National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

# White Sands National Monument

## *Natural Resource Condition Assessment*

Natural Resource Report NPS/WHSA/NRR—2017/1508

**ON THE COVER**
Photograph of the rolling transverse barchan dune field in White Sands National Monument
Photograph by Kathy Allen, SMUMN GSS

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Natural Resource Report NPS/WHSA/NRR—2017/1508

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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 White Sands National Monument (WHSA) 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 WHSA. The final project framework contains 13 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 WHSA resource managers, NPS Chihuahuan Desert Network staff, or outside experts.

Existing literature, short- and long-term datasets, and input from NPS and other outside agency scientists support condition designations for components in this assessment. However, in some cases, data were unavailable or insufficient for several of the measures of the featured components. In other instances, data establishing reference condition were limited or unavailable for components, making comparisons with current information inappropriate or invalid. In these cases, it was not possible to assign condition for the components. Current condition was not able to be determined for 8 of the 13 components (62%) due to these data gaps.

For those components with sufficient available data, the overall condition varied. One component was determined to be of good condition (breeding birds). However, a trend analysis was not possible for that component, and the the overall condition score was at the edge of the good condition range; any small decline in the community could shift it into the moderate concern range. Viewscape was the only component that was of moderate concern, and it exhibited a stable trend at current. Three components were determined to be of significant concern. Both hydrologic components (ground water and surface water) exhibited declining trends, primarily due to increased water demand in the area. The Cenozoic trackways component was also of significant concern, although this component had a stable trend largely due to the erradic nature of when and where these trackways are revealed. 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 WHSA. Those of primary concern include invasive exotic plant species, climate change, neighboring military-related developments and activities, and increased water demand in nearby communities. Understanding these threats, and how they relate to the condition of park resources, can help the NPS prioritize management objectives and better focus their efforts to maintain the health and integrity of the park ecosystem, as well as its cultural landscape.

# Acknowledgments

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## Acronyms and Abbreviations

AOR – Alive-on-Road

AP – Ammonium Perchlorate

APZ – Accident Protection Zone

ARD – Air Resources Division

ASTER – Advanced Spaceborne Thermal Emission and Reflection

ATWG – Agency Technical Working Group

BBS – Breeding Bird Survey

BCC – Birds of Conservation Concern

BCR – Bird Conservation Region

BP – Before Present

BPP – Bird Phenology Program

$Ca^{2+}$ – Calcium Ion

$CaCO_3$ – Calcium Carbonate

CBC – Christmas Bird Count

CHDN – Chihuahuan Desert Network

Cl – Chlorine

$CO_3$ – Carbon Trioxide

dB – Decibels

dBA – A-weighted Decibels

DEM – Digital Elevation Model

DNL – Day-night Average Level

DOD – Department of Defense

DOR – Dead-on-Road

dv – Deciview

EA – Environmental Assessment

## Acronyms and Abbreviations (continued)

EIS – Environmental Impact Statement

EPA – Environmental Protection Agency

EPMT – Exotic Plant Management Team

Esri – Environmental Systems Research Institute

GCM – Clogal Climate Models

GIS – Geographic Information System

GPS – Global Positioning System

GRTS – Generalized Random-Tessellation Stratification

GUMO – Guadalupe Mountains National Park

$H_2O$ – Water

HAFB – Holloman Air Force Base

HIS – Habitat Similarity Index

$HNO_3$ – Nitric Acid

Hz – Hertz

I&M – Inventory and Monitoring

IMBCR – Integrated Monitoring in Bird Conservation Regions

IMPROVE – Interagency Monitoring of Protected Visual Environments

IPCC – Intergovernmental Panel on Climate Change

IRMA –Integration of Resource Management Applications

K – Potassium

LiDAR – Light Detection and Ranging

Mg – Magnesium

MODIS – Moderate Resolution Imaging Spectroradiometer

MRLC – Multi-Resolution Land Characteristics

Na – Sodium

## Acronyms and Abbreviations (continued)

NAAQS – National Ambient Air Quality Standards

NASA – National Aeronautics and Space Administration

NCDC – National Climate Data Center

NED – National Elevation Dataset

NMMNHS – New Mexico Museum of Natural History and Science

NLCD – National Land Cover Dataset

NM CWCS – New Mexico Comprehensive Wildlife Conservation Strategy

NMDGF – New Mexico Department of Game and Fish

NOAA – National Oceanic and Atmospheric Administration

NPS – National Park Service

NRCA – Natural Resource Condition Assessment

NVCS – National Vegetation Classification System

NWS – National Weather Service

OSL – Optically Stimulated Luminescence

PCB – Polychorinated Biphehyl

PIF – Partners in Flight

PM – Particulate Matter

QRC – Quantitative Road Cruising

RfD – Reference Dose

RFS – Random Foot Search

RMBO – Rocky Mountain Bird Observatory

SANWR – San Andres National Wildlife Refuge

SELA – Solar Energy Industries Associates

$SiO_2$ – Silicon Dioxide

SMUMN GSS – Saint Mary's University of Minnesota GeoSpatial Services

## Acronyms and Abbreviations (continued)

$SO_4^{2-}$ – Sulfate Ion

SPL – Sound Pressure Level

SVOC – Semi-Volatile Organic Compound

TDS – Total Dissolved Solids

US – United States

USFS – U.S. Forest Service

USFWS – U.S. Fish and Wildlife Service

USGS – U.S. Geological Survey

UXO – Unexploded Ordnance

VOC – Volatile Organic Compound

WHSA – White Sands National Monument

WRCC – Western Regional Climate Center

WSMR – White Sands Missile Range

# Chapter 1. NRCA Background Information

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

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

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

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

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

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

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

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

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

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

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

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

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

***Important NRCA Success Factors***

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

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

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

***NRCA Reporting Products…***

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

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

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

[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*

WHSA was established by Congress in 1933 to preserve a portion of the largest gypsum dune field in the world. President Herbert Hoover signed the 1933 proclamation to designate 57,865 ha (142,987 ac) of White Sands as part of the NPS, which was created in 1916 (Welsh 1995). According to the park's resource management plan, WHSA was established "under the provisions of the Antiquities Act of 1906, in order to preserve the unique geology of the gypsum sand dunes and to protect all of its other scenic, scientific and educational values" (NPS 1981, p. 2).

### *2.1.2. Geographic Setting*

WHSA is part of the Chihuahuan Desert Ecoregion in south-central New Mexico and includes 58,275 ha (144,000 ac) of bajadas, alkali flats, playas, and about 40% of the world's largest gypsum dune field (Photo 1). The park lies inside one of many basins within the tri-state, Tertiary Rio Grande Rift (Fryberger 2001). The basin is considered endorheic or "closed," meaning it is disconnected hydrologically from the surrounding Rio Grande watershed and retains any incoming water (KellerLynn 2012). WHSA is within the Tularosa Basin watershed and includes one of the basin's largest playas, Lake Lucero, which is located in the southwest corner of the park. White Sands Missile Range, operated by the U.S. Army, completely surrounds WHSA (KellerLynn 2012).

**Photo 1.** The white gypsum dunes of WHSA (Photo: Kathy Allen, SMUMN GSS).

### *2.1.3. Visitation Statistics*

Visitors come to WHSA for a variety of reasons, but many come to experience the incredible beauty of the pure white sand dunes. The dunes are visible by vehicle, but visitors can choose from a number of viewing opportunities that the park provides. There are scheduled sunset strolls guided by a park ranger that provide a descriptive tour of the park's flora, fauna, and the local geology. In addition to guided hikes, there are interpretive programs that visitors can attend to learn about the area's current and historical features. Other visitor opportunities at WHSA include stargazing, picnicking, camping, bike rides, photography, and, perhaps most unique within the NPS, dune sledding.

Typically, the highest visitation estimates in the park occurs between March and July (Table 1); the highest visitation estimate in a given month (since 1979) occurred in March 1986, when 112,288 people visited WHSA (NPS 2016b). On average, WHSA receives 521,349 visitors per year. The highest number of visitors in a calendar year occurred in 1986 (666,879), while the lowest number of visitors in a year occurred in 2011 (428,924).

**Table 1.** Average monthly visitation estimates for WHSA from 1979-2016 (NPS 2016b).

| Month | Visitors |
|---|---:|
| January | 24,078 |
| February | 29,283 |
| March | 61,147 |
| April | 55,187 |
| May | 54,871 |
| June | 53,639 |
| July | 65,141 |
| August | 53,973 |
| September | 40,575 |
| October | 36,359 |
| November | 28,448 |
| December | 26,670 |

## 2.2. Natural Resources

### *2.2.1. Ecological Units and Watersheds*

WHSA has three major ecological units: the gypsiferous dunes, low-mountain bajadas, and the Chihuahuan basins and playas (Figure 1, NPS 2010).

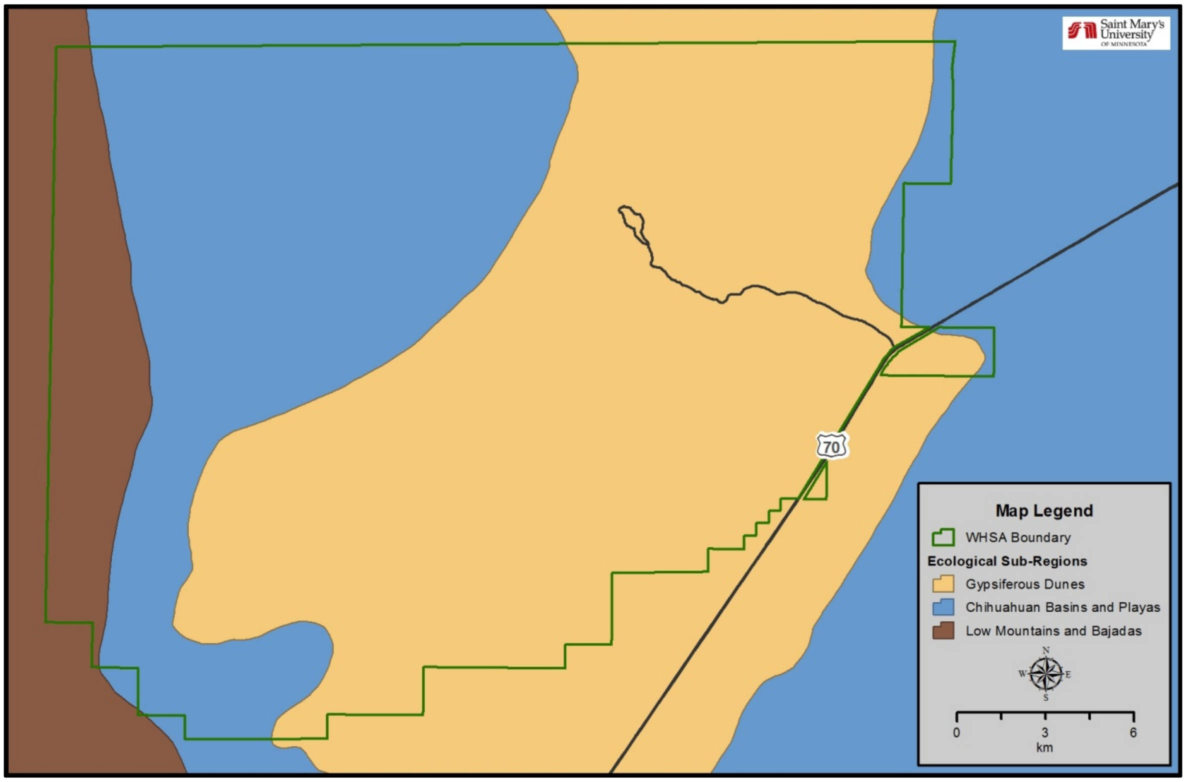


**Figure 1.** Ecoregions within and near WHSA.

Rain runs down intermittent stream channels on the San Andres Mountain slopes creating the bajadas (alluvial plains) that drain onto the alkali or salt flat where water accumulates in the playas (ephemeral lakes) within the active Holocene lake basin (Fryberger 2001). The dune field underlayment and the Lucero Playa consist of basin fill that is lithologically complex. There are fine-grained rock deposits with low permeability amongst more conductive rock outcrops that function as recharge areas for the underlying basin aquifer; this makes permeability highly variable from place to place (Fryberger 2001). The WHSA interior includes five watershed sub-units of the greater Tularosa Valley unit, though the Lake Lucero sub-watershed covers the most park area (Figure 2).

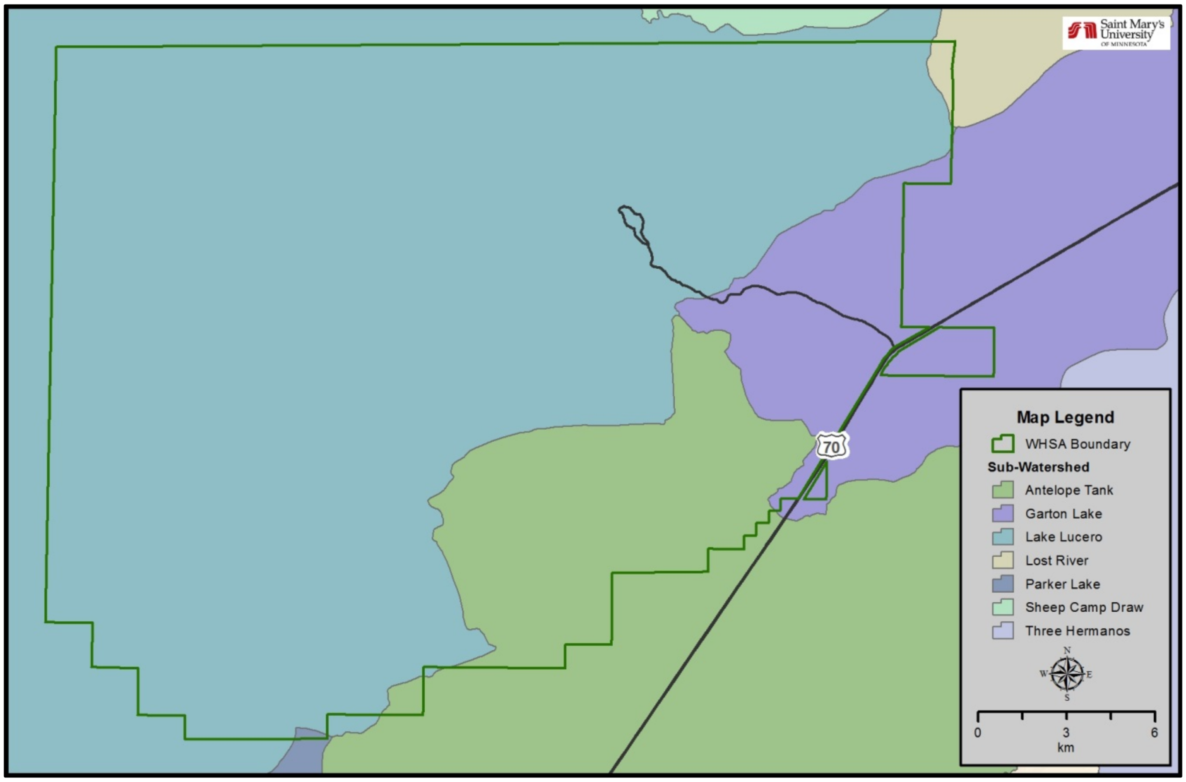


**Figure 2.** The Tularosa Basin and sub-watersheds of WHSA.

Weather in WHSA is characterized by sporadic weather events (droughts and precipitation) that vary spatially, annually and seasonally; this is typical of the climatic features of the greater Chihuahuan Desert where WHSA is situated (Davey 2007). The basin experiences cool winters and hot summers with around 27-28 cm (10.6-11.0 in) of mean annual precipitation (WRCC 2016), much of which falls during the months of July-September (Table 2). Summer high temperatures at WHSA average around 35°C (95°F) and at times exceed 38°C (100°F) during the day, cooling off at night (NPS 2014, WRCC 2016). Winter low temperatures are frequently below freezing (WRCC 2016, Table 2). Spring is the peak wind season in WHSA and wind speeds average around 37 km per hour (23 mph) from the southwest, which appears to be the historic directional trend for the area (Bennett and Wilder 2009).

**Table 2.** 30-year climate normals (1981-2010) for the White Sands National Monument weather station (299686) (WRCC 2016).

| Metric | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Average temperature (°C)** | | | | | | | | | | | | | |
| Max | 13.9 | 16.9 | 21.1 | 25.9 | 31.1 | 35.7 | 35.8 | 34.4 | 31.3 | 25.8 | 18.8 | 13.4 | 25.4 |
| Min | -5.6 | -3.4 | -0.2 | 4.3 | 9.7 | 14.9 | 17.7 | 16.7 | 12.4 | 5.2 | -2.0 | -5.9 | 5.4 |
| **Average precipitation (cm)** | | | | | | | | | | | | | |
| Total | 1.4 | 1.1 | 0.7 | 0.8 | 1.2 | 2.4 | 3.9 | 6.0 | 3.7 | 2.6 | 1.3 | 2.2 | 27.4 |

#### *2.2.2. Resource Descriptions*

The resources at WHSA are valuable from a perspective of hydrology, geology, ecology, paleontology, and are even used as a terrestrial analog for scientists studying the planet Mars. The Tularosa Valley is bounded by the San Andres and Sacramento Mountain ranges. The valley was once a large lake basin, ancient Lake Otero, formed 24,000-12,000 years ago during the Holocene. The lake occupied much of the valley basin for nearly 20,000 years of cool, wet climate, until the end of the last ice age when it and the regional climate began to dry up (KellerLynn 2012). Precipitation during the wet period carried dissolved solids such as salt and other soluble materials from the valley margins (ancient uplifted sea beds) into the lake where it accumulated and became expansive, sedimentary deposits as Lake Otero slowly evaporated (Fryberger 2001). Because the Tularosa Valley is a closed basin, meaning no exterior drainage for the lakes within it, the dissolved gypsum and other sediments have become trapped around and within the modern desert playas or ephemeral lakes (Bennet and Wilder 2009). Playas experience high evaporation rates which continually leave behind evaporates such as salt and gypsum that are transported by eolian processes that dominate the arid region. Lake Lucero is the largest of the 48.3-km (30-mi) string of playas and occupies the lowest topographical point in the basin (Bennett and Wilder 2009). Under normal hydrologic conditions, the easily dissolved gypsum and other solutes would be transported to the sea by rivers rather than re-precipitated and deposited as a solid, making the gypsum sand (hydrous calcium sulfate) dune field a fascinating geologic structure and a scientifically significant research topic. The bajadas, alkali flats (Photo 2), and playas within WHSA boundaries are an integral part of the dune field stability.

**Photo 2.** An alkali flat in western WHSA (Photo: Kathy Allen, SMUMN GSS).

The dune field covers much of the park’s area. The gypsum accumulations formed from a complex interaction between climate, tectonics, and hydrology that involves underground geochemical recycling of sulfur (a very long-term process) that underlays and surrounds the basin floor (Szynkiewicz et al. 2010). The ancient lacustrine sedimentary formations and the modern gypsumcrusted playas and alkali flats, are continuously eroded by eolian deflation, as winds carry away sand that feeds the dune field (Langford 2003). The huge dune field is unique; the accumulation in New Mexico is 99% pure gypsum and attracts visitors from all over the world to WHSA to view the stunning and bizarre landscape of nearly pure white sand. The gypsiferous dune field covers 712 $km^2$ (275 $mi^2$) of the Tularosa Basin with about 298 $km^2$ (115 $mi^2$) of it inside the 581 $km^2$ (224 $mi^2$) WHSA boundary (Figure 1, Bennett and Wilder 2009). The dune field is constantly changing as the dunes migrate; wind behavior, water table levels, and vegetation all affect the shape and movement of the dunes.

Dunes inadvertently create interdune microenvironments where various organisms have adapted to colonize the ever-shifting interdune areas (Bennett and Wilder 2009). The dunes create turbulence and wind deflection in the interdune areas which tend to contribute to these more hospitable microclimates by slowing wind and trapping moisture that aids in soil crust formation. The interdune areas are often damp and even have standing water at times, also aiding soil crust formation (Fryberger 2001). It is important to note that the water table is highly variable in salinity depending on location; the dissolved salt and gypsum in the ground reach the surface during rain events followed by rapid evaporation and in some places become very concentrated. The formation of soil crusts is an important component at WHSA and have two basic forms, physical and biological. The physical crusts form from inorganic materials filling interstitial spaces at the substrate surface. Particle sorting from rain drops cause the crust to form by packing small grains in between larger grains, and rapid evaporation leaves a salt crust making the soil resistant to eolian (wind) processes. The biological crust is formed by living things (e.g., lichens, algae, and/or bacteria) at the soil surface that hold surface particles together with organic material (KellerLynn 2012). Both types contribute to the dune processes and ecological functions, but the biological soil crusts can be indicators of ecosystem health and stability (KellerLynn 2012). The living, biological crusts are critical to plant growth; they not only bind soil and protect it from blowing away, but also fix nitrogen and promote water infiltration on silty soils (KellerLynn 2012).

Flora in WHSA consists of drought tolerant species associated with the Chihuahuan Desert (Bennett and Wilder 2009). The plants are also adapted to the nutrient poor, alkaline soils found in WHSA and its high gypsum content (Bennett and Wilder 2009). There are six distinct ecological sub-units (Table 3) that contain the majority of WHSA flora; each is categorized by soil type, dune activity, mineral concentration, and water availability. Plants in some sub-units must endure burial by moving dunes and extreme temperature fluctuations (Bennett and Wilder 2009).

**Table 3.** WHSA ecological sub-units and the flora generally found within them (Bennett and Wilder 2009).

| Ecological sub-unit | Description | Associated plant communities |
|---|---|---|
| Unit A (Lake Lucero)<br>Unit B (Alkali Flat) | Lake Lucero and the Alkali flat, sparsely vegetated. Occasional flooding and highly alkaline soil prevent most plant growth. | Sparse grasses, pickleweed and salt cedar |
| Unit C (dome, transverse, and barchan dunes) | Extreme conditions as dunes move across at a rate of up to 9 m (30 ft) per year | (Interdune plants) sand verbena, evening primrose, wooly paperflower, Indian rice grass, yucca, ephedra, alkali sacaton |
| Unit D (parabolic dunes) | Vegetated dunes with grassy interdune areas | Dropseed grasses, gypsum grama, little bluestem, sandhill muhly, alkali sacaton, soaptree yucca, rosemary mint, skunkbush sumac, Rio Grande cottonwood, and salt cedar |
| Unit E (saltbush/alkali sacaton) | Extremely flat area having gypsum/alkali soils | Occasional sumac, hedgehog cactus, and cane cholla |
| Unit F | Floodplain margins of quartz dunes, rather than gypsum | Mesquite, creosote bush, alkali sacaton, and sparse grasses |

The fauna found in WHSA are typical arid desert types that are often nocturnal in behavior and habits; this allows them to forage for food during the cooler night temperatures to avoid water loss from the hot sun (Bennett and Wilder 2009). Approximately 44 species of mammals, six amphibians, 26 reptiles, and extensive insect families have been recorded for WHSA. The dunes and interdune areas provide a unique opportunity for scientists and students interested in unlocking the mechanisms of adaptation observed in the organisms found in WHSA (Bennett and Wilder 2009). Some have evolved white coloration that allows them to blend in with the white sand. Most animals inhabit the interdunal flats, margins of the dune field, or adjacent desert plain and are not often seen at the center of the dunes (Bennett and Wilder 2009). The White Sands pupfish (*Cyprinodon tularosa*) is an endemic fish species in the Tularosa Basin. It is considered a Species of Concern by the U.S. Fish and Wildlife Service (USFWS) and is listed as threatened by the New Mexico Department of Game and Fish (NMDGF) (DOD et al. 2006). It lives in four separate areas of the basin, but the Lost River, which formerly held water suitable for their survival, was the only habitat within WHSA where the pupfish had been living. No pupfish currently inhabit the park, although some may temporarily enter during high rain events (KellerLynn 2012).

Hydrogeology

Groundwater tables at WHSA have some interesting aspects that are currently under study and are important to the eolian processes that control the dune field activity. There is supporting evidence that a “perched aquifer” or aquitard, is suspected to lie beneath the dune field, separate from the basin wide groundwater table (KellerLynn 2012). There was a large difference in the water table levels reported for instance; the water levels beneath the dunes was 24 m (80 ft) above the regional water table level, this is possibly explained by the contrast in permeability of sediment accumulations of the dune field that are rather porous and the less-porous strata of ancient Lake Otero that lies below (KellerLynn 2012), or the suggestion that there is a layer of clay beneath the dune field that holds a separate groundwater table that is perched above the basin wide aquifer. Groundwater recharge contributions are infiltrated into the main, basin-fill aquifer by intermittent surface water that enters at the proximal ends of alluvial fans associated with the bajadas at the mountain base (KellerLynn 2012). Less of the recharge is contributed by precipitation in WHSA because precipitation rates are not only low, but evaporation rates are very high 152-203 cm/yr (60-80 in/yr [Bennett and Wilder 2009]), which contributes greatly to the salinity of the playas and ephemeral lakes (KellerLynn 2012). Dissolved ion concentration is relatively high in general within the Tularosa Basin water tables (>65,000 mg/L [Bennett and Wilder 2009]). Rocks contribute sulfate, chloride, and carbonate ions that become dissolved in meteoric (rain) surface water that flows inward from the margins of the basin and is transported down the slopes where it accumulates due to the endorheic nature of the basin (Syzynkiewicz 2010). Dewatering for municipal use represents the largest draw of freshwater resources in the area, but is largely restricted to the eastern basin (Bennett and Wilder 2009).

The ancient Lake Otero strata found at WHSA and within the greater Tularosa Basin hold a rich geologic history that serves to explain how this unique system was developed over geologic time and how it is functioning now. The strata hold the sequence of climatic changes, significant fossil records, and geomorphic formations found in the Tularosa Basin (Szynkiewicz et al. 2010). The National Aeronautics and Space Administration (NASA) conducts studies on the gypsum dune complex and its crystal pedestals and domes at WHSA because these evaporate structures are remarkably similar to the structures recently discovered on Mars (KellerLynn 2012). Analyzing and interpreting remote-sensing images of Mars is thought to be greatly assisted by the study of crystal pedestals and domes at WHSA (KellerLynn 2012).

#### Fossil Trackways

WHSA contains a growing number of fossil trackways (hundreds discovered since 2007) that are primarily from mastodons and mammoths (*Proboscidea*), camels (*Artiodactyla*), and possibly a dire wolf (*Canis dirus*) (NPS 2013). These ancient animal trackways are from the late Pleistocene Epoch. As sand layers erode continuously, more tracks are revealed to researchers, adding to the extensive list of fossil tracks recorded for the Tularosa Basin. The fossil prints are fragile and erode quickly since they are preserved in the soft gypsum layers that once formed the shorelines of Lake Otero (NPS 2013). Continued research is needed to document the trackways, as they are short-lived and valuable to unlocking ancient history (NPS 2013).

#### Soil Moisture and Soil Crusts

Formation of soils is reliant on vegetation and the sub-surface water supply; without the near-surface water table, there may not be a cycle of growth and adherence of plant life in WHSA and the greater Tularosa basin (KellerLynn 2008). Dune stability and active formation and deflation by eolian processes is also reliant on the moisture that is drawn up just below the surface of the ground by capillary action and forms damp areas in between the dunes that harbor vegetation, these interdune areas are where soils can accumulate (KellerLynn 2012). Soil moisture allows abiotic crusts to form which hold particles and create a stable environment where seeds sprout and promote biotic crust formation (KellerLynn 2012).

The White Sands Dune Field has been interpreted as a wet aeolian system where soil moisture plays an important role in the sediment dynamics (Crabaugh 1994, Kocurek and Havholm 1994, Kocurek et al. 2007, Langford et al. 2009). As the sediment dries it can be moved exponentially with a given velocity of wind (Allmendinger 1972). The vast majority of habitats east of the western mountain bajada are susceptible to climate change and drought. If the soil moisture that stabilizes the system were to change the dune systems grassland, cottonwood (*Populus* sp.) stands and surrounding scrubland would all likely be directly affected by shifting dunes.

The level of diversity of organisms in soil affects the trophic cascade at the very top, and is heavily reliant upon the soil biota to function efficiently (Belnap 2001). This is increasingly clear for desert environments, where living soil crust plays a crucial role in ecological functions (Belnap 2001). Soil faunal communities (e.g., bacteria, microbes, and invertebrates) in conjunction with living soil crusts (e.g., cyanobacteria, fungi, lichens, and mosses) recycle organic material in a manner that fixes nitrogen and carbon, and stabilizes and balances soil in terms of structure and function (Belnap 2001). These living soil organisms are resilient to the regional conditions found at WHSA. However, they can also be sensitive to prolonged or repeated periods of abnormal conditions (e.g., moisture, salinity, atmospheric carbon increases, and temperature levels), disturbance (e.g., foot/vehicle traffic, land use activities/development, invasive species), and contaminants (e.g., fuel spills, explosive debris). There are likely many more soil faunal species than have been documented in WHSA, and there will be continued interest in the soil faunal communities in WHSA where there is high potential of endemism and additional species to document.

#### *2.2.3. Resource Issues Overview*

The Tularosa Basin once supported rich perennial grasslands but has gradually transformed to shrubland through periods of severe drought, exacerbated by anthropogenic activity such as overgrazing livestock, which was common with historic (1800s) ranching practices in the area (KellerLynn 2008). Erosion has been accelerated by this shift in plant communities and also in many areas from anthropogenic activity such as culvert construction, installation of fiber optic cable, and the increased aridity from loss of grassland and the changing climate (KellerLynn 2012). Dewatering for municipal, agricultural, and industrial uses has contributed to declining water levels that have caused flow reductions to the Lost River and reduction in wetland areas; loss of wetland area indicates a decline in the water table and could become a threat to dune stability if the water table is lowered significantly or even modestly (Bennett and Wilder 2009). Dune mobility increases when water level declines, causing a destabilization of interdunal areas where the bulk of biological activity is found within the dune field (Bennett and Wilder 2009). The invasive salt cedar (*Tamarix chinesis*) has been known to consume enough water to lower the water table in its immediate vicinity and cause erosion of the interdune areas (Bennett and Wilder 2009). WHSA has several large patches of invasive salt cedar, or tamarisk, which was introduced in the 1850s to the United States as an ornamental tree used for shade and wind breaks in areas where other shrubbery would struggle due to the salinity of the ground water (KellerLynn 2012). Salt cedar has infested hundreds of acres of the Lost River (KellerLynn 2012). One lone salt cedar tree can use up to 100 gallons of water per day and the infestations found at WHSA threaten to severely impact the eolian processes by dropping the water table, reducing dune stability (KellerLynn 2012).

The oryx (*Oryx gazella*; Photo 3), a large antelope native to Africa, was introduced to the Tularosa Basin for big game hunting by the NMDGF (Bennett and Wilder 2009). It has occurred within

WHSA and is considered a threat to the park's native plants and animals. The park has been completely fenced in for nearly 20 years and efforts to eradicate oryx inside WHSA were believed to have eliminated the species from the park by 2005 (David Bustos, WHSA Resource Program Manager, oral communication, 3 December 2013). However, oryx still occur on surrounding lands and may get in when damage to the fence occurs from wash-outs and dune migration.

**Photo 3.** An oryx in the desert grasslands. The oryx is a non-native species in the U.S. and was introduced to the WHSA area as a big game species (NPS photo).

Water resources within the basin are near the surface, between 0.9 and 2.7 m (3 and 9 ft) below the surface, which creates a potential for contamination by surface activities. Contaminants from spills on Highway 70, errant missiles, and over 50 hazardous waste sites on the Department of Defense (DOD) lands around the park are of great concern to the ecological resources and groundwater in and around WHSA (Bennett and Wilder 2009). The military-owned lands completely surrounding WHSA and the operations conducted there are a serious threat to the integrity of the groundwater that lies beneath the entire basin; research and development of weapons and weapons delivery systems involve the use of various petrochemicals, heavy metals, and radioactive compounds (Bennett and Wilder 2009). Accidental spills inevitably occur from time to time during normal operations and pose a serious threat to the water supply that lies just beneath the land-surface (Bennett and Wilder 2009). Hazardous waste such as volatile organic compounds (VOCs), fuel, polychlorinated biphenyls (PCBs), nitrate compounds, dioxins, and pesticides are some of the potential contaminants that are found at the DOD waste sites (Bennett and Wilder 2009).

Executive order No. 9029 created the Alamogordo Bombing range in 1941, which later became known as the White Sands Missile Range (Welsh 1995). A permit drafted in 1949 by both the U.S. Army and the NPS gave the two agencies joint or "cooperative use" of the western half of the park. This permit requires that the park be given 24-hour notice of testing and compensation or reimbursement for damages from military activities in and around park boundaries (Welsh 1995).

There are occasional accounts of military activities over time and the associated clean-up disturbing the dunes and other park ecosystems (Welsh 1995). Access to the co-use area of the park is by special permit only due to safety concerns, which has limited research activities in this portion of the park.

Climate Change

In WHSA, the regional climate is arid and the ecology has adapted to the abiotic surroundings, specifically the lack of much precipitation throughout the year. Even a subtle change in climate can dramatically affect the ecology of an arid region because of shifts in precipitation, especially in the case of desert ecology, since water is the primary limiting resource (Brown et al. 1997). According to Brown et al. (1997) the most significant changes observed in Chihuahuan Desert ecology due to climatic changes since the late 1970s are precipitation, vegetation, and animal populations. Monitoring effectiveness is reliant on accurate and consistent data that spans long period of time in order to maximize detection of climatic shifts that are other than typical fluctuations in climate since extreme variability occurs naturally in the region of WHSA (Davey et al. 2007).

Trends in temperature in the WHSA area have been consistently increasing at a statistically signicant level since 1930, with major increases being observed in the park since 1950 (NPS 2016a). A warming trend of 3-5°F, and a reduction in precipitation of 1-4% annually is expected to occur over the next 50-100 years (NPS 2016a). These climatic changes will likely influence several aspects of the WHSA landscape, perhaps most notably the dune structure, distribution of non-native species, and the regional aquifer.

## 2.3. Resource Stewardship

### *2.3.1. Management Directives and Planning Guidance*

Monitoring conditions and trends of resources within the park is an essential tool for stewardship of the land and the valuable resources it holds (NPS 2010). Knowing how the local climate, hydrology, and geology interact from both a historical and current perspective is important for determining management strategies that should or could be implemented to obtain the desired level of preservation and accessibility within the park and surrounding area (NPS 2010). The NPS defines vital signs for parks such as WHSA that are a set of parameters of chemical, biological, and physical elements and processes of the ecosystems within the park boundaries as well as the surrounding area when possible (NPS 2010).

