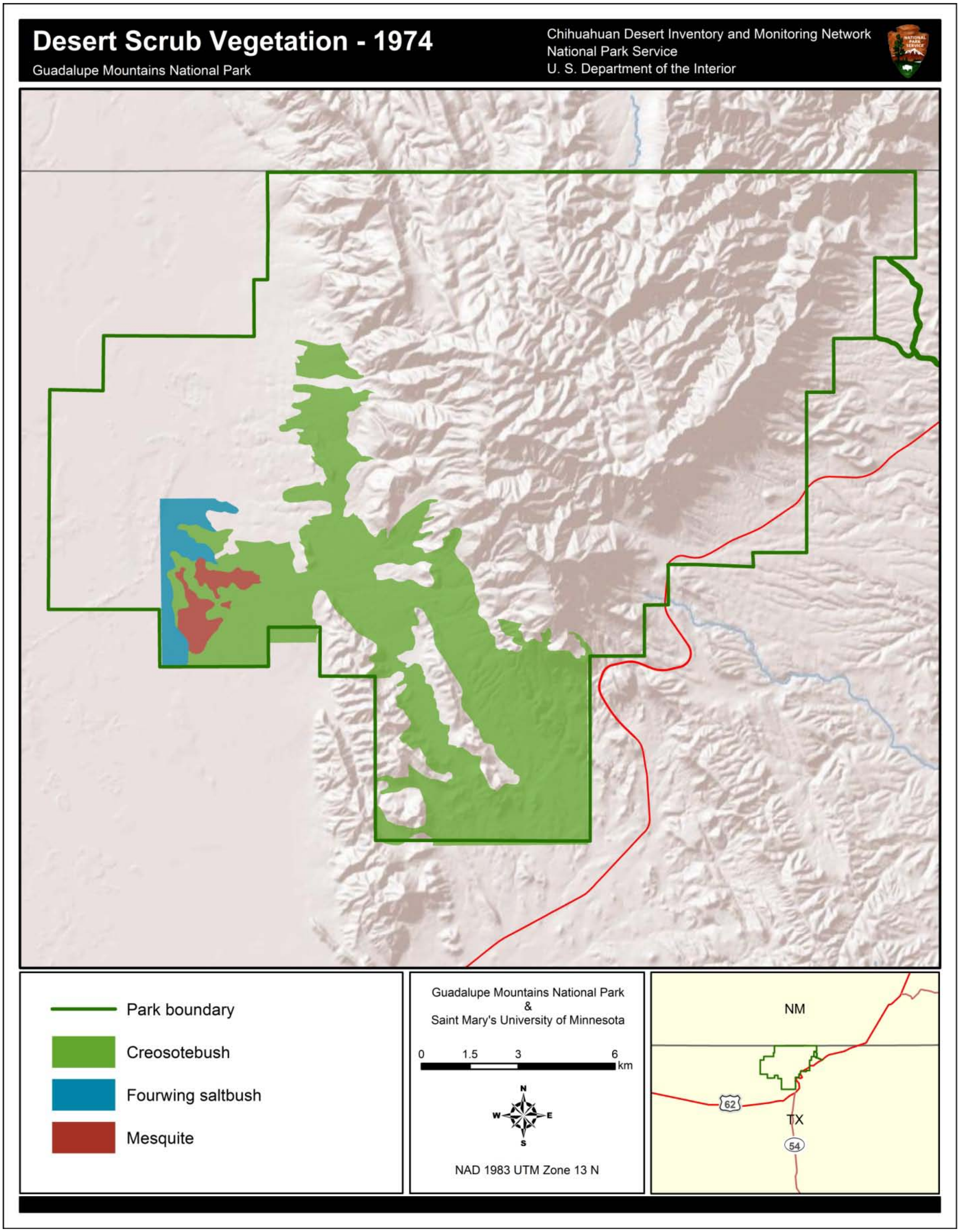


**Plate 17.** Distribution of desertscrub within GUMO in 1974 (Glass et al. 1974). Note that the far western portion of the park was not mapped as it did not become part of GUMO until the late 1980s.

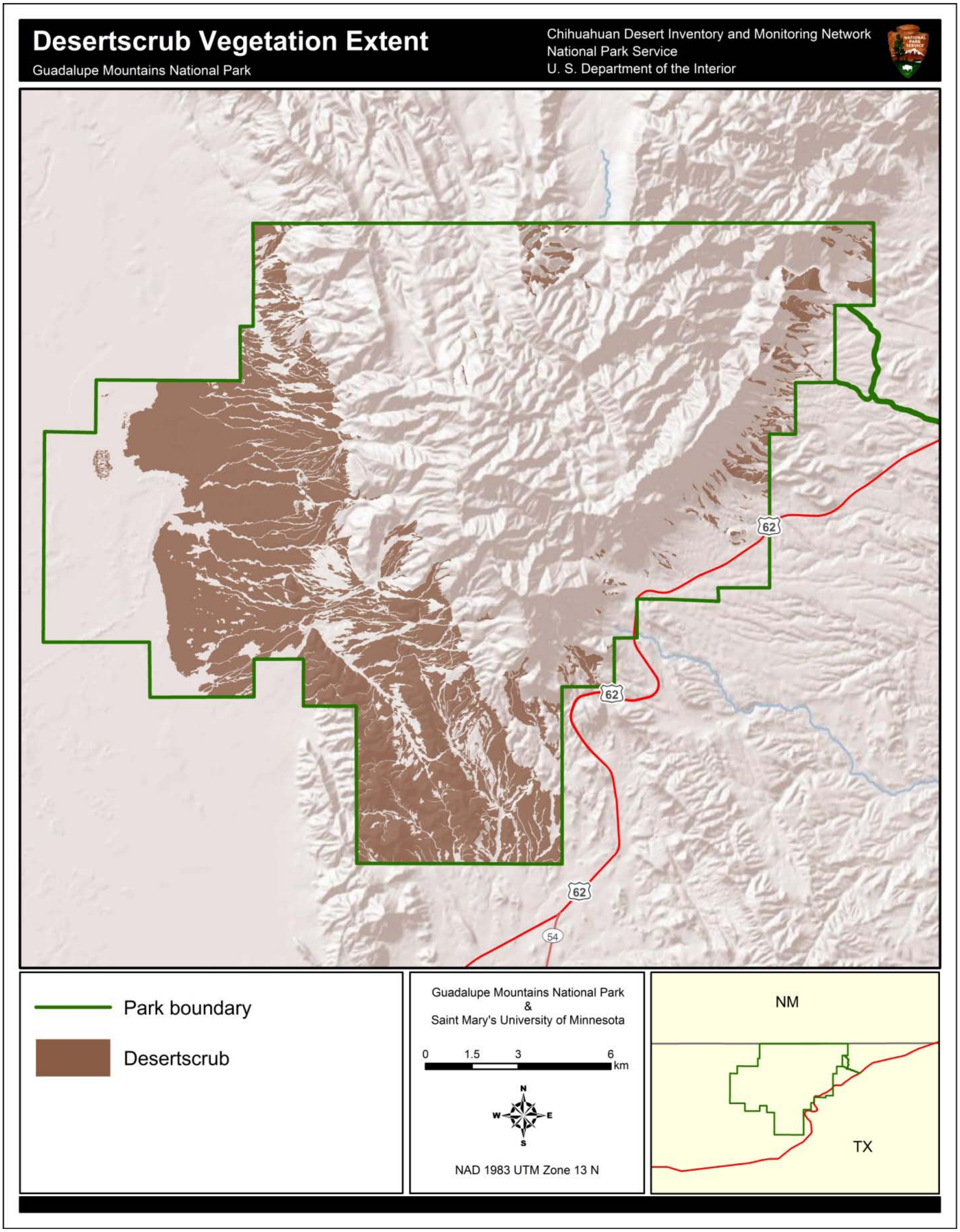


**Plate 18.** Current extent of desertscrub vegetation within GUMO (Muldavin et al., *in prep.*)

## 4.7 Birds

### *Description*

Bird populations often act 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). The unique ecosystems and physical formations in GUMO provide bird species with a wealth of habitat types and food sources. Within the CHDN, GUMO is home to the greatest elevation gradient and the most extreme habitats; GUMO provides high elevation mixed-conifer habitat, mid elevation riparian and canyon habitats, and low elevation gypsum dune habitat.

GUMO has confirmed the presence of at least 260 bird species within the park, and another 27 species have been identified as probably occurring in the park (NPS 2012a). Among the confirmed species are several birds designated as species of concern by at least one government agency or organization (Appendix D). Several of the raptor species that are found in the park have been designated by the USFWS or the state of Texas as either endangered or threatened; examples of these species include the aplomado falcon (*Falco femoralis*), common black-hawk (*Buteogallus anthracinus*), ferruginous hawk (*Buteo regalis*), and the gray hawk (*Buteo nitidus*). GUMO is also home to the largest population of breeding Mexican spotted owls (*Strix occidentalis lucida*) in the CHDN; the isolated riparian canyons of the park provide abundant habitat for the species (Photo 16). The Mexican spotted owl is listed as a threatened species by both the USFWS and the state of Texas.

**Photo 16.** Mexican spotted owl in GUMO (NPS photo by Tim Mullet).

### *Measures*

- Species richness
- Breeding bird diversity
- Mexican spotted owl occupancy
- Population trends of species of concern

### *Reference Conditions/Values*

The reference condition for birds in GUMO is the bird population of the park during the summers of 1972-1974, as reported by Newman (1975).

***Data and Methods***

Newman (1975) conducted a breeding bird survey in five different locations within GUMO (Main McKittrick, South McKittrick, North McKittrick, Dog Canyon, The Bowl) from 1972-1974. Newman (1975) documented species richness, species density, and species diversity at each site. Data sets collected prior to this reference condition were not included in this analysis.

West (1985) surveyed the vertebrate populations of the gypsum dunes and surrounding areas of GUMO. Many of the bird observations were compared to a previous study (Scudday 1977) and either confirmed/rejected the results of that survey. West (1985) noted that the dunes typically displayed low densities and low diversity of bird species. SMUMN GSS made the following adjustment to the data reported in West (1985): the text of West (1985) indicated 52 species were observed, although descriptions of the bird observations revealed that only 49 species were observed during the study; SMUMN GSS used the 49 species estimate for this assessment.

Burckhalter (1991) completed a brief summer inventory of the bird species at Smith Spring in the summer of 1991. Birds that were seen or heard by observers were recorded during visits between June and August. Another bird survey did not take place in the park until 2002, when Andersen (2003) conducted a baseline avian survey that sampled three locations in the park (Choza, Smith, and Juniper Springs). Originally, the survey was going to utilize a point count methodology, but this plan was abandoned due to time constraints. Birds were instead sampled by recording what species were seen or heard during each site visit.

From 2004-2006, Meyer and Griffin (2011) surveyed five low elevation riparian sites in GUMO that were identical to the survey sites of Newman (1975) (although survey methods and timing were different than Newman [1975]). Sites surveyed included Choza Spring, Guadalupe Canyon/Spring, East McKittrick Canyon, North McKittrick Canyon, and South McKittrick Canyon. All birds that were detected within a 5-minute sampling period were recorded, and surveys began no earlier than 15 minutes before sunrise and concluded before 11:30 a.m. (Meyer and Griffin 2011).

Koprowski (2008) surveyed forested areas in GUMO (The Bowl, Frijole Ridge, and the drainage between Juniper and Tejas Trails) for sign of red squirrels (*Tamiasciurus hudsonicus*). During the survey, researchers identified and recorded all mammals, birds, and herpetofauna that were encountered.

As part of a network-wide landbird monitoring project, the Rocky Mountain Bird Observatory (RMBO), in partnership with the CHDN, began monitoring birds in GUMO in June of 2010. The overall objective of the project was to detect potential changes in population parameters over time in GUMO (White 2011, White and Valentine-Darby 2012). The RMBO land bird monitoring in GUMO closely parallels the RMBO's Integrated

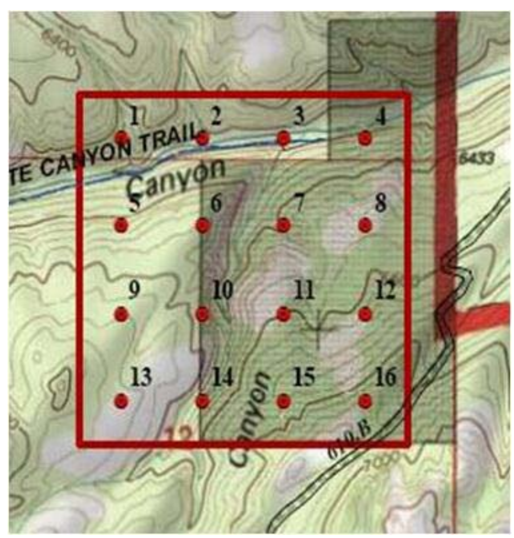


**Figure 8.** Example of a grid cell created by the RMBO using the IMBCR design. Reproduced from White et al. (2011).

Monitoring in Bird Conservation Regions (IMBCR) program, which utilizes a spatially-balanced sampling design during survey efforts (White 2011, White and Valentine-Darby 2012). Across a landscape, the RMBO establishes a series of strata and super-strata (White 2011). Within these strata, the RMBO and its partners utilize generalized random-tessellation stratification (GRTS) to select sample units (Stevens and Olson 2004, White 2011, White and Valentine-Darby 2012). According to White (2011, p. 8):

> The IMBCR design defined sampling units as 1-km$^2$ cells that were used to create a uniform grid over the entire BCR. Within each grid cell we established a 4 x 4 grid of 16 points spaced 250 m apart (Figure 8).

Using this procedure, eight grids in grassland habitat were sampled once, and one transect in riparian habitat (Plate 19) was sampled twice during June 2010 (White 2011). In May 2011, nine grassland grids were sampled once, and one riparian transect was sampled twice (White and Valentine-Darby 2012) (Plate 20).

The GUMO breeding bird survey route is part of the large-scale North American Breeding Bird Survey (BBS), which began in 1966 and is coordinated by the U.S. Geological Survey (USGS) and the Canadian Wildlife Service (Robbins et al. 1986). The standard BBS route is approximately 40 km (25 mi) long with survey points at every 0.8 km (0.5 mi). The survey begins ½ hour before sunrise, and at each survey point, the number of birds seen/heard within a 0.4-km (0.25-mi) radius during a 3-minute interval is recorded. GUMO has one active route within the park, Salt Flat (route 83344) (Plate 21). Data are available for the Salt Flat route from 1995, 2003, 2005-06, and 2009-2011.

The Christmas Bird Count conducted in GUMO is part of the International Christmas Bird Count (CBC), which started in 1900 and is coordinated internationally by the Audubon Society. The GUMO CBC has been conducted annually since 1981 (the only gap in the data occurred from 1995-96). Multiple volunteers survey a 24-km (15-mi) diameter on one day, typically between 14 December and 5 January. The center point of the 24-km diameter is 31.8833ºN, -104.8167ºW (Plate 21). Unlike the BBS, the CBC surveys overwintering and resident birds that are not territorial and singing; this often results in different survey results than the BBS and should not be directly compared to the BBS. The total number of species and individuals are recorded each year; data for the GUMO CBC are current through the winter of 2009-2010. SMUMN GSS made the following transformations to the CBC data (obtained from http://audubon2.org/cbchist/count_table.html):

- Observations that were not resolved to species (e.g., vireo sp., wren sp.) were omitted from analyses;
- Observations of canyon towhee and brown towhee were merged as these are both common names for *Pipilo fuscus*;
- Observations of rufous-sided towhee and spotted towhee were merged as these are both names referring to *Pipilo maculatus*;

- Observations for northern flicker, red-shafted northern flicker, and yellow-shafted northern flicker were merged and renamed to *Colaptes auratus*. Yellow- and red-shafted flickers were previously believed to be separate species, but genetic analysis has classified them as one species (Sibley and Ahlquist 1983);

- Observations of American pipit and water pipit were merged as these are both accepted common names for *Anthus rubescens*;

- Yellow-rumped warbler and Audubon's yellow-rumped warbler observations were treated as one species (*Dendroica coronata*) (Sibley and Ahlquist 1983, Hunt and Flaspohler 1998);

- Dark-eyed junco, gray-headed dark-eyed junco, dark-eyed junco (Oregon race), pink-sided dark-eyed junco, slate-sided dark-eyed junco, white-winged dark-eyed junco, and red-backed dark-eyed junco observations were treated as one species (*Junco hyemalis*) (Sibley and Ahlquist 1983).

### ***Current Condition and Trend***

<u>Species Richness</u>
The species richness measure allows for an assessment of the number of species present across the park for the entire land bird community. This measure can also indicate overall habitat suitability for land birds. However, there may be undetected changes in species richness of native species compared to non-native species, or in Neotropical migrant species compared to resident species. Such changes would not be apparent in the tables and figures presented in this document. Species richness comparisons made to the reference condition of Newman (1975) should be treated with caution, as the bird surveys of the park have utilized different methodologies, habitats, and seasons. Because of this, each survey will present unique results that may or may not accurately compare to the reference condition.

*NPS Certified Species List*
The NPS Certified Bird Species List (NPS 2012a) (accessible from: https://irma.nps.gov/App/Species/Search) confirms the presence of 240 bird species within GUMO; an additional 27 species are identified as being "probably present" in the park. Three species (black swift [*Cypseloides niger*], broad-winged hawk [*Buteo platypterus*], and tree swallow [*Tachycineta bicolor*]) are identified as unconfirmed species, and the black-billed magpie (*Pica hudsonia*) and the purple martin (*Progne subis*) are indicated as "historic" species (NPS 2012a).

*Newman (1975) Bird Survey*
Newman (1975) serves as the reference condition for the species richness and breeding bird diversity measures of this component. From 1972-74, Newman (1975) observed a total of 57 unique species in GUMO (Appendix D). Newman (1975) further broke down the results of the surveys to isolate the number of species observed in each habitat zone that was sampled. The number of species observed each year in Main McKittrick Canyon, North McKittrick Canyon, South McKittrick Canyon, Upper Dog Canyon, and The Bowl are reported in Table 30. Dog Canyon exhibited the highest species richness values each year of the survey, while the other

four sample sites were comparable to each other, with species richness values ranging from 20-28 species (Table 30). Dog Canyon also had the highest number of species observed for the duration of the survey with 42 (Table 30).

**Table 30.** Species richness information collected by Newman (1975) at five study sites from 1972-1974.

| Survey site | Year | # of species observed each year | # of unique species observed for duration of survey |
|---|---|---|---|
| **Main McKittrick** | 1972 | 26 | 34 |
| | 1973 | 25 | |
| | 1974 | 28 | |
| **North McKittrick** | 1972 | 23 | 27 |
| | 1973 | 20 | |
| | 1974 | 24 | |
| **South McKittrick** | 1972 | 28 | 32 |
| | 1973 | 28 | |
| | 1974 | 27 | |
| **Upper Dog** | 1972 | 37 | 42 |
| | 1973 | 33 | |
| | 1974 | 38 | |
| **The Bowl** | 1972 | 25 | 32 |
| | 1973 | 26 | |
| | 1974 | 26 | |

*West (1985)*

From May 1983 to June 1984, West (1985) investigated the vertebrate fauna of the gypsum dunes of present-day GUMO. This survey focused on bird species, and the results were compared to previous work completed by Scudday (1977) to identify any discrepancies or errors that the previous report may have contained.

Over the duration of the study, West (1985) identified 49 unique bird species in the gypsum dunes (Figure 9). West (1985) identified 11 of the 57 species observed by Newman (1975); 37 additional species were reported for the first time in GUMO (Appendix D). The species richness reported by West (1985) was much lower than the reference condition for this measure, which may be partially explained by a difference in sampling site. West (1985) was the first formal survey of the gypsum dune area, and Newman (1975) did not contain a sample from this location. It is likely that several species that were present during the reference survey (Newman 1975) do not occupy the dune habitat.

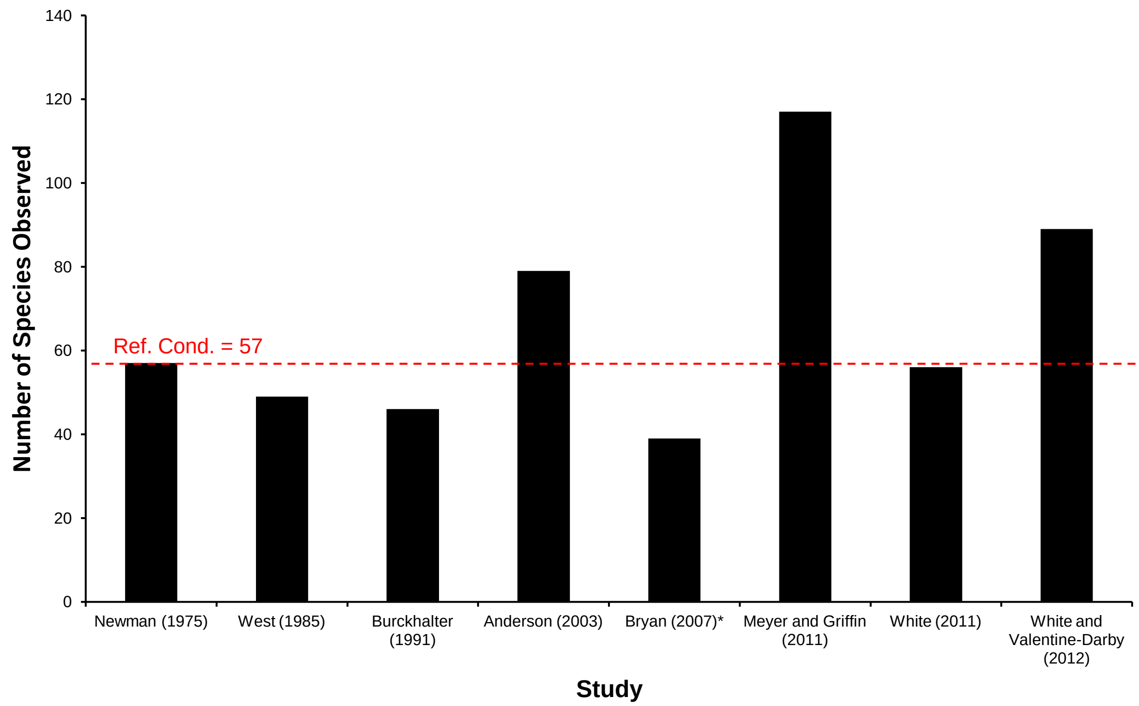


**Figure 9.** Number of bird species observed during the seven independent bird surveys conducted in GUMO. The red dotted line represents the reference condition for species richness, which was 57 species, from Newman (1975).

*Burckhalter (1991)*

From June-August 1991, Burckhalter (1991) surveyed the birds of the Smith Spring area in GUMO. The surveys identified 46 bird species (Figure 9); of the 57 species observed by the Newman (1975) reference survey, 26 were observed by Burckhalter (1991). Eleven additional species were reported for the first time in GUMO (Appendix D).

*Andersen (2003)*

Andersen (2003) investigated the plant and animal communities in the Choza, Smith, and Juniper Spring areas of the park during the summer months of 2002. Bird surveys did not follow a strict protocol, instead, birds were recorded whenever they were observed or heard in an area. Despite the lack of survey design, species richness values were high throughout the study. Andersen (2003) identified 79 bird species (Figure 9), and confirmed the presence of 36 of the 57 reference condition species. Twenty-two additional species were reported for the first time in GUMO (Appendix D). The species richness observed in this study (79) is second only to the species richness reported by Meyer and Griffin (2011) (117), and is well above the species richness reported by the reference survey (57).

*Meyer and Griffin (2011)*

Meyer and Griffin (2011) inventoried birds in low elevation riparian habitats from 2004-2006; inventories took place during the breeding (early-to-mid June) and migration (fall and spring) seasons (summer and winter inventories took place in East McKittrick Canyon, and were only conducted once). These inventories sampled North, South, and East McKittrick Canyons, Guadalupe Canyon Spring, and Choza Spring, and identified 117 species (the highest species richness estimate for GUMO in published literature). Forty-five of the 57 reference condition species were observed, and 25 species were recorded for the first time in the park (Appendix D). The large species abundance value is likely attributed to the intensity and design of the survey, and the fact that multiple habitats were inventoried. The species richness estimate of 117 species is almost double that of the Newman (1975) reference condition.

*Bryan (2007)*
Bryan (2007) is the first winter grassland bird survey to be completed in GUMO (with the exception of the limited winter surveys that took place in Meyer and Griffin [2011]). This survey looked at the bird population of GUMO's grasslands, and sampled these areas six times from 2002-2004. Thirty-nine bird species were identified during the surveys (Figure 9), and much like the Newman (1975) reference condition, Dog Canyon provided the most diverse study area (22 observed species) (Bryan 2007). Only 16 of the 57 species from the Newman (1975) reference survey were identified (Appendix D), although this is likely due to the differing habitat and sampling season.

*Koprowski (2008)*
Koprowski (2008) focused primarily on red squirrel trapping and observations during the summer of 2007; however, the study did record all of the bird species that were encountered during their efforts. This survey took place in The Bowl (previously sampled by only Newman [1975]) and the drainage between Juniper and Tejas Trails (not previously sampled). Forty-one species were observed during the 2007 survey (Figure 9) and 32 of the 57 species from the Newman (1975) reference study were observed (Appendix D).

*White (2011)*
White (2011) sampled nine transects/grids in two habitat types (grassland and riparian) in GUMO and counted a total of 741 individual birds of 56 different species (Figure 9, Appendix D). Of the 56 observed species, 27 were also found in the Newman (1975) reference survey. Along the grassland transects, 363 individual birds of 34 species were counted. Along the riparian transect, 378 individual birds of 33 species were counted. White (2011, p. 48) further suggested that this riparian area "was probably the most diverse survey area in the CHDN in terms of birds and vegetation."

**Photo 17.** The greater roadrunner (*Geococcyx californianus*), one of the species observed by White (2011) in GUMO grasslands (NPS photo by Cookie Ballou).

*White and Valentine-Darby (2012)*
White and Valentine-Darby (2012) sampled ten transects/grids in two habitat types (the grassland habitat was sampled once, and the riparian habitat was sampled twice) in GUMO and counted a total of 1,073 birds of 89 species (Plate 21; Figure 9). The results of this survey marked a notable increase in both the number of individuals and species compared to the 2010 survey (White 2011). Of the 89 species observed in 2011, 28 were also found in the Newman (1975) reference survey.

*Breeding Bird Surveys (1995, 2003, 2005-06, 2009-2011)*
An index count is a method that tallies the number of bird detections during surveys of points, transects, or other defined regions (Kendeigh 1944, Verner 1985, Bibby et al. 1992, Ralph et al. 1995, Rosenstock et al. 2002). Index counts are frequently used to quantify bird species' distribution, occurrence, habitat relationships, and population trends (Rosenstock et al. 2002). In GUMO, the annual BBS and CBC efforts are the only established long-term index counts.

The GUMO BBS surveys a very small portion of the park, and has reported an average of 30.57 species/year (Figure 10); the number of species observed each year has ranged from 27 (2010, 2011) to 37 (2006). These values fall well short of the species richness reported by the Newman (1975) reference condition; however, the BBS uses only roadside survey locations and does not sample the same type of habitat as previous studies (particularly the reference survey). Direct estimates of park-wide species richness using BBS data are impossible due to the potential bias of using only roadside locations.

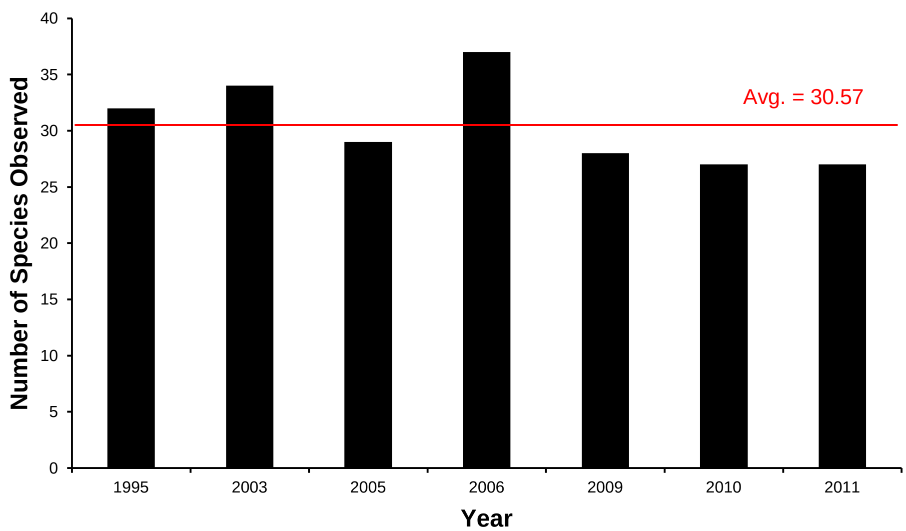


**Figure 10.** Number of species observed during the GUMO Breeding Bird Survey from 1995-2011. The red line represents the average species richness value for the duration of the survey.

*Christmas Bird Counts (1980-81 to 2009-10)*
The CBC efforts in GUMO have been conducted on a regular basis since 1980-81, and represent the largest source of continuous bird data for the park. Unlike the BBS and most other bird surveys conducted in the park, the CBC surveys overwintering, migratory, and resident birds that

are not territorial and singing. Because of this, the species richness estimates obtained from the CBC may not be directly comparable to Newman (1975).

The total number of bird species identified annually during GUMO CBC efforts is presented in Figure 11. From 1980-81 to 2009-2010, the average number of bird species observed on the CBC was 66.72 species (Figure 11), and the number of species observed each year ranged from 46 (1998-99) to 90 (2005-06). The large range of species observed per year may be attributed to the level of effort for the survey, which may have a direct effect on the number of species observed.

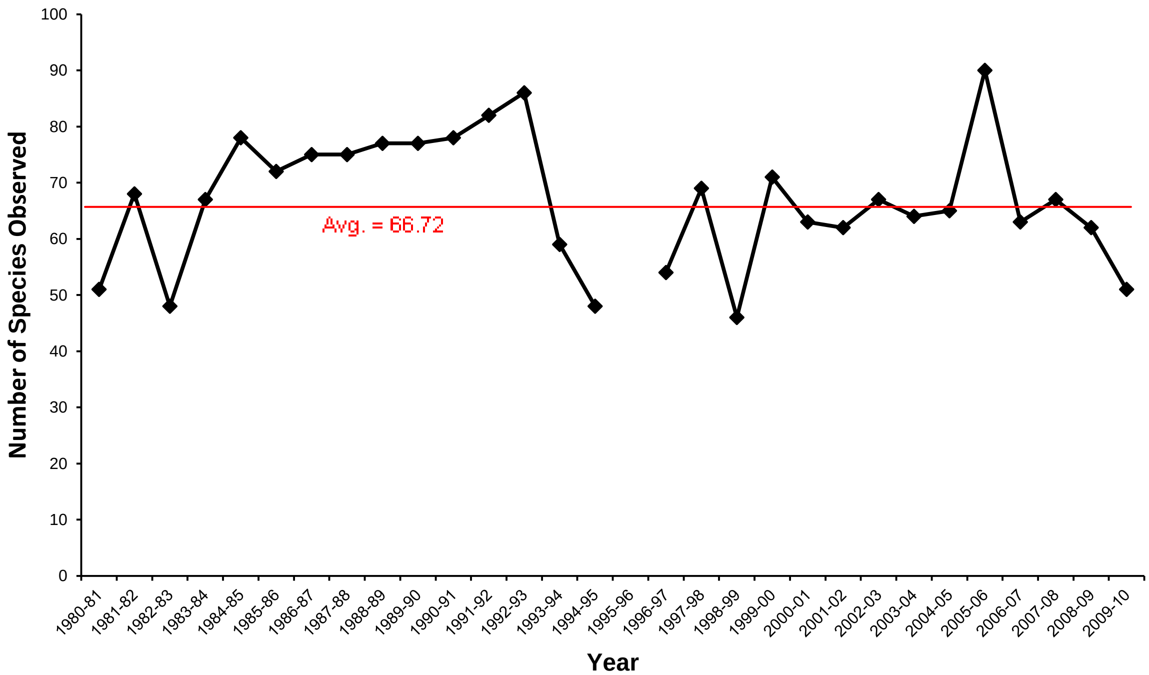


**Figure 11.** Number of species observed during the GUMO Christmas Bird Counts from 1980-2010. The red line represents the average species richness value for the duration of the survey.

Breeding Bird Diversity

Breeding bird diversity is a measure that takes into consideration both species richness and the relative abundance of different species. Often, the Shannon-Wiener species diversity index (H') is used to represent this measure, and when properly calculated, this index can "… determine the uncertainty that an individual picked at random will be of a given species" (UC 2012, p. L 5-2). The equation for the Shannon-Wiener diversity index is listed below.

$$H' = -\sum_{i=1}^{s}(p_i)(\ln p_i)$$

$p_i$ = proportion of individuals of species ($i$) in a community (=$n_i$/N; where $n_i$ is the number of individuals of a given species and $N$ is the total number of individuals in a sample) (UC 2012).

The diversity index will result in an H' value that will typically be between 0 and 4; a value of 0 indicates a community that displays low/no species complexity, while a value of 4 indicates a community of high species complexity. For this measure, only studies that surveyed breeding birds and recorded the number of individuals in a survey were included.

*Newman (1975) Reference Condition*

Breeding bird diversity remained stable during the 3-year Newman (1975) surveys, and the average breeding bird diversity in Main McKittrick Canyon, North McKittrick Canyon, South McKittrick Canyon, Upper Dog Canyon, and The Bowl from 1972-74 was H'= 3.11 (Figure 12). This average H' value serves as the reference condition for this measure; yearly values are also reported in Figure 12.

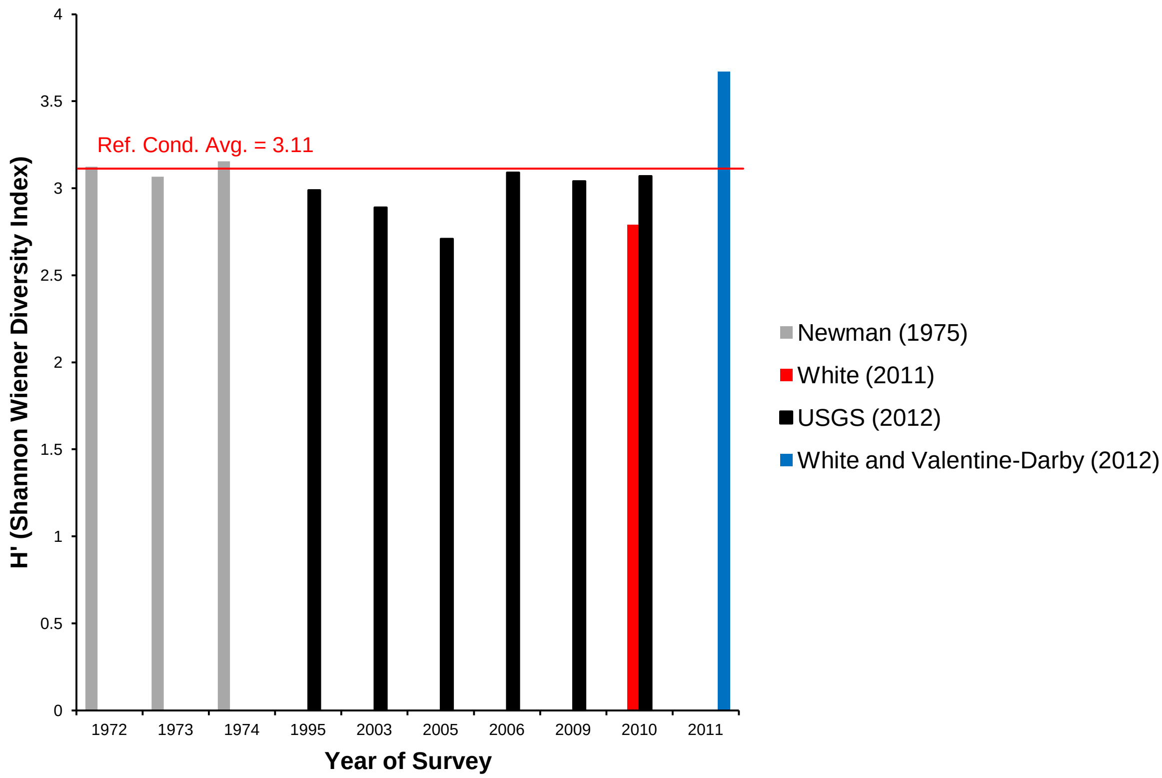


**Figure 12.** Observed species diversity on three bird surveys completed in GUMO. The red line indicates the average Shannon-Wiener Diversity value from the Newman (1975) reference condition.

*White (2011)*

The nine riparian and grassland transects/grids sampled by White (2011) resulted in an H' value of 2.79 (Figure 12). This value is lower than the reference condition (H'=3.11), although White (2011) sampled habitats not previously documented by Newman (1975) and had a broader period of sampling.

*White and Valentine-Darby (2012)*

The ten riparian and grassland transects/grids sampled by White and Valentine-Darby (2012) resulted in an H' value of 3.67 (Figure 12). This value represents the highest diversity value observed in the park, and is higher than the reference condition value of Newman (1975).

*Breeding Bird Surveys (1995, 2003, 2005-06, 2009-2011)*
The BBS efforts at the park have resulted in relatively stable H' values, with the highest value being 3.09 (2006) and the lowest value being 2.71 (2005) (Figure 12). The average for the 7 years of the survey is H'=2.97, which is slightly below the reference condition (H'= 3.11). While the yearly and average H' values are below the reference condition, potential biases in the BBS's design, observer identification skills, and habitats sampled may explain the discrepancy.

Mexican Spotted Owl Occupancy
The Mexican spotted owl is one of three subspecies of the spotted owl endemic to North America, and has the broadest range of the three subspecies (Figure 13). In the American Southwest, Mexican spotted owls typically nest in one of two habitats: mixed-conifer forests or steep canyon systems (Gainey and Dick 1995, Mullet 2008). GUMO is home to some of the most pristine Mexican spotted owl habitat in the CHDN; the steep-walled canyons and dense mixed-forests provide suitable nesting habitat for the species (Mullet 2008).

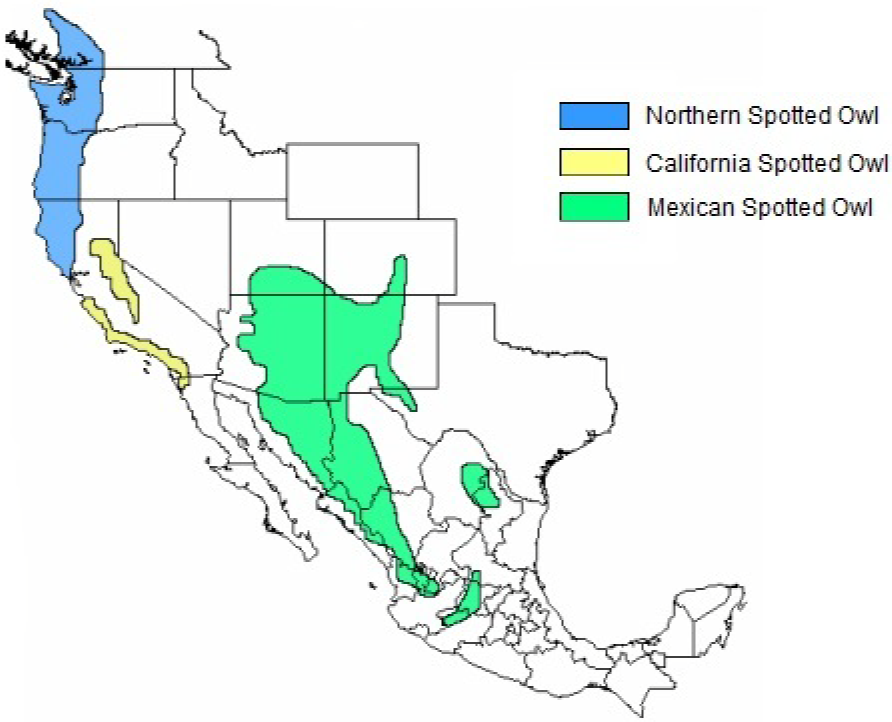


**Figure 13.** Distribution of the three spotted owl subspecies in North America. Image reproduced from Mullet (2008)

The NPS has conducted occupancy surveys for Mexican spotted owls at a semi-regular frequency since 1969. NPS researchers conducted these surveys at locations where owls had previously been observed; a territory was deemed to be active if an adult was seen in the vicinity of (or on) a nesting/roosting site, or observers were able to detect nighttime vocalizations of a bird in a nesting territory. Areas that did not produce a vocal or visualization were deemed unoccupied. Intensive surveys from 2003-2005 identified 11 "protected activity centers" (PACs). These PACs are located in areas of "steep, cool canyon systems consisting of multi-layered conifer-broadleaved vegetation" (Mullet 2008, p. 10-11). Currently, there are 29 nest sites located within the 11 identified PACs.

Annual occupancy rates have varied in GUMO, and much of this variation may be explained by survey intensity from year to year. The highest reported occupancy during GUMO surveys occurred in 2005 (12 active sites) (Figure 14); this year was also the last year of the intensive surveys that were responsible for identifying the 11 PACs in the park. Prior to the identification of the PACs, the highest reported occupancy was nine active sites (1999). Yearly occupancy rates are displayed in Figure 14.

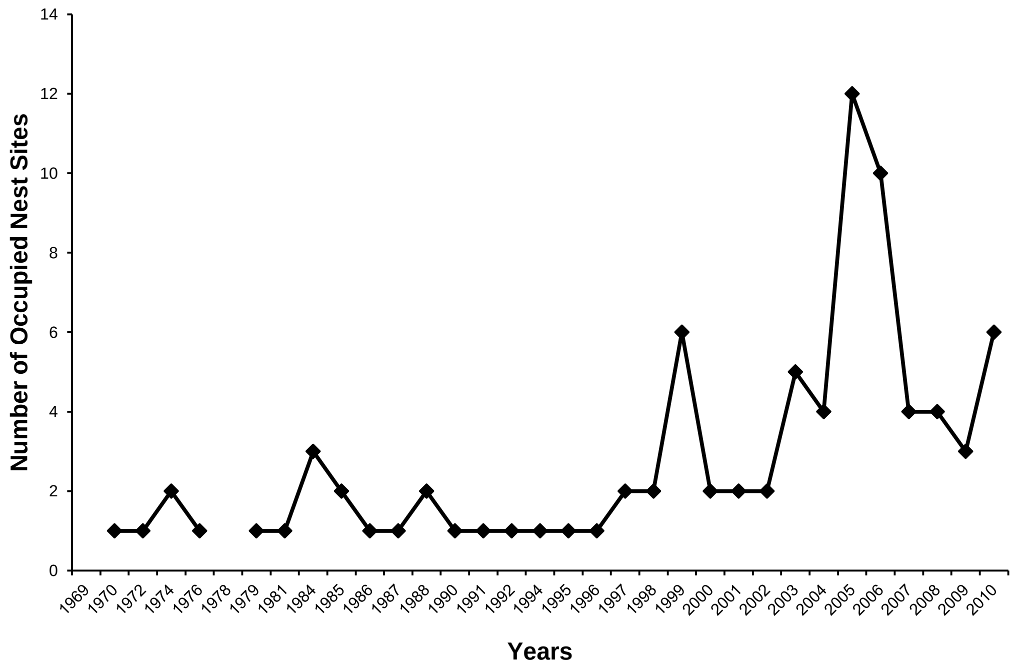


**Figure 14.** Annual Mexican spotted owl territory occupancy in GUMO, 1969-2010.

<u>Population Trends of Species of Concern</u>

For this component, a species was considered a species of concern if it appeared on one of the following conservation lists:

- USFWS Birds Species of Conservation Concern (BCC) for Bird Conservation Region (BCR) 35 (Chihuahuan Desert) (USFWS 2008);
- Listed by Partners in Flight (PIF) on the:
  - North American Landbird Conservation Plan (NALCP) (Rich et al. 2004);
  - Saving our Shared Birds (SOS) shared species list (SOS 2012);
- Texas Rare, Threatened, and Endangered Species List (TPWD 2012a);
- USFWS Endangered Species List;

- Texas Conservation Action Plan (TCAP) “Species of Greatest Conservation Need” (SGCN) (TPWD 2012b).

According to the NPS Certified Bird Species List (NPS 2012a), 73 species that have been confirmed in GUMO are listed by at least one of the above agencies as a species of conservation concern (Appendix D). However, there are no established monitoring protocols or programs that track the population trends of these species. The bird surveys that have occurred in the park have identified 48 species of birds that appear on one of the conservation concern lists (Appendix D); all bird surveys have observed more species of conservation concern than the Newman (1975) reference condition (Figure 15). Figure 15 displays the number of priority species observed during each bird survey in the park; the BBS and CBC efforts took place over many years and may not be comparable to the other studies because of this discrepancy. Without species-specific trend data, an analysis of condition for this measure is not appropriate at this time.

**Photo 18.** The black-throated sparrow (*Amphispiza bilineata*), one of the species of concern documented in GUMO (NPS photo by Robert Shantz).

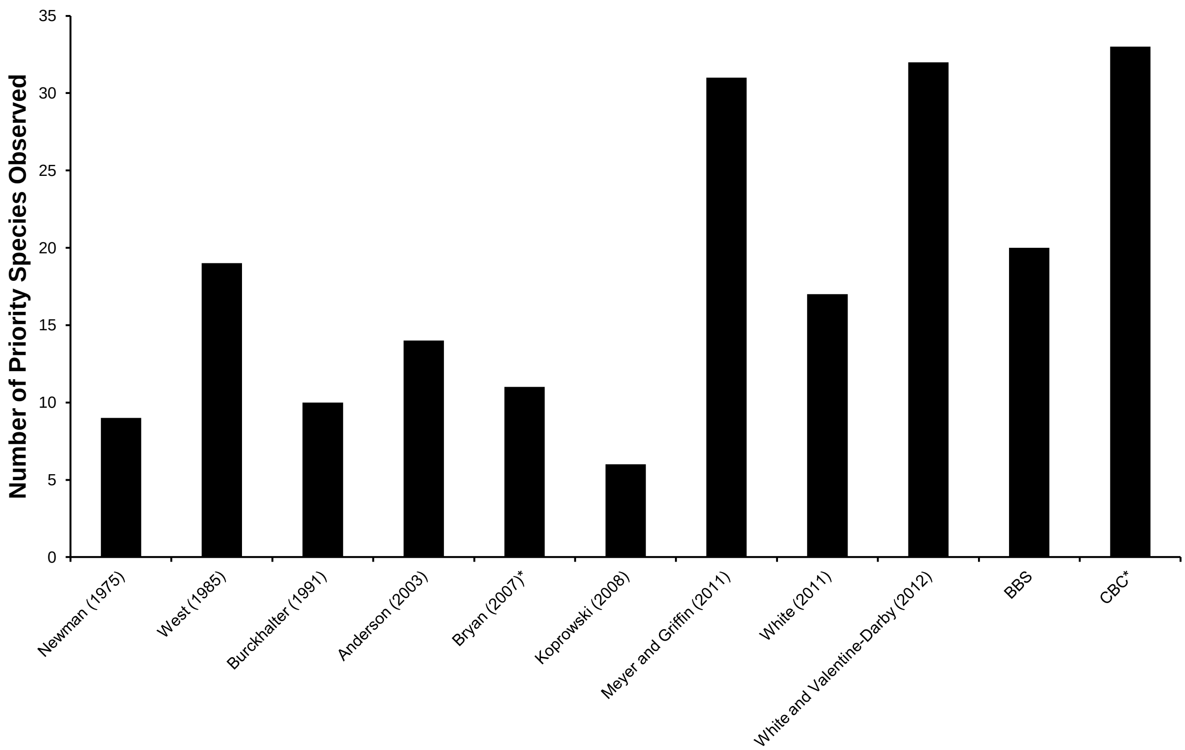


**Figure 15.** The number of priority bird species observed during ten bird surveys that were completed within GUMO. An * indicates a survey that took place exclusively during winter.

Threats and Stressor Factors

One of the major threats facing land bird populations across all habitat types is land cover change (Morrison 1986). Land cover change is not restricted to the breeding habitat; many species depend on specific migratory and wintering habitat types that are also changing. The encroachment of exotic plant species may be a contributor to land cover change in all habitats (NABCI 2009). Altered habitats can compromise the reproductive success or wintering survival rates of species adapted to that habitat. They can also allow generalist, non-native species, such as the European starling (*Sturnus vulgaris*), to move in and outcompete native bird species (NABCI 2009). Priority species in GUMO, such as the eastern meadowlark (*Sturnella magna*) and Brewer's sparrow (*Spizella atrogularis*), often require specific vegetative communities (e.g., dense stands of desert shrubs) for successful nesting to occur. A loss or alteration of these vegetative structures, or competition for resources from non-native species could compromise the nesting success of these native species in GUMO.

One of the major threats to the bird species in GUMO, particularly the grassland species, is grassland degradation and fragmentation. Energy development/exploration (oil, gas, solar, and wind) in the region surrounding GUMO, and potentially the large-scale development of desalination plants, primarily affects the grassland habitats. Species that depend on the Chihuahuan Desert grasslands (especially the Janos grasslands of Chihuahua, Mexico) are likely to be greatly affected by changes in grassland composition (Ceballos et al. 2010, Shackelford 2010). Solar power developments have also been proposed in New Mexico, just north of the park boundary (Hearst, interview, 24 January 2012). These solar developments could further fragment the landscape and alter the species composition of these sites.

Over 97% of the native grasslands in the United States have been lost, primarily due to land conversion to agricultural fields (NABCI 2009). In the Chihuahuan Desert alone, more than one million acres of grasslands have been converted to agricultural lands in the last five years (NABCI 2009). Drought conditions, desertification, and overgrazing of ranch lands all contribute to the degradation of grasslands in the Chihuahuan Desert. The Chihuahuan Desert grasslands are expected to become drier due to higher temperatures and lower precipitation levels associated with global climate change (NABCI 2010); the loss of a continuous grassland habitat across GUMO and the Chihuahuan Desert could greatly influence the breeding success and population size of the park's grassland bird species.

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 farms 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 small wind farm consisting of 139 wind turbines is located to the south of the GUMO boundary (USDA 2010); future research could be focused on the mortality caused by these turbines if population declines are noticed in the GUMO area.

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 few buildings and towers in the immediate GUMO area, birds that migrate to/from the park may encounter such obstacles during migration periods.

Fire is a natural process in GUMO and was historically an important source of disturbance in mixed conifer forests throughout the southwestern U.S. (Sakulich and Taylor 2007, NPS 2012b). Fire influences the park's vegetation communities and ecosystem processes, which in turn impacts wildlife habitat (NPS 2009). However, only 58 fires in the past 40 years have burned more than 0.1 acre, and only 50 fires have burned more than 0.5 acre (NPS 2010; see Chapter 4.1 of this document for further discussion). High winds frequently prevent controlled burns in the park, and the presence of a high fuel load in critical bird areas represents a significant threat to the bird populations in the park. A catastrophic fire (in terms of size and severity) could reduce the amount of bird habitat for several seasons and reduce the availability of suitable nesting sites for cavity-nesting species.