More recently, a purpose statement was identified in WHSA’s foundation document (NPS 2016a). NPS (2016a, p. 5) states:

> *An island white within the Chihuahuan Desert, White Sands National Monument provides and promotes scenic, scientific, and educational opportunities while preserving the world’s largest gypsum dune field a dynamic environment created and sustained by wind and water and protects endemic flora and fauna, unique human and paleontological history, and the quiet solitude of the dunes.*

NPS (2016a, p. 6) continues to identify significant statements for WHSA. These include:

- *In 1933, President Hoover established White Sands National Monument to preserve the world's largest gypsum dune field and its sources of gypsum sand. This enormous dune field more than 275 square miles is used by astronauts in space as a geographic reference.*
- *The hydrologic, geologic, and climatic forces of the Tularosa Basin create the gypsum cycle that gave birth to and sustains this active and dynamic gypsum dune field. Rainfall, groundwater, and a regional aquifer are essential ingredients that nourish the world's largest gypsum dune field.*
- *Vast and brilliant white, the geologically young less than 10,000 years old gypsum dune field has provided the conditions for evolution through rapid adaptation in the flora and fauna of dune field and surrounding desert scrub communities. Adapted white-colored species include an animal from every class of vertebrate, except birds, in North America.*
- *Legislated to protect resources of scientific interest, White Sands National Monument promotes a wide range of innovative research that globally leads the way in the fields of rapid evolution and dune dynamics. Internationally recognized experts study aspects of the monument to expand understanding in subjects as diverse as soil microfauna to space exploration.*
- *At first glance, the dune field appears inhospitable and uninhabitable, yet the monument protects numerous and diverse evidence of more than 10,000 years of human history. The physical properties of gypsum create time capsules when heated, preserving dateable charcoal, plant, and animal remains, and other cultural material, which leads to the production of unique archeological sites called gypsum hearth mounds not known to occur anywhere else on earth.*
- *The monument contains a mega-track site with the largest and highest density of Cenozoic era fossilized-gypsum footprints in North America. These highly ephemeral tracks are found in sediments of ancient Lake Otero and range in age from 20,000 to 40,000 years BP (before present). The trackways, found in gypsum sand and lake sediments, are revealed in an unpredictable manner by wind and rain.*
- *White and stark, the awe-inspiring gypsum dune field offers distinctive opportunities to hike barefoot on cool, moist sands, sand sled year-round, and experience solitude broken only by wind and occasional military-related sound events. This unique setting inspires learning, appreciation, and stewardship.*

#### *2.3.2. Status of Supporting Science*

The Chihuahuan Desert Network (CHDN) identifies key resources network-wide and for each of its parks that can be used to determine the overall health of the parks. These key resources are called Vital Signs. In 2010, the CHDN completed and released a Vital Signs monitoring plan (NPS 2010). Table 4 shows the network Vital Signs selected for monitoring in WHSA.

**Table 4.** CHDN Vital Signs selected for monitoring in WHSA (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 for which the network will implement monitoring protocols 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 as this time due to limited staff and funding.

| Category | CHDN vital signs |
|---|---|
| Air and Climate | **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, aquatic invertebrates* |
| Biological Integrity | *Invasive/non-native plants, plant community composition, bird communities,* and heteromyid rodent communities |
| Landscapes | *Land cover, land-use changes* |

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# Chapter 3. Study Scoping and Design

This NRCA is a collaborative project between the NPS and SMUMN GSS. Project stakeholders include the WHSA 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 from 3-5 December 2013. At this meeting, SMUMN GSS and NPS staff confirmed that the purpose of the WHSA 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 WHSA 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 WHSA resource management and the NRCA template.

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 WHSA 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: WHSA 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 possible, 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., soil moisture), 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 WHSA 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 WHSA in some way, or are of greatest concern or highest management priority in WHSA. 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., no oryx in the monument) (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-introduction of oryx or salt cedar.” 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 CHDN Vital Signs monitoring plan (NPS 2010). 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 May 2014 following acceptance from NPS resource staff. It contains a total of 13 components (Figure 3) 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.

**WHSA NRCA Project Framework**
**Natural Resource Condition Assessment Framework**

| | Component | Measures | Stressors | Reference Condition |
|---|---|---|---|---|
| Ecosystem Extent and Function<br>Biotic Composition | | | | |
| Ecological Communities | | | | |
| | Dune Communities | Dune Moisture, Plant Species Richness, Extent of Vegetation Communities, Changes in Dune Morphology, Movement, and Mass, Change in Boundaries of Dune Community/dune Type, Depth to Ground Water | Dune road construction and maintenance , climate change and its relation to dune morphology, saltcedar, desalinization plants and solar energy farms, missile/debris retreaval efforts. *These threats may affect portions of the dune field(s) and not necessarily the entire dune field at once.* | Pre-water diversion conditions (pre-1950s) . Historic nformation regarding dune moisture, vegetation community extent, and depth to groundwater are not availablle. Vegetation community composition was described by Emerson (1935), which serves as a reference condition for plant species richness. |
| | Semidesert Grasslands | Vegetation Community Extent, Plant Species Richness, Winter Grassland Bird Diversity, Percent Cover of Gopher Holes/burrows in Semidesert Grasslands | Invasion of desertscrub species (creosote, honey mesquite), climate change, historic cattle grazing practices in Tularosa Basin | Pre-ranching/Pre-Anglo settlement (1850s) would be ideal, but historical information regarding semidesert grasslands in the WHSA region is purely anecdotal. Specific (i.e., measurable) reference conditions were not defined for the measures in this component. |
| Birds | | | | |
| | Migratory Birds | Species Richness, Species Diversity, Trends in Species of Conservation Concern, Cottonwood Stand Abundance | Land cover change and habitat fragmentation, energy development, climate change, changes/loss of overwintering habitat, presence of surface water | The period of time before ranching and Anglo settlements were present in the area (approximately the 1850s). |
| | Breeding Birds | Species Richness, Species Diversity, Species Density | Land cover change and habitat fragmentation, energy development, (wind, solar), climate change, presence of surface water | The period of time before ranching and Anglo settlements were present in the area (approximately the 1850s). |
| Herpetofauna | | | | |
| | Reptiles | Distribution of Species, Distribution of Color Phases of the Species, Species Richness, Species Diversity | Poaching, land cover change and habitat fragmentation, energy development, (wind, solar), climate change, changes in predators (roadrunners, shrikes), roads in and outside of park | Period when ranching became established on the monument. Additionally, the time period before the State Highway 70 was upgraded to a paved road serves as a secondary reference condition. |

**Figure 3.** White Sands National Monument Natural Resource Condition Assessment framework.

**WHSA NRCA Project Framework**
**Natural Resource Condition Assessment Framework**

| | Component | Measures | Stressors | Reference Condition |
|---|---|---|---|---|
| Ecosystem Extent and Function | | | | |
| Biotic Composition | | | | |
| Ecological Communities | | | | |
| Mammals | | | | |
| | Desert Faunal Community | Species Richness in Habitat Types, Species Distribution, Species Abundance | Roads in and outside of park, drought and disease, climate change (and its influence on prey abundance/fluctuations), hunting and trapping outside the monument, oryx fence, prey density/abundance shifts | Pre-ranching/Pre-Anglo settlement (1850s) |
| Microbiota | | | | |
| | Terrestrial and Aquatic Invertebrates | Species Richness, Timing and Amount of Precipitation | Drought, climate change (patterns and timing of precip, amount of precip), distribuition of precipitation and standing water, landcover change and habitat fragmentation, water quality impairments | Community at the time of monument establishment (1933). |
| | Soil Faunal Community | Species Diversity, Species Diversity for Species Associated with Carbon Sequestration | Soil moisture, salinity, contaminants, invasive species, | Currently undefined. |
| Environmental Quality | | | | |
| | Soundscape and Acoustical Environment | Sound Pressure Levels, Frequency, Duration of Sounds | Highway traffic and noise, visitor traffic on dune road, Holloman Air Force Base (flights, sonic booms, air strip, UXO recovery), sonic booms from the test track | Natural ambient sound level in the absence of human-caused noise. This reference condition would be analogous to the soundscape prior to the advent of military installations in the Tularosa Basin in the 1940s. |
| | Viewscape | Change in Internal Viewscape, Change in External Viewscape, Visibility | Holloman AFB lights and expansion, energy development (wind, solar), desalinization plant, traffic and road use, air pollution reducing visibility, dust, climate change | Viewscape comparible to the period prior to the establishment of Holloman Air Force Base and WSMR |
| Physical Characteristics | | | | |
| Geologic and Hydrologic | | | | |
| | Surface Water Hydrology | Frequency of Surface Water, Geochemistry of Surface Water, Persistence of Surface Water, Timing and Amount of Surface Precipitation, Groundwater Recharge and Discharge | Drought, climate change, increased water drawdown from humans, saltcedar, perchlorate from rocket fuel | Climate normals for amount/timing of precip. Other measures - pre-diversions era (pre-1950). |
| | Ground Water Hydrology | Depth to Groundwater, Regional Aquifer Flow Rate and Direction, Lost River Stream Flow, Soil Moisture | Drought, climate change, ground water withdrawl - desalinization plants, solar energy farms - saltcedar, Note: Loss of cottonwood community may indicate saltwater intrusion | Pre-water diversion conditions (pre-1950s) of the park's ground water features |
| | Cenozoic Trackways | Rate of Erosion of the Trackways, Number of Prints in Trackway (length, width, stride, pace, type of track maker), Condition of Prints in Trackway | Trampling, erosion (wind and water), missile impacts and recovery efforts, exposure, flooding, climate change | Currently undefined. |

**Figure 3 (continued).** White Sands National Monument Natural Resource Condition Assessment framework.

### *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 WHSA 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 WHSA 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 5. 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 5.** 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 6). This is based on all the available literature and data reviewed for the component, as well as communications with park and outside experts.

**Table 6.** 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: good condition (WCS = 0.0 – 0.33); condition of moderate concern (WCS = 0.34 - 0.66); and condition of significant concern (WCS = 0.67 to 1.0). Table 7 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 that a resource is in good condition. White 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 horizontal arrow indicates an unchanging condition or trend, and an arrow pointing down indicates deterioration 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. In situations where the trend of the component's condition is currently unknown, no arrow is given. Table 8 provides some examples for interpretation of symbols.

**Table 7**. Description of symbology used for individual component assessments.

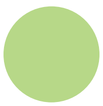
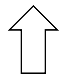
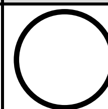
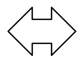
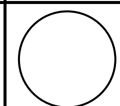
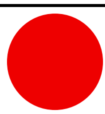
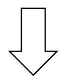
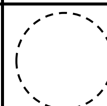
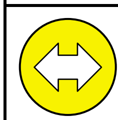
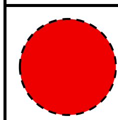
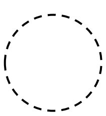
| Condition Status | | Trend in Condition | | Confidence in Assessment | |
|---|---|---|---|---|---|
|  | Resource is in Good Condition |  | Condition is Improving |  | High |
|  | Resource warrants Moderate Concern |  | Condition is Unchanging |  | Medium |
|  | Resource warrants Significant Concern |  | Condition is Deteriorating |  | Low |

**Table 8.** Examples of how the symbols should be interpreted.

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

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 WHSA 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 WHSA 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 are 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.

### 3.3. Literature Cited


Great Lakes Environmental Indicators Project (GLEI). 2010. Glossary, Stressor. http://glei.nrri.umn.edu/default/glossary.htm (accessed 31 January 2013).

National Park Service (NPS). 2010. Chihuahuan Desert Network vital signs monitoring plan. Natural Resource Report NPS/CHDN/NRR—2010/188. National Park Service, Fort Collins, Colorado.

The H. John Heinz III Center for Science, Economics, and the Environment. 2008. The state of the nation’s ecosystems 2008: Measuring the land, waters, and living resources of the United States. Island Press, Washington, D.C.

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 13 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 (Figure 3):

4.1. Dune Communities
4.2. Semidesert Grasslands
4.3. Migratory Birds
4.4. Breeding Birds
4.5. Reptiles
4.6. Desert Faunal Community
4.7. Terrestrial and Aquatic Invertebrates
4.8. Soil Faunal Community
4.9. Soundscape and Acoustic Environment
4.10. Viewscape
4.11. Surface Water Hydrology
4.12. Ground Water Hydrology
4.13. Cenozoic Trackways

**Note:** At the time of this document's preparation, there were two research efforts still underway that were unable to be summarized: A report that categorizes and interprets the many fossil trackways in the park and helps to plan for their preservation and interpretation (being completed by the NPS and cooperators), and a park-wide vegetation mapping report (being completed by the University of New Mexico's Natural Heritage Program). Both of these efforts will provide park managers with a great deal of information that will help to better describe the current condition of the natural resources in the park, particularly the Cenozoic trackways and vegetation communities. Upon completion, there exists the possibility that WHSA staff will update this chapter of the NRCA via an addendum. In this published NRCA, however, the natural resources in the park have been assessed using the most current (2013-early 2016) data and published material.

## 4.1. Dune Communities

### *4.1.1. Description*

The White Sands Dune Field is the largest known gypsum dune field in the world (Kocurek et al. 2007, Bennett and Wilder 2009). Approximately 712 $km^2$ (115 $mi^2$) of the dune field falls within WHSA boundaries (Bennett and Wilder 2009), which is the primary reason the park was established (Photo 4). Many of the park's animals have adapted to dune conditions by modifying their color to blend in with the white sand, and some have actually evolved into distinct species or subspecies (Bennett and Wilder 2009). Some portions of the dune community are constantly changing in response to environmental variables such as wind, moisture, and vegetation (KellerLynn 2012); dune dynamics (dune formation and stability, dune morphology) have been recognized as a Vital Sign by the CHDN (NPS 2010). Interestingly, the gypsum dunes at WHSA have also served as a geochemical analogue for dunes on Mars (Szynkiewicz et al. 2009). Scientists studying the planet have explored the development of WHSA's dunes in an effort to better understand land forms on Mars.

**Photo 4.** The gypsum dune field within WHSA (NPS photo).

The WHSA dune community includes several types of dunes (classified by shape) and the associated "interdune" areas. The four dune types are dome, barchan (or barchanoid), transverse, and parabolic (McKee 1966, Fryberger 2001; Figure 4). Dome dunes are low, circular dunes that occur only on the upwind edge of the dune field; they are often considered "embryonic forms" that eventually transition into barchan or transverse dunes (McKee 1966, Fryberger 2001). Barchan dunes are crescent-shaped, with points or horns extending downwind. Most of the active dune field within WHSA consists of barchan dunes, which support little or no vegetation (KellerLynn 2012). These dunes average 8-12 m (26-39 ft) in height (KellerLynn 2012). Transverse dunes are nearly straight-line sand ridges that form perpendicular to the dominant wind direction (McKee 1966). They may be formed by the joining together of several barchan dunes (Bennet and Wilder 2009). Lastly, parabolic dunes are U-shaped forms where the middle of the dune has migrated past the horns or arms (McKee 1966, Fryberger 2001). This often occurs when vegetation becomes established on the arms, stabilizing them against the wind (McKee 1966, KellerLynn 2012). Parabolic dunes are typically found on the downwind edge of the dune field (McKee 1966); at WHSA, they are found on the north, east, and south edges of the dune field (Kocurek et al. 2007; Figure 4).

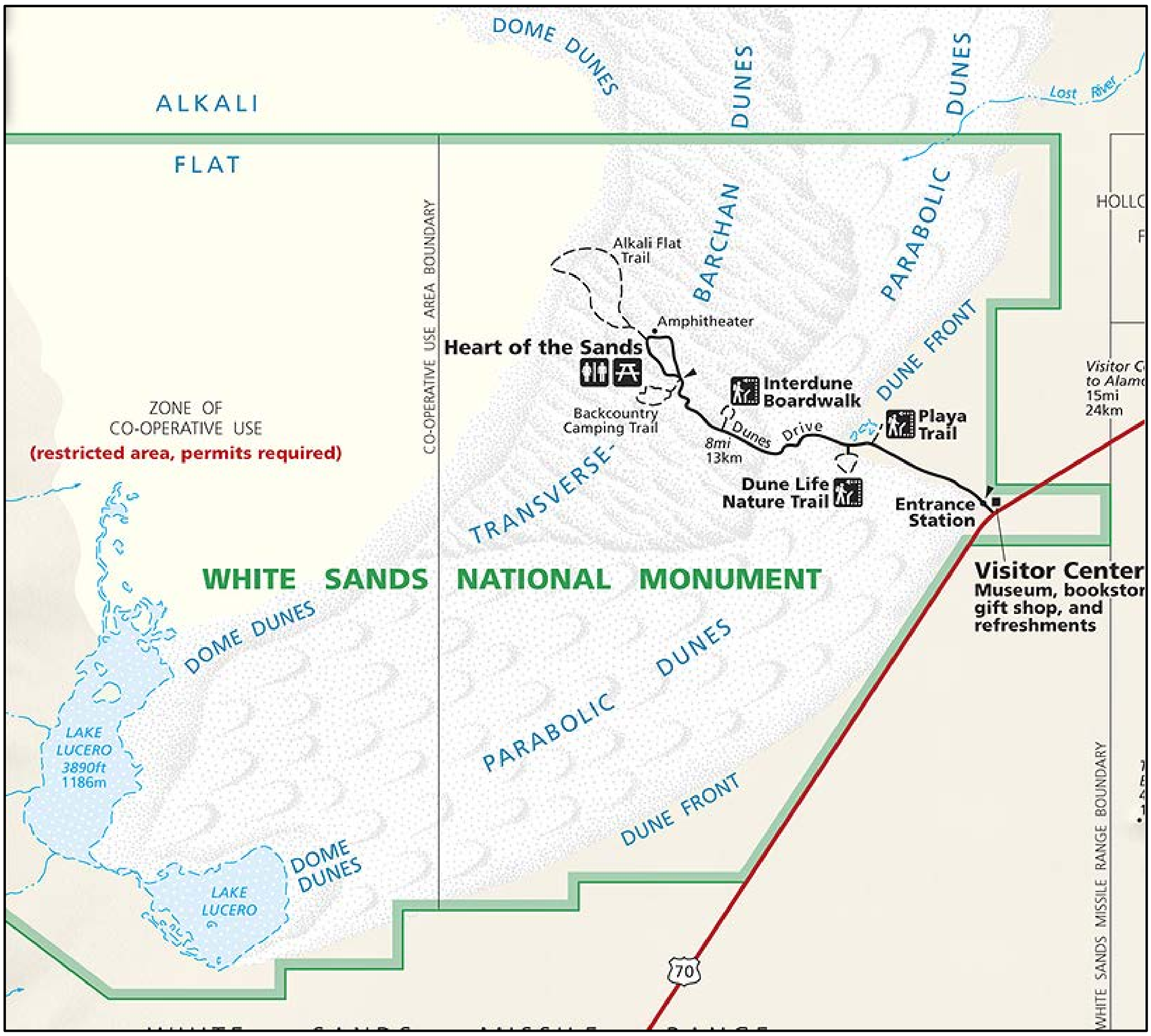



**Figure 4.** A map of the major dune types at WHSA and their relative locations within the dune field (NPS graphic).

The low areas between dunes are called interdunes, and various types of interdunes are also found within WHSA (Photo 5; Fryberger 2001). These areas support much of the vegetation and wildlife that live within the dune community, due to their more sheltered nature and the presence of moisture and nutrients (Fryberger 2001). The water table is often near the surface of the interdunes, which makes the sands here less vulnerable to wind erosion; however, interdune areas can also be covered or filled in by actively migrating dunes (Kocurek et al. 2007, KellerLynn 2012). As a result, the interdunes are constantly shifting and changing (Fryberger 2001, KellerLynn 2012). The most common type of interdune area within the active dune field at WHSA is the evaporitic type. These areas are dominated by ripple-like salt ridge structures that form when dissolved salts precipitate from saline groundwater evaporating near the interdune surface (Fryberger 2001). The structures form a crust layer, which increases resistance to wind erosion (KellerLynn 2012). Crusts of cemented gypsum may also form after rain storms (Rachal and Dugas 2009). Mats of algae and other microorganisms often occur just below these crusts and in other damp areas within the interdunes and can further stabilize the areas where they are present (Kocurek et al. 2007, Langford et al. 2009).

**Photo 5.** Sparsely vegetated interdune areas within WHSA's active dune field (NPS photo).

Plants that live within the dune field must be able to survive harsh environmental conditions, including water stress, high temperatures, intense sunlight, and nutrient scarcity (Borer et al. 2012). Gypsum also contains high levels of calcium and sulfur that can be harmful to plants (Borer et al. 2012). The sparse vegetation of the more active barchan dunes consists primarily of the grasses alkali sacaton (*Sporobolus airoides*) and little blue stem (*Schizachyrium scoparium*, formerly considered *Schizachyrium neomexicanum*), with scattered longleaf jointfir (*Ephedra trifurca*), soaptree yucca (*Yucca elata*), skunkbush sumac (*Rhus trilobata*), and sand verbena (*Abronia angustifolia*) (Langford et al. 2009). Vegetation in the older parabolic dunes is more diverse and includes the species found in the barchan dunes as well as the shrubs rosemary mint (*Poliomintha incana*), fourwing saltbush (*Atriplex canescens*), and sagebrush (*Artemisia* sp.) (Muldavin et al. 1994, Langford et al. 2009).

Additional plant species found within dune communities include Indian rice grass (*Achnatherum hymenoides*), gypsum grama (*Bouteloua breviseta*), and occasional cottonwood groves (Muldavin et al. 1994).

In simple terms, dunes form “where sand is abundant, and wind flow is sufficient to mobilize and transport it” (Rasmussen 2012, p. 164). In the case of WHSA, dune formation began approximately 7,000 years ago (Kocurek et al. 2007). The sand originated as sediment from the Pleistocene-era Lake Otero (Allmendinger and Titus 1973, Kocurek et al. 2007). As Lake Otero retreated due to an increase in regional aridity and a falling water table, these sediments dried up, and evaporation caused minerals such as gypsum to precipitate. These precipitates (also called evaporites) eventually break down into sand that can be eroded and moved by the wind, a process called “deflation” (Allmendinger and Titus 1973, Kocurek et al. 2007). Sand transport typically requires wind speeds of 16-32 kmph (10-20 mph) and occurs through two processes: suspension and saltation. Suspension involves the airborne transport of sand particles; in saltation, sand particles hop and bounce over the ground (Bennett and Wilder 2009). Deflation has occurred in several “steps” over time at WHSA as Lake Otero retreated, forming “terraced” historic shorelines (Kocurek et al. 2012). The parabolic dunes in the northeast, which are topographically the highest point in the dune field, formed first and began stabilizing approximately 3,500 years ago (Langford et al. 2009, KellerLynn 2012). The lower, younger barchan dunes began forming around 2,100 years ago (Langford et al. 2009, KellerLynn 2012). While the majority of sand in the dune field is believed to be derived from Lake Otero sediments, more recently precipitated gypsum from Lake Lucero (a currently active playa in the southwest corner of the park) also contributes some sand to the dunes (Allmendinger and Titus 1973, Kocurek et al. 2007).

The current White Sands dune field is classified as a “wet aeolian” system, meaning that accumulation and other processes are primarily controlled by water table depth (Fryberger 2001, Kocurek et al. 2007). The water table is typically close enough to the surface that moisture can seep up to the surface and stabilize the dune sands against wind erosion (Figure 5). A drop in the water table results in deflation (a loss of sand) while a rise in the water table allows sand accumulation to increase, building up the dune area (Kocurek et al. 2007). According to McKee (1966, p. 60), the dunes at WHSA, “are basically the result of sand being transported by the wind in one direction only.” The dominant winds are from the southwest and are strongest in the winter and spring, accounting for most of the active dune migration within the field (McKee 1966, Fryberger 2001, Kocurek et al. 2007). Winds occasionally shift to come from the north-northwest in the fall and winter and from the south-southeast in the summer, which causes some variation in dune form and migration (Fryberger 2001, Kocurek et al. 2007).

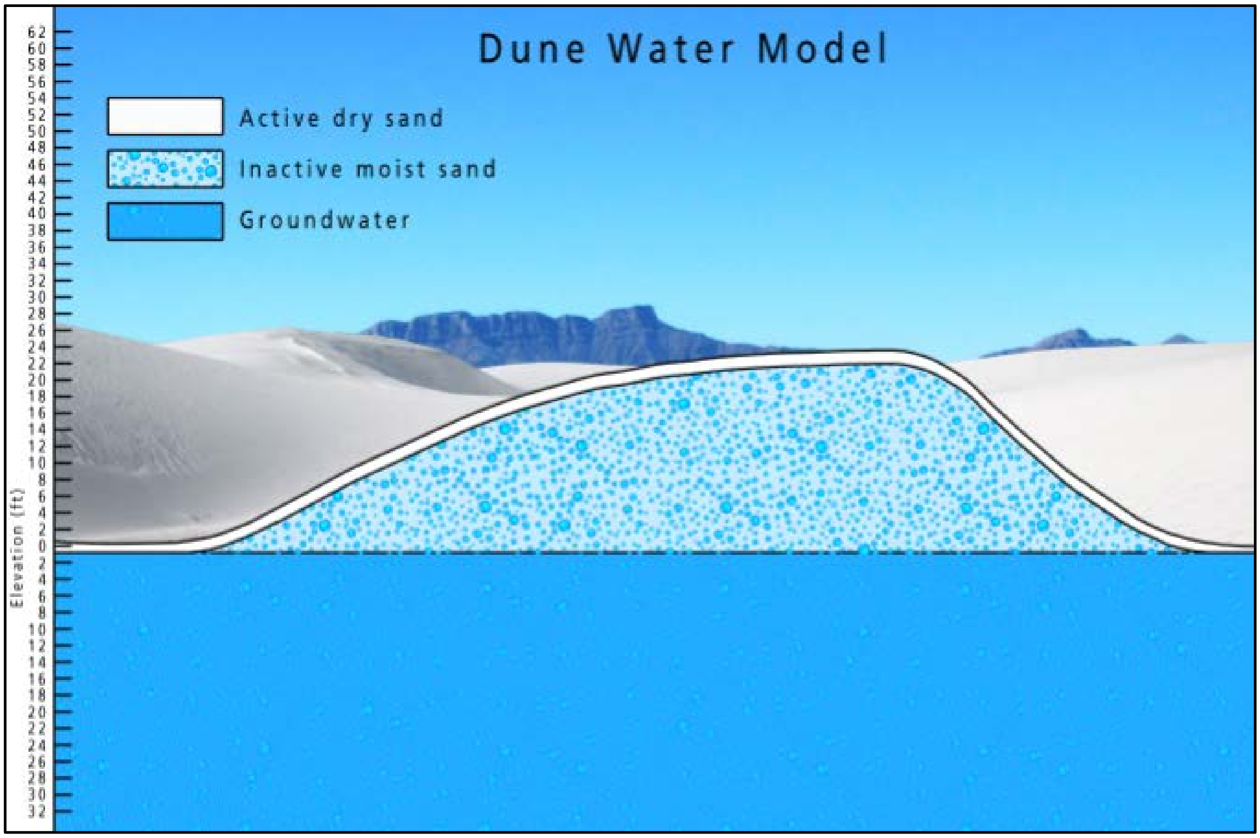



**Figure 5.** A model showing the importance of groundwater table depth to dune morphology and processes (image courtesy of NPS).

Several theories have been put forward as to what drives the transition process from barchan dunes to more stable parabolic dunes. The establishment of stabilizing vegetation appears to be the key factor in the transition (Reitz et al. 2010, Jerolmack et al. 2012), but what exactly allows this vegetation to become established in some areas and not others is less clear. Jerolmack et al. (2012) proposed that an increase in surface "roughness" causes a decrease in surface wind stress at the downwind end of the dune field. This leads to a decline in sand flux/transport, which creates a more stable environment and allows vegetation to become established (Jerolmack et al. 2012). However, Langford et al. (2009) theorized that the transition was linked to differences in groundwater salinity. In lower elevation barchan dune areas, the saline groundwater table is near the surface and little vegetation is able to grow in such high salinity conditions (Langford et al. 2009). However, the topographically higher parabolic dunes have accumulated enough sediment above the saline groundwater table that freshwater from precipitation can be stored there, allowing higher densities of vegetation growth (Langford et al. 2009, KellerLynn 2012).

The White Sands dune field is known as a premier U.S. site for yardangs, which are streamlined, wind-eroded ridges found in arid environments around the world (Photo 6; Fryberger 2001, Bennett and Wilder 2009). At WHSA, yardangs have formed, "in the lightly-cemented dune and interdune sands at various places in the barchanoid dune field, especially in upwind areas" (Fryberger 2001, p. 95). Yardangs at WHSA range from a few centimeters high to around 3 m (10 ft) in height

(Fryberger 2001). Similar features called "pedestal dunes" form when areas of the active dunes are stabilized by vegetation, and remain in place after the rest of the dune migrates on (Photo 7). These areas often support "islands" of wildlife in an otherwise barren area (Fryberger 2001).

**Photo 6.** A yardang at WHSA (Fryberger 2001).

**Photo 7.** A large salt cedar pedestal dune at WHSA (Photo: Andy Nadeau, SMUMN GSS).

#### 4.1.2. Measures

- Dune moisture
- Plant species richness
- Extent of vegetation communities
- Changes in dune morphology, movement, and mass
- Change in boundaries of dune community/dune type
- Depth to groundwater

#### 4.1.3. Reference Conditions/Values

Given the constantly shifting nature of dune fields, it can be challenging to identify a "reference condition" for these areas. The reference condition selected by the project team for the dune communities is pre-water diversion conditions (pre-1950s). This time period also pre-dates the invasion of the non-native salt cedar. Unfortunately, information regarding dune moisture, vegetation community extent, and depth to groundwater are not available from this time. Vegetation community composition was described by Emerson (1935), which can serve as a reference condition for plant species richness.

#### 4.1.4. Data and Methods

One of the earliest studies of dune form, structure, and physical processes at WHSA was conducted by McKee (1966). This report describes "the type, scale, and relative abundance of sedimentary structures in four kinds of dunes" as determined from examining the walls of trenches cut through the dunes (McKee 1966, p. 1; Photo 8). McKee (1966) also measured dune movement using aerial photos taken by the U.S. Air Force every 6 months over approximately 2 years (December 1962-June 1964). McKee and Douglas (1971) calculated average movement rates for various dune types at WHSA from 1962-1968 by measuring distances on aerial photos. Patrick (1980) compared the positions of three dunes in October 1979 to positions reported by McKee (1966) in order to calculate average movement rates over that time.

Fryberger (2001) prepared a geological overview for WHSA, which summarized the geologic evolution of the area, including dune systems and interdunes. This effort also produced the first complete aerial photo mosaic of the White Sands Dune Field and a detailed geomorphic map highlighting the dune types and other significant terrain features (Fryberger 2001).

Kocurek et al. (2007) studied recent dune and interdune dynamics. Trenches were excavated in three areas and transects were surveyed to monitor dune migration rates and document changes in morphology (Kocurek et al. 2007). Recent accumulation rates were determined from the trenches and compared to long-term accumulation rates identified from cores taken near the "Heart of the Dunes Loop." Kocurek et al. (2007) also reported approximate dune field ages determined through optically stimulated luminescence (OSL) analysis of a core sample.

**Photo 8.** Researchers standing in a dune trench (McKee 1966).

Langford et al. (2009) tested the hypothesis that freshwater accumulations from precipitation in parabolic dunes allowed vegetation to grow, stabilizing the dunes. The authors collected groundwater and soil samples from six sites along a transect stretching across the boundary between barchan and parabolic dunes between December 2004 and June 2005 (Langford et al. 2009). Soil salinity was estimated from conductivity, based on methods described by Bower and Wilcox (1965).

Rachal and Dugas (2009) used repeat aerial photography to quantify changes in WHSA's barchan dunes over time. Imagery was available from 5 years over a nearly 60-year period: 1948, 1963, 1985, 1996 and 2003. Dune crests were digitized in geographic information system (GIS) from these images and then used to determine parameters such as crest length, spacing, orientation, and sinuosity. Sinuosity is calculated by dividing the entire distance of the crest length line by the distance between the start and finish point of the line (Rachal and Dugas 2009).

Ewing and Kocurek (2010) used historic aerial photos (1963, 1985, 1996, 2003, and 2005) and a 2007 light detection and ranging (LiDAR) generated digital elevation model (DEM) to study dune patterns and interactions at WHSA over time. Dune parameters including crest length, spacing, dune height, and migration rates were calculated for seven different zones along a 500 m x 3,500 m box transect starting at the upwind edge of the dune field (Figure 6). Average annual dune migration rates were calculated for the period 1996-2007, while other dune characteristics were presented as means for the period 1985-2007 (Ewing and Kocurek 2010).

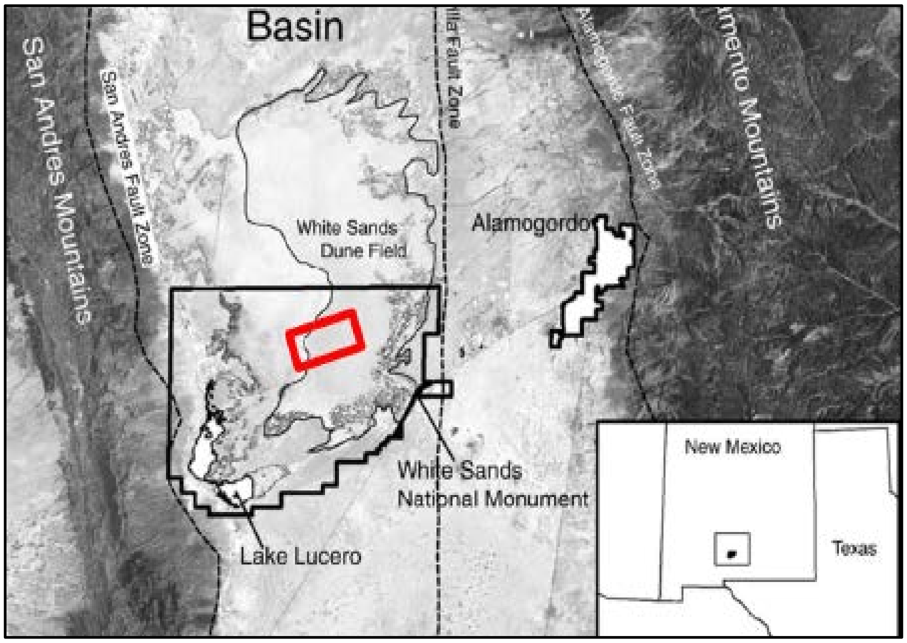



**Figure 6.** General location of the study area (red box) utilized by Ewing and Kocurek (2010) and Kocurek et al. (2012) (Kocurek et al. 2012). Ewing and Kocurek's (2010) transect was in the southwest portion of this area.