Data Needs/Gaps

Continuation of the grassland and riparian bird monitoring efforts spearheaded by White (2011) and White and Valentine-Darby (2012) are essential for monitoring not only the health of habitat-specific bird species, but also for monitoring the health of the grassland communities of the park. By utilizing a spatially balanced sample design with skilled observers, the survey efforts should yield an excellent baseline for future comparisons. This monitoring continued in 2012, but results were not available in time to be included in this assessment (see White and Valentine-Darby 2013). Additional study efforts that highlight the use of the park by wintering grassland bird species may also be useful to track potential trends in migration and overwintering populations.

BBS and CBC efforts provide snapshots in time of species richness. Even though these single surveys/visits per year yield little information in terms of population data for any individual survey, the longevity of these two activities is very useful for detecting trends. Commitment by the park and outside cooperators and volunteers to ensure that the BBS and CBC continue would provide data useful for understanding population trends. For example, to potentially help the park better understand the status of breeding bird species in the park, annual surveys on BBS route 83344 (Salt Flat), despite its limited coverage of GUMO, would be beneficial for future analyses. Currently this route has only been surveyed sporadically, with surveys occurring in 1995, 2003, 2005-06, and 2009-10.

Increased sampling (>1 sample per year) using the White (2011) spatially balanced land bird protocol would allow for density and occupancy estimates in the future. These estimates could provide baseline values that would serve as sources of comparison for future studies. Visits in the winter would also allow for a more accurate description of the overwintering species that use the park.

Overall Condition

*Species Richness*

The species richness measure was assigned a *Significance Level* of 3. Various studies have surveyed several areas of GUMO in the years following the Newman (1975) reference condition.

The fact that several of these surveys failed to achieve Newman (1975)'s species richness value can likely be attributed to the surveys differing in habitat type and methodology. The species richness values reported showed no cause for concern; in fact, two surveys (Andersen 2003, Meyer and Griffin 2011) far exceeded the reference condition for this measure. The species richness measure was assigned a *Condition Level* of 0.

*Breeding Bird Diversity*
Breeding bird diversity was assigned a *Significance Level* of 3 during project scoping. GUMO is home to a large variety of bird species (240 species confirmed), and is one of the more unique birding locations in the NPS. Diversity values for the studies that allowed analyses indicated that current diversity in the park is near the Newman (1975) reference condition. While there are not optimal data for this measure, there are certainly enough to ascertain condition; the continuation of surveys initiated by White (2011) and White and Valentine-Darby (2012, 2013) will only strengthen this data set. Current condition of the breeding bird diversity is of low concern (*Condition Level* = 1).

*Mexican Spotted Owl Occupancy*
This measure was assigned a *Significance Level* of 2. Annual surveys that have occurred in the park indicate a constant, steady presence of the species since 1969. However, the inference of occupancy using only visual or aural cues may result in biased estimates of territory distribution, occupancy, and density (Mullet 2008). Indications from the available data are that the GUMO population is in a relatively stable state; however, since the species is federally-threatened and the available data are less than optimal, a *Condition Level* of 2 was assigned to this measure.

*Population Trends of Species of Concern*
A *Significance Level* of 2 was assigned to the population trends of species of concern measure. While there are several species of concern in the park, there are no data available to accurately assess the current trends and condition of these species. Long-term trend data are needed to analyze potential trends in abundance. The CBC data that are available for these species can only be interpreted with caution, as count data are largely dependent upon the effort of the observers and may not always provide an accurate depiction of a species' abundance in GUMO. Because of these limitations, no *Condition Level* was assigned to this measure.

*Weighted Condition Score*
The *Weighted Condition Score* for birds at GUMO is 0.292, indicating that the component is of low concern. A stable trend across the measures was assigned to this component.

## Birds

| Measures | SL | CL |
|---|---|---|
| • Species richness | 3 | 0 |
| • Breeding bird diversity | 3 | 1 |
| • Mexican spotted owl occupancy | 2 | 2 |
| • Population trends of species of concern | 2 | n/a |

WCS = 0.292

***Sources of Expertise***
Fred Armstrong, former GUMO Chief of Natural Resources, current Chief of Resource Management and Research, Zion National Park.

Hildy Reiser, CHDN Science Advisor

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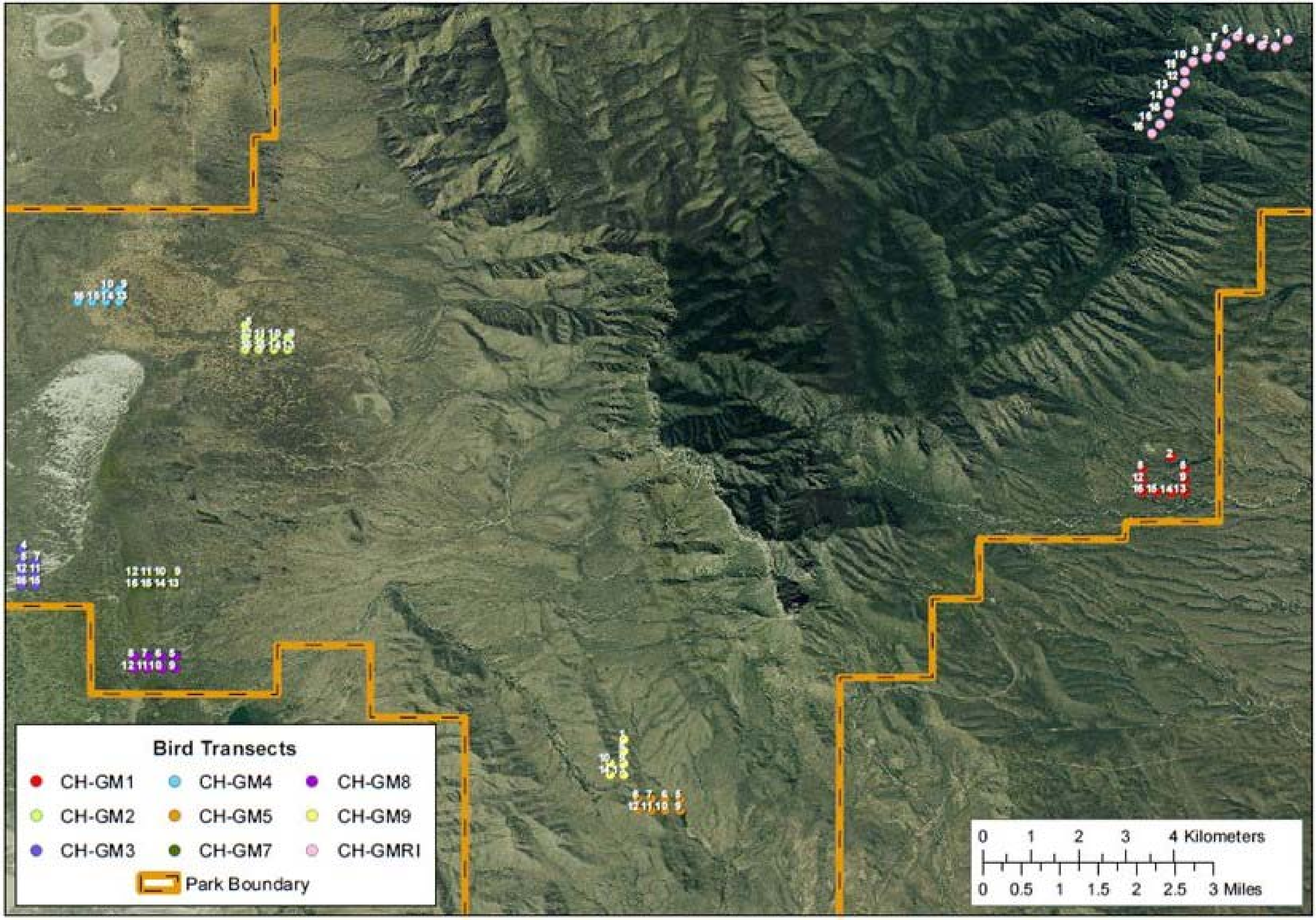


**Plate 19.** Point locations in Guadalupe Mountains National Park sampled in 2010 by White (2011). Image reproduced from White (2011).

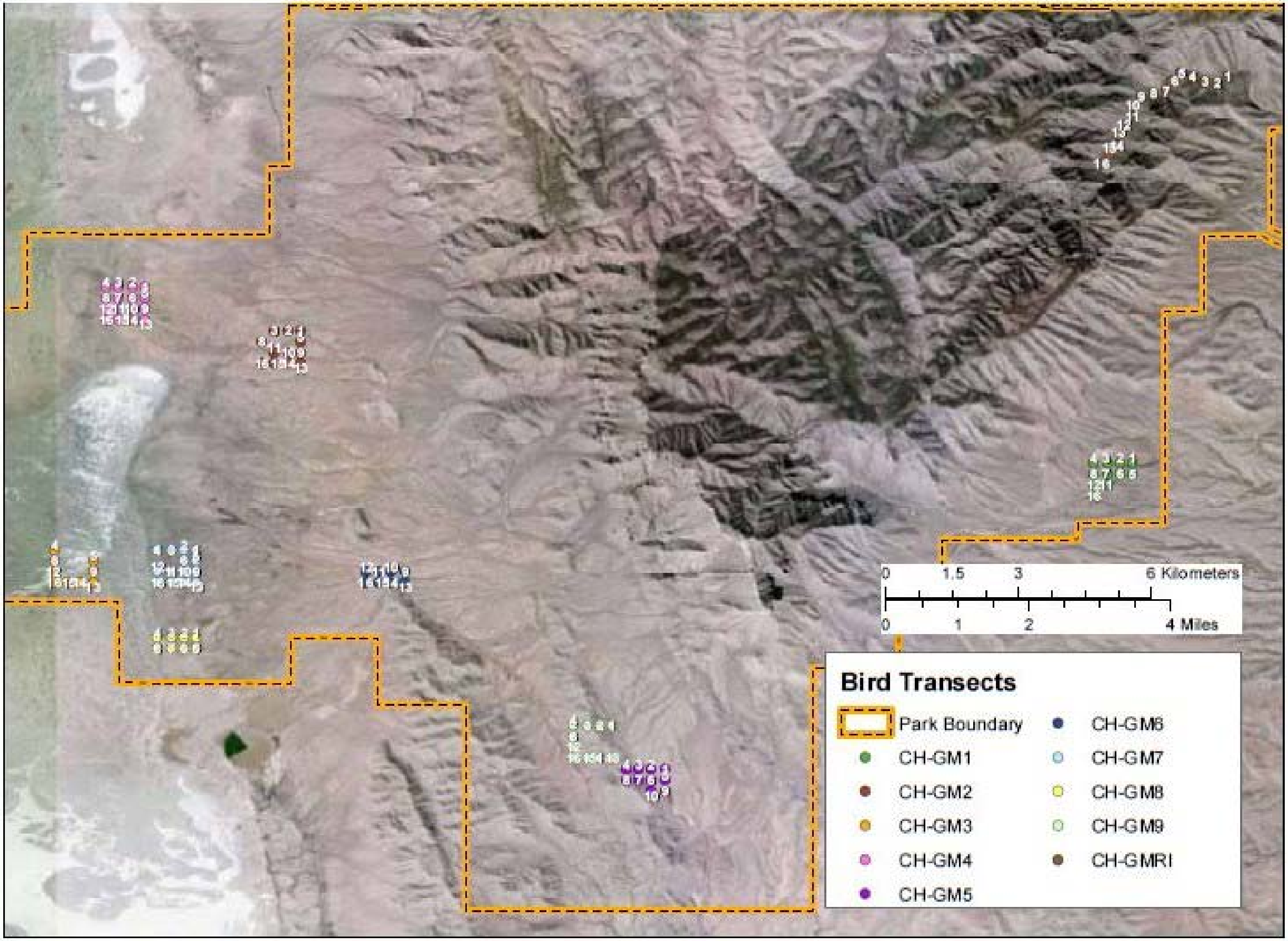


**Plate 20.** Point locations in Guadalupe Mountains National Park sampled in 2011 by White and Valentine-Darby (2012). Image reproduced from White and Valentine-Darby (2012).

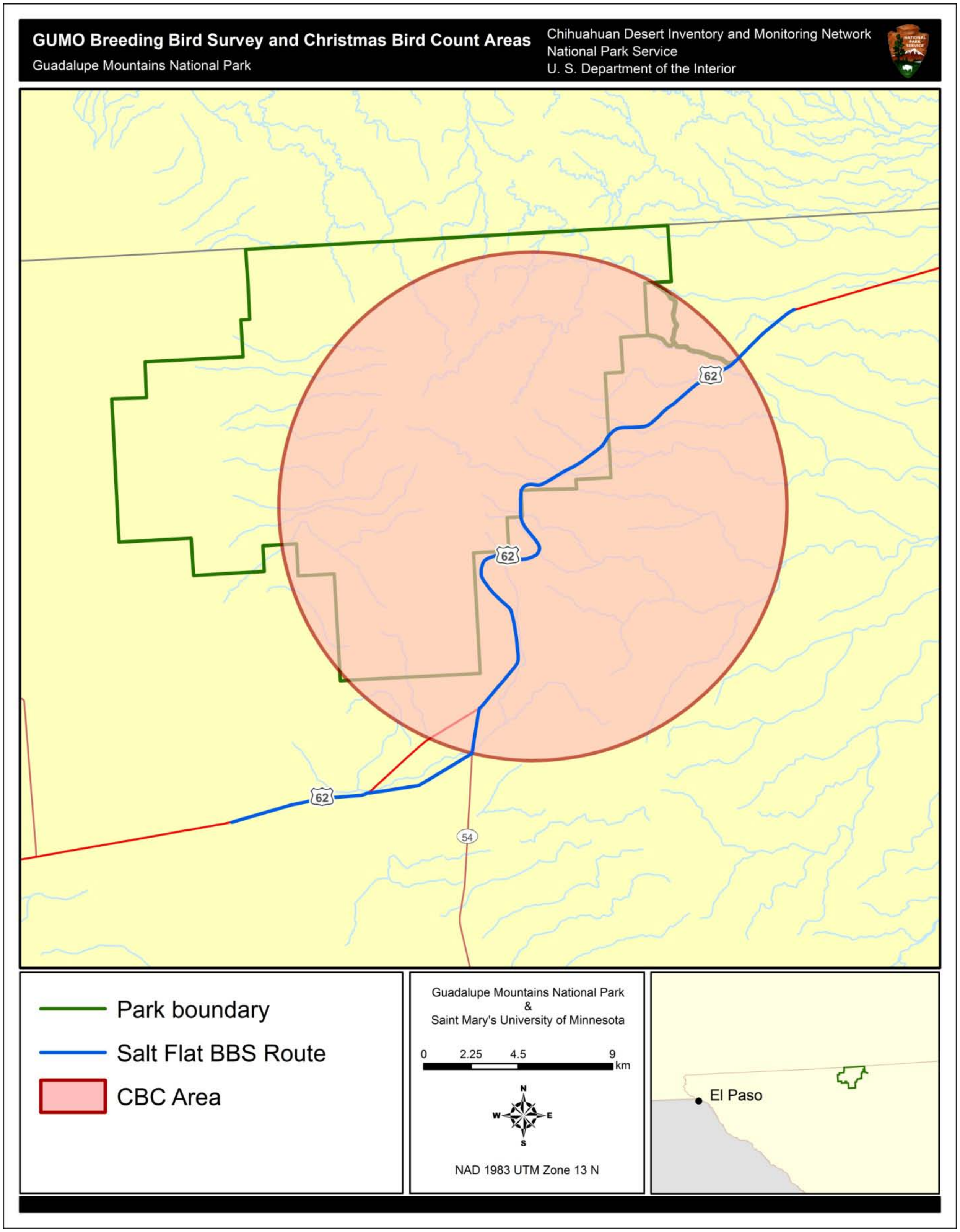


**Plate 21.** Breeding Bird Survey and Christmas Bird Count study areas in relation to GUMO.

## 4.8 Reptiles

### *Description*

GUMO provides habitat for a number of reptiles, including snakes, lizards, and turtles. Snakes are the most diverse reptile group in GUMO, with 22 species documented in the park (NPS 2012). There are also two turtle species and 19 lizard species confirmed in GUMO, including a white variety of the lesser earless lizard (*Holbrookia maculata*) which is found at only one other site in the world (NPS 2009, 2012). Reptiles play an important role in the park's food web as some act as both predators and prey species (Grace 1980, ESI 2011).

**Photo 19**. Eastern collared lizard (*Crotaphytus collaris*) (NPS photo).

### *Measures*

- Species diversity
- Distribution

### *Reference Conditions/Values*

A reference condition has not been established for reptiles in GUMO. The earliest published survey of reptiles in west Texas is Bailey's 1905 "Biological Survey of Texas." However, this survey described reptile occurrence by zone and did not provide diversity or distribution information specific to the area that is now GUMO. Since there are no other sources that provide adequate historical information on the reptiles in the park, the species and distribution information in Bailey (1905) will serve as a "potential species list" for this assessment.

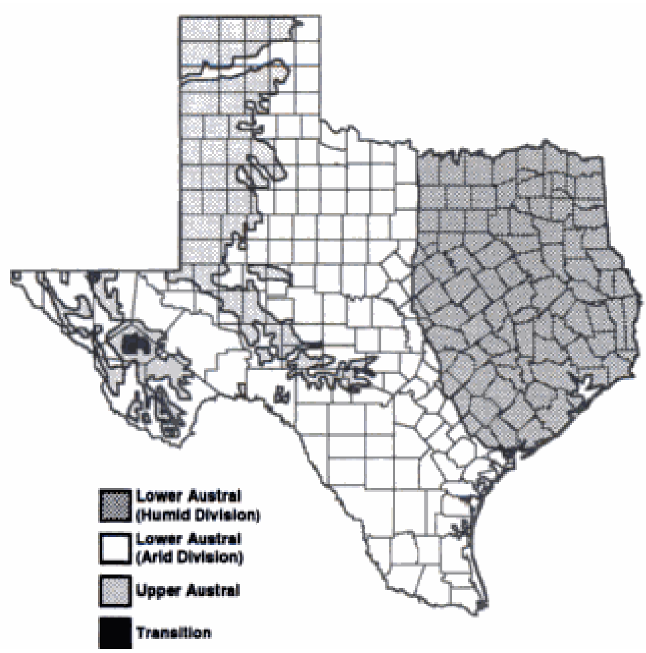


**Figure 16.** Bailey's life zones of Texas (Schmidly 2002).

### *Data and Methods*

Bailey (1905) conducted a biological survey of Texas, which included reptile species. This survey describes the ranges and distributions of native species in relation to "life zones" located throughout Texas. The four main life zones are the Lower Austral zone (including the Lower Sonoran zone), Upper Austral zone (including the Upper Sonoran zone), Transition zone, and Canadian zone (Figure 16). Reptile species were only addressed for the Upper and Lower Austral zones.

Mecham (1979) encountered 50 species of amphibians and reptiles in a study of GUMO and nearby locations. Records include a description of local distribution for most species said to be present in GUMO. Most species were also associated with biogeographical locations such as the plains belt (lower elevations), roughlands belt (mid-mountain range), and montane belt (elevations above 2,130 m [7,000 ft]).

Grace (1980) conducted a study of reptiles and amphibians in GUMO between 1978 and 1979. The herpetofauna were documented along with the respective plant communities in which they were observed. Extensive searches were conducted in the major areas of the park, which include ten vegetative communities (as identified by Grace 1980): grassland, perennial forb, mountain shrub, conifer, pinon-juniper, hardwood, creosotebush, mesquite, fourwing saltbush, and desert shrub. Several trapping methods were utilized during this survey. Specimens were caught by hand, nooses, shot with .22 caliber dust shot, dip nets, seines, drift fences, and pit-fall traps.

In 2002, Andersen (2003) conducted a baseline study that characterizes the plant and animal communities at three GUMO riparian sites. The three sites were Choza, Smith, and Juniper Springs. These three springs are located in close proximity to each other in the eastern part of the park. Animal records included reptiles, which were documented when observed; some were captured to ensure a more accurate identification.

Prival and Goode (2005) conducted an inventory of reptiles and amphibians found in the CHDN parks between 2003 and 2004. Trapping methods varied among the parks surveyed; the GUMO survey was performed by a team from the University of Arizona and park staff. Observation and trapping methods included pit-fall traps, foot searches, road-cruising survey, and collection vouchers.

Rotenberry et al. (2008) used ecological niche modeling to assess habitat suitability for reptiles and amphibians in CHDN parks. Habitat suitability maps were produced for 12 lizard and five snake species at GUMO.

### *Current Condition and Trend*

<u>Species Diversity</u>

According to NPS (2012), there are currently 43 reptile species present in GUMO (Table 31). All 43 reptiles are native to the area. Two species are listed as threatened in Texas: the Texas horned lizard (*Phrynosoma cornutum*; Photo 20) and the greater (or mountain) short-horned lizard (*P. hernandesi*) (TPWD 2012).

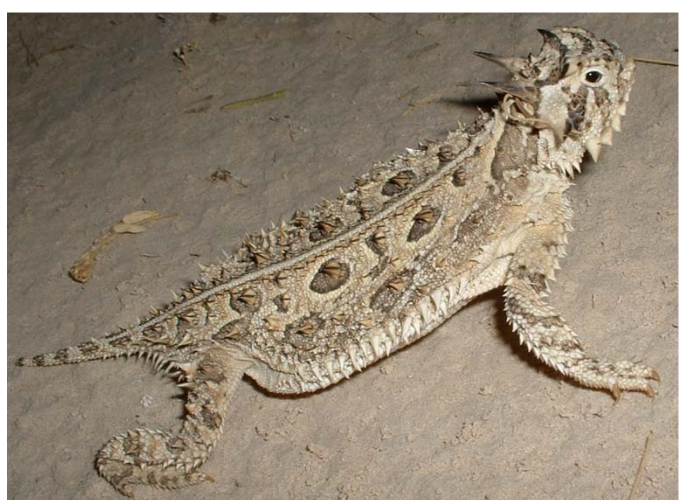

**Photo 20.** Texas horned lizard (photo from Prival and Goode 2005).

Bailey (1905) observed 33 reptile species (18 lizard and 15 snake species) in the Lower Sonoran Zone, which includes the western edge of the park. Twenty reptile species were observed in the Upper Sonoran Zone (10 lizards and 10 snake species), which covers most of the park outside the mountains. These species are shown below in Table 31.

**Table 31.** Reptile species observed or possibly present historically (in the case of Bailey 1905) within GUMO (Mecham 1979, Grace 1980, Prival and Goode 2005, NPS 2012).

| Scientific Name | Bailey (1905) | Mecham (1979) | Grace (1980) | Prival & Goode (2005) | NPSpecies (2012) |
|---|---|---|---|---|---|
| *Arizona elegans* | | x | x | x | x |
| *Aspidoscelis tigris* | | x | x | | x |
| *Bogertophis subocularis* | | x | x | x | x |
| *Aspidoscelis exsanguis* | | x | x | x | x |
| *Aspidoscelis  inornatus* | | x | x | x | x |
| *Aspidoscelis gularis* | x | x | | | |
| *Aspidoscelis marmoratus* | | | | x | x |
| *Aspidoscelis tesselatus* | x | x | x | x | x |
| *Coleonyx brevis* | x | x | x | x | x |
| *Cophosaurus texanus* | x | x | x | x | x |
| *Crotalus atrox* | x | x | x | x | x |
| *Crotalus lepidus* | x | x | x | x | x |
| *Crotalus molossus* | x | x | x | x | x |
| *Crotalus scutulatus* | | x | x* | | |
| *Crotalus viridis* | x | x | x | x | x |
| *Crotaphytus collaris* | x | x | x | x | x |
| *Diadophis punctatus* | x | x | x | x | x |
| *Elaphe obsoleta* | x | | | | |
| *Elaphe guttata emoryi* | | x | x | x | x |
| *Eumeces multivirgatus* | | x | x | x | x |
| *Eumeces obsoletus* | x | x | x | x | x |
| *Eumeces tetragrammus* | x | | | | |
| *Gambelia wislizenii* | x | | x | x | x |
| *Gyalopion canum* | | x | x* | x | x |
| *Heterodon nasicus* | x | x | | x | x |
| *Holbrookia maculata* | x | x | x* | x | x |
| *Hypsiglena torquata* | | x | x | x | x |
| *Kinosternon flavescens* | | x | x | x | x |
| *Lampropeltis alterna* | | | | | x |
| *Lampropeltis getula* | | x | x | | |
| *Lampropeltis mexicana* | | x | x | | |
| *Leptotyphlops dulcis dissectus* | | x | x | x | x |
| *Leptotyphlops humilis* | | | | x | |
| *Masticophis flagellum* | x | x | x | x | x |
| *Masticophis taeniatus* | x | x | x | x | x |
| *Opheodrys vernalis* | x | x | | | |
| *Phrynosoma cornutum* | x | x | x | x | x |
| *Phrynosoma douglasii* | | x | x | | |
| *Phrynosoma hernandesi* | x | | | x | x |
| *Phrynosoma modestum* | x | x | x | x | x |
| *Pituophis catenifer* | x | | | x | x |
| *Pituophis melanoleucus* | | x | x | | |
| *Rhinocheilus lecontei* | x | x | x | x | x |
| *Salvadora grahamiae* | | x | x | x | x |

**Table 31.** Reptile species observed or possibly present historically (in the case of Bailey 1905) within GUMO (Mecham 1979, Grace 1980, Prival and Goode 2005, NPS 2012). (continued)

| Scientific Name | Bailey (1905) | Mecham (1979) | Grace (1980) | Prival & Goode (2005) | NPSpecies (2012) |
|---|---|---|---|---|---|
| *Sceloporus cowlesi* | | | | x | x |
| *Sceloporus magister* | | | x* | | |
| *Sceloporus merriami* | x | | | | |
| *Sceloporus poinsettii* | x | x | x | x | x |
| *Sceloporus undulatus* | x | x | x | | |
| *Sonora semiannulata* | x | x | x | x | x |
| *Tantilla atriceps* | | x | x | | |
| *Tantilla nigriceps* | | x | x* | | |
| *Tantilla hobartsmithi* | | | | x | x |
| *Terrapene ornata* | | x | x | x | x |
| *Thamnophis cyrtopsis* | x | x | x | x | x |
| *Thamnophis proximus* | x | | | | |
| *Urosaurus ornatus* | x | x | x | x | x |
| *Uta stansburiana* | | x | x | x | x |

* indicates species documented near but not in the park by Grace (1980).

Mecham (1979) recorded 46 reptile species in GUMO including 26 snakes, 18 lizards, and two turtles (Table 31). Several rare species were observed including the gray-banded kingsnake (*Lampropeltis mexicana*) and the Mojave rattlesnake (*Crotalus scutulatus*). The lesser earless lizard, also rare, had not been previously recorded in the park. The smooth green snake (*Opheodrys vernalis*) was not observed during the study, but Mecham (1979) stated that the species was possibly present in the park based on a recent reported sighting by another researcher.

Grace (1980) encountered 35 reptile species within the park and an additional nine species nearby, including 23 snakes, 19 lizards, and two turtles (Table 31). The most commonly observed species were the common side-blotched lizard (*Uta stansburiana*) and western whiptail (*Aspidoscelis tigris*). Two currently state threatened species were observed during this study: the Texas horned lizard and plains black-headed snake (*Tantilla nigriceps*).

Andersen (2003) recorded three reptile species during a 2002 study of three riparian sites in the eastern portion of the park. All of the species recorded were lizards: the Big Bend tree lizard (*Urosaurus ornatus schmidti*), Great Plains skink (*Eumeces obsoletus*; Photo 21), and Chihuahuan spotted whiptail (*Aspidoscelis exsanguis*). According to Andersen (2003), the lack of diversity could be due to the timing of the study (during daylight hours) and limited attention paid toward herpetofauna.

**Photo 21.** Great Plains skink (photo from Prival and Goode 2005).

**Photo 22.** Western diamondback rattlesnake (photo from Prival and Goode 2005).

Prival and Goode (2005) observed 41 reptile species in GUMO, including 21 snakes, 18 lizards, and two turtle species (Table 31). The two most commonly observed lizards during the study were the Chihuahuan spotted whiptail and southwestern fence lizard (*Sceloporus cowlesi*). The least frequently observed lizard species were the lesser earless lizard and the eastern collared lizard (*Crotaphytus collaris*). Lizards were observed more frequently during the study than snakes and turtles. The two most commonly observed snakes were the western diamondback rattlesnake (Photo 22) and the black-tailed rattlesnake (*Crotalus molossus*). The only turtles encountered during the study were the desert box turtle (*Terrapene ornata luteola*) and yellow mud turtle (*Kinosternon flavescens*). Only one state threatened species, the Texas horned lizard, was documented during the study, although it was observed 11 times.

Prival and Goode (2005) state that the following species were not observed during the study, but are thought to occur in the park: twin-spotted spiny lizard (*Sceloporus magister bimaculosus*), Mojave rattlesnake, desert kingsnake (*Lampropeltis getula splendida*), and plains black-headed snake.

<u>Distribution</u>

Bailey (1905) documented reptile species present in Texas life zones, including the Lower Sonoran Zone and Upper Sonoran Zone in the GUMO region. Thirty-three species were found in the Lower Sonoran Zone, which is characterized as a desert with a hot, arid climate throughout low elevations. Twenty reptile species were found throughout the Upper Sonoran Zone, which is described as desert steppe, a transition between desert and woodlands. Several of these species are highly unlikely to have occurred in or near GUMO. A list of the species documented by Bailey that could have occurred in the Upper and Lower Sonoran zone within GUMO is presented in Appendix E.

Mecham (1979) recorded local distributions for many of the species known to occur in GUMO. Distributions were described in relation to elevation ranges. The three ranges were the desert plains belt (<1,370 m [4,500 ft]), roughlands belt (1,370-2,130 m [4,500-7,000 ft]), and montane belt (>2,190m [7,200 ft]). Six species were limited to the lower elevation of the desert plains belt. One species, the lesser earless lizard, was found primarily in the gypsum dunes. Two species were dependent on permanent ponds: the yellow mud turtle and black-necked snake (*Thamnophis cyrtopsis*). Eight reptiles were commonly observed in the plains belt but were also documented at the lower elevations of the roughlands belt. Five species were mainly found in the roughlands belt. One lizard and two snake species were recorded in the evergreen and coniferous forest, which ranges from the upper elevation of the roughlands belt to the highest elevations (2,500 m [8,200 ft]) in the park (Mecham 1979). Five species were observed at all altitudes or to have extreme elevational ranges in the park: many-lined skink (*Eumeces multivirgatus*), crevice spiny lizard (*Sceloporus poinsettii*), eastern fence lizard (*S. undulatus*), ornate tree lizard (*Urosaurus ornatus*), and pine snake (*Pituophis melanoleucus*). Mecham (1979) did not describe distributions for 15 reptiles observed in the study, but did mention three species that are associated with the Chihuahuan Desert and two species that are associated with the Southern Great Plains. Appendix E displays all of the reptiles encountered during the study and their respective distributions if applicable.

Grace (1980) created general distribution maps for the reptiles encountered during the study in 1979. Grace (1980) also documented the vegetative habitat(s) where each reptile was observed. Appendix E displays a table of all the reptile species observed and the habitat in which they were observed. The black-tailed rattlesnake was observed in all ten habitats in GUMO. The three habitats with the highest diversity of species were desert shrub, creosotebush, and mountain shrub with 30, 28, and 28 species, respectively (Grace 1980).

Prival and Goode (2005) recorded local distributions for all species found during their 2003-2004 study. Reptiles were observed in several locations at various elevations, and distribution maps were created to display each location where a species was observed. The three most widely distributed species in the park were the crevice spiny lizard, southwestern fence lizard, and Big Bend tree lizard. Several reptiles were observed on the foothills and lower slopes of the mountains. Some species were only observed in certain locations. Species found only in the far western section of the park were the western marbled whiptail (*Aspidoscelis marmorata marmorata*), green prairie rattlesnake (*Crotalus viridis viridis*), and the Texas nightsnake (*Hypsiglena torquata janii*).

Rotenberry et al. (2008) mapped the habitat suitability (i.e., potential distribution) within GUMO for 12 lizard and five snake species. According to their niche modeling, only five of the studied reptile species showed limited suitable habitat within the park: the Chihuahuan spotted whiptail, eastern collared lizard, rock rattlesnake (*Crotalus lepidus*), coachwhip (*Masticophis flagellum)*, and the Big Bend spotted whiptail (*Aspidoscelis septemvittata*), which has never been documented in the park. Species with broader habitat suitability in the park, along with a general description of habitat locations, are listed in Table 32.

**Table 32.** General locations of suitable reptile habitat within GUMO, according to Rotenberry et al. (2008).

| Scientific name | Habitat locations |
|---|---|
| **Lizards** | |
| *Aspidoscelis inornata heptagramma* | southern and western park |
| *Aspidoscelis tesselata* | southern park and edge of western escarpment |
| *Coleonyxis brevis* | throughout, except at high elevations |
| *Cophosaurus texanus* | throughout, except at high elevations |
| *Sceloporus cowlesi* | southern, eastern, and northern park |
| *Sceloporus poinsettii* | throughout, except for western park |
| *Urosaurus ornatus schmidti* | mountain slopes throughout park |
| **Snakes** | |
| *Crotalus atrox* | throughout |
| *Crotalus molossus* | far northeast corner, southern, and western portions of park |
| *Hypsiglena torquata janii* | southern portion and eastern edge of park |

Threats and Stressor Factors

Potential threats to the reptiles in the park include poaching, increased visitor use, and habitat change. Currently, poaching (primarily for the pet trade) does not seem to be an issue due to the inaccessibility of much of the park (Armstrong, interview, 24 January 2012). Locked gates limit access to most of the reptile habitat, although visitors can obtain a key at the Visitor Center. Proposals have been made to open these access points, which would likely increase visitor use and the potential for poaching (Armstrong, interview, 24 January 2012). Increased use could also raise the risk of road kills and general disturbance of these typically solitary reptile species. Changes in reptile habitat (e.g., vegetation) are also a concern, and could be triggered by exotic species invasion, drought, fire, or park maintenance/development, for example.

Data Needs/Gaps

Information is available that characterizes reptile distribution and species diversity parameters in GUMO. Bailey (1905) provides potential species found in the park region but is over a century old; Mecham (1979) and Grace (1980) provide good distributional information, but are over 20 years old. Prival and Goode (2005) is the most recent study available, but it too is 7 years old. Regular monitoring of reptile diversity and distribution in the park would allow for more accurate assessment of these parameters.

Overall Condition

*Species Diversity*

The project team defined the *Significance Level* for species diversity as a 3. According to NPS (2012), over 40 native reptile species are present or probably present in GUMO. There is no evidence that reptile diversity has decreased in the park over time (see Table 31). Because of this, the *Condition Level* for this measure is 0 or of no concern.

*Distribution*

The project team defined the *Significance Level* for species distribution as a 2. There are no current data for reptile distribution in GUMO. Because of this data gap, a *Condition Level* for this measure was not assigned.

*Weighted Condition Score*

A *Weighted Condition Score* for reptiles in GUMO was not assigned because 50% of the measures had an unknown *Condition Level*. A wide variety of snakes, lizards, and turtles has been documented in GUMO and can be found throughout the various habitats in the park. However, the studies and inventories that address reptile diversity and distribution are outdated. Thus, it is not possible to assess the condition of reptiles in GUMO at this time.

# Reptiles

| Measures | SL | CL |
|---|---|---|
| • Species diversity | 3 | 0 |
| • Distribution | 2 | n/a |

**WCS = N/A**

***Sources of Expertise***

Fred Armstrong, former GUMO Chief of Resource Management, currently Chief of Resource Management and Research at Zion National Park

Dave Prival, Partner, Southwestern Ecological Research Company

Matt Goode, Research Scientist, University of Arizona School of Natural Resources & Environment

John Rotenberry, Assistant for Special Projects, University of Minnesota College of Biological Sciences

Ken Halama, Reserve System Director, University of California.

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## 4.9 Mountain Lion

### *Description*

Mountain lions (*Puma concolor*) (also referred to as cougar, puma, and panther) have been present in the Chihuahuan Desert since at least 1929 (Borrell and Bryant 1942). The mountain lion was once abundant throughout Texas; however, predator control practices and habitat loss have caused a decrease in lion numbers (TPWD 2008). In the early 20$^{th}$ century, ranchers frequently hunted mountain lions because the species killed local livestock (Borell and Bryant 1942). The animal ranges through all ecosystems in GUMO, although they are most common in areas with adequate prey, especially mule deer (NPS 2012). Smith et al. (1986) had estimated the mountain lion population within the park to be five to six animals. According to Carpenter (1993), mountain lion numbers increased after GUMO was established in 1972 because predator control practices were limited to outside the park area. In Texas, the home range of a male mountain lion typically varies from 207 to 518 $km^2$ (80 to 200 $mi^2$), depending on factors such as prey abundance, topography, and the presence of other lions (TPWD 2008). Female home ranges are smaller at approximately 52 to 260 $km^2$ (20 to 100 $mi^2$) and may overlap (TPWD 2008). With its area of 350 $km^2$ (135 $mi^2$), GUMO may only support one or two male mountain lions and two to eight females strictly within its boundaries.

**Photo 23.** Mountain lion in Big Bend National Park (NPS photo).

Mountain lions (Photo 23) are the largest of the wild cat species in Texas, with the average male measuring 2 m (7 ft) in length, and weighing between 45-68 kg (100-150 lbs) (McKinney 2012). Mountain lions in GUMO feed predominantly on mule deer (Genoways et al. 1979, Smith et al. 1986). However, mountain lions are opportunistic and also feed on species such as skunks (Mustelidae), lagomorphs (Leporidae), and porcupines (Erethizontidae) (Pence et al. 1986). They are rare, independent, and solitary creatures that are more active during low-light hours of the day (McKinney 2012). Sightings in the park are rare, but signs can be found and used to estimate mountain lion presence (Harveson et al. 1997, 1998, 1999).

### *Measures*

- Population trends

### *Reference Conditions/Values*

The reference condition for mountain lions in GUMO is described in Genoways et al. (1979). Historic accounts of mountain lion occurrence in the current park area are somewhat conflicting.

According to Bailey (1932, as cited in Genoways et al. 1979, p. 305), mountain lions were common in the Guadalupe Mountains, “where the numerous rock cliffs and canyons furnish them excellent cover.” However, Davis (1940, as cited in Genoways et al. 1979) stated that mountain lions were rare in the Guadalupe Mountains of Texas. In the 1970s, Genoways et al. (1979, p. 305) estimated that several lions (five or less) were “at least part-time residents of the park.”

### *Data and Methods*

Smith et al. (1986) conducted a 3-year study of the ecology of mountain lions in GUMO, which began in 1982. Mountain lions were tracked using trained hounds, and then sedated to obtain dental characteristics, weight, age, sex and reproductive condition, and foot and pad measurements. Smith et al. (1986) also put radio collars on 22 mountain lions.

Davila (1988, 1989, 1990) conducted a mountain lion monitoring program in the park from 1988 to 1990. Six or seven transect segments (approximately 74 km [46 mi]) were surveyed for mountain lion sign each year.

Russ (1995a, b) collected data on mountain lion mortality and sightings throughout Texas, as well as combining data from other studies in the state. The TPWD’s Wildlife and Law Enforcement Division collected data from the beginning of January to the end of May between 1983 and 1989. Additional reports were collected from each Texas ecoregion between 1989 and 1994. These two data sets were combined with data collected by Russ (1995b) to create a long-term study. Reports were received from several sources including USDA Animal Damage Control personnel, landowners, the general public, and TPWD personnel. Mortalities were verified and sightings were validated and accepted by TPWD (Russ 1995a). Reports provided the description of the animal, distance, habitat type found in, and activity. The 10 ecoregions identified in Russ’s (1995a) study were divided and characterized by Gould (1969).

Harveson et al. (1997, 1998, 1999) conducted a multiple sign survey (e.g., tracks, scat, scrapes, and kills) between 1987 and 1996 to assess mountain lion trends in GUMO and Carlsbad Caverns National Park. For every year of the survey, multiple transects (76) were set up and run during the spring and fall.

Miller (2002, 2003) conducted a mountain lion transect study in GUMO during 2002 and 2003. Four types of mountain lion sign were recorded: kills, scats, tracks, and scrapes. The area and the type of sign were photographed for each sign located. The six transects were Dog Canyon loop, Bush Mountain, Frijole Ridge, Upper South McKittrick, Middle McKittrick, and Shumard Canyon (Plate 22). Surveys took place between 18 April and 17 May in the spring of 2002 and between 23 September and 4 November in the fall of 2002. No transects were surveyed in the spring of 2003, but surveys did take place from 6 September through 29 September in the fall of 2003. Miller (2002, 2003) corrected for any signs that were potentially from the same lion by calculating Standardized Units of Sign (SUS) values.

### *Current Condition and Trend*

#### Population Trends

Smith et al. (1986) captured and radio collared 22 mountain lions during a 3-year study in GUMO and CAVE. There was an estimate of no more than 58 mountain lions (adults, juveniles, and cubs) in the adjacent parks and surrounding areas. By the end of the study, a total of 56 mountain lions had been killed, including 11 radio collared mountain lions. A majority of these mortalities were likely caused by predator control, as most occurred near ranches that bordered the parks. Smith et al. (1986) concluded that the reproduction rates and animals moving into the area outweighed the number of mountain lions killed.

Davila (1988) observed a total of 18 mountain lion signs (scat, scrapes). An SUS value of eight was given to transect kilometers from 32 to 13 (between Pine Top and Dog Canyon); this means at least eight signs were observed. Six signs were observed on transect kilometers 34-37 (above Bear Canyon). There were two signs observed on transect kilometers 32-33 (Frijole Peak to Pine Top) and two signs recorded in the Dog Canyon area (kilometers 1-13). Several transects had no observed signs, including kilometers 48-60 (Dog Canyon to McKittrick Canyon) and kilometers 62-74 (Williams Ranch to Pine Springs campground).

Davila (1989) observed a total of five mountain lion signs (scat, scrapes). There were three signs on transect kilometers 14-31. The other two signs were observed on transects 32-33. Several transects had no observed signs, including kilometers 34-37 and 1-13 where sign was found the previous year. According to Davila (1989), there were 43 mountain lions killed just north of the park two years prior to the study. This is important to know, as predator control is a major threat to mountain lions in and around the park.

Davila (1990) observed a total of five mountain lion signs (scat only). Several transects had no observed signs. Four signs were observed between transect kilometer 33 and Dog Canyon. The other two signs were observed on transect kilometers 33-38 (Frijole area). Heavy rains and flooding occurred prior to the study, and many sites were affected by the rain event. Accelerated vegetation growth due to the rains made it difficult to see the ground, and flooding washed away the main canyon bottom at transect kilometers 48-61 (Dog Canyon to McKittrick Canyon). There may have been more mountain lion signs, but they were hidden or washed away by the rain events. The small number of signs could also be attributed to the 43 mountain lion mortalities mentioned in the Davila (1989) report.

Russ (1995a) compiled mountain lion mortality and sighting reports to determine the current distribution and population status in Texas. Between 1983 and 1994, 1,144 mortalities and 457 sightings were recorded in the ecological region which encompasses GUMO. According to Russ (1995a), the mountain lion population is widely distributed and stable in Texas.

Harveson et al. (1997) collected population trend data for the mountain lion populations of GUMO and CAVE. Transects were surveyed from 1987-1996, with the exception of the fall of 1992 and the spring of 1993. Because of this gap in the data, Harveson et al. (1997) separated the data into two groups: fall 1987-spring 1992, and fall 1993-spring 1996. Results of these surveys found that GUMO mountain lion numbers declined during the first portion of the study (fall 1987-spring 1992). Conversely, the second portion of the study (fall 1993-spring 1996) showed an increase in GUMO mountain lion numbers. There are several potential reasons hypothesized for the declining trend from 1987-1992 (declining prey base, predator control efforts), but it is interesting to note that the peak in mountain lion mortalities in the GUMO region (as reported in Russ [1995a]) corresponds with the observed decrease in mountain lion numbers from 1987-

1992. Table 33 displays the number of mountain lion mortalities and sightings documented by Russ (1995a) in the Trans Pecos, Mountains and Basins ecological region.

**Table 33**. Mountain lion survey records of mortality and sighting in the Trans-Pecos, Mountains and Basins ecological region (Russ 1995a).

| Year | Number of mortalities | Number of sightings |
|---|---|---|
| 1983 | 56 | 10 |
| 1984 | 71 | 23 |
| 1985 | 93 | 17 |
| 1986 | 100 | 26 |
| 1987 | 111 | 25 |
| 1988 | 131 | 28 |
| 1989 | 113 | 35 |
| 1990 | 82 | 28 |
| 1991 | 95 | 53 |
| 1992 | 74 | 73 |
| 1993 | 112 | 69 |
| 1994 | 106 | 70 |
| **Total** | **1,144** | **457** |

Miller (2002, 2003) recorded totals of 100, 62, and 53 mountain lion signs during spring 2002, fall 2002, and fall 2003, respectively. Table 34 displays the number of signs from several locations in GUMO between spring of 2002 and fall of 2003. The highest number of signs recorded in 2002 were from the Dog Canyon transect. In 2003, the highest number of mountain lion signs occurred on the Frijole Ridge transect. The SUS values for spring and fall of 2002 were 57 and 35, respectively. The SUS value for the fall of 2003 was 30. Each SUS value is roughly half of the recorded number of signs per season. This may mean that several signs were found in close proximity to each other, indicating they were from the same lion. This large number of mountain lion signs suggests that more lions may have been utilizing the park at this time than during the earlier transect surveys (Davila 1988-1990).

**Table 34**. The number of mountain lion signs (kills, scat, scratches, scrapes) recorded at each transect in GUMO, between 2002 and 2003 (No survey took place in spring of 2003) (Miller 2002, 2003). See Plate 22 for general locations of transects.

| Transect Location | Spring 2002 | Fall 2002 | Fall 2003 |
|---|---|---|---|
| Dog Canyon Loop | 31 | 24 | 11 |
| Bush Mountain | 27 | 22 | 9 |
| Frijole Ridge | 7 | 12 | 23 |
| Upper McKittrick | 20 | 1 | 8 |
| Middle McKittrick | 15 | 2 | 1 |
| Shumard Canyon | 0 | 1 | 1 |
| **Total** | **100** | **62** | **53** |

Miller (2002, 2003) also reviewed SUS values from previous GUMO transect surveys to assess a possible trend. According to Miller (2003), the total SUS values per year (spring and fall) increased between 1999 and 2003. There also seemed to be more activity during the spring in most years. Figure 17 displays the SUS values for spring and fall between 1995 and 2003.

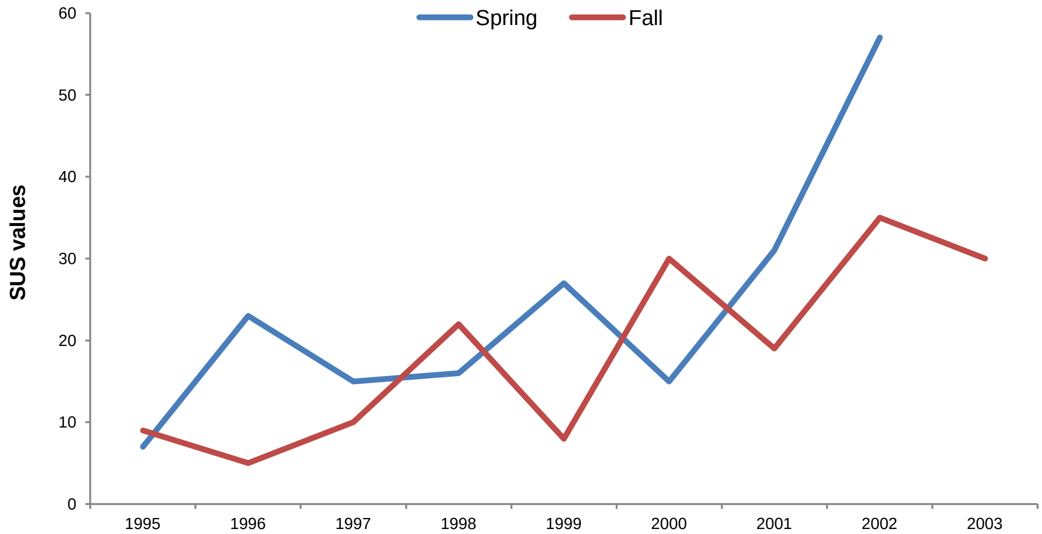


**Figure 17**. SUS values from a mountain lion multiple sign transect study in GUMO between 1995 and 2003 (Miller 2003).

Threats and Stressor Factors

A major threat to mountain lions in GUMO is predator control activity occurring outside of the park. As a non-game species, mountain lions can be harvested with no established season or bag limit. Because of this, harvest statistics are not available from the TPWD. According to Russ (1995a), the Trans Pecos, Mountains and Basins ecological region in which GUMO is located has the highest mountain lion mortality rate in Texas. There were 1,144 mountain lion mortalities recorded between 1983 and 1994. Private hunters caused a majority of the deaths in 1994, with 40 kills out of 106 total recorded mortalities (Russ 1995a).

**Photo 24.** Aoudad (NPS photo).

The aoudad (*Ammotragus lervia*; Photo 24), a non-native sheep species historically introduced by ranchers, is another threat to the mountain lion population in GUMO. Aoudads browse on many plant species, including forbs and grasses, and can out-compete mule deer for food (Armstrong and Harmel 1981). Reduction of available browse is one factor causing mule deer population declines in GUMO (Uhler 2007), and mule deer are the primary prey species for mountain lions. If mule deer populations decline, mountain lions may have to travel further outside the park in search of prey, contributing to increased lion mortality due to predator control actions by ranchers.

Data Needs/Gaps

Several studies have documented mountain lion abundance and population size (Smith et al. 1986, Russ 1995a, b, Harveson et al. 1997, 1998, 1999, Miller 2002, 2003), although no study has taken place in GUMO since 2002. Regular monitoring of mountain lion population trends in the park would allow for more accurate assessment of this resource. Results of a contemporary monitoring project could be compared to the historic surveys discussed here to gauge the health of the population. Further studies of mountain lion movements in and out of the park, as well as how competition between aoudad and mule deer may impact mountain lions, would help managers better understand the status of the park's lion population.

Overall Condition

*Population Trends*

The project team defined the *Significance Level* for population trends as a 3. There are data that help describe mountain lion population trends in GUMO, as well as in the surrounding areas; however, these data are outdated. While available survey data suggest that the mountain lion population was increasing during the late 1990s and early 2000s, a *Condition Level* was not assigned due to a lack of more recent data.

*Weighted Condition Score*

A *Weighted Condition Score* for mountain lions in GUMO was not assigned because the only measure for this component did not have an assigned *Condition Level*. Mountain lions can be found throughout the various habitats in the park and population trends have been documented in the past. However, the studies and inventories that address mountain lion population trends are outdated. Thus, it is not possible to assess the condition of mountain lions in GUMO at this time.

**Mountain Lion**

| Measures | SL | CL |
|---|---|---|
| • Population trends | 3 | n/a |

**WCS = N/A**

***Sources of Expertise***

Janet Coles, GUMO Chief of Resource Management

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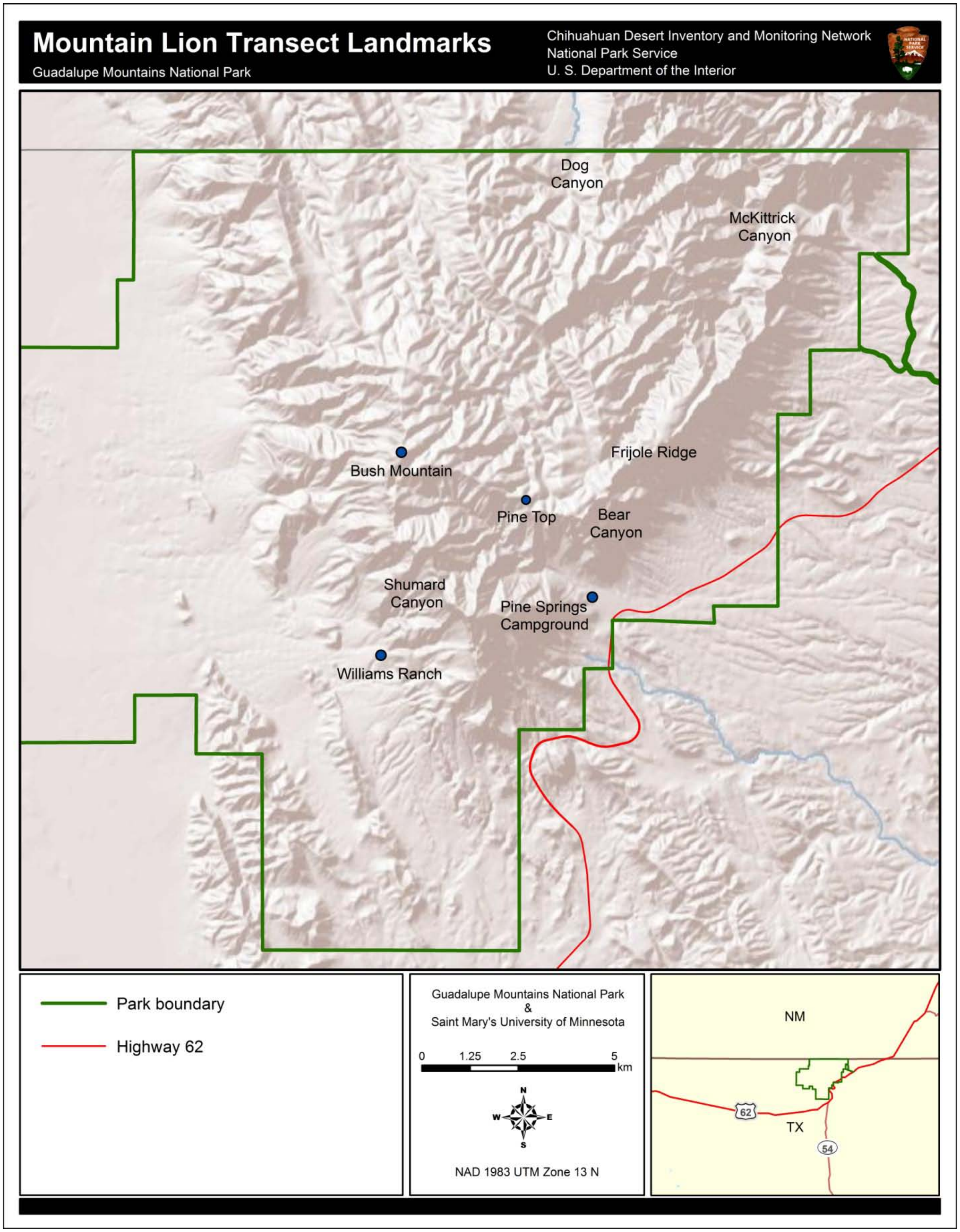


**Plate 22.** General locations of places/areas referenced in the GUMO mountain lion transect surveys (Davila 1988-1990, Miller 2002, 2003).

## 4.10 Air Quality

### *Description*

Air pollution can significantly affect natural resources and their associated ecological processes. Consequently, air quality in parks and wilderness areas is protected and regulated through the 1916 Organic Act and the Clean Air Act of 1977 (CAA) and the CAA's subsequent amendments. The CAA defines two distinct categories of protection for natural areas, Class I and Class II airsheds. Class I airsheds are defined as national parks over 6,000 acres (2,428 ha), national wilderness areas, national memorial parks over 5,000 acres (2,023 ha), or international parks in existence as of August 7, 1977 (NPS 2011). GUMO was designated by Congress as a Class I airshed in 1977.

Class I airsheds receive the highest level of air quality protection as offered through the CAA (EPA 2008a). There are two main components of the CAA that apply specifically to Class I areas. First, only small increments of additional air pollution above a baseline level are permitted in the airshed; these are limits on allowable emissions that are much lower than what is permitted in Class II areas (EPA 2008a). These increments are assessed as part of the EPA-mandated Prevention of Significant Deterioration (PSD) permitting program. A permit applicant must also assess the impacts of operations on air quality related values (AQRVs) associated with the Class I area (EPA 2008a). AQRVs typically include visibility, and health of streams, lakes, soils, and vegetation. The second component comprises visibility protection in Class I areas. The CAA requires states with Class I airsheds to develop plans to achieve reasonable progress toward improving visibility on the haziest days and maintaining visibility on the clearest days (EPA 2008a).

### *Measures*

- Sulfate deposition
- Nitrogen deposition
- Ozone
- Particulate matter ($PM_{2.5}$)
- Visibility

<u>Atmospheric Deposition of Nitrogen and Sulfates</u>

Nitrogen and sulfur oxides are emitted into the atmosphere primarily through the burning of fossil fuels, industrial processes, and agricultural activities (EPA 2008b). While in the atmosphere, these emissions form compounds that may be transported long distances and settle out of the atmosphere in the form of pollutants such as particulate matter (e.g., sulfates, nitrates, ammonium) or gases (e.g., nitrogen dioxide, sulfur dioxide, nitric acid, ammonia) (EPA 2008b, NPS 2008). Atmospheric deposition can be in wet (i.e., pollutants dissolved in atmospheric moisture and deposited in rain, snow, low clouds, or fog) or dry (i.e., particles or gases that settle on dry surfaces as with windblown dusts) form (EPA 2008b). Deposition of sulfur and nitrogen can have significant effects on ecosystems, including acidification of water and soils, excess fertilization or increased eutrophication, changes in the chemical and physical characteristics of water and soils, and accumulation of toxins in soils, water, and vegetation (NPS 2008, reviewed in Sullivan et al. 2011a and 2011b). The native vegetation in the arid uplands and desert scrub communities in GUMO are adapted to low nitrogen conditions and, thus, are sensitive to excess nitrogen deposition (Sullivan et al. 2011c, 2011d).

Ozone

Ozone occurs naturally in the earth's atmosphere where, in the upper atmosphere, it protects the earth's surface against ultraviolet radiation (EPA 2008b). However, it also occurs at the ground level (i.e., ground-level ozone) where it is created by a chemical reaction between nitrogen oxides and volatile organic compounds (VOCs) in the presence of heat and sunlight (NPS 2008). Ozone is also one of the most widespread pollutants affecting vegetation and human health in the U.S. (NPS 2008). Considered phytotoxic, ozone can cause significant foliar injury and growth effects for sensitive plants in natural ecosystems (EPA 2008a, NPS 2008). Specific effects include reduced photosynthesis, premature leaf loss, and reduced biomass, and prolonged exposure can increase vulnerability to insects and diseases or other environmental stresses (NPS 2008). At high concentrations, ozone can aggravate respiratory and cardiovascular diseases in humans, reduce lung function, cause acute respiratory problems, and increase susceptibility to respiratory infections (EPA 2008b, EPA 2010a); this could be a concern for visitors and particularly park staff engaging in aerobic activities in the park, such as hiking on days when ozone concentrations are elevated.

Particulate Matter (PM) and Visibility:

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets suspended in the atmosphere. Fine particles ($PM_{2.5}$) are those smaller than 2.5 micrometers in diameter (EPA 2009). Particulate matter largely consists of acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (EPA 2008a, EPA 2009). Fine particles are a major cause of reduced visibility (haze) in many national parks and wildernesses (EPA 2010b). $PM_{2.5}$ can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries, and/or vehicles react in the atmosphere (EPA 2009, EPA 2010b). Particulate matter either absorbs or scatters light. As a result, the clarity, color, and distance seen by humans decreases. Water in the atmosphere causes particles like nitrates and sulfates to expand, increasing their light-scattering efficiency (EPA 2010b). $PM_{2.5}$ is also a concern for human health as these particles can easily pass through the throat and nose and enter the lungs (EPA 2008b, EPA 2009, EPA 2010b). Short-term exposure to these particles can cause shortness of breath, fatigue, and lung irritation (EPA 2008b, EPA 2009).

### *Reference Conditions/Values*

The NPS Air Resources Division (ARD) developed an approach for rating air quality conditions in national parks, based on the current National Ambient Air Quality Standards (NAAQS), ecosystem thresholds, and visibility improvement goals (Table 35; NPS 2010a). Assessment of current condition of nitrogen and sulfur atmospheric deposition is based on wet (rain and snow) deposition. Ozone condition is based on the NAAQS standard of 75 parts per billion (ppb). Visibility conditions are assessed in terms of a Haze Index, a measure of visibility derived from calculated light extinction (NPS 2010a). Finally, NPS ARD recommends the following values for determining air quality condition (Table 35). The "good condition" metrics may be considered the reference condition for GUMO.

**Table 35.** NPS Air Resources Division air quality index values (NPS 2010a).

| Condition | Ozone concentration (ppb) | Wet Deposition of N or S (kg/ha/yr) | Visibility (dv) |
|---|---|---|---|
| Significant Concern | ≥76 | >3 | >8 |
| Moderate Condition | 61-75 | 1-3 | 2-8 |
| Good Condition | ≤60 | <1 | <2 |

### *Data and Methods*

Monitoring in the Park

An air quality monitoring program was established in GUMO in the mid-1980s in response to the CAA mandate to monitor and protect air quality and related resources from the adverse effects of air pollution (NPS 2010b). Air quality monitoring in the park currently includes deposition of atmospheric pollutants, such as nitrate, sulfate, and ammonium samples collected weekly (National Atmospheric Deposition Program [NADP]; active monitoring from 1984 to present) and visibility monitoring (Interagency Monitoring of Protected Visual Environments Program [IMPROVE]; active monitoring from 1988 to present) (NPS 2005, NPS 2010b). Data from these on-site monitors are used to evaluate trends in air quality at the park, most recently for the period 1999-2008.

Visibility in the park has been monitored since the early 1980s. From 1983-1995, an automated 35 mm camera system took pictures three times a day to assess visibility conditions. A transmissometer operated in the park from 1993 until 2006, measuring light extinction through the ambient atmosphere.

An IMPROVE particulate sampler was installed in 1988 and still operates today, providing data for assessment of long-term trends in visibility and for establishing baseline conditions and tracking progress in improving visibility under the regional haze program. The goal established by the Regional Haze Program is to achieve natural visibility conditions by 2064 in Class I areas and to make progress towards that goal by improving visibility on the haziest days while maintaining good visibility on the clearest days.

NPS Data Resources

In addition, NPS ARD provides estimates of ozone, wet deposition of nitrogen and sulfur, and visibility that are based on interpolations of data from all air quality monitoring stations operated by NPS, EPA, various states, and other entities, averaged over five-year periods with available data (e.g., 2005-2009) (NPS 2012). The most recent five-year estimate is 2006-2010, which is reported as the most recent NPS five-year average for several parameters. These estimates are available from the Explore Air website (NPS 2012) and are used to evaluate air quality conditions. On-site or nearby data are needed for a statistically valid trends analysis, while a five-year average interpolated estimate is preferred for the condition assessment. NPS ARD (2010c) reports on air quality conditions and trends in an annual report for over 200 park units, including GUMO.

Special Air Quality Studies

Sullivan et al. (2011a) assessed the relative sensitivity of national parks to the potential effects of acidification caused by acidic atmospheric deposition from nitrogen and sulfur compounds. The relative risk for each park was assessed by examining three variables: the level of exposure to emissions and deposition of nitrogen and sulfur; inherent sensitivity of park ecosystems to acidifying compounds (N and/or S) from deposition; and level of mandated park protection against air pollution degradation (i.e., Wilderness and Class I). The outcome was an overall risk assessment that estimates the relative risk of acidification impacts to park resources from atmospheric deposition of nitrogen and sulfur (Sullivan et al. 2011a). Using the same approach, Sullivan et al. (2011b) assessed the sensitivity of national parks to the effects of nutrient enrichment by atmospheric deposition of nitrogen. The outcome was an overall risk assessment that estimates the relative risk to park resources of nutrient enrichment from increased nitrogen deposition.

EA Engineering, Science, and Technology, Inc. completed an air emissions inventory in GUMO in 2003 (EA Engineering 2003). This inventory identified air emission sources within or directly adjacent to the park, including stationary, area, and mobile sources. The number and type of emission sources were used to calculate estimated emissions, including pollutants emitted, experienced at the park based on average or observed use. These estimates are compared to adjacent counties and emissions across the state.

Perez and Gill (2009) evaluated the characteristics of dust emitted from the Salt Flat Basin in western Texas and the potential effects on air quality in GUMO. Dust samples were collected twice a year from mid-2005 through mid-2007 at three sites in the basin and at the IMPROVE monitor site in GUMO. Lee et al. (2009) examined the sources of dust that contributed to a single dust storm event affecting parts of the Southern High Plains and Chihuahuan Desert region (which includes GUMO) in December 2003. The authors used satellite data to detect source areas of dust by evaluating landcover and atmospheric aerosols. Point sources of dust were determined using a geographic information system (ArcGIS) and high resolution MODIS (Moderate-resolution Imaging Spectroradiometer) imagery. Field verification was carried out to ensure accurate designation of landcover and dust sources.

Sullivan (2008) conducted an analysis of particulate matter data collected at a specific monitor in GUMO from April 2006 through January 2007. Samplers collected particulate matter with diameters less than 2.5 micrometers and a nephlometer collected continuous measurements of visibility. Wind, temperature, and humidity were also measured. Data on $PM_{2.5}$ mass and speciation are used to understand the sources and nature of the haze experienced in GUMO and west Texas.

### ***Current Condition and Trend***

Nitrogen and Sulfate Deposition

Five-year interpolated averages of total nitrogen (from nitrate and ammonium) wet deposition and total sulfur (from sulfate) wet deposition are used to estimate condition for deposition; using a five-year average smoothes out annual variations in precipitation, such as heavy precipitation one year versus drought conditions in another. The current 5-year average (2006-2010) estimates total wet deposition of nitrogen in GUMO at 1.4 kg/ha/yr, while total wet deposition of sulfur is

1.1 kg/ha/yr (NPS 2012). Relative to the NPS ratings for air quality conditions (see Table 35 for ratings values), atmospheric deposition of both nitrogen and sulfur falls into the *Moderate Concern category*. However, several factors are considered when rating the condition of atmospheric deposition, including effects of deposition on different ecosystems (NPS 2010a). Based on the NPS process for rating air quality conditions, ratings for parks with ecosystems considered potentially sensitive to nitrogen or sulfur deposition typically are adjusted up one condition category. In general, arid and semi-arid ecosystems are considered to be sensitive to increased levels of nitrogen and sulfur, as acidification and nutrient enrichment can cause shifts in native species composition and allow encroachment of exotic species and grasses (reviewed in Sullivan et al. 2011a and 2011b). GUMO comprises arid and semi-arid vegetation communities, which may be at risk from increased deposition, particularly nitrogen. Thus, the condition for deposition of nitrogen and sulfur in GUMO may be considered to be of *Significant Concern*. Despite significant concern for atmospheric deposition, trend analysis of wet deposition data collected in GUMO from 1999-2008 indicates a statistically significant improvement in ammonium, nitrate, and sulfate concentrations in precipitation (NPS 2010c).

Concentrations (mg/L) of nitrogen, sulfur, and ammonium compounds in wet deposition can be used to evaluate trends in deposition of total nitrogen and sulfur. Since atmospheric wet deposition can vary greatly depending on the amount of precipitation that falls in any given year, it can be useful to examine concentrations of pollutants, which factor out the variation introduced by precipitation. Annual averages from 1995-2010 indicate that nitrate concentrations in GUMO are decreasing, sulfate concentrations have increased in recent years, and ammonium concentrations have remained stable (NADP 2012) (Figure 18).

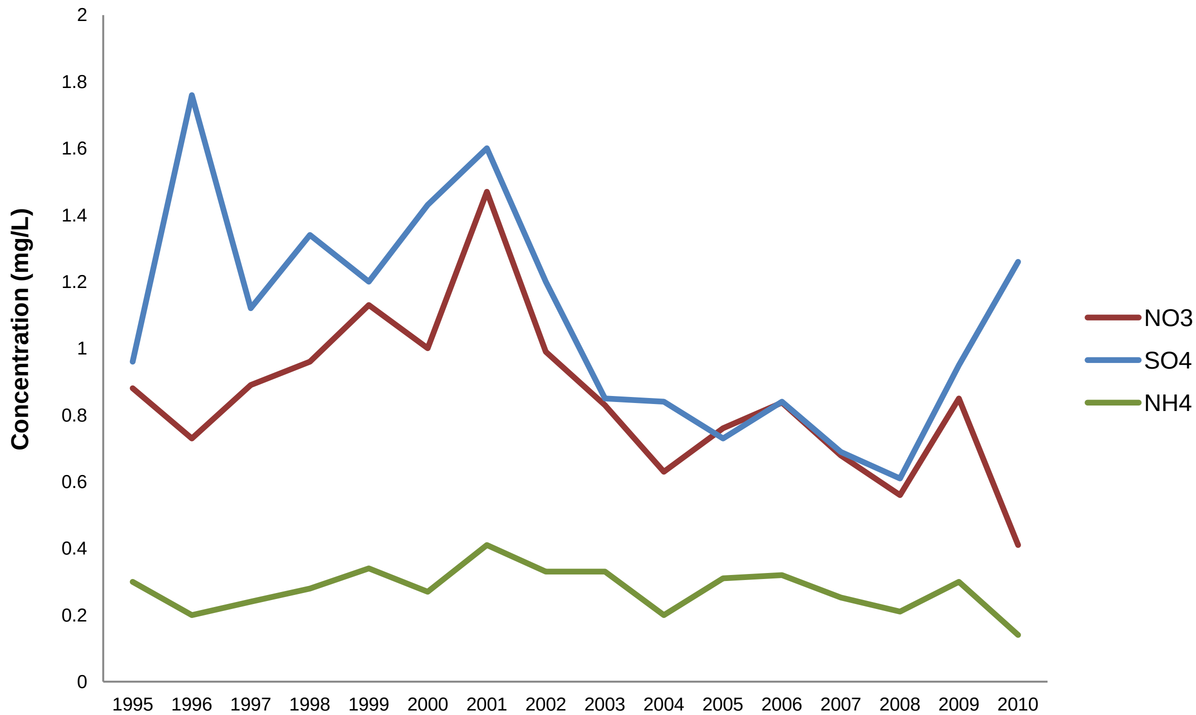


**Figure 18.** Annual average concentrations of sulfate ($SO_4$), nitrate ($NO_3$), and ammonium ($NH_4$) (mg/L) in GUMO, 1995-2010 (NADP monitoring site TX22) (Source: NADP 2012). Note: Ammonium ($NH_4$) is included because it adds significantly to total nitrogen deposition.

Sullivan et al. (2011a, 2011c) ranked GUMO as having low acidifying (nitrogen and sulfur) pollutant exposure, high sensitivity to acidification in its arid and semi-arid ecosystems, and very high park protection due to its Class I airshed status. The overall ranking of risk from acidification due to acid deposition was deemed high relative to other parks (Sullivan et al. 2011a, 2011c). In a separate examination, Sullivan et al. (2011b, 2011d) used the same approach to assess the sensitivity of national parks to nutrient enrichment effects from atmospheric nitrogen deposition relative to other parks. Relative risk was assessed by examining exposure to nitrogen deposition, inherent sensitivity of park ecosystems, and mandates for park protection. GUMO was ranked as having low risk for nitrogen pollutant exposure, very high ecosystem sensitivity of arid and semi-arid systems, and very high park protection mandates (Class I air shed). The relative ranking of overall risk of effects from nutrient enrichment due to atmospheric nitrogen deposition was very high relative to other parks (Sullivan et al. 2011b, 2011d).

Ozone

The NAAQS standard for ground-level ozone is the benchmark for rating current ozone conditions within park units. In 2008, the standard was strengthened from 80 ppb to 75 ppb, based on the annual $4^{th}$ highest daily maximum 8-hour concentration, averaged over 3 years. The condition of ozone in NPS park units is determined by calculating the 5-year average of the fourth-highest daily maximum of 8-hour average ozone concentrations measured at each monitor within an area over each year (NPS 2010a). The current 5-year average (from 2006-2010) for GUMO indicates an average ground-level ozone concentration of 70.0 ppb (NPS 2012), which falls under the *Moderate Concern* category based on NPS guidelines. Figure 19 illustrates the average annual ozone concentrations (in ppm) with respect to the national standard for the ozone monitor nearest GUMO, located in Carlsbad, New Mexico approximately 80 km (50 mi) northeast of the park. Ozone data from Carlsbad may not accurately represent conditions at GUMO, but the data provide information on regional ozone trends since rural concentrations are broadly consistent in the Southwest. Monitoring at Carlsbad began in 1998, with data available through 2010. Monitoring suggests ozone levels have remained consistent at levels around the national standard.

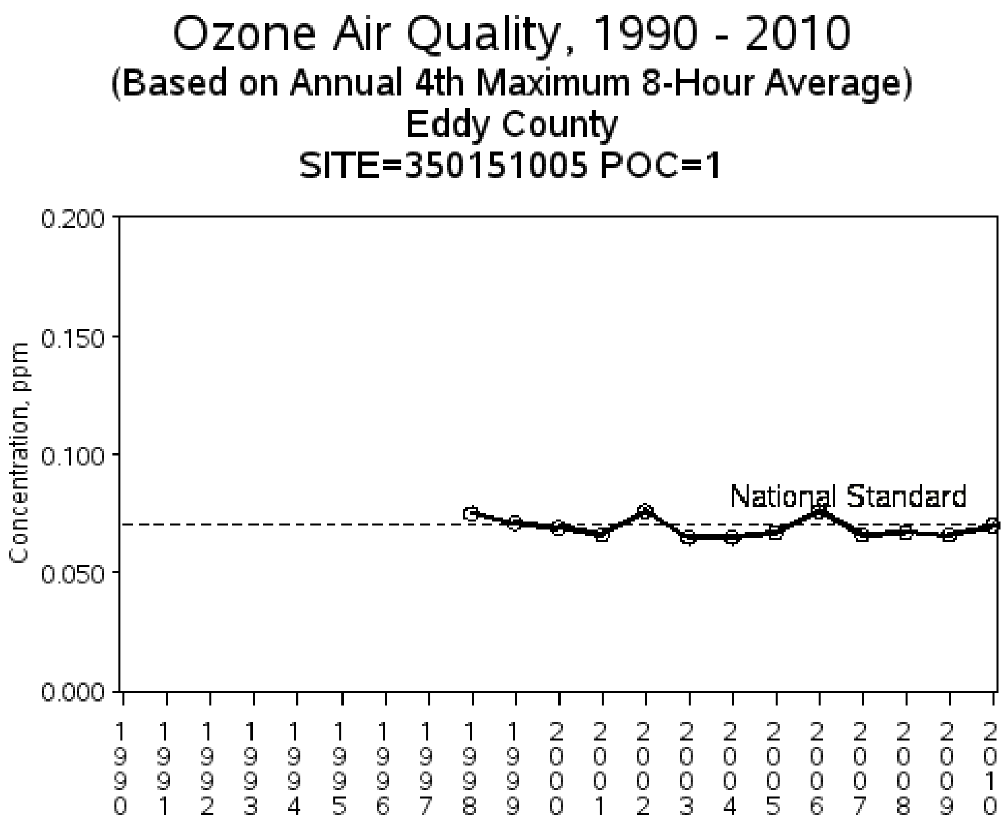


**Figure 19.** Average annual ozone ($O_3$) concentration (ppm) for the GUMO region, 1998-2010 (EPA 2012), compared to the national standard of 75 ppb that became effective in 2008. Note: Site 350151005 is the monitor located in Carlsbad, New Mexico, approximately 80 km (50 miles) northeast of GUMO.

Kohut (2004) assessed ozone concentrations in the CHDN and the risk of injury to plant species that are sensitive to sustained ozone exposure. Data from 1995-1999 indicate ozone concentrations in GUMO during this time frequently exceeded 60 ppb for a few hours each year and occasionally exceeded 80 ppb (Kohut 2004). For instance, ozone concentrations exceeded 80 ppb for 44 hours in 1995, 43 hours in 1996, 30 hours in 1997, 31 hours in 1998, and 21 hours in 1999 (Kohut 2004). No year during observation experienced more than nine hours in which concentrations exceeded 100 ppb; however, at these levels, it is possible for vegetation to sustain injury. Sensitive plant species begin to experience foliar injury when exposed to ozone concentrations of 80-120 ppb/hour for extended periods of time (8 hours or more) (Kohut 2004). Overall, the frequently dry soil conditions in GUMO and the low levels of ozone exposure make the risk of foliar injury to plants low (Kohut 2004). However, if ozone concentrations should increase in the future, an on-site monitoring program that assesses foliar injury and growth progress may be appropriate (Kohut 2004). Also, although dry conditions induce plants to close their stomates to limit water loss (which also limits ozone uptake), in areas with sufficient moisture (near springs, seeps, and streams, plants may experience more gas exchange with subsequent ozone uptake and injury (Kohut et al. 2012).

Various species of plants and trees are often monitored to track air pollution impacts. GUMO has several species known to be sensitive to excessive or extended concentrations of ozone: black cherry (*Prunus serotina),* chokecherry (*Prunus virginiana*, Photo 25), Gooding's willow (*Salix gooddingii*), ponderosa pine, quaking aspen, skunkbush, and white sage (*Artemisia ludoviciana*) (Kohut 2004, NPS 2006). Managers can decide which species would be most helpful in monitoring for foliar damage due to ozone exposure in the park.

**Photo 25.** Chokecherry (*Prunus virginiana*) is sensitive to elevated ozone concentrations (NPS photo).

Particulate Matter ($PM_{2.5}$)

Data on average particulate matter concentrations in GUMO are available from 1991 through 2010, and are summarized as an annual average concentration and average concentrations on the 20% haziest and 20% clearest days in the park (IMPROVE 2011). Overall, average annual $PM_{2.5}$ concentrations in GUMO have been decreasing since 2003 (Figure 20). $PM_{2.5}$ is the main cause of haze; as concentrations of fine particulate matter increase, haze also increases. The NAAQS human health-based standard for $PM_{2.5}$ is a weighted annual mean of 15.0 µg/m$^3$ or 35 µg/m$^3$ in a 24-hour period over an average of 3 years (EPA 2010b). Although $PM_{2.5}$ concentrations in GUMO are well within the EPA standards for levels that are protective of human health, concentrations on the haziest days contribute significantly to impaired visibility in the park.

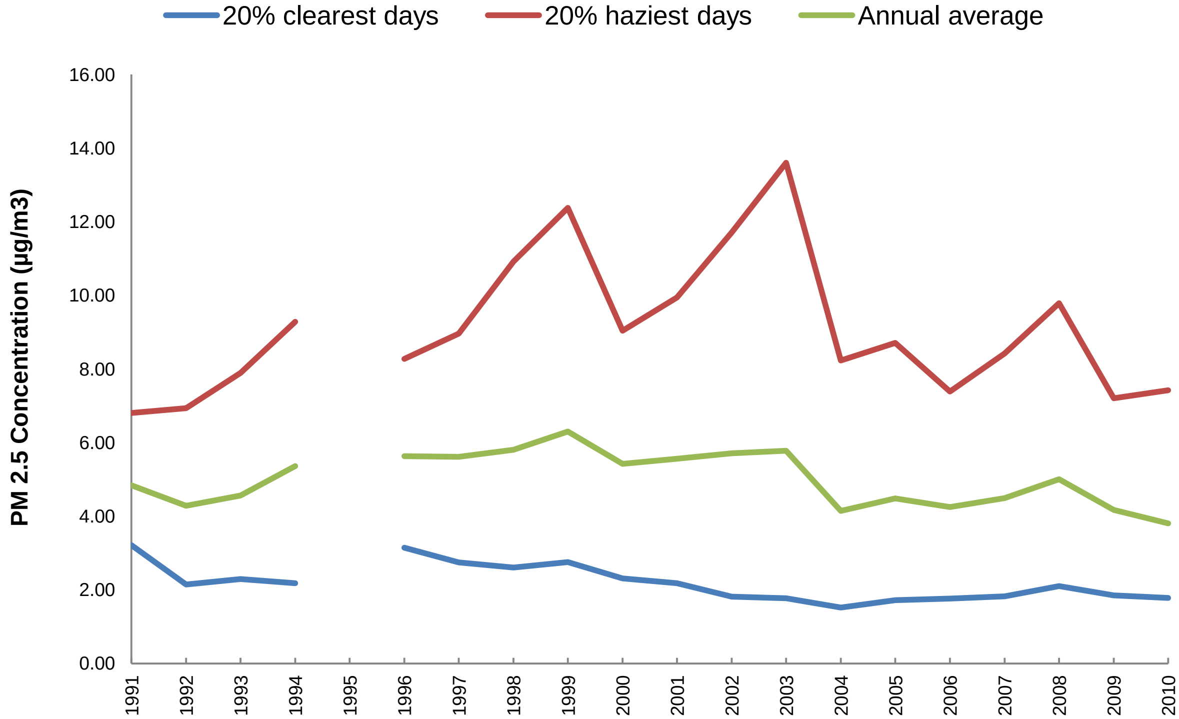


**Figure 20**. Particulate matter ($PM_{2.5}$) concentration in GUMO, 1991-2010 (Source: IMPROVE 2011).

Sullivan (2008) analyzed samples of particulate matter collected in GUMO from May through October 2006 in an effort to characterize particle mass composition and sources of haze in the region. Average $PM_{2.5}$ concentrations were the second lowest (5.51 µg/m$^3$) among monitoring sites in the region for the May-October 2006 data collection time period. Concentrations were found to be higher east of GUMO and in the urbanized region to the west of the park (El Paso, Texas and Ciudad Juarez, Mexico). Overall, much of the particulate matter is composed of ammonium sulfate ($(NH_4)_2SO_4$), with some organic carbon contributing to mass. The highest concentrations of PM recorded during the sample period were 10.4 µg/m$^3$ and 9.2 µg/m$^3$, occurring August 31 and September 1, 2006, respectively; these events significantly reduced visibility in GUMO. Sample composition for these dates revealed that windblown soil was a major component of particulate matter, most of which originated in the arid regions of North Africa. Sullivan (2008) concludes that sulfate transport and soil are significant components of $PM_{2.5}$ that affect air quality in GUMO. Local wind-blown surface materials containing salt were also detected. However, this is a short-term study and may not be representative of more typical conditions and sources of particulate in and around the park. Particulate data from 2004-2010 indicate that sulfate if the main component of haze; coarse particles (dust, soil) also contribute significantly to haze. The contribution of salt is generally negligible (VIEWS 2012).

Lee et al. (2009) examined the various sources of dust that contributed to a single dust storm event affecting parts of the Southern High Plains and Chihuahuan Desert region (which includes GUMO) in December 2003. They found that playa and rangeland account for the main sources of dust in the Chihuahuan Desert region, which includes GUMO. Primary dust sources in landcover designated as playa include dried saline lakebeds and basins (including Salt Flat Basin and parts of the White Sands complex), clay/silt lakebeds, and some sand sheets or coppice dunes. Sources in landcover designated as rangeland include creosote bush/mesquite desert scrub and coppice dunes. Perez and Gill (2009) examined the characteristics of the dust emitted from the Salt Flat Basin (approximately 20 km west of GUMO) and evaluated the significance of the basin as a major contributor to aerosol dust affecting the park. Data revealed that dust flux in the basin is highly variable depending on the season and location in the basin. Dust emitted from the basin consists of fine silt and clay-sized particles that may travel more than 100 km during the spring season when winds are high. Researchers concluded that, although producing dust that affects the region, the Salt Flat Basin did not appear to be a major contributor of aerosols in GUMO, as measured at the IMPROVE monitoring site in the park.

Visibility

Visibility impairment occurs when airborne particles and gases scatter and absorb light; the net effect is called “light extinction,” which is a reduction in the amount of light from a view that is returned to an observer (EPA 2003). In response to the mandates of the CAA of 1977, federal and regional organizations established IMPROVE in 1985 to aid in monitoring of visibility conditions in Class I airsheds. The goals of the program are to 1) establish current visibility conditions in Class I airsheds; 2) identify pollutants and emission sources causing the existing visibility problems; and 3) document long-term trends in visibility (NPS 2010c).

The most current 5-year average (2006-2010) estimates average visibility in GUMO to be 6.3 dv above average natural visibility conditions (NPS 2012). This falls into the *Moderate Concern* category for NPS air quality condition assessment.

The clearest and haziest 20% of days each year also are examined for parks (NPS 2011), as these are the measures used by States and the EPA to assess progress towards meeting the national visibility goal. Conditions measured near 0 dv are clear and provide excellent visibility, and as dv measurements increase, visibility conditions become hazier. The most current 5-year average (2006-2010) estimates visibility at 5.0 dv on the 20% clearest days and 14.8 dv on the 20% haziest days (NPS 2011). Figure 21 shows average visibility data (in dv) collected for the 20% best (clearest) and 20% worst (haziest) days in GUMO from 1999 to 2008, as well as the default natural conditions for both (VIEWS 2012). Trend analysis of data from 1999-2008 indicate that visibility has improved significantly on the clearest days but has neither improved nor degraded on the haziest days (NPS 2010c). Photo 26 provides examples of visibility conditions during the least hazy and haziest days.

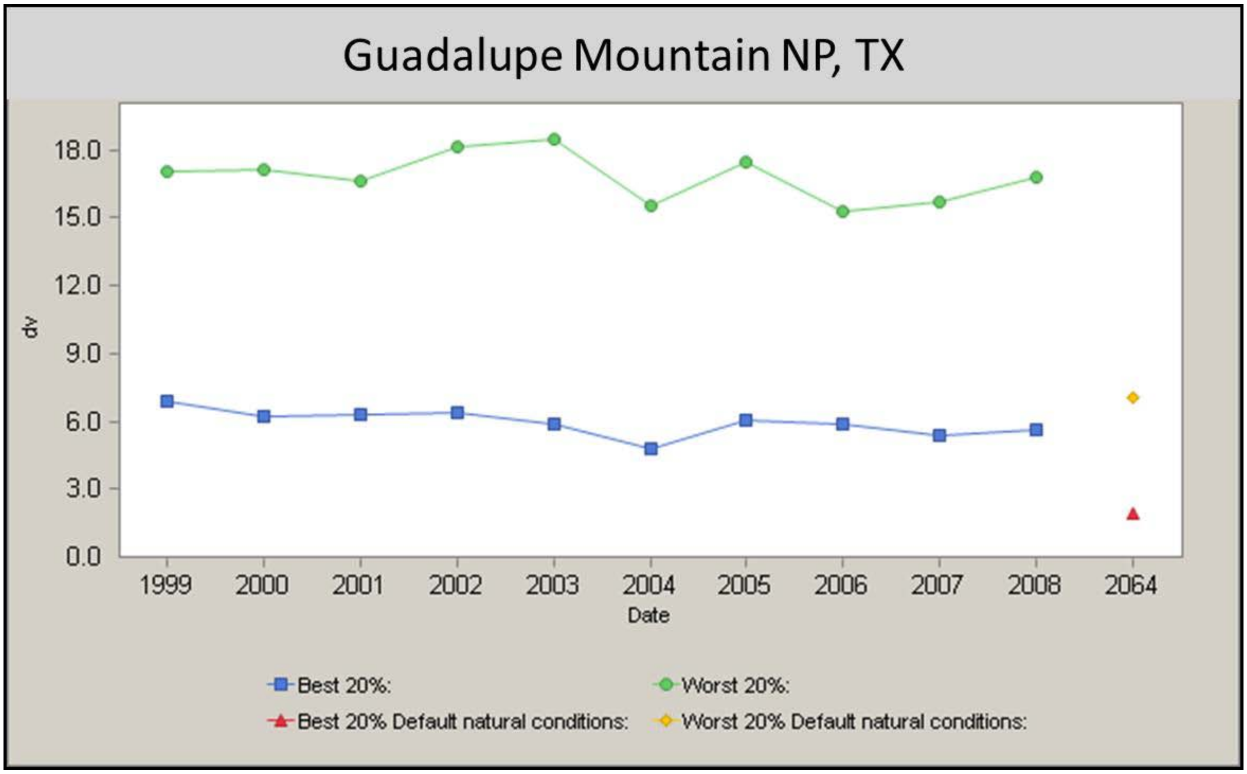


**Figure 21.** Annual visibility in GUMO, 1999-2008, on best (clearest) and worst (haziest) days (VIEWS 2012). Red and yellow symbols represent estimated natural background visibility conditions for best and worst visibility days, respectively, at GUMO. States are required by the Regional Haze Rule to achieve natural visibility conditions in all Class I areas by 2064.


**Photo 26.** (left to right) Views of Sierra Prieta from GUMO during “excellent” (dv 5) and “poor” (dv 17) visibility (Source: IMPROVE 2011).

Threats and Stressor Factors

Park managers have identified a number of threats and stressors to air quality in GUMO, including increased oil and gas development in the region; smog and pollution from urbanized areas including industrial and vehicle emissions; and windblown soils and dust from unpaved roads, dried basins and lakebeds, and fallow agricultural fields. NPS (2005) identifies power-generating plants, natural gas compressor stations, flaring at natural gas wells, vehicle traffic in and around the park, and emissions from nearby cities in Texas and New Mexico as threats to the park's air quality. Periodic dust storms also occur in the western Texas region, which can temporarily impair visibility in the park. Park managers expressed concern about the potential emissions from the proposed desalination plant and the potential for increased particulate matter (salts) carried from the plant's drying pond (Hearst, personal interview, 24 January 2012).

EA Engineering, Science, and Technology, Inc. (2003) identified a number of stationary point, area, and mobile sources of in-park emissions that likely affect air quality in the park. Wildfires, prescribed burning, and emissions from vehicle traffic are identified as the most significant sources of emissions in the park (Table 36). A variety of emission sources exist in the GUMO region (surrounding Texas counties) and emissions may affect air quality in the park depending on wind patterns. Of emissions sources located outside GUMO, area sources are the most significant for $PM_{10}$ emissions, while mobile sources, likely vehicle exhaust, are the most significant for nitrogen oxide emissions (Table 37). In general, emissions in the park are minimal compared to emissions in the surrounding counties or the state overall.

**Table 36**. Estimated annual emissions from various sources in GUMO (from EA Engineering, Science, and Technology, Inc. 2003).

| Emissions source | $PM_{10}$ (tons/yr) | Sulfur dioxide (tons/yr) | Nitrogen oxides (tons/yr) | Carbon monoxide (tons/yr) | VOCs (tons/yr) |
|---|---|---|---|---|---|
| **Point sources** | | | | | |
| Heating equipment | <0.01 | <0.01 | 0.08 | 0.01 | <0.01 |
| Generators | <0.01 | <0.01 | 0.01 | 0.27 | 0.01 |
| Gasoline storage tanks | -- | -- | -- | -- | 0.66 |
| Subtotal | <0.01 | <0.01 | 0.09 | 0.29 | 0.68 |
| **Area sources** | | | | | |
| Wildland fires | 18.8 | -- | -- | 91.60 | 6.40* |
| Prescribed burning | 1.59 | -- | -- | 7.76 | 0.54* |
| Subtotal | 20.39 | -- | -- | 99.36 | 6.94* |
| **Mobile sources** | | | | | |
| Road vehicles | 6.37 | | 1.28 | 6.35 | 0.35 |
| Nonroad vehicles** | 0.10 | -- | 0.65 | 0.31 | 0.12 |
| Subtotal | 6.47 | -- | 1.94 | 6.66 | 0.47 |
| **Totals** | 26.86 | <0.01 | 2.03 | 14.71 | 1.69 |

*as methane
** including graders, backhoes, sweepers, mowers, tractors, etc.

**Table 37.** Estimated annual emissions from counties in Texas surrounding GUMO (from EA Engineering, Science, and Technology, Inc. 2003).

| Geographic area | $PM_{10}$ (tons/yr) | Sulfur dioxide (tons/yr) | Nitrogen oxides (tons/yr) | Carbon monoxide (tons/yr) | VOCs (tons/yr) |
|---|---|---|---|---|---|
| **Point sources** | | | | | |
| Culberson County | 67 | 5 | 654 | 73 | 7 |
| Hudspeth County | 21 | <1 | 219 | 13 | 2 |
| Surrounding county totals | 88 | 5 | 873 | 86 | 9 |
| **Area sources** | | | | | |
| Culberson County | 914 | 3 | 4 | 9 | 145 |
| Hudspeth County | 2,385 | 4 | 6 | 54 | 140 |
| Surrounding county totals | 3,299 | 7 | 10 | 63 | 285 |
| **Mobile sources** | | | | | |
| Culberson County | 57 | 55 | 1,682 | 5,063 | 567 |
| Hudspeth County | 100 | 102 | 2,897 | 8,519 | 969 |
| Surrounding county totals | 157 | 157 | 4,579 | 13,582 | 1,536 |
| **Totals** | 3,544 | 169 | 5,462 | 13,731 | 1,830 |

Data Needs/Gaps

In an effort to quantify harmful pollution levels and set goals for resource protection on federal lands, natural resources managers are increasingly using a "critical loads" approach for tracking and monitoring a variety of pollutants, in particular nitrogen and sulfur compounds (Porter et al. 2005). Critical loads are defined as "the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt 1988, as cited in Porter et al. 2005, p. 603). Essentially, critical loads describe the amount of pollution that stimulates negative impacts or harmful changes to sensitive ecosystems (Jefferies and Maron 1997, Porter et al. 2005). Porter et al. (2005) developed an approach for determining critical loads for nitrogen and sulfur on federal lands using two national parks as case studies, and research is underway in other park units to aid in communicating resource condition. The methodology can be tailored to most NPS lands, depending on available baseline information. Since some plant communities in GUMO are likely sensitive to increases in nitrogen, park managers may be able to develop and implement a critical load approach for managing air pollutants and to set goals for resource protection within the park.

To date, there is no consistent monitoring effort in GUMO that tracks the plant and animal species known to be sensitive to increases in certain pollutants. However, some of the long-term monitoring data currently being collected by the I&M Program may provide insights on plant health (for instance, increased growth of cheatgrass or other annual grasses may indicate increased nitrogen deposition). Nitrogen and sulfur deposition can affect plant communities (e.g., promoting invasive species, loss of biodiversity, or encouraging transition/succession of plant communities), while ozone can cause foliar injury and inhibit growth. Despite having a low risk of exposure to nitrogen and sulfur deposition, Sullivan et al. (2011a, 2011b) indicate that the highly sensitive arid and semi-arid vegetation communities and soils in GUMO are at high risk of acidification due to acid deposition (relative to other parks), and at very high risk of various effects from increased nitrogen enrichment (relative to other parks) if pollutant exposure increases in the future. Monitoring of plant communities in conjunction with monitoring of nitrogen deposition and soil nitrogen levels can be used to evaluate impacts from increased nitrogen levels.

If ozone levels increased, several plant and tree species in the park could be used to evaluate injury from ozone, including such species as chokecherry, black cherry, ponderosa pine, and quaking aspen (NPS 2006). Although at the edge of their range, such species could be used as bioindicators to track potential increases in ozone, as well as long-term impacts to the health of the ecosystem. Likewise, ozone injury is more likely to occur in areas with more moisture, so efforts to monitor for evidence of ozone injury could focus on those areas (Ellen Porter, Biologist, NPS ARD, written communication, 8 November 2012).

Overall Condition

*Nitrogen Deposition*

The *Significance Level* for atmospheric deposition of nitrogen was defined as a 3. Sullivan et al. (2011b, 2011d) and NPS (2010a) rate the arid and semi-arid ecosystems in GUMO as highly sensitive to nutrient enrichment by nitrogen deposition, despite an estimate that the park is at low risk of exposure to nitrogen deposition. Nitrogen deposition has decreased in recent years. Current measurements are still considered of moderate to significant concern based on NPS criteria for rating air quality when factoring in the sensitivity of the ecosystem. However, NPS (2010b) trend analysis from 1999-2008 indicates significant improvement in both nitrate and ammonium concentrations in precipitation. Therefore, deposition of nitrogen is of moderate concern (*Condition Level* = 2).

*Sulfate Deposition*

The *Significance Level* for atmospheric deposition of sulfate was defined as a 3. Sullivan et al. (2011a, 2011c) and NPS (2010a) also rate the arid and semi-arid ecosystems in GUMO as highly sensitive to acidification by sulfur deposition and other acids, despite an estimate of very low risk of pollutant exposure. NPS (2010b) trend analysis from 1999-2008 indicates significant decrease in sulfate concentrations in precipitation during that period. However, NADP data suggest sulfate concentrations have increased since 2008. Current measurements still fall into the moderate to significant concern category based on NPS criteria for rating air quality when factoring in sensitivity of the ecosystem. Therefore, deposition of sulfur is of moderate concern (*Condition Level* = 2).

*Ozone Concentration*

The *Significance Level* for ozone concentration was defined as a 2. Current average ground-level ozone concentrations fall into the moderate concern category based on NPS criteria for rating air quality. Annual average concentrations (1998 through 2010) have remained relatively unchanged over time. Kohut (2004) suggests concentrations rarely exceed 80 ppb each year and that dry soil conditions and overall low ozone exposure make risk of foliar injury to plants low. Therefore, the *Condition Level* for ozone concentration is a 1, of low concern.

*Particulate Matter Concentration ($PM_{2.5}$)*
The *Significance Level* for concentration of fine particulate matter ($PM_{2.5}$) was defined as a 3. $PM_{2.5}$ concentrations in GUMO are well within the EPA standards for levels that are protective of human health. Trends in average concentrations show a slight decline (meaning increased visibility) over the last decade; however, concentrations on the haziest days contribute significantly to impaired visibility in the park. The *Condition Level* for $PM_{2.5}$ is a 1, of low concern.

*Visibility*
The *Significance Level* for visibility was defined as a 3. Current average visibility falls into the moderate concern category based on NPS criteria. Trend analysis of data from 1999-2008 indicate visibility to be of moderate concern with statistically significant improvement in visibility conditions on the clearest days and no improvement or degradation on the haziest days (NPS 2010c). Averages for both are well above the specified default natural conditions, which are the target for visibility conditions in the park. The *Condition Level* for visibility is a 2, of moderate concern.

*Weighted Condition Score*
The *Weighted Condition Score* for the air quality component is 0.533, indicating the condition is of moderate concern with a stable trend.


***Sources of Expertise***
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Mike George, Air Resource Field Specialist, NPS Intermountain Region

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## 4.11 Water Quality

### *Description*

In 2007, the Texas State Legislature designated two of GUMO's creeks (McKittrick and Choza) as "ecologically unique river and stream segments" because they are known to have excellent water quality (Porter et al. 2009). Water quality is a Vital Sign for parks in the CHDN, including GUMO. Total dissolved solids, chloride, sulfate, dissolved oxygen, coliform bacteria, aquatic macroinvertebrates, and stream and spring flow rates are core water quality measures identified by the park.

McKittrick Creek runs through McKittrick Canyon in GUMO (Photo 27). Most of the park's surface water is contained in McKittrick Creek; however, there are numerous springs that also comprise the surface waters in GUMO. McKittrick Creek and several springs support numerous aquatic species; they also support a number of terrestrial animals within the arid ecosystem typical of the Chihuahuan Desert. Changes in surface-water dynamics (including degradation of water quality) can cause the loss of pollution-intolerant species, shift biodiversity, and alter animal and plant species distribution. With many species and vegetation communities dependent upon surface water, GUMO managers are concerned about degradation of water quality (NPS 2010).

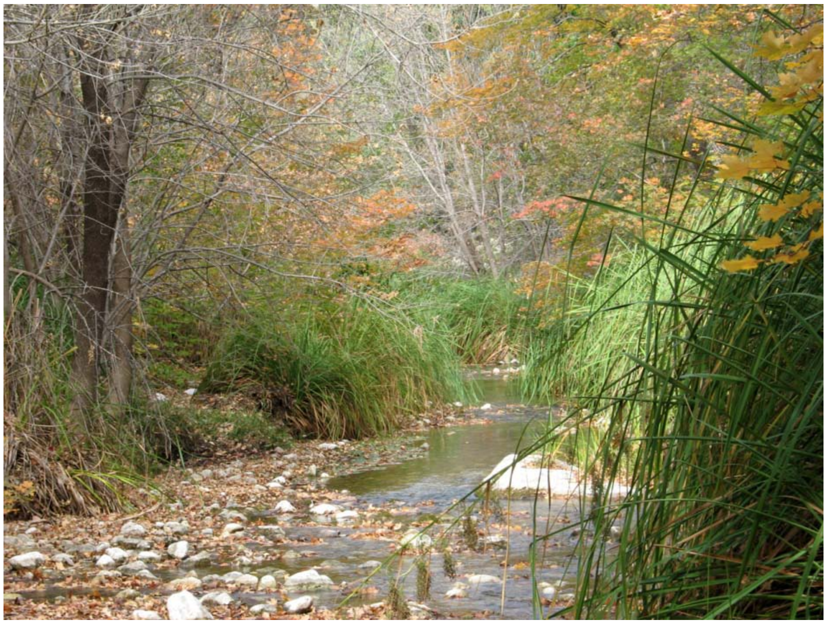


**Photo 27.** McKittrick Canyon stream in GUMO (NPS photo).

### *Measures*

- Total dissolved solids
- Chloride
- Sulfate
- Dissolved oxygen
- Coliform bacteria
- Aquatic macroinvertebrates
- Stream and spring flow rates

Total Dissolved Solids

Total dissolved solids (TDS) represent the concentration of dissolved inorganic and organic matter in the water. Most TDS are inorganic salts such as calcium, magnesium, carbonates, nitrates, chlorides, and sulfates (SDWF 2012). Sources of TDS often include mineral springs and agricultural or urban runoff. The concentration of TDS affects the water balance in the cells of aquatic organisms (EPA 2012a); if the TDS are extremely low, an organism's cells will swell, and if the TDS are too high, an organism's cells will shrink. The TDS determines the ease of an organism's ability to remain in the water column (EPA 2012a).

Chloride

Chloride is an inorganic salt that can be washed into surface waters from several sources, including road salting, agricultural runoff, and oil and gas wells (McDaniel 2012). Large amounts of chloride in surface water are toxic to aquatic life such as fish and macroinvertebrates. Chloride becomes more toxic when combined with potassium or magnesium (NHDES 2008). Toxic metals can also be released when chloride is present in water. Dissolved oxygen levels, a core water quality measurement, are reduced when these metals are released, causing added stress to the aquatic life in the area (NHDES 2008).

Sulfate

Sulfate, like chloride, is an inorganic salt that can be found naturally in water. Elevated levels of sulfate can prove toxic to aquatic life (Lenntech 2011). Some aquatic species are more sensitive to sulfate than others, such as intolerant macroinvertebrates. Possible sources of excess sulfate include sulfate ores and industrial wastes (Lenntech 2011).

Dissolved Oxygen

Dissolved oxygen (DO) is critical for organisms that live in water. Fish and zooplankton filter out or "breathe" dissolved oxygen from the water to survive (USGS 2010). Oxygen enters water from the atmosphere or through ground water discharge. As the amount of DO drops, it becomes more difficult for water-based organisms to survive (USGS 2010). The concentration of DO in a water body is closely related to water temperature; cold water holds more DO than does warm water (USGS 2010). Thus, DO concentrations are subject to seasonal fluctuations as low temperatures in the winter and spring allow water to hold more oxygen, and warmer temperatures in the summer and fall cause water to hold less oxygen (USGS 2010).