Scheidt et al. (2010) explored the relationships among soil moisture, potential soil erosion, and thermal inertia (approximated from remote sensing data) within the White Sands dune field. Thermal inertia data for 2002-2008 were gathered by the Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer deployed on a NASA satellite (Figure 7). Thermal inertia refers to the resistance of a material to changes in temperature; wet soil or sand has a higher thermal inertia than dry soil (Scheidt et al. 2010).

Kocurek et al. (2012) used LiDAR data to establish base physical parameters that characterize the White Sands dune field, study dune activity over a 1-year period, and identify spatial variability in dune patterns. The LiDAR imagery was obtained in June of 2007 and 2008 for a 39 $km^2$ (15 $mi^2$) area spanning the edge of the alkali flat, the core barchan dunes, and the barchan-parbolic dune transition area (Figure 6). The LiDAR data have a 1 m/pixel (3.3 ft/pixel) spatial resolution with a vertical resolution of approximately 0.1 m (3.9 in) (Reitz et al. 2010). A wide variety of dune field parameters can be accurately calculated using DEMs created from this LiDAR data (Kocurek et al. 2012). Parameters reported include maximum and average dune height, dune length, crestline length, crest-to-crest spacing, crestline orientation and sinuosity, crescent length, and dune horn length (Figure 8). The LiDAR data also allowed for calculations of total dune surface area, dune volume, and dune footprint area (Kocurek et al. 2012). To determine topographic change in the dune field between June 2007 and 2008, Kocurek et al. (2012) constructed a "difference map" in GIS by subtracting the 2007 DEM from the 2008 DEM. This map was used to calculate more dynamic parameters including dune morphology changes, dune migration rates, and spatial variation in dune activity within the dune field (Kocurek et al. 2012).

The vegetation of the WHSA dune communities was described early on by Wooton and Standley (1915) and Emerson (1935). Emerson (1935) compiled a plant species list for the White Sands area based on Wooton and Standley (1915) and personal observations. Reid (1979, 1980) conducted a natural resources inventory and ecosystem analyses at WHSA, with a focus on vegetation and soil properties. The reports describe dominant plant associations but do not include comprehensive species lists by plant community. More recently, vegetation classifications and maps were created for WHSA (Muldavin et al. 1994) and White Sands Missile Range (WSMR) (Muldavin et al. 2000a, b). The digital vegetation map generated for WSMR also included WHSA and will be used in this NRCA to assess vegetation community extent.

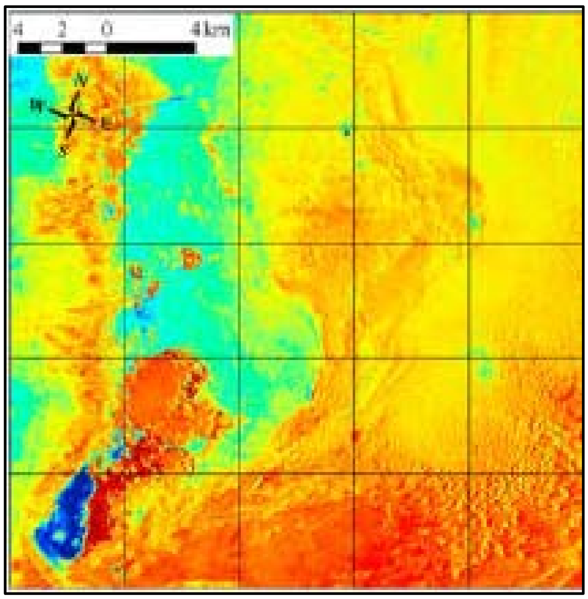



**Figure 7.** Example of a thermal inertia image derived from ASTER data (Scheidt et al. 2010). Blue indicates higher thermal inertia and soil moisture levels and red indicates low values.

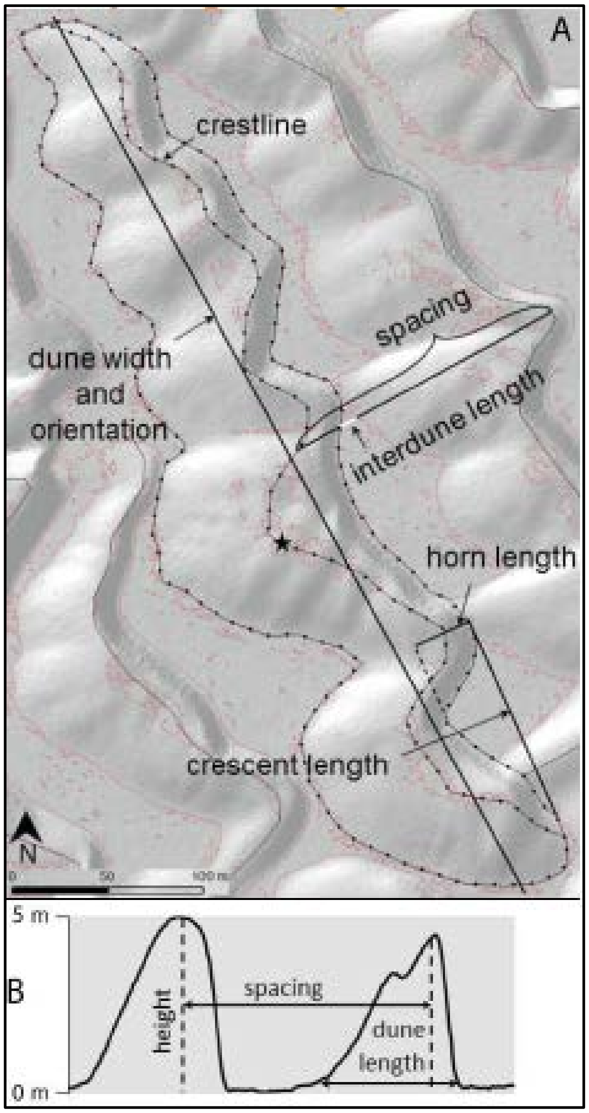



**Figure 8.** Visual representation of the dune field parameters calculated by Kocurek et al. (2012) from LiDAR data (Kocurek et al. 2012).

### *4.1.5. Current Condition and Trend*

<u>Dune Moisture</u>

Dune moisture plays a key role in maintaining the White Sands dune field. Moisture helps to hold sand particles together, making them more resistant to wind erosion (Kocurek et al. 2007, Scheidt et al. 2010). Moist areas are also more likely to capture and accumulate additional sand, potentially building up the dunes (Kocurek et al. 2007). Despite the importance of this parameter, field investigations of dune moisture are often challenging, especially over a relatively large geographical area. Such studies require specialized (usually expensive) equipment and significant time commitments. Moisture levels can also change rapidly in arid environments such as dune fields (Scheidt et al. 2010).

Actual data regarding dune moisture within WHSA are very limited. Reid (1979) found that soil moisture in the top 30 cm (11.8 in) of a vegetated interdune (dominated by hairy crinklemat [*Tiquilia hispidissima*]) ranged from approximately 14-16%, while soil moisture in a bare, Heart of the Dunes interdune ranged from 23-26%. According to Reid and Patrick (1979, p. 4), the park's interdunes "are always moist to the touch 10 or 20 cm below the surface," and moisture at those shallow depths is rarely less than 15%.

Scheidt et al. (2010) estimated dune moisture for several areas in the dune field between 2002 and 2008 using remotely-sensed thermal inertia data. Results show that interdune areas in both the central and southern dune field consistently have higher moisture levels than the dunes themselves, ranging from approximately 17-38% in the central dune field and 13-32% in the southern dune field (Figure 9). Lower soil moisture in the dunes may be related to the fact that they are further away from and less connected to the groundwater table (Scheidt et al. 2010). The central barchan dunes typically had higher moisture levels (~16-25%) than the southern parabolic dunes (~13-19%) (Scheidt et al. 2010). Although sample size and timing were limited, it appeared that moisture levels were highest in late winter (February) and declined as summer approached (Figure 9). Scheidt et al. (2010) concluded that the amount and duration of precipitation has a major influence on soil moisture, as well as the number of days since precipitation has occurred.

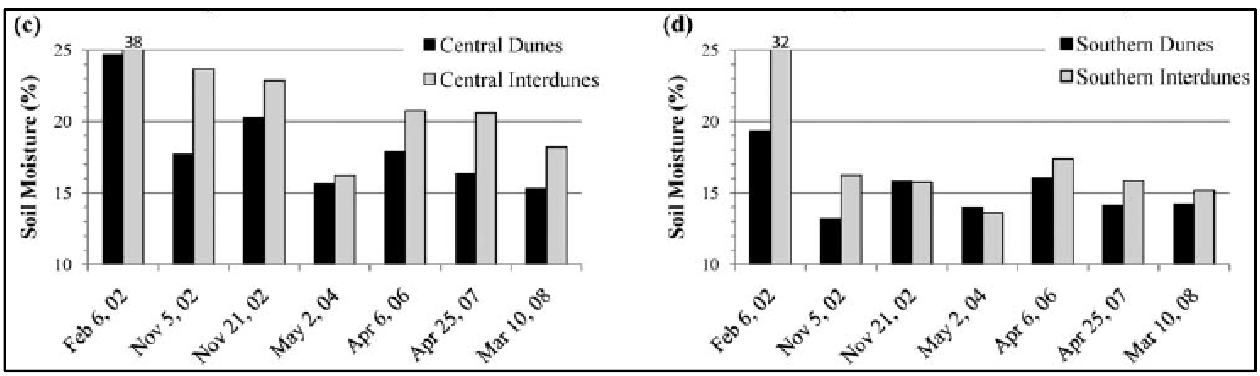



**Figure 9.** Dune (soil) moisture estimates for central barchan (crescentic) and southern parabolic dunes and interdune areas within WHSA (Scheidt et al. 2010).

Plant Species Richness

Emerson (1935) identified 62 species known to occur in the dune communities of WHSA (Appendix A). Fifty-eight of these were first documented by Wooton and Standley (1915), and Emerson (1935) added an additional five based on personal observations. Two of these species are endemic: purple sand verbena (*Abronia angustifolia*) and whitepole evening primrose (*Oenothera pallida* ssp. *gypsophila*). Emerson (1935) also noted that seven species are able to grow upward through encroaching sand dunes through meristematic activity (Shields 1956) and adventitious root production (Emerson 1935) (Photo 9). These species are noted in Appendix A.

**Photo 9.** Vegetation in a dune community: cottonwood (background), rosemary mint (front right) and rubber rabbitbrush (*Ericameria nauseosa*). Note that the cottonwoods are beginning to be engulfed by the encroaching dune (photo by Kathy Allen, SMUMN GSS).

Patrick (1979) found that plant species richness decreased with distance into the dune field. In this study, 19 species were identified in the parabolic dunes on the edge of the dune field, three species were found on transverse dune crests, and no plant species were found in the barchan dunes (Patrick 1979). Patrick (1979) also found that, in general, fewer plant species grow on dune crests than on dune slipfaces throughout the dune field.

Extent of Vegetation Communities

For mapping purposes, the dune communities of WHSA can be divided into two vegetation classes: Gypsum Duneland - Barren and Gypsum Duneland - Vegetated (Muldavin et al. 2000b). Together, these classes cover 9,085 ha (22,450 ac) of the park (Table 9, Figure 10). Barren dunes comprise the vast majority of this area, totaling 8,399 ha (20,674 ac) (Muldavin et al. 2000b).

**Table 9.** Extent of dune vegetation classes within WHSA in hectares and acres (Muldavin et al. 2000b).

| Vegetation class | Acres | Hectares |
|---|---:|---:|
| Gypsum Duneland - Barren | 20,674 | 8,366 |
| Gypsum Duneland - Vegetated | 1,776 | 719 |
| **Total** | **22,450** | **9,085** |

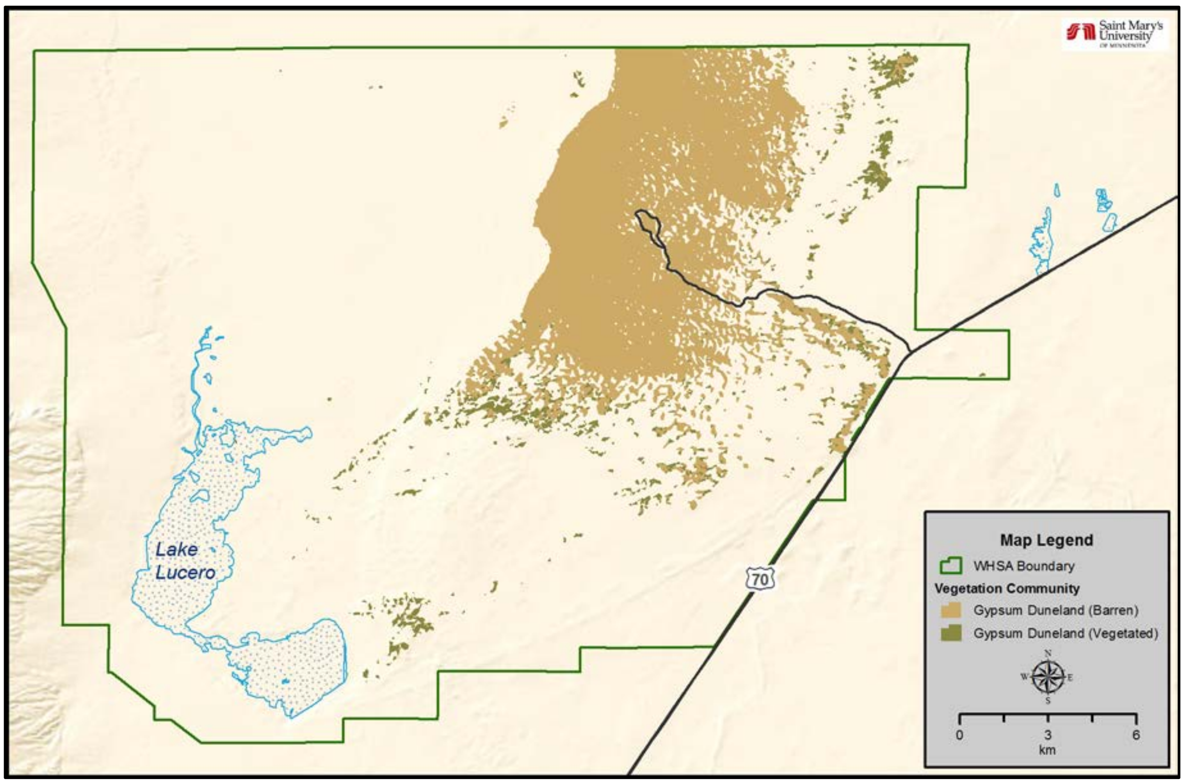



**Figure 10.** The extent of dune vegetation communities within WHSA (Muldavin et al. 2000b).

Changes in Dune Morphology, Movement, and Mass

*Dune Movements*

Dune migration at WHSA has been studied since the 1960s. McKee (1966) compared the migration of a barchan dune and a parabolic dune over several years. Nearly all parts of the barchan dune showed forward movement, with some parts advancing as much as 7.6 m (25 ft) in one 6-month period (McKee 1966). The parabolic dune, which was further downwind from the barchan dune, moved less along its advancing edge and actually retreated on part of its inner (typically upwind) side. This supported McKee's (1966) conclusion that dune migration rates are higher on the "upwind" end of the dune field than on the "downwind" end. Barchan dunes were observed to move up to 12 m (39 ft) per year (McKee 1966, Reid 1980).

McKee and Douglas (1971) reported migration rates between 1962 and 1968 for various dune types at WHSA (Table 10). The observed rates supported McKee's (1966) previous conclusion that dune movement rates are higher on the upwind edge of the dune field. Dome dunes showed the highest migration rates, averaging 10.0 m/yr (32.8 ft/yr) while parabolic dunes averaged just 1.1 m/yr (3.6 ft/yr) (McKee and Douglas 1971). One parabolic dune on the eastern margin of the dune field did not move at all during the study period.

**Table 10.** Annual movement rates (m/yr) by dune type at WHSA, 1962-1968 (McKee and Douglas 1971).

| Dune type | # of dunes measured | Range of rates | Mean annual rate |
|---|---|---|---|
| Dome | 4 | 7.3-11.6 | 10.0 |
| Transverse/Barchanoid Ridge | 4 | 1.2-3.7 | 2.3 |
| Barchan | 3 | 2.1-3.0 | 2.6 |
| Parabolic | 4 | 0-2.1 | 1.1 |

Patrick (1980) calculated movement rates for several dunes at WHSA between the mid- to late-1960s and 1979. A parabolic dune near the Dunes Drive migrated 29 m (95 ft) between 1964 and 1979, for an average rate of 1.8 m/yr (5.9 ft/yr) (Patrick 1980). An active marginal dune west of park headquarters migrated 24.2 m (79.4 ft) along its axis between 1968 and 1979, or at an average rate of 2.1 m/yr (6.9 ft/yr). A comparison of 1946 and 1968 aerial photos of this marginal dune suggested that movement was slower during that earlier period, but that the dune experienced a substantial change in shape (Patrick 1980). Lastly, aerial photos of a large, active parabolic dune from three years (1946, 1972, and 1979) were compared. Analysis indicated that dune movement rates throughout this time were high, ranging from 2.8-3.1 m/yr (9.2-10.2 ft/yr).

Ewing and Kocurek (2010) calculated mean annual dune migration rates for seven different zones along a 3,500 m (11,483 ft) box transect through the White Sands dune field in WHSA. The first zone (i.e., box 1) was at the upwind edge of the dune field and each subsequent zone was further into the dune field and further downwind (Ewing and Kocurek 2010). This study showed that dune migration rates are highest at the upwind edge of the dune field (5.6 m/yr) and decrease sharply over the first 1,500 m (4,921 ft) of the dune field (Table 11).

**Table 11.** Mean dune migration rates (m/yr) for various portions of the WHSA dune field, 1996-2007 (Ewing and Kocurek 2010). Box 1 is at the more active, upwind end of the dune field and each subsequent box is further downwind.

| Migration rate | Box 1 | Box 2 | Box 3 | Box 4 | Box 5 | Box 6 | Box 7 |
|---|---|---|---|---|---|---|---|
| Mean | 5.6 | 3.8 | 2.9 | 3.1 | 3.4 | 3.1 | 3.9 |
| SD | 1.8 | 1.5 | 1.2 | 1.1 | 1.2 | 1.0 | 1.0 |

*Dune Morphology and Mass*

Kocurek et al. (2007) calculated cumulative and incremental dune accumulation rates using core samples taken near WHSA's Heart of the Dunes loop. Calculating incremental rates is difficult, as compaction, gypsum dissolution, and deflation (removal of sand by wind) can all "shorten" sections of the dune core (Kocurek et al. (2007). Assuming that the White Sands dune field is approximately 7,000 years old, the average accumulation rate since its formation is 1.2 mm/yr (0.05 in/yr). Dune cores suggest that accumulation rates in the Heart of the Dunes area peaked between 3,200 and 3,600 years ago at 2.5 mm/yr (0.1 in/yr) and have averaged a lower 0.5 mm/yr (0.02 in/yr) for the past 2,000 years (Kocurek et al. 2007). However, calculations of recent accumulation rates based on trench observations during the same study suggest that recent accumulation rates are higher than the long-term average determined from the core sample (Kocurek et al. 2007). These differences may reflect significant variation in accumulation rates over time or deflation of accumulations during some time periods (Kocurek et al. 2007).

Rachal and Dugas (2009) documented changes in barchan dune morphology using repeat aerial photography of WHSA from five different years between 1948 and 2003. Their analysis showed that several morphology parameters were highly variable during the study period and did not show any steady trends (Table 12). However, an inverse relationship between crest length and sinuosity was detected; in years when crest lengths were longer (e.g., 1985), sinuosity was lower, and when crest lengths were shorter (e.g., 1996), sinuosity was higher (Figure 11) (Rachal and Dugas 2009).

**Table 12.** Summary of dune pattern attributes for WHSA barchan dunes over time (Rachal and Dugas 2009). All measurements are in meters (m).

| Dune attributes | 1948 | 1963 | 1985 | 1996 | 2003 |
|---|---|---|---|---|---|
| **Crest length** | | | | | |
| Mean | 132 | 126 | 150 | 117 | 119 |
| SD | 100 | 75 | 110 | 81 | 97 |
| **Spacing (Transect 1)** | | | | | |
| Mean | - | 199 | 179 | 216 | 147 |
| SD | - | 135 | 174 | 176 | 122 |
| **Spacing (Transect 2)** | | | | | |
| Mean | - | 227 | 194 | 293 | 223 |
| SD | - | 165 | 103 | 197 | 163 |
| **Sinuosity** | | | | | |
| Mean | 1.2 | 1.3 | 1.2 | 1.3 | 1.1 |
| SD | 0.26 | 0.2 | 0.1 | 0.2 | 0.13 |

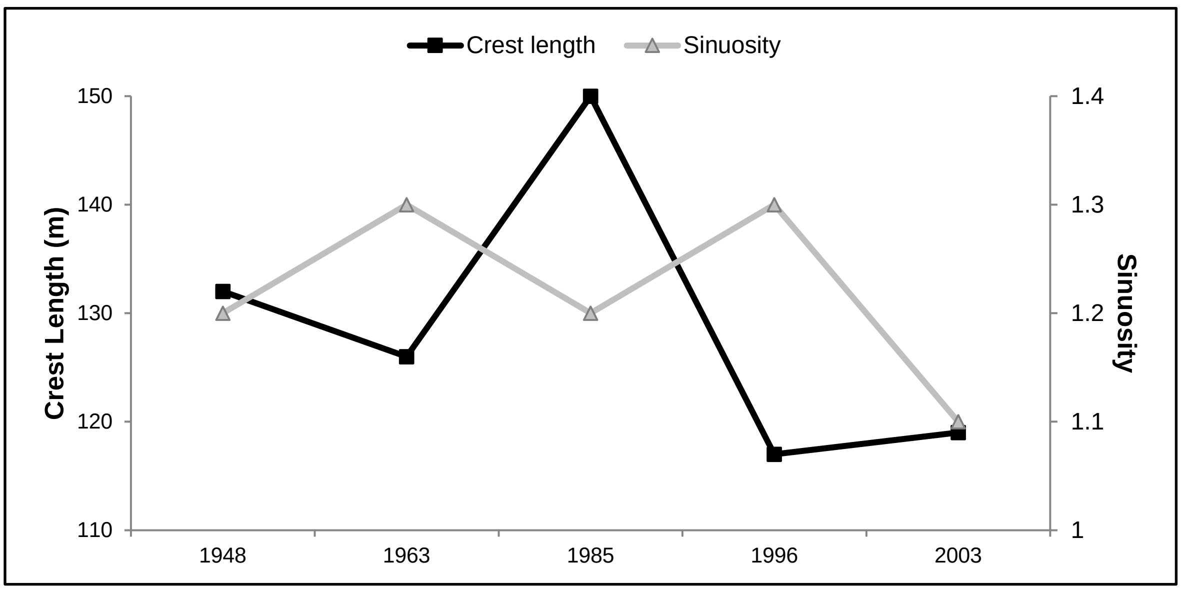



**Figure 11.** The inverse relationship between crest length (m) and sinuosity in the WHSA dune field from 1948-2003, as detected by Rachal and Dugas (2009).

Ewing and Kocurek (2010) reported various dune morphology parameters over their 3,500 m (11,483 ft) box transect using aerial imagery from 5 years between 1985 and 2007. The study also explored interactions between dunes (i.e., merging, linking, and dune splitting). Across the transect as a whole, dunes had an average length of 247 m (810 ft) and an average spacing of 136 m (446 ft). Over the first 1,500 m (4,921 ft) of the dune field transect, mean crest length and mean dune height steadily increased, while the number of dunes (i.e., crestlines), migration rates, and number of dune interactions decreased (Table 13, Figure 12). In the remainder of the transect, mean dune height shifted to a declining trend, while spacing continued to increase and the number of dune interactions remained relatively constant (Figure 12). Ewing and Kocurek (2010) concluded that dunes near the upwind margin are smaller, migrate faster, and show less of an organized pattern than dunes further into the field.

**Table 13.** Dune morphology parameter means within seven zones along a dune field transect at WHSA, 1985-2007 (Ewing and Kocurek 2010). Box 1 is at the more active, upwind end of the dune field and each subsequent box is further downwind.

| Dune parameter | Box 1 | Box 2 | Box 3 | Box 4 | Box 5 | Box 6 | Box 7 |
|---|---|---|---|---|---|---|---|
| **Dune count** | | | | | | | |
| Mean | 30.6 | 22.6 | 15.8 | 10.6 | 12.8 | 11.4 | 9.4 |
| SD | 5.7 | 9.8 | 6.6 | 4.4 | 5.3 | 4.7 | 3.7 |
| **# of interactions** | | | | | | | |
| Mean | 4.8 | 3.2 | 2.0 | 0.8 | 1.2 | 0.6 | 0.6 |
| SD | 3.6 | 3.3 | 1.9 | 1.3 | 1.8 | 0.96 | 0.96 |
| **Crest length (m)** | | | | | | | |
| Sum | 17,132 | 16,443 | 14,142 | 11,526 | 11,411 | 8,570 | 7,870 |
| Mean | 111.97 | 145.51 | 179.01 | 217.47 | 178.30 | 150.35 | 167.44 |
| SD | 79.90 | 116.87 | 138.71 | 160.52 | 157.98 | 102.64 | 124.50 |
| **Spacing (m)** | | | | | | | |
| Mean | 73.46 | 76.65 | 88.74 | 108.69 | 110.16 | 146.75 | 159.24 |
| SD | 6.85 | 7.57 | 6.14 | 5.74 | 9.25 | 12.36 | 8.97 |
| **Height in 2007 (m)** | | | | | | | |
| Mean | 5.3 | 6.5 | 7.1 | 6.3 | 5.4 | 5.1 | 3.7 |
| SD | 2.3 | 2.5 | 2.7 | 2.6 | 2.4 | 2.2 | 1.7 |

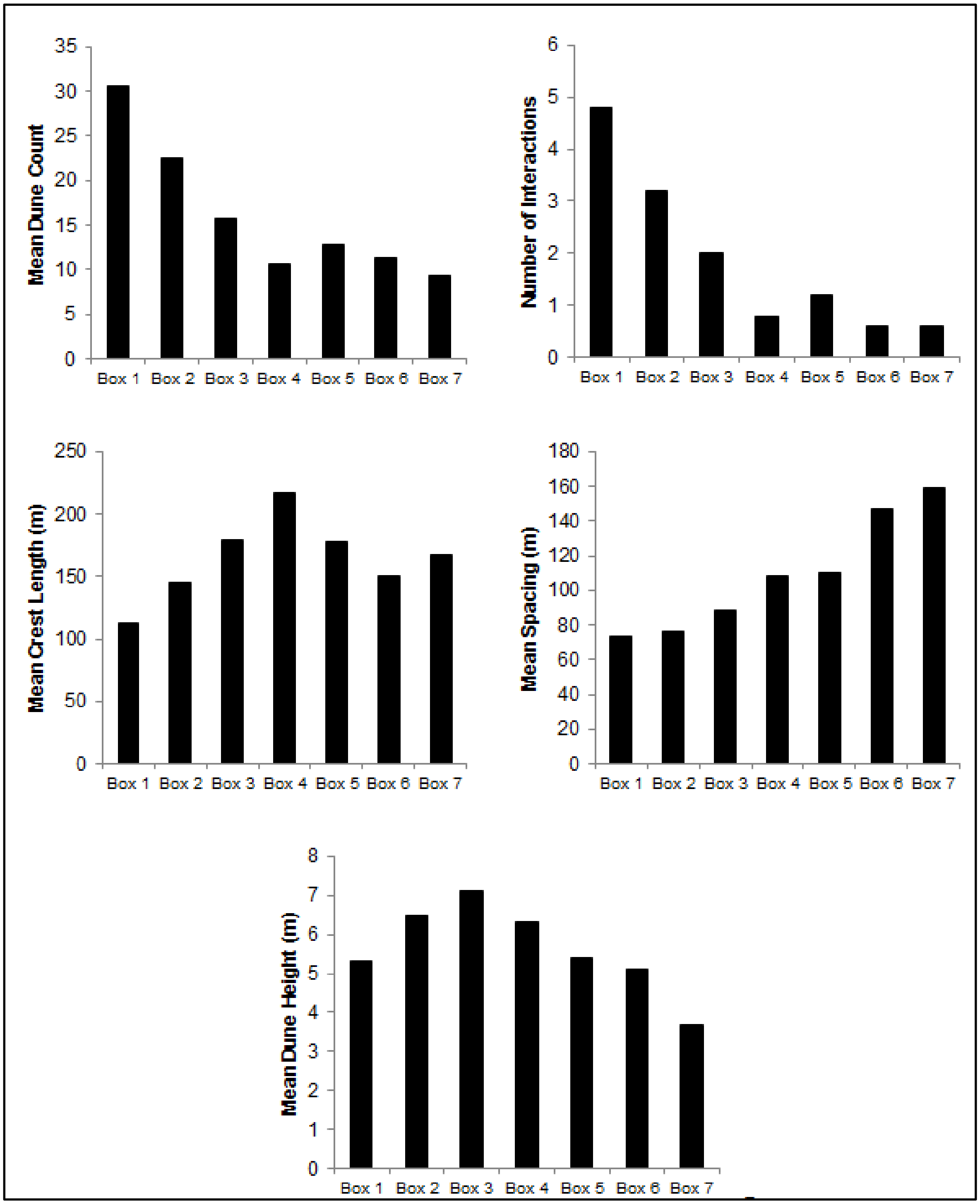



**Figure 12.** Changes in measured dune parameter means over the length of the WHSA dune field transect (Ewing and Kocurek 2010). Boxes are at 500-m intervals; Box 1 consists of the first 500 m in from the upwind margin and Box 7 ends 3,500 m into the dune field. All parameters are means for the period 1985-2007, with the exception of mean dune height, which shows only 2007 measurements.

Kocurek et al. (2012) used 2007 and 2008 LiDAR imagery to document basic characteristics of the dune field within WHSA (e.g., height, spacing, and sinuosity). These characteristics, based on a random sample of 110 dunes, are presented in Table 14. As was found in previous studies, many of the parameters showed a high level of variation (e.g., crestline length, dune width, dune footprint and surface areas, and dune volume).

**Table 14.** Dune parameter measurements from a random sample of 110 dunes at WHSA (Kocurek et al. 2012).

| Parameter | Range | Mean | Standard Deviation |
|---|---:|---:|---:|
| Average dune height (m) | 2.1-9.3 | 4.7 | 1.3 |
| Spacing (with interdunes) (m) | 50.9-302.1 | 134.1 | 46.2 |
| Crestline length (m) | 80.7-1,555.6 | 559.0 | 335.1 |
| Dune width (m) | 80.0-1,282.2 | 448.6 | 250.0 |
| Dune length (m) | 24.6-164.3 | 86.7 | 23.7 |
| Crescent length (m) | 28.0-238.0 | 93.0 | 37.6 |
| Average horn length (m) | 1.5-91.0 | 26.0 | 16.6 |
| Sinuosity | 1.2-2.7 | 1.53 | 0.41 |
| Dune footprint area ($m^2$) | 2,640-107,764 | 36,140 | 24,601 |
| Dune total surface area ($m^2$) | 2,713-110,136 | 37,027 | 25,231 |
| Orientation (degrees) | 32.6-285.7 | 337.5 | 21.9 |
| Dune volume ($m^3$) | 4,900-473,434 | 123,348 | 98,874 |

Kocurek et al. (2012) also documented dune characteristics within four different zones in the dune field with distinct visual patterns (Figure 13). Zone 1 is closest to the upwind margin of the dune field and each subsequent zone is further downwind. Measurements show that dunes in zone 1 are generally smaller, in both height and length, and more closely spaced than dunes in other zones (Table 15, Figure 14) (Kocurek et al. 2012). Dunes in zone 2 showed the greatest mean height of all four zones, with dune lengths and spacing greater than in zone 1 but less than in zones 3 and 4 (Figure 14). Zone 3 dunes had the longest dune lengths and spacing of all four zones. Dune characteristics in zone 4 were generally closest to the means calculated for the dune field study area as a whole (as presented in Table 14 above) (Kocurek et al. 2012).