Coliform Bacteria

Coliform bacteria are an accurate indicator of fecal contamination in water by warm-blooded animals. It is tested by counting colonies that grow on micron filters placed in an incubator for 22-24 hours. High numbers of fecal coliform can indicate the presence of harmful bacteria as well as other disease-causing organisms such as viruses and protozoans (USGS 2011).

Aquatic Macroinvertebrates

Macroinvertebrates are organisms that can be seen by the naked eye. Mussels, snails, worms, and larval insects are some types of macroinvertebrates (EPA 2012b). They inhabit a variety of streams and rivers (e.g., slow and fast moving, clear, muddy), but species diversity is usually higher in clean and unpolluted waters (EPA 2011). Macroinvertebrates are generally considered good indicators of stream quality because they are affected by physical, chemical, and biological stream conditions. Some macroinvertebrates are more sensitive to water quality than others and are considered intolerant species, such as stonefly larvae. Stoneflies (Order Plecoptera) may be absent in a stream due to low DO levels, elevated temperatures, or agricultural and urban runoff (EPA 2012b).

Stream and Spring Flow Rates

Stream and spring flow rates can be described as the amount or volume of water that flows through a section of stream over a length of time. Flow rates are important to water quality as well as aquatic and terrestrial organisms (EPA 2012c). Larger streams with faster flow rates can dilute pollutants and reduce their impact, but pollutants will be more concentrated in small streams with low flow rates and less water. The organisms living in a stream or spring are influenced by the stream's flow rate; some organisms need fast flowing waters while others require calm pools or springs (EPA 2012c).

### *Reference Conditions/Values*

The reference conditions for GUMO's water quality are the TCEQ water quality criteria for surface waters, which ensure the safety of waters for freshwater organisms and bathing, as well as drinking water standards. Table 38 displays water quality parameter standards set by the TCEQ. The park also seeks to maintain their two "ecologically unique river and stream segment" designations (Hearst, personal communication, 24 January 2012).

**Table 38.** TCEQ and EPA standards for surface-water quality (TCEQ 2010, EPA 2012d).

| Parameter | TCEQ standard | EPA standard |
|---|---|---|
| Total dissolved solids | ≤ 1,550 mg/L | N/A |
| Chloride | ≤ 300 mg/L | ≤250 mg/L* (≤860 for fresh water) |
| Sulfate | ≤ 570 mg/L | ≤250 mg/L* |
| Dissolved oxygen | > 5.0 mg/L | ≥4.0 mg/L |
| Coliform bacteria | ≤126 CFU/100 mL | ≤200 CFU/100 mL |
| Macroinvertebrates | N/A | N/A |

* standard for drinking water

### *Data and Methods*

In 1997, the NPS published results of surface-water quality data retrievals for GUMO using six of the EPA national databases: Storage and Retrieval (STORET) water quality database management system, River Reach File (RF3), Industrial Facilities Discharge (IFD), Drinking Water Supplies (DRINKS), Flow Gages (GAGES), and Water Impoundments (DAMS) (NPS 1997). The retrieval resulted in 7,540 observations for various parameters at 33 monitoring stations operated by the NPS and EPA from 1959 to 1997. There were a number of stations (14) found within the park that yielded long-term records (Plate 23). Five of these stations (GUMO0009, GUMO0015, GUMO0003, GUMO0012, and GUMO0006) yielded the longest-term records. The stations were assigned these IDs specifically for the 1997 inventory, but are recognized by different station IDs by EPA and NPS personnel who also collect samples (as discussed in further detail below).

Walsh (2007, 2008) performed a macroinvertebrate survey in three GUMO springs (Choza, Manzanita, and Upper Pine) in 2007 and 2008. The data collected included TDS levels. The TDS levels were originally written in grams per liter, but were converted to milligrams per liter for this document.

Walsh (2009) conducted a macroinvertebrate survey in Guadalupe Canyon Spring in June of 2009. The data include water quality measurements from three seeps within the spring complex. The TDS levels, originally written in grams per liter, were converted to milligrams per liter for this document.

The EPA (2012e) STORET database was accessed to collect data for the stations located in GUMO, between 1990 and 1997. There were four stations on McKittrick Creek (Mk 2, Mk 4, Mk 6, Mk 8) and one at Choza Spring. STORET contained data on chloride, sulfate, and DO. Sulfur records were included with sulfate records. These five stations correspond to five of the NPS (1997) stations (GUMO0003, GUMO0006, GUMO0009, GUMO0012, and GUMO0015). The stations may have overlapping years; however, the STORET data display what chloride levels have averaged in most recent years. Table 39 displays how the NPS (1997) stations match up to the station IDs used in the EPA (2012e) database and in recent NPS sampling efforts.

**Table 39.** Water quality monitoring and sampling location IDs as they correspond to one another across NPS 1997 inventory, the EPA database, and NPS sampling (see Plate 23 for station locations).

| NPS 1997 Station ID | EPA 2012 Station ID* |
|---|---|
| GUMO003 | Mk 8 |
| GUMO006 | Mk 6 |
| GUMO009 | Choza Spring |
| GUMO0012 | Mk 2 |
| GUMO0015 | Mk 4 |

*station IDs used in recent NPS monitoring/sampling

NPS (2011) collected data from stations located in GUMO, between 2009 and 2011. There were four stations on McKittrick Creek (Mk 2, Mk 4, Mk 6, Mk 8) and one at Choza Spring. The dataset contained records for several water quality measurements, including DO, chloride, and sulfate. Several observations were recorded for each measure at all five locations; however, it must be noted that the data were collected on one day each month They are, therefore, not considered continuous and do not capture the fluctuations that may occur throughout each month as a result of numerous environmental and seasonal factors. These data are summarized and presented but are not used to determine trends in water quality condition over time.

### *Current Condition and Trend*

<u>Total Dissolved Solids</u>

According to TCEQ water quality standards, the acceptable TDS level for aquatic life is less than or equal to 1,550 mg/L (TCEQ 2010). Currently, there are limited data regarding TDS in GUMO. Water quality monitoring in GUMO is expected to include sampling for total dissolved solids in the near future (Hearst, written communication, 3 December 2012).

Walsh (2007, 2008) collected eight total measurements; one measurement was taken per spring for each year. The lowest TDS level was 292 mg/L at Choza Spring in 2008, and the highest TDS level was 337 mg/L at Manzanita Spring in 2007. All measurements were below the TCEQ standard. Table 40 displays the TDS measurements for all springs sampled.

**Table 40.** TDS measurements from three springs in GUMO including minimum, maximum, and mean values (mg/L), 2007-2008 (Walsh 2007, 2008).

| Spring Name | Number of Observations | Minimum | Maximum | Mean |
|---|---|---|---|---|
| Choza Spring | 1 | 292 | 292 | 292 |
| Manzanita Spring | 3 | 303 | 337 | 315.6 |
| Upper Pine Spring (pool 1) | 2 | 322 | 325 | 323.5 |
| Upper Pine Spring (pool 2) | 2 | 295 | 303 | 299 |

According to Walsh (2009), the three seeps in Guadalupe Canyon Spring showed no exceedences of TDS. TDS at seeps 1, 2, and 3 were 315 mg/L, 200 mg/L, and 270 mg/L respectively; these levels were well below the TCEQ limits. Additional samples are needed to determine trends in TDS levels.

Chloride

TCEQ standards state that the acceptable chloride level for aquatic life is less than or equal to 300 mg/L (TCEQ 2010). This is more restrictive than the EPA standard of 860 mg/L for freshwater aquatic life, which was the standard used in determining water quality exceedences in the NPS (1997) baseline water quality study for GUMO (NPS 1997).

NPS (1997) reviewed a total of 721 chloride observations among monitoring stations within the park. None of the observations from the 14 stations exceeded the TCEQ limit of 300 mg/L; all values were well below this standard. The maximum chloride value between 1975 and 1997 was 30 mg/L, observed at station GUMO0009. Table 41 displays the chloride values from each station.

**Table 41.** Chloride records from 14 water quality stations in GUMO including minimum, maximum, median, and mean values (mg/L) (NPS 1997).

| Station | Time Period | Observations | Minimum | Maximum | Median | Mean |
|---|---|---|---|---|---|---|
| 0003 | 1979-1997 | 119 | 0 | 8 | 1 | 1.4 |
| 0005 | 1979-1987 | 12 | 2 | 6 | 3.5 | 3.8 |
| 0006 | 1979-1997 | 118 | 0 | 22 | 1 | 1.7 |
| 0009 | 1975-1997 | 123 | 0 | 30 | 1 | 2.2 |
| 0010 | 1979-1987 | 12 | 2 | 25 | 3.5 | 5.8 |
| 0011 | 1979-1987 | 12 | 1 | 9 | 3 | 3.8 |
| 0012 | 1979-1997 | 119 | 0 | 16 | 0.5 | 1.5 |
| 0015 | 1979-1997 | 119 | 0 | 20 | 0.5 | 1.6 |
| 0016 | 1979-1987 | 12 | 3 | 13 | 4 | 5.3 |
| 0020 | 1975-1987 | 17 | 2 | 15 | 5 | 5.3 |
| 0022 | 1975-1987 | 17 | 2 | 10 | 5 | 5.5 |
| 0024 | 1975-1987 | 17 | 1 | 10 | 3 | 4.5 |
| 0028 | 1975-1987 | 15 | 2 | 10 | 5 | 4.9 |
| 0032 | 1975-1979 | 9 | 3 | 15 | 8 | 8.1 |

The EPA (2012e) STORET database had a total of 389 chloride observations among five stations. None of the chloride observations from the five stations exceeded the TCEQ standard. Table 42 displays the chloride values at these stations between 1990 and 1997.

**Table 42.** Chloride values from five monitoring stations in GUMO including minimum, maximum, and mean values (mg/L), 1990-1997 (EPA 2012e).

| Monitoring Station | Number of Observations | Minimum | Maximum | Mean |
|---|---|---|---|---|
| Mk 2 | 78 | 0 | 5 | 0.62 |
| Mk 4 | 78 | 0 | 8 | 0.81 |
| Mk 6 | 78 | 0 | 6 | 0.87 |
| Mk 8 | 78 | 0 | 6 | 0.72 |
| Choza Spring | 77 | 0 | 4 | 0.68 |

NPS (2011) recorded 225 chloride observations among the five stations in GUMO between 2009 and 2011. There were no exceedences at the five stations during this time. The chloride levels ranged from 0 mg/L to 2.3 mg/L collectively. Table 43 displays the mean and range of chloride values from each station.

**Table 43.** Chloride records from five monitoring stations in GUMO, including minimum, maximum, and mean values (mg/L), 2009-2011 (NPS 2011).

| Monitoring Station | Observations | Minimum | Maximum | Mean |
|---|---|---|---|---|
| Mk 2 | 45 | 0.1 | 2 | 0.63 |
| Mk 4 | 45 | 0.1 | 2.3 | 0.67 |
| Mk 6 | 45 | 0 | 2.2 | 0.65 |
| Mk 8 | 45 | 0 | 2.1 | 0.65 |
| Choza Spring | 45 | 0.1 | 1.7 | 0.62 |

Sulfate

According to the TCEQ, the upper sulfate limit considered acceptable for aquatic life is 570 mg/L (TCEQ 2010b). The EPA has established a sulfate standard of 400 mg/L for safe drinking water, which was used to determine sulfate exceedences during the NPS (1997) baseline water quality data inventory and analysis study.

NPS (1997) recorded a total of 746 sulfate observations from 14 stations. None of the observations from these stations exceeded the TCEQ sulfate standard of 570 mg/L or the EPA standard of 400 mg/L. The maximum sulfate value recorded was 230 mg/L, which occurred between 1975 and 1979, at station GUMO0009. Table 44 displays the sulfate values from each station.

**Table 44.** Sulfate records from 14 water quality stations in GUMO including minimum, maximum, median, and mean values (mg/L) (NPS 1997).

| Station | Time Period | Observations | Minimum | Maximum | Median | Mean |
|---|---|---|---|---|---|---|
| 0003 | 1979-1997 | 123 | 0 | 17 | 10 | 8.6 |
| 0005 | 1979-1987 | 13 | 6 | 12 | 10 | 9.8 |
| 0006 | 1979-1997 | 120 | 0 | 15 | 7 | 6.3 |
| 0009 | 1975-1997 | 122 | 0 | 36 | 12 | 10.4 |
| 0010 | 1979-1987 | 14 | 1 | 13 | 6 | 6.2 |
| 0011 | 1979-1987 | 14 | 7 | 18 | 14 | 12.6 |
| 0012 | 1979-1997 | 122 | 0 | 17 | 10 | 8.4 |
| 0015 | 1978-1997 | 125 | 0 | 19 | 7 | 6.6 |
| 0016 | 1979-1987 | 17 | 1 | 15 | 9 | 9.1 |
| 0020 | 1975-1987 | 18 | 3 | 26 | 13.5 | 13.0 |
| 0022 | 1975-1987 | 18 | 2 | 31 | 16.5 | 16.8 |
| 0024 | 1975-1987 | 18 | 1 | 31 | 5 | 7.6 |
| 0028 | 1975-1987 | 14 | 1 | 19 | 4.5 | 5.6 |
| 0032 | 1975-1979 | 8 | 6 | 230 | 146 | 142.6 |

The EPA (2012e) STORET database had a total of 387 observations among five stations. None of the observations exceeded the TCEQ or EPA standards for sulfate concentration. The maximum value observed was 29 mg/L, which occurred on 24 July 1993. Table 45 displays the sulfate values from these five stations between 1990 and 1997.

**Table 45.** Sulfate records from five monitoring stations in GUMO including minimum, maximum, and mean values (mg/L), 1990-1997 (EPA 2012e).

| Monitoring Station | Number of Observations | Minimum | Maximum | Mean |
|---|---|---|---|---|
| Mk 2 | 78 | 0 | 15 | 6.8 |
| Mk 4 | 78 | 0 | 14 | 5.1 |
| Mk 6 | 78 | 0 | 14 | 4.8 |
| Mk 8 | 77 | 0 | 16 | 7.2 |
| Choza Spring | 76 | 0 | 29 | 7.8 |

NPS (2011) recorded 230 sulfate observations among the five stations in GUMO. There were no exceedences among the five stations during the period of record (2009-2011). The sulfate levels ranged from 3 mg/L to 16.5 mg/L collectively. Table 46 displays the sulfate values from each station.

**Table 46.** Sulfate records from five monitoring stations in GUMO, including minimum, maximum, and mean values (mg/L), 2009-2011 (NPS 2011).

| Monitoring Station | Time Period | Observations | Minimum | Maximum | Mean |
|---|---|---|---|---|---|
| Mk 2 | 2009-2011 | 46 | 4 | 16.5 | 12.85 |
| Mk 4 | 2009-2011 | 46 | 3 | 16 | 0.67 |
| Mk 6 | 2009-2011 | 46 | 4 | 16 | 10.97 |
| Mk 8 | 2009-2011 | 46 | 3 | 16 | 13.02 |
| Choza Spring | 2009-2011 | 46 | 6 | 15.5 | 11.48 |

Dissolved Oxygen

The TCEQ considers DO levels equal to or greater than 5 mg/L adequate to support freshwater aquatic life. The EPA standard for protection of freshwater aquatic life is equal to or greater than

4 mg/L. NPS (1997) and EPA (2012e) STORET database reported data from several stations within GUMO. NPS (1997) reported observations between 1975 and 1997. EPA STORET (2012e) had data from five stations for 1990 through 1997.

NPS (1997) reported a total of 743 DO observations between 1975 and 1997. This inventory used the EPA standard of $\geq$4 mg/L for dissolved oxygen to assess trends in water body condition. Observations from three of the 14 stations show minimum values below the EPA standard for DO, while observations from nine of 14 stations show minimum values below the TCEQ standard. NPS (1997) reported a total of six exceedences among the stations (based on the EPA standard). Because these data are summarized as a range and mean value for each station and individual records are not presented in the report, it is difficult to know how many additional observations would exceed the more conservative TCEQ standard for DO (5 mg/L) for each station. The average mean among the stations was 7.865 mg/L, which is protective of freshwater life. Table 47 displays the DO values and exceedences for each of the 14 stations.

**Table 47.** DO records from 14 water quality stations in GUMO including the number of exceedences, minimum, maximum, median, and mean values (mg/L) (NPS 1997).

| Station | Time Period | Observations | Exceedences | Minimum | Maximum | Median | Mean |
|---|---|---|---|---|---|---|---|
| 0003 | 1978-1997 | 123 | 1 | 3 | 10.5 | 7.1 | 7.0 |
| 0005 | 1979-1987 | 17 | 1 | 4 | 9.5 | 8 | 7.1 |
| 0006 | 1979-1997 | 122 | 0 | 4.5 | 20.4 | 8 | 8.1 |
| 0009 | 1975-1997 | 120 | 2 | 2.6 | 14.5 | 7.5 | 7.6 |
| 0010 | 1978-1987 | 18 | 0 | 5.4 | 10.9 | 7.75 | 7.9 |
| 0011 | 1979-1987 | 17 | 0 | 4.2 | 10 | 8.2 | 7.7 |
| 0012 | 1979-1997 | 122 | 1 | 4 | 14.1 | 8 | 7.9 |
| 0015 | 1978-1997 | 124 | 1 | 3.2 | 15.2 | 8 | 7.9 |
| 0016 | 1979-1987 | 18 | 0 | 4.5 | 14 | 7.75 | 7.6 |
| 0020 | 1975-1987 | 13 | 0 | 4.1 | 18.5 | 10 | 10.5 |
| 0022 | 1975-1987 | 14 | 0 | 5.5 | 9.5 | 6.2 | 7 |
| 0024 | 1975-1987 | 17 | 0 | 5.7 | 10.5 | 8 | 7.9 |
| 0028 | 1975-1987 | 12 | 0 | 6.2 | 10 | 7.35 | 7.7 |
| 0032 | 1975-1979 | 6 | 0 | 5.5 | 13 | 7.15 | 7.9 |

The EPA STORET database had a total of 378 DO observations between 1990 and 1997 (EPA 2012e). Five DO observations during this time were below 5 mg/L. Stations Mk 2 and Choza both had one DO value that did not meet TCEQ standards in fall 1996 (October and November, respectively). Station Mk 8 recorded three DO values below the standard (4.3 mg/L, 4.7 mg/L, 4.9 mg/L) in 1991 and 1992. Table 48 displays the DO values (minimum, maximum, mean) for each station between 1990 and 1997.

**Table 48**. DO records from five monitoring stations in GUMO including exceedances, minimum, maximum, and mean values (mg/L), 1990-1997 (EPA 2012e).

| Monitoring Station | Observations | Exceedences | Minimum | Maximum | Mean |
|---|---|---|---|---|---|
| Mk 2 | 76 | 1 | 4.5 | 14.1 | 7.9 |
| Mk 4 | 76 | 0 | 5.1 | 12.3 | 7.9 |
| Mk 6 | 76 | 0 | 5.1 | 10.7 | 7.9 |
| Mk 8 | 75 | 3 | 4.3 | 8.4 | 6.8 |
| Choza Spring | 75 | 1 | 2.6 | 11.7 | 7.4 |

NPS (2011) recorded 230 DO observations among five stations in GUMO between 2009 and 2011. Twenty DO observations were below the TCEQ standard. Eleven of those exceedences were from Mk 2, five were from Mk 4, two from Mk 6, and two from Choza Spring. The largest DO range was 3.7 mg/L – 9.3 mg/L at the Mk2 station. Table 49 displays any DO exceedences as well as DO values (range and mean) for each station between 2009 and 2011.

**Table 49.** DO records from five monitoring stations in GUMO, including exceedences, minimum, maximum, mean values (mg/L), 2009-2011 (NPS 2011).

| Monitoring Station | Observations | Exceedences | Minimum | Maximum | Mean |
|---|---|---|---|---|---|
| Mk 2 | 46 | 11 | 3.7 | 9.3 | 6.03 |
| Mk 4 | 46 | 5 | 4.8 | 8.7 | 6.18 |
| Mk 6 | 46 | 2 | 4.2 | 8.1 | 6.35 |
| Mk 8 | 46 | 0 | 5.2 | 6.9 | 6.09 |
| Choza Spring | 46 | 2 | 4.9 | 8 | 6.32 |

Aquatic Macroinvertebrates

Macroinvertebrates are considered an indicator of stream and river health. For a detailed description of the park's aquatic macroinvertebrates, refer to the riparian/canyon assessment (Chapter 4.4) within this document.

Stream and Spring Flow Rates

Stream and spring flow rate data are limited and sporadic in GUMO. For a more in-depth discussion of stream and spring flow rates, refer to the hydrology portion (Chapter 4.15) of this document.

Threats and Stressor Factors

Park staff have identified two potential threats to the park's water quality: the proposed desalination plant, which is to be located near the western boundary of the park, and groundwater withdrawals.

The demand for drinking water is increasing in Texas. Groundwater aquifers in the Chihuahuan Desert area are considered brackish, but a desalination plant could make the water drinkable (Kever 2011). A proposed desalination plant would be built approximately 10.5 km (6.5 mi) west of the park. A concern about this plant is that the brine byproduct could pollute the groundwater if it were disposed of on the salt flats just outside the park (Younos 2005, Hirai 2011). Chemicals used in the desalination process could also be present in this brine solution (see section 4.2 for further discussion).

Groundwater mining (i.e., withdrawal) is considered a threat to both water quality and quantity. Water mining has been occurring for years to irrigate crops, both locally (i.e., Dell City) and in the region surrounding GUMO. When groundwater mining occurs over a long period of time, it can lower the groundwater tables (Aiken and Supalla 1979). According to Aiken and Supalla (1979), surface water supplies are impacted by groundwater mining. There is also a chance (depending on extent of mining) that use of ground water for irrigation may result in pollution of the groundwater source as well as the surface water.

Data Needs/Gaps

The greatest data gap is a lack of comparable historic and recent data. The data reported in NPS (1997) and the EPA (2012e) STORET database are outdated, with the most recent measurements recorded in 1997. The data presented in NPS (1997) also used EPA standards for comparisons and to determine exceedences, which are different than the TCEQ water quality standards (which are less conservative than EPA standards) that are commonly used for water quality studies in the region. Observations reported in NPS (1997) include only the date of observation and minimum, mean, median, and maximum values; individual records of observation are not included. This makes it impossible to know with certainty the total number of observations that met or also exceeded TCEQ standards for this study in addition to exceeding EPA standards.

The NPS (2011) dataset is current and contains almost three full years of observations for DO, chloride, and sulfate; however, the data are not continuous. Samples are taken at one date each month, and thus, are not likely to capture the variation in water quality parameters that occurs across time and seasons. Regular, consistent water quality sampling would provide GUMO managers with better insight into current water quality conditions and potentially provide information on trends in water quality parameters across time.

Overall Condition

The water quality for GUMO is difficult to assess due to a lack of consistent long-term monitoring. There is little or no data from 1997-2009. Because data are not continuous, no trends could be determined. Due to significant data gaps, *Condition Levels* could not be assigned for several water quality measures.

*Total Dissolved Solids*

The project team assigned this measure a *Significance Level* of 3. There are limited data for total dissolved solids in GUMO. Walsh (2007, 2008, 2009) collected several TDS measurements from park springs, but no data is available for McKittrick Creek. Because of this data gap, a *Condition Level* was not assigned for this measure.

*Chloride*

The project team defined the *Significance Level* for chloride as a 3. There are limited data for this water quality measure, and none was collected between 1997 and 2009. During the NPS (1997) study, there were a total of 661 observations recorded for chloride levels. Fourteen long-term (1975-1997) monitoring stations in the park collected chloride data. There were no observations that exceeded the TCEQ standard (300 mg/l). From 2009-2011, chloride measurements were well below the TCEQ and EPA standards (NPS 2011). As a result, this measure was assigned a *Condition Level* of 0, indicating no concern.

*Sulfate*

The project team defined the *Significance Level* for sulfate as a 3. The NPS (1997) study collected 746 measurements from 14 long-term (1979-1997) gages in the park, and none of the observations exceeded EPA standards (400 mg/L). Measurements taken from 2009-2011 were also below the TCEQ and EPA standards (NPS 2011). Therefore, this measure was also assigned a *Condition Level* of 0.

*Dissolved Oxygen*
The project team defined the *Significance Level* for dissolved oxygen as a 3. During the NPS (1997) study, a total of 743 DO measurements were recorded. When examining the data from the NPS (1997) study, there were nine stations that had minimum values below the TCEQ standard (>5 mg/L); however, there were a total of six exceedences because the standard limit used in the study was ≥4 mg/L (EPA standard). The EPA (2012e) STORET database had a total of 378 DO observations from 1990 through 1997. There were five records (2.6, 4.3, 4.5, 4.7, and 4.9 mg/L) from all five stations that did not meet the TCEQ standard for supporting freshwater aquatic life. From 2009-2011, 20 measurements from four stations did not meet the TCEQ standard (NPS 2011). Since the number of exceedences appears to be increasing slightly over time, this measure is considered of moderate concern (*Condition Level* = 2).

*Coliform Bacteria*
The project team defined the *Significance Level* for coliform bacteria as a 1. There are limited data for this water quality measure, and the data that are available are at least 10 years old. The NPS (1997) baseline water quality inventory and analysis report for GUMO included fecal coliform records between 1975 and 1997. Station GUMO0015 was the only station to have long-term records during this time. The other stations recorded only in 1979, or between 1975 and 1979. There were no records that exceeded the TCEQ standard for fecal coliform; the highest amount of fecal coliform was 119 CFU/100 ml. The average mean among the 14 stations was 22 CFU/100 ml. Due to the lack of recent data, a *Condition Level* was not assigned for fecal coliform.

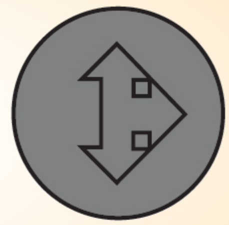
*Aquatic Macroinvertebrates*
The project team defined the *Significance Level* for aquatic macroinvertebrates as a 3. As described in the riparian/canyon assessment (section 4.4), a *Condition Level* could not be assigned for this measure because of a lack of current data.

*Stream and Spring Flow Rates*
The project team assigned this measure a *Significance Level* of 2. According to the hydrology assessment (section 4.15), a *Condition Level* could not be assigned due to an inconsistency of historic measurements and lack of recent stream flow data.

*Weighted Condition Score*
A *Weighted Condition Score* for water quality in GUMO was not calculated due to a lack of current data for a majority of the measures. The current condition and trend for this component is unknown.

## Water Quality

| Measures | SL | CL |
|---|---|---|
| • Total Dissolved Solids | 3 | n/a |
| • Chloride | 3 | 0 |
| • Sulfate | 3 | 0 |
| • Dissolved Oxygen | 3 | 2 |
| • Coliform Bacteria | 1 | n/a |
| • Aquatic Macroinvertebrates | 3 | n/a |
| • Stream and Spring Flow Rates | 2 | n/a |



**WCS = N/A**

***Sources of Expertise***
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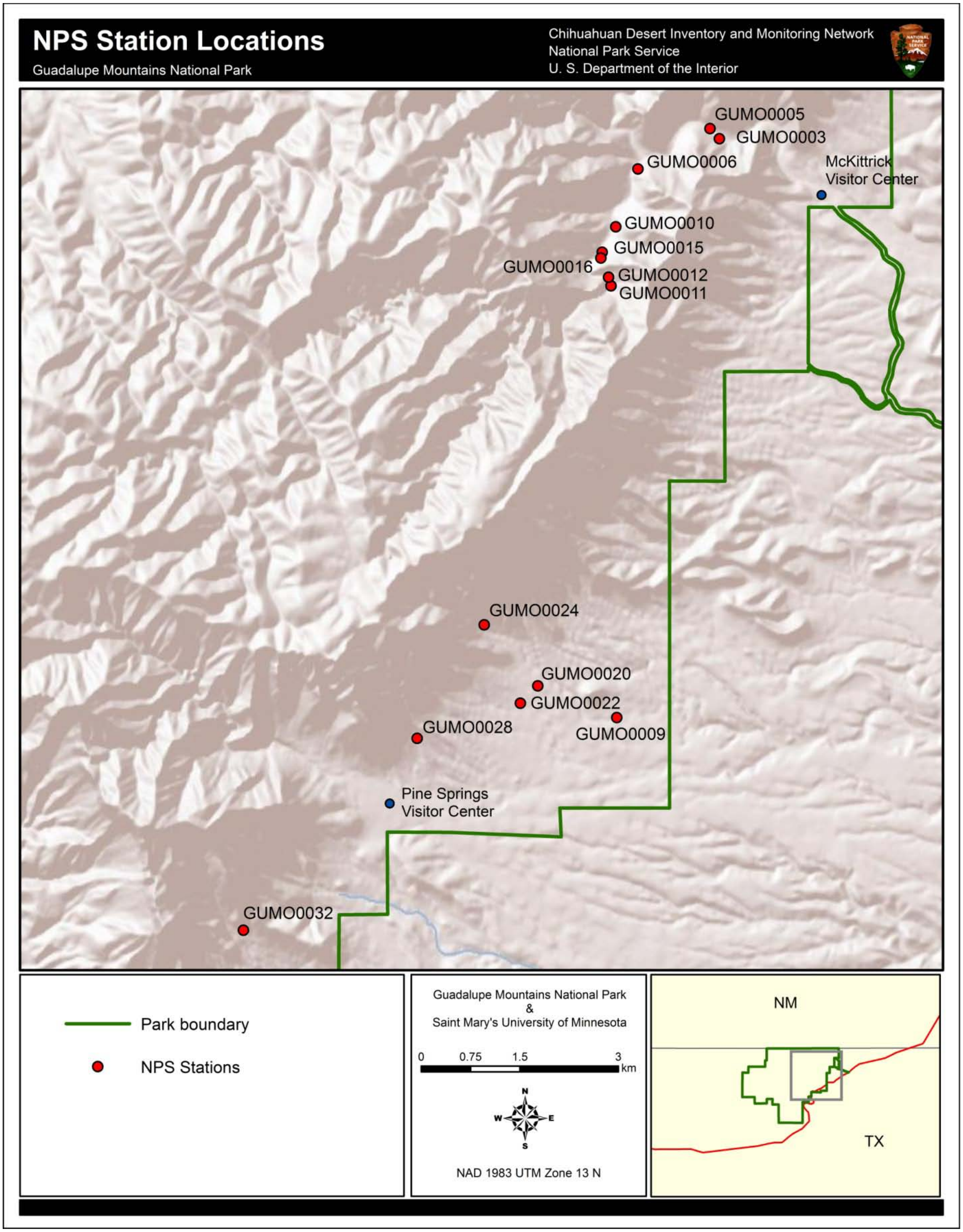



**Plate 23.** Water quality sampling station locations within GUMO (station IDs from NPS 1997).

## 4.12 Soundscape

### *Description*

The definition of soundscape in a national park is the total ambient sound level of the park, comprised of both natural ambient sound and human-made sounds (NPS 2000). The NPS's mission is to preserve natural resources, including natural soundscapes associated with the national park units. Intrusive sounds are of concern to park visitors, as they detract from their natural and cultural resource experiences (NPS 2000). According to a survey conducted at GUMO in 1996-97, nearly 40% of visitors listed solitude/quiet as one of their reasons for coming to the park (Bergdahl et al. 1998).

Natural sound levels are also of vital importance to many wildlife species (Armstrong, phone communication, 27 September 2011). Unusual noises can prevent animals from detecting predators and disrupt natural behaviors such as migration, establishing territory, courtship, and rearing young (NPS 2010). In extreme cases, certain sounds could trigger physiological or behavioral responses that affect an animal's ability to survive and reproduce (NPS 2010). According to a 2006 Management Policy, NPS staff are directed to "monitor human activities that generate noise that adversely affects park soundscapes, including noise caused by mechanical or electronic devices," and "take action to prevent or minimize all noise that through frequency, magnitude, or duration adversely affects the natural soundscape or other park resources or values, or that exceeds levels that have been identified through monitoring as being acceptable to or appropriate for visitor uses at the sites being monitored" (NPS 2006).

### *Measures*

- Percent of time human-caused sounds are audible (backcountry and frontcountry; daytime and nighttime)

- Sound level as expressed by hourly decibel (dB) level (backcountry and frontcountry; daytime and nighttime)

### *Reference Conditions/Values*

Interim reference conditions for GUMO's soundscape were established in the park's RSS and are shown below (NPS 2009, Table 50).

**Table 50.** Soundscape reference conditions for GUMO, by location (back or frontcountry) and time of day (NPS 2009).

| | % of time human-caused sounds are audible | Sound level |
|---|---|---|
| Backcountry, daytime | <25% of each hour for 90% of the day | hourly change does not exceed 3 dB for 70% of the day & 6dB for 90% of the day; human-caused sounds never >65 dB |
| Backcountry, nighttime | <20% of each hour for 90% of the night | hourly change does not exceed 3 dB for 90% of the night & 6dB for 95% of the night; human-caused sounds never >45 dB |
| Frontcountry, daytime | <50% of each hour for 60% of the day | hourly change does not exceed 3 dB for 40% of the day & 6 dB for 90% of the day; human-caused sounds never >65 dB |
| Frontcountry, nighttime | <30% of each hour for 80% of the night | hourly change does not exceed 3 dB for 70% of the night & 6 dB for 95% of the night; human-caused sounds never >45 dB |

### *Data and Methods*

There are no existing soundscape data or information sources for the park. The GUMO RSS (NPS 2009) recognized the need for baseline soundscape data and a monitoring protocol, particularly given the importance of sound in maintaining the park's wilderness character.

### *Current Condition and Trend*

Percent of Time Human-caused Sounds are Audible

No data have been gathered on the percent of time human-caused sounds are audible at any location in the park.

Sound Level as Expressed by Hourly Decibel (dB) Level

Sound level data also have not been collected at GUMO.

Threats and Stressor Factors

Threats to the park's soundscape include noise from local development, highway traffic, aircraft, and humans (e.g., recreational users) (NPS 2009). Potential developments include a proposed desalination plant west of the park and energy developments.

Data Needs/Gaps

Baseline data and a soundscape monitoring protocol are needed for the park. GUMO plans to obtain protocols in use at other parks from the NPS Natural Sounds Program to provide a starting point for the park's monitoring program (NPS 2009).

Overall Condition

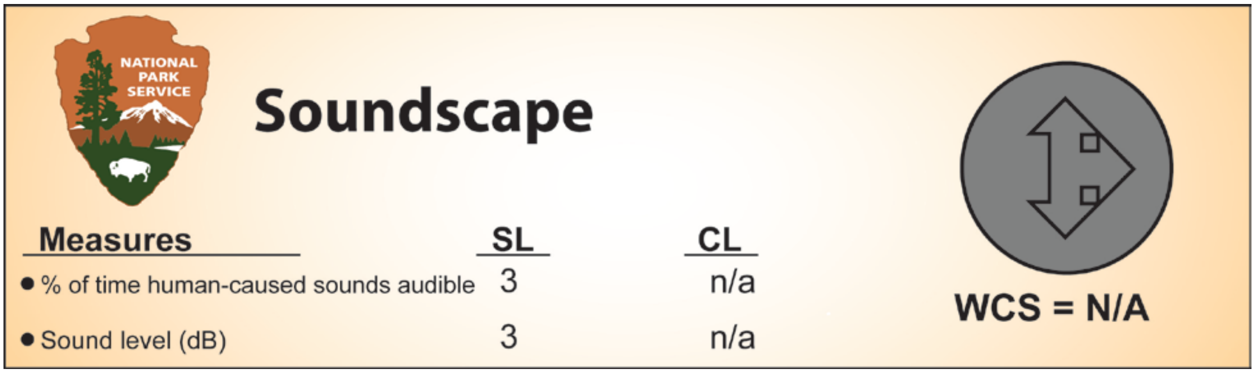
*Percent of Time Human-caused Sounds are Audible*

The project team assigned this measure a *Significance Level* of 3. However, since no soundscape data have been gathered in the park, a *Condition Level* could not be assigned.

*Sound Level as Expressed by Hourly Decibel (dB) Level*

This measure was assigned a *Significance Level* of 3. No data are available for this measure, so a *Condition Level* also could not be assigned.

*Weighted Condition Score*
Since a *Condition Level* was not assigned for either of this component's measures, a *Weighted Condition Score* could not be calculated. The overall condition of GUMO's soundscape is unknown with an unknown trend.




***Sources of Expertise***
Fred Armstrong, former GUMO Chief of Resource Management, currently Chief of Resource Management and Research at Zion National Park

***Literature Cited***

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### 4.13 Viewscape

***Description***

**Photo 28.** High mesas and ridges in GUMO (NPS photo by William Leggett).

For this assessment, viewscape refers to the visible features on the landscape in GUMO. A viewshed is the area that is visible from a particular location or set of locations, often developed 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 from 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. Analyzing layers that identify areas of undesirable impacts on the landscape within viewsheds creates a quantitative description of visual stress on a viewshed; repeating this process for multiple viewshed layers in a pre-defined landscape, such as a national park, provides a quantitative description of stress across the viewscape in the area.

**Photo 29.** PX Flat and Cutoff Ridge (NPS photo by William Leggett).

Multiple studies indicate that people prefer natural compared to developed landscapes (Sheppard 2001, Kearney et al. 2008, Han 2010). The National Park Service Organic Act (16 U.S.C. l) implies the need to protect the viewscapes of national parks, monuments, and reservations. At GUMO, landscape viewing is a primary visitor activity. Many of the views from atop the peaks in the park are expansive and include large amounts of area (Photo 28, Photo 29).

***Measures***

- Change in land use cover type inside the park (internal viewscape)
- Change in land use cover type outside the park (external viewscape)

***Reference Conditions/Values***

The reference condition for this component, as defined in the park's RSS (NPS 2009), is no significant change in viewscape (internal and external) as measured by GIS and aerial photography.

***Data and Methods***

Park staff identified four priority observation points and one trail within the park for this analysis: Guadalupe Mountain Peak, Bartlett Peak, Cutoff Mountain, Permian Reef, and the Permian Reef Trail. Since several iconic views of the park are actually from points outside the GUMO boundary, park staff also requested an analysis using U.S. Highway 180 as a line feature. For each of these points or lines, a viewshed was calculated using ESRI's Spatial Analyst Viewshed Tool in ArcGIS 10.0, which requires point or polyline GIS data (representing the viewing location) and a DEM. For each of the observation points, a point shapefile was created for use with the Viewshed Tool. For line features, a polyline was created; the Viewshed Tool uses each vertex in the line to determine the viewshed of the feature as a whole. The DEM used for each observation point was mosaicked from the National Elevation Dataset (NED), which has a resolution of approximately 10 m (32.8 ft). A 1.7-m (5.5-ft) offset was applied to each observation point shapefile to account for average human height. The result of the operation is a theoretical viewshed layer that represents the visible area from a point without correcting for visibility factors (e.g, vegetation, smoke, humidity, heat shimmer, or curvature of the earth).

Methods for development of GIS viewshed layers used by Melanie Myers (NPS Contractor, GIS Analyst) are provided in Appendix F. In summary, two raster layers were developed for this analysis: an internal viewshed layer and an external viewshed layer. The internal viewshed layer represents the area of the park visible from U.S. Hwy 180 that runs along the eastern and southern portions of the park. The external viewshed layer represents the view looking out from the park from high-use viewing areas, limited to 97 km (60 mi) (the approximate visibility from the park peaks) (Hearst, interview, 24 January 2012).

***Current Condition and Trend***

Change in Land Use Cover Type Inside the Park (Internal Viewscape)

A 129-km (80-mi) portion of U.S. Hwy 180 was used to determine the internal viewscape. The resulting total visible area from that feature was 18,130 ha (44,800 ac), about 50% of the park's total area. Most of the area not visible from the highway is on the northern plateau portion of the park (Plate 24).

The primary 2006 National Land Cover Dataset (NLCD) landcover classes within GUMO are Shrub/Scrub and Evergreen Forest, at 73% and 21%, respectively (Table 51; Fry et al. 2011). Evergreen Forest is "dominated by trees generally greater than 5 m tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage" (MRLC 2012). Shrub/Scrub is "dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation." This class includes "true shrubs, young trees in an early successional stage or trees stunted from environmental conditions" (MRLC 2012).

**Table 51.** 2006 NLCD landcover composition in GUMO (Fry et al. 2011).

| Class | Hectares | Percent cover |
|---|---|---|
| Open water | 0.8 | <1 |
| Developed, open space | 94.7 | <1 |
| Developed, low intensity | 2.8 | <1 |
| Developed, medium intensity | 0.4 | <1 |
| Barren land (rock/sand/clay) | 1,585.6 | 4 |
| Deciduous forest | 112.9 | <1 |
| Evergreen forest | 7,493.2 | 21 |
| Shrub/scrub | 26,108.3 | 73 |
| Grassland/herbaceous | 317.7 | 1 |

Analysis of NLCD change data indicates very little change within the internal viewscape from 2001 to 2006; only about 80.5 ha (199 ac) changed over that time (less than 0.5% total visible area from U.S. Hwy 180) (Table 52). The change that did occur is likely due to succession from Shrub/Scrub class to Evergreen and Deciduous Forest classes.

**Table 52.** NLCD 2001 to 2006 change within GUMO lands visible from Texas State Highway 180 (Fry et al. 2011).

| LC Change Type | Hectares |
|---|---|
| Not visible | 17,560.9 |
| Visible, but unchanged | 18,704.5 |
| Evergreen Forest to Deciduous Forest | <0.4 |
| Shrub/Scrub to Deciduous Forest | 5.3 |
| Shrub/Scrub to Evergreen Forest | 74.9 |

<u>Change in Land Use Cover Type Outside the Park (External Viewscape)</u>

Similar to the internal viewscape, the external viewscape changed little between 2001 and 2006 according to the NLCD change product. Of the 1.9 million ha identified as visible from the viewpoints established for the park, approximately 9,900 ha experienced a change in classification - about 0.5%. A vast majority of this change (3,377 ha) was from Shrub/Scrub to Cultivated Crops ("areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled" [MRLC 2012]). In relation to the park, about 2,100 ha of area changed to Cultivated Crops within 24 km (15 mi) of the park boundary (Plate 25). Six hundred seven hectares of the visible area changed to developed area, with much of this developed area being the open space designation (i.e., area with a mix of constructed materials, less than 20% impervious surfaces, and mostly lawn-grass type vegetation [MRLC 2012]). Similar to within the park, the primary NLCD cover class in the external viewscape is Shrub/Scrub designation. Appendix F provides a complete listing of designation changes between 2001 and 2006.

Threats and Stressor Factors

Wind energy development poses a threat to the external viewscape of the park. Aerial photo interpretation of 2010 National Agricultural Inventory Program (NAIP) imagery identified 139 wind turbines to the south of GUMO (USDA 2010, Plate 26). Comparing the locations of these turbines with the visible areas according to the external viewshed analysis, 85 of the 139 identified wind turbines were within the viewshed. Furthermore, it is possible that more of the turbines were visible in 2010, since correction for turbine height was not incorporated. Solar power developments have also been proposed in New Mexico, just north of the park boundary, which could be visible from the park's wilderness area (Hearst, interview, 24 January 2012). Additional threats to the park's viewscape include encroaching urbanization, traffic use, and air pollution that reduces visibility (NPS 2009).

Data Needs/Gaps

Continued development of spatial data that explain landscape change will enable accurate and up-to-date viewscape assessments of the metrics examined in this analysis. In 1980, the view from Guadalupe Peak was identified by the NPS as an "integral vista" and panoramic photos were taken from the summit (NPS 1980, Photo 30). These panoramic photos could be repeated in the future for comparison, to determine if visible change has occurred since 1980.


**Photo 30.** View from Guadalupe Peak looking south in 1980, featuring El Capitan (labeled "C") (NPS photo).

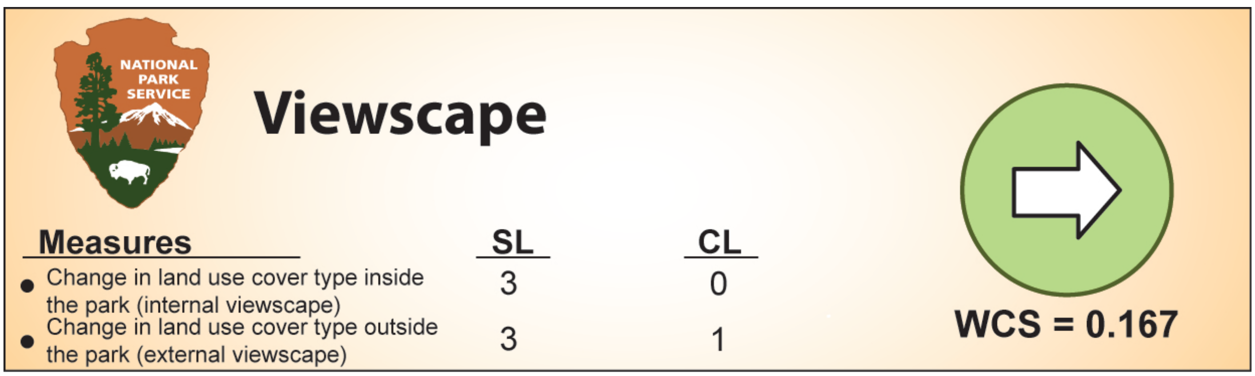
Overall Condition

*Change in Land Use Cover Type Inside the Park (Internal Viewscape)*

The *Significance Level* for this measure is 3, indicating it is of high importance in determining the condition of the viewscape. Overall, little landcover change occurred within the internal viewscape from 2001 to 2006. The change that did occur is likely due to natural succession of vegetation; no change occurred that could be designated as anthropogenic. Therefore, the *Condition Level* of this measure is 0, indicating no concern.

*Change in Land Use Cover Type Outside the Park (External Viewscape)*
The *Significance Level* for this measure is 3, indicating it is of high importance in determining the condition of the viewscape. Similar to the internal viewscape, landcover change was minimal from 2001-2006 within the external viewscape of the park. Change to developed cover classes was also minimal in the external viewshed. However, concentrated patches of land converted to Cultivated Crops existed to the south and the west of the park boundary (Plate 25). Some potential causes for concern include the development of wind energy infrastructure, such as the wind turbines south of the park. In addition, because the external viewscape is not controlled by NPS, development that deteriorates the viewscape is possible. Therefore, even though change was minimal from 2001-2006, the potential for development and the current wind turbines warrants a *Condition Level* of 1, or low concern.

*Weighted Condition Score*
The *Weighted Condition Score* for this component is 0.167, indicating the condition is currently of low concern.