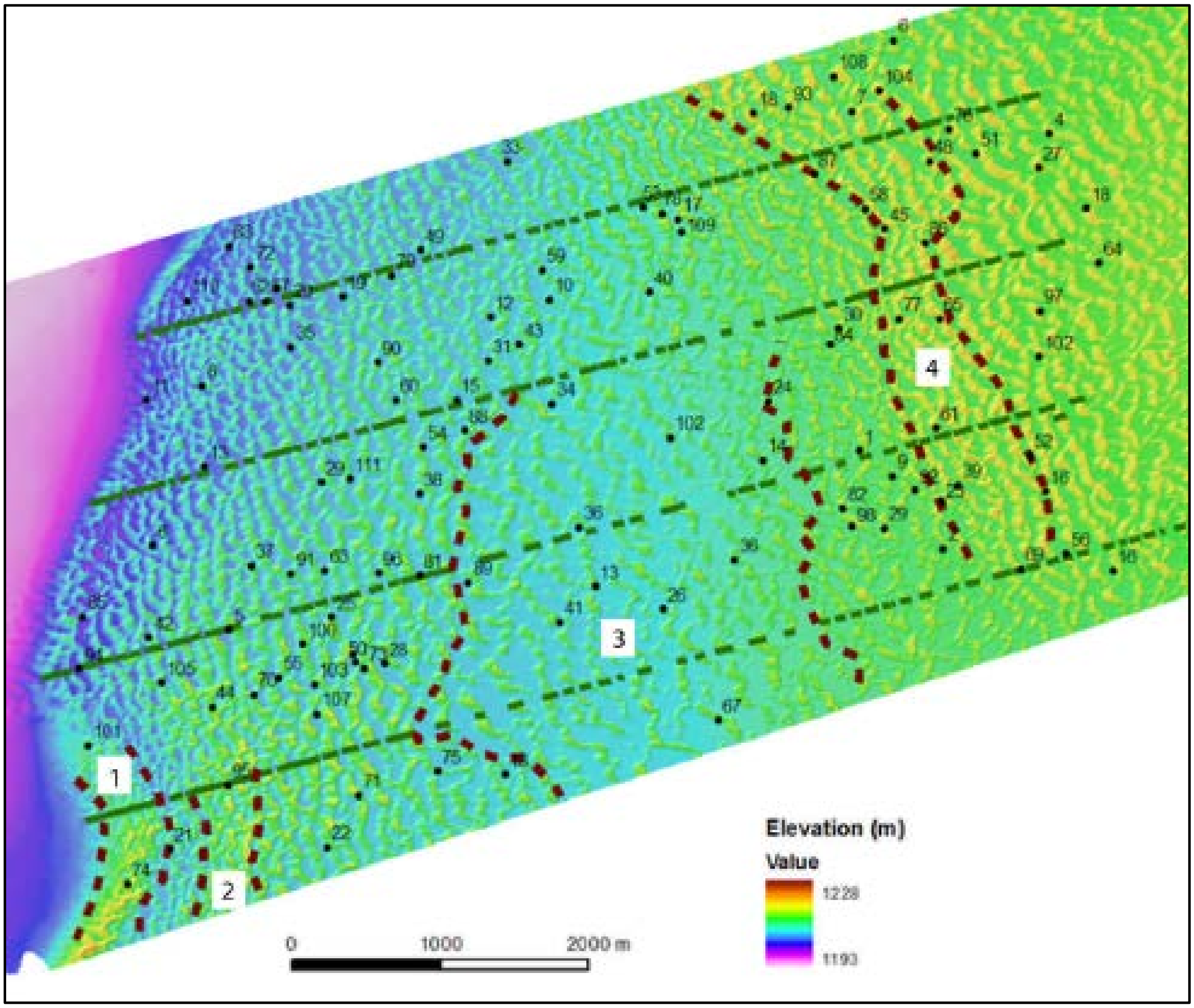



**Figure 13.** Location of the four dune field zones characterized by Kocurek et al. (2012).

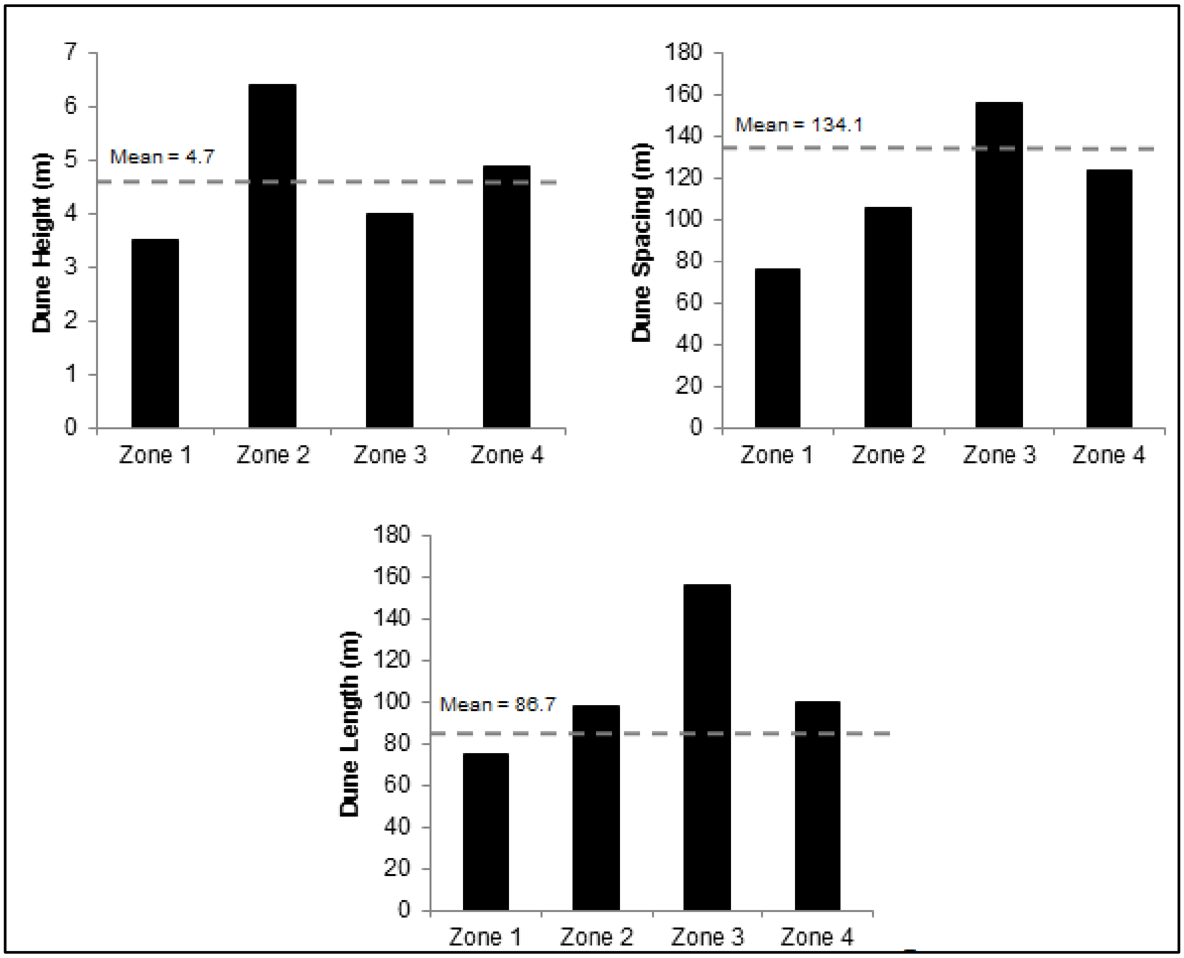



**Figure 14.** Dune parameter means in four zones within the WHSA dune field (Kocurek et al. 2012). Dashed lines show the overall mean for the dune field based on 110 randomly sampled dunes (Table 14). Zone 1 is closest to the upwind margin of the dune field and each subsequent zone is further downwind.

**Table 15.** Dune parameters in four zones within the WHSA dune field, as shown in Figure 14 (Kocurek et al. 2012). All measurements are in meters; n = sample size.

| Parameters | Range | Mean | Standard Deviation |
|---|---|---|---|
| **Zone 1 (n = 45)** | | | |
| Dune height | 1.1-6.5 | 3.5 | 1.5 |
| Spacing (with interdunes) | 38.6-115.8 | 76.0 | 19.0 |
| Dune length | 28.1-130.8 | 75.4 | 24.3 |
| **Zone 2 (n = 41)** | | | |
| Dune height | 1.8-11.2 | 6.4 | 2.4 |
| Spacing (with interdunes) | 37.4-161.0 | 106.0 | 29.0 |
| Dune length | 47.8-167.5 | 97.8 | 26.7 |
| **Zone 3 (n = 44)** | | | |
| Dune height | 0.5-9.5 | 4.0 | 1.9 |
| Spacing (with interdunes) | 43.6-359.6 | 156.0 | 68.0 |
| Dune length | 40.7-133.8 | 90.5 | 24.9 |
| **Zone 4 (n = 42)** | | | |
| Dune height | 1.2-8.6 | 4.9 | 1.9 |
| Spacing (with interdunes) | 53.0-204.1 | 124.0 | 41.0 |
| Dune length | 45.0-146.1 | 99.4 | 21.8 |

Lastly, Kocurek et al. (2012) documented topographic change within the dune field between June 2007 and 2008 by generating a difference map from the two sets of LiDAR imagery. The resulting map for the entire study area is shown in Figure 15. Blue represents areas of erosion (loss of elevation) while red represents dune deposition (gain in elevation, or dune building). Based on this map, it is apparent that dune activity is much greater on the upwind (west) side of the dune field (Kocurek et al. 2012). Close-up maps of selected areas within the dunes further illustrate this trend and can be found in Appendix B.

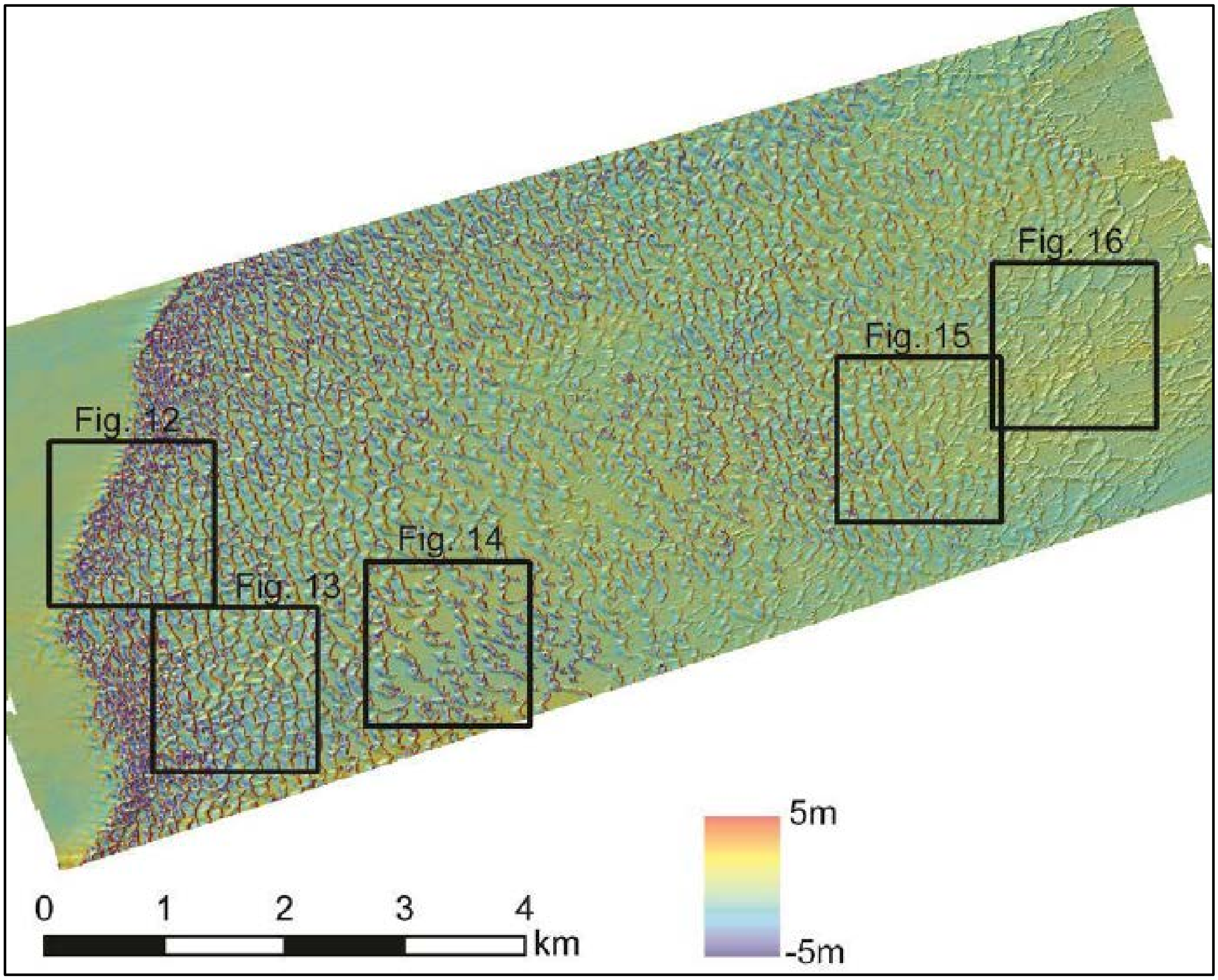



**Figure 15.** Difference map showing dune field change between June 2007 and 2008 LiDAR imagery. Red represents areas of deposition (e.g., dune building) and blue represents areas of erosion (reproduced from Kocurek et al. 2012). Enlarged maps, as represented by black boxes, are found in Appendix B.

Change in Boundaries of Dune Community/Dune Type

The leading edge of the dune field is known to be advancing to the northeast, but it is unknown if the overall extent of the dune field is growing or shrinking (Fryberger 2001, Bennett and Wilder 2009). Figure 5 shows the general location and extent of each of the four dune types at WHSA (dome, barchan, transverse, and parabolic). However, the boundaries between dune types over time have not been studied; while it is almost certain that the boundaries between the types have changed over time, these have not been documented. Given the existence of historic aerial imagery and the recent addition of LiDAR data (Kocurek et al. 2012), an analysis of such boundary changes could likely be conducted in the future.

Depth to Groundwater

The systems and processes that formed and maintain the dunes are heavily influenced by the groundwater table (Allmendinger and Titus 1973, Fryberger 2001). Groundwater levels impact whether sand is held in place within the dunes and interdunes or scoured away by the wind

(Fryberger 2001). Groundwater also influences the production of new gypsum sediment on the playa at Lake Lucero, which supplies some sand for the dunes (Fryberger 2001). The groundwater table beneath the White Sands dune field fluctuates seasonally, typically reaching its high point in the winter and dropping during the summer due to high evaporation rates (KellerLynn 2012). Information regarding the depth to groundwater at WHSA is discussed in detail in Chapter 4.12 of this report.

Threats and Stressor Factors

Threats to the WHSA dune communities include groundwater table declines, the invasive species salt cedar, climate change, Dune Drive construction and maintenance, and missile/debris retrieval efforts. Some of these threats (e.g., road maintenance, debris retrieval, and salt cedar) will likely only affect portions of the dune field while others (particularly climate change and groundwater decline) will have community-wide impacts.

The invasive salt cedar (or tamarisk; Photo 10) has become established in several dune areas due to the high water table, particularly in some interdunes, along the dune field edges, and around Lake Lucero (Conrod 2005, KellerLynn 2012). As its name implies, the species is able to tolerate saline groundwater conditions (KellerLynn 2012). Salt cedar roots can stabilize dune sands, creating pedestals as the surrounding sands are blown away (Bennet and Wilder 2009, Photo 10). The presence of these pedestals or the plants alone can alter wind patterns, influencing dune patterns and movement (Bennett and Wilder 2009, KellerLynn 2012). Removing or controlling the species is difficult at WHSA, due to the remote, roadless nature of much of the park and the dispersed distribution of the plants (Conrod 2005).

**Photo 10.** Salt cedar creating a pedestal within the WHSA dune field (NPS photo by David Bustos).

Due to the key role of moisture within the dune field, climate change has the potential to significantly impact dune communities. Potential effects of climate change in the desert southwest include increased temperatures, changes in the amount and timing of precipitation, and more climate extremes (e.g., heat waves, droughts) (NAST 2001, Davey et al. 2007). Plants in desert environments are often already stressed by limited water availability, and any change in the amount or timing of precipitation can have a large impact (Munson and Reiser 2013). New Mexico's Agency Technical Working Group (ATWG 2005) estimated that the state's mean temperatures could increase 3.3-6.7°C (6-12°F) by 2100. These warmer temperatures will accelerate water loss through evapotranspiration, contributing to overall drier conditions and water stress for plants. A loss of vegetative cover may destabilize dunes, particularly the more vegetated parabolic dunes on the downwind side of the field (Bennet and Wilder 2009, NPS 2010). The dunes themselves are also influenced by soil moisture and the depth to groundwater (Kocurek et al. 2007, Scheidt et al. 2010) and could be impacted by shifts in precipitation, particularly if the frequency and duration of droughts increases (KellerLynn 2012; Photo 11). According to Fryberger (2001), a long-term rise or fall in the groundwater table of only a meter would trigger major changes in the dune dynamics at WHSA.


**Photo 11.** Aerial photos of a March 2008 dust storm during dry conditions that blew sand from the WHSA dune field nearly to Oklahoma (NPS photos).

Climate change will also likely impact the timing and amount of surface runoff/recharge into the low-lying areas south and east of the White Sands dune field (ATWG 2005, Spera 2011). If the water table in these areas drops, more sediment will dry up and be available for deflation/transportation into the dune field (Bennet and Wilder 2009, Spera 2011). If this occurs, the overall extent of the dune field may increase (Spera 2011).

Human activities can also impact dune communities. Sand from actively migrating dunes is constantly moving on to the park's Dunes Drive, to the point that the road is regularly plowed to allow continued access for visitors and park staff. While this is a necessary operation, the plowing does affect the natural processes of dune movement and migration. Occasional road maintenance may also disrupt dunes along the road.

Occasionally, missile parts or other debris from missile range tests needs to be retrieved from WHSA's dune communities. The vehicles required for these activities have varying impacts on different parts of the dunes. In highly active, unvegetated portions of the dune field, any evidence of human activity is essentially erased by sand and dune movement (Kocurek et al. 2012). However, in wetter interdune areas and the more stable parabolic dunes, human trails and vehicle tracks can be longer lasting and have a larger impact (Kocurek et al. 2012).

Data Needs/Gaps

Information regarding WHSA's dune vegetation communities is limited. Currently, only one source of data regarding their areal extent is available (Muldavin et al. 2000b) and the dunes have not been specifically surveyed for plant species richness in several decades. An updated vegetation classification and mapping project is currently underway and is scheduled for completion in 2016 (Julie Christian, former CHDN Ecologist/Field Coordinator, written communication, 9 September 2015).

The processes involved in the mobilization and transport/flow of sediment into the WHSA dunes is not fully understood (Fryberger 2001, Bennett and Wilder 2009). Further research on these subjects would provide valuable knowledge of dune dynamics and how they may be impacted by various threats. A study of evaporation rates, which are important in predicting soil moisture, could contribute to a better understanding of the relationship between dune moisture and other dune parameters (Scheidt et al. 2010). An inventory of yardangs (i.e., locations and condition) is also needed to understand and protect this unique resource (Fryberger 2001, Bennet and Wilder 2009). Additional LiDAR data collection, particularly from different seasons, will allow for efficient monitoring and a further understanding of dune activity in the dune field at WHSA (Kocurek et al. 2012).

Overall Condition

*Dune Moisture*

The project team assigned this measure a *Significance Level* of 3. Although moisture is critical in maintaining the White Sands dune field, limited data are available for this measure. Scheidt et al. (2010) found that interdunes consistently have higher moisture levels than the surrounding dunes and that barchan dune moisture is typically higher than parabolic dune moisture levels. However, due to a lack of data, a *Condition Level* could not be assigned. The information presented in this report may serve as a baseline for future assessments.

*Plant Species Richness*

The plant species richness measure was assigned a *Significance Level* of 2. Emerson (1935) created a plant list for the White Sands dune field that included 62 species. While the dune communities have not been specifically surveyed for plant species more recently, nearly all of these 62 species are still found on the current NPS certified species list for the park (NPS 2015). At the present time, plant species richness is of low concern (*Condition Level* = 1).

*Extent of Vegetation Communities*

This measure was also assigned a *Significance Level* of 2. Vegetation mapping conducted during the late 1990s showed that gypsum duneland communities covered 9,085 ha (22,450 ac) of the park, the vast majority (92%) of which consisted of barren gypsum dunes (Muldavin et al. 2000b). No prior or more recent community extent data were available for comparison to determine if extent has changed over time. As a result, a *Condition Level* cannot be assigned for this measure.

*Changes in Dune Morphology, Movement, and Mass*

The project team assigned this measure a *Significance Level* of 3. Although data regarding these dune parameters have been collected at WHSA, the methods and locations of study have not always been consistent, making it difficult to determine if change is actually occurring over time. The highly variable nature of the White Sands dune field also makes it difficult to determine if any observed differences are a result of actual changes over time or simply natural variation. It is also unclear at this time what level of change would be cause for concern and what is a natural part of the process of dune field development. At the present time, a *Condition Level* will not be assigned to this measure. The continuation of data collection and analysis using LiDAR imagery, as in Kocurek et al. (2012), should allow researchers to better understand variation within the dune field and to detect any changes of concern that may be occurring.

*Change in Boundaries of Dune Community/Dune Type*

This measure was also assigned a *Significance Level* of 3. Due to the dynamic nature of the White Sands dune field, it is almost certain that boundaries between the different dune types have changed over time. However, dune type boundaries have not been studied and changes in the boundaries have not been documented. Therefore, a *Condition Level* could not be assigned.

*Depth to Groundwater*

The depth to groundwater measure received a *Significance Level* of 3. As mentioned previously, the processes that formed and maintain the dunes are heavily influenced by the groundwater table (Fryberger 2001). Based on the assessment of depth to groundwater in Chapter 4.12 of this NRCA and concern over projected changes in evaporation rates due to climate change, this measure is assigned a *Condition Level* of 2.

*Weighted Condition Score*

A *Weighted Condition Score* was not calculated for WHSA’s dune communities due to the limited data available for many of the measures. The current condition and trend of this resource are unknown. The data presented in this report could be used as a baseline for comparison in determining the community’s condition in future assessments.

| Dune Communities | | | |
|---|---|---|---|
| Measures | Significance Level | Condition Level | WCS = N/A |
| Dune moisture | 3 | n/a | |
| Plant species richness | 2 | 1 | |
| Extent of vegetation communities | 2 | n/a | |
| Changes in dune morphology, movement, and mass | 3 | n/a | |
| Change in boundaries of dune community/dune type | 3 | n/a | |
| Depth to groundwater | 3 | 2 | |

#### 4.1.6. Sources of Expertise

- Julie Christian, former CHDN Ecologist/Field Coordinator
- David Bustos, WHSA Resource Program Manager

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## 4.2. Semidesert Grasslands

### *4.2.1. Description*

Semidesert grasslands (Photo 12), which cover approximately 25% of the Northern Chihuahuan Subregion where WHSA lies, are often a mix of grass and shrubs (NPS 2010). These are the most arid of all North American grasslands, with extremely high evaporation rates due to warm temperatures, low humidity, and relatively high winds (Humphrey 1958). At the time of European settlement, much of southern New Mexico was dominated by grasses (Humphrey 1953). Since that time, many of these grasslands have shifted to scrub or brush, dominated by desert shrubs (Humphrey 1953, Branscomb 1958, Buffington and Herbel 1965). Humphrey (1953) proposed that semidesert grasslands are not a true climax plant community (i.e., an “endpoint” of vegetative succession) but are a subclimax (i.e., a “stage” in succession) maintained by fire.

**Photo 12.** A semidesert grassland within WHSA (Photo: Andy Nadeau, SMUMN GSS).

Plant community composition of desert, grassland, and shrub communities has been selected as a Vital Sign by the CHDN, as vegetation structure and composition often define ecological communities and heavily influence ecosystem processes (NPS 2010). For example, shifts in vegetation composition and structure can significantly impact soil properties and nutrient cycling (NPS 2010). Vegetative cover is also important in preventing soil erosion (Buffington and Herbel 1965, NPS 2010).

In the area around WHSA, semidesert grasslands occur on foothills, alluvial fan slopes (piedmonts), and alluvial flats (Muldavin et al. 2000b). Common grasses include several grama species (*Bouteloua* spp.), alkali sacaton, gyp dropseed (*Sporobolus nealleyi*), and little bluestem (Photo 13) (Muldavin et al. 1994, 2000b). Biological (i.e., crytobiotic) soil crusts are also common in some areas (Muldavin et al. 1994).

**Photo 13.** A little bluestem grassland in WHSA (Photo: Kathy Allen, SMUMN GSS).

#### *4.2.2. Measures*

- Vegetation community extent
- Plant species richness
- Winter grassland bird diversity
- Percent cover of gopher holes/burrows in semidesert grasslands

#### *4.2.3. Reference Conditions/Values*

The ideal reference condition for WHSA's semidesert grasslands would be the condition of these grasslands prior to European settlement and ranching (~1850s). Information from this time is limited to descriptions of the area written by travelers or early settlers. Several travelers along the "Jornada del Muerto," a portion of the Santa Fe Trail just west of the San Andres Mountains in southern New Mexico, mentioned passing through grasslands. Beale (1858) wrote "The whole extent, as far as vision reached ahead, was a level plain, covered thickly with the most luxurious grass, and filled with beautiful wild flowers" (as cited by Humphrey 1958, p. 24). Froebel (1959) observed that the Jornada supported "excellent grass the whole way" (as cited by Humphrey 1958, p. 24). Given that historical information regarding semidesert grasslands in the WHSA region is purely anecdotal, specific (i.e., measurable) reference conditions were not defined for the measures in this assessment. The data presented here may serve as a baseline for future assessments.

#### *4.2.4. Data and Methods*

Reid (1979, 1980) conducted a natural resources inventory and ecosystem analyses at WHSA, with a focus on vegetation and soil properties. The reports describe dominant plant associations but do not include comprehensive species lists by plant community. Reid (1979) documented areas within park boundaries where historic grazing and associated disturbance has occurred.

Muldavin et al. (1994) completed a vegetation classification and mapping project for WHSA. Initial classifications were based on 1991 satellite imagery of the area; field verification involved sampling vegetation in 243 plots across the park (Muldavin et al. 1994). This information was later integrated into a vegetation classification and map for WSMR, based on 1,739 ground plots surveyed between 1991 and 1995 (Muldavin et al. 2000a, b). The WSMR vegetation classification conforms to the National Vegetation Classification System (NVCS) data standard and the New Mexico Vegetation Classification (Muldavin et al. 2000a). The digital vegetation map generated for WSMR covers WHSA and will be used in this NRCA to assess vegetation community extent.

In 2011, the CHDN initiated a terrestrial vegetation monitoring protocol at WHSA. The primary goal of the program is to detect any broad-scale changes in vegetation and soil properties and potential links to changes in ecological drivers or stressors (Hubbard et al. 2012). A total of 54 monitoring plots have been established within WHSA; one-fifth of these plots are visited each year, so that individual plots are sampled on a 5-year rotation. Of these established plots, 18 fall within areas mapped as semidesert grassland vegetation by Muldavin et al. (2000b) (Figure 16). Data collected include plant species present, relative cover by species, and estimates of erosional feature impacts (including burrowing) (Cheryl McIntyre, CHDN physical scientist, email communication, 29 February 2016). Monitoring data for 2011-2015 (CHDN 2016) were provided to SMUMN GSS by the CHDN.

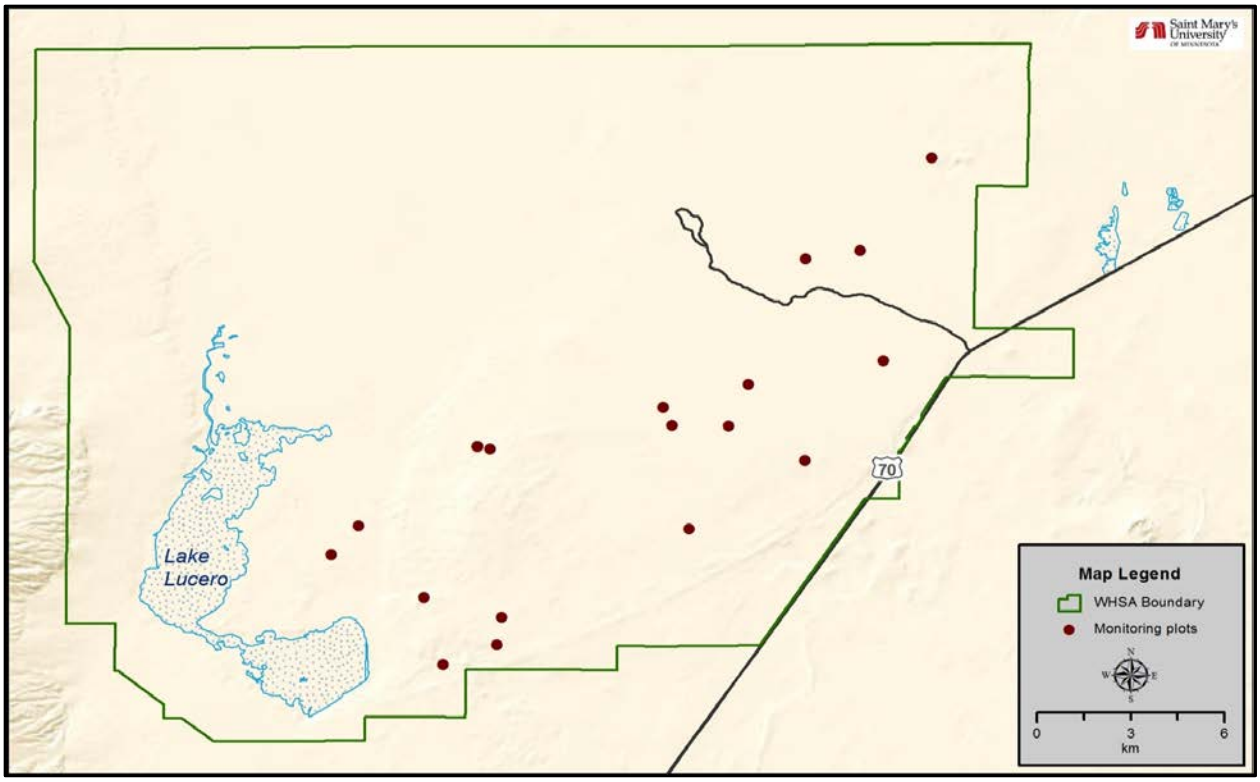


**Figure 16.** CHDN vegetation monitoring plots within semidesert grassland vegetation communities, as mapped by Muldavin et al. (2000b) (CHDN 2016).

#### *4.2.5. Current Condition and Trend*

Vegetation Community Extent

Muldavin et al. (2000b) divided WHSA's semidesert grasslands into three mapping units: Gypsum Interdune Swale Grasslands, Lowland Basin Grasslands, and Mixed Foothill-Piedmont Desert Grasslands. Altogether, these grasslands comprised 13,642 ha (33,714 ac) of the park (Table 16). Gypsum Interdune Swale Grasslands covered the greatest area with 12,280 ha (30,345 ac) while Mixed Foothill-Piedmont Desert Grasslands covered just 9 ha (23 ac) near the park's western boundary (Figure 17).

**Table 16.** Extent of semidesert grassland vegetation classes within WHSA in hectares and acres (Muldavin et al. 2000b).

| Vegetation class | Acres | Hectares |
|---|---|---|
| Gypsum Interdune Swale Grasslands | 30,345 | 12,280 |
| Lowland Basin Grasslands | 3,346 | 1,354 |
| Mixed Foothill-Piedmont Desert Grasslands | 23 | 9 |
| **Total** | **33,714** | **13,643** |

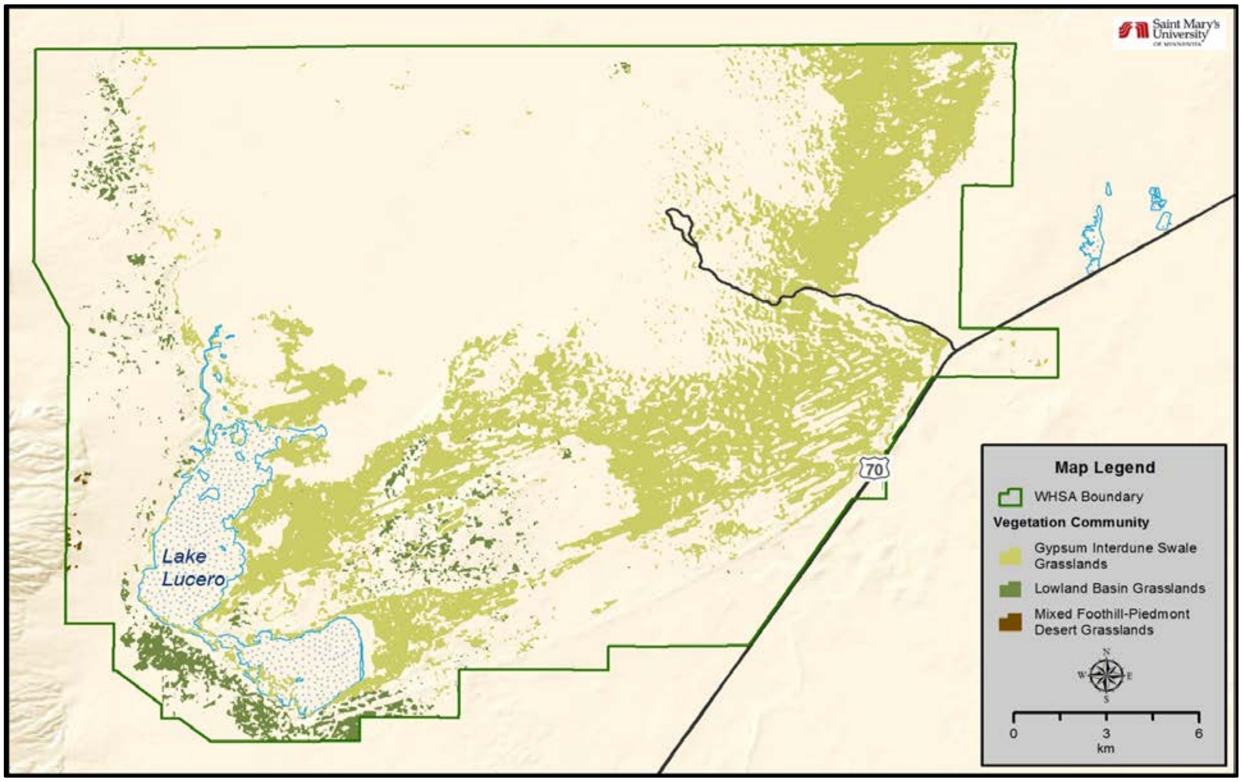


**Figure 17.** The extent of semidesert grassland vegetation communities within WHSA (Muldavin et al. 2000b).

<u>Plant Species Richness</u>

The semidesert grasslands of WHSA have not been comprehensively surveyed for plant species richness or composition. Muldavin et al. (1994) stated that some of the grassland types (e.g., alkali sacaton communities) are very low in species richness. In vegetation class descriptions for the grassland types of WHSA, Muldavin et al. (1994) mentioned only 11 plant species. However, these descriptions listed only the characteristic or most common plant species in each community and did not provide comprehensive species lists. An additional 11 species were described for alkali sacaton and gyp dropseed grasslands in WSMR that likely also occur in WHSA's grasslands (Muldavin et al. 2000a). These species are listed in Table 17.

**Table 17.** Species present in WHSA semidesert grasslands (Muldavin et al. 1994) and in similar grassland types on WSMR (Muldavin et al. 2000a).

| Scientific name | Common name |
|---|---|
| **WHSA grasslands (Muldavin et al. 1994)** | |
| *Sporobolus airoides* | alkali sacaton |
| *Asclepias subverticillata* | horsetail milkweed |
| *Ephedra torreyana* | Torrey's jointfir |
| *Bouteloua breviseta* | gypsum grama |
| *Schizachyrium scoparium* | little bluestem |
| *Heliotropium greggii* | fragrant heliotrope |
| *Frankenia jamesii* | James' seaheath |
| *Tiquilia hispidissima* | hairy crinklemat |
| *Sporobolus nealleyi* | gyp dropseed |
| *Abronia angustifolia* | purple sand verbena |
| *Achnatherum hymenoides* | Indian rice grass |
| **Additional WSMR grassland species (Muldavin et al. 2000a)** | |
| *Yucca elata* | soaptree yucca |
| *Prosopis glandulosa* | honey mesquite |
| *Lycium berlandieri* | Berlandier's wolfberry |
| *Atriplex canescens* | fourwing saltbush |
| *Allenrolfea occidentalis* | iodinebush |
| *Scleropogon brevifolius* | burrograss |
| *Suaeda moquinii* | Mojave seablite |
| *Calylophus hartwegii* | Hartweg's sundrops |
| *Selinocarpus lanceolatus* | lanceleaf moonpod |
| *Larrea tridentata* | creosote bush |
| *Lepidium montanum* | mountain pepperweed |

To date, CHDN terrestrial vegetation monitoring has documented 59 plant species across 18 plots within WHSA's semidesert grasslands (CHDN 2016). These species are listed in Appendix C.

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 (NABCI 2009).

Unfortunately, no winter bird surveys have been conducted recently at WHSA. Borell's (1938) survey in the mid-1930s extended through the winter, but was opportunistic and did not follow a scientific methodology. The report documented only three grassland bird species during winter months (December-January): horned lark (*Eremophila alpestris*), Say's phoebe (*Sayornis saya*), and western meadowlark (*Sturnella neglecta*) (Borell 1938).

Threats and Stressor Factors

Threats and stressors to WHSA's semidesert grasslands include invasion of scrub species, historic cattle grazing practices, and climate change. Although cattle grazing has not occurred in the park for decades, its impacts may still affect the vegetation communities. Areas where grazing occurred historically, as reported by Reid (1979), are shown in Figure 18.

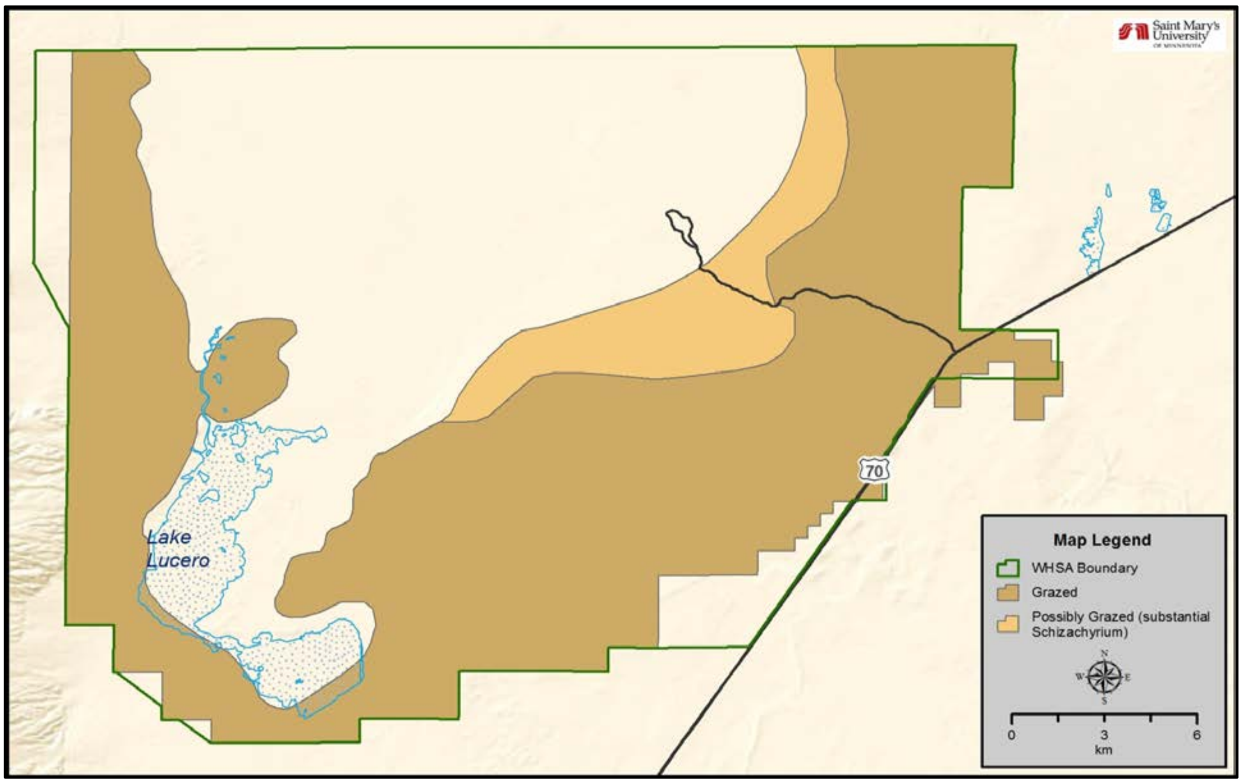


**Figure 18.** Approximate areas within current WHSA boundaries that were formerly grazed, based on historical sites, water resources, bones, and the presence of acceptable forage species (reproduced from Reid 1979). Borders in the southeast corner do not match exactly due to changes in the official park boundary over time.

Since the mid- to late 1800s, many southwestern grasslands have been invaded by desert scrub species such as creosote bush (*Larrea tridentata*), mesquite (*Prosopis glandulosa*), and tarbush (*Flourensia cernua*) (Humphrey 1953, Branscomb 1958, Buffington and Herbel 1965). At WHSA, park staff have noted that the landscape around the Visitor Center is more dense and brushy today than it was in a historic photo from 1939, where bunch grasses were dominant (Conrod 2005). The invasion appears to coincide with the beginning of livestock ranching in the region (Martin 1975). Scrub/shrub encroachment affects nutrient cycling and habitat structure, which impacts both the plant community and the associated wildlife (NPS 2010). The loss of grasslands has been documented at the Jornada Experimental Range, approximately 30 km (19 mi) southwest of WHSA. Between 1915 and 1946, grassland area on the Jornada mesa decreased 28%, from 25,167 ha (62,189 ac) to 18,076 ha (44,666 ac) (Branscomb 1958). The most likely drivers of shrub invasion are livestock grazing and reduced fire occurrence (Humphrey 1953, Branscomb 1958, Boykin 2008). Livestock typically graze grasses before shrubs; this weakens the grasses and reduces competition for desert shrubs (Humphrey 1958, Buffington and Herbel 1965, Boykin 2008). Grazing animals also increased the dispersal or spread of shrub/scrub seeds (Humphrey 1958, Boykin 2008). Livestock can also trample vegetation and increase soil erosion, which may increase a site's vulnerability to exotic plant species invasion (Boykin 2008, NPS 2010).

Grazing and ranching activity have been linked to a reduction in fire occurrence, which also favors shrub encroachment (Humphrey 1958, Boykin 2008). Grazing removes the fine fuels (i.e., grasses) necessary to carry fires (Humphrey 1958, Boykin 2008). Prior to settlement and ranching, researchers believe that fire played an important role in maintaining semidesert grasslands by preventing or controlling shrub encroachment (Humphrey 1953, 1958, NPS 2004, Boykin 2008). Prior to grazing, grassland fires are thought to have occurred in the WHSA area, on average, every 30 years (NPS 2004, citing personal communication with Dan Abercrombie, Natural Resource Conservation Service). The primary fire season for southern New Mexico runs from May to early July, when temperatures are hot and humidity is low (Boykin 2008). Further research is needed to better understand the historic role of fire in semidesert grasslands and the benefits it may provide today after decades of absence.

Potential effects of climate change in the desert southwest include increased temperatures, changes in the amount and timing of precipitation, and more climate extremes (e.g., heat waves, droughts) (NAST 2001, Davey et al. 2007). Long dry periods, especially those accompanied by hot, dry winds, can cause significant perennial grass mortality (NPS 2010). In desert environments, plants are often already stressed by limited water availability, and any change in the amount or timing of precipitation can have a large impact (Munson and Reiser 2013). The increases in atmospheric carbon dioxide that are contributing to climate change also favor the growth of shrubs and exotic grasses over native grasses (NPS 2010).

Data Needs/Gaps

Information regarding WHSA's semidesert grasslands is limited. Currently, only once source regarding their extent is available (Muldavin et al. 2000b). An updated vegetation classification and mapping project is currently underway and is scheduled for completion in 2016 (Christian, written communication, 9 September 2015). This will provide an update regarding the extent of grasslands within WHSA. The grasslands have not been comprehensively surveyed for plant species richness, and winter bird surveys have not been conducted within park boundaries. Further research is needed into the historical role of fire in the Tularosa Basin and the potential benefits of fire to semidesert grasslands today. It is unclear how much or even if burning would benefit grasslands already degraded by shrub encroachment. In some environments, burning may actually increase a community's vulnerability to exotic plant invasion (Brooks and Pyke 2000). A better understanding of how the frequency, timing (i.e., seasonality), and intensity of fire affect various grassland and shrub species, as well as the community as a whole, is necessary to determine if burning could be an effective management tool for grasslands at WHSA.

<u>Overall Condition</u>

*Vegetation Community Extent*

The project team assigned this measure a *Significance Level* of 3. According to the vegetation classification and mapping project completed by Muldavin et al. (2000b), semidesert grasslands comprised 13,642 ha (33,714 ac) of the park during the early 1990s. A majority of these were Gypsum Interdune Swale Grasslands, covering 12,280 ha (30,345 ac) within WHSA. Unfortunately, since no earlier or more recent data are available on semidesert grassland area, it is unclear if the extent of this community is changing over time. As a result, a *Condition Level* cannot be assigned.

*Plant Species Richness*

This measure was also assigned a *Significance Level* of 3. Muldavin et al. (1994, 2000a) described the characteristic or most common plant species in WHSA and WSMR grassland vegetation types, but did not provide a comprehensive species list for the park's semidesert grasslands. CHDN monitoring has also recorded plant species present within sampling plots, documenting a total of 59 species. However, neither of these sources represent thorough searches of all semidesert grassland areas within the park, and it is likely that additional species occur within the plant community. Therefore, a *Condition Level* was not assigned for this measure.

*Winter Grassland Bird Diversity*

The winter grassland bird diversity measure was assigned a *Significance Level* of 2. No recent bird surveys at WHSA have occurred during winter months. Because of this data gap, a *Condition Level* could not be assigned.

*Percent Cover of Gopher Holes/Burrows in Semidesert Grasslands*

This measure was assigned a *Significance Level* of 1. Measures with a *Significance Level* of 1 are not discussed in depth in the current condition section of this assessment, but available information is summarized here in the overall condition section. Pocket gophers and other rodents can influence vegetation communities through their burrowing and herbivory (Kerley et al. 2004, NPS 2010). The impacts may be beneficial (e.g., nutrient cycling, increasing community heterogeneity and plant species richness) or harmful (e.g., increased vulnerability to erosion, introduction of invasive shrub seeds) to grasslands (Kerley et al. 2004, Whitford and Bestelmeyer 2006). Rodents have sometimes been suggested as a factor in the invasion of scrub/shrubs into grasslands, due to their consumption of grass and grass seed, as well as dispersal of shrub seeds (Humphrey 1958).

Three species of pocket gopher occur at WHSA: the desert pocket gopher (*Geomys arenarius*), yellow-faced pocket gopher (*Cratogeomys castanops*), and Botta's pocket gopher (*Thomomys bottae*) (NPS 2001, 2015). The distribution and abundance of pocket gophers at WHSA, as well as their effects on vegetation communities, have not been studied. However, the CHDN estimated the proportion of sampling plots affected by burrowing as part of their monitoring of erosional features (McIntyre, email communication, 29 February 2016). Of the 18 plots in semidesert grassland, 12 showed evidence of burrowing, but no more than 5% of any plot was impacted by burrowing activity

(CHDN 2016). At this time, percent cover of gopher holes is of low concern (*Condition Level* = 1). In the future, it may be possible to identify and map gopher burrow areas on aerial imagery of the park, and track how these areas change over time.

*Weighted Condition Score*

A *Weighted Condition Score* was not calculated for WHSA's semidesert grasslands due to a lack of data for the selected measures. The current condition and trend of these communities is unknown at this time.

| Semidesert Grasslands | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = N/A** |
| Vegetation Community Extent | 3 | n/a | |
| Plant Species Richness | 3 | n/a | |
| Winter Grassland Bird Diversity | 2 | n/a | |
| Percent Cover of Gopher Holes/Burrows | 1 | 1 | |

#### *4.2.6. Sources of Expertise*

- Cheryl McIntyre, CHDN physical scientist

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## 4.3. Migratory Birds

### *4.3.1. Description*

Bird populations often act as excellent indicators of an ecosystem's health (Morrison 1986, Hutto 1998, NABCI 2009). Birds are often highly visible components of ecosystems (Photo 14), and bird communities typically reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010). Migratory birds serve as excellent ecological indictors because a disturbance adversely affecting any of the habitats used by these species (e.g., stopover, wintering, or breeding habitats) can cause declines in populations and a decrease in species' reproductive success (Hilty and Merenlender 2000, Zöckler 2005). Global Christmas Bird Count (CBC) data indicate significant declines in migratory bird numbers in recent years (Peterjohn and Sauer 1999, Vicerky and Herkert 2001).

**Photo 14.** Black-throated sparrow (*Amphispiza bilineata*) (Photo from http://www.allaboutbirds.org).

Situated along the central migratory flyway (Figure 19), WHSA's unique ecosystems and physical formations provide bird species with stopover and overwintering habitats, and represents a vital area for many migratory bird species of North and South America. WHSA has confirmed the presence of over 160 species of birds, of which approximately 58% are migratory species (NPS 2014a).

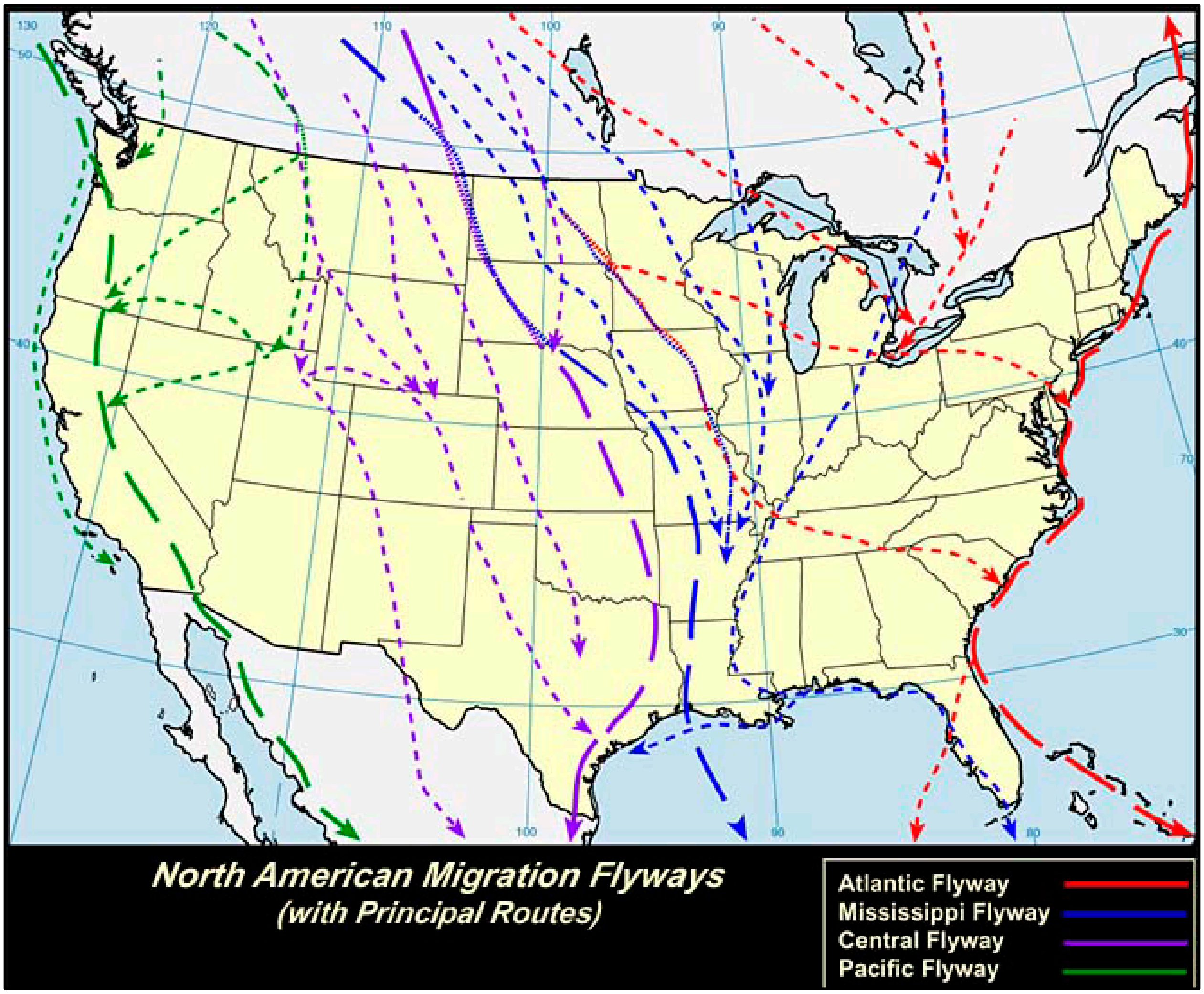


**Figure 19.** North American migration flyways (from NPS 2014b).

WHSA is also home to several migratory species of conservation concern; perhaps most notable of these species is the least tern (*Sterna antillarum*), which is federally listed as endangered. Several other species, such as the Baird's sparrow (*Ammodramus bairdii*), Brewer's sparrow (*Spizella breweri*), and chestnut-collared longspur (*Calcarius ornatus*) are listed as priority species by various national lists (Rich et al. 2004, NMDGF 2006, USFWS 2008, Berlanga et al. 2010)

#### *4.3.2. Measures*

- Species Richness
- Species Diversity
- Trends in Species of Conservation Concern
- Cottonwood Stand Abundance

#### *4.3.3. Reference Conditions/Values*

The reference condition for this component was defined as the period of time before ranching and Anglo settlement (approximately the 1850s). While data may not exist for this time period, current condition can likely be assessed using best professional judgment, and by analyzing recent trends in species richness, diversity, populations of species of conservation concern, and cottonwood stand abundance. The results of this assessment may be used as a baseline for comparison for future condition assessments of the migratory bird community.

#### *4.3.4. Data and Methods*

This component focuses exclusively on the migratory bird species of the park, and does not discuss any resident/breeding bird species (these species are discussed in Chapter 4.4 of this document). A species was classified as migratory based on the NPS Certified Bird Species List (NPS 2014a, Appendix D). Species in NPS (2014a) that had residency designations of "Migratory" and "Vagrant" were included in this component's discussion and analysis. Species that were identified as "Resident" and "Breeder" are discussed in Chapter 4.4 of this document. In instances where NPS (2014) did not assign residency, the Cornell University Lab of Ornithology's All About Birds online database (http://www.allaboutbirds.org) was used to approximate a species' residency as either breeding, migratory, resident, or vagrant. While it is certainly possible that species classified as "Breeder" are also migratory species, this assessment is focused on the non-breeding, migratory species of WHSA. The classification schemes used by NPS (2014) may not be entirely accurate, but are sufficient for this assessment.

Borell (1938) conducted sporadic surveys in WHSA and the adjacent marsh habitats (in an area that would later be added to WHSA's boundaries) from 1935-1938. Observations occurred in portions of every month except for August. Survey efforts resulted in an annotated list of species observed and collected during the 3 years of research.

Meyer and Griffin (2011) surveyed the low elevation riparian avifauna of CHDN parks from 2004-2006. The objectives of this study were to:

- Apply survey methodologies in spring, summer, and fall seasons in riparian habitat study sites to document species presence, species richness, and relative abundances.
- Relate the project findings to existing information of the avifauna at each of the sampling areas and update species lists.
- Provide the baseline data and site evaluations necessary for the development of monitoring programs in the CHDN (Meyer and Griffin 2011, p. 1).

Researchers surveyed two areas in the park (Andrecito Creek, WHSA Headquarters) and utilized both point count transects (Andrecito Creek) and timed area searches (WHSA Headquarters) (Meyer and Griffin 2011). Surveys were conducted during the breeding (5-15 June) and fall migration (10 September - 20 October) periods in 2004, and during the spring migration (10-20 May), breeding season (5-15 June), and fall migration (10-25 September) in 2005. Complete methodology is described in Meyer and Griffin (2011).

As part of a network-wide landbird monitoring project, the Rocky Mountain Bird Observatory (RMBO), in partnership with the CHDN, began monitoring birds in WHSA in the spring of 2010. The overall objective of the project was to detect potential changes in population parameters over time (White 2011, White and Valentine-Darby 2012, 2013, 2014). Surveys across the CHDN in 2014 were completed by the Tucson Audubon Society (Ali and Valentine-Darby 2014).

The RMBO land bird monitoring in WHSA closely parallels the RMBO's "Integrated Monitoring in Bird Conservation Regions (IMBCR)" program, which utilized a spatially-balanced sampling design during survey efforts (White et al. 2011). Across a landscape, the RMBO establishes a series of strata and super-strata (White et al. 2011). Within these strata, the RMBO and its partners utilized generalized random-tessellation stratification (GRTS) to select sample units (Stevens and Olson 2004, White et al. 2011). According to White et al. (2011, p. 8):

> *The IMBCR design defined sampling units as 1-km² cells that were used to create a uniform grid over the entire [Bird Conservation Region] BCR. Within each grid cell we established a 4 x 4 grid of 16 points spaced 250 m apart* (Figure 20).

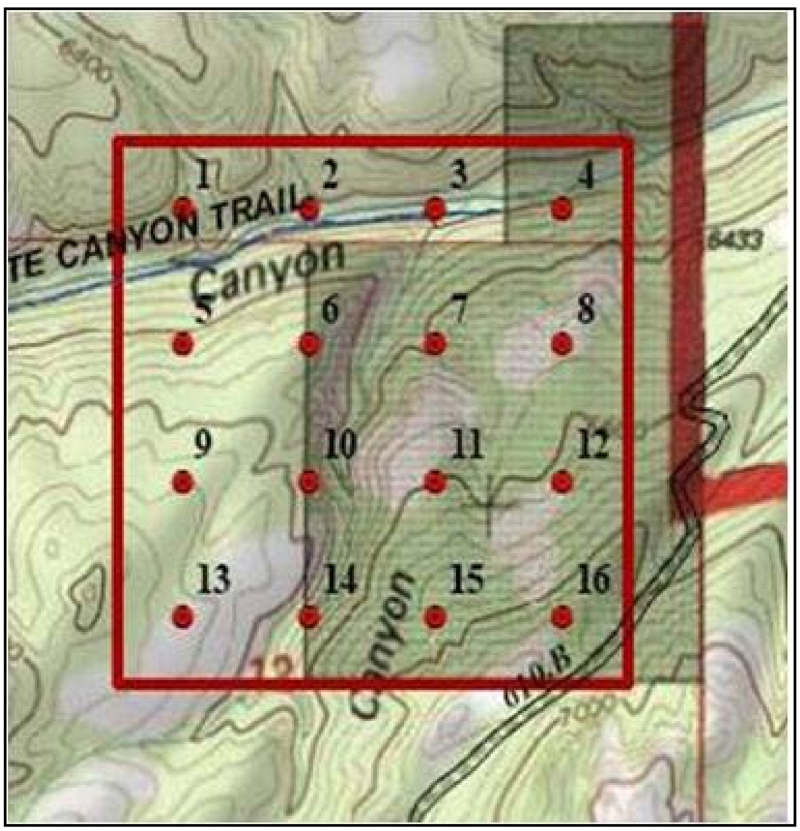


**Figure 20.** Example of a grid cell created by the RMBO using the IMBCR design. Reproduced from White et al. (2011).

#### *4.3.5. Current Condition and Trend*

<u>Species Richness</u>

The species richness measure allows simultaneous assessment of abundance or presence for the entire migratory bird community. This measure can also indicate overall habitat suitability for migratory birds, and is vital to understand the effects of changing landscapes on native biodiversity. Species richness is assessed here as the total number of migratory species observed during a given year/survey period.

*NPS Certified Species List*

The NPS Certified Bird Species List contains 156 species, 93 (60%) of which are migratory bird species (Appendix D). This list, however, did not allow for a specific analysis of annual species richness, as no data were collected other than the presence (or historic presence) of the identified species. The species included on this list are the representative species that have been identified by the survey efforts described below.

*Holloman Air Force Base Species List*

Similar to the NPS Certified Bird Species List (NPS 2014a), the nearby Holloman Air Force Base has a checklist of bird species (MVAS 1996) that identifies 226 species, 147 (65%) of which are migratory bird species (Appendix D). Similar to NPS (2014a) this list does not allow an analysis of annual species richness, but it does provide a comprehensive list of species known to occur (or potentially occur) on the base.

*Borell (1938)*

From 1935-1938, Borell (1938) conducted sporadic avian surveys in WHSA, and focused primarily on the marsh habitats of the park. At the conclusion of the surveys, 84 migratory species were documented (Appendix D); 61% of all observed species in the study were migratory.

*Meyer and Griffin (2011)*

Meyer and Griffin (2011) surveyed the low elevation riparian bird communities of the park during both the migration and breeding seasons. The study areas in the park were located near Andrecito Creek and WHSA Headquarters/Visitor Center, and surveys were conducted from 2004-2005. Total species richness for the study was 81 species, of which 37 species were migratory (46%, Figure 21. Sixty-three species were observed at the Andrecito Creek transect, with 28 of those species being migratory (44%). Fifty-five species were observed in the WHSA Headquarters/Visitor Center study area, with 26 of those species being migratory (47%).

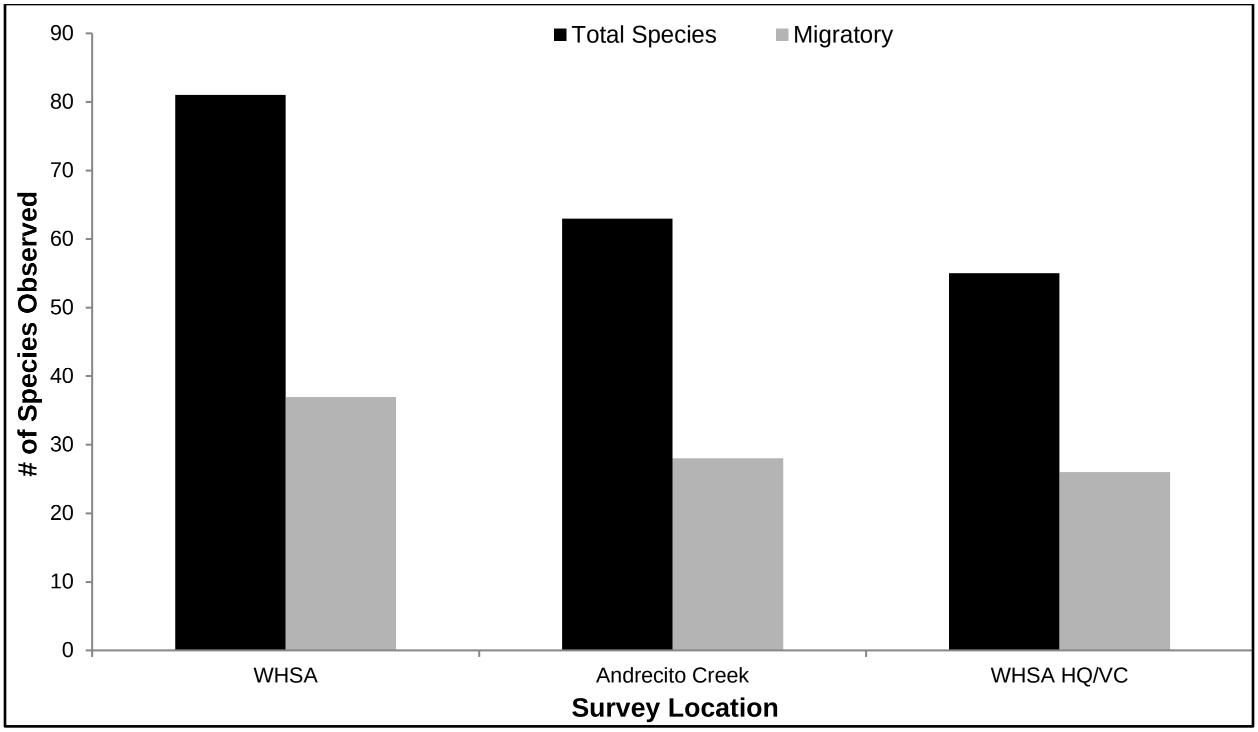


**Figure 21.** Species richness values observed in WHSA during the Meyer and Griffin (2011) low elevation riparian avifauna surveys from 2004-2005.

*CHDN Landbird Monitoring*

Beginning in 2010, the CHDN initiated landbird surveys for most of the parks located within the network. Surveys across the network were timed to coincide with the breeding season (typically March-June, in WHSA surveys were in Late-May and June); because of this, these surveys were less likely to observe high numbers of migratory species. In June 2010, White (2011) surveyed two grassland locations within WHSA; additional locations were supposed to be surveyed, but the researchers did not have access to the zone of co-operative use. Fourteen species were observed at the two survey locations, and only one (7%) of the observed species was a migratory species (Brewer's sparrow).

Landbird monitoring efforts in WHSA resumed in 2011, as White and Valentine-Darby (2012) expanded the White (2011) survey area. There were 111 point count locations on 10 grids that were surveyed in WHSA from 19-21 May, 2011. Fifty-one species were observed during the surveys, and 11 (20%) of the observed species were migratory (White and Valentine-Darby 2012).

In 2012, White and Valentine-Darby (2013) conducted 118 point counts on 10 grids from 27 May – 8 June. Thirty-three species were observed on the surveys, and five (15%) of the observed species were migratory species.

White and Valentine-Darby (2014) conducted 105 point counts on 10 grids in May 2013. Thirty-seven species were observed during the survey, and 10 (27%) of the observed species were migratory species (the highest percentage of migratory species observed in the 4 years of the surveys).

Ali and Valentine-Darby (2014) conducted 160 point counts on 10 grids in May 2014. Fifty-three species were observed during the survey, with 18 species representing migratory species (Figure 23). This year's survey marked the highest number of total and migratory species observed in the park during the 5-year effort, although the number of point counts in 2014 increased to 160 which is more than 50 counts more than the previous year. One new species to the park, the northern cardinal (*Cardinalis cardinalis*), was also observed. A comparison of migratory species richness in the park from 2010-2014 is presented in Figure 22.

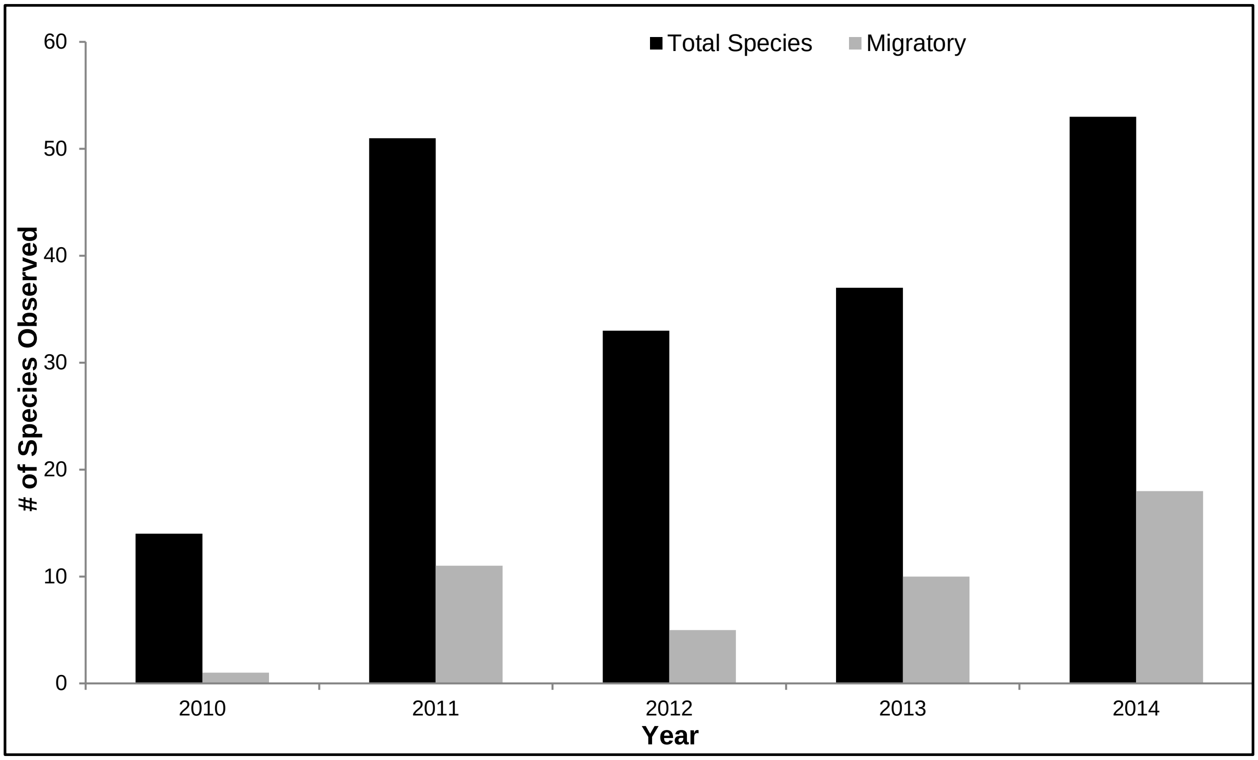


**Figure 22.** Species richness values observed during the White (2011), White and Valentine-Darby (2012, 2013, 2014), and Ali and Valentine-Darby (2014) landbird surveys in WHSA.

Species Diversity

Migratory 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.

While no study in WHSA has analyzed species diversity, Meyer and Griffin (2011) documented both species richness and species abundance. With these data, SMUMN was able to estimate migratory bird species diversity using H'; these results are estimates only, and they should be interpreted with care, as they look only at the diversity of the migratory bird community, and not the bird community of the park as a whole (i.e., estimates only include migratory species, resident and breeding species are omitted).

*Meyer and Griffin (2011)*

H' estimates were created for the Andrecito Creek study site and the WHSA Headquarters/Visitor Center study site for the breeding season, fall migration, and spring migration periods. The data were also pooled at each site to create an H' value for the duration of the surveys (Table 18). The WHSA Headquarters/Visitor Center site had the highest H' of the two sites during all survey periods (Table 18).

**Table 18.** Shannon-Wiener species diversity index estimates (H') for the two study sites used in Meyer and Griffin (2011).

| Season | Andrecito Creek H' value | WHSA HW/VC H' value |
|---|---|---|
| Breeding | n/a* | n/a* |
| Fall | 1.06 | 1.29 |
| Spring | 0.61 | 1.06 |
| Duration | 0.61 | 1.33 |

* indicates low sample size

Trends in Species of Conservation Concern

Several species of conservation concern lists exist in the literature. In addition to the federally and state-listed species that occur in WHSA, the following lists were used in this assessment:

- USFWS Birds of Conservation Concern (BCC) for Bird Conservation Region (BCR) 35 (USFWS 2008)
- Partners in Flight (PIF) North American Landbird Conservation Plan (Rich et al. 2004)
- Saving our Shared Birds: PIF Tri-National Vision for Landbird Conservation (Berlanga et al. 2010)
- Species of Greatest Conservation Need, as identified in the New Mexico Comprehensive Wildlife Conservation Strategy (NM CWCS) (NMDGF 2006)

Reiser (2012) compiled all of the bird species with special conservation designations in the CHDN (Appendix E). In WHSA, there were 66 species with one or more conservation designations; 33 of these species were migratory species. It should be noted that three of the migratory species identified in Appendix E are no longer listed as ‘confirmed’ in WHSA by NPS (2014a) (brown pelican [*Pelecanus occidentalis*], short-eared owl [*Asio flammeus*], and Wilson’s warbler [*Cardellina pusilla*]), this is likely due to an update in the Certified Species List since Reiser’s (2012) completion.