***Sources of Expertise***
Melanie Myers, I&M GIS analyst

Jonena Hearst, GUMO geologist

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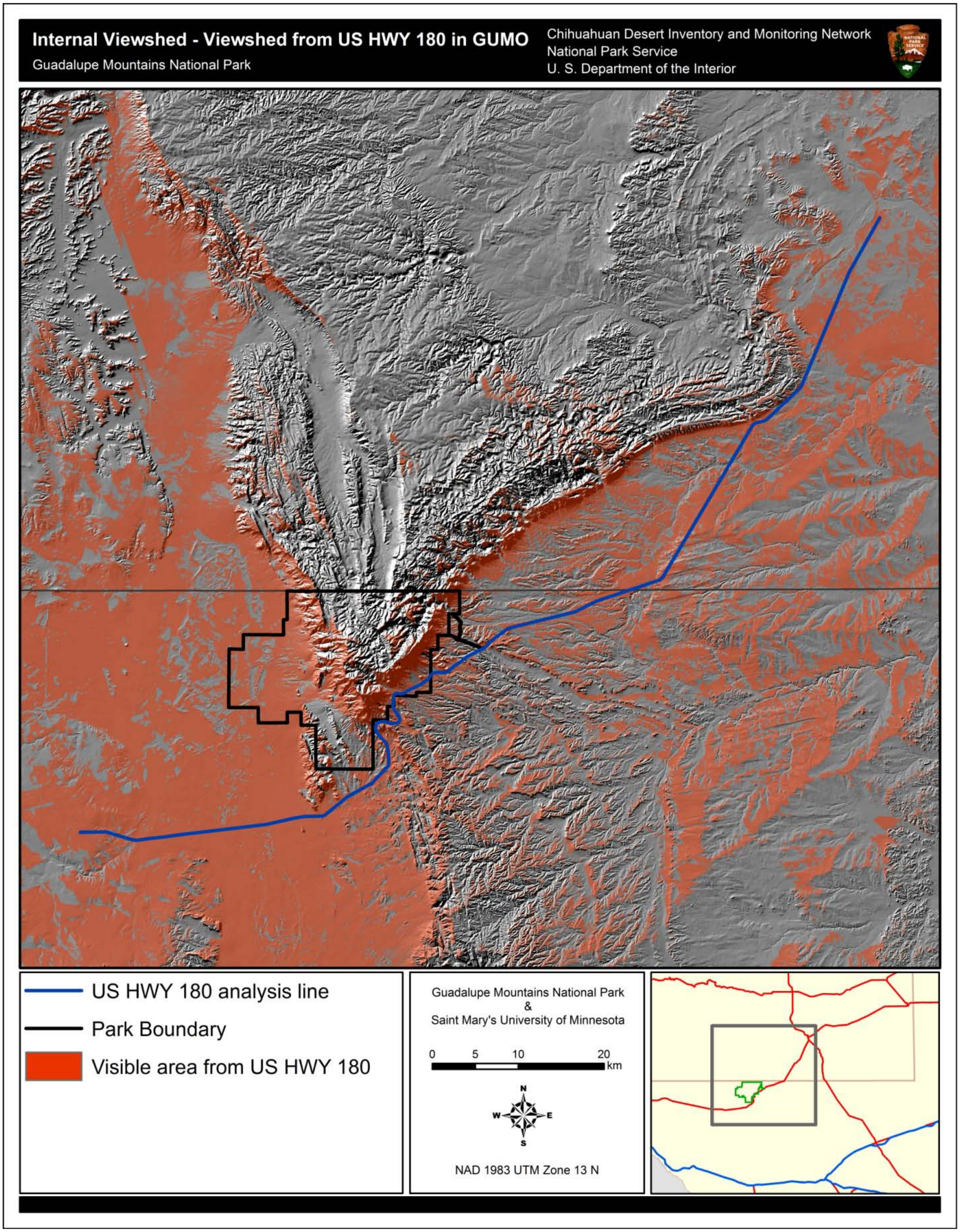



**Plate 24.** GUMO internal viewshed from U.S. Hwy 180.

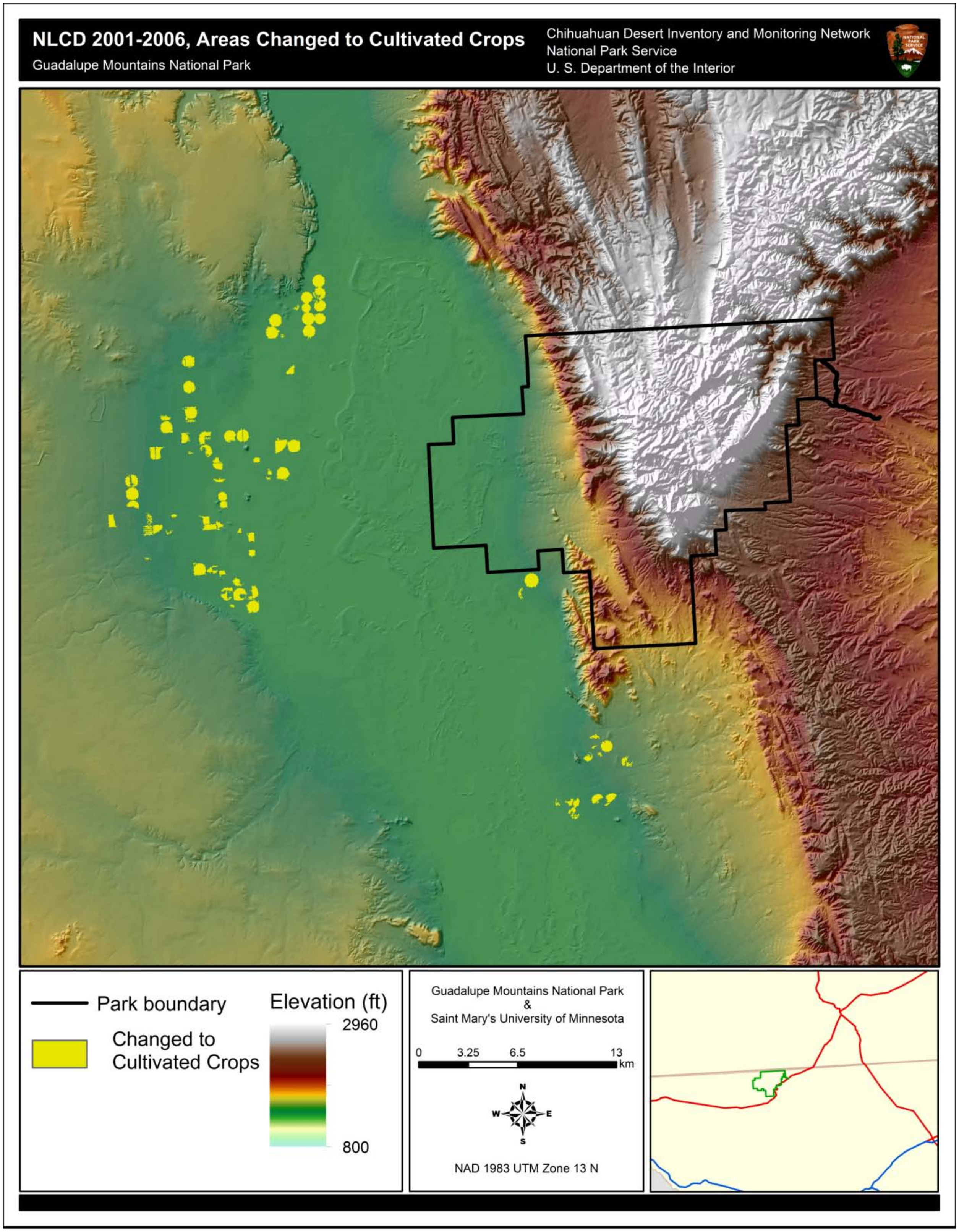



**Plate 25.** Areas changed to Cultivated Crops NLCD Class, 2001-2006.

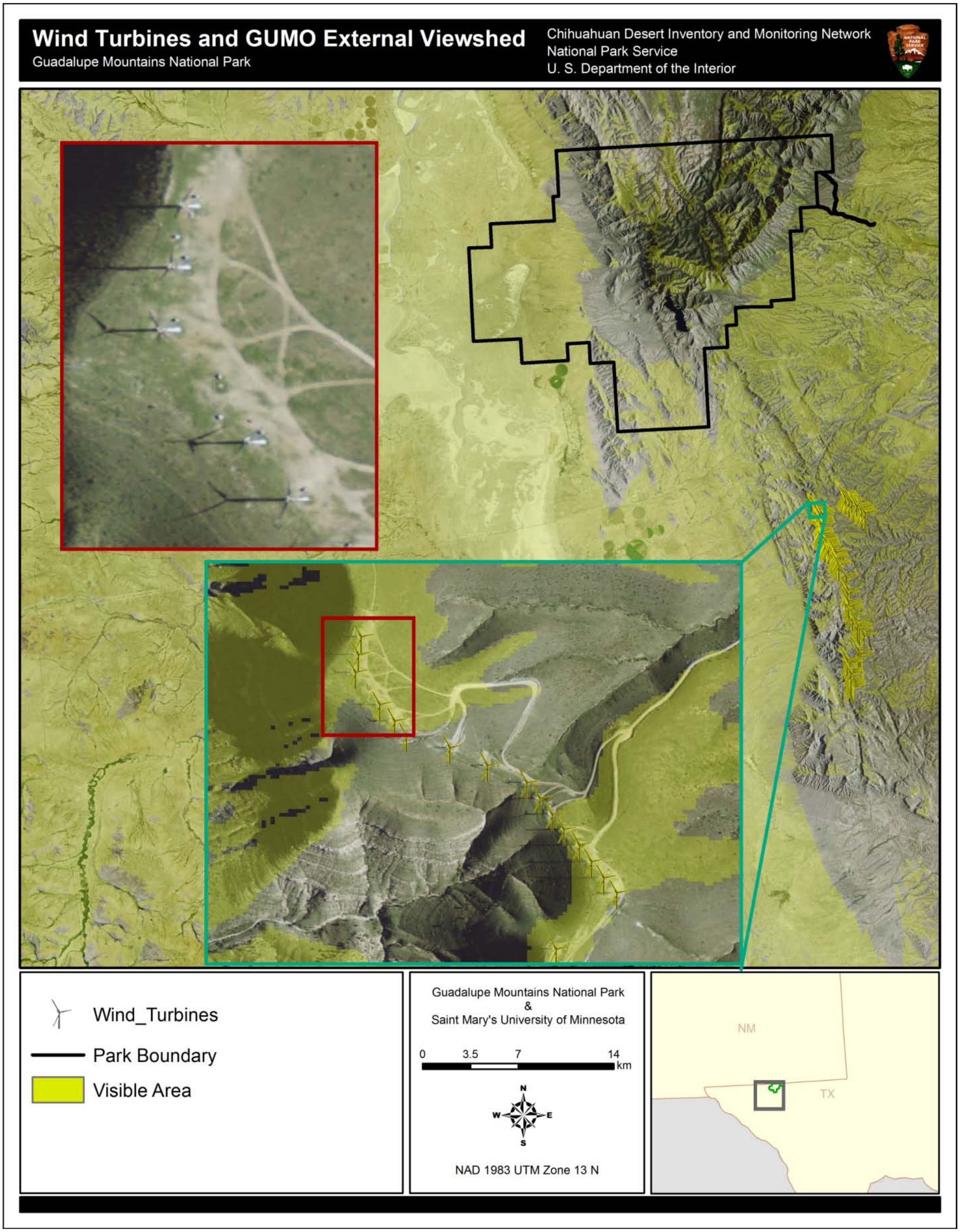



**Plate 26.** Wind turbines and GUMO external viewshed.

## 4.14 Dark Night Skies

### *Description*

A 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 2012). The NPS directs each of its units to preserve, to the greatest extent possible, these natural lightscapes (NPS 2006). 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 2006, 2012). Several species require darkness to hunt, hide their location, navigate, or reproduce (NPS 2012). 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. GUMO is home to several areas of designated wilderness, and NPS (2009, p. 59) states, "wilderness character will be evaluated primarily by assessing the condition of dark night skies and natural sounds." Monitoring of the dark night sky quality in GUMO will help to gauge the wild qualities of not only the wilderness areas, but of the park as a whole.

### *Measures*

During site visits, the NPS Night Sky Team (NST) collects data for a suite of measures in order to define the current condition of dark night skies in a park unit. These measures typically 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 or milli-candela per square meter) or relative to natural conditions, often shown as a sky brightness contour map of the entire sky. V magnitude 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 (such as the Wilderness boundary), in milli-Lux;

- Visual observations by a human observer, such as Bortle Class and Zenithal limiting magnitude;

- Integrated synthesized measure of the luminance of the sky within 50 degrees of the Zenith, as reported by the Unihedron Sky Quality Meter, in V magnitudes per square arc second.

***Reference Conditions/Values***

The reference condition for dark night skies in GUMO is defined as the absence of anthropogenic light. For comparison, the GUMO RSS defined the target value (or desired condition) of dark night skies to be a condition that exhibits a decline of no greater than five percent when compared to a baseline measurement of Zenith Sky Brightness.

The NST defines reference condition 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 Night Sky Team, pers. comm., 2011).

Achieving this reference condition for preserving natural night skies is well summarized in section 4.10 of the NPS Management Policies (NPS 2006, p. 57) 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 GUMO requires that facilities within the park and local communities around 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.

***Data and Methods***

Data were collected for baseline dark sky documentation in GUMO from atop Guadalupe Peak on 25 June 2009. Images were collected by Dan Duriscoe of the NPS NST. Data were collected for a suite of measures during this visit. A final report from the NST's visit is not yet available, but is expected to be delivered to GUMO in the near future.

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.

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 22 and Figure 23, 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 NST.

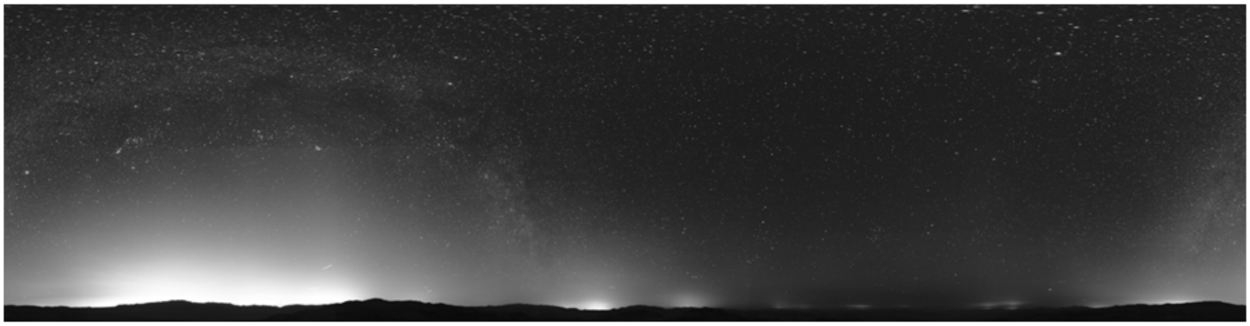


**Figure 22.** Grayscale representation of sky luminance from a location in Joshua Tree National Park (Figure provided by Dan Duriscoe, NPS Night Sky Team).

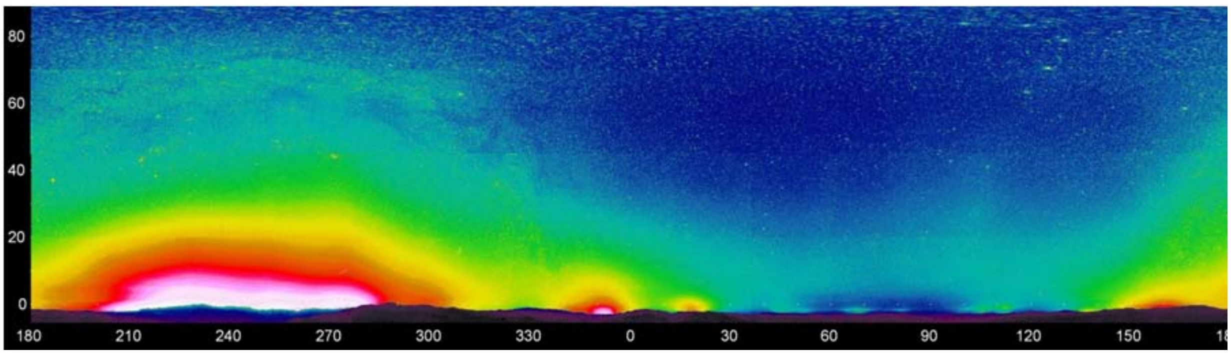



**Figure 23.** False color representation of Figure 22 after a logarithmic stretch of pixel values (Figure provided by Dan Duriscoe, NPS Night Sky Team).

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 NST 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 22 and Figure 23 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 NST 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 24). Figure 23 represents "total sky brightness" while Figure 24 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.

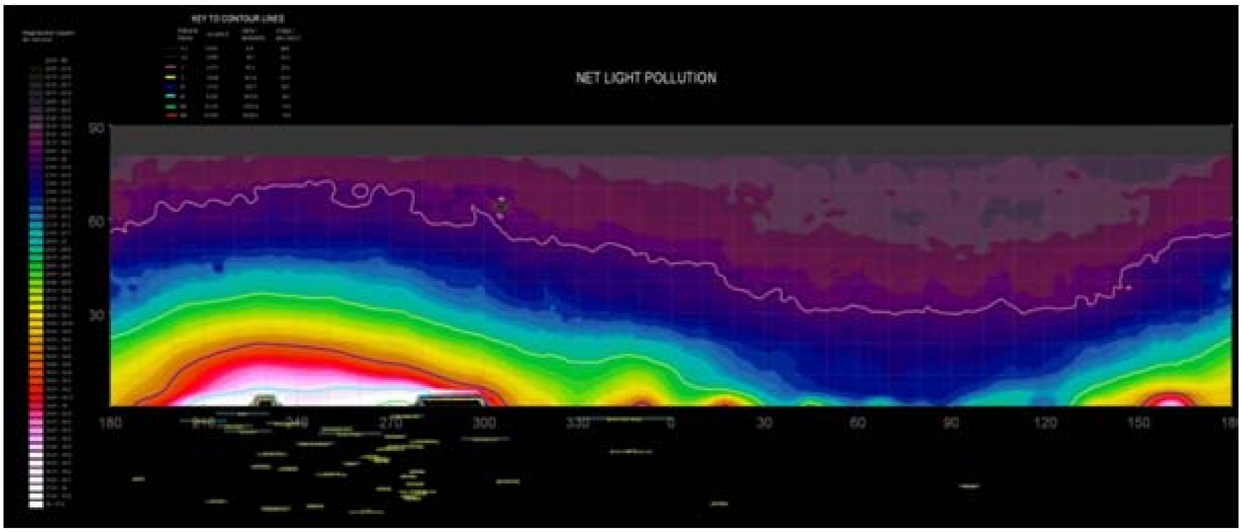



**Figure 24.** Contour map of anthropogenic sky glow at a location in Joshua Tree National Park, analogous to Figure 23 with natural sources of light subtracted (Figure provided by Dan Duriscoe, NPS Night Sky Team).

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. Both luminance and illuminance for the entire sky or a given area of the sky may be described in this manner (Hollan 2008). 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 NST data, the atmospheric conditions determined from each individual data set.

The reference conditions for anthropogenic sky luminance were identified as no more than 200 percent brighter than natural conditions in *any* area of the sky and no more than 10 percent brighter at the Zenith. These values correspond to light pollution ratios of 2.0 and 0.1, respectively. The NST has obtained values of 50-100 for this measure at the core of city light domes seen from several areas administered by the NPS, including Lake Mead National Recreation Area, Saguaro National Park, and Colorado National Monument (NPS Night Sky Team, unpublished data). This is because these NPS areas are very close to the cities of Las Vegas, Nevada; Tucson, Arizona; and Grand Junction, Colorado, respectively.

A quick and accurate method of quantifying sky brightness near the Zenith is the use of a Unihedron Sky Quality Meter. The Unihedron Sky Quality Meter 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 NST 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 Sky Quality Meter. The performance of the Sky Quality Meter has been tested and reviewed by Cinzano (2005). 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, a 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.

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 Zenithal Limiting Magnitude (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. Zenith Limiting Magnitude is 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 NST 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.

### ***Current Condition and Trend***

<u>NPS Suite of Measures</u>

GUMO night sky mosaics were collected from atop Guadalupe Peak (note the pylon in Figure 25 and Figure 26) on 25 June 2009. In the false color image (Figure 25), light intrusions from surrounding communities are visible from Guadalupe Peak. Communities that are visible in Figure 25 include El Paso, TX (bearings 255-270), Carlsbad, NM (bearings 40-50), and Artesia, NM (bearings 20-25). In the black and white mosaic (Figure 26), the arc of the Milky Way is clearly visible, as is the glow from El Paso, TX on the right horizon, and the glow from

Carlsbad-Artesia, NM on the left horizon. The pylon atop Guadalupe Peak is also visible in the center of Figure 26.

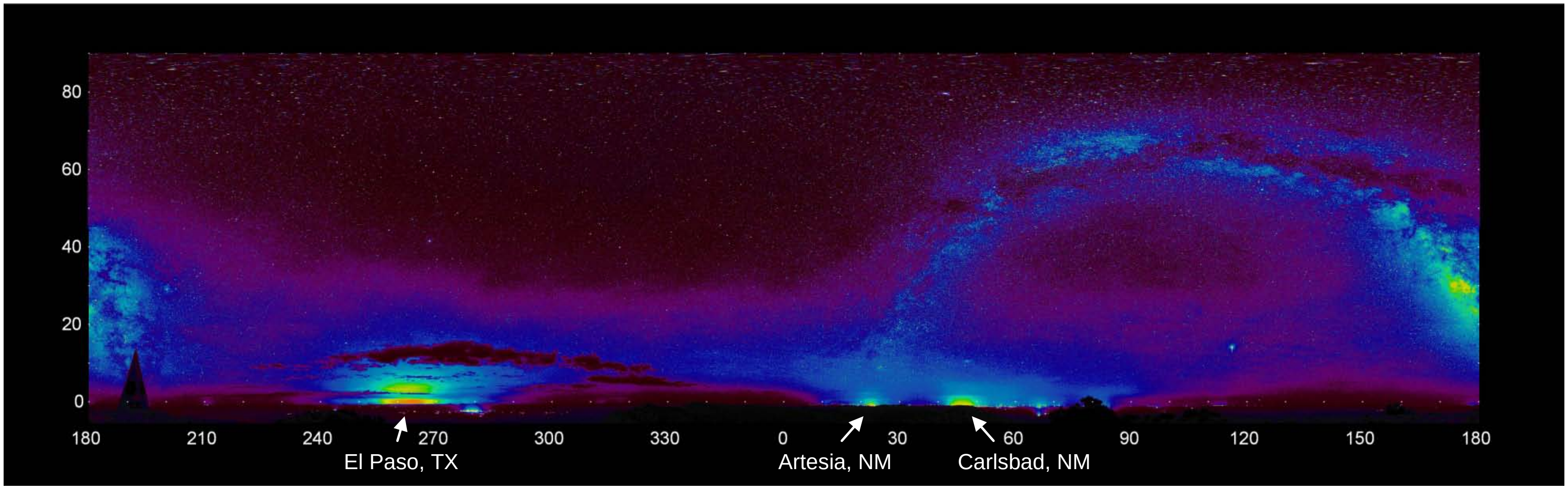



**Figure 25**. False color mosaic image of the GUMO night sky. Image taken from the top of Guadalupe Peak; notice the pylon from the summit of Guadalupe Peak on the left horizon. Night sky glow from El Paso, TX, Artesia, NM, and Carlsbad, NM are visible. The Milky Way is also clearly visible as an arc across the mosaic image. Image provided by Dan Duriscoe of the NPS Night Sky Team.

**Figure 26.** Black and white mosaic image of the GUMO night sky. Image taken from the top of Guadalupe Peak; notice the pylon from the summit of Guadalupe Peak in the center of the image. Sky glow from El Paso, TX (right horizon), and Carlsbad-Artesia, NM (left horizon) are visible.

While the NST has produced night sky mosaic images for GUMO, a detailed final report has not yet been completed. However, the NST provided GUMO with an interim summary report in August 2012. The data and conclusions of this summary report were preliminary and are not appropriate to directly cite or quote at this time.

Satellite generated models of light pollution (Figure 27) predict that GUMO has a nearly natural dark night sky. GUMO's distance from large sources of light pollution (i.e., major cities) is a main factor in the park's excellent night sky visibility. However, without the NPS Night Sky Team's final report, the current condition of the night skies in GUMO cannot be estimated. This final report is expected to be completed soon, and will provide GUMO managers with an accurate assessment of the resource's current condition.

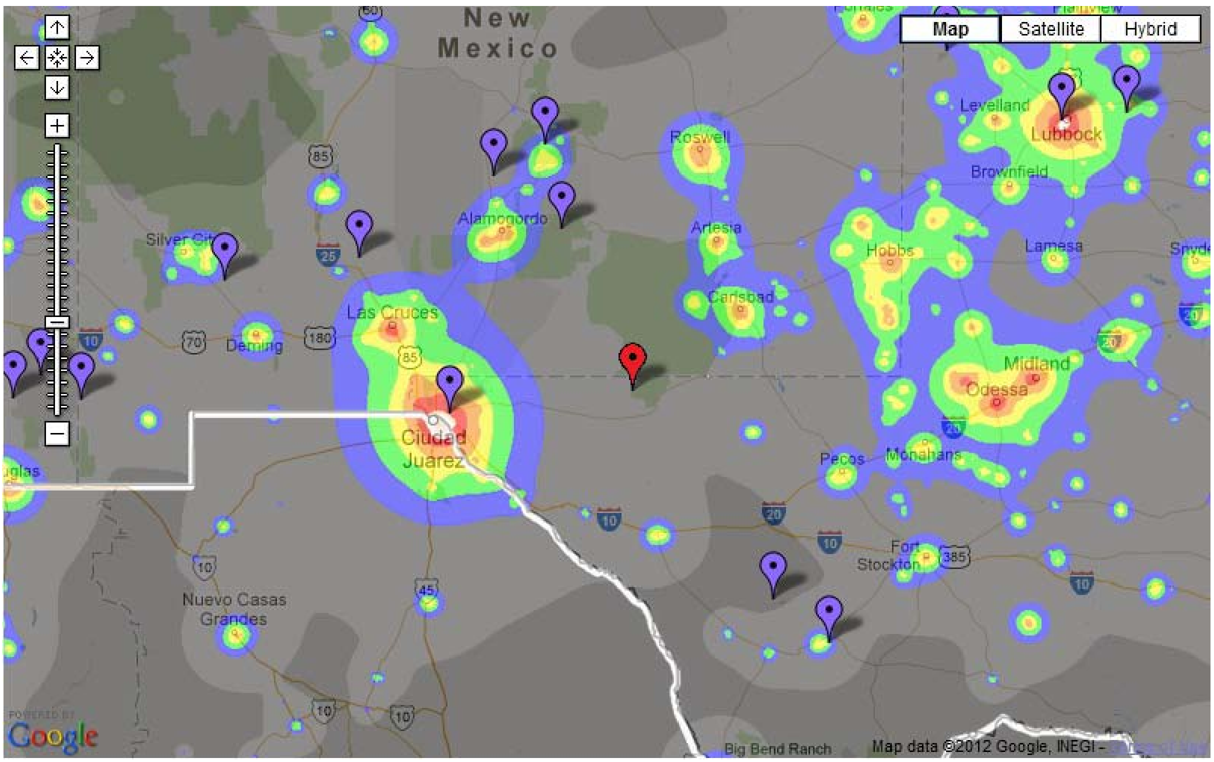



**Figure 27.** Modeled night sky quality in the areas surrounding GUMO; the red marker indicates Guadalupe Peak in GUMO. Dark gray and gray shaded areas represent regions that are predicted to have excellent sky quality near the zenith (image from: http://www.jshine.net/astronomy/dark_sky).

Threats and Stressor Factors

One of the major threats to the dark night skies in GUMO is human development in the areas surrounding the park. These areas and developments include U.S. Hwy 62/180, the proposed desalination plant near the park's boundaries, cellular phone towers (e.g., the tower present on Signal Peak), and lights from energy production plants (e.g., oil developments, air traffic lights present on the wind turbines located approx 48 km [30 mi] south of the park). One of the more recent developments that likely has an effect on the park's dark night skies is the rest area located on U.S. Hwy 62/180 near the entrance to the McKittrick Canyon day use area. This development is likely to have a huge impact on the quality of night skies in this area of the park (Fred Armstrong, interview, 24 January 2012). The Corn Ranch spaceport, which is being developed north of Van Horn, TX (south of the park), may also represent a threat (Graczyk 2005).

More distant sources of light pollution stemming from human development include the light domes from local communities. The light domes from El Paso, TX; Carlsbad, NM; and Artesia, NM are visible from Guadalupe Peak on clear nights. Other nearby cities, such as Dell City, TX, and Van Horn, TX may also contribute light pollution that could be visible in the park.

Another area of human development in GUMO that threatens the quality of night skies is the park infrastructure. External light fixtures that have not been retrofitted to meet night sky requirements contribute levels of light trespass that could alter visitor's perception of the night sky. Examples of park structures that may contribute to anthropogenic light pollution include the Pine Springs Visitor Center, the McKittrick Canyon day use Visitor Center, Dog Canyon Visitor Center, and the maintenance/dorm facilities located south of U.S. Hwy 62/180.

Data Needs/Gaps

The NPS Night Sky Team visited GUMO in 2009 and took baseline measurements on the condition of dark night skies. However, the results of this visit have not been provided to GUMO staff; the delivery of this document will provide managers at GUMO with the data needed to accurately assess the current condition of the dark night skies in the park.

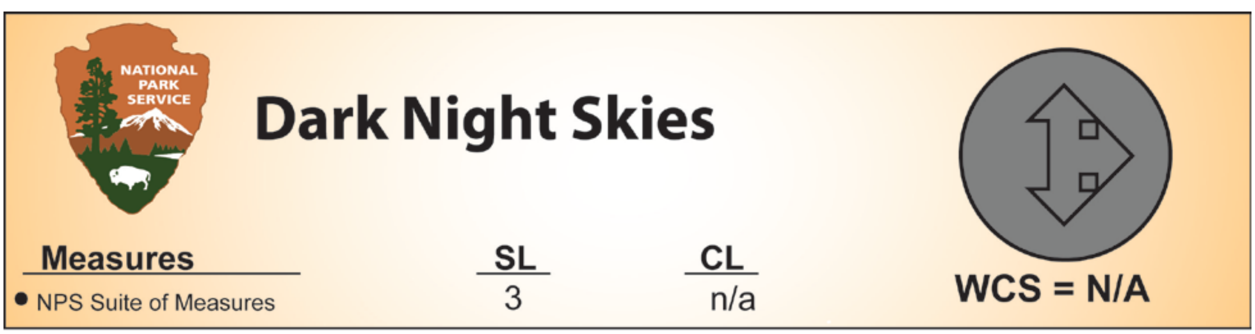
Overall Condition

*NPS Suite of Measures*

GUMO staff assigned the NPS suite of measures a *Significance Level* of 3 during project scoping. However, until the NPS Night Sky Team's final report is completed, a detailed analysis regarding the current condition of this resource cannot be conducted. Because of this, a *Condition Level* was not assigned to this measure.

*Weighted Condition Score*

A *Weighted Condition Score* for dark night skies was not assigned due to a lack of appropriate data.



***Sources of Expertise***

National Park Service Night Sky Team members Dan Duriscoe, Chad Moore, Teresa Jiles, Jeremy White, and Robert Meadows

Fred Armstrong, former GUMO Chief of Resource Management, currently Chief of Resource Management and Research at Zion National Park

Janet Coles, GUMO Chief of Resource Management

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## 4.15 Hydrology

### *Description*

Water availability influences every component within the biological community and can limit human use and enjoyment of an area. Therefore, to understand the ecology of an ecosystem, it is vital to have some knowledge of its hydrology. This is particularly important in arid environments such as the region around GUMO. Surface waters, including springs and seeps, are integral to maintaining the natural diversity found within the park (NPS 1990). McKittrick Creek (Photo 31), Choza Spring, and Choza Creek are of particular interest in the park "for perennial discharges that support stable riparian ecosystems" (Huff et al. 2006, p. 14) and were recognized by the Texas State Legislature in 2007 as "ecologically unique river and stream segments" (Porter et al. 2009, p. 11).

**Photo 31.** McKittrick Creek in Lower McKittrick Canyon (photo by Andy Nadeau, SMUMN GSS, 2012).

The hydrology of GUMO is influenced by three separate aquifers. In order of relevance to the park's water supply, these aquifers are: 1) the Capitan, 2) the Bone Spring-Victorio Peak, and 3) the Salt Bolson and Delaware Mountain Group (Porter et al. 2009). Within the park, the Capitan aquifer has both confined (overlain by another layer that limits groundwater flow) and unconfined (in direct contact with the surface or water table) components (Hearst, written communication, 4 October 2012). The confined portion currently supplies the majority of the park's domestic water through the Pine Springs well, as well as fresh water for the city of Carlsbad, New Mexico. The unconfined portion supports numerous natural springs and seeps throughout the park (Maher 2009, Porter et al. 2009). The Bone Spring-Victorio Peak aquifer underlies the Capitan aquifer in the park, and extends west of the park into Hudspeth County.

This aquifer is the source of the public water supply for Dell City, Texas, just west of the park, but otherwise is used primarily for irrigation (Porter et al. 2009). The final aquifer, the Salt Bolson and Delaware Mountain Group, lies under the salt flats on GUMO's western edge. Water from this aquifer is typically of low quality and not suitable as drinking water (Porter et al. 2009). All three aquifers are recharged by precipitation infiltration, subsurface inflow from adjacent aquifers, leakage from surface water bodies, and irrigation returns (Porter et al. 2009). In the GUMO region, aquifer recharge is limited by precipitation patterns (frequency and amount) and extremely high evaporation rates (Porter et al. 2009).

For this assessment, hydrology will be evaluated using stream and spring flow rates and depth to groundwater, which can indicate groundwater availability. Shallow groundwater aquifer flow rate and direction (important for recharge) and groundwater water quality will also be discussed, as they are important to the park (Hearst, interview, 25 January 2012).

### *Measures*

- Stream and spring flow rates
- Depth to groundwater
- Shallow groundwater aquifer flow rate and direction
- Groundwater water quality

### *Reference Conditions/Values*

Historic information regarding hydrology in the GUMO region is extremely limited. Therefore, the reference conditions for this component will be to maintain the current (2012) shallow groundwater table and no further degradation of groundwater water quality.

### *Data and Methods*

A wide variety of hydrological data and observations have been gathered in the GUMO area. Several unpublished NPS reports, summaries, and records of correspondence from the late 1960s and 1970s are on file at the park, which include some information on spring and well flow rates and test well findings. Several years of flow rate data are available for Smith Spring from this time period. A 1976 USGS report on the Dog Canyon water supply provides some information regarding spring flow and groundwater in that area (USGS 1976). The park's springs were surveyed and described in 1990 and 1991, and flow rates were again measured (NPS 1990, 1991). Springs and seeps were also visited, photographed, and described in 2000; flow rates were not measured, although observers did note if a spring or seep was dry (NPS 2000).

More recently, Andersen (2003) measured stream flow rates below Choza and Smith Springs. Porter et al. (2009) provides basic information regarding hydrology in GUMO and the surrounding region, as well as some depth to groundwater readings. Additional groundwater depth and some water quality data were obtained online through the Texas Water Development Board (TWDB) website (http://www.twdb.state.tx.us/groundwater/data/gwdbrpt.asp). Brown (1997) and Huff and Chace (2006) provided information on groundwater water quality for the aquifers as a whole.

***Current Condition and Trend***

Stream and Spring Flow Rates

Flow rate data for the park's springs and streams are limited and sporadic. The most consistent records are for Smith Spring (Photo 32), which was sampled somewhat regularly from 1969 to 1974. During this time, the spring flow generally ranged from 30 to 45 gallons per minute (gpm) (Table 53). When the flow rate was measured in 1990 and 1991, it was much lower, at 7.6 and 9.6 gpm respectively (NPS 1990, 1991). While some of this variation could be due to different sampling methods, it seems highly likely that the flow rate at Smith Spring declined between the 1970s and 1990s. However, the spring was flowing at 20.45 gpm during a 2010 CHDN spring survey, which is closer to historical measurements (NPS 2010).

**Photo 32.** Smith Spring at its source in 2000 (NPS photo).

**Table 53.** Smith Spring flow rates in gallons per minute (gpm) (NPS 1972, 1976, 1990, 1991, 2010). Measurements from 1968-1972 were primarily calculated with a formula for a 90° v-notch weir. 1990-91 readings were measured by timing how long it took for the spring flow to fill a one-quart bottle. These measurements are therefore not directly comparable, as the weir method is likely more accurate than the bottle method (Gallo, written communication, 25 September 2012).

| Date | Flow (gpm) | Date | Flow (gpm) | Date | Flow (gpm) |
|---|---|---|---|---|---|
| 1968 | | 6/26 | 36 | 11/10 | 36 |
| 12/4 | 27 | 8/28 | 36-40 | 12/24 | 36 |
| 1969 | | 9/4 | 36-40 | 1974 | |
| 4/23 | 49 | 10/24 | 36-40 | 1/30 | 38 |
| 4/24 | 54 | 11/21 | 36 | 2/7 | 38 |
| 5/9 | 49 | 12/12 | 36 | 3/23 | 36 |
| 5/22 | 49 | 1972 | | 4/8 | 36 |
| 10/3 | 45 | Jan.-Feb. | 36 | 5/12 | 35 |
| 10/27 | 40 | 3/13 | 36 | 6/11 | 33 |
| 11/21 | 40 | 5/28 | 34 | 6/21 | 32 |
| 12/10 | 58 | 6/27 | 36 | 7/14 | 32 |
| 1970 | | 7/30 | 36-38 | 8/18 | 35 |
| 1/17 | 45 | 8/26 | 40 | 9/22 | 48 |
| 1/27 | 31 | 9/24 | 42 | 10/27 | 46 |
| 1/31 | 40 | 10/22 | 42 | 11/10 | 40 |
| 2/13 | 36 | 1973 | | 12/15 | 36 |
| 3/13 | 36 | 1/31 | 38 | 1975 | |
| 4/4 | 31 | 2/28 | 54-56 | 6/3 | 34 |
| 5/2 | 36 | 3/31 | 48 | 12/18 | 29 |
| 5/29 | 31 | 4/23 | 42 | | |
| 7/1 | 49 | 5/21 | 36-38 | 1990 | |
| 7/24 | 31 | 6/30 | 36-38 | 11/2 | 7.6 |
| 1971 | | 7/31 | 36-38 | 1991 | |
| 1/18 | 25 | 8/19 | 36-38 | 5/30 | 9.6 |
| 3/27 | 36 | 9/12 | 38-40 | 2010 | |
| 5/22 | 36 | 10/20 | 38-39 | 9/15 | 20.45 |

Some flow rate measurements were taken by the USGS and NPS at Dog Canyon Spring during the 1970s. According to USGS (1976), spring flow was measured at 0.5 gpm in 1972, 0.75 gpm in summer 1975, and ranged from 0.33 to 0.5 gpm from August to October of 1976. USGS (1976) also noted that in October 1976, Goat Spring was dry and silted in.

During 1969, 1990, 1991, and 2010 surveys, park staff measured flow rates at several springs in GUMO. These results are presented in Table 54, and locations of many of the sampled springs are shown in Plate 27. While flow rates were not measured during a 2000 spring and seep survey, staff did note if the site was dry (i.e., no water flow). Table 55 is a list of these dry springs and seeps. When the majority of these sites were revisited during a 2010 CHDN springs survey, they were all flowing but typically at low rates (<1 gpm) (NPS 2010).

**Table 54.** Flow rates in gallons per minute (gpm) for additional GUMO springs (NPS 1969, 1990, 1991, 2010). “Negligible” indicates flows were less than 0.2 gpm.

| | 1969 | Oct.-Dec. 1990 | May-June 1991 | Sept.-Oct. 2010 |
|---|---|---|---|---|
| Goat Spring | ~ 1 | .75 | -- | -- |
| Bone Spring | 2-3 | 7.81 | 0.8 | 2.34 |
| Vertical Spring | -- | 0.8 | -- | dry |
| Lower Guadalupe Spring | -- | -- | 2.7 | unmeasurable |
| Middle Guadalupe Spring | -- | -- | 2.1 | 3.14 |
| Upper Guadalupe Spring | 10 | >4.0 | 6.8 | 23.78 |
| Upper Pine Spring | 3-4 | >5.6 | 0.6 | 11.89 |
| Frijole Spring | 2-4 | >4.8 | 5.9 | 7.45 |
| Juniper Spring | very low | 1.25 | 0.2 | 1.14 |
| Choza Spring | 30 | 1.4 (at source) | -- | -- |
| Algae Spring | -- | 1.2 | negligible | 0.26 |
| McKittrick Nature Loop Spring | -- | 0.65 | negligible | 3.04 |
| Big Seep | -- | 0.5 | dry | 8.63 |
| Dam (Hunter's) Spring | -- | -- | 0.3 | 19.81 (at channel) |

**Table 55.** Springs and seeps with no flow during the 1991 and/or 2000 surveys (NPS 1991, 2000).

| Dry in 1991 and 2000* | Dry in 2000 |
|---|---|
| Cherry Seep | Mural Seep |
| Sharp Rock Seep | Madrone Spring |
| McKittrick Loop Seep | Algae Spring* |
| Big Seep | McKittrick Nature Loop Spring* |

* All springs that were dry in 1991 and 2000, along with Algae and McKittrick Nature Loop Springs, had low flows (<1 gpm) during a 2010 CHDN survey. Mural Seep and Madrone Spring were not surveyed in 1991 or 2010 (NPS 1991, 2010).

Stream flow rate data for the park are even more limited than spring flow data. Historical reports indicate that South McKittrick Creek flowed at 30-35 gpm near its source (NPS 1969), but stream flow was reported to range from 54 gpm above the Pratt Cabin to 328 gpm just below the cabin (USGS 1968). Andersen (2003) gathered stream flow data at several locations below Choza and Smith Springs (Table 56). At the time of his study, flow at Juniper Spring was “too low to measure”, but was estimated at <1 gpm (Andersen 2003).

**Table 56.** Seasonal and average stream flow rates in gpm below Choza and Smith Springs (Andersen 2003). Higher numbered sites are closer to the spring source and lower numbers are further downstream. In the case of Choza, CF3 is at the highway while CF1 is near the park boundary to the east. Coordinates for each location are provided in Andersen (2003).

| Location | Spring | Summer | Fall | Winter | Average |
|---|---|---|---|---|---|
| Choza Spring | | | | | |
| CF1 | 10.5 | 8.1 | 14.3 | 20.1 | 13.3 |
| CF2 | 16.2 | 12.1 | 16.9 | 21.0 | 16.6 |
| CF3 | 16.4 | 19.1 | 21.5 | 23.2 | 20.1 |
| Smith Spring | | | | | |
| SF1 | 35.2 | 44.0 | 49.0 | 29.2 | 39.3 |
| SF2 | 44.5 | 68.9 | 67.7 | 64.3 | 61.4 |

Depth to Groundwater

Few depth to groundwater readings are available for the park itself. Single measurements from wells in the park were published in Porter et al. (2009) and are given in Table 57 (locations shown in Plate 27).

**Table 57.** Depth to groundwater at five wells within GUMO (Porter et al. 2009).

| Well name | Water level (m) | Substrate/Aquifer |
|---|---|---|
| Pine Springs (Glover #13) | 666.3 | Capitan aquifer (Permian limestone) |
| McKittrick Canyon Ranger Station | 17.5 | coarse alluvium |
| Sara Ann (Dog Canyon) | 757.1 | limestone |
| Signal Peak | 109.0 | Capitan aquifer (Permian limestone) |
| PX | 71.4 | --- |

In 2010, the NPS initiated a groundwater level monitoring program at three wells in or near the park. Signal Peak, PX, and Lemonade Wells (Plate 27) are manually sampled on a quarterly basis, and sensors record water levels every 6 hours (Filippone et al. 2012). This effort has not yet yielded enough data to assess condition, but early results are included in Appendix G.

Longer-term, more consistent groundwater level records from wells near GUMO may provide some insight regarding groundwater conditions within the park. There is a privately-owned well tapping the Capitan aquifer south of the park (Culberson County Well 47-17-302), and a public observation well tapping the Bone Spring-Victorio Peak aquifer in Dell City (Hudspeth County Well 48-07-516) to the west of the park (see Plate 27 for locations). Records for the Culberson well are somewhat sporadic from 1958 to 2005, but the Dell City well has fairly consistent monthly readings from 1966 through the present (TWDB 2012a, b). Figure 28 shows quarterly measurements (January, April, July, October) from the Dell City well over the period of record, and Figure 29 presents the available annual measurements (all taken between November and February) for the Culberson County well. Readings from the Dell City well (Figure 28) clearly show the seasonal influence of withdrawals for irrigation.

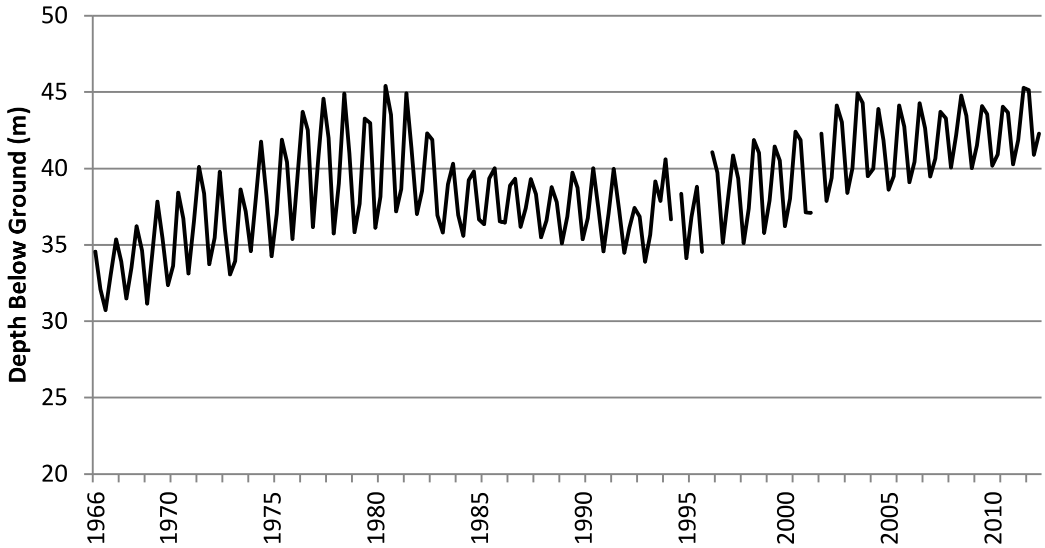



**Figure 28.** Quarterly depth to groundwater readings (Jan., April, July, Oct.) from the Dell City well (Hudspeth County Well 48-07-516), 1966- April 2012 (TWDB 2012a). Breaks represent months when readings were not taken. Peaks show the seasonal impact of withdrawals for irrigation.

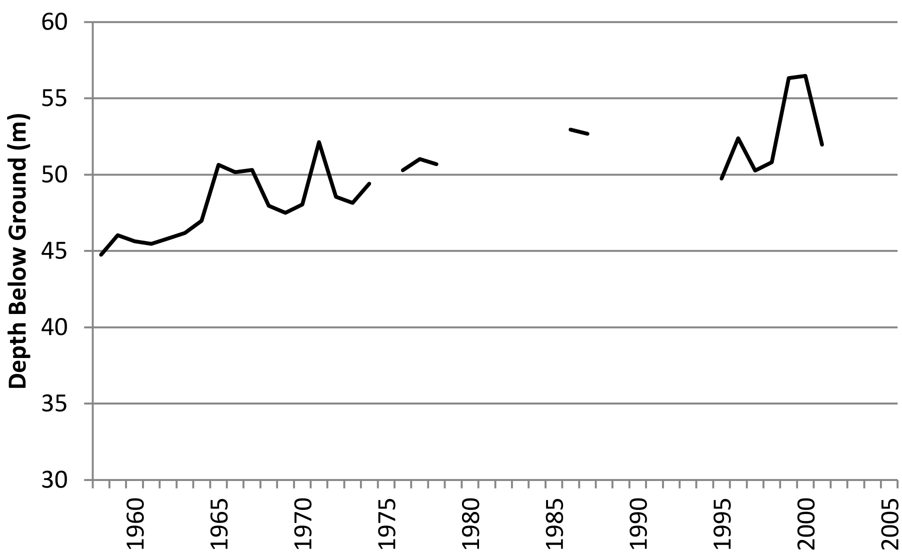



**Figure 29.** Annual depth to groundwater readings from Culberson County Well 47-17-302, 1958-2005 (TWDB 2012b). Gaps indicate years when measurements were not taken.

While water levels in these wells have not shown any dramatic changes over the period of record, the shallowest depths to groundwater at the Dell City Well appear to be increasing (i.e., the groundwater table is not rising as high). In the late 1960s and early 1970s, groundwater regularly rose to less than 35 m below ground during the winter. For the past several years, groundwater has not risen to within 40 m of ground level (Figure 28). The high water levels in the mid-1990s are likely associated with three years (1994-1996) of increased precipitation in the region (Porter et al. 2009).

Shallow Groundwater Aquifer Flow Rate and Direction

The flow rate and direction of shallow groundwater specifically under the park have not been studied. However, regional patterns in direction have been identified for the individual aquifers. In the Capitan aquifer, groundwater flow is primarily toward the east, away from GUMO (Uliana 2001). Groundwater in the Salt Basin (Bone Spring-Victorio Peak and Salt Bolson aquifers) west of the park generally flows to the south or southeast, away from recharge areas in the north (Huff and Chace 2006). No information could be found regarding groundwater flow rates.

Groundwater Water Quality

Little quantitative data exists regarding groundwater water quality within the park. The results from a single water quality sample collected during a 1971 pumping test of the Pure Well (location shown in Plate 27), which taps the Bone Spring-Victorio Peak aquifer, are presented in Table 58. Groundwater in the Bone Spring-Victorio Peak aquifer is described as hard and brackish with high dissolved solids concentrations, generally ranging from 1,000-6,500 mg/L (Ashworth 1995, Huff and Chace 2006). Groundwater from the Salt Bolson and Delaware Mountain Group aquifer is typically “too highly mineralized to be suitable drinking water” (Porter et al. 2009, p. 87).

**Table 58.** Groundwater water quality sampling results for the Pure Well, 1971 (USGS 1971). All values, with the exception of specific conductance and pH, are in mg/L.

| Parameter | Concentration (mg/L) | Parameter | Concentration (mg/L) |
|---|---|---|---|
| specific conductance | 2,100 µmhos | bicarbonate | 260 |
| pH | 7.3 | sulfate | 360 |
| silica | 18 | chloride | 380 |
| iron | 0.17 | fluoride | 0.7 |
| calcium | 150 | nitrate | 29 |
| magnesium | 80 | phosphate | 0.01 |
| sodium | 190 | dissolved solids | 1,350 |
| potassium | 4.1 | hardness (as $CaCO_3$) | 710 |

Some high-quality water is found in the Capitan aquifer, “on and near areas of recharge where the reef is exposed at the surface in the Guadalupe and Glass Mountains” (Uliana 2001, p. 164). In most areas, the Capitan aquifer groundwater is high in dissolved solids including sodium, chloride, and sulfate. The average total dissolved solid concentration of water samples from 17 wells across the Capitan reef was 3,059 mg/L, with an average chloride concentration of 881 mg/L (Brown 1997). Several groundwater samples from the GUMO region also showed high levels of iron and manganese (Brown 1997). pH across all samples averaged 7.1 with an average total alkalinity of 245 mg/L, while samples from Culberson and Hudspeth Counties yielded an average specific conductance of 1,552 micromhos. A summary of selected groundwater water quality measurements from Capitan aquifer wells in Culberson and Hudspeth Counties over time, as compiled by Brown (1997), is presented in Table 59.

**Table 59.** Average selected groundwater water quality measurements (in mg/L) from wells in Culberson and Hudspeth Counties over time (Brown 1997).

| | 1950-1959 | 1960-1969 | 1970-1979 | 1980-1989 | 1990-1995 |
|---|---|---|---|---|---|
| Chloride | 117 | 142 | 265 | 185 | 283 |
| Dissolved solids | 986 | 1,050 | 1,493 | 1,002 | 1,289 |
| Fluoride | 1.20 | 1.36 | 1.56 | -- | 0.94 |
| Hardness | 634 | 671 | 823 | 673 | 625 |
| Sulfate | 423 | 430 | 615 | 395 | 453 |

Groundwater sampling was conducted on the Culberson County well (Well 47-17-302) tapping the Capitan aquifer near GUMO in 1967 and 2003 (TWDB 2012c). Table 60 shows these results. The majority of these measures have remained relatively stable over time.

**Table 60.** Groundwater water quality sampling results from Culberson County Well 47-17-302 (TWDB 2012c). All measurements are in mg/L, with the exception of pH and specific conductance, which is measured in µmhos.

| | June 1967 | March 2003 |
|---|---|---|
| pH | 7.9 | 6.15 |
| silica | 15 | 17.8 |
| calcium | 156 | 160 |
| magnesium | 66 | 66.1 |
| sodium | 83 | 82.4 |
| sulfate | 411 | 403 |
| chloride | 117 | 111 |
| fluoride | 1.4 | 1.03 |
| dissolved solids | 996 | 991 |
| specific conductivity | 1,870 µmhos | 1,422 µmhos |
| hardness (as $CaCO_3$) | 660 | 674 |

Threats and Stressor Factors

Threats to the park's hydrology include a proposed desalination plant just west of the park, water withdrawals for irrigation and development, and increasing demand from growing cities in the region, such as El Paso and Fort Bliss, Texas. Groundwater withdrawals from the Bone Spring-Victorio Peak aquifer in recent times have been primarily for irrigation; these withdrawals have reportedly stabilized or even declined since the 1980s (Huff and Chace 2006). While some water is withdrawn from the Capitan aquifer for irrigation, most of the withdrawals are for oil developments in counties east of the park. These developments have actually influenced regional groundwater flow patterns in the aquifer (Hiss 1980, as cited in Porter et al. 2009). Other energy developments in the area, such as solar farms, could also increase the demands on regional groundwater. Groundwater levels in observation wells near GUMO seem to be negatively impacted by droughts, which could potentially increase in frequency and severity with future climate change (Porter et al. 2009).

Perhaps the greatest threat to the park's hydrology is the desalination plant, which has been proposed to meet increasing demand for freshwater in the region, particularly in growing urban areas such as El Paso (U.S. Water News 2004). This plant in the Dell City area could remove approximately 60,000 acre feet of groundwater from the Bone Spring-Victorio Peak aquifer annually for transport to El Paso's Public Water Utilities (Mrkvicka 2004). Groundwater water quality is also threatened by the disposal of brine, a byproduct of the desalination process. A private landowner in the area has proposed pumping the brine into playas on salt flats on his property (Mrkvicka 2004). If the brine were to "leak" out of the playa, the underlying groundwater would become contaminated (Younos 2005).

Data Needs/Gaps

Updated information is needed regarding spring and stream flow rates, depth to groundwater (being addressed by recent NPS monitoring effort), and groundwater water quality. Consistent monitoring of these measures would be required to determine if changes are occurring over time. Also, there is no information on shallow groundwater flow rate or direction within the park. Lastly, research into groundwater recharge rates would help managers better understand the potential impacts of further development on the aquifers under the park (Huff and Chace 2006).

Overall Condition

*Stream and Spring Flow Rates*

The project team assigned this measure a *Significance Level* of 2. While spring flow rates seemed low during the 1990s (e.g., many springs and seeps were dry), measurements taken during a 2010 CHDN survey were higher and not a particular cause of concern. However, given the inconsistency of historic measurements and lack of recent stream flow data, *Condition Level* could not be assigned for this measure.

*Shallow Groundwater Aquifer Flow Rate and Direction*

This measure was assigned a *Significance Level* of 3. Little is known about groundwater flow direction and no flow rate measurements are available for the park's aquifers. Therefore, a *Condition Level* could not be determined.