Meyer and Griffin (2011) recorded eight migratory species of conservation concern during lowland riparian surveys in the park from 2004-2005; six species were observed at the WHSA Headquarters/Visitor Center survey site, while all eight species were observed at the Andrecito Creek location. No migratory species of conservation concern were observed during summer (breeding) surveys. While determining trends from only 2 years of data is not advisable, Figure 23 and Figure 24 present the annual abundance of these species for the duration of the study.

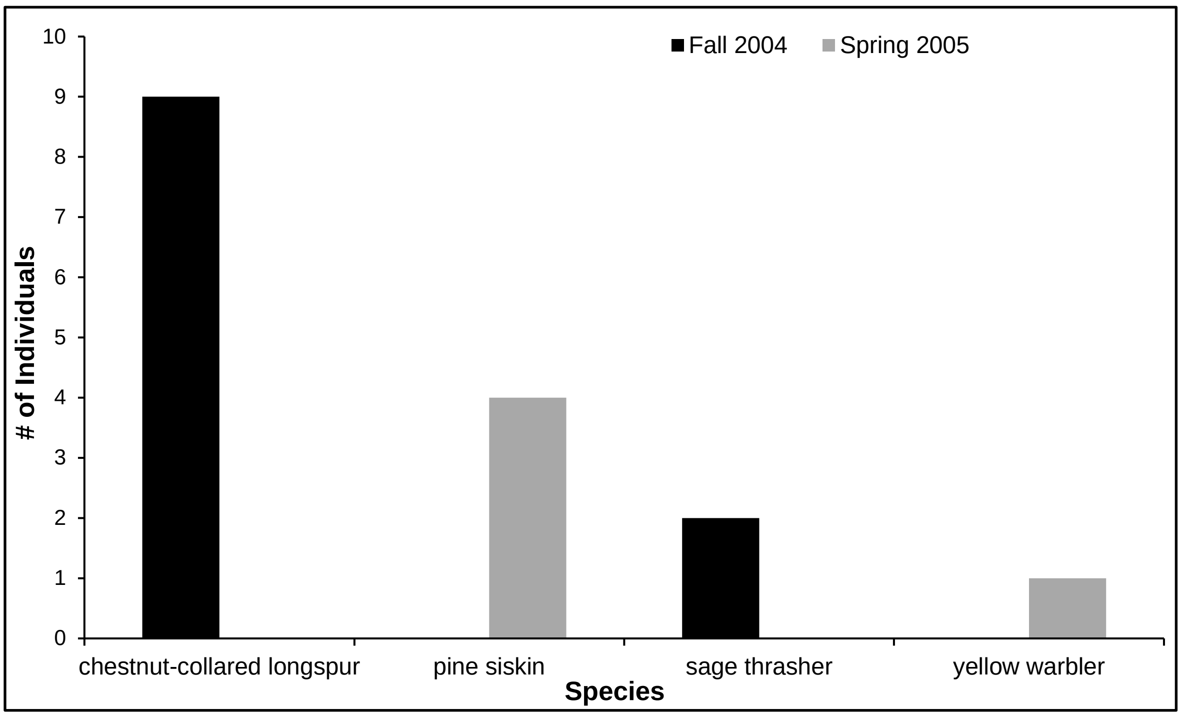


**Figure 23.** Abundance data for migratory species of conservation concern observed in WHSA during the fall-2004 and spring-2005 bird surveys conducted by Meyer and Griffin (2011). Species included in this figure are those that had fewer than 10 individuals observed in a season.

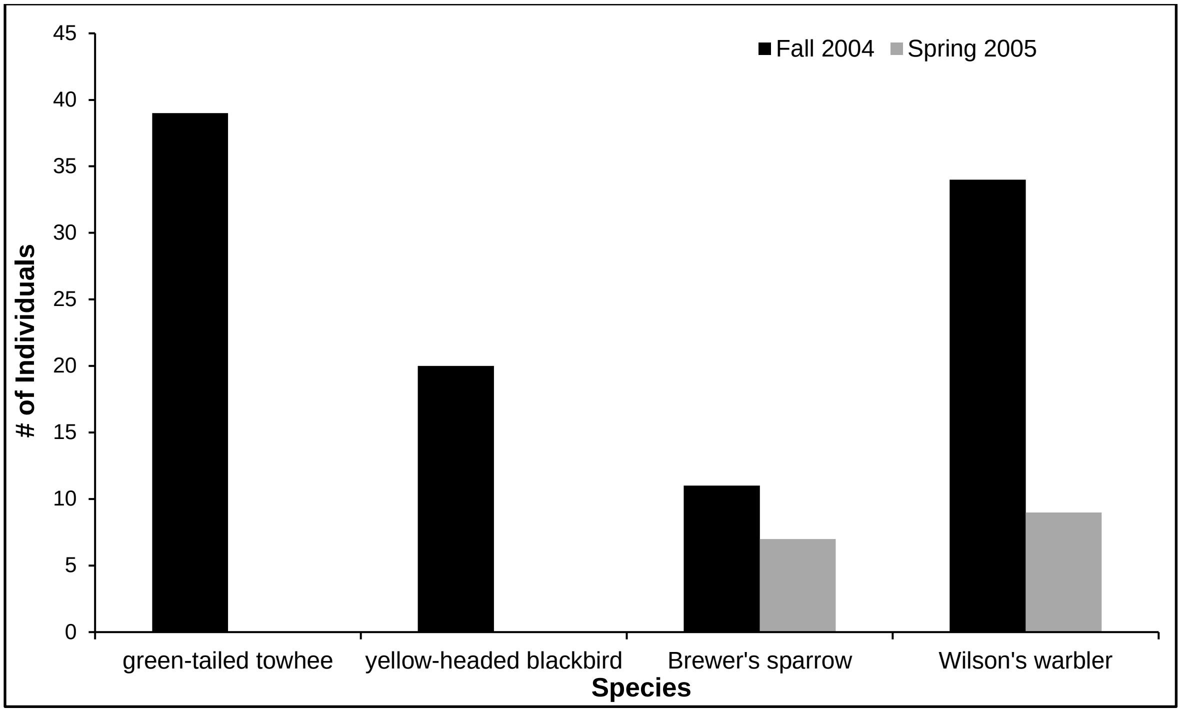


**Figure 24.** Abundance data for migratory species of conservation concern observed in WHSA during the fall-2004 and spring-2005 bird surveys conducted by Meyer and Griffin (2011). Species included in this figure are those that had at least one season where more than 10 individuals were observed.

During the 2010-2014 CHDN landbird monitoring in WHSA, six migratory species of concern were observed, with the Brewer’s sparrow being the most abundant of these species. The surveys were conducted during the breeding season for most species, so it is not unusual that so few migratory species were observed (White 2011, White and Valentine-Darby 2012, 2013, 2014, and Ali and Valentine-Darby 2014). Figure 25 presents the annual abundance of the observed species from 2010-2014.

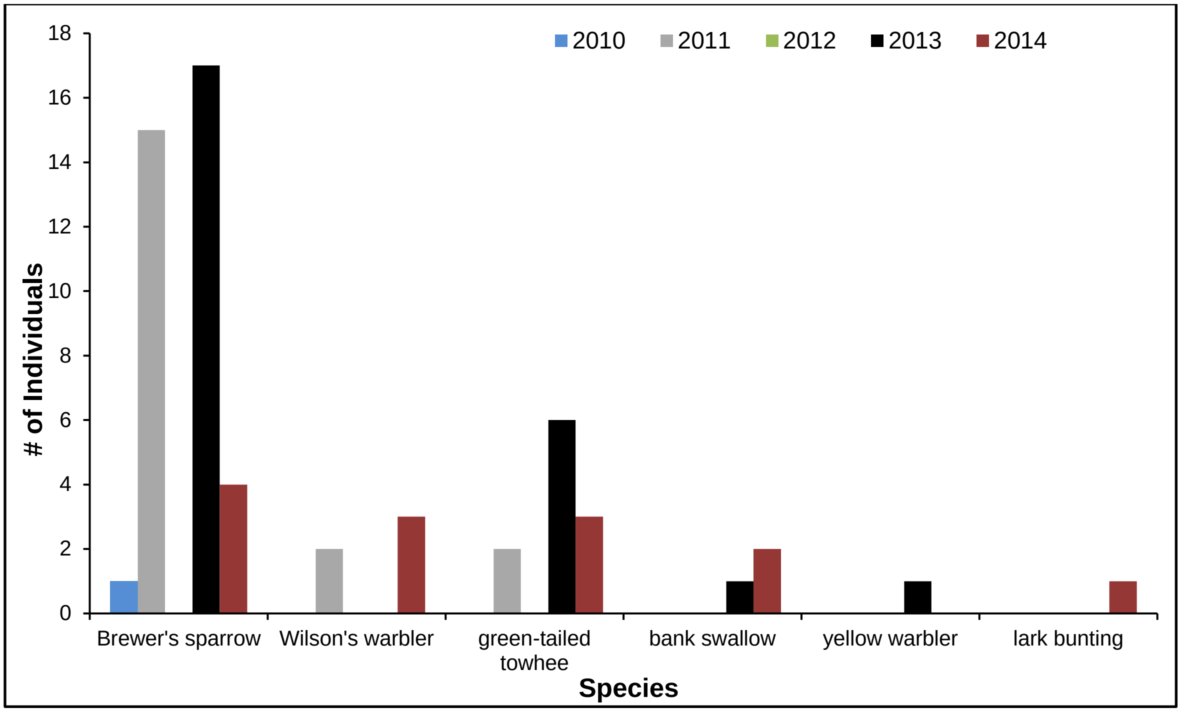


**Figure 25.** Abundance data for migratory species of conservation concern observed in WHSA during the CHDN landbird monitoring surveys from 2010-2014; no species were observed in 2012 (White 2011, White and Valentine-Darby 2012, 2013, 2014, Ali and Valentine-Darby 2014).

While there have been relatively few studies that focused on the migratory species of the park, there is strong evidence that migratory species have experienced significant population declines in the last 50 years (Robbins et al. 1989, Butcher and Niven 2007, ABC 2009). Butcher and Niven (2007) synthesized Breeding Bird Survey (BBS) and CBC data and determined that 127 Neotropical migratory species were declining. The Brewer's sparrow and Wilson's warbler, two species observed during both the CHDN monitoring and Meyer and Griffin (2011) surveys, have experienced estimated population declines in the last 40 years of 47% and 45%, respectively. Long-term monitoring of the migratory bird population in the park may provide valuable insight into the health of the park's bird community, and may also help to provide vital information regarding the population trends for several species of concern.

<u>Cottonwood Stand Abundance</u>

WHSA is home to several isolated stands of cottonwoods (*Populus deltoides*). These stands serve as vital bird habitat for both the breeding and migratory species in the park, and they likely represent an important stopover habitat for long-distance migrants. Reduction in available stopover habitat along migratory routes has been proposed as a potential cause of population decline in some migratory species (Moore et al. 1995, Swanson et al. 2003).

White and Valentine-Darby (2012, 2014) and Ali and Valentine-Darby (2014) conducted walking surveys of the cottonwood stand near the WHSA Visitor Center and noted that this area attracted a large population of birds. While most of the park had low numbers of observed birds, the cottonwood stands tend to attract higher numbers of migratory and riparian species than the rest of the park

(White and Valentine-Darby 2014). The recent monitoring of these cottonwood stands has resulted in the addition of two new migratory species to the park's species list: the Tennessee warbler (*Oreothlypis peregrina*) and Steller's jay (*Cyanocitta stelleri*). Additional monitoring of this community in WHSA is needed in order to assess the current condition of this measure.

Threats and Stressor Factors

One of the major threats to bird species in the park, particularly the grassland species, is grassland degradation. Species that depend on the Chihuahuan Desert grasslands (including the grasslands of Mexico) are likely to be greatly affected by changes in grassland composition. Over 97% of the native grasslands in the United States have been lost, primarily due to land conversion to agricultural fields (NABCI 2011).

In the Chihuahuan Desert alone, more than one million acres of grasslands were converted to agricultural lands in the last five years (NABCI 2009). Drought conditions, desertification, and overgrazing of ranch lands all contributed 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 (NABCI 2010); the loss of a continuous grassland habitat across the park and the Chihuahuan Desert could greatly influence the population size of migratory grassland bird species in the park.

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

Recent efforts to develop alternative energy sources have resulted in more wind farm development across the planet (de Lucas et al. 2008). Collisions with wind turbines are likely more frequent among raptors and Neotropical migrants. However, the exact effects that these wind farms have on birds are still poorly understood. Some studies have found that wind farms are responsible for no more mortalities than other human-made structures (e.g., buildings, communication towers) (Osborn et al. 2000), while other studies have found that turbines are responsible for unusually high numbers of bird mortalities (Smallwood and Thelander 2007).

A more understood threat to bird species is collisions with human-made structures. Bird collisions with buildings, power lines, communication towers, and windows may result in between 97-976 million bird deaths across the globe (USFWS 2002). While there are relatively few buildings and towers in the immediate WHSA area, birds that migrate to/from the park may encounter such obstacles during migration periods. Collisions with structures and vehicles in the Holloman Air Force Base are also possible.

Another threat facing land bird populations is shifts in the reproductive phenology of land birds, which is primarily driven by climate change. Several bird species depend on temperature ranges or weather cycles to cue their movement patterns (typically due to breeding requirements). As global temperatures change, some bird species have adjusted by moving their home ranges north (Hitch and Leberg 2007). Other species have adjusted their migratory period and have begun returning to their breeding grounds earlier in the spring (Bradley et al. 1999, Inouye et al. 2000, Lane and Pearman 2003, Butler 2003, Murphy-Klassen et al. 2005). For example, American robins (*Turdus migratorius*) in the Colorado Rocky Mountains are now migrating to their breeding grounds 14 days earlier compared to 1981 (NABCI 2009). A concern is that this shift in migration may be out of sync with food availability and could ultimately lead to lowered reproductive success.

The North American Bird Phenology Program (BPP) is analyzing the migration patterns and distribution of migratory bird species across North America (USGS 2008). Information from this analysis will provide new insights into how bird distribution, migration timing, and migratory flyways have changed since the later part of the 19$^{th}$ century. This information may also be applied to estimate changes in breeding initiation periods in specific habitats.

The presence of water in Lake Lucero and the playas in WHSA provides habitat for many migratory species in WHSA, especially shorebird and waterfowl species; however, the availability of this habitat fluctuates widely, as the lake level depends on the precipitation in the Tularosa Basin. Situated in a low depression in the basin, Lake Lucero is dry most of the year and only contains water after sustained rain events. The lake has no river outlet, so water will remain in Lake Lucero until it has evaporated. Shifts in precipitation in the area could result in sustained periods where the lake is dry, thus leaving shorebird species without a critical habitat during the migratory period.

<u>Data Needs/Gaps</u>

Continued monitoring of the park's bird population is needed to establish baseline values for species richness and to estimate species diversity. Because trend analysis is not recommended for brief surveys, long-term bird surveys are vital to understanding the health of the bird community. While the CHDN monitoring of WHSA is a vital source of bird information, the timing of the survey does not allow for an accurate assessment of condition for migratory species in the park. An additional survey(s) during the key spring and fall migration periods (similar to the Meyer and Griffin 2011 study periods) would provide important information regarding the migratory species that pass through and overwinter in the park.

Populations of migratory species of conservation concern are monitored by various agencies on a global scale. However, monitoring of these species' abundance in the park would help managers to understand how many species and individuals are present in the park, and would also provide approximate estimates of what seasons the species are present in WHSA. The cottonwood stands of WHSA likely represent a vital bird habitat for both migratory and resident species. Monitoring the health of the bird populations in these areas would provide managers with insights into the health of many bird communities, and the overall health of the cottonwood stands.

Overall Condition

*Species Richness*

The species richness measure was assigned a *Significance Level* of 3 during project scoping. Borell (1938) was the park's earliest survey effort, and resulted in 88 migratory species being observed in the area. There have only been a few studies in WHSA that have documented species richness, namely Meyer and Griffin (2011) and the CHDN landbird monitoring (White 2011, White and Valentine-Darby 2012, 2013, 2014, and Ali and Valentine-Darby 2014). The 2004-2005 surveys of Meyer and Griffin (2011) resulted in 37 migratory species being observed. The CHDN landbird monitoring of the park took place during the breeding season and missed most of the migratory species that frequent the park; migratory species richness values never exceeded 20 species during survey efforts.

While survey efforts have increased in recent years, there have not been enough surveys during the migratory periods to accurately assess the current condition of migratory bird species richness. Because of this, a *Condition Level* was not assigned to this measure.

*Species Diversity*

WHSA staff assigned a *Significance Level* of 3 to the species diversity measure. There have been no studies that reported the species diversity of the migratory birds in WHSA. A summary document of the CHDN landbird monitoring will be completed in 2014-15 that will document species diversity of the most abundant species in the park. However, the timing of these surveys does not coincide with the presence of most migratory species at the park. Due to the lack of data for this measure, a *Condition Level* was not assigned.

*Trends in Species of Conservation Concern*

The trends in species of conservation concern measure was assigned a *Significance Level* of 3 during project scoping. Reiser (2012) documented the species of conservation concern that occurred in the park using several conservation concern lists. No annual monitoring, outside of the CHDN landbird monitoring, occurred for migratory species of concern. Without data collected within WHSA, a *Condition Level* cannot be assigned to this measure. Many of these species are experiencing habitat loss and degradation along their migratory routes and overwintering areas, and monitoring their presence in WHSA during the migratory season will provide managers with a better understanding of the health of the WHSA bird habitat, as well as the habitat that these species frequent throughout their migration.

*Cottonwood Stand Abundance*

Cottonwood stand bird abundance was assigned a *Significance Level* of 3. The cottonwood community of the park likely represents a critical stopover point for migratory species, and a great deal of avifaunal diversity can be found in these stands during the migratory period. While White and Valentine-Darby (2012, 2014) and Ali and Valentine-Darby (2014) have begun searches of this area, a point count or plot area has not yet been established. Additionally, a park-wide inventory of bird abundance and distribution in cottonwood stands is needed in order to accurately assess the current condition of this measure. Because of this, a *Condition Level* was not was assigned to this measure.

*Weighted Condition Score*

The migratory birds component was not assigned a *Weighted Condition Score* due to a lack of data for the specified measures. The current condition and trend for this resource is considered unknown.

| Migratory Birds | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = N/A** |
| Species Richness | 3 | n/a | |
| Species Diversity | 3 | n/a | |
| Trends in Species of Conservation Concern | 3 | n/a | |
| Cottonwood Stand Abundance | 3 | n/a | |

#### *4.3.6. Sources of Expertise*

- David Bustos, Resource Program Manager, WHSA
- Hildy Reiser, Science Advisor, CHDN (Retired)

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## 4.4. Breeding Birds

### *4.4.1 Description*

The unique ecosystems and physical formations in WHSA provide over 60 breeding and resident bird species with a variety of habitat types, nesting locations, and food sources (Appendix F). Much like migratory bird communities, breeding bird species can act as indicators of an ecosystem's overall health (Morrison 1986, Hutto 1998, NABCI 2009). While some of the species in the park migrate to and from the park for the breeding season, several breeding species, such as the pyrrhuloxia (*Cardinalis sinuatus*; Photo 15), reside in WHSA year-round. Unlike migratory birds, trends in resident breeding bird species' populations are likely due to changes occurring in their immediate habitat or ecosystem, and (in theory) it is possible to study all of their population processes directly throughout the year (Koskimies 1989).

**Photo 15.** A pyrrhuloxia in a stand of dense brush in WHSA. (Photo copyright Sandra Noll, 2010.)

WHSA is also home to several breeding and resident species of conservation concern. Species such as the Bell's vireo (*Vireo bellii*), peregrine falcon (*Falco peregrinus*), and gray vireo (*Vireo vicinior*) are listed as threatened by the State of New Mexico. Several additional species, such as the black-chinned sparrow (*Spizella atrogularis*) and burrowing owl (*Athene cunicularia*), are identified as priority species by various agencies (Appendix G).

### 4.4.2. Measures

- Species Richness
- Species Diversity
- Species Density

### 4.4.3. Reference Conditions/Values

The reference condition for this component was defined as the period of time before ranching and Anglo settlement (approximately the 1850s). While data may not exist for this time period, current condition can likely be assessed using best professional judgment, and by analyzing recent trends in species richness, diversity, and density. The results of this assessment may be used as a baseline for comparison for future condition assessments for the breeding bird community.

### 4.4.4. Data and Methods

This component focuses exclusively on the breeding bird species of the park, and does not discuss any migratory or vagrant bird species (these species are discussed in Chapter 4.5 of this document). A species was classified as breeding based on the NPS Certified Bird Species List (NPS 2014, Appendix F). Species in NPS (2014) that had residency designations of "Breeding" and "Resident" were included in this component's discussion and analysis. Species that were identified as "Migratory" and "Vagrant" are discussed in Chapter 4.3 of this document. In instances where NPS (2014) did not assign residency, the Cornell University Lab of Ornithology's All About Birds online database (http://www.allaboutbirds.org) was used to approximate a species' residency as either breeding, migratory, resident, or vagrant.

Borell (1938) conducted sporadic surveys in WHSA and the adjacent marsh habitats (in an area that would later be added to WHSA's boundaries) from 1935-1938. Observations occurred in portions of every month except for August. Survey efforts resulted in an annotated list of species observed and collected during the 3 years of research.

Meyer and Griffin (2011) surveyed the low elevation riparian avifauna of CHDN parks from 2004-2006. The objectives of this study were to:

- Apply survey methodologies in spring, summer, and fall seasons in riparian habitat study sites to document species presence, species richness, and relative abundances.
- Relate the project findings to existing information on the avifauna at each of the sampling areas and update species lists.
- Provide the baseline data and site evaluations necessary for the development of monitoring programs in the CHDN (Meyer and Griffin 2011, p. 1).

Researchers surveyed two areas in the park (Andrecito Creek, WHSA Headquarters) and utilized both point count transects (Andrecito Creek) and timed area searches (WHSA Headquarters) (Meyer and Griffin 2011). Surveys were conducted during the breeding (5-15 June) and fall migration (10 September -20 October) periods in 2004, and during the spring migration (10-20 May), breeding season (5-15 June), and fall migration (10-25 September) in 2005. Complete methodology is described in Meyer and Griffin (2011).

As part of a network-wide landbird monitoring project, the RMBO, in partnership with the CHDN, began monitoring birds in WHSA in the spring of 2010. The overall objective of the project was to detect potential changes in population parameters over time (White 2011, White and Valentine-Darby 2012, 2013, 2014, Ali and Valentine-Darby 2014).

### *4.4.5. Current Condition and Trend*

Species Richness

The species richness measure allows simultaneous assessment of abundance or presence for the entire breeding bird community. This measure can also indicate overall habitat suitability for breeding birds, and is vital to understand the effects of changing landscapes on native biodiversity. Species richness is assessed here as the total number of breeding species observed during a given year/survey period.

*NPS Certified Species List (NPS 2014)*

The NPS Certified Bird Species List contains 156 species, 63 (40%) of which are breeding bird species (Appendix F). This list, however, did not allow for a specific analysis of annual species richness, as no data were collected other than the presence (or historic presence) of the identified species. The species included on this list are the representative species that have been identified by the survey efforts described below.

*Holloman Air Force Base Species Checklist (MVAS 1996)*

Similar to the NPS Certified Bird Species List (NPS 2014), the nearby Holloman Air Force Base has a checklist of bird species (MVAS 1996) that identifies 226 species, 79 (35%) of which are breeding bird species (Appendix F). While this list does not allow an analysis of species richness, it does provide a comprehensive list of species known to occur (or potentially occur) on and near the base.

*Borell (1938)*

Borell (1938) conducted avian surveys in WHSA from 1935-1938. While these surveys were sporadic in nature and focused exclusively on the marsh habitats of the park, 137 species were observed in the park, 53 (39%) of which were breeding bird species (Appendix F).

*Meyer and Griffin (2011)*

Meyer and Griffin (2011) surveyed WHSA during both the breeding and migratory periods from 2004-2005. The surveys focused on the low elevation riparian habitats of the park, and had two survey locations: Andrecito Creek, and the area near the WHSA Headquarters and Visitor Center. Total species richness during the study was 81 species, of which 42 (52%) were breeding species (Figure 26). The Andrecito Creek transect had the highest species richness value during the study, with 63 species being observed (35 species [56%] were breeding bird species). Fifty-five species were observed at the WHSA Headquarters/Visitor study site, with 29 (53%) of those species being breeding (Figure 26).

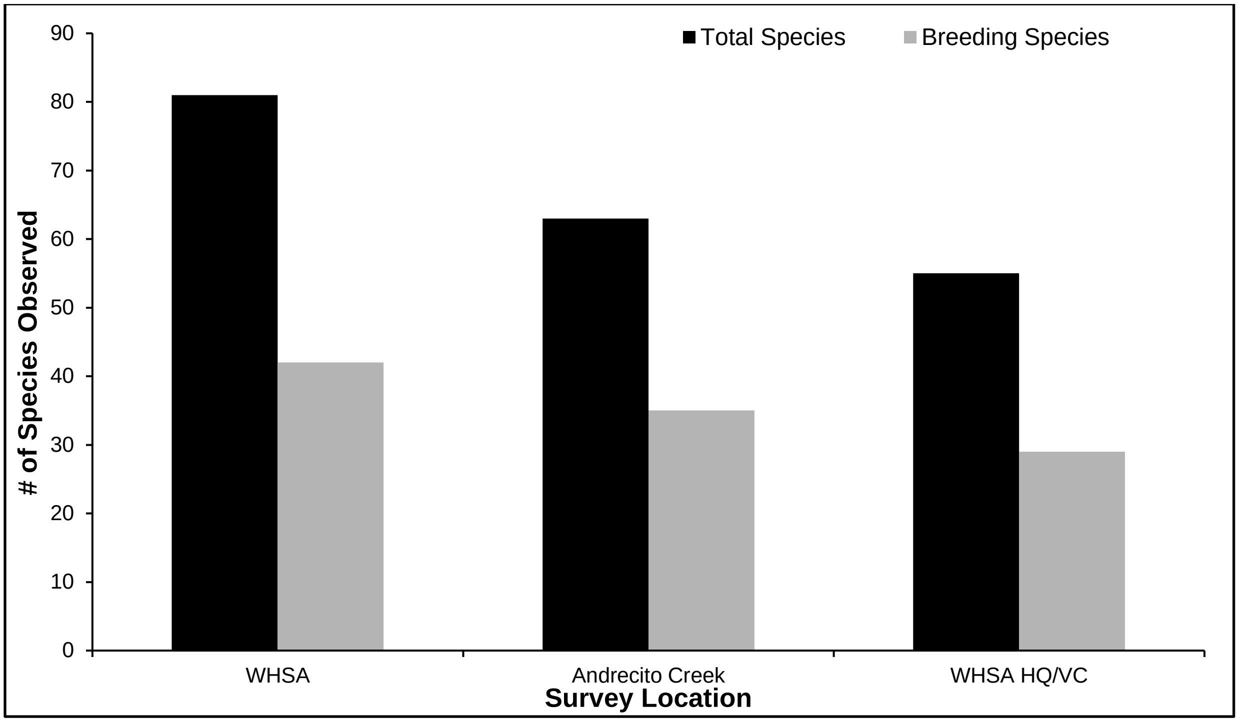


**Figure 26.** Species richness values observed in WHSA during the Meyer and Griffin (2011) low elevation riparian avifauna surveys from 2004-2005.

*CHDN Landbird Monitoring*

In the pilot year (2010) of the landbird monitoring in the CHDN, White (2011) surveyed two grassland locations within WHSA. Originally, additional survey locations in the Zone of Co-operative Use were to be surveyed; however, researchers did not have access to this area during the survey period and these areas were not covered in 2010. Fourteen species were observed in the two survey locations in 2010 and 13 of those species (93%) were breeding species (Figure 27). The timing of the CHDN landbird monitoring is favorable for observing breeding species, and a majority of the species observed during all 4 years were breeding species.

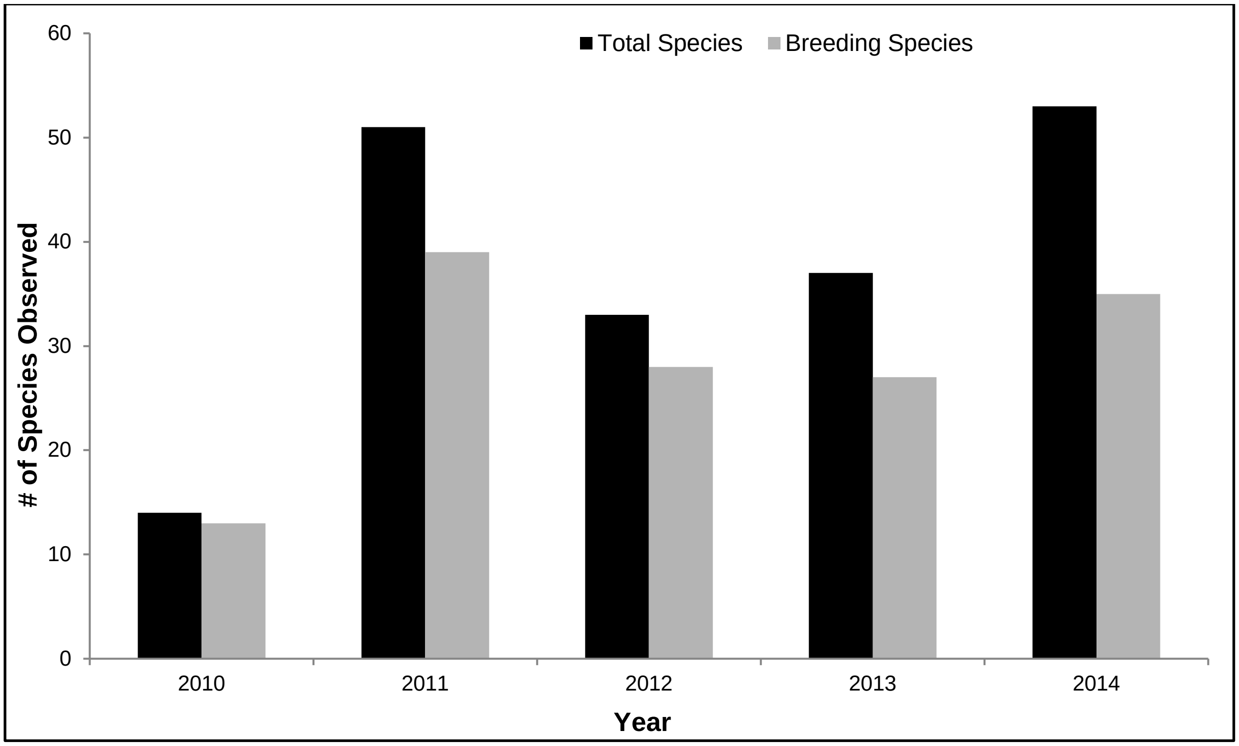


**Figure 27.** Species richness values observed during the White (2011), White and Valentine-Darby (2012, 2013, 2014), and Ali and Valentine-Darby (2014) landbird surveys in WHSA.

White and Valentine-Darby (2012) expanded the White (2011) survey area and included 111 point count locations on 10 grids. The surveys lasted from 19-21 May 2011. Fifty-one species were observed during the surveys, and 39 (76%) of the species observed were breeding species.

In 2012, White and Valentine-Darby (2013) conducted 118 point counts on 10 grids from 27 May – 8 June. Thirty-three species were observed on the surveys, and 28 (85%) of the observed species were breeding species.

White and Valentine-Darby (2014) conducted 105 point counts on 10 grids in May 2013. Thirty-seven species were observed during the survey, and 27 (73%) of the observed species were breeding bird species. Ali and Valentine-Darby (2014) resumed the survey effort in May 2014, and conducted 160 point counts on 10 grids. Fifty-three species were observed during the survey, with 35 of those species representing breeding bird species. The total number of species observed was the highest of all surveys to date, although the elevated number of species may be in part due to the higher number of point counts in 2014 (160 counts).

Species 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.

While no study in WHSA has analyzed species diversity, a few studies have documented both species richness and species abundance. With these data, SMUMN GSS was able to estimate breeding bird species diversity using H'; these results are estimates only, and they should be interpreted with care, as they look only at the diversity of the breeding bird community, and not the bird community of the park as a whole.

*Meyer and Griffin (2011)*

H' estimates were created for the Andrecito Creek study site and the WHSA Headquarters/Visitor Center study site for the breeding season, fall migration, and spring migration periods. The data were also pooled at each site to create an H' value for the duration of the surveys (Table 19). The Andrecito Creek site had the highest H' of the two sites during all survey periods (Table 19).

**Table 19.** Shannon-Wiener species diversity index estimates (H’) for the two study sites used in Meyer and Griffin (2011).

| Season | Andrecito Creek H’ value | WHSA HW/VC H’ value |
|---|---|---|
| Breeding | 2.407 | 1.56 |
| Fall | 1.801 | 1.28 |
| Spring | 1.947 | 1.06 |
| Duration | 2.346 | 1.32 |

*CHDN Landbird Monitoring*

Unlike Meyer and Griffin (2011), the CHDN monitoring has occurred annually and is timed to coordinate with the breeding season in the park. H' values were created for each survey year from 2010-2014. All values have been ≥2.00, with 2011 and 2012 having the highest values (2.52; Table 20).

**Table 20.** Shannon-Wiener species diversity index estimates (H’) for the CHDN landbird monitoring in WHSA from 2010-2013.

| Index | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| H' Value | 2.00 | 2.52 | 2.52 | 2.19 | 2.49 |

Species Density

No bird survey that has been completed at the park has reported on the species density measure. The CHDN landbird monitoring project synthesis and trend report (scheduled to be completed in 2016) will summarize species density for the most abundant species in the larger parks in the network, but it is not certain that WHSA will be included.

Threats and Stressor Factors

Many of the threats that face breeding birds at the park mirror the threats that face the migratory bird community of WHSA. During scoping, the identified threats and stressors for the breeding bird community were land cover change/habitat fragmentation, energy development, climate change, and the presence of surface water. These threats and stressors have been discussed in detail in Chapter 4.3 of this document.