*Depth to Groundwater*

The depth to groundwater measure was also assigned a *Significance Level* of 3. Measurements from the Dell City Well west of the park suggest that groundwater in the Bone Spring-Victorio Peak may not be rising as high during times of recharge as in the past (see Figure 28). This may be a concern for the park, but with very limited information from wells within GUMO boundaries, a *Condition Level* could not be assigned. In the future, depth to groundwater data currently being gathered by the new NPS monitoring program can serve as baseline data for evaluating the condition and any trends for this measure.

*Groundwater Water Quality*

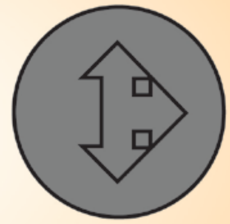
The project team assigned the groundwater water quality measure a *Significance Level* of 3. While some information is available regarding the water quality of the aquifers underlying GUMO as a whole, no measurements have been taken specifically within the park. As a result, a *Condition Level* could not be assigned.

*Weighted Condition Score*

A *Weighted Condition Score* was not calculated for GUMO hydrology, since *Condition Levels* could not be assigned for any of the measures. Further information is needed regarding the park's hydrology before its overall condition can be fully assessed.

# Hydrology

| Measures | SL | CL |
|---|---|---|
| • Stream & spring flow rates | 2 | n/a |
| • Groundwater flow rate & direction | 3 | n/a |
| • Depth to groundwater | 3 | n/a |
| • Groundwater water quality | 3 | n/a |



WCS = N/A

***Sources of Expertise***

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Kirsten Gallo, CHDN Program Coordinator

Jonena Hearst, GUMO Geologist

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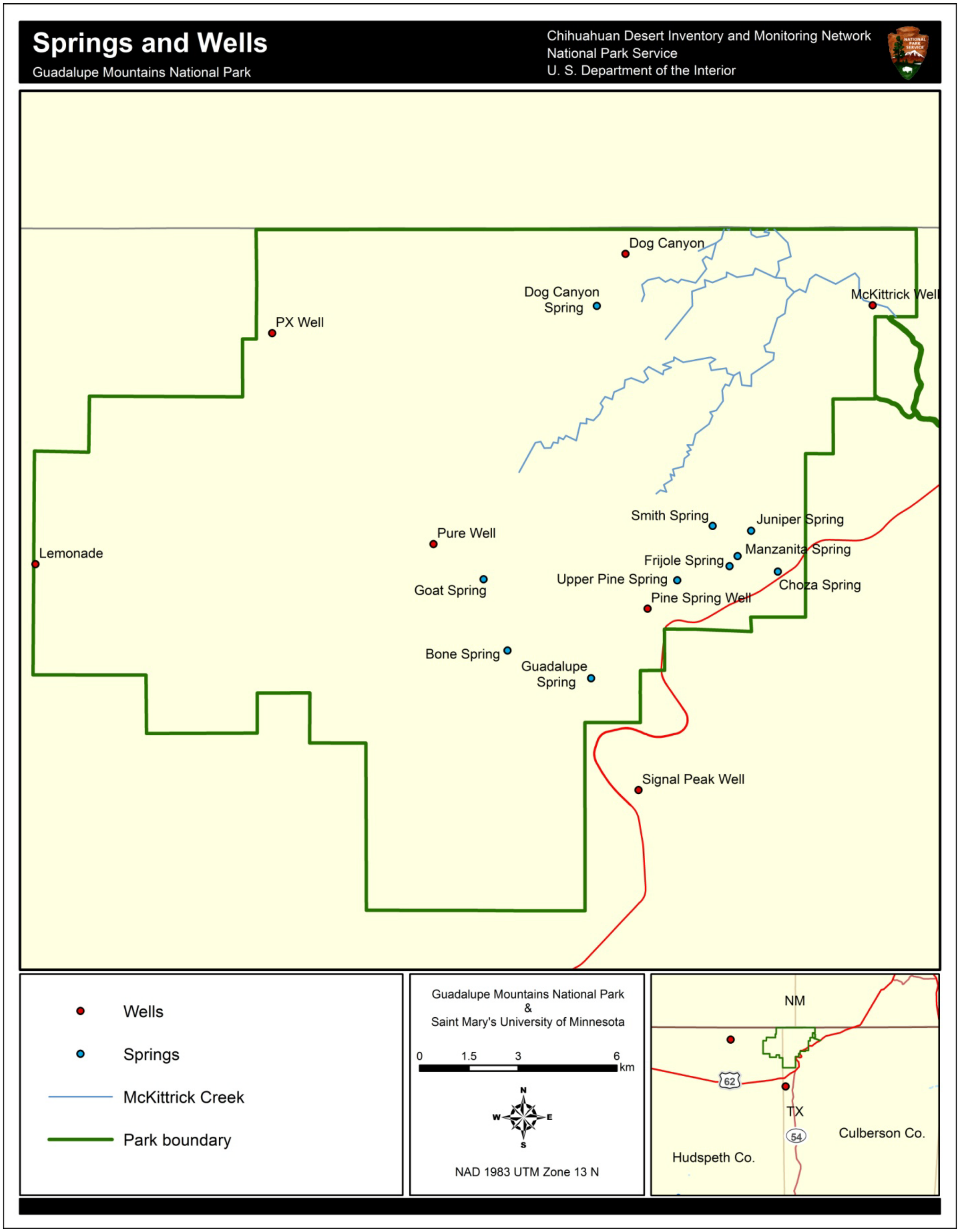



**Plate 27.** Springs and wells with available flow rate or depth to groundwater data. The locator map in the lower right shows the locations of the two TWDB observation wells outside the park.

## 4.16 Geological and Paleontological Resources

***Description***

The geological and paleontological resources found within GUMO were among the primary reasons for the park's establishment. The park contains nearly 18 km (11 mi) of the western edge of the Capitan Reef, "the world's most extensive and well-exposed fossil reef" (NPS 2009, p. 3). This reef formed during the Middle Permian Period (260-270 million years ago [mya]), when an ancient inland sea in a depression called the Delaware Basin covered part of present-day west Texas (Weeks et al. 2008, NPS 2009). Three global stratotypes (the reference examples in the geological world from a given time period) and several type sections (where geological formations were first described and to which all similar rocks can be compared) occur within park boundaries (Santucci et al. 2007, NPS 2009). The park's geologic units are broadly divided into three groups based on lithology and hydrogeology (Weeks et al. 2008, Figure 30):

- the backreef or shelf (formed in shallow lagoon waters behind the reef);
- the Capitan reef and forereef;
- basin sediments (material deposited on the deep ocean floor).

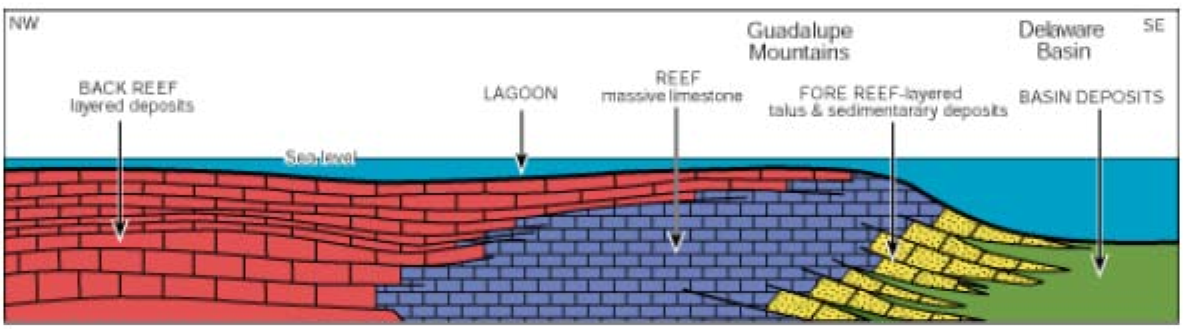



**Figure 30.** Relative locations of the three geological unit groups: basin sediments (green), Capitan reef and forereef (purple and yellow), and back reef or shelf (red) (from Weeks et al 2008).

The Capitan Reef was formed over millions of years by lime-secreting organisms such as sponges and algae, as well as by lime ($CaCO_3$) precipitating out of seawater directly (NPS 2009). When the inland sea evaporated, the reef was buried in sediment and remained covered until 20-30 million years ago, when the reef was uplifted and exposed by erosion, forming the Guadalupe Mountains. Permian fossils are common and diverse in the Capitan Reef formation, and at least 22 fossil type localities (where a fossil species was first reported) exist in the park (NPS 2009). An estimated 800-1,200 fossil species occur in GUMO, although this may be an underestimate as a thorough census has not been completed, and weathering constantly exposes new specimens (NPS 2009). Identified fossil species include calcareous sponges and algae, bryozoans, brachiopods, fusulinids (unicellular organisms that went extinct at the end of the Permian), echinoderms (e.g., sea urchins and sea lilies), mollusks (snails, clams, and cephalopods), trilobites, conodonts (extinct eel-like chordates), and fish, including sharks (Santucci et al. 2007, Weeks et al. 2008, Photo 33). GUMO's Permian Reef Trail (located in the northeast corner of the park) has been characterized as a "premier outdoor geology exhibit" and is visited by 40-50 geology classes each year (Bell et al. 2002).


**Photo 33**. Fossils of GUMO (clockwise from top left): sponges, a cephalopod, an echinoderm (SMUMN GSS photo by Andy Nadeau, 2012), a brachiopod, and a crinoid (sea lily) (photos from Coleman and Coleman 2010, unless otherwise indicated).

The park formations also contain at least five limestone caves which have yielded fossils of Pleistocene and early Holocene animals and plants (Santucci et al. 2001, NPS 2009). More than 100 fossil species have been identified in these caves, including ground sloths, horses, antelope, and a large vulture (NPS 2009). As part of the RSS process, the park produced a map showing relative concentrations of paleontological resources (e.g., known paleontological sites, areas of high paleontological potential, critical specimens, etc.) (Figure 31).

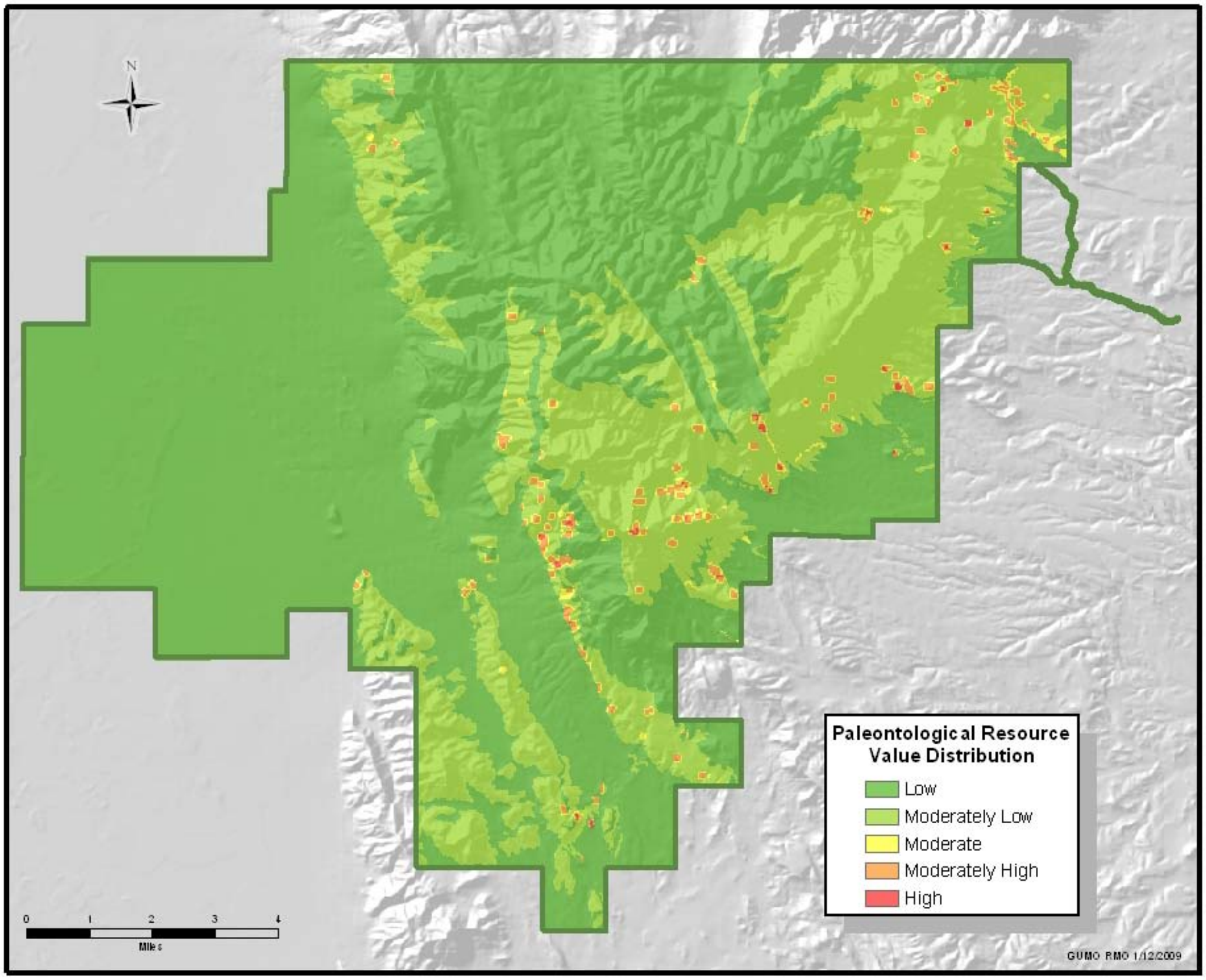



**Figure 31.** Relative concentration of paleontological resources across GUMO (NPS 2009).

### *Measures*

- Change in specimen abundance at paleontological localities (based on "actual loss score")
- Annual number of case incident reports related to geological/paleontological sites
- Documentation of geological/paleontological sites in the park

### *Reference Conditions/Values*

The reference condition for change in specimen abundance, based on the park's RSS (NPS 2009), is an actual loss score of 20 for each locality. For number of case incident reports, reference condition will be no annual increase over a 5-year period. The ideal reference condition for site documentation would be 100% documentation of all sites in the park. However, this is not practical since new features and sites are constantly exposed by natural processes. As a result, no reference condition is designated for this measure.

### *Data and Methods*

Paleontological and geological research at GUMO has been extensive. The majority of this work is specific to testing of geological and paleontological hypotheses, and is not applicable to a park-wide assessment of paleontological/geological resource condition. Santucci et al. (2007) prepared a paleontological resource inventory report for the CHDN which included GUMO. The goal of this report was "to consolidate baseline paleontological resource data for each park to support management operations and decision-making" (Santucci et al. 2007, p. 5). This inventory included an intensive literature search covering databases maintained by the American Geological Institute, NPS, and USGS, "gray literature" such as park files and museum archives, and even interviews with local experts (Santucci et al. 2007). The results were compiled into a report which includes a history of paleontological research in the parks and a comprehensive list of related publications.

Additional sources with broader overviews that were useful for this assessment include Weeks et al. (2008), Santucci et al. (2001), and the GUMO RSS (NPS 2009). Weeks et al. (2008) reviews the geology and paleontological features of the area as well as discussing potential inventory and monitoring efforts and threats to the resources. Santucci et al. (2001) summarizes the paleontological resources associated with the park's caves, while the RSS (NPS 2009) provided a variety of information regarding the park's paleontology and geology.

### *Current Condition and Trend*

Change in Specimen Abundance at Paleontological Localities (based on "actual loss score")

The park has chosen to evaluate the condition of its geological and paleontological resources using the actual loss score variable on the Paleontological Locality Condition Evaluation Form (NPS 2005) developed by the NPS Geologic Resources Division (NPS 2009). Actual loss scores range from zero to 20, with zero indicating "significant and noticeable disappearance of fossils" from a locality on a seasonal basis and 20 meaning no significant change in the number of fossils at a site from year to year (NPS 2005). As of 2010, 100 paleontological localities in the park had been evaluated with this method. Ninety-eight received a score of 20 while two showed moderate loss and received a score of 10 (Hearst, e-mail communication, 16 July 2012).

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

Since 2006, there have only been two case incident reports (in separate years) involving geological or paleontological sites (Hearst, e-mail communication, 16 July 2012). The loss of two fossils from the Permian Reef Trail was noted in March of 2010; the exact date (or dates) of the loss is unknown. One specimen on the Tejas Trail was lost due to trail work. This prompted the development of maintenance protocols to identify areas of concern prior to trail work, and no specimens have been impacted since (Hearst, e-mail communication, 16 July 2012).

Threats and Stressor Factors

Most of GUMO's geological and paleontological resources are protected by their inaccessibility. Resources located along trails or other areas accessible to visitors are of the highest concern and are most frequently monitored by park staff. Threats to the park's paleontological and geological resources include theft and vandalism, visitor use, trail maintenance and development, and inappropriate sampling techniques by researchers.

One visitor use of high concern is geology classes and field schools. Many of these groups contact the park prior to visiting so that staff can provide guidance and monitor their use. However, there have been occasions when groups arrive without notifying the park. Staff may be unaware of their presence and are therefore unable to guide or monitor their visit (Hearst, pers. comm., 25 January 2012). Inappropriate sampling techniques, particularly tool use, are also a threat from both geology field schools and other researchers, as these techniques could damage or even destroy fossils and render outcrops difficult for researchers to use (Hearst, written communication, 4 September 2012).

Data Needs/Gaps

Weeks et al. (2008) provided a list of data gaps or other needs for the paleontological and geological resources of GUMO which included the following:

- Continue to explore areas for undocumented paleo resources;
- Map new localities;
- Protect specific stratotype and fossil locations;
- Catalog collected and salvaged fossils of significance;
- Incorporate protection of paleontological resources into planning efforts such as a trail management plans and develop a geological resources management plan;
- Partnership opportunities on research – develop a park needs list for research and market it to researchers;
- Document specimens and localities from other institutions;
- Database management and GIS inventory upkeep for paleo resources.

Survey and mapping work is currently limited to locations where new construction or other projects will disturb the ground (Hearst, e-mail communication, 27 June 2012). The park's geological resource management plan should be completed within the next 2-3 years and trail monitoring guides are in development.

Overall Condition

*Change in Specimen Abundance at Paleontological Localities (based on actual loss score)*
The project team assigned this measure a *Significance Level* of 3. As of 2010, 98 of 100 localities evaluated received an actual loss score of 20, which has been defined as the reference condition for this measure. Only two localities did not meet this standard with scores of 10, indicating moderate loss. The *Condition Level* for change in specimen abundance is therefore a 1, or of low concern.

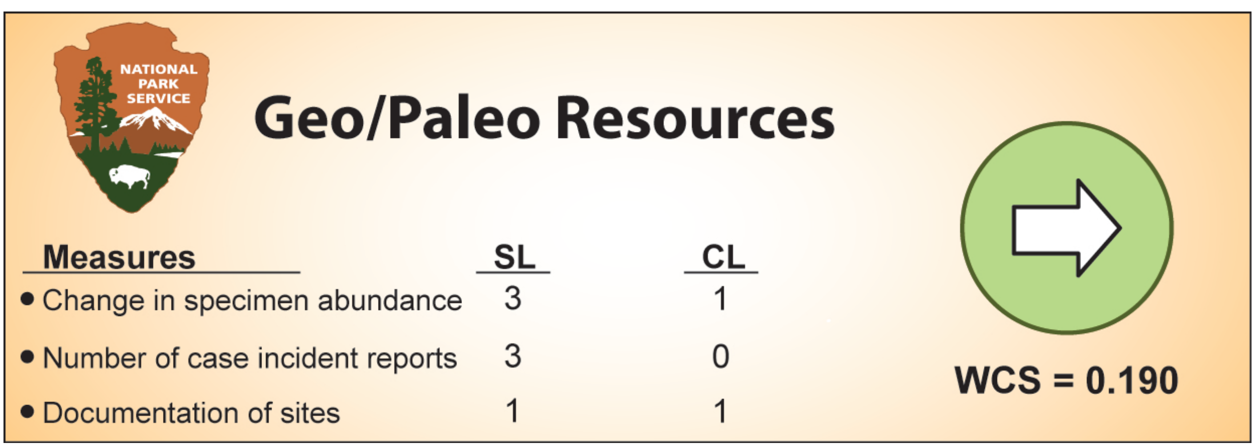
*Annual Number of Case Incident Reports Related to Geological/Paleontological Sites*
This measure was also assigned a *Significance Level* of 3. No more than one case incident involving geological or paleontological sites has been reported over the past six years, and only two total incident reports occurred during this time. As a result, this measure is currently of no concern (*Condition Level* = 0).

*Documentation of Geological/Paleontological Sites in the Park*
The documentation measure was assigned a *Significance Level* of 1. According to Weeks et al. (2008, p. 49), "no comprehensive systematic inventory of paleontological resources has occurred at the park due to the overwhelming scope of the task." An estimated 11,000 ha (27,000 ac) of the park are considered to have a high potential to contain fossil resources (Weeks et al. 2008). A formal inventory of GUMO's paleontological resources began in 2000 and is ongoing. As of July 2012, 574 paleontological and geological localities have been documented in the park (Table 61; Hearst, e-mail communication, 16 July 2012). Documentation efforts will continue as personnel and resources are available. Given the size of the park, the wide distribution and prevalence of resources, and the fact that new resources are constantly exposed by natural processes, complete documentation of every site is highly unlikely. Therefore, this measure is of low concern (*Condition Level* = 1).

**Table 61.** Number of paleontological and geological localities by significant feature type (Hearst, e-mail communication, 16 July 2012).

| Significant features | Number of localities |
|---|---|
| Caves/karst features only | 28 |
| Geology only | 150 |
| Geology and historic site | 1 |
| Paleontology only | 72 |
| Geology and paleontology | 312 |
| Caves and paleontology | 7 |
| Caves, paleontology, and archeology | 2 |
| Geology, archeology, and paleontology | 2 |

*Weighted Condition Score*
The *Weighted Condition Score* for GUMO's geological and paleontological resources is 0.190, indicating good condition. Given the high actual loss scores and rarity of case incident reports, the trend in condition appears to be stable. Continued monitoring efforts should ensure that these significant physical resources are available for study and visitor enjoyment for many years to come.




***Sources of Expertise***
Jonena Hearst, GUMO Geologist

***Literature Cited***

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# Chapter 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 62 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 62.** Identified data gaps or needs for the featured components.

| Component | Data Gaps/Needs |
|---|---|
| Fire Regime | ➢ Impacts of fuel reduction methods on forest structure<br>➢ Natural role of fire in park plant communities other than montane forest<br>➢ Potential for exotic plant species invasion following fire |
| Dune Communities | ➢ Acquire high-resolution mapping (e.g., LiDAR) of the dunes and surrounding areas to evaluate dune dynamics<br>➢ Inventory and mapping of biological soil crusts<br>➢ Status of rare plant species<br>➢ Potential effects of climate change, particularly drought<br>➢ Potential impacts of proposed desalination plant |
| Sky Islands (Montane Forests) | ➢ Data regarding incidence of diseases and pests<br>➢ Potential effects of climate change |
| Riparian and Canyon Communities | ➢ Updated macroinvertebrate sampling of McKittrick Creek<br>➢ Application of a broad, multidimensional riparian assessment tool, repeated over time<br>➢ Exotic plant survey to better understand these species' impacts on park riparian areas |
| Semidesert Grasslands | ➢ Grassland response to elimination of grazing<br>➢ Effects of climate change (increased potential for drought)<br>➢ Establishment of annual winter grassland bird survey |
| Desertscrub | ➢ Vegetation's response to cessation of grazing<br>➢ Thorough study of heteromyid community for comparison to 1970s research |
| Birds | ➢ Continuation of annual BBC and CBC<br>➢ Increased sampling frequency (more than once per year) to allow for density and occupancy estimation. |

**Table 62.** Identified data gaps or needs for the featured components. (continued)

| Component | Data Gaps/Needs |
|---|---|
| Reptiles | ➢ Updated surveys to determine current diversity and distribution, and for comparison to earlier research |
| Mountain Lion | ➢ Contemporary survey of park for comparison to previous surveys<br>➢ Further study of lion movements in and out of the park<br>➢ Effects of competition between mule deer (primary prey) and aoudad |
| Air quality | ➢ Monitoring of pollution-sensitive plant species/communities |
| Water quality | ➢ Lack of comparable historic and recent data; need for consistent sampling (methodology and timing) over time |
| Soundscape | ➢ Collection of baseline data<br>➢ Development of a monitoring protocol |
| Viewscape | ➢ Continued development of spatial data to explain landscape change |
| Dark night skies | ➢ Obtain baseline data/analysis from NPS Night Sky Team |
| Hydrology | ➢ Updated information on spring/stream flow rates and groundwater water quality<br>➢ Shallow groundwater flow rate and direction information<br>➢ Research into groundwater recharge rates |
| Paleontological features | ➢ Continued exploration, mapping, documentation, and monitoring efforts |

Many of the park's data needs involve repeating previous surveys in order to compare current information to historic data (e.g., reptiles, mountain lions, rare plants); such a comparison would help to determine any changes in resource condition over time. Other components, such as water quality and hydrology, would benefit from more consistent sampling efforts (both timing and methodology); some of these needs are being addressed through recently implemented CHDN monitoring efforts. Data are lacking for several measures within the dune communities component (e.g., biological soil crusts, mapping to study dune dynamics), partially due to the fact that this area was not added to GUMO until 1987. The only component for which no data exists is soundscape. Park staff plan to use protocols from the NPS Natural Sounds Program to begin gathering information regarding this resource.

## 5.2 Component Condition Designations

Table 63 displays the conditions assigned to each resource component presented in Chapter 4 (definitions of condition graphics are located in Figure 32 below). It is important to remember that the graphics presented 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 Figure 32) 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 GUMO, current condition could not be determined for 9 of the 16 components (56%) due to these data or knowledge gaps.

For featured components with sufficient data and fewer knowledge gaps, assigned conditions varied. Four components are considered to be of low concern: semidesert grasslands, birds, viewscape, and geological and paleontological resources. Just two components (air quality and sky islands [montane forest]) are of moderate concern. Fire regime is the only component of high concern, primarily due to the fuel buildup from past land management and weather conditions that often prohibit fuel-reducing prescribed burns.

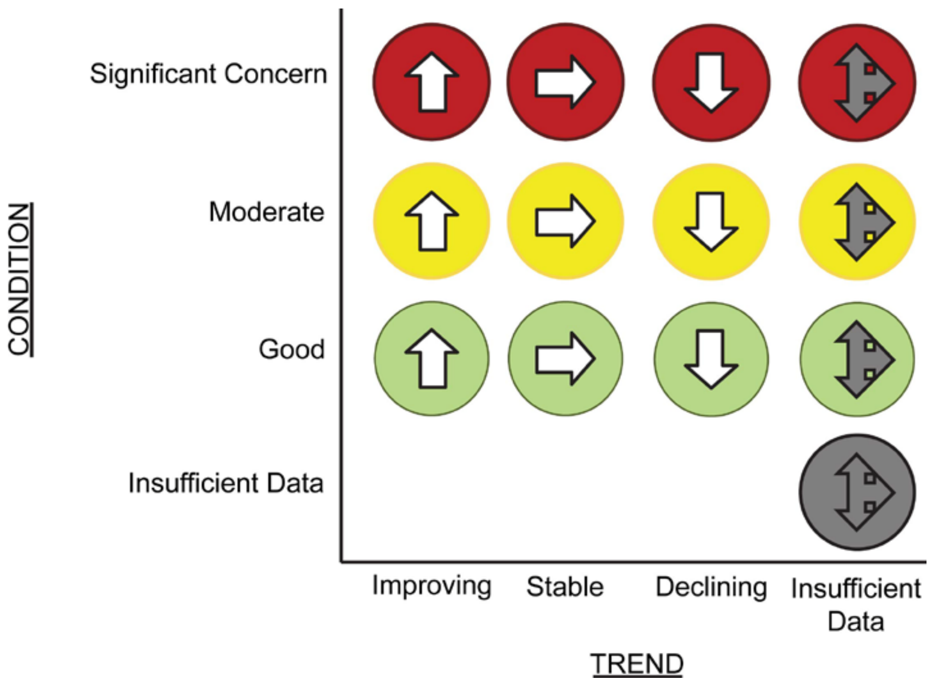



**Figure 32.** Symbols used for individual component assessments with condition or concern designations along the vertical axis and trend designations along the horizontal.

**Table 63.** Summary of current condition and condition trend for featured NRCA components. Higher Weighted Condition Scores indicate higher concern.

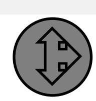
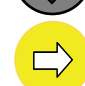
| Component | WCS | Condition |
|---|---|---|
| **Ecosystem Extent and Function** | | |
| *Disturbance Regimes* | | |
| Fire regime | 0.758 |  |
| **Biological Composition** | | |
| *Ecological communities* | | |
| Dune communities | N/A |  |
| Sky islands (montane forest) | 0.167 |  |

**Table 63.** Summary of current condition and condition trend for featured NRCA components. (continued)

| Component | WCS | Condition |
|---|---|---|
| Riparian and canyon | N/A | |
| Semidesert grasslands | 0.333 | |
| Desertscrub | N/A | |
| *Wildlife* | | |
| Birds | 0.292 | |
| Reptiles | N/A | |
| Mountain lion | N/A | |
| **Environmental Quality** | | |
| Air quality | 0.533 | |
| Water quality | N/A | |
| Soundscape | N/A | |
| Viewscape | 0.167 | |
| Dark night skies | N/A | |
| **Physical Characteristics** | | |
| *Geologic & Hydrologic* | | |
| Hydrology | N/A | |
| Geological and paleontological resources | 0.190 | |

## 5.3 Park-wide Condition Observations

Despite the great variety in vegetation and physical features within GUMO's boundaries, many of the resources discussed in this report are interrelated and share similar management concerns (e.g., data gaps, threats from outside the park).

*Native Vegetation Communities*
The native vegetation communities of GUMO are vital resources for the park, providing habitat for wildlife and performing critical ecological functions, while attracting many visitors to the area. Due to a lack of comparable data over time (either historic information or current data for comparison), condition could not be assessed for three of the selected ecological communities: dune communities, riparian and canyon communities, and desertscrub. Of the communities that could be assessed, semidesert grasslands are considered of low concern while sky islands are of moderate concern. The condition of semidesert grasslands has improved since grazing ceased with park establishment (NPS 2012). Sky islands are considered stable, although a shift in forest structure (e.g., increased density, particularly of smaller trees and brush) since European settlement is of concern.

*Other Biotics*
Animals featured as NRCA components were birds, reptiles, and mountain lions. Due to a lack of recent data for comparison to historic information, condition and trend could not be determined for reptiles and mountain lions. However, there is no particular cause for concern for these species within the park. Predator control programs outside the park are of some concern for the mountain lion population, as animals that frequent GUMO likely also range outside the park. Birds are considered to be of low concern within GUMO with a stable trend. The variety of habitats within the park support a great diversity of bird species, including many species of conservation concern (see Appendix D).

*Environmental Quality*
Environmental quality is important in maintaining healthy functioning ecosystems. The health of terrestrial and aquatic organisms in parks can be affected substantially by the condition of air and water quality. The park’s air quality is currently of moderate concern with a stable trend. Nitrogen and sulfate deposition are a potential issue, due to the sensitivity of arid and semi-arid ecosystems to acidification and/or nutrient enrichment from these pollutants. A condition could not be assigned for GUMO water quality due to a lack of consistent, comparable data over time. However, of the water quality measurements that are available, the vast majority fall within established state and federal standards. No exceedences were detected for TDS, chloride, sulfate, or coliform bacteria.

The park’s viewscape is currently of low concern, with little land use change (e.g., conversion for development) occurring within the park or in outside areas visible from within park boundaries. Conditions could not be determined for soundscape or dark night skies because of little or no available data. Programs are in place or in development to address these data needs.

*Park-wide Threats and Stressors*
Several threats and stressors influence the condition of multiple resources throughout GUMO. These include the presence of exotic plants, energy development (e.g., oil, gas, wind), and the proposed desalination plant just west of the park. Exotic plant species are a threat to all of the park’s vegetation communities, as they can out-compete native plants and alter ecological processes such as fire regime and nutrient cycling (Brooks and Pyke 2001, Reiser et al. 2012). Non-native grasses, in particular, are a concern for semidesert grassland and desertscrub communities; these grasses may increase the frequency and/or intensity of fires beyond the natural regime, harming native plant species (Brooks and Pyke 2001).

Energy development (e.g., oil and gas, wind farms) in the area around GUMO would potentially affect the park's viewscape, dark night skies, soundscape, and air quality. If these developments require groundwater withdrawals, the park's hydrology and water quality could also be impacted. The proposed desalination plant, if approved, would result in major groundwater withdrawals from local aquifers. Waste byproducts from the desalination process may be stored in a playa basin on private property just 8 km (4.9 mi) west of the park (Mrkvicka 2004). If these waste products were to leak from the playa or from transport pipes, they may leach through the soil and contaminate the groundwater (Younos 2005). Dried waste products could also blow into the park, threatening its air quality and pollution-sensitive organisms, such as the biological soil crusts of the dune communities (Coles, written communication, November 2012).

*Overall Conclusions*

GUMO is an extremely diverse park, supporting a range of unique features, from the rare gypsum sand dune community to the internationally significant geological and paleontological features, and a great variety of wildlife species. 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 many components due to existing data gaps; several of these data gaps are being addressed through recently implemented CHDN monitoring programs. These programs will provide valuable information for condition assessment in the near future. For resources where condition could be assessed, the majority were of low concern with a stable trend. 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.** Lichen and plant species of dune communities

**Appendix A.** Lichen and plant species documented in GUMO dune communities, with habitat types and abundance (from Worthington and Reid 1985). Habitat types: 1 = gypsum dunes/interdunes, 2 = gypsum flats, 3 = playas, 4 = stabilized gypsum ridges, 5 = quartzose sand, 6 = gypsum-quartzose sand ecotone. Abundance: A = common, B = infrequent, C = rare, D = patchy. The second column indicates species that are considered rare or unique, according to Northington and Burgess (1979b). The final two columns show plant species that were also observed by Burgess and Klein (1978) in a survey of northern salt basin vegetation.

| Scientific name | Rare/unique species | Habitat types | Abundance | Burgess and Klein 1978 | |
|---|---|---|---|---|---|
| | | | | quartzose | gypsum |
| **Lichens** | | | | | |
| *Dermatocarpon lachneum* | | 4 | A | | |
| *Diploschistes steppicus* | | 4 | B | | |
| *Fulgensia desertorum* | | 4 | B | | |
| *Psora concava* | | 4 | B | | |
| *Psora decipiens* | | 4 | B | | |
| *Psora* sp. | | 4 | B | | |
| **Vascular Plants** | | | | | |
| *Ephedra torreyana* | | 1, 2, 5, 6 | A | x | x |
| *Yucca elata* | | 1, 2, 4, 5 | A | x | x |
| *Andropogon hallii* | | 1 | A, D | | x |
| *Aristida adscensionis* | | 2 | B | | |
| *Aristida purpurea* | | | | x | |
| *Bouteloua barbata* | | 1, 2, 6 | A, D | x | |
| *Bouteloua breviseta* | | 1, 2, 4, 6 | A | | x |
| *Muhlenbergia phleoides* | | 2 | B | | |
| *Munroa squarrosa* | | 1, 6 | A, D | x | |
| *Achnatherum hymenoides* | x | 1 | D | x | x |
| *Sporobolus airoides* | | 2 | A | | x |
| *Sporobolus contractus* | | 1, 2, 5, 6 | A | x | |
| *Sporobolus cryptandrus* | | 6 | B | x | |
| *Sporobolus flexuosus* | | 1, 5, 6 | A | x | x |
| *Sporobolus giganteus* | x | 1 | B | x | x |
| *Sporobolus nealleyi* | | 1 | B | | x |
| *Setaria reverchonii* ssp. *ramiseta* | x | | | x | |
| *Tidestromia lanuginosa* | | 2, 5 | A | x | |
| *Tiquilia hispidissima* | | 1, 2, 4, 5, 6 | A | | x |
| *Coryphantha scheeri* | | 6 | C | | |
| *Cylindropuntia imbricata* | | 2 | B | | |
| *Cylindropuntia leptocaulis* | | 2 | B | | x |
| *Opuntia polyacantha* | | 1, 2 | A | | x |
| *Opuntia macrocentra* | | 2 | B | | |
| *Allenrolfea occidentalis* | | 3 | A | | |
| *Atriplex canescens* | | 1, 2, 4, 5, 6 | A | x | x |

| Scientific name | Rare/unique species | Habitat types | Abundance | Burgess and Klein 1978 | |
|---|---|---|---|---|---|
| | | | | quartzose | gypsum |
| | | 1 | C, D | | |
| *Corispermum americanum* var. *rydbergii* | | | | | |
| *Suaeda suffrutescens* | | 3 | A | | |
| *Ericameria nauseosa* var. *glabrata* | | 2 | C | | |
| *Chrysothamnus pulchellus* | | 1 | B | | |
| *Dicranocarpus parviflorus* | x | 2 | A | | |
| *Gaillardia multiceps* | x | 1, 2, 6 | A | | x |
| *Gutierrezia microcephala* | | 5 | A | | |
| *Isocoma pluriflora* | | 2 | A | | x |
| *Lepidospartum burgessii* | | 4 | B | | |
| *Machaeranthera pinnatifida* var. *scabrella* | | 1, 2, 5, 6 | A | x | x |
| *Machaeranthera tanacetifolia* | | 2 | C | | |
| *Pectis papposa var. grandis* | | 5, 6 | B | x | |
| *Psilostrophe tagetina* | | 1, 2 | A | | |
| *Sartwellia flaveriae* | | 1, 2, 4 | A | | x |
| *Senecio flaccidus* var. *douglasii* | | 4 | B | | |
| *Senecio riddellii* | | 4 | C | | |
| *Senecio warnockii* | x | 2, 4 | B | | x |
| *Thelesperma megapotamicum* | | 1 | A | | |
| *Townsendia annua* | | 6 | B | | |
| *Gutierrezia sphaerocephala* | | 2 | B | | |
| *Dimorphocarpa wislizeni* | | 1, 2, 5, 6 | A | x | |
| *Lepidium alyssoides* var. *alyssoides* | | 2 | B | | x |
| *Nerisyrenia linearifolia* | | 1, 2, 4, 6 | A | | x |
| *Ibervillea tenuisecta* | | 1 | B, D | | |
| *Chamaesyce glyptosperma* | | 1 | B, D | x | |
| *Chamaesyce parryi* | | 6 | B | x | |
| *Chamaesyce serpyllifolia* | | 2 | B, D | | |
| *Croton dioicus* | | 5, 6 | B | x | |
| *Nama carnosum* | x | 1 | C | | |
| *Phacelia integrifolia* var. *texana* | | 1, 2, 4, 6 | A | | |

| Scientific name | Rare/unique species | Habitat types | Abundance | Burgess and Klein 1978 | |
|---|---|---|---|---|---|
| | | | | quartzose | gypsum |
| *Krameria erecta* | | 1 | A | x | |
| *Poliomintha incana* | | 1, 6 | A | | x |
| *Dalea lanata* var. *terminalis* | | 1 | B | x | x |
| *Prosopis glandulosa* | | 5, 6 | A | x | |
| *Psorothamnus scoparius* | x | 1 | B | x | x |
| *Mentzelia humilis* | x | 1, 2, 4, 6 | A | | x |
| *Abronia angustifolia* | | 1, 6 | A | x | |
| *Allionia choisyi* | | 2 | A, D | | |
| *Selinocarpus lanceolatus* | x | 4 | A | | x |
| *Oenothera pallida* | | 1, 6 | A | x | |
| *Penstemon ambiguus* | x | 1, 6 | B | | |
| *Lycium berlandieri* | | 4 | C | x | |
| *Tamarix ramosissima* | | 3 | C | | |
| *Kallstroemia parviflora* | | 2, 6 | B | | |
| *Larrea tridentata* | | 2 | B | | |
| *Gutierrezia sarothrae* | | | | x | |
| *Sphaeralcea hastulata* | | along road only | | x | |
| *Ephedra trifurca* | | | | x | |
| *Artemisia filifolia* | | | | x | |
| *Melampodium leucanthum* | | | | x | |
| *Chamaesyce fendleri* | | | | x | |
| *Amaranthus acanthochiton* | | | | x | |
| *Zephyranthes longifolia* | | | | x | |
| *Pomaria jamesii* | on red dunes only | | | | |

# **Appendix B.** Riparian/canyon plant and aquatic macroinvertebrate species lists

**Table B-1.** Plant species documented in McKittrick Canyon by Gehlbach (1965, 1967) and Lind (1979). Note that this list is not comprehensive as Gehlbach (1967, 1967) focused on dominant species and did not produce a full species list, while Lind (1979) listed only aquatic/riparian plants.

| Scientific name | Common name | Gehlbach (1965) - along trail | Gehlbach (1967) | Lind (1979) |
|---|---|---|---|---|
| **Trees** | | | | |
| *Acer grandidentatum* | bigtooth maple | x | x | |
| *Quercus muehlenbergii* | chinkapin oak | x | x | |
| *Ostrya knowltoni* | Knowlton's hophornbeam | x | | |
| *Quercus grisea* | gray oak | x | x | |
| *Mahonia haematocarpa* | red mahonia | x | | |
| *Arbutus xalapensis* | Texas madrone | x | x | |
| *Juniperus deppeana* | alligator juniper | x | x | |
| *Juniperus monosperma* | oneseed juniper | x | x | |
| *Juniperus scopulorum* | Rocky Mountain juniper | x | | |
| *Prunus serotina* | black cherry | | x | |
| **Shrubs** | | | | |
| *Rhus copallinum* | winged sumac | x | | |
| *Rhus trilobata* | skunkbush sumac | x | x | |
| *Lonicera albiflora* | white honeysuckle | x | | |
| *Rhus virens* | evergreen sumac | x | | |
| *Garrya wrighti* | Wright silktassel | x | | |
| *Fallugia paradoxa* | Apache plume | x | x | |
| *Mimosa biuncifera* | catclaw mimosa | | x | |
| *Mimosa borealis* | fragrant mimosa | | x | |
| *Nolina microcarpa* | sacahuista | | x | |
| **Ground layer** | | | | |
| *Cylindropuntia imbricata* | tree cholla | x | x | |
| *Yucca baccata* | banana yucca | x | | |
| *Opuntia engelmanni* | Engelmann pricklypear | x | x | |
| *Dasylirion leiophyllum* | green sotol | x | x | |
| *Muhlenbergia emersleyi* | bullgrass | x | | |
| *Piptochaetium fimbriatum* | pinyon ricegrass | x | | |
| *Rhynchosia senna* var. *texana* | Texas snoutbeam | x | | |
| *Tridens muticus* | slim tridens | | x | |
| *Erioneuron pilosum* | hairy woolygrass | | x | |
| *Bouteloua hirsuta* | hairy grama | | x | |
| *Bouteloua curtipendula* | sideoats grama | | x | |
| *Aristida purpurea* var. *nealeyii* | blue threeawn | | x | |
| **Riparian/Aquatic** | | | | |
| *Equisetum laevigatum* | smooth horsetail | | | x |
| *Polypogon viridis* | beardless rabbitsfoot grass | | | x |
| *Adiantum capillus-veneris* | common maidenhair | | | x |
| *Leersia* sp. | cutgrass | | | x |
| *Hygroamblystegium tenax* var. *tenax* | hygroamblystegium moss | | | x |

| Scientific name | Common name | Gehlbach (1965) - along trail | Gehlbach (1967) | Lind (1979) |
|---|---|---|---|---|
| *Nasturtium officinale* | watercress | | | x |
| *Potamogeton illinoensis* | Illinois pondweed | | | x |
| *Galium microphyllum* | bracted bedstraw | | | x |
| *Eleocharis montevidensis* | sand spikerush | | | x |
| *Valeriana texana* | Guadalupe valerian | | | x |
| *Cladium mariscus* ssp. *jamaicense* | Jamaican sawgrass | | | x |
| *Senecio* sp. | groundsel | | | x |
| *Carex microdonta* | littletooth sedge | | | x |
| *Carex hystericina* | bottlebrush sedge | | | x |
| *Najas* sp. | waternymph | | | x |
| *Juncus dudleyi* | Dudley's rush | | | x |
| *Juncus interior* | inland rush | | | x |
| *Spirogyra* sp. | filamentous green algae | | | x |
| *Chara* sp. | muskgrass, stonewort (algae) | | | x |
| *Nitella* sp. | stonewort, brittlewort (algae) | | | x |

**Table B-2.** Plant species lists for Choza, Smith, and Juniper Springs (Andersen 2003, Ferris 2006) and Manzanita Spring (Walsh and Worthington 1996). Ferris (2006) provides a plant list only for Choza and Smith Springs. Species found by Ferris in 2006 but not by Andersen (2003) are indicated with a "#" rather than an "x". An asterisk (*) indicates exotic species.