Data Needs/Gaps

Continued monitoring of the breeding bird community, particularly the work of White (2011), White and Valentine-Darby (2012, 2013, 2014), and Ali and Valentine-Darby (2014) is necessary for park managers to establish baseline values for the identified measures in this component. Continuation of these surveys will also allow for trend analysis after 5-10 years of data collection. A survey dedicated to reporting the density and diversity of the breeding community would also be beneficial to park managers.

While not an identified measure in this assessment, monitoring of the trends in breeding species of conservation concern is needed. As climate change, habitat fragmentation, and energy development efforts threaten bird communities, it will be important to identify potential trends in these indicator species.

Overall Condition

*Species Richness*

The species richness measure was assigned a *Significance Level* of 3 during project scoping. The first informal survey of WHSA (Borell 1938) documented 53 breeding bird species. It would be almost 70 years until another survey/inventory documented the breeding bird species richness of the park (Meyer and Griffin 2011). While the NPS Certified Species List identifies 63 breeding species, recent surveys have found, on average, between 25-40 species each year (Meyer and Griffin 2011, White 2011, White and Valentine-Darby 2012, 2013, 2014). There do not appear to be any major concerns regarding species richness fluctuations in recent years, although trends from only a few years of data are not completely distinguishable. Continued monitoring of the species richness at the park is needed, but for the time being the *Condition Level* of this measure was identified as a 1.

*Species Diversity*

WHSA staff assigned a *Significance Level* of 3 to the species diversity measure. There have been no studies that reported the species diversity of the breeding birds in WHSA. SMUMN created species diversity estimates for the Meyer and Griffin (2011) and CHDN surveys. From these estimates, it appears the breeding population of WHSA is moderately diverse (most H' values were near 2.0, indicating moderate species diversity), but these estimates are short-term and do not provide enough data to observe trends at the park. A detailed study on the species diversity of the park is recommended, but the estimates obtained from the existing studies indicate that this measure's current condition is likely of low concern (*Condition Level* = 1).

*Species Density*

Species density was assigned a *Significance Level* of 3 during project scoping. There have been no studies that have reported the species density of breeding birds in WHSA. A summary document of the CHDN land bird monitoring will be completed in 2015 that will document species density for the most abundant species in some of the parks. However, it is not clear if WHSA will have density metrics estimated in this report. Due to the lack of data for this measure, a *Condition Level* was not assigned.

*Weighted Condition Score*

The breeding bird component was assigned a *Weighted Condition Score* of 0.33, which is on the threshold between low concern and moderate concern. A trend arrow was not assigned to this measure, as many of the data have been collected recently and don't lend themselves to long-term trend analysis.

| Breeding Birds | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = 0.33** |
| Species Diversity | 3 | 1 | |
| Species Richness | 3 | 1 | |
| Species Density | 3 | n/a | |

#### *4.4.6. Sources of Expertise*

- David Bustos, Resource Program Manager, WHSA
- Hildy Reiser, Science Advisor, CHDN (Retired)

#### *4.4.7. Literature Cited*


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## 4.5. Reptiles

### *4.5.1. Description*

WHSA is home to many reptile species that utilize the unique habitats found within the park and the greater Tularosa Basin. NPS (2014) identifies 32 species of reptiles that are present or probably present in WHSA, as well as one unconfirmed species, the Big Bend tree lizard (*Urosaurus ornatus*) (NPS 2014). The reptiles found at WHSA are typical of the Chihuahuan Desert ecoregion; this ecosystem provides habitat for the numerous desert reptile species, including one endemic species, the bleached earless lizard (*Holbrookia maculate ruthveni*) (Photo 16).

**Photo 16**. The endemic bleached earless lizard is the subject of study for researchers interested in the mechanisms of speciation, natural selection, and evolution (NPS photo).

There are 14 lizard species of seven genera (*Aspidoscelis, Crotaphytus, Gambelia, Cophosaurus, Holbrookia, Phrynosoma, Sceloporus,* and *Uta*) that are found in the park; the Big Bend tree lizard may also occur in the park, although its presence has not been confirmed (NPS 2014). The *Aspidoscelis* genus was formerly *Cnemidophorus*, and is referred to as such within literature published prior to the change in nomenclature which occurred with Reeder et al. (2002)'s publication on the phylogenetic relationships of whiptail lizards.

The park is also home to 17 snake species, including three venomous species: the western diamond-backed rattlesnake (*Crotalus atrox*), green prairie rattlesnake (*Crotalus viridis*), and the desert massasauga (*Sistrurus catenatus*). Most of the nonvenomous snakes in the park are of the colubrid family, except the Trans-Pecos threadsnake (*Leptotyphlops humilis segregus*, also referred to as the Trans-Pecos blind snake), which is of the leptotyphlopidae family (Photo 17). The leptotyphlops are considered a primitive snake, as they have vestigial hind limbs and a pelvic girdle, a trait that has been lost in the more modern snake species. The Trans-Pecos threadsnake is totally blind, and lives underground in burrows feeding on macro-invertebrates.

**Photo 17.** Trans-Pecos threadsnakes are sightless and live underground in burrows, only vestigial eyes remain (NPS photo).

There are a few lizard species in the park that have developed lighter, or "blanched," coloration that allows them to blend into the white sand of the gypsum dunes (Rosenblum and Harmon 2011, McKeever 2009a). The unique ecological speciation of the little striped whiptail (*Aspidoscelis inornata*), eastern fence lizard (*Sceloporus undulatus*), and the common lesser earless lizard (*Holbrookia maculate*; Figure 28), is discussed in Rosenblum and Harmon (2011). The evolutionary divergence of these species has occurred in a relatively short time period, as the accumulation of the gypsiferous dune fields occurred around 7,000 years ago (Kocurek et al. 2007). This recent and rapid speciation event in WHSA is unique in that it is observable in species that are distantly related, referred to as “replicated ecological speciation,” and share the same environment (Rosenblum and Harmon 2011). The area where observable speciation has occurred has been the topic of study prior to the formation of the park, with the oldest mention being in Ruthven (1907).

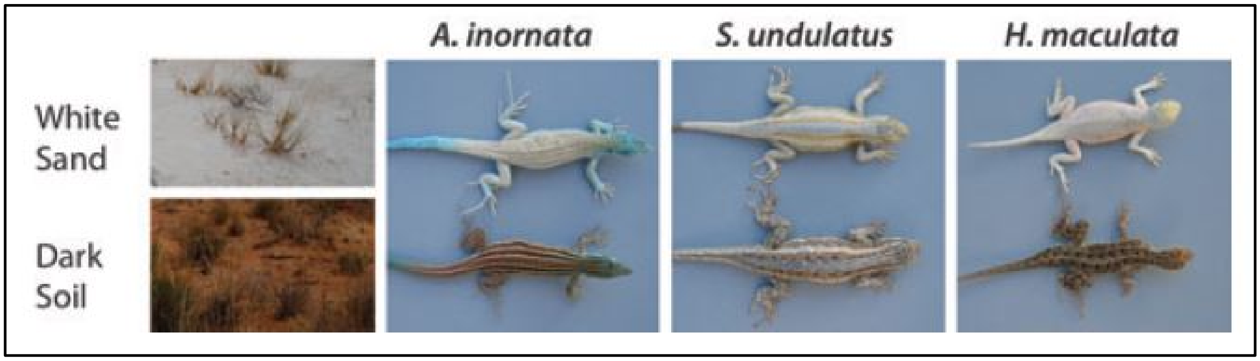


**Figure 28.** Examples of lighter skin coloration in three lizard species that are found at WHSA (Photo from Rosenblum and Harmon 2001).

The Tularosa Basin features three distinct landscapes: the adobe soil of the desert scrublands, the pure white gypsum dunes, and the northerly Carrizozo lava flow. According to Hardwick et al. (2013), each landscape has a locally-adapted eastern fence lizard population with color morphs matching the surrounding substrata. In this setting, two mechanisms of selection are occurring simultaneously, natural and sexual, to drive the rapid speciation (Hardwick et al. 2013). Rosenblum et al. (2009) conducted a genetic analysis of the three lizard species and found that the lighter phenotype is due largely to a single mutation in the melanocortin-1 receptor gene, though there are other genes likely contributing to the lighter coloration in these lizards. Hager (2000) found that the *H. maculata* of lighter color also thermoregulated differently than the brown-colored morphs, and had lower average body temperature.

A similar phenomenon has been observed north of the park, near where the Carrizozo lava flow sits within the greater Tularosa Basin. Lewis (1949) described darker coloration with five reptile species examined at the lava flow site: the common side-blotched lizard (*Uta stansburiana*), eastern fence lizard, eastern collared lizard (*Crotaphytus collaris*), Sonoran gopher snake (*Pituophis catenifer affinis*) and the black-tailed rattlesnake (*Crotalus molossus*). These species all were observed having markedly darker coloration compared to individuals inhabiting the surrounding Chihuahuan desert (Lewis 1949).

#### *4.5.2. Measures*

- Color Phase Species Distribution
- Species Richness
- Species Distribution
- Species Diversity

### *4.5.3. Reference Conditions/Values*

The reference condition for the reptile component is the period of time when ranching became established on the park. Additionally, the time period before the upgrade of State Highway 70 to a paved road also serves as a reference period. State Highway 70 was upgraded to a paved, two-lane highway sometime in the early 1960s and expanded to a four-lane highway sometime in the 1980s (Hildy Reiser, retired CHDN Science Advisor, written communication, 15 July 2014).

### *4.5.4. Data and Methods*

Bugbee (1942) recorded observations of vertebrates and invertebrates during the summer months in WHSA in 1940 and 1941. The study described the occurrence and activity of animals encountered, and also described the surroundings, physical conditions, and animals observed during both daytime and nighttime surveys in 1941. It should be noted that not all reptiles observed in Bugbee (1942) were identified down to the species level.

Lewis (1950) conducted a herpetofauna survey of the Tularosa Basin and Organ Mountains. The herpetofauna collection consisted of 350 specimens that were obtained from 1947-1949. Lewis (1950) also noted the vegetation and terrain, past encounters and specimens found in previous literature, and described the specimen behavior. Lewis (1950) also compiled a list of herpetofauna that were associated with the areas mentioned above.

Lowe and Norris (1956) conducted laboratory experiments on specimens of eastern fence lizards (referred to as 'swifts') and the plains striped whiptail that were of the lighter color morphs collected at the dune field. The living specimens were kept in cages for periods of time that ranged from several months to just over 1 year. The lizards were monitored for any changes in their coloration using two color reference standards: Ridgeway (1912) color standards and nomenclature and the Maerz and Paul (1930) dictionary of color. Lizards were exposed to various temperature extremes, humidity levels, and substrate colors and textures during the study to test for any change in coloration.

From 1963-1965, Dixon (1967) conducted a study on the biology of lizard species in WHSA. The study observed the behavior, reproduction, and habitat of the lizards during the summer months. Sampling also took place, and there were two methods of capture: by hand, and by .22 caliber dust shots. Cloacae body temperatures were collected and compared to ambient air temperatures.

Worthington (1976) conducted a study on the densities of two lizard species at WHSA, the eastern fence lizard and the little striped whiptail. An elongate, rectangular plot area of 3.9 ha (9.6 ac) was delineated with stakes, and within the plot, transects of 5 and 10 m were randomly selected. Lizards within the study plot were collected by noosing in the mornings and afternoons of May 27-30, 1976. Each lizard was marked with water-based acrylic paint and toe clipping. Capture positions and sightings were recorded for marked and unmarked lizards on a map of the plot area.

Hager (2000) conducted a study to determine the influence of the thermal environment on the *H. maculata* lizards at two thermally divergent locations, the dune fields at WHSA and an adjacent, analogous area where gypsum dunes are absent. The data collection occurred 2 days per week from

April through August over the course of 3 years (1995-1997). Lizards were caught by noosing, and cloacal temperature, snout-vent length, snout-tail length, and body mass (10 g Pesola spring scale) were measured for each individual. Additional data collected at the time of capture were air temperature and soil temperature in the precise location of each lizard, along with the assigned microhabitat category. Categories of microhabitat included: open, open-hummock, edge, under, perched, and arboreal (see Hager [2000] for an in-depth discussion on the categorization of microhabitat).

Mckeever (2009a) surveyed the park for herpetofauna during parts of 6 months between May and October of 2009. Objectives of the survey were to reaffirm presence of herptiles that had been previously observed on the park, compare relative abundances to data from March 1971 through November 1977, and provide baseline herpetofauna data for future herpetofauna research and surveys (McKeever 2009a). Survey methods included quantitative road cruising (QRC) where the observer recorded species, date and time, location, and whether the animal was alive or dead; in addition, the lengths of snakes were visually estimated, young (of all herptiles encountered) of the current year were identified, and the rattles of rattlesnakes were described along with the number of dark tail rings, when possible, were also noted for *C. atrox* encountered on RR-7 (McKeever 2009a). Random foot searches (RFS) were also conducted adjacent to roads that were included in the QRCs; roads are shown in Figure 29. Observations that occurred outside of the QRCs and RFSs were recorded as 'incidental'; observations by others were included only if there were confirmed by the author, a photograph, or if the observer had confirmed knowledge of the species reported (McKeever 2009a). The locations of each observation were recorded with a global positioning system (GPS) unit (Garmin eTrex vista C). Detailed weather observations were made at the beginning of each survey effort, and attempts to collect digital photographs of each species was made.

Rosenblum et al. (2004) conducted a study to investigate the role of the melanocortin-1 receptor gene (Mc1r) in reptiles with locally adapted populations that have developed coloration matched to substrata in their environments, specifically the lighter dune field inhabitants found at WHSA. The study focused on three taxa, eastern fence lizards, earless lizards, and the little stripe whiptail. Genomic DNA was extracted in a laboratory from frozen tissue or blood from several taxa, followed by amplification of the portion containing the Mc1r gene for this study.

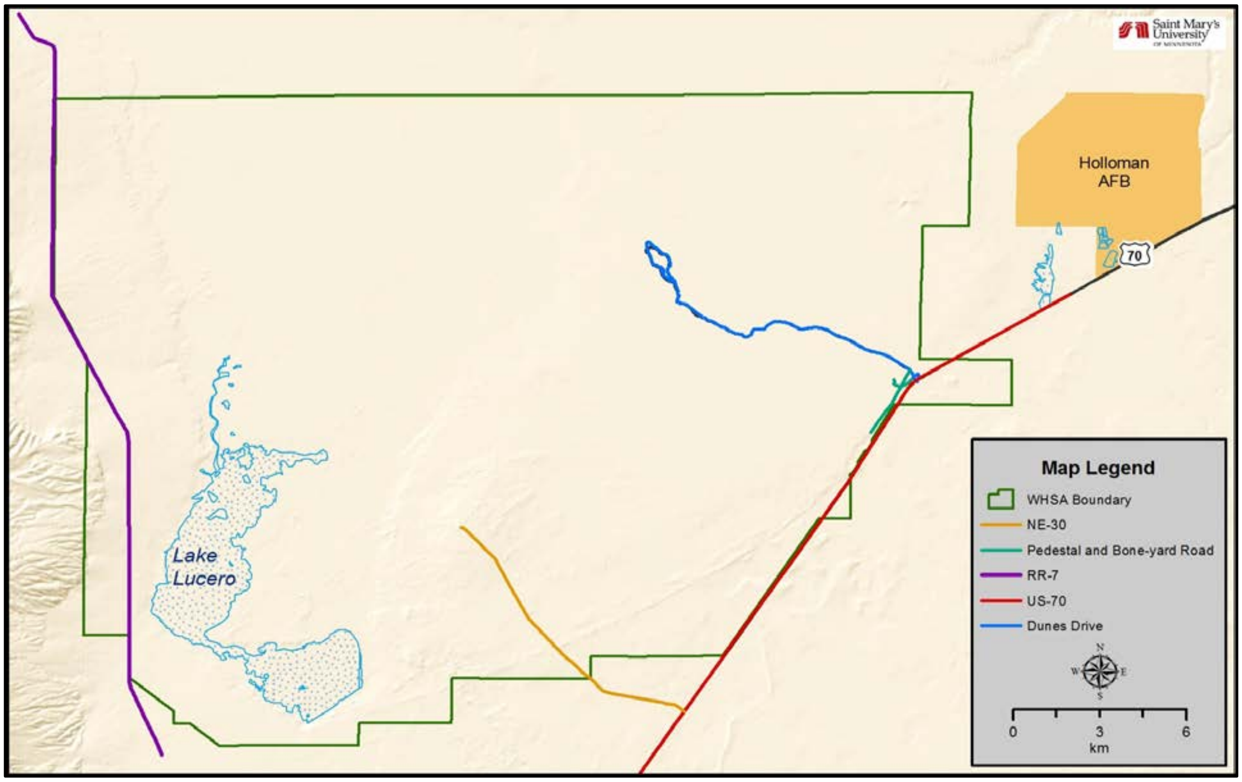


**Figure 29.** The QRC routes used in the 2009 herpetological surveys by McKeever (2009a).

Rosenblum (2005) investigated three lizard species, the eastern fence lizard, the little striped whiptail, and the common lesser earless lizard that inhabit the dune field at WHSA, as well as the Carrizozo lava flow. The lizard species all had variation in body color, in that the body color typically matched the substrate; the study evaluated the role of phenotypic plasticity in the three lizard species compared with ontogenetic plasticity. Lizards were collected by hand or noose at locations in the study areas from May 15-June 29, 2003. Dorsal coloration was quantified using a spectrophotometer for each specimen. The physiological plasticity was analyzed by conducting experiments on the lizards looking at temperature variability and by collecting body temperatures using a laser thermometer, as well as additional spectrophotometric recordings. Further experiments were conducted to examine ontogenetic plasticity and involved capturing gravid females and housing them until egg deposition. The eggs were housed until hatched; all hatchlings were then compared to determine instances of divergent color morphologies. The hatchlings of each color morph were then compared to their parental populations to determine instances of ontogenetic trajectories.

Rosenblum (2006) investigated how the lizard species at WHSA have responded to natural selection across a common ecotone. Three habitat categories were sampled: dune field (white sand substrate), brown adobe substrate of the surrounding desert, and ecotones (transition zones) that are found along the margins of the dune field. Three lizard species were the focus of the study, the eastern fence lizard, little striped whiptail, and the lesser earless lizard. A tissue sample and spectrophotometric data were collected for each specimen before releasing them at the collection site; some specimens of each species were retained for vouchers and stored at the Museum of Vertebrate Zoology at the University of California, Berkeley.

Rotenberry et al. (2008) investigated the applicability of GIS to accurately predict the distribution of herpetofauna based on previous spatially documented herptile observations within CHDN park units, including WHSA. Ecological niche modeling was conducted by testing models that incorporate biotic and abiotic factors (as map layers) with previously collected herpetological data points from the CHDN parks. Data with sufficient non-redundant herptile locations were selected for calibration and validation of the various niche models. The process included generating habitat similarity indexes (HSI)s where the herptile points were compared and evaluated with various environmental variables; variables included the vegetation communities, precipitation levels, temperature averages, elevation, aspect, slope, seasonality of precipitation and temperature (Rotenberry et al. 2008).

Rosenblum et al. (2009) focused on three lizard species in WHSA that have the blanched coloration to pinpoint the mechanism of convergent evolution that is occurring with eastern fence lizards, little striped whiptails, and the lesser earless lizard. Experimental processes involved functional assays, cell culture and transfection, ALPHAScreen cAMP assay, ELISAs, color quantification, Mc1r genotyping, and statistical analysis (see Rosenblum et al. [2009] for an in depth explanation of these methods).

Des Roches et al. (2011) conducted field surveys in the dune fields of WHSA and the Jornada Long-tern Ecological Research Station, where primarily dark soil habitat is found, in order to identify suspected ecological opportunity and test for ecological release occurring at the dune field. To determine the presence of ecological opportunity, species richness and relative abundance were measured in each habitat for predators, competitors, and three lizard species by performing visual encounter surveys on foot from May to June in 2009. In addition, avian surveys were conducted in each area along 2,000 m (6,562 ft) transects of roads to test for differences in avian predators. Three components of ecological release were tested: density compensation, broadened resource use, and increased morphological trait variation.

Prival and Goode (2011) conducted surveys to inventory the reptile and amphibian species of the entire CHDN, including WHSA, between 2003 and 2004. The searches consisted of road-cruising, foot search efforts, incidental observations, and pitfall trapping. The inventory documented 22 reptile species in WHSA.

Hardwick et al. (2013) conducted a study involving the locally-adapted eastern fence lizard populations that are found in the dune fields of WHSA, the Carrizozo lava flow, and the surrounding desert scrubland of the Chihuahuan Desert in New Mexico. Hardwick et al. (2013) used mate preference experiments to determine whether the lizards would exhibit early stages of behavioral reproductive isolation. Experiments were conducted in the field during the breeding season (May-July) in 2010. Several females of reproductive maturity were captured by hand or noose from a number of different locations in each environment; measurements of dorsal and ventral coloration were taken with a spectrometer under consistent lighting along with a digital photograph for each individual. Each experimental trial involved capture of a male in his natural territory by hand or noose and immediately placed in a circular behavioral arena where the experiment was then recorded with a digital video camera. Previously captured females were then introduced individually, in the male's direct line of sight to observe and record behavior; each male was observed for courtship behavior with introductions of a local female and a foreign female.

The NPS Certified Species list (NPS 2014) identifies 33 reptile species as present or probably present within WHSA. The list is compiled from previous accounts documented in various inventories and historic literature on WHSA biotic inhabitants.

#### *4.5.5. Current Condition and Trend*

Species Richness

The species richness measure allows simultaneous assessment of abundance or presence for the entire reptile community. This measure can also indicate overall habitat suitability for reptiles. The NPS Certified Species List (accessible from: https://irma.nps.gov/App/Species/Search) confirms the presence of 17 snake species, 16 lizard species, and one turtle species within WHSA (Appendix H). This list, however, does not allow for specific analysis of species richness as no data are collected other than the presence of the listed species.

Smith (1943) focused on the bleached earless lizard, but also identified three other lizard species during the study: common side-blotched lizard, eastern fence lizard, and *Cnemidophorus perplexus* (Appendix H). *C. perplexus* was previously thought to be a distinct species; however, it is now classified as *C. neomexicanus.*

From 1947-1949, Lewis (1950) collected herpetofauna as part of a survey that compared historic collection efforts and literature to further describe the herpetofauna of the Tularosa Basin and Organ Mountains of New Mexico. Eighteen reptile species were collected during these surveys (Appendix H).

Dixon (1967) recorded four reptile species during surveys of the WHSA area from 1963-1965: the eastern fence lizard, the bleached earless lizard, common side-blotched lizard, and the little striped whiptail (Appendix H). There was no mention of other reptile species, presumably because the focus of the study was on lizards.

McKeever (2009a) documented herpetofauna encountered from 1971 through 1977 and included them in the herpetological survey that was conducted from May to October in 2009. The documentation and survey resulted in the observation of 26 herptiles; one turtle, 12 lizard, and 13 snake species were recorded within the park (Appendix H).

Prior to conducting surveys, Prival and Goode (2011) obtained an annotated species checklist from two herptologists with extensive experience in WHSA (Jerry Johnson and Doug Burkett) (Prival and Goode 2011). The checklist identified 31 reptile species that are likely to occur in WHSA (Appendix H). This list is treated in this document the same way as the NPS Certified Species List (NPS 2014); because no data were collected other than the presence/absence of species over time, the list does not allow for a specific analysis of species richness. It is useful, however, as a reference of species that are likely to occur in the park at any given time.

Prival and Goode (2011) surveyed the reptile community of WHSA from 2003-2004 and identified 22 reptile species (11 snake species, 10 lizard species, and one turtle species; Appendix H). The survey efforts of Prival and Goode (2011) identified approximately 71% of the species expected to occur based on the annotated checklist of Johnson and Burkett, and approximately 65% of the species identified on the NPS Certified Species List (Appendix H).

During the Prival and Goode (2011) survey there was a direct relationship between the number of person-days and the total number of species observed in both years (Figure 30). The likelihood of documenting species that have been listed to probably occur on the park, or that have areas of suitable habitat in the park, is high.

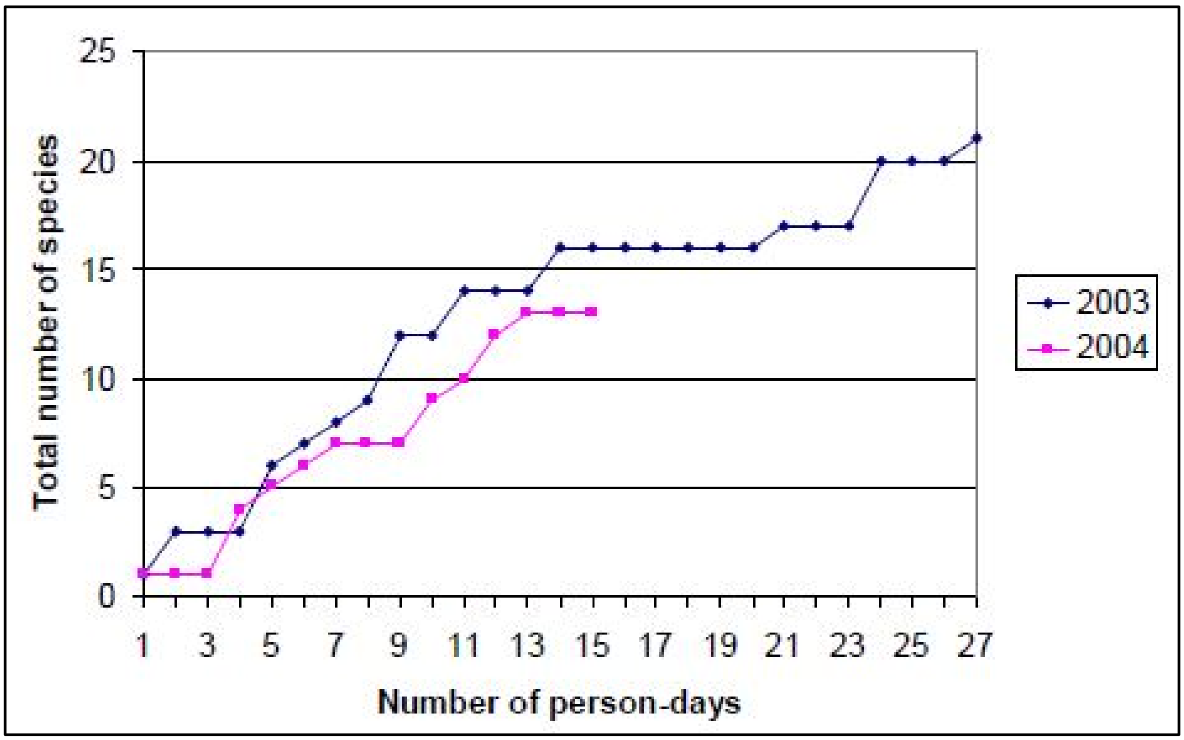


**Figure 30.** Prival and Goode (2011) surveys had increasing numbers of species observed with each addition person-day (Reproduced from Prival and Goode 2011).

Species Distribution

Bugbee (1942) noted the occurrence and activity of animals within the park along with brief descriptions of where the animal was observed. There are no maps depicting site locations, but rather a short description of the microhabitat; there are only notes on three lizards: the *Sceloporus* spp., *Holbrookia* spp., and *Cnemidophorus* spp. (*Aspidoscelis* spp.) (Bugbee et al. 1942). The lizards were observed primarily in the interdune flats, often seeking refuge beneath bushy plants; the exception to this was the *Aspidoscelis* sp. that was often observed on the dune faces as well as utilizing burrows and tunnels in the flats to conceal themselves during the hottest part of the day (Bugbee et al. 1942).

Lewis (1950) described the vegetation communities and which herpetofauna species were observed in each distinct area within the Tularosa Basin and adjacent Organ Mountains. Although the notes are not specific to the park, there is clearly habitat described that exists within the park. The area described as having the highest density of reptile populations is the transitional area where the open desert and the bajadas intersect; the area with the highest observed number of species was the yucca grassland area (Table 21). This information is relevant to the general distribution of reptiles in the park when comparing the notes to current areas similar to the descriptions provided by Lewis (1950).

Rotenberry et al. (2008) used ecological niche modeling in the CHDN parks to determine if the models could accurately predict the distribution of herptile species or herptile communities based on HSIs. Three determinations were made for target herptile species involved in the modeling project: 1) which set of variables best predicted individual park distributions, 2) whether the set of variables that were accurate for one park would be applicable to other parks, and 3) whether a park preserved suitable habitats for species relative to non-park lands adjacent to the park boundaries. Species chosen for this project were selected based on whether there were sufficient data points for a target species. For WHSA, there were seven reptile species selected for calibration and validation of the niche models (Table 22).

The areas with suitable habitat determined by the niche modeling are described visually for each species and are summarized in Table 23.

**Table 21.** Common and scientific names of the reptile species observed by Lewis (1950). The approximate area where the species were observed was identified to habitat type.

| Scientific name | Common name | Areas where observed |
|---|---|---|
| *Uta s. stejnegeri* | side-blotched lizard | yucca grassland/mesquite-salt bush dunes/playas |
| *Salvadora h. deserticola* | Big Bend patch-nosed snake | yucca grassland |
| *Arizona e. philipi* | painted desert glossy snake | yucca grassland |
| *Cnemidophorus tigris tigris* | great basin whiptail | yucca grassland/mesquite-salt bush dunes/playas |
| *Masticophis flagellum testaceus* | western coachwhip | yucca grassland/playas |
| *Pituophis sp.* | bull, gopher, and pine snakes | bajadas/yucca grassland |
| **Crotaphytus w.w. (Gambelia wislizenii wislizenii)* | long-nosed leopard lizard | yucca grassland/mesquite-salt bush dunes |
| *Crotaphytus collaris* | eastern collared lizard | yucca grassland |
| **Elaphe subocularis (Bogertophis subocularis)* | Trans-Pecos rat snake | yucca grassland |
| *Phrynosoma modestum* | round-tailed horned lizard | mesquite-salt bush dunes |
| *Phrynosoma cornutum* | Texas horned lizard | yucca grassland |
| *Terrepene ornata* | desert box turtle | yucca grassland |
| *Sceloporus m. magister* | desert spiny lizard | yucca grassland/mesquite-salt bush dunes |
| *Sceloporus u. consobrinus* | prairie lizard | yucca grassland-exclusively |
| *Eumeces obsoletus* | great plains skink | yucca grassland-exclusively |
| *Rhinocheilus l. tessellatus* | Texas long-nosed snake | yucca grassland-exclusively |
| *Urosaurus* | brush lizards | bajadas |
| *Holbrookia* | lesser earless lizard | bajadas/transition zone-exclusively |
| *Cnemidophorus tesselatus* | checkered whiptail | bajadas-exclusively |
| *Masticophis taeniatus taeniatus* | desert striped whipsnake | bajadas-exclusively |
| *Salvadora* | patch-nosed snakes | bajadas |
| *Thamnophis* | garter snakes | bajadas |
| *Crotalus viridis viridis* | prairie rattlesnake | mesquite-salt bush dunes/playas |
| *Crotalus molossus mollosus* | black-tailed rattlesnake | bajadas-exclusively |
| *Heterodon* | hog-nosed snakes | playas |

**Table 22.** Reptile species with sufficient spatially non-redundant location records for WHSA and the selected type of model for each species (Rotenberry et al. 2008).

| Scientific name | Common name | Selected model type |
|---|---|---|
| *Aspidoscelis marmorata* | marbled whiptail | abiotic and biotic |
| *Crotalus atrox* | western diamond-backed rattlesnake | biotic only |
| *Crotaphytus collaris* | eastern collared lizard | abiotic and biotic |
| *Hypsiglena torquata janii* | Texas nightsnake | abiotic only |
| *Masticophis flagellum* | coachwhip | abiotic only |
| *Sceloporus cowlesi* | southwestern fence lizard | abiotic only |
| *Uta stansburiana* | common side-blotched lizard | abiotic only |

**Table 23.** Summary of the distribution of suitable habitats for reptiles at WHSA (Rotenberry et al. 2008).

| Scientific name | Habitat locations |
|---|---|
| **Lizards** | |
| *Aspidoscelis marmorata* | western park |
| *Coleonyx brevis* | throughout, except east-central dune field |
| *Aspidoscelis tesselata* | limited; southeast park |
| *Cophosaurus texanus* | throughout park |
| *Crotophytus collaris* | throughout park; except north central area |
| *Sceloporus cowlesi* | none |
| *Uta stansburiana* | throughout park |
| **Snakes** | |
| *Crotalus atrox* | western park; small patches northwestern park |
| *Crotalus molossus molossus* | patches throughout except north central area |
| *Hypsiglena torquata jani* | throughout park; especially western side |
| *Masticophis flagellum* | western side of park |

The Texas banded gecko (*Coleonyx brevis*) map representation of the niche model indicated that the park has extensive suitable habitat for this species and suggested the possibility of its existence at WHSA may have gone undetected (Figure 31; Rotenberry et al. 2008). Additional survey efforts could determine whether the Texas banded gecko has been in WHSA for some time, or if it may immigrate to this area in the future. The other reptiles that are displayed in the niche models for the park had varied results in regard to HSI.