| Family | Species | Choza | Smith | Juniper | Manzanita |
|---|---|---|---|---|---|
| Aceraceae | *Acer grandidentatum* | # | x | | |
| Agavaceae | *Agave parryi* ssp. *neomexicana* | x | | | x |
| | *Yucca baccata* | x | x | x | |
| | *Yucca elata* | x | x | x | x |
| Amaranthaceae | *Froelichia floridana* var. *campestris* | | | | x |
| Anacardiaceae | *Rhus aromatica* | # | x | x | x |
| | *Rhus lanceolata* | x | x | x | |
| | *Rhus microphylla* | x | | | x |
| | *Rhus virens* | x | x | x | |
| Apocynaceae | *Apocynum cannabinum* | | x | | |
| Asclepiadaceae | *Asclepias asperula* | | | | x |
| | *Asclepias latifolia* | | | | x |
| | *Asclepias subverticillata* | | | | x |
| | *Asclepias tuberosa* | x | x | x | |
| Aspleniaceae | *Asplenium resiliens* | | # | | |
| Asteraceae | *Amphiachyrus dracunculoides* | x | | x | |
| | *Artemisia ludoviciana* | x | | | x |
| | *Baccharis havardii* | | # | x | |
| | *Baccharis pteronoides* | x | | x | x |
| | *Baccharis salicifolia* | # | | | |
| | *Baccharis salicina* | x | | | |
| | *Berlandiera lyrata* | | | x | x |
| | *Bidens bigelovii* | x | | | x |
| | *Brickellia brachyphylla* | | x | x | x |

| Family | Species | Choza | Smith | Juniper | Manzanita |
|---|---|---|---|---|---|
| | *Brickellia californica* | x | x | x | x |
| | *Brickelia laciniata* | x | | | |
| | *Chaetopappa ericoides* | # | | | |
| | *Chrysactinia mexicana* | x | | x | |
| | *Chrysothamnus baileyi* | x | | | |
| | *Cirsium ochrocentrum* | x | | x | |
| | *Conyza canadensis* | x | | x | x |
| | *Dyssodia papposa* | | | | x |
| | *Erigeron modestus* | x | | | |
| | *Evax verna* | x | | | |
| | *Grindelia havardii* | x | | | |
| | *Gutierrezia microcephala* | | # | | x |
| | *Gutierrezia sarothrae* | x | | x | |
| | *Gymnosperma glutinosum* | x | | | x |
| | *Heterotheca fulcrata* | x | | | |
| | *Hieracium fendleri* | | | ? | |
| | *Hymenoxys odoratus* | | | x | |
| | *Lygodesmia texana* | | | | x |
| | *Machaeranthera blephariphylla* | x | | x | |
| | *Machaeranthera pinnatifida* | x | | | x |
| | *Melampodium leucanthum* | x | | | x |
| | *Parthenium confertum* | x | x | | x |
| | *Parthenium incanum* | x | | | x |
| | *Perityle quinqueflora* | x | | | |
| | *Pseudognaphalium stramineum* | | | | x |
| | *Psilostrophe tagetina* | | | x | |
| | *Ratibida columnifera* | x | | x | x |
| | *Sanvitalia abertii* | | | | x |
| | *Senecio flaccidus* var. *douglasii* | x | x | | |
| | *Senecio flaccidus* var. *flaccidus* | | | | x |
| | *Solidago wrightii* | | x | | |
| | *Sonchus asper** | | | | x |
| | *Symphyotrichum ericoides* | x | | x | |
| | *Symphyotrichum subulatum* | | | | x |
| | *Taraxacum officinale** | | | | x |
| | *Tetraneuris scaposa* | x | | x | x |
| | *Thelesperma longipes* | | | | x |
| | *Thelesperma megapotamicum* | | | | x |
| | *Thymophylla acerosa* | # | | | x |
| | *Thymophylla setifolia* var. *radiata* | | | | x |
| | *Verbesina encelioides* | x | | | x |
| | *Verbesina oreophila* | | | x | |
| | *Viguiera dentata* | x | x | x | x |
| | *Viguiera stenoloba* | | x | x | x |
| | *Xanthium strumarium* | x | | | |
| | *Zinnia grandiflora* | x | | | x |

| Family | Species | Choza | Smith | Juniper | Manzanita |
|---|---|---|---|---|---|
| Berberidaceae | *Berberis haematocarpa* | x | # | | |
| | *Berberis trifoliolata* | x | x | | |
| Boraginaceae | *Lappula redowskii* | x | | | |
| | *Lithosperma viride* | | x | | |
| Brassicaceae | *Descurainia pinnata* | x | | | |
| | *Lesquerella fendleri* | x | | | x |
| | *Rorripa nasturtium-aquatium* | x | | | |
| | *Schoenocrambe linearifolium* | x | x | | x |
| | *Streptanthus sparciflorus* | x | | | |
| Cactaceae | *Echinocereus triglochidiatus* | # | | | |
| | *Opuntia engelmannii* | x | x | x | |
| | *Opuntia imbricata* | x | x | x | |
| Campanulaceae | *Lobelia cardinalis* | x | x | x | x |
| Caprifoliaceae | *Lonicera albiflora* | x | # | | x |
| Caryophyllaceae | *Arenaria lanuginosa* | | ? | | |
| | *Paronychia jamesii* | | | | x |
| Celastraceae | *Mortonia sempervirens* | x | | x | |
| Chenopodiaceae | *Salsola collina* | | | | x |
| Commelinaceae | *Commelina erecta* | x | x | | |
| | *Tradescantia wrightii* | | | | x |
| Convolvulaceae | *Convolvulus equitans* | x | | x | x |
| | *Evolvulus nuttallianus* | | | | x |
| | *Ipomoea costellata* | | | | x |
| | *Ipomoea lindheimeri* | x | | | x |
| Cucurbitaceae | *Cucurbita foetidissima* | | | | x |
| Cupressaceae | *Juniperus deppeana* | x | x | x | x |
| | *Juniperus monosperma* | x | # | | |
| | *Juniperus pinchotii* | x | # | x | x |
| Cyperaceae | *Carex hystericina* | x | | | |
| | *Carex microdonta* | | x | x | |
| | *Cladium mariscus* ssp. *jamaicense* | x | | | x |
| | *Cyperus onerosus* | # | | | |
| | *Eleocharis montevidensis* | x | x | x | x |
| | *Eleocharis rostellata* | x | | x | x |
| | *Schoenoplectus acutus* | ? | | | x |
| | *Fuirena simplex* | | | | x |
| | *Schoenoplectus americanus* | ? | | | x |
| Ericaceae | *Arbutus xalapensis* | x | x | x | x |
| Equisetaceae | *Equisetum laevigatum* | x | | | |
| Euphorbiaceae | *Acalypha neomexicana* | x | | | x |
| | *Acalypha phleoides* | x | x | | x |
| | *Chamaesyce chaetocalyx* | | | | x |
| | *Chamaesyce serrula* | x | | | x |
| | *Chamaesyce stictospora* | | | | x |
| | *Croton dioicus* | | | x | x |
| | *Croton pottsii* | x | | x | x |
| | *Euphorbia dentata* | | | | x |

| Family | Species | Choza | Smith | Juniper | Manzanita |
|---|---|---|---|---|---|
| | *Euphorbia exstipulata* | | | | x |
| | *Phyllanthus polygonoides* | | | | x |
| | *Tragia ramosa* | | | | x |
| Fabaceae | *Acacia angustissima* | | | | x |
| | *Acacia constricta* | x | | | |
| | *Astragalus missouriensis* | # | | | |
| | *Astragalus mollissimus* | x | | x | |
| | *Dalea candida* | | | x | |
| | *Dalea formosa* | x | | x | |
| | *Dalea frutescens* | | | | x |
| | *Dalea jamesii* | x | | | x |
| | *Dalea nana* | | | | x |
| | *Dalea pogonathera* | | | | x |
| | *Desmanthus velutinus* | | | | x |
| | *Hoffmannseggia drepanocarpa* | | | | x |
| | *Melilotus officinalis** | x | | | x |
| | *Mimosa aculeaticarpa* | x | x | x | x |
| | *Mimosa microphylla* | # | | | |
| | *Senna roemeriana* | x | | | x |
| Fagaceae | *Quercus grisea* | x | x | x | x |
| | *Quercus mohriana* | x | | x | |
| | *Quercus muehlenbergii* | # | x | | |
| | *Quercus pungens* | x | x | | x |
| | *Quercus vaseyana* | # | # | | |
| Fouquieriaceae | *Fouquieria splendens* | x | | | x |
| Garryaceae | *Garrya ovata* | x | # | | |
| Geraniaceae | *Erodium cicutarium** | | | | x |
| Hydrangeaceae | *Fendlera rupicola* | x | x | | |
| | *Philadelphus microphyllus* | | x | | |
| Hydrophyllaceae | *Phacelia rupestris* | x | x | | |
| Juglandaceae | *Juglans microcarpa* | | | | |
| Juncaceae | *Juncus tenuis* | | | | x |
| | *Juncus torreyi* | | | x | x |
| Krameriaceae | *Krameria lanceolata* | x | | | x |
| Lamiaceae | *Hedeoma costata* | x | x | | x |
| | *Hedeoma drummondii* | | | | x |
| | *Marrubium vulgare* | x | | x | x |
| | *Salvia lycioides* | x | | | |
| | *Salvia reflexa* | x | | | x |
| Liliaceae | *Allium cernuum* | x | | | |
| | *Allium kunthii* | | | | x |
| | *Dasylirion leiophyllum* | x | x | x | x |
| | *Nolina* sp.[1] | x | x | | x |
| | *Nothoscordum bivalve* | | | | x |
| Loasaceae | *Mentzelia oligosperma* | | | | x |
| Malvaceae | *Abutilon incanum* | | | | x |
| | *Rhynchosida physocalyx* | | | | x |
| | *Sida abutifolia** | | | | x |
| | *Sphaeralcea angustifolia* | x | | | |

| Family | Species | Choza | Smith | Juniper | Manzanita |
|---|---|---|---|---|---|
| | *Sphaeralcea digitata* | | | | x |
| | *Sphaeralcea hastulata* | | | | x |
| Moraceae | *Morus microphylla* | | x | | |
| Nyctaginaceae | *Ammocodon chenopodiodes* | | | | x |
| | *Mirabilis linearis* | | | | x |
| Oleaceae | *Fraxinus velutina* | # | | | |
| | *Menodora longiflora* | x | | | |
| Onagraceae | *Calylophus hartwegii* | x | | | x |
| | *Gaura coccinea* | x | | | x |
| Orobanchaceae | *Conopholis alpina* | x | | | |
| Pinaceae | *Pinus edulis* | x | | | |
| | *Pinus ponderosa* | x | x | | |
| | *Pinus strobiformis* | x | | | |
| Plantaginaceae | *Plantago major** | | | | x |
| | *Plantago patagonica* | x | | | |
| Poaceae | *Andropogon gerardii* | x | x | x | x |
| | *Andropogon glomeratus* | x | | | |
| | *Aristida purpurea* | x | x | x | x |
| | *Bothriochloa barbinodis* | | | | x |
| | *Bothriochloa laguroides* | ? | | | x |
| | *Bouteloua curtipendula* | x | x | x | x |
| | *Bouteloua gracilis* | | | | x |
| | *Bouteloua hirsuta* | x | | | x |
| | *Bromus anomalus* | x | | x | |
| | *Bromus arvensis** | | | | x |
| | *Cenchrus spinifex* | | | | x |
| | *Cynodon dactylon** | x | | | |
| | *Dichanthelium acuminatum* | | | | x |
| | *Digitaria cognata* | | | | x |
| | *Echinochloa crus-galli** | x | | | x |
| | *Elymus canadensis* | x | | | x |
| | *Elymus elymoides* | x | x | x | x |
| | *Enneapogon desvauxii* | | | | x |
| | *Eragrostis cilianensis** | | | | x |
| | *Eragrostis intermedia* | x | x | x | x |
| | *Eragrostis pectinacea* | x | | | |
| | *Erioneuron pilosum* | | | | x |
| | *Glyceria striata* | x | x | x | |
| | *Leptochloa dubia* | | | | x |
| | *Lycurus phleoides* | | | | x |
| | *Muhlenbergia arenicola* | | | | x |
| | *Muhlenbergia emersleyi* | | | x | x |
| | *Muhlenbergia setifolia* | | | | x |
| | *Nassella tenuissima* | | | | x |
| | *Panicum bulbosum* | x | | | x |
| | *Panicum capillare* | | | | x |
| | *Panicum hirticaule* | | | | x |
| | *Panicum obtusum* | | | | x |
| | *Pascopyrum smithii* | x | | | x |
| | *Paspalum distichum* | | | | x |

| **Family** | **Species** | **Choza** | **Smith** | **Juniper** | **Manzanita** |
|---|---|---|---|---|---|
| | *Piptochaetium fimbriatum* | | x | | |
| | *Polypogon viridis** | | | | x |
| | *Schedonorus pratensis** | | | | x |
| | *Schizachyrium scoparium* | x | x | x | x |
| | *Setaria grisebachii* | x | | | |
| | *Setaria leucopila* | x | x | x | x |
| | *Setaria pumila** | x | | | |
| | *Setaria viridis** | | | | x |
| | *Sorghastrum nutans* | x | | x | |
| | *Sphenopholis obtusata* | x | x | x | x |
| | *Stipa neomexicana* | | x | | |
| Polemoniaceae | *Gilia rigidula* | x | | | x |
| | *Phlox nana* | x | | | |
| | *Phlox triovulata* | | | | x |
| Polygalaceae | *Polygala barbeyana* | | | | |
| | *Polygala scoparioides* | | | | x |
| Polygonaceae | *Eriogonum hieraciifolium* | | | | x |
| Portulacaceae | *Portulaca suffrutescens* | | | | x |
| Potamogetonaceae | *Potamogeton illinoensis* | | | | x |
| Pteridaceae | *Adiantum capillus-veneris* | x | x | | |
| | *Pellaea atropurpurea* | # | # | | |
| Ranunculaceae | *Clematis pitcheri* | x | x | | |
| Rhamnaceae | *Ceanothus greggii* | x | # | | x |
| | *Condalia ericoides* | x | | | |
| Rosaceae | *Cercocarpus montanus* | x | x | | x |
| | *Fallugia paradoxa* | x | | | x |
| | *Petrophytum caespitosum* | | x | | |
| | *Prunus serotina* | x | x | x | |
| Rubiaceae | *Galium microphyllum* | x | x | | |
| | *Galium wrightii* | | | | x |
| | *Hedyotis nigricans* | x | x | | x |
| | *Houstonia acerosa* | | | | x |
| Salicaceae | *Salix gooddingii* | x | | | |
| Sapindaceae | *Ungnadia speciosa* | x | x | x | |
| Scrophulariaceae | *Castilleja integra* | x | | | |
| | *Maurandya antirrhiniflora* | x | | | x |
| | *Verbascum thapsus* | # | | | |
| Solanaceae | *Chamaesaracha sordida* | x | | | x |
| | *Physalis hederifolia* | | | x | |
| | *Solanum elaeagnifolium* | x | | x | x |
| Typhaceae | *Typha domingensis* | x | | | x |
| Ulmaceae | *Celtis laevigata* var. *reticulata* | x | x | | x |
| Verbenaceae | *Aloysia wrightii* | x | x | x | x |
| | *Glandularia bipinnatifida* | x | x | x | |
| | *Verbena perennis* | | | | x |
| Violaceae | *Viola sororia* | | x | | |
| Viscaceae | *Phoradendron villosum* | x | x | | x |
| Vitaceae | *Parthenocissus vitacea* | | x | | |
| | *Vitis arizonica* | x | x | x | x |

| Family | Species | Choza | Smith | Juniper | Manzanita |
|---|---|---|---|---|---|
| **Total** | | 159 | 77 | 68 | 164 |

[1] Most likely *N. micrantha*, but *N. texana* and *N. erumpens* are also possible.

**Table B-3**. Rare and unique plants observed in McKittrick Canyon in the 1970s (Northington and Burgess 1979). Some scientific names were updated to match those accepted by the Integrated Taxonomic Information System (ITIS).

| Species | Notes |
|---|---|
| *Nama xylopodum* | endemic |
| *Chaetopappa hersheyi* | endemic |
| *Pinaropappus parvus* | endemic |
| *Salvia summa* | endemic |
| *Hedeoma apiculata* | endemic |
| *Valeriana texana* | endemic |
| *Polygala rimulicola* | endemic |
| *Fragaria vesca* ssp. *bracteata* | disjunct Rocky Mountain species |
| *Frasera speciosa* | disjunct Rocky Mountain species |
| *Physocarpus monogynus* | disjunct Rocky Mountain species |
| *Aquilegia chaplinei* | concentrated along streams & adjacent gravel; found on limestone ledges in S. McKittrick Canyon |
| *Glyceria striata* | concentrated along streams & adjacent gravel, also found at Smith Spring |
| *Stephanomeria wrightii* | concentrated along streams & adjacent gravel |
| *Sisyrinchium demissum* | concentrated along streams & adjacent gravel |
| *Lactuca graminifolia* | concentrated along streams & adjacent gravel |
| *Rosa woodsii* | concentrated along streams & adjacent gravel; found in S. McKittrick Canyon |
| *Streptanthus sparsiflorus* | concentrated along streams & adjacent gravel |
| *Equisetum laevigatum* | concentrated along streams & adjacent gravel |
| *Symphyotrichum lanceolatum* ssp. *hesperius* | concentrated along streams & adjacent gravel |
| *Penstemon cardinalis* | concentrated along streams & adjacent gravel also found in Smith Canyon |
| *Asclepias tuberosa* | concentrated along streams & adjacent gravel; also found in Smith Canyon |
| *Maianthemum racemosa* | found in S. McKittrick Canyon |
| *Corallorhiza striata* | found in S. McKittrick Canyon |
| *Zigadenus elegans* | found on limestone ledges in S. McKittrick Canyon |
| *Physocarpus monogynus* | found on limestone ledges in S. McKittrick Canyon |
| *Cystopteris bulbifera* | grows in crevices in the Narrows west of Pratt Cabin |
| *Phanerophlebia auriculata* | grows in crevices in the Narrows west of Pratt Cabin |
| *Viola missouriensis* | grows in the Narrows west of Pratt Cabin and at Smith Spring |
| *Celastrus scandens* | grows in Devil's Den, N. McKittrick Canyon |
| *Streptanthus sparsiflorus* | grows in Devil's Den, N. McKittrick Canyon, and in Smith Canyon |
| *Yucca faxoniana* | grows in lower McKittrick Canyon |
| *Sophora secundiflora* | grows in lower McKittrick Canyon |
| *Grindelia havardii* | grows in lower McKittrick Canyon |
| *Heterotheca viscida* | found in Smith Canyon |

**Table B-4.** Aquatic macroinvertebrate taxa documented in McKittrick Creek (Lind 1979, Meyerhoff and Lind 1987, Green 1993). Table adapted from Green (1998). Note that the results for Meyerhoff and Lind (1987) are not directly comparable to other McKittrick Creek surveys, as it focused exclusively on insects.

| **Taxa** | **Lind (1979)** | **Meyerhoff and Lind (1987)** | **Green (1993)** |
|---|---|---|---|
| **Cnidaria** | | | |
| *Chlorohydra* sp. | x | | |
| *Hydra* sp. | | | x |
| **Turbellaria** | | | |
| *Dugesia tigrina* | x | | x |
| **Nematomorpha** | | | |
| *Gordius* sp. | x | | x |
| **Nematoda** | | | x |
| **Annelida** | | | |
| Oligochaeta | x | | |
| *Pristina* sp. | | | x |
| *Lumbricus* sp. | | | x |
| Naididae | | | x |
| **Mollusca** | | | |
| Physidae | x | | |
| *Physa* sp. | | | x |
| *Pisidium* sp. | | | x |
| **Crustacea** | | | |
| Ostracoda | x | | |
| Cytheridae | | | x |
| Amphipoda | | | |
| *Hyallela azteca* | x | | x |
| Copepoda | | | |
| Cyclopoida | | | x |
| *Ectocyclops phaleratus* | x | | |
| Cladocera | | | |
| *Alona* sp. | | | x |
| *Daphnia pulex* | x | | |
| *Ceriodaphnia quadrangula* | x | | |
| **Acarina (Acari)** | x | | 7 unique taxa |
| **Collembola** | | | x |
| **Insecta** | | | |
| Diptera | x | | |
| Dixidae | | | x |
| *Pedicia* sp. | | | x |
| Tipulidae | x | | |
| *Tipula* sp. | | | x |
| *Hexatoma* sp. | | | x |
| Heleidae | x | | |
| Simulidae | | | |
| *Simulium* sp. | x | | |
| Chironomidae | 5 genera | | 8 chironomids |
| *Psectrocladius* sp. | | x | |
| *Nilotanypus* sp. | | x | |
| *Conchapelopia* sp. | | x | |
| *Microtendipes* cf. *caducus* | | x | |

| Taxa | Lind (1979) | Meyerhoff and Lind (1987) | Green (1993) |
|---|---|---|---|
| *Stictochironomus* sp. | | | |
| *Stenochironomus hilaris* | | x (?) | |
| *Pseudochironomus richardsoni* | | x | |
| Tabanidae | | | |
| *Tabanus* sp. | x | | x |
| Stratiomyidae | | | |
| *Euparyphus* sp. | x | | x |
| *Caloparyphus* sp. | | | x |
| Ceratopogonidae | | | x |
| *Probezzia* sp. | x | | |
| Empididae | | | |
| *Haemerodromia* sp. | | | x |
| Trichoptera | | | |
| Calamoceratidae | | | |
| *Notiomyxia* sp. | x | | |
| *Phylloicus* sp. | | x | x |
| Psychomyiidae | x | | |
| Odontoceridae | 1 genus | | |
| *Marilia* sp. | | x | x |
| Helicopsychidae | | | |
| *Helicopsyche* sp. | x | | x |
| *Helicopsyche mexicana* | | x | |
| Limnephilidae | | | |
| *Hesperophylax* sp. | x | x | x |
| *Limnephilus* sp. | | x | x |
| Hydroptilidae | | | |
| *Agraylea* sp. | x | | |
| *Hydroptila* sp. | | x | x |
| *Oxyethira* sp. | | x | x |
| *Neotrichia* sp. | | | x |
| *Ochrotrichia* sp. | | | x |
| unidentified genus | | x | |
| Hydropsychidae | | | |
| *Hydropsychae* sp. | x | x | x |
| Leptoceridae | | | |
| *Athripsodes* sp. | x | | |
| Lepidostomatidae | | | |
| *Lepidostoma* sp. | | x | x |
| Philopotamidae | | | |
| *Wormaldia* sp. | | x | x |
| Polycentropodidae | | | |
| *Cernotina* sp. | | | x |
| Lepidoptera | | | |
| *Petrophila* sp. | | | x |
| Odonata | | | |
| Agrionidae | | | |
| *Argia* sp. | x | | |
| *Argia lugens* | | x | x |
| *Argia plana* | | x | x |

| Taxa | Lind (1979) | Meyerhoff and Lind (1987) | Green (1993) |
| --- | --- | --- | --- |
| Coenagrionidae | | | |
| *Archilestes* sp. | x | | x |
| *Archilestes grandis* | | x | |
| Libellulidae | x | | |
| *Paltothemis* sp. | | | x |
| *Paltothemis lineatipes* | | x | |
| Aeshnidae | | | |
| *Aeshna* sp. | | | x |
| *Aeshna umbrosa* | | x | |
| Hemiptera | | | |
| Belostomatidae | | | |
| *Belostoma* sp. | x | | |
| Gerridae | | | |
| *Gerris* sp. | | | x |
| *Gerris remigis* | | x | |
| *Trepobates* sp. | | | x |
| *Limnoporus* sp. | | | x |
| Veliidae | | | |
| *Rhagovelia* sp. | | | x |
| *Rhagovelia distincta* | | x (?) | |
| *Microvelia* sp. | | x | x |
| Naucoridae | | | |
| *Ambryssus* sp. | | | x |
| *Ambryssus buenoi* | | x | |
| *Cryphocricos* sp. | | | x |
| Corixidae | | | |
| *Graptocorixa abdominalis* | | x | |
| Notonectidae | | | |
| *Notonecta* sp. | | | x |
| *Notonecta lobata* | | x | |
| Ephemeroptera | | | |
| Baetidae | | | |
| *Baetis* sp. | x | | x |
| Leptophlebiidae | | | |
| *Choroterpes* sp. | x | | x |
| Caenidae | | | |
| *Caenis* sp. | | | x |
| Coleoptera | | | |
| Psephenidae | | | |
| *Psephenus* sp. | x | | |
| Chrysomelidae | | | |
| *Neohaemonia* sp. | x | | |
| Elmidae | x | | |
| *Dubiraphia* sp. | | x | |
| *Macrelmis* sp. | | x | |
| *Neoelmis* sp. | | x | x |
| *Heterelmis* sp. | | | x |
| *Elsianus* sp. | | | x |
| *Stenelmis* sp. | | | x |

| Taxa | Lind (1979) | Meyerhoff and Lind (1987) | Green (1993) |
|---|---|---|---|
| *Microcylloepus* sp. | | | x |
| *Ordobrevia* sp. | | | x |
| *Hexacylloepus* sp. | | | x |
| Curculionidae | x | | |
| *Hyperodes* sp. | | | x |
| *Lixus* sp. | | | x |
| Georyssidae | | | |
| *Georyssus* sp. | x | | |
| Dytiscidae | | | |
| *Hydroporus* sp. | | | x |
| *Hydroporus psedovilis* | | x (?) | |
| *Hydroporus dimidiatus* | | x | |
| *Neoclypeodytes* sp. | | | x |
| *Neoclypeodytes discretus* | | x | |
| *Laccophilus* sp. | | | x |
| *Laccophilus horni* | | x | |
| *Liodessus* sp. | | | x |
| *Thermonectes* sp. | | | x |
| *Thermonectes marmoratus* | | x | |
| *Derovatellus* sp. | | | x |
| Hydrophilidae | | | |
| *Tropisternus* sp. | | x | |
| *Berosus* sp. | | | |
| Dryopidae | | | |
| *Helichus* sp. | | | x |
| *Helichus triangularis* | | x | |
| *Helichus confluentus* | | x | |
| **Total taxa** | 42 | 39 | 84 |

**McKittrick Creek Aquatic Macroinvertebrate Pollution Tolerance Analysis**
Analysis by Kirsten Gallo of the CHDN

Aquatic macroinvertebrates were assigned a pollution tolerance value at the genus level based on *Tolerance Values for Benthic Macroinvertebrates* used by the Texas Commission on Environmental Quality (TCEQ 2007). Where genera-specific values were not available (24 of 82 genera), tolerance values assigned to family were used, when available. TCEQ did not identify pollution tolerance values for sixteen of the families found in McKittrick Creek. TCEQ pollution tolerance values are scaled from 0-10, where 0 is highly intolerant and 10 is highly tolerant to pollution (TCEQ 2007). These values are used to calculate metrics such as the percent tolerant taxa (defined as having pollution tolerance values $\geq 8.5$) and intolerant taxa, which is the total number of intolerant taxa (tolerance value $\leq 4$).

In McKittrick Creek, a total of 82 unique genera were collected in the three studies between 1979 and 1993 (Lind 1979, Meyerhoff and Lind 1987, Green 1993). Of these genera, 25 (30%) are categorized as “intolerant” and 9 (11 %) are categorized as tolerant. The remaining 35 genera (43 %) are in the mid-range. Metrics, such as percent tolerant taxa, are typically calculated using species abundance data, which are not available in the studies conducted on McKittrick Creek. The calculations presented here are the percentage of genera or families in different tolerance categories. They do not account for differences in abundance across taxa, and cannot be used in comparison to metrics calculated using abundance data.

Comparisons among the three studies could be completed only at the family level, as the studies didn’t consistently identify individuals to the species (or genus) level. Green (1993) collected about twice the number of taxa than the previous studies (see Table B-4) even though taxa were identified to the genus level. The majority (56-77 %) of the invertebrate families were in the mid-range of tolerance values (4-8.5), across the three studies (Table B-5). Roughly the same percentage of families were found in the intolerant class as in the tolerant class, with the exception of Green (1993), in which 16 % of taxa were classified as intolerant, and 6 % were classified as intolerant (Table B-5).

At first glance, one might conclude that water quality has improved, because fewer tolerant families were detected by Green (1993) than in previous studies. However, the level of uncertainty in the results of this analysis as an indicator of water quality is high, for two primary reasons: 1) tolerance values for genera within families can vary across all three tolerance classes, and 2) abundance data are lacking. Across all three studies, 25 genera in the intolerant class and nine genera in the tolerant class were detected, which appears positive from a water quality perspective. However, if the nine tolerant genera were far more abundant than the intolerant, this would lead to concern about the quality of water in McKittrick Creek. Given that the majority of macroinvertebrate genera are in the mid-range tolerance class, the water quality in McKittick Creek is likely not pristine, nor is it cause for concern.

**Table B-5.** Number of macroinvertebrate families detected in each study and percentage of families in the intolerant, mid-range, and tolerant categories.

| | Lind (1979) | Meyerhoff and Lind (1987) | Green (1993) |
|---|---|---|---|
| # Families | 34 | 22 | 43 |
| Intolerant | 17% | 22% | 16% |
| Mid-range | 71% | 56% | 77% |
| Tolerant | 13% | 22% | 6% |

**Table B-6.** Aquatic macroinvertebrate taxa documented in GUMO springs. The first four springs were sampled by Maher (2009); Manzanita Spring was sampled by Gelhaus and Flint (1994 - trichopterans only) and Walsh and Worthington (1996). Note that Manzanita Spring results may not be directly comparable to other springs since sampling methods were different.

| Taxa | Choza Spring | Guadalupe Spring | Smith Spring | Upper Pine Spring | Manzanita Spring |
|---|---|---|---|---|---|
| **Cnidaria** | | | | | |
| *Hydra* sp. | | | | | x |
| **Turbellaria** | | | | | |
| Planaridae | x | x | x | x | |
| *Dugesia tigrina* | | | | | x |
| **Nematomorpha** | | x | | | |
| *Gordius* sp. | | | | | |
| **Nematoda** | | x | x | | |
| **Mollusca** | | | | | |
| Sphaeriidae | x | | x | x | |
| Physidae | x | | x | x | |
| *Physella* sp. | x | x | | | |
| **Crustacea** | | | | | |
| Ostracoda | | | | | x |
| Podocopida | x | x | x | x | |
| Amphipoda | | | | | |
| *Hyallela azteca* | x | x | x | x | |
| Copepoda | | | x | | x |
| Cladocera | | | | | x |
| **Acariformes** | x | | | x | |
| **Collembola** | | | x | | |
| **Insecta** | | | | | |
| Diptera | | | | | |
| Dixidae | | | | | |
| *Dixella* sp. | x | | x | x | |
| Tipulidae | | | | | |
| *Holorusia hespera* | | x | | | |
| *Tipula* sp. | | | x | | |
| Simulidae | | | | | |
| *Simulium* sp. | x | | x | x | |
| *Prosimulium* sp. | | x | x | x | |
| Chironomidae | x | x | x | x | |
| Tabanidae | | | | | |
| *Tabanus* sp. | | | x | | |
| Stratiomyidae | | | | | |
| *Euparyphus* sp. | | | x | x | |
| *Caloparyphus* sp. | x | x | x | x | |
| Ceratopogonidae | x | | | | |
| Trichoptera | | | | | |
| unknown | | x | | | |
| Calamoceratidae | | | | | |
| *Phylloicus* sp. | x | x | x | x | x |
| Odontoceridae | | | | | |
| *Marilia* sp. | | x | | | x |
| *Marilia flexuosa* | | | | x | |

| Taxa | Choza Spring | Guadalupe Spring | Smith Spring | Upper Pine Spring | Manzanita Spring |
|---|---|---|---|---|---|
| Helicopsychidae | | | | | |
| *Helicopsyche* sp. | x | x | x | x | |
| Limnephilidae | | | | x | |
| *Limnephilus* sp. | x | x | x | | x |
| Hydropsychidae | | | | | |
| *Hydropsychae* sp. | | | x | x | |
| *Ceratopsyche* sp. | x | | x | | |
| *Cheumatopsyche* sp. | | | | x | |
| Lepistomatidae | | | | | |
| *Lepistoma* sp. | | | | x | |
| Philopotamidae | | | | | |
| *Wormaldia* sp. | x | x | | x | |
| *Wormaldia arizonensis* | x | | x | | |
| Lepidoptera | | | | | |
| *Petrophila* sp. | | | | x | |
| Odonata | | | | | |
| Coenagrionidae | | | | | |
| *Argia* sp. | x | x | x | x | |
| *Hesperagrion* sp. | | x | | | |
| Lestidae | | | | | |
| *Archilestes* sp. | x | x | x | x | |
| Libellulidae | | | | | |
| *Orthemis ferruginea* | x | x | | | |
| Aeshnidae | | | | | |
| *Aeshna* sp. | | | | x | |
| *Anax* sp. | x | | | x | |
| Hemiptera | | | | | |
| Belostomatidae | | | | | |
| *Abedus* sp. | x | | | | |
| *Belostoma* sp. | x | | | | |
| Gerridae | | | | | |
| *Aquarius* sp. | x | x | x | x | |
| *Gerris* sp. | | | x | | |
| *Trepobates* sp. | | | | x | |
| Veliidae | | | | | |
| *Microvelia* sp. | x | x | | | |
| Naucoridae | | | | | |
| *Ambrysus* sp. | | x | | | |
| Corixidae | | | | | |
| *Graptocorixa* sp. | x | | | | |
| Notonectidae | | | | | |
| *Notonecta* sp. | x | x | x | x | |
| Ephemeroptera | | | | | |
| Baetidae | | | | | |
| *Baetis* sp. | | | | x | |
| *Baetis magnus* | | x | x | | |
| *Callibaetis* sp. | x | x | | x | |
| *Fallceon* sp. | | x | | | |
| Leptophlebiidae | | | | | |
| *Farrodes mexicanus* | x | | | | |

| Taxa | Choza Spring | Guadalupe Spring | Smith Spring | Upper Pine Spring | Manzanita Spring |
|---|---|---|---|---|---|
| Caenidae | | | | | |
| *Caenis* sp. | x | | | | |
| Coleoptera | | | | | |
| Elmidae | | | | | |
| *Macrelmis* sp. | | x | | | |
| *Heterelmis* sp. | x | | x | x | |
| *Microcylloepus* sp. | | x | x | | |
| Gyrinidae | | | | | |
| *Gyrinus* sp. | x | | | | |
| Haliplidae | | | | | |
| *Peltodytes* sp. | x | | | | |
| Dytiscidae | | | | | |
| *Agabus* sp. | x | x | x | x | |
| *Laccophilus fasciatus* | | x | | x | |
| *Laccophilus maculosus* | | x | | | |
| *Rhantus gutticollis* | x | x | | x | |
| *Stictotarsus striatellus* | | x | | | |
| *Thermonectes marmoratus* | | x | | | |
| Dryopidae | | | | | |
| *Helichus* sp. | x | x | x | x | |
| *Postelichus* sp. | x | x | | | |
| **Total taxa** (to genus level) | 38 | 37 | 32 | 35 | 8 |

# **Appendix C.** Winter grassland bird survey results

**Appendix C.** Comparison of bird species observed during a winter grassland bird survey (Bryan 2007) and two summer grassland bird surveys (White 2011, White and Valentine-Darby 2012).

| **Species** | **Bryan (2007)** | **White (2011)** | **White and Valentine-Darby (2012)** |
|---|---|---|---|
| ladder-backed woodpecker | x | x | x |
| house finch | x | x | x |
| rock wren | x | x | x |
| scrub jay | x | x | x |
| bushtit | x | | |
| Bewick's wren | x | x | x |
| rufous-crowned sparrow | x | x | x |
| rufous-sided towhee (spotted towhee) | x | | x |
| hermit thrush | x | | x |
| mountain chickadee | x | | |
| chipping sparrow | x | | x |
| white-breasted nuthatch | x | | |
| western bluebird | x | | |
| common flicker (northern flicker) | x | | |
| acorn woodpecker | x | | |
| red-tailed hawk | x | x | x |
| northern harrier | x | | x |
| greater roadrunner | x | x | |
| Say's phoebe | x | x | x |
| horned lark | x | x | x |
| cactus wren | x | x | x |
| curve-billed thrasher | x | x | x |
| crissal thrasher | x | x | x |
| loggerhead shrike | x | x | x |
| black-throated sparrow | x | x | x |
| sage sparrow | x | | |
| dark-eyed junco | x | | |
| eastern meadowlark | x | | x |
| black-tailed gnatcatcher | x | x | x |
| cedar waxwing | x | | |
| phainopepla | x | | x |
| canyon towhee | x | x | x |
| ruby-crowned kinglet | x | | |
| mountain bluebird | x | | |
| Townsend's solitaire | x | | |

| Species | Bryan (2007) | White (2011) | White and Valentine-Darby (2012) |
|---|---|---|---|
| American robin | x | | |
| red-naped sapsucker | x | | |
| verdin | x | x | x |
| eastern blubird | x | | |
| Scott's oriole | | x | x |
| northern mockingbird | | x | x |
| plumbeous vireo | | x | x |
| mourning dove | | x | x |
| blue grosbeak | | x | |
| Cassin's Sparrow | | x | x |
| pyrrhuloxia | | x | x |
| white-winged dove | | x | x |
| ash-throated flycatcher | | x | x |
| western kingbird | | x | x |
| scaled quail | | x | x |
| lesser nighthawk | | x | x |
| turkey vulture | | x | x |
| burrowing owl | | x | x |
| common poorwill | | x | x |
| common nighthawk | | x | |
| golden eagle | | | x |
| northern rough-winged swallow | | | x |
| pine siskin | | | x |
| vermillion flycatcher | | | x |
| American kestrel | | | x |
| juniper titmouse | | | x |
| cave swallow | | | x |
| gray flycatcher | | | x |
| western meadowlark | | | x |
| western tanager | | | x |
| black-chinned hummingbird | | | x |
| Bullock's oriole | | | x |
| Chihuahuan raven | | | x |
| gray vireo | | | x |
| great horned owl | | | x |
| great-tailed grackle | | | x |
| Townsend's warbler | | | x |
| brown-headed cowbird | | | x |
| green-tailed towhee | | | x |

| Species | Bryan (2007) | White (2011) | White and Valentine-Darby (2012) |
| --- | --- | --- | --- |
| white-crowned sparrow | | | x |
| Cassin's kingbird | | | x |
| cliff swallow | | | x |
| Swainson's hawk | | | x |
| lazuli bunting | | | x |
| lesser goldfinch | | | x |
| black-headed grosbeak | | | x |
| yellow-rumped warbler | | | x |
| Wilson's warbler | | | x |
| lark sparrow | | | x |
| barn swallow | | | x |
| Brewer's sparrow | | | x |
| lark bunting | | | x |
| **Number of Species** | **39** | **34** | **69** |

**Photo C-1.** The cactus wren (*Campylorhynchus brunneicapillus*) and verdin (*Auriparus flaviceps*), two birds observed in GUMO grasslands during the winter season (NPS photos by Robert Shantz).

# **Appendix D.** Bird survey data for GUMO

**Table D-1.** GUMO bird species with special concern designations (compiled by NPS 2012c).

| | | | USFWS BCC BCR #35 | Partners in Flight | | Texas listed | Federal listed | Texas CAP SGCN |
|---|---|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | **Park Status** | **Chihuahuan Desert** | **NA LCP** | **SOS** | | | **Chihuahuan Desert & AZ-NM mountains** |
| *Falco sparverius* | American kestrel | Documented in park | | | | | | X |
| *Falco femoralis* | Aplomado falcon | Documented in park | | | | E | E | X |
| *Haliaeetus leucocephalus* | bald eagle | Documented in park | X | | | T | DM | |
| *Patagioenas fasciata* | band-tailed pigeon | Documented in park | | M | | | | |
| *Vireo bellii* | Bell's vireo | Documented in park | X | IA | Tri-national | | | X |
| *Cypseloides niger* | black swift | Unconfirmed | | | Tri-national | | | |
| *Spizella atrogularis* | black-chinned sparrow | Documented in park | X | M | Steep decline | | | |
| *Baeolophus atricristatus* | black-crested titmouse | Probably present | | LPR | | | | |
| *Polioptila melanura* | black-tailed gnatcatcher | Documented in park | | LPR | | | | |
| *Amphispiza bilineata* | black-throated sparrow | Documented in park | | M | | | | |
| *Spizella breweri* | Brewer's sparrow | Documented in park | | M | Steep decline | | | |
| *Athene cunicularia* | burrowing owl | Documented in park | X | | | SCC | | X |
| *Campylorhynchus brunneicapillus* | cactus wren | Documented in park | | LPR | | | | |
| *Carpodacus cassinii* | Cassin's finch | Documented in park | | | Steep decline | | | |

| | | | USFWS BCC BCR #35 | Partners in Flight | | Texas listed | Federal listed | Texas CAP SGCN |
|---|---|---|---|---|---|---|---|---|
| Scientific Name | Common Name | Park Status | Chihuahuan Desert | NA LCP | SOS | | | Chihuahuan Desert & AZ-NM mountains |
| *Aimophila cassinii* | Cassin's sparrow | Documented in park | X | M | | | | X |
| *Calcarius ornatus* | chestnut-collared longspur | Documented in park | X | | Tri-national | | | |
| *Vermivora crissalis* | Colima warbler | Documented in park | X | IA | | | | X |
| *Buteogallus anthracinus* | common black-hawk | Documented in park | X | | | T | | X |
| *Toxostoma crissale* | crissal thrasher | Documented in park | | LPR | | | | |
| *Toxostoma curvirostre* | curve-billed thrasher | Documented in park | | LPR | | | | |
| *Sturnella magna* | eastern meadowlark | Documented in park | | | Steep decline | | | X |
| *Micrathene whitneyi* | elf owl | Documented in park | X | LPR | | | | |
| *Buteo regalis* | ferruginous hawk | Documented in park | X | | | SCC | | X |
| *Spizella pusilla* | field sparrow | Documented in park | | | Steep decline | | | |
| *Otus flammeolus* | flammulated owl | Documented in park | X | LPR | | | | |
| *Callipepla gambelii* | Gambel's quail | Documented in park | | LPR | | | | |
| *Aquila chrysaetos* | golden eagle | Documented in park | X | | | | | X |
| *Dendroica graciae* | Grace's warbler | Documented in park | X | M | | | | |
| *Ammodramus savannarum* | grasshopper sparrow | Documented in park | | | Steep decline | | | X |
| *Buteo nitidus* | gray hawk | Probably present | | | | T | | X |

| | | | USFWS BCC BCR #35 | Partners in Flight | | Texas listed | Federal listed | Texas CAP SGCN |
|---|---|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | **Park Status** | **Chihuahuan Desert** | **NA LCP** | **SOS** | | | **Chihuahuan Desert & AZ-NM mountains** |
| *Vireo vicinior* | gray vireo | Documented in park | X | LPR | | | | |
| *Pipilo chlorurus* | green-tailed towhee | Documented in park | | LPR | | | | |
| *Parabuteo unicinctus* | Harris's hawk | Documented in park | | | | | | X |
| *Dendroica occidentalis* | hermit warbler | Documented in park | | M | | | | |
| *Calamospiza melanocorys* | lark bunting | Documented in park | X | | Steep decline | | | |
| *Chondestes grammacus* | lark sparrow | Documented in park | | | | | | X |
| *Carduelis lawrencei* | Lawrence's goldfinch | Documented in park | | LPR | | | | |
| *Melanerpes lewis* | Lewis's woodpecker | Documented in park | | M | | | | |
| *Lanius ludovicianus* | loggerhead shrike | Documented in park | X | | | | | X |
| *Numenius americanus* | long-billed curlew | Probably present | X | | | | | X |
| *Calcarius mccownii* | McCown's longspur | Probably present | X | LPR | | | | X |
| *Strix occidentalis lucida* | Mexican spotted owl | Documented in park | | IA | Tri-national | T | T | X |
| *Cyrtonyx montezumae* | Montezuma quail | Documented in park | | M | | SCC | | X |
| *Charadrius montanus* | mountain plover | Probably present | X | | | | | |
| *Colinus virginianus* | northern bobwhite | Documented in park | | | | | | X |
| *Circus cyaneus* | northern harrier | Documented in park | | | | | | X |

| | | | USFWS BCC BCR #35 | Partners in Flight | | Texas listed | Federal listed | Texas CAP SGCN |
|---|---|---|---|---|---|---|---|---|
| Scientific Name | Common Name | Park Status | Chihuahuan Desert | NA LCP | SOS | | | Chihuahuan Desert & AZ-NM mountains |
| *Contopus cooperi* | olive-sided flycatcher | Documented in park | | | Tri-national | | | |
| *Icterus spurius* | orchard oriole | Probably present | | | | | | X |
| *Passerina ciris* | painted bunting | Documented in park | X | M | | | | X |
| *Falco peregrinus* | peregrine falcon | Documented in park | X | | | T | | X |
| *Phainopepla nitens* | phainopepla | Documented in park | | LPR | | | | |
| *Carduelis pinus* | pine siskin | Documented in park | | | Steep decline | | | |
| *Gymnorhinus cyanocephalus* | pinyon jay | Documented in park | | | Tri-national | | | |
| *Cardinalis sinuatus* | pyrrhuloxia | Documented in park | | M | | | | |
| *Cardellina rubrifrons* | red-faced warbler | Documented in park | X | LPR | | | | |
| *Aimophila ruficeps* | rufous-crowned sparrow | Documented in park | | | | | | X |
| *Peucaea carpalis* | rufous-winged sparrow | Documented in park | | LPR | | | | |
| *Euphagus carolinus* | rusty blackbird | Documented in park | | | Steep decline | | | |
| *Callipepla squamata* | scaled quail | Documented in park | | M | | | | X |
| *Tyrannus forficatus* | scissor-tailed flycatcher | Probably present | | | | | | X |
| *Icterus parisorum* | Scott's oriole | Documented in park | | LPR | | | | |
| *Piranga rubra* | summer tanager | Documented in park | | | | | | X |

| | | | USFWS BCC BCR #35 | Partners in Flight | | Texas listed | Federal listed | Texas CAP SGCN |
|---|---|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | **Park Status** | **Chihuahuan Desert** | **NA LCP** | **SOS** | | | **Chihuahuan Desert & AZ-NM mountains** |
| *Buteo swainsoni* | Swainson's hawk | Documented in park | | M | | | | X |
| *Passerina versicolor* | varied bunting | Probably present | X | M | | | | |
| *Auriparus flaviceps* | verdin | Documented in park | | M | | | | |
| *Vermivora virginiae* | Virginia's warbler | Documented in park | X | LPR | | | | |
| *Aeronautes saxatalis* | white-throated swift | Documented in park | | M | | | | |
| *Meleagris gallopavo* | wild turkey | Documented in park | | | | | | X |
| *Wilsonia pusilla* | Wilson's warbler | Documented in park | | | Steep decline | | | |
| *Dendroica petechia* | yellow warbler | Documented in park | X | | | | | |
| *Coccyzus americanus* | yellow-billed cuckoo | Historic | X | | | SCC | C | X |
| *Xanthocephalus xanthocephalus* | yellow-headed blackbird | Documented in park | | LPR | | | | |
| *Buteo albonotatus* | zone-tailed hawk | Documented in park | | | | T | | X |

BCC = Bird species of conservation concern

NA LCP = North American Land Conservation Plan

IA = Immediate action is recommended

LPR = Long-term planning and responsibility is recommended

Tri-national = Temperate breeders of high tri-national concern (Canada, U.S., & Mexico) (Berlanga et al. 2010)

Steep decline = Based on % population loss according to BBS or CBC trend since mid-1960s (Berlanga et al. 2010)

SGCN = Species of greatest conservation need

BCR # 35 = Chihuahuan Desert bird conservation region

SOS = Saving Our Shared Birds (Canada, U.S., & Mexico)

Federal or state listing categories:

DM = Delisted, but being monitored

SCC = Species of conservation concern

M = Continued active management is recommended

C = Candidate

E = Endangered

T = threatened

**Table D-2.** Species identified during eight independent bird surveys conducted at various locations within Guadalupe Mountains National Park. Studies are arranged in order of survey date, with the earliest study on the left and the most recent study on the right.

| Species | Newman (1975) | West (1985) | Burckhalter (1991) | Anderson (2003) | Meyer and Griffin (2011) | Bryan (2007)* | Koprowski (2008) | White (2011) | White and Valentine-Darby (2012) |
|---|---|---|---|---|---|---|---|---|---|
| gray vireo | X | | | | X | | | | X |
| brown towhee | X | X | | | | | | | |
| olive-sided flycatcher | X | | | | X | | X | | |
| blue grosbeak | X | X | X | X | X | | | X | |
| elf owl | X | | | | X | | | | |
| ladder-backed woodpecker | X | X | X | X | X | X | | X | X |
| house finch | X | X | X | X | X | X | | X | X |
| rock wren | X | X | X | X | X | X | | X | X |
| scrub jay | X | | X | X | X | X | | X | X |
| Cassin’s kingbird | X | X | X | X | X | | X | X | X |
| Scott’s oriole | X | X | X | X | X | | | X | X |
| bushtit | X | | X | X | X | X | X | | |
| Virginia’s warbler | X | | | X | X | | | | X |
| canyon wren | X | | X | | X | | | X | X |
| lesser goldfinch | X | | X | X | X | | | X | X |
| hepatic tanager | X | | X | X | X | | X | X | |
| blue-gray gnatcatcher | X | | | X | X | | | X | X |
| Bewick’s wren | X | | X | X | X | X | | X | X |
| rufous-crowned sparrow | X | | X | X | X | X | | X | X |
| black-chinned sparrow | X | | X | X | X | | | X | X |
| black-chinned hummingbird | X | | | X | X | | | X | X |
| ash-throated flycatcher | X | X | X | X | X | | | X | X |
| brown-headed cowbird | X | | | X | X | | X | X | X |
| western wood pewee | X | | X | X | X | | X | X | |
| solitary vireo | X | | X | | | | | | |
| western tanager | X | | X | X | X | | X | X | X |
| black-headed grosbeak | X | | X | X | X | | X | X | X |

| Species | Newman (1975) | West (1985) | Burckhalter (1991) | Anderson (2003) | Meyer and Griffin (2011) | Bryan (2007)* | Koprowski (2008) | White (2011) | White and Valentine-Darby (2012) |
|---|---|---|---|---|---|---|---|---|---|
| rufous-sided towhee (spotted towhee) | X | | | X | X | X | X | X | X |
| violet-green swallow | X | | X | X | X | | X | X | X |
| broad-tailed hummingbird | X | | X | X | X | | X | X | X |
| western flycatcher (Cordillarian flycatcher) | | X | | X | X | | X | | |
| hermit thrush | X | | | X | X | X | X | | X |
| warbling vireo | X | | | X | X | | X | X | |
| house wren | X | | | | X | | X | | |
| mountain chickadee | X | | X | X | X | X | X | | |
| Rivoli’s (magnificent) hummingbird | X | | | | X | | | | |
| chipping sparrow | X | X | X | X | X | X | X | | X |
| hairy woodpecker | X | | | | X | | X | | |
| Grace’s warbler | X | | X | | X | | X | | |
| white-breasted nuthatch | X | | | X | X | X | X | X | |
| blue-throated hummingbird | X | | | X | | | | | |
| western bluebird | X | | | X | X | X | X | | |
| common flicker (northern flicker) | X | | | X | X | X | X | | |
| acorn woodpecker | X | | | X | | X | X | | |
| great horned owl | X | X | | | | | | | X |
| Cooper’s hawk | X | | | | X | | | | X |
| pygmy nuthatch | X | | | | | | X | | |
| yellow-rumped warbler | X | | X | X | X | | X | | X |
| Steller’s jay | X | | | X | | | X | | |
| gray-headed junco | X | | | | | | X | | |
| orange-crowned warbler | X | | | X | X | | X | | |
| brown creeper | X | | | | | | X | | |
| whip-poor-will | X | | | | | | X | | |
| flammulated owl | X | | | | | | | | |

| Species | Newman (1975) | West (1985) | Burckhalter (1991) | Anderson (2003) | Meyer and Griffin (2011) | Bryan (2007)* | Koprowski (2008) | White (2011) | White and Valentine-Darby (2012) |
|---|---|---|---|---|---|---|---|---|---|
| red crossbill | X | | | | X | | | | |
| saw-whet owl | X | | | | | | X | | |
| red-tailed hawk | X | X | | X | X | X | X | X | X |
| turkey vulture | | X | X | X | X | | X | X | X |
| northern harrier | | X | | X | | X | | | X |
| sharp-shinned hawk | | X | | X | X | | X | | |
| Swainson’s hawk | | X | | | | | | | X |
| golden eagle | | X | | | X | | | X | X |
| American kestrel | | X | | | X | | | | X |
| prairie falcon | | X | | | | | | | |
| scaled quail | | X | | X | X | | | X | X |
| sandhill crane | | X | | | | | | | |
| killdeer | | X | | | | | | | |
| mourning dove | | X | X | X | X | | X | X | X |
| greater roadrunner | | X | | | X | X | | X | X |
| burrowing owl | | X | | | | | | X | X |
| common poorwill | | X | | X | X | | | X | X |
| white-throated swift | | X | X | X | X | | X | X | X |
| Say’s phoebe | | X | X | X | X | X | | X | X |
| western kingbird | | X | | | X | | | X | X |
| horned lark | | X | | | | X | | X | X |
| cactus wren | | X | X | | X | X | | X | X |
| northern mockingbird | | X | X | X | X | | | X | X |
| sage thrasher | | X | | X | | | | | |
| curve-billed thrasher | | X | | | X | X | | X | X |
| crissal thrasher | | X | | | X | X | | X | X |
| loggerhead shrike | | X | | | | X | | X | X |
| Wilson’s warbler | | X | | X | X | | | | X |
| green-tailed towhee | | X | | | X | | | | X |

| Species | Newman (1975) | West (1985) | Burckhalter (1991) | Anderson (2003) | Meyer and Griffin (2011) | Bryan (2007)* | Koprowski (2008) | White (2011) | White and Valentine-Darby (2012) |
|---|---|---|---|---|---|---|---|---|---|
| Cassin’s sparrow | | X | | | X | | | X | X |
| clay-colored sparrow | | X | | | | | | | |
| Brewer’s sparrow | | X | | | X | | | | X |
| black-throated sparrow | | X | X | X | X | X | | X | X |
| sage sparrow | | X | | | | X | | | |
| lark bunting | | X | | | | | | | X |
| white-crowned sparrow | | X | | X | X | | | | X |
| dark-eyed junco | | X | | X | X | X | | | |
| eastern meadowlark | | X | | | X | X | | | X |
| western meadowlark | | X | | | | | | | X |
| house sparrow | | X | | | | | | | |
| white-winged dove | | | X | X | X | | | X | X |
| common nighthawk | | | X | X | X | | | X | |
| Cordilleran flycatcher | | | X | | X | | X | X | |
| black phoebe | | | X | X | X | | | | |
| plain titmouse | | | X | | | | | | |
| black-tailed gnatcatcher | | | X | | X | X | | X | |
| cedar waxwing | | | X | X | X | X | | | |
| phainopepla | | | X | X | X | X | | | X |
| canyon towhee | | | X | X | X | X | | X | X |
| lark sparrow | | | X | X | X | | | | X |
| red-winged blackbird | | | X | | X | | | | |
| evening grosbeak | | | X | | | | | | |
| ruby-crowned kinglet | | | | X | X | X | | | |
| mountain bluebird | | | | X | | X | | | |
| Townsend’s solitaire | | | | X | X | X | | | |
| American robin | | | | X | | X | | | |
| band-tailed pigeon | | | | X | X | | X | | |
| red-naped sapsucker | | | | X | X | X | X | | |

| Species | Newman (1975) | West (1985) | Burckhalter (1991) | Anderson (2003) | Meyer and Griffin (2011) | Bryan (2007)* | Koprowski (2008) | White (2011) | White and Valentine-Darby (2012) |
|---|---|---|---|---|---|---|---|---|---|
| plumbeous vireo | | | | X | X | | X | X | X |
| red-breasted nuthatch | | | | X | X | | | | |
| gray catbird | | | | X | | | | | |
| black-throated gray warbler | | | | X | X | | | | X |
| black-and-white warbler | | | | X | | | | | |
| MacGillivray's warber | | | | X | X | | | | |
| song sparrow | | | | X | X | | | | |
| Lincoln's sparrow | | | | X | X | | | | |
| northern cardinal | | | | X | X | | | X | |
| great-tailed grackle | | | | X | | | | | X |
| pine siskin | | | | X | X | | X | | X |
| American goldfinch | | | | X | X | | | | |
| Williamson's sapsucker | | | | X | | | | | |
| varied thrush | | | | X | | | | | |
| hooded warbler | | | | X | | | | | |
| summer tanager | | | | X | X | | | | X |
| barn swallow | | | | | X | | | | X |
| belted kingfisher | | | | | X | | | | |
| blue-headed vireo | | | | | X | | | | |
| calliope hummingbird | | | | | X | | | | |
| Carolina wren | | | | | X | | | | |
| Cassin's vireo | | | | | X | | | | X |
| cliff swallow | | | | | X | | | | X |
| common raven | | | | | X | | | | X |
| crissal flycatcher | | | | | X | | | | |
| dusky flycatcher | | | | | X | | | | |
| gray flycatcher | | | | | X | | | | X |
| Hammond's flycatcher | | | | | X | | | | X |
| hermit warbler | | | | | X | | | | X |

| Species | Newman (1975) | West (1985) | Burckhalter (1991) | Anderson (2003) | Meyer and Griffin (2011) | Bryan (2007)* | Koprowski (2008) | White (2011) | White and Valentine-Darby (2012) |
|---|---|---|---|---|---|---|---|---|---|
| Hutton's vireo | | | | | X | | | | |
| indigo bunting | | | | | X | | | | |
| juniper titmouse | | | | | X | | | | X |
| lazuli bunting | | | | | X | | | | X |
| pyrrhuloxia | | | | | X | | | X | X |
| ruby-throated hummingbird | | | | | X | | | | |
| rufous hummingbird | | | | | X | | | | |
| Swainson's thrush | | | | | X | | | | X |
| Townsend's warbler | | | | | X | | | | X |
| verdin | | | | | X | X | | X | X |
| yellow warbler | | | | | X | | | | X |
| yellow-breasted chat | | | | | X | | | X | |
| eastern bluebird | | | | | | X | | | |
| peregrine falcon | | | | | | | X | X | |
| lesser nighthawk | | | | | | | | X | X |
| wild turkey | | | | | | | | | X |
| Chihuahuan raven | | | | | | | | | X |
| Bullock's oriole | | | | | | | | | X |
| cave swallow | | | | | | | | | X |
| Bell's vireo | | | | | | | | | X |
| vermilion flycatcher | | | | | | | | | X |
| northern waterthrush | | | | | | | | | X |
| northern rough-winged swallow | | | | | | | | | X |
| **# of Species on Ref. Cond.** | n/a | 11/57 | 26/57 | 36/57 | 45/57 | 16/57 | 32/57 | 27/57 | |
| **# of Species not previously observed** | n/a | 37 | 11 | 22 | 25 | 1 | 1 | 1 | |

* Indicates winter survey

**Table D-3.** Species of conservation concern observed during 10 independent bird surveys within Guadalupe Mountains National Park. Studies are arranged in order of survey date, with the earliest study on the left and the most recent study on the right.

| Species | Newman (1975) | West (1985) | Burckhalter (1991) | Anderson (2003) | Meyer and Griffin (2011) | Bryan (2007)* | Koprowski (2008) | White (2011) | White and Valentine-Darby (2012) | NAS (2012) (BBS) | USGS (2012) (CBC) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| gray vireo | X | | | | X | | | | X | | |
| olive-sided flycatcher | X | | | | X | | X | | | | |
| elf owl | X | | | | X | | | | | | |
| Scott's oriole | X | X | X | X | X | | | X | X | X | |
| Virginia's warbler | X | | | X | X | | | | | | |
| rufous-crowned sparrow | X | | X | X | X | X | | X | X | | X |
| black-chinned sparrow | X | | X | X | X | | | X | X | X | X |
| Grace's warbler | X | | X | | X | | X | | | | |
| flammulated owl | X | | | | | | | | | | |
| northern harrier | | X | | X | | X | | | X | | X |
| Swainson's hawk | | X | | | | | | | X | X | |
| golden eagle | | X | | | X | | | X | X | X | X |
| American kestrel | | X | | | X | | | | X | X | X |
| scaled quail | | X | | X | X | | | X | X | X | X |
| burrowing owl | | X | | | | | | X | X | X | |
| white-throated swift | | X | X | X | X | | X | X | X | X | X |
| cactus wren | | X | X | | X | X | | X | X | X | X |
| curve-billed thrasher | | X | | | X | X | | X | X | X | X |
| crissal thrasher | | X | | | X | X | | X | X | | X |
| loggerhead shrike | | X | | | | X | | X | X | X | X |
| Wilson's warbler | | X | | X | X | | | | X | | |
| green-tailed towhee | | X | | | X | | | | X | | X |
| Cassin's sparrow | | X | | | X | | | X | X | X | X |
| Brewer's sparrow | | X | | | X | | | | X | | X |
| black-throated sparrow | | X | X | X | X | X | | X | X | X | X |
| lark bunting | | X | | | | | | | X | X | X |

| Species | Newman (1975) | West (1985) | Burckhalter (1991) | Anderson (2003) | Meyer and Griffin (2011) | Bryan (2007)* | Koprowski (2008) | White (2011) | White and Valentine-Darby (2012) | NAS (2012) (BBS) | USGS (2012) (CBC) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| eastern meadowlark | | X | | | X | X | | | X | X | X |
| black-tailed gnatcatcher | | | X | | X | X | | X | | X | X |
| phainopepla | | | X | X | X | X | | | X | | X |
| lark sparrow | | | X | X | X | | | | X | X | X |
| band-tailed pigeon | | | | X | X | | X | | | | |
| pine sisken | | | | X | X | | X | | X | | X |
| summer tanager | | | | X | X | | | | X | | |
| hermit warbler | | | | | X | | | | X | | |
| pyrrhuloxia | | | | | X | | | X | X | X | X |
| verdin | | | | | X | X | | X | X | X | X |
| yellow warbler | | | | | X | | | | X | | |
| peregrine falcon | | | | | | | X | X | | | X |
| Bell's vireo | | | | | | | | | X | X | |
| wild turkey | | | | | | | | | X | | X |
| northern bobwhite | | | | | | | | | | | X |
| Montezuma quail | | | | | | | | | | | X |
| Harris's hawk | | | | | | | | | | | X |
| Lewis's Woodpecker | | | | | | | | | | | X |
| pinyon jay | | | | | | | | | | | X |
| black-crested titmouse | | | | | | | | | | | X |
| field sparrow | | | | | | | | | | | X |
| Cassin's finch | | | | | | | | | | | X |
| **# of Species Of Conservation Concern** | 9 | 19 | 10 | 14 | 31 | 11 | 6 | 17 | 32 | 20 | 33 |

* Indicates winter survey

**Table D-4**. Number of birds detected of each species in each habitat class in GUMO during 2010 and 2011 RMBO surveys. Table reproduced from White (2011) and White and Valentine-Darby (2012).

| Species | 2010 | | | | 2011 | | | |
|---|---|---|---|---|---|---|---|---|
| | Habitat Class | | # of Birds Detected | | Habitat Class | | # of Birds Detected | |
| | Grassland | Riparian | Total | % of Total | Grassland | Riparian | Total | % of Total |
| black-throated sparrow | 92 | -- | 92 | 12% | 80 | 1 | 81 | 8% |
| spotted towhee | -- | 46 | 46 | 6% | 1 | -- | 1 | 0% |
| cactus wren | 34 | -- | 34 | 5% | 14 | -- | 14 | 1% |
| Scott’s oriole | 21 | 10 | 31 | 4% | 32 | 11 | 43 | 4% |
| western wood-pewee | -- | 30 | 30 | 4% | -- | -- | 0 | 0% |
| rufous-crowned sparrow | 10 | 19 | 29 | 4% | 8 | 28 | 36 | 3% |
| northern mockingbird | 26 | 2 | 28 | 4% | 11 | 2 | 13 | 1% |
| plumbeous vireo | 1 | 27 | 28 | 4% | -- | 6 | 6 | 1% |
| violet-green swallow | -- | 28 | 28 | 4% | -- | 25 | 25 | 2% |
| mourning dove | 27 | -- | 27 | 4% | 10 | 1 | 11 | 1% |
| Bewick's wren | 7 | 17 | 24 | 3% | 7 | 19 | 26 | 2% |
| western tanager | -- | 24 | 24 | 3% | 1 | 2 | 3 | 0% |
| black-headed grosbeak | -- | 21 | 21 | 3% | 2 | 19 | 21 | 2% |
| blue-gray gnatcatcher | -- | 20 | 20 | 3% | -- | 4 | 4 | 0% |
| blue grosbeak | 13 | 6 | 19 | 3% | -- | -- | 0 | 0% |
| Cassin's sparrow | 19 | -- | 19 | 3% | 8 | -- | 8 | 1% |
| pyrrhuloxia | 18 | -- | 18 | 2% | 9 | -- | 9 | 1% |
| white-winged dove | 3 | 14 | 17 | 2% | 7 | 4 | 11 | 1% |
| ash-throated flycatcher | 10 | 6 | 16 | 2% | 19 | 5 | 24 | 2% |
| lesser goldfinch | -- | 13 | 13 | 2% | 16 | -- | 16 | 1% |
| white-throated swift | -- | 12 | 12 | 2% | -- | 24 | 24 | 2% |
| brown-headed cowbird | -- | 11 | 11 | 1% | 5 | -- | 5 | 0% |
| Cassin’s kingbird | -- | 11 | 11 | 1% | 4 | 5 | 9 | 1% |
| black-chinned sparrow | -- | 9 | 9 | 1% | -- | 6 | 6 | 1% |
| western kingbird | 9 | -- | 9 | 1% | 13 | 1 | 14 | 1% |
| broad-tailed hummingbird | -- | 8 | 8 | 1% | -- | 6 | 6 | 1% |
| canyon towhee | 8 | -- | 8 | 1% | 7 | 12 | 19 | 2% |
| scaled quail | 8 | -- | 8 | 1% | 36 | 1 | 37 | 3% |
| canyon wren | -- | 7 | 7 | 1% | -- | 24 | 24 | 2% |
| loggerhead shrike | 7 | -- | 7 | 1% | 10 | -- | 10 | 1% |
| black-tailed gnatcatcher | 5 | 1 | 6 | 1% | 1 | -- | 1 | 0% |
| lesser nighthawk | 6 | -- | 6 | 1% | 1 | 1 | 2 | 0% |
| Say's phoebe | 6 | -- | 6 | 1% | 9 | 2 | 11 | 1% |
| warbling vireo | -- | 6 | 6 | 1% | -- | -- | 0 | 0% |
| hepatic tanager | -- | 5 | 5 | 1% | -- | -- | 0 | 0% |
| house finch | 1 | 4 | 5 | 1% | 20 | 1 | 21 | 2% |
| curve-billed thrasher | 4 | -- | 4 | 1% | 13 | 1 | 14 | 1% |

| Species | 2010 | | | | 2011 | | | |
|---|---|---|---|---|---|---|---|---|
| | Habitat Class | | # of Birds Detected | | Habitat Class | | # of Birds Detected | |
| | Grassland | Riparian | Total | % of Total | Grassland | Riparian | Total | % of Total |
| ladder-backed woodpecker | 2 | 2 | 4 | 1% | 1 | 5 | 6 | 1% |
| turkey vulture | 3 | -- | 3 | 0% | 40 | 29 | 69 | 6% |
| verdin | 3 | -- | 3 | 0% | 3 | -- | 3 | 0% |
| black-chinned hummingbird | -- | 2 | 2 | 0% | 1 | 3 | 4 | 0% |
| burrowing owl | 2 | -- | 2 | 0% | 2 | -- | 2 | 0% |
| common poorwill | 2 | -- | 2 | 0% | 1 | -- | 1 | 0% |
| white-breasted nuthatch | -- | 2 | 2 | 0% | -- | -- | 0 | 0% |
| yellow-breasted chat | -- | 2 | 2 | 0% | -- | -- | 0 | 0% |
| common nighthawk | 1 | -- | 1 | 0% | -- | -- | 0 | 0% |
| Cordilleran flycatcher | -- | 1 | 1 | 0% | -- | -- | 0 | 0% |
| crissal thrasher | 1 | -- | 1 | 0% | 1 | -- | 1 | 0% |
| golden eagle | -- | 1 | 1 | 0% | 1 | -- | 1 | 0% |
| greater roadrunner | 1 | -- | 1 | 0% | -- | 1 | 1 | 0% |
| horned lark | 1 | -- | 1 | 0% | 3 | -- | 3 | 0% |
| northern cardinal | -- | 1 | 1 | 0% | -- | -- | 0 | 0% |
| peregrine falcon | -- | 1 | 1 | 0% | -- | -- | 0 | 0% |
| red-tailed hawk | 1 | -- | 1 | 0% | 3 | -- | 3 | 0% |
| rock wren | 1 | -- | 1 | 0% | 6 | 9 | 15 | 1% |
| western scrub-jay | 1 | -- | 1 | 0% | 4 | 3 | 7 | 1% |
| lark bunting | -- | -- | 0 | 0% | 52 | -- | 52 | 5% |
| Brewer’s sparrow | -- | -- | 0 | 0% | 50 | -- | 50 | 5% |
| barn swallow | -- | -- | 0 | 0% | 31 | -- | 31 | 3% |
| lark sparrow | -- | -- | 0 | 0% | 27 | -- | 27 | 3% |
| Wilson’s warbler | -- | -- | 0 | 0% | 10 | 16 | 26 | 2% |
| yellow-rumped warbler | -- | -- | 0 | 0% | 13 | 8 | 21 | 2% |
| chipping sparrow | -- | -- | 0 | 0% | 14 | 3 | 17 | 2% |
| lazuli bunting | -- | -- | 0 | 0% | 6 | 9 | 15 | 1% |
| Swainson’s hawk | -- | -- | 0 | 0% | 10 | -- | 10 | 1% |
| cliff swallow | -- | -- | 0 | 0% | 10 | -- | 10 | 1% |
| white-crowned sparrow | -- | -- | 0 | 0% | 4 | 4 | 8 | 1% |
| Hammond’s flycatcher | -- | -- | 0 | 0% | -- | 8 | 8 | 1% |
| hermit thrush | -- | -- | 0 | 0% | 2 | 5 | 7 | 1% |
| summer tanager | -- | -- | 0 | 0% | -- | 5 | 5 | 0% |
| green-tailed towhee | -- | -- | 0 | 0% | 2 | 3 | 5 | 0% |
| wild turkey | -- | -- | 0 | 0% | -- | 4 | 4 | 0% |
| Townsend’s warbler | -- | -- | 0 | 0% | 1 | 3 | 4 | 0% |
| great-tailed grackle | -- | -- | 0 | 0% | 4 | -- | 4 | 0% |
| great horned owl | -- | -- | 0 | 0% | 2 | 2 | 4 | 0% |

| Species | 2010 | | | | 2011 | | | |
|---|---|---|---|---|---|---|---|---|
| | Habitat Class | | # of Birds Detected | | Habitat Class | | # of Birds Detected | |
| | Grassland | Riparian | Total | % of Total | Grassland | Riparian | Total | % of Total |
| gray vireo | -- | -- | 0 | 0% | 1 | 3 | 4 | 0% |
| chihuahuan raven | -- | -- | 0 | 0% | 4 | -- | 4 | 0% |
| Bullock's oriole | -- | -- | 0 | 0% | 2 | 2 | 4 | 0% |
| western meadowlark | -- | -- | 0 | 0% | 3 | -- | 3 | 0% |
| gray flycatcher | -- | -- | 0 | 0% | 2 | 1 | 3 | 0% |
| eastern meadowlark | -- | -- | 0 | 0% | 3 | -- | 3 | 0% |
| cave swallow | -- | -- | 0 | 0% | 2 | 1 | 3 | 0% |
| Virginia's warbler | -- | -- | 0 | 0% | -- | 2 | 2 | 0% |
| Swainson's thrush | -- | -- | 0 | 0% | -- | 2 | 2 | 0% |
| phainopepla | -- | -- | 0 | 0% | 2 | -- | 2 | 0% |
| northern harrier | -- | -- | 0 | 0% | 2 | -- | 2 | 0% |
| juniper titmouse | -- | -- | 0 | 0% | 2 | -- | 2 | 0% |
| Cassin's vireo | -- | -- | 0 | 0% | -- | 2 | 2 | 0% |
| black-throated gray warbler | -- | -- | 0 | 0% | -- | 2 | 2 | 0% |
| Bell's vireo | -- | -- | 0 | 0% | -- | 2 | 2 | 0% |
| American kestrel | -- | -- | 0 | 0% | 2 | -- | 2 | 0% |
| yellow warbler | -- | -- | 0 | 0% | -- | 1 | 1 | 0% |
| vermilion flycatcher | -- | -- | 0 | 0% | 1 | -- | 1 | 0% |
| pine siskin | -- | -- | 0 | 0% | 1 | -- | 1 | 0% |
| northern waterthrush | -- | -- | 0 | 0% | -- | 1 | 1 | 0% |
| northern rough-winged swallow | -- | -- | 0 | 0% | 1 | -- | 1 | 0% |
| hermit warbler | -- | -- | 0 | 0% | -- | 1 | 1 | 0% |
| Cooper's hawk | -- | -- | 0 | 0% | -- | 1 | 1 | 0% |
| common raven | -- | -- | 0 | 0% | -- | 1 | 1 | 0% |
| *unidentified bird* | 8 | 5 | 13 | 2% | 29 | -- | 29 | 3% |
| *unidentified hummingbird* | 1 | 3 | 4 | 1% | 2 | 1 | 3 | 0% |
| *unidentified dove* | -- | 1 | 1 | 0% | -- | -- | 0 | 0% |
| *unidentified thrasher* | -- | -- | 0 | 0% | 3 | -- | 3 | 0% |
| *unidentified flycatcher* | -- | -- | 0 | 0% | 1 | 2 | 3 | 0% |
| *unidentified kingbird* | -- | -- | 0 | 0% | 2 | -- | 2 | 0% |
| *unidentified blackbird* | -- | -- | 0 | 0% | 2 | -- | 2 | 0% |
| *unidentified swallow* | -- | -- | 0 | 0% | 1 | -- | 1 | 0% |
| *unidentified sparrow* | -- | -- | 0 | 0% | 1 | -- | 1 | 0% |
| **Total** | **363** | **378** | **741** | **100%** | **717** | **356** | **1,073** | **100%** |

# **Appendix E.** Reptile species distribution tables

**Table E-1.** Reptile species in relation to the "Life Zones" from Bailey (1905). Some scientific names were updated to match those accepted by the Integrated Taxonomic Information System (ITIS). Other species were removed, at the recommendation of experts familiar with current and historical reptile distribution (see "Sources of Expertise"), as never occurring near GUMO.

| Scientific Name | Common Name | Lower Sonoran Zone | Upper Sonoran Zone |
|---|---|---|---|
| *Aspidocelis gularis* | Texas spotted whiptail | X | |
| *Aspidocelis neomexicanus* | New Mexico whiptail | X | |
| *Aspidocelis tesselatus* | checkered whiptail | X | |
| *Cophosaurus texanus* | greater earless lizard | X | |
| *Coleonyx brevis* | Texas banded gecko | X | |
| *Crotalus atrox* | western diamondback rattlesnake | X | |
| *Crotalus lepidus* | rock rattlesnake | | X |
| *Crotalus molossus* | black-tailed rattlesnake | | X |
| *Crotalus viridis* | prairie rattlesnake | | X |
| *Crotaphytus collaris* | eastern collared lizard | | X |
| *Crotaphytus collaris baileyi* | western collared lizard | | X |
| *Diadophis punctatus regalis* | regal ringneck snake | X | X |
| *Elaphe obsoleta* | Texas ratsnake | X | |
| *Eumeces guttulatus* * | blue-tailed skink | | X |
| *Eumeces obsoletus* | Great Plains skink | | X |
| *Eumeces tetragrammus* | Four-lined skink | | X |
| *Gambelia wislizenii* | long-nosed leopard lizard | X | |
| *Heterodon nasicus* | western hognose snake | X | X |
| *Holbrookia maculata* | lesser earless lizard | X | |
| *Opheodrys vernalis* | smooth green snake | | X |
| *Masticophis flagellum* | coachwhip | X | X |
| *Masticophis taeniatus* | striped whipsnake | X | |
| *Phrynosoma cornutum* | Texas horned lizard | X | |
| *Phrynosoma hernandesi* | greater short-horned lizard | | X |
| *Phrynosoma modestum* | round-tailed horned lizard | X | |
| *Pituophis catenifer sayi* | Bullsnake | | X |
| *Rhinocheilus lecontei* | long-nosed snake | X | |
| *Sceloporus undulatus consobrinus* | prairie lizard | X | X |
| *Sceloporus merriami* | canyon lizard | X | |
| *Sceloporus poinsettii poinsettii* | crevice spiny lizard | | X |
| *Sonora semiannulata* | ground snake | | X |
| *Thamnophis cyrtopsis* | black-necked garter snake | | X |
| *Thamnophis elegans* | western terrestrial garter snake | X | |
| *Thamnophis proximus* | western ribbon snake | X | |
| *Urosaurus ornatus* | tree lizard | | X |

* This is now considered a synonym for *Eumeces obsoletus*

**Photo E-1.** Texas banded gecko (photo from Prival and Goode 2005).

**Table E-2**. Reptile species and local distributions recorded during a herpetofauna study by Mecham (1979). Rare species are indicated with an 'R'. Some scientific names were updated to match those accepted by the Integrated Taxonomic Information System (ITIS).

| Scientific Name | Common Name | Distribution |
|---|---|---|
| *Arizona elegans* | glossy snake | Mostly found in the plains belt but can be seen on mountains at low elevations |
| *Bogertophis subocularis* | Trans-Pecos rat snake | Associated with Chihuahuan desert |
| *Aspidocelis exsanguis* | Chihuahuan spotted whiptail | Common in roughlands belt up to 6,000 ft |
| *Aspidocelis gularis* | Texas spotted whiptail | Confined to desert plains below 4,500 ft |
| *Aspidocelis inornatus* | little striped whiptail | Confined to desert plains below 4,500 ft |
| *Aspidocelis tesselatus* | checkered whiptail | Common in roughlands belt up to 6,000 ft |
| *Aspidocelis tigris* | western whiptail | Confined to desert plains below 4,500 ft, mesquite dunes bordering salt flats |
| *Coleonyx brevis* | Texas banded gecko | Partly desert plains but also in lower parts of roughland belt (4,200-7,000 ft) |
| *Cophosaurus texanus* | greater earless lizard | Common in roughland belt up to 6,000 ft |
| *Crotalus atrox* | western diamondback rattlesnake | N/A |
| *Crotalus lepidus* | rock rattlesnake | Common in roughlands belt and extend to high altitudes (7,400-8,200 ft) |
| *Crotalus molossus* | black-tailed rattlesnake | Common in roughlands belt and extend to high altitudes (7,400-8,200 ft) |
| *Crotalus scutulatus* (R) | Mojave rattlesnake | Mostly found in the plains belt but can be seen on mountains at low elevations |
| *Crotalus viridis* | prairie rattlesnake | Mostly found in the plains belt but can be seen on mountains at low elevations |
| *Crotaphytus collaris* | eastern collared lizard | Common in roughland belt up to 6,000 ft |
| *Diadophis punctatus* | ring-necked snake | Subspecies (*arnyi, regalis*) exist in GUMO distinct sp |
| *Elaphe guttata* | corn snake | *Elaphe guttata emoryi* associated with Southern Great plains |
| *Eumeces obsoletus* | Great Plains skink | Common in roughlands belt up to 6,000 ft |
| *Eumeces multivirgatus* | many-lined skink | Occurs at all altitudes |
| *Gyalopion canum* | Chihuahuan hook-nose snake | Associated with Chihuahuan desert |
| *Heterodon nasicus* | western hognose snake | Mostly found in the plains belt but can be seen on mountains at low elevations |
| *Holbrookia maculata* (R) | lesser earless lizard | Museum collections collected from gypsum dunes |
| *Hypsiglena torquata* | night snake | N/A |
| *Kinosternon flavescens* | yellow mud turtle | Associated with permanent to semi permanent water bodies |
| *Lampropeltis getula* | common kingsnake | Mostly found in the plains belt but can be seen on mountains at low elevations |
| *Lampropeltis mexicana* (R) | gray-banded kingsnake | Only record in Pine Springs (its northern extent) Associated with Chihuahuan desert |
| *Leptotyphlops dulcis* | Texas thread snake | Limited to Texas, and isolated pop in NM |
| *Masticophis flagellum* | coachwhip | N/A |
| *Masticophis taeniatus* | striped whipsnake | N/A |
| *Opheodrys vernalis* | smooth green snake | Sub recent fossil record in McKittrick Canyon (6,000ft) |
| *Phrynosoma cornutum* | Texas horned lizard | Occurs widely in plains belt, ranges to 6,000 ft |
| *Phrynosoma douglasii* | short-horned lizard | Occurs in evergreen and conifer woodlands |
| *Phrynosoma modestum* | round-tailed horned lizard | Partly desert plains but also in lower parts of roughland belt (4,200-7,000 ft) |
| *Pituophis melanoleucus* | pine snake | Wide ecological tolerance (3,600 – 8,000 ft) |
| *Rhinocheilus lecontei* | long-nosed snake | Mostly found in the plains belt but can be seen on mountains at low elevations |

| Scientific Name | Common Name | Distribution |
| --- | --- | --- |
| *Tantilla atriceps* | Mexican black-headed snake | Associated with Chihuahuan desert |
| *Tantilla nigriceps* | plains black-headed snake | Mostly found in the plains belt but can be seen on mountains at low elevations |
| *Terrapene ornata* | ornate box turtle | Distributed along lower elevations (terrestrial) |
| *Thamnophis cyrtopsis* | black-necked garter snake | Dependent on permanent water and lower elevations (E or NE side of mountains) |
| *Salvadora grahamiae* | mountain patch-nosed snake | N/A |
| *Salvadora hexalepis* (R) | western patch-nosed snake | A specimen in the Carlsbad Cavern NP collection |
| *Sceloporus poinsettii* | crevice spiny lizard | Extremely wide range of at least 8,000 ft |
| *Sceloporus undulatus* | eastern fence lizard | Occurs at all altitudes |
| *Sonora semiannulata* | ground snake | Associated with Southern Great Plains |
| *Urosaurus ornatus* | ornate tree lizard | Extremely wide range of at least 8,000 ft |
| *Uta stansburiana* | common side-blotched lizard | Confined to desert plains below 4,500 ft |

**Photo E-2.** Black-necked garter snake (photo from Prival and Goode 2005).

**Table E-3.** Reptile species and local distributions in relation to respective plant communities in GUMO (Grace 1980). Some scientific names were updated to match those accepted by the Integrated Taxonomic Information System (ITIS).

| Species | Common Name | Grassland | Perennial Forb | Mountain shrub | Conifer | Pinon-juniper | Hardwood | Creosotebush | Mesquite | Fourwing saltbush | Desert shrub |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Arizona elegans* | glossy snake | x | | | | | | x | | | |
| *Bogertophis subocularis* | Trans-Pecos rat snake | | | | | | | x | | | x |
| *Aspidocelis exsanguis* | Chihuahuan spotted whiptail | x | | x | | x | x | x | | | x |
| *Aspidocelis inornatus* | little striped whiptail | | | | | | | x | | | x |
| *Aspidocelis tesselatus* | checkered whiptail | | | x | | | | x | | | x |
| *Aspidocelis tigris* | western whiptail | | | | | | | x | x | x | x |
| *Coleonyx brevis* | Texas banded gecko | | | x | | | | | | | x |
| *Crotalus atrox* | western diamondback rattlesnake | x | x | x | | | | x | x | | x |
| *Crotalus lepidus* | rock rattlesnake | | | x | x | | x | | | | |
| *Crotalus molossus* | black-tailed rattlesnake | x | x | x | x | x | x | x | x | x | x |
| *Crotalus scutulatus* | Mojave rattlesnake | | | | | | | x | x | x | |
| *Crotalus viridis* | prairie rattlesnake | | | x | | x | | x | x | x | x |
| *Crotaphytus collaris* | eastern collared lizard | x | x | x | | | | x | | | x |
| *Cophosaurus texanus* | greater earless lizard | | | x | | | | x | | | x |
| *Diadophis punctatus* | ring-necked snake | x | | x | | | x | | | | x |
| *Elaphe guttata* | corn snake | x | | x | | | x | | | | x |
| *Eumeces obsoletus* | Great Plains skink | | | x | | x | x | | | | |
| *Eumeces multivirgatus* | many-lined skink | | | | x | | x | | | | |
| *Gambelia wislizeni* | long-nosed leopard lizard | | | | | | | x | x | x | x |
| *Gyalopion canum* | Chihuahuan hooknose snake | | | | | | | x | | | |
| *Holbrookia maculata* | lesser earless lizard | | | | | | | | | x | |
| *Hypsiglena torquata* | night snake | | | | | | | x | | | x |
| *Kinosternon flavescens* | yellow mud turtle | x | | x | | | | | | | |

| Species | Common Name | Grassland | Perennial Forb | Mountain shrub | Conifer | Pinon-juniper | Hardwood | Creosotebush | Mesquite | Fourwing saltbush | Desert shrub |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lampropeltis getula* | common kingsnake | | | | | | | x | | | |
| *Lampropeltis mexicana* | gray-banded kingsnake | | | x | | | | | | | |
| *Leptotyphlops dulcis* | Texas threadsnake | | | x | | | x | | | | x |
| *Masticophis flagellum* | coachwhip | | | x | | | | x | | x | x |
| *Masticophis taeniatus* | striped whipsnake | x | | x | x | x | x | | x | | x |
| *Phrynosoma cornutum* | Texas horned lizard | x | x | x | | | | | | x | x |
| *Phrynosoma douglasii* | short-horned lizard | | | x | x | x | | | | | |
| *Phrynosoma modestum* | round-tailed horned lizard | x | | x | | | | x | | x | x |
| *Pituophis melanoleucus* | pine snake | | x | x | x | x | x | x | x | x | x |
| *Rhinocheilus lecontei* | long-nosed snake | | | | | | | x | | | |
| *Salvadora grahamiae* | mountain patch-nosed snake | x | x | x | | x | x | x | | | x |
| *Sceloporus magister* | desert spiny lizard | | | | | | | x | | x | |
| *Sceloporus poinsettii* | crevice spiny lizard | | | x | x | | x | x | | | x |
| *Sceloporus undulatus* | eastern fence lizard | x | | x | x | x | x | | | | x |
| *Sonora semiannulata* | ground snake | | | | | | x | | | | |
| *Tantilla nigriceps* | plains black-headed snake | | | | | | | x | | | |
| *Tantilla atriceps* | Mexican black-headed snake | | | x | | | x | | | | x |
| *Terrapene ornata* | ornate box turtle | | | x | | | | x | | x | x |
| *Thamnophis cyrtopsis* | black-necked gartersnake | | | x | x | x | x | | | | x |
| *Urosaurus ornatus* | ornate tree lizard | | | x | | | x | x | | | x |
| *Uta stansburiana* | common side-blotched lizard | | | | | | x | x | x | x | x |

# **Appendix F.** Viewscape analysis methods

Analysis and write-up by Melanie Myers

The project team agreed to consider two different analyses for the GUMO viewscape component based on different reference frames. The first analysis focused on viewsheds from points within the park boundary, looking outside of the park to the surrounding landscape. Observation points were selected by park staff. The selected points were observation areas on different peaks within the park. Many of the observation points were the same points used during the development of an RSS for GUMO. The second analysis focused on State Highway 180/62 to the south and east of the park and what features within the park are visible from it. Both analyses utilized a 60-mile (96.5-km) buffered area around the park as an analysis boundary.

### ***Data***

Data used in the viewshed analysis:

1. Digital Elevation Data – downloaded from: http://viewer.nationalmap.gov/viewer/ Downloaded 10m National Elevation Data for the following 100k Quads: Crow Flats and Carlsbad in New Mexico and Dell City and Guadalupe quads in Texas. The tiles were then mosaicked, re-projected to NAD 83 UTM Zone 13 N, and the 60 mile analysis area around the park was then extracted.

2. ESRI ArcGIS shapefiles **-** obtained from Jonena Hearst:
   - Highways_StateRdLocal.shp
   - RSS_viewshed.mdb
   - Peaks.shp

Observation points: Guadalupe Mountain Peak, Bartlett Peak, Cutoff Mountain, and Permian Reef point were exported from the above shapefiles and merged into one shapefile called Viewpts_inPark. In a couple of cases, the points in this file were moved if there was a cell that had a higher elevation next to where the point was.

The line segment that was used for the Highway 180/62 viewshed was exported from the Highways_StateRdLocal shapefile and then generalized to have fewer vertices, to simplify data for the viewshed analysis. This layer was named TX_Highway180.

3. Wind Turbine data - There are wind turbines that are visible from the park that the NRCA team wanted included in the analysis. Once the locations of the wind turbines were obtained from Heather Glaze, the turbines were heads up digitized using Bing maps from ArcGIS Online. This layer was called Wind_Turbines.

### ***Methods***

Once the observation points and the highway line segment were finalized, an Offset A of 1.68 m (5.5 ft) was added to the layer's attribute table. This simulates the average height of a person during the viewshed analysis.

I used ESRI ArcGIS v10 software to add information to the attribute tables.

I used ESRI ArcCatalog v10 tools: buffer, mosaic to new raster, extract by mask, and viewshed to create the DEM used in the analysis and the viewsheds.

ESRI ArcGIS v10 Spatial Analyst Viewshed inputs for within park analysis:

Input Raster: DEM_10meter.tiff
Input Point: Viewpts_inPark

ESRI ArcGIS v10 Spatial Analyst Viewshed inputs for outside park analysis:

Input Raster: DEM_10meter.tiff
Input Line: TX_Highway180

**Table F-1.** NLCD cover class change (2001-2006) within GUMO external viewshed (gray indicates class with actual change).

| Change Type | Acres | Percent Visible Area |
|---|---|---|
| Shrub/Scrub to Shrub/Scrub | 4,229,650 | 86 |
| Grassland/Herbaceous to Grassland/Herbaceous | 246,151.9 | 5 |
| Barren Land to Barren Land | 152,609.4 | 3 |
| Cultivated Crops to Cultivated Crops | 46,716.3 | 0.95 |
| Developed, Open Space to Developed, Open Space | 28,846.05 | 0.58 |
| Evergreen Forest to Evergreen Forest | 18,288.79 | 0.37 |
| Open Water to Open Water | 10,535.02 | 0.21 |
| Woody Wetlands to Woody Wetlands | 9,365 | 0.19 |
| Shrub/Scrub to Cultivated Crops | 8,347 | 0.17 |
| Emergent Herbaceous Wetlands to Emergent Herbaceous Wetlands | 8,005 | 0.16 |
| Developed, Low Intensity to Developed, Low Intensity | 4,231 | 0.08 |
| Shrub/Scrub to Open Water | 2,195 | 0.04 |
| Barren Land to Open Water | 2,061 | 0.04 |
| Shrub/Scrub to Barren Land | 1,835 | 0.03 |
| Shrub/Scrub to Woody Wetlands | 1,479 | 0.03 |
| Shrub/Scrub to Developed, Open Space | 1,256 | 0.02 |
| Cultivated Crops to Shrub/Scrub | 1,120 | 0.02 |
| Grassland/Herbaceous to Shrub/Scrub | 1,035 | 0.02 |
| Shrub/Scrub to Pasture/Hay | 725 | 0.01 |
| Shrub/Scrub to Evergreen Forest | 673 | 0.01 |
| Barren Land to Shrub/Scrub | 650 | 0.01 |
| Developed, Medium Intensity to Developed, Medium Intensity | 629.8197 | 0.01 |
| Grassland/Herbaceous to Woody Wetlands | 550.4251 | 0.01 |
| Barren Land to Cultivated Crops | 458.7987 | <0.01 |
| Emergent Herbaceous Wetlands to Woody Wetlands | 389.1894 | <0.01 |
| Shrub/Scrub to Emergent Herbaceous Wetlands | 308.4604 | <0.01 |
| Grassland/Herbaceous to Cultivated Crops | 219.5028 | <0.01 |
| Shrub/Scrub to Developed, Low Intensity | 212.831 | <0.01 |
| Barren Land to Pasture/Hay | 162.3476 | <0.01 |
| Developed, High Intensity to Developed, High Intensity | 138.5514 | <0.01 |
| Emergent Herbaceous Wetlands to Cultivated Crops | 108.973 | <0.01 |
| Woody Wetlands to Open Water | 106.3043 | <0.01 |
| Grassland/Herbaceous to Pasture/Hay | 62.27031 | <0.01 |
| Open Water to Shrub/Scrub | 61.82552 | <0.01 |
| Shrub/Scrub to Grassland/Herbaceous | 57.37764 | <0.01 |
| Deciduous Forest to Deciduous Forest | 56.93285 | <0.01 |
| Evergreen Forest to Shrub/Scrub | 40.03091 | <0.01 |
| Barren Land to Developed, Open Space | 35.58303 | <0.01 |
| Shrub/Scrub to Developed, Medium Intensity | 30.24558 | <0.01 |

| Change Type | Acres | Percent Visible Area |
|---|---|---|
| Cultivated Crops to Barren Land | 30.24558 | <0.01 |
| Shrub/Scrub to Deciduous Forest | 26.68728 | <0.01 |
| Woody Wetlands to Emergent Herbaceous Wetlands | 19.34827 | <0.01 |
| Woody Wetlands to Developed, Open Space | 18.68109 | <0.01 |
| Cultivated Crops to Developed, Open Space | 16.45715 | <0.01 |
| Emergent Herbaceous Wetlands to Open Water | 16.45715 | <0.01 |
| Cultivated Crops to Deciduous Forest | 14.678 | <0.01 |
| Open Water to Emergent Herbaceous Wetlands | 13.34364 | <0.01 |
| Barren Land to Woody Wetlands | 13.34364 | <0.01 |
| Woody Wetlands to Cultivated Crops | 11.78688 | <0.01 |
| Barren Land to Grassland/Herbaceous | 10.8973 | <0.01 |
| Grassland/Herbaceous to Evergreen Forest | 10.8973 | <0.01 |
| Cultivated Crops to Emergent Herbaceous Wetlands | 9.785334 | <0.01 |
| Grassland/Herbaceous to Developed, Open Space | 8.895758 | <0.01 |
| Barren Land to Developed, Low Intensity | 7.561395 | <0.01 |
| Open Water to Barren Land | 6.227031 | <0.01 |
| Cultivated Crops to Open Water | 5.782243 | <0.01 |
| Grassland/Herbaceous to Open Water | 5.115061 | <0.01 |
| Open Water to Woody Wetlands | 4.447879 | <0.01 |
| Emergent Herbaceous Wetlands to Grassland/Herbaceous | 4.225485 | <0.01 |
| Open Water to Cultivated Crops | 4.003091 | <0.01 |
| Emergent Herbaceous Wetlands to Barren Land | 3.558303 | <0.01 |
| Grassland/Herbaceous to Barren Land | 3.335909 | <0.01 |
| Grassland/Herbaceous to Emergent Herbaceous Wetlands | 3.335909 | <0.01 |
| Grassland/Herbaceous to Developed, Low Intensity | 3.113515 | <0.01 |
| Shrub/Scrub to Developed, High Intensity | 2.668728 | <0.01 |
| Emergent Herbaceous Wetlands to Developed, Open Space | 2.446334 | <0.01 |
| Developed, Low Intensity to Open Water | 2.001546 | <0.01 |
| Barren Land to Emergent Herbaceous Wetlands | 2.001546 | <0.01 |
| Evergreen Forest to Cultivated Crops | 2.001546 | <0.01 |
| Deciduous Forest to Shrub/Scrub | 1.779152 | <0.01 |
| Cultivated Crops to Developed, Medium Intensity | 1.779152 | <0.01 |
| Deciduous Forest to Emergent Herbaceous Wetlands | 1.556758 | <0.01 |
| Cultivated Crops to Woody Wetlands | 1.556758 | <0.01 |
| Cultivated Crops to Grassland/Herbaceous | 1.11197 | <0.01 |
| Cultivated Crops to Developed, Low Intensity | 0.889576 | <0.01 |
| Woody Wetlands to Developed, Medium Intensity | 0.667182 | <0.01 |
| Woody Wetlands to Developed, Low Intensity | 0.444788 | <0.01 |
| Open Water to Deciduous Forest | 0.222394 | <0.01 |
| Evergreen Forest to Deciduous Forest | 0.222394 | <0.01 |
| Grassland/Herbaceous to Developed, Medium Intensity | 0.222394 | <0.01 |

**Appendix G.** Depth to groundwater data for three wells in or near GUMO

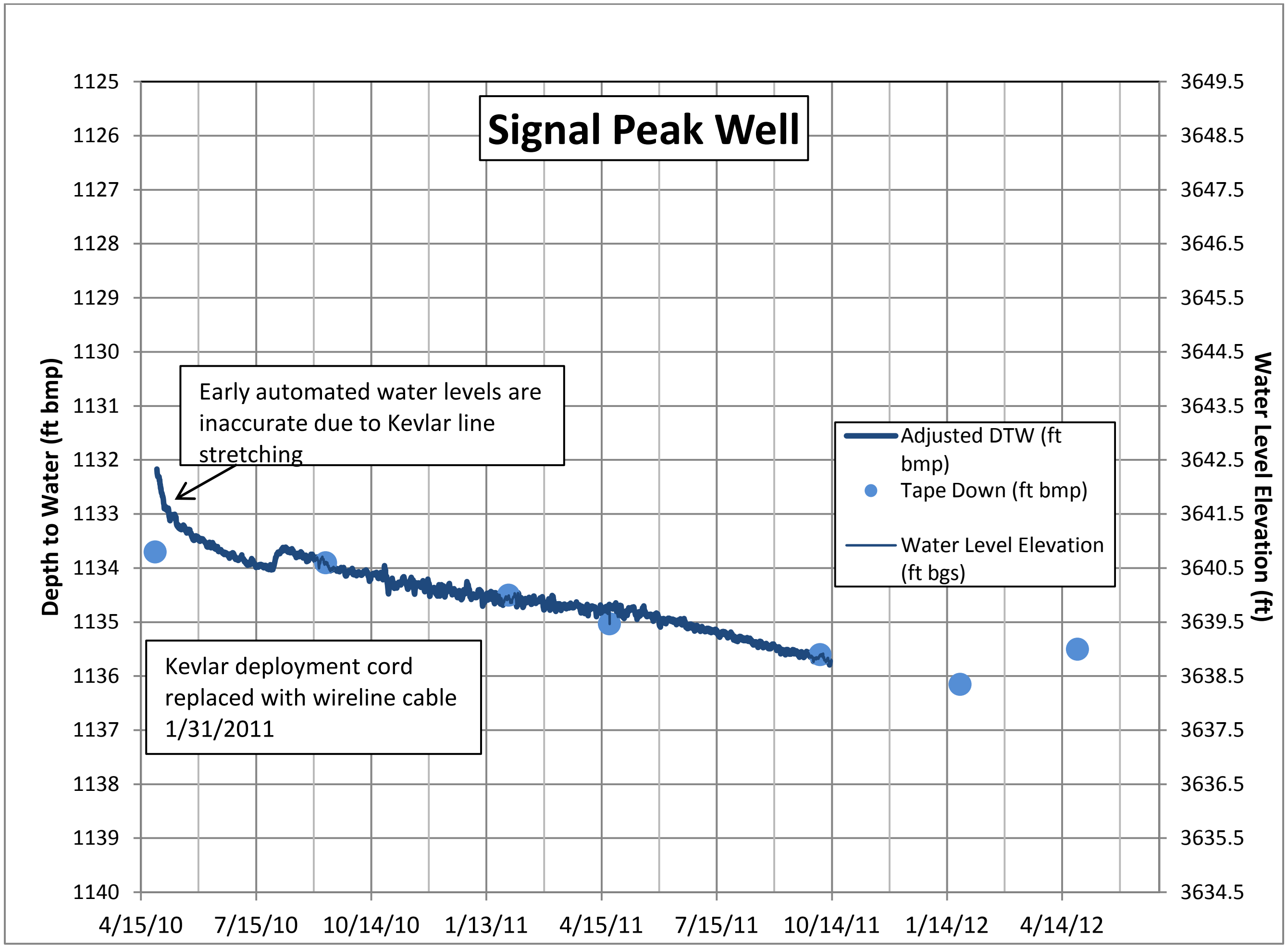


**Figure G-1.** Depth to groundwater measurements from Signal Peak Well just east of GUMO (graphic provided by Colleen Filippone, 2012).

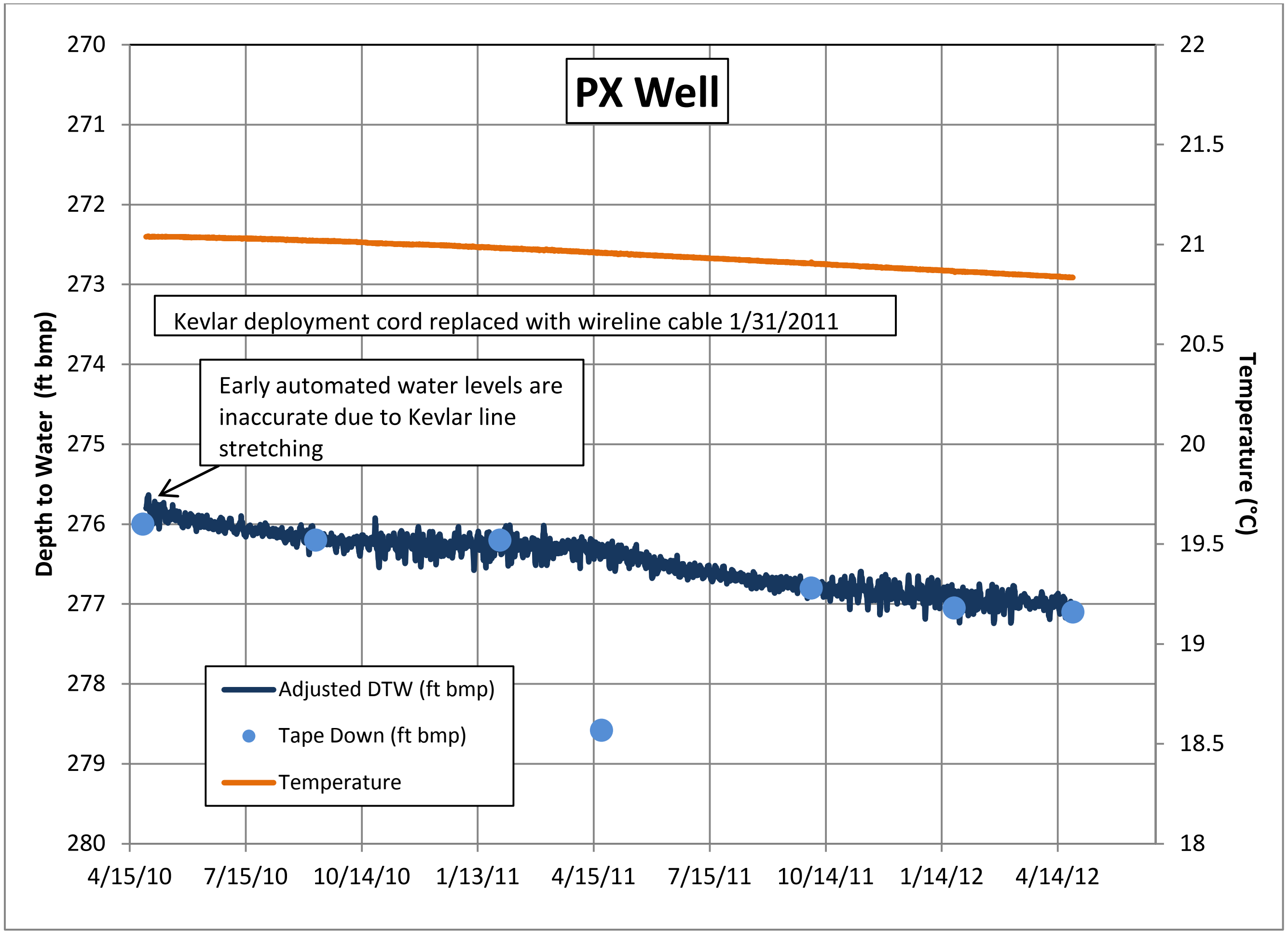


**Figure G-2.** Depth to groundwater measurements from PX Well in northwest GUMO (graphic provided by Colleen Filippone, 2012).

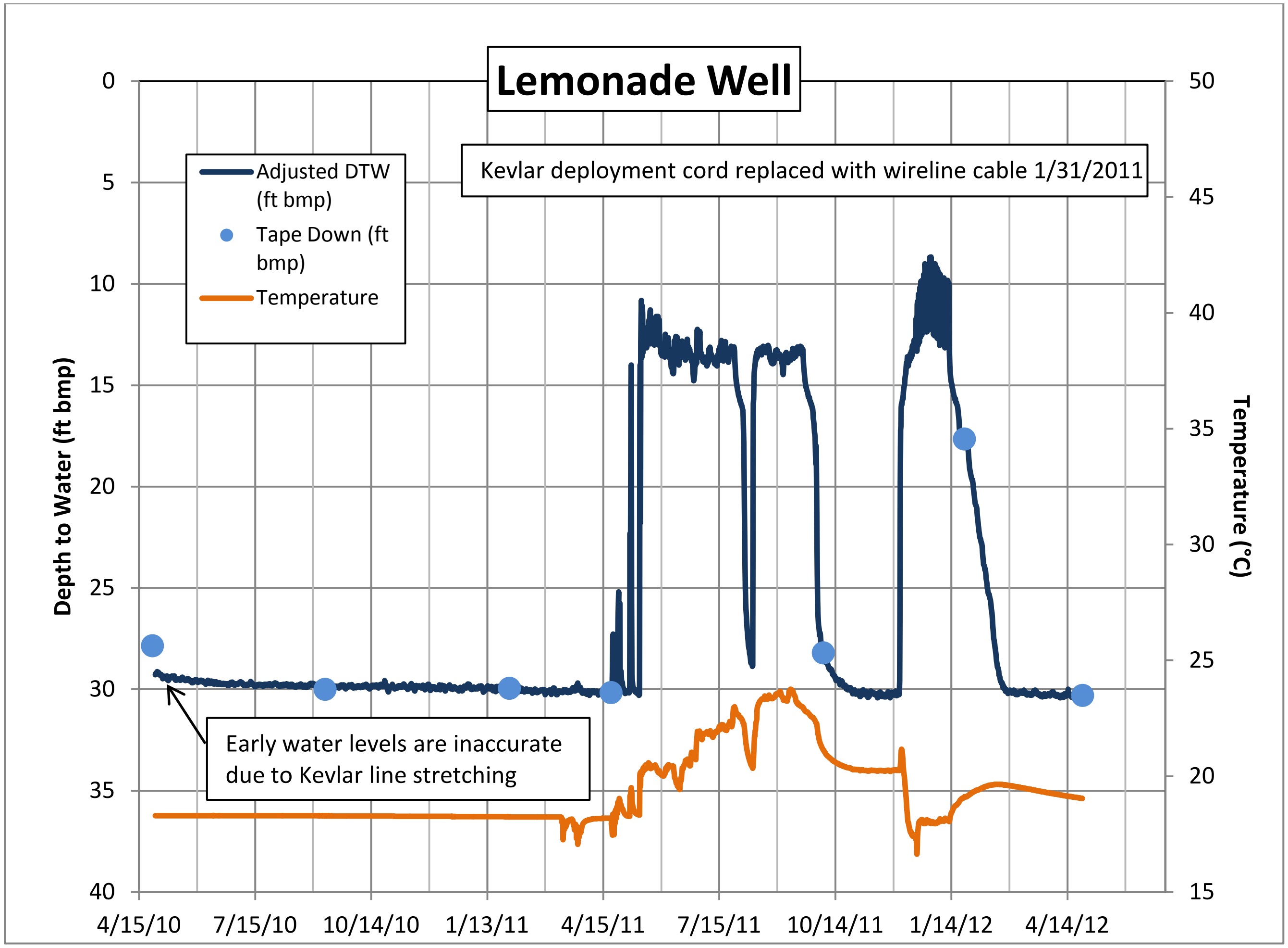


**Figure G-3.** Depth to groundwater measurements from Lemonade Well on the western border of GUMO (graphic provided by Colleen Filippone, 2012). Sudden peaks during 2011 and early 2012 were due to leaks in an old line that previously connected the well to a network of stock tanks, allowing water to leak into the subsurface and skew depth readings. This line has since been capped at both ends (Hearst, written communication, 4 October 2012).

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 166/121239, June 2013

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