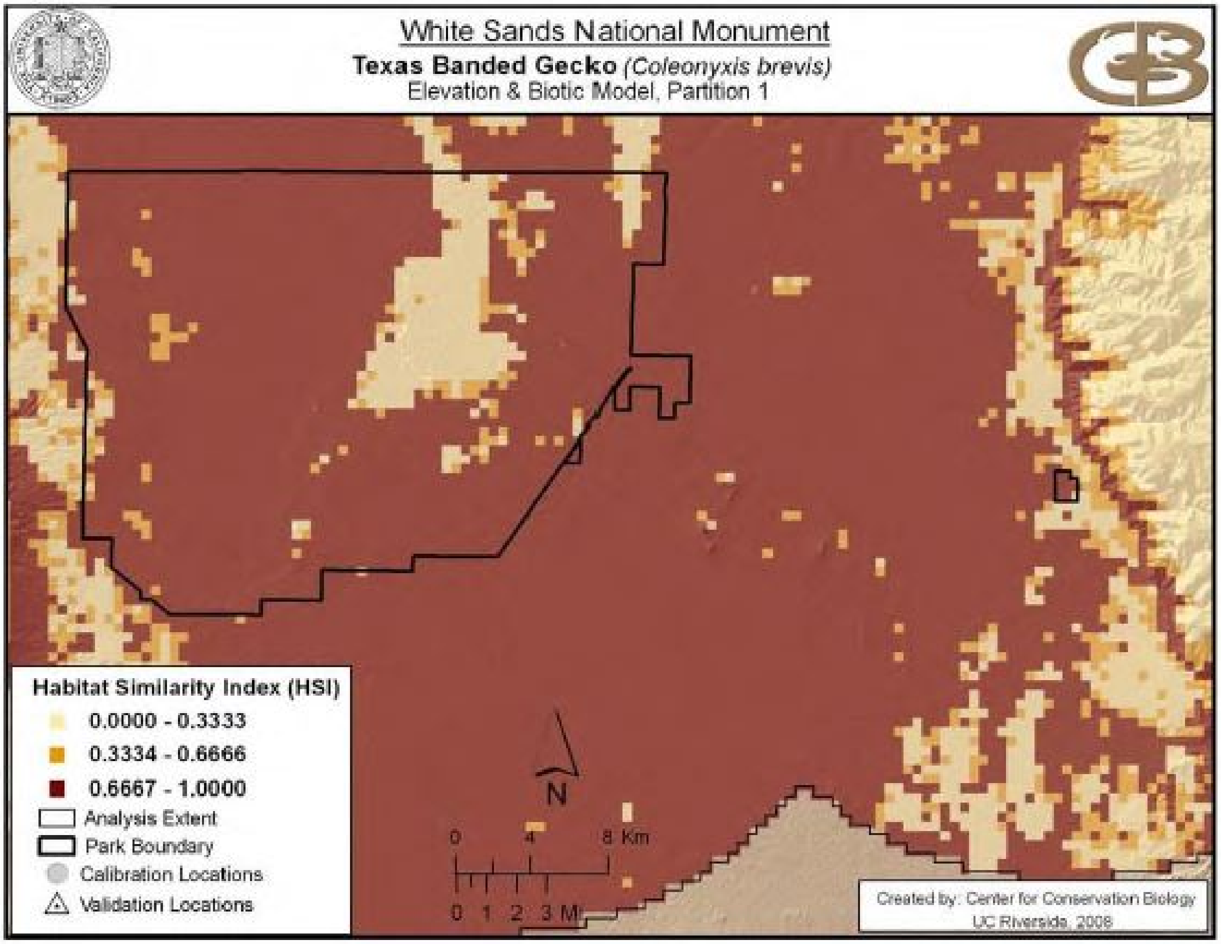


**Figure 31**. The niche model developed from the Rotenberry et al. (2008) niche model shows abundant and widespread habitat suitable for the Texas banded gecko at WHSA. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the southwestern fence lizard (*Sceloporus cowlesi*) indicates an overall lack of suitability in habitat at WHSA (Figure 32; Rotenberry et al. 2008). This is not consistent with the Prival and Goode (2011) inventory results, where there were 56 individuals observed, the sixth highest number during the 2-year survey period.

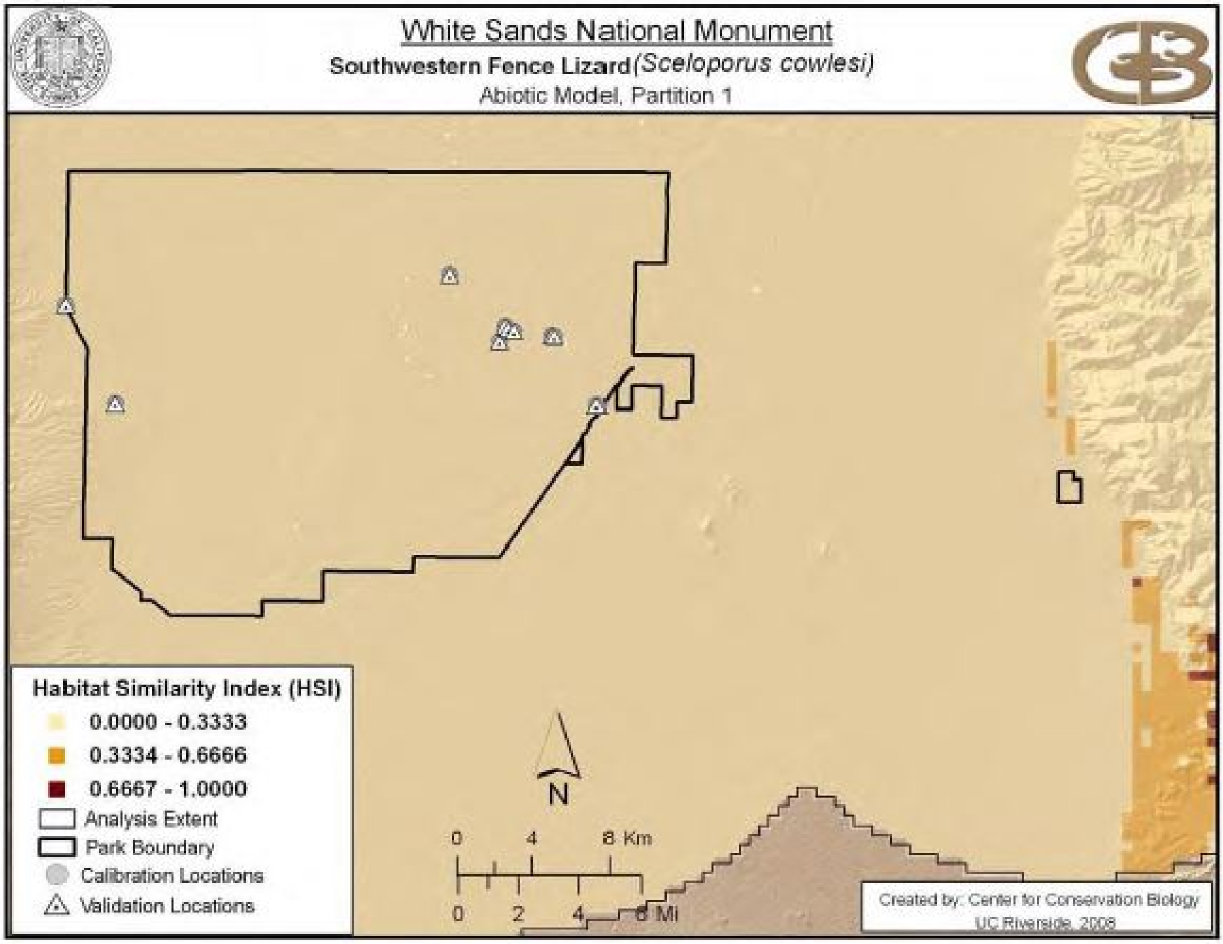


**Figure 32.** The niche model developed from the Rotenberry et al. (2008) for the southwestern fence lizard. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the common side-blotched lizard indicated the park is almost entirely suitable for the species, which is consistant with the high number of individuals counted in the CHDN inventory (Figure 33). A total 240 common side-blotched lizards were observed during the surveys conducted in 2003 and 2004 (Rotenberry et al. 2008, Prival and Goode 2011).

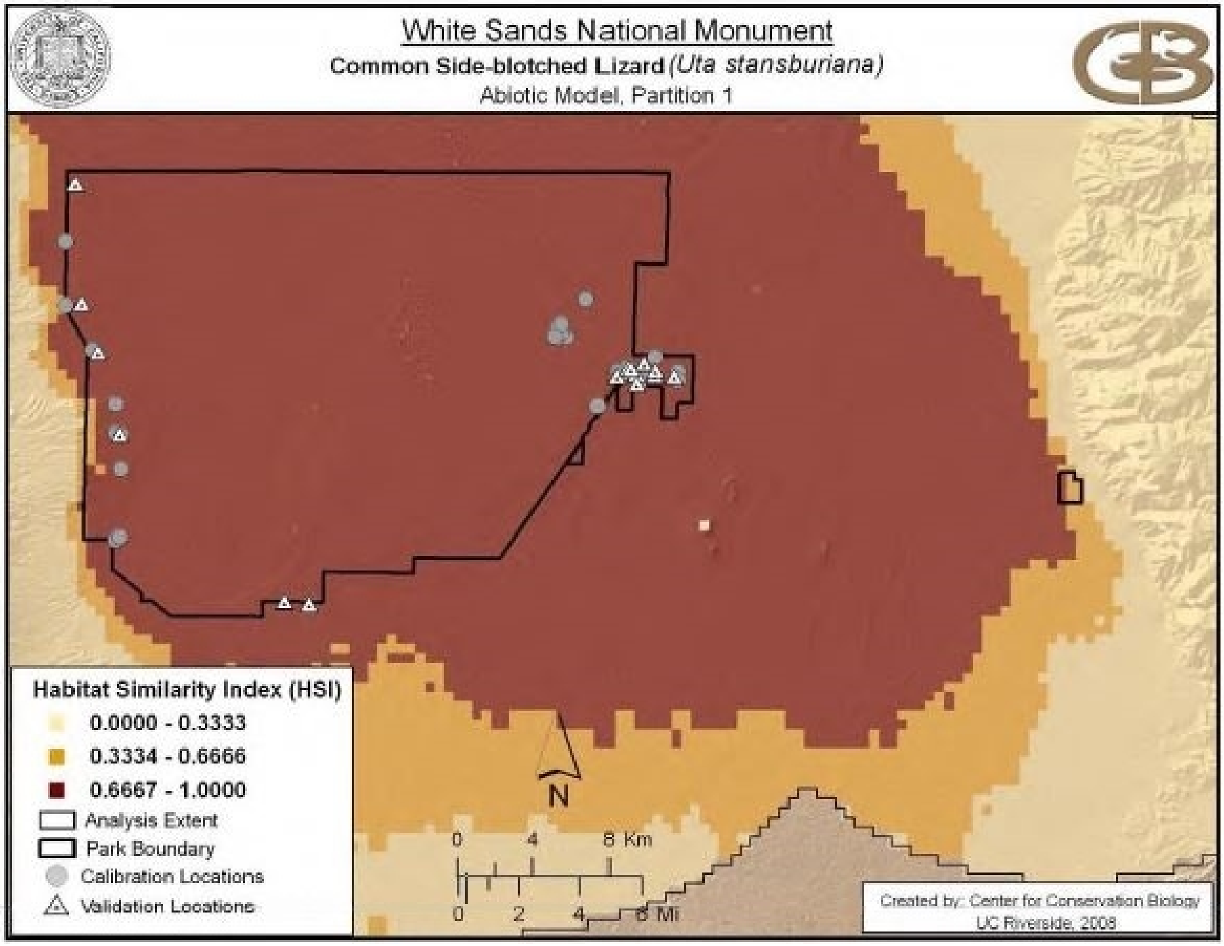


**Figure 33.** The niche model developed from the Rotenberry et al. (2008) for the common side-bloched lizard. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the common checkered whiptail lizard (*Aspidoscelis tesselata*) at WHSA indicated very limited habitat that is suitable for the species, which is consistent with the lack of any observations recorded at the park (Figure 34; Rotenberry et al. 2008; NPS 2014).

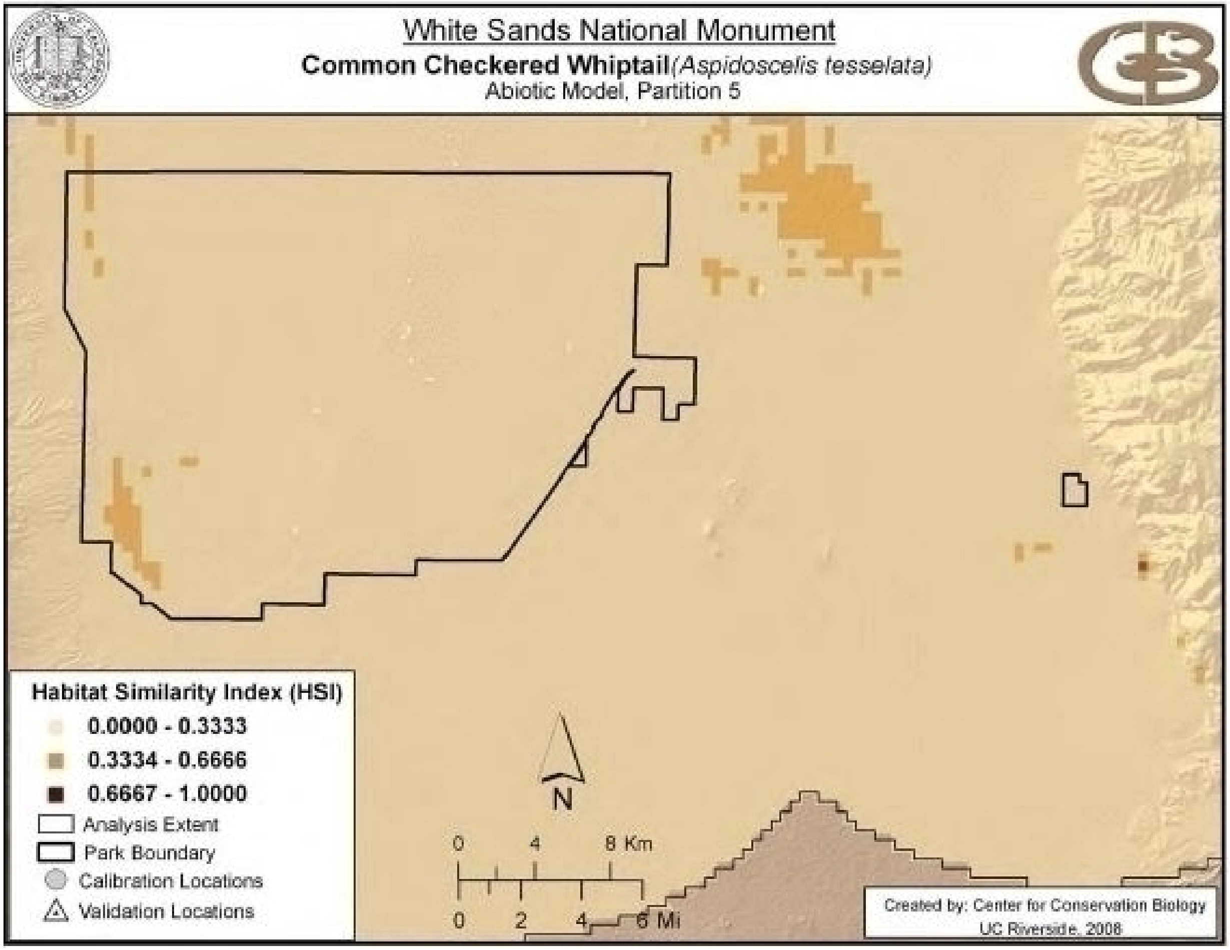


**Figure 34.** The niche model developed from the Rotenberry et al. (2008) for the common checkered whiptail. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the eastern collared lizard indicates there is highly suitable habitat in almost half of the park area, yet there was not a large number observed there during the CHDN herptile inventory (Rotenberry et al. 2008). In 2003, there were a total of four individuals observed, and zero in 2004 (Prival and Goode 2011); this niche model suggests that a higher number of individuals would be likely (Figure 35).

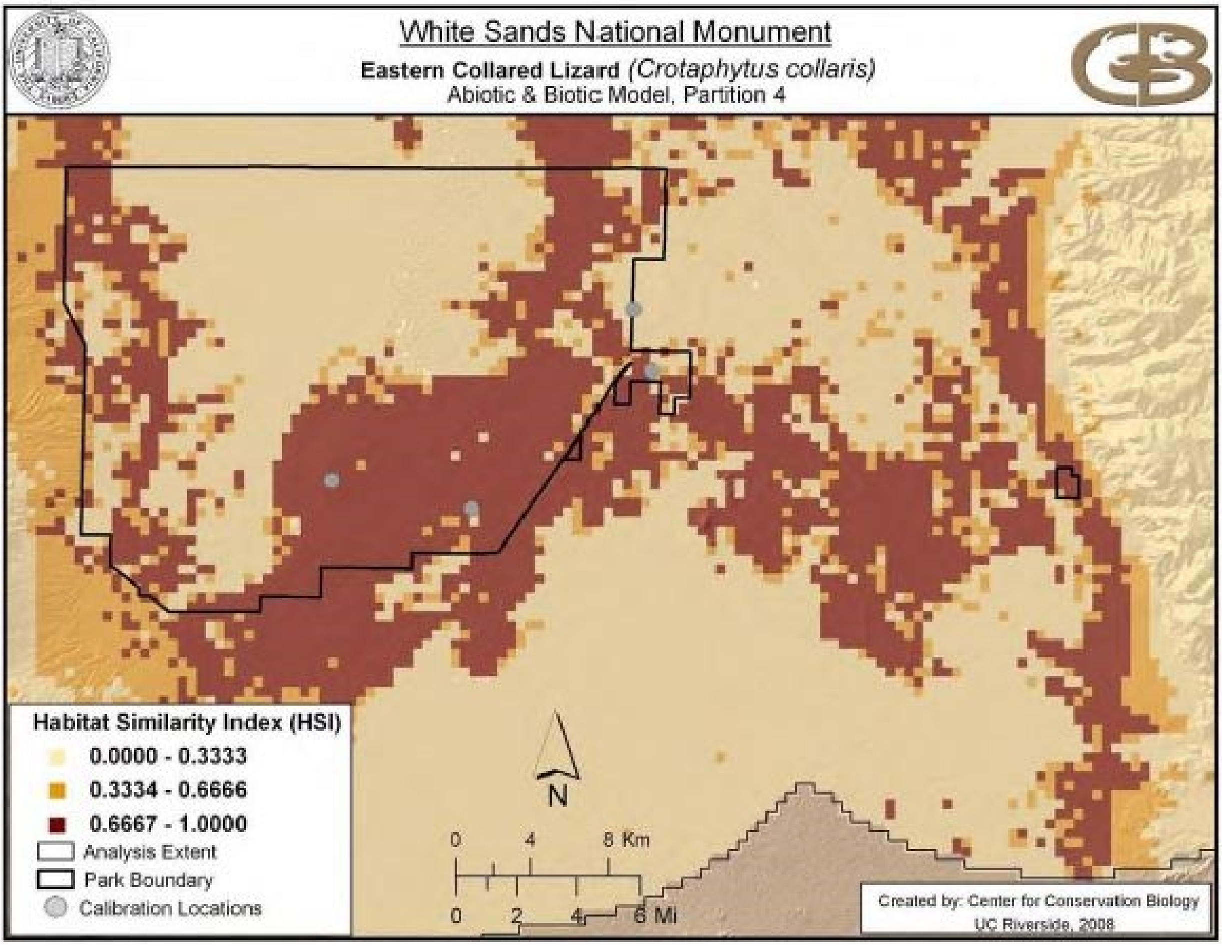


**Figure 35.** The niche model developed from the Rotenberry et al. (2008) for the eastern collared lizard. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the greater earless lizard (*Cophosaurus texanus*) shows that the entire park area has highly suitable habitat (Figure 36; Rotenberry et al. 2008). The data that confirms the presence of the lizard is from the NPSpecies (2014) list, although this is not indicative of the population size living on the park and there were no observations in the CHDN inventory (Prival and Goode 2011).

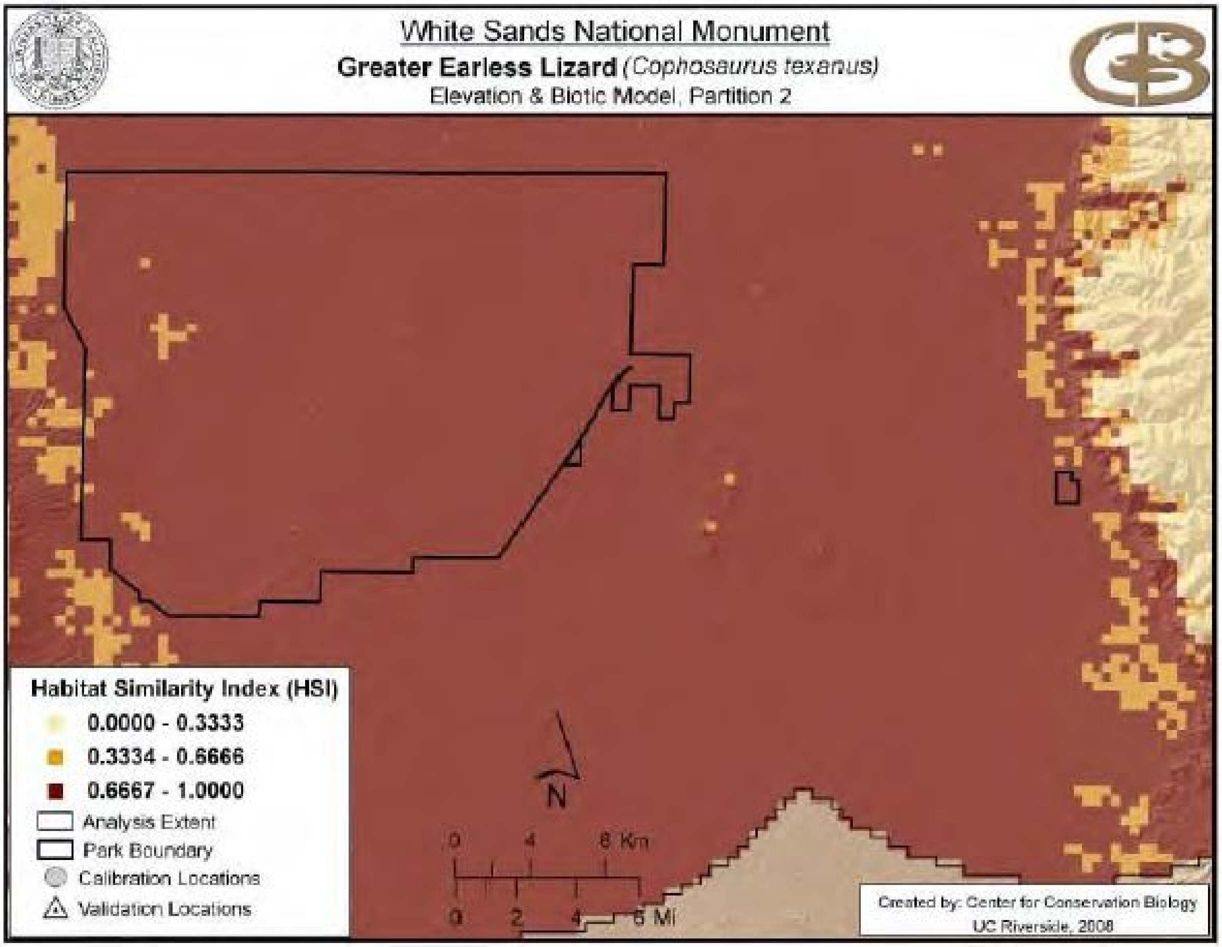


**Figure 36.** The niche model developed from the Rotenberry et al. (2008) for the greater earless lizard. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the marbled whiptail (*Aspidoscelis marmorata*) indicates a very small amount of highly suitable habitat scattered along the western edge of the park with some moderatley suitable habitat in patches along the west and central park area (Figure 37; Rotenberry et al. 2008). Despite this, the Prival and Goode (2011) inventory lists this lizard as second highest in abundance with a total of 123 observed in the 2002-2003 survey of WHSA.

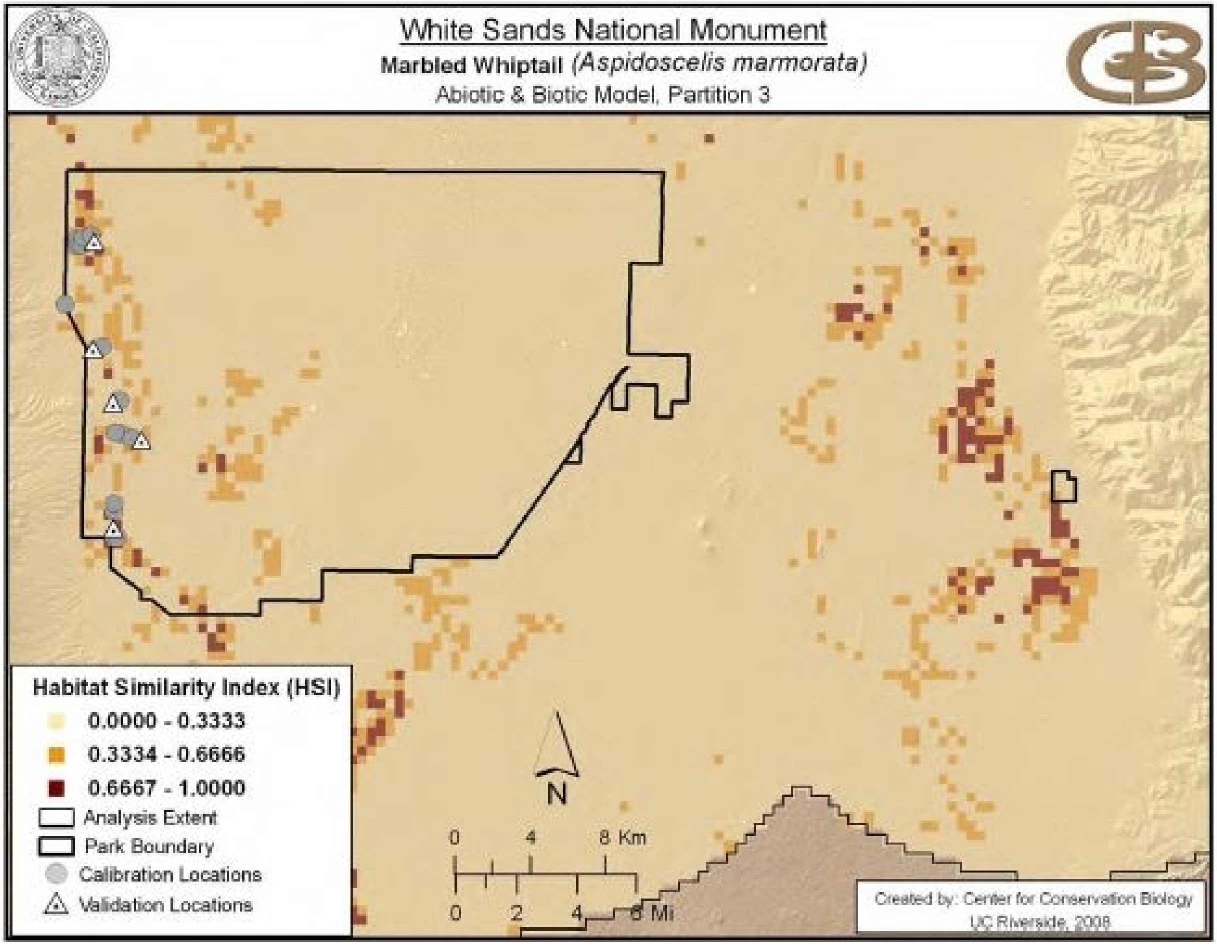


**Figure 37.** The niche model developed from the Rotenberry et al. (2008) for the marbled whiptail. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the coachwhip (*Masticophis flagellum*) shows that most of the park has low habitat suitablility, while an area of moderate suitablitlity exists along the western border (Figure 38; Rotenberry et al. 2008). This is consistent with the low number of observed individuals during surveys in 2003 for the CHDN herptile inventory (Prival and Goode 2011).

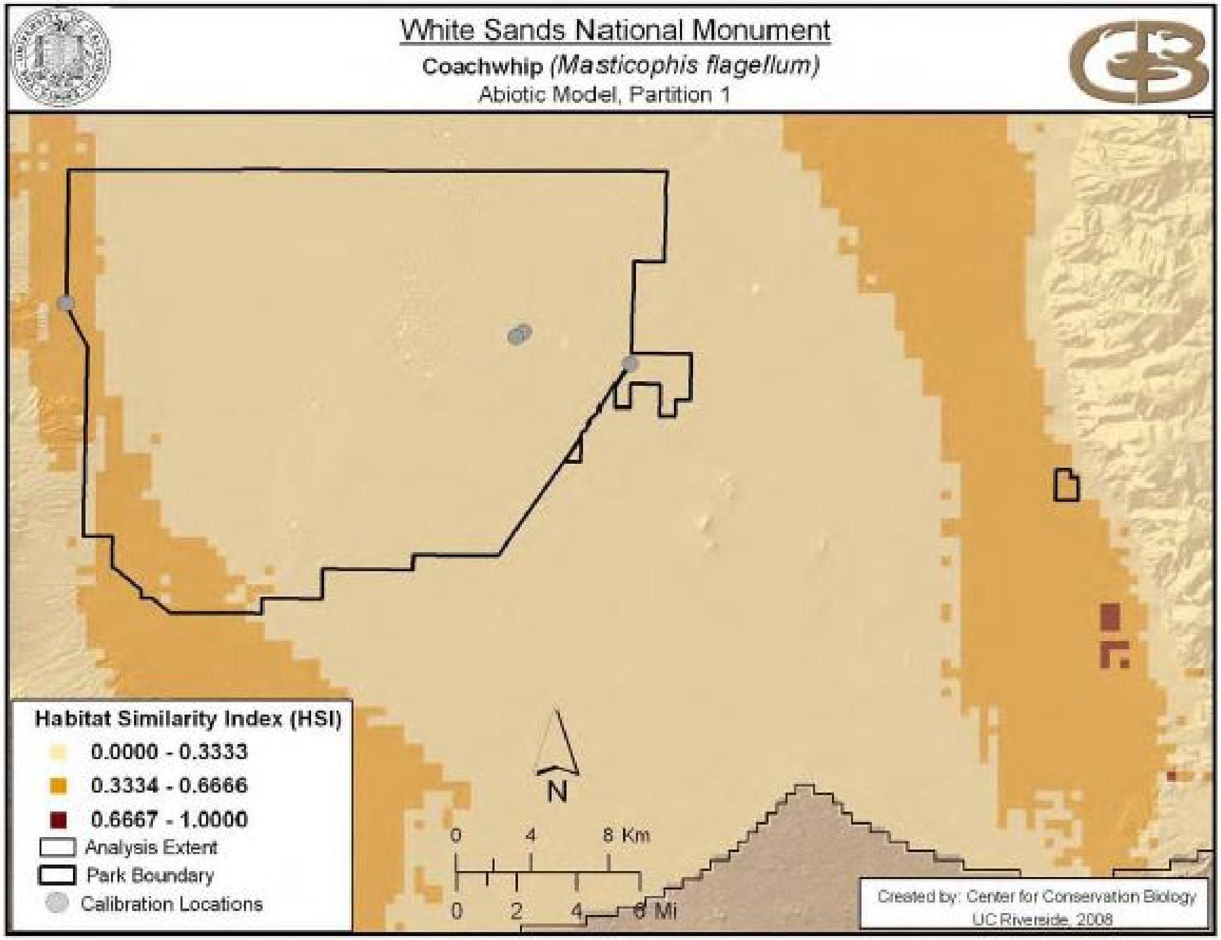


**Figure 38.** The niche model developed from the Rotenberry et al. (2008) for the coachwhip. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the Texas nightsnake (*Hypsiglena torquata janii*) indicates highly suitible habitat along the western park border, and moderate suitability in most of the park aside from one large patch to the east (Figure 39; Rotenberry et al. 2008). Although much of the park has suitable habitat for the snake, there were only four observed during the 2003 survey, and zero during 2004 for the CHDN herptile inventory (Prival and Goode 2011).

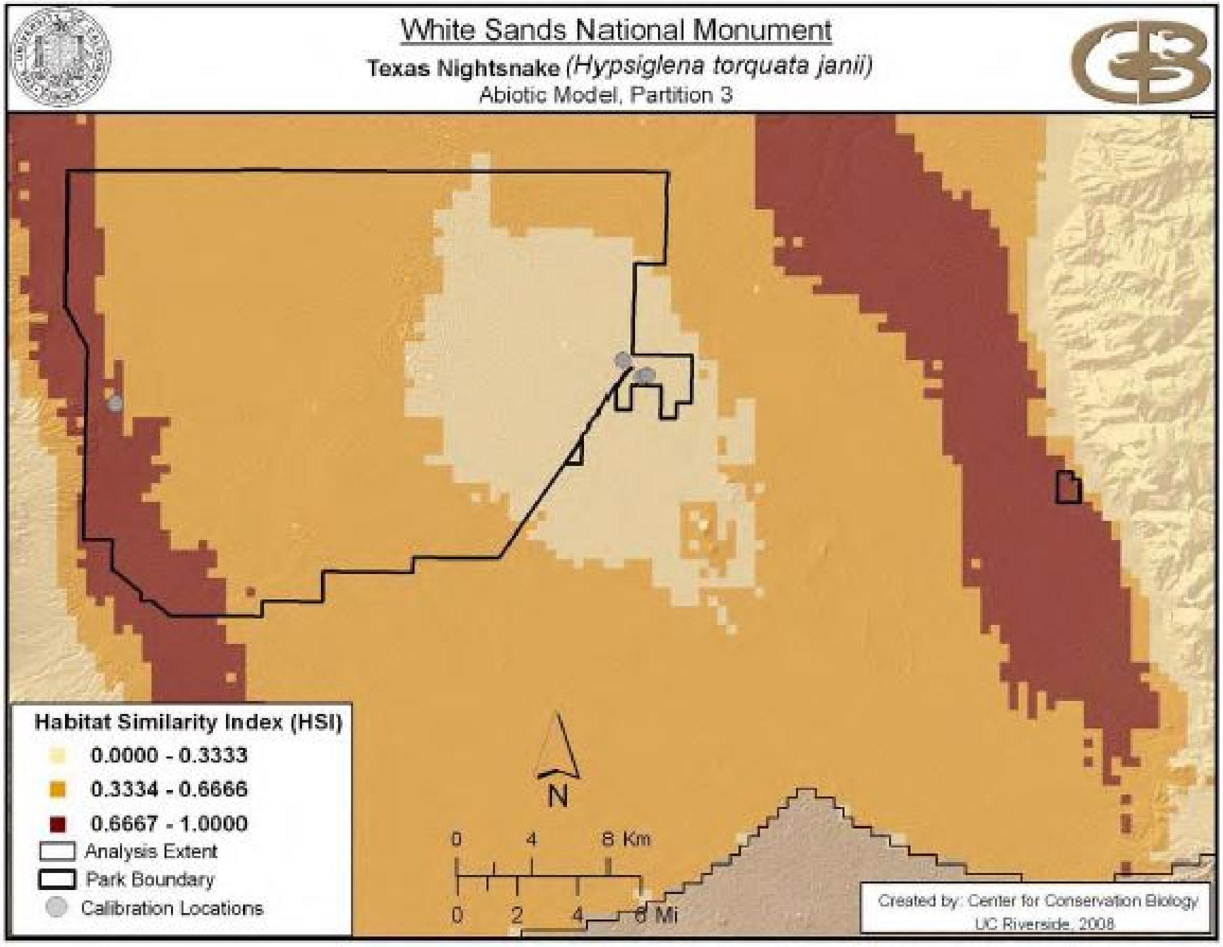


**Figure 39.** The niche model developed from the Rotenberry et al. (2008) for the Texas nightsnake. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the western diamond-backed rattlesnake indicates the park has moderate to highly suitable habitat on the west side of the park only, the remaining are was of low suitability with only a small patch suitable on the east side (Figure 40; Rotenberry 2008). The snake was not abundant according to data from the CHDN herptile inventory; observations totaled only three for the 2 year (2003-2004) survey period which may be due to the cryptic nature of this species (Prival and Goode 2011).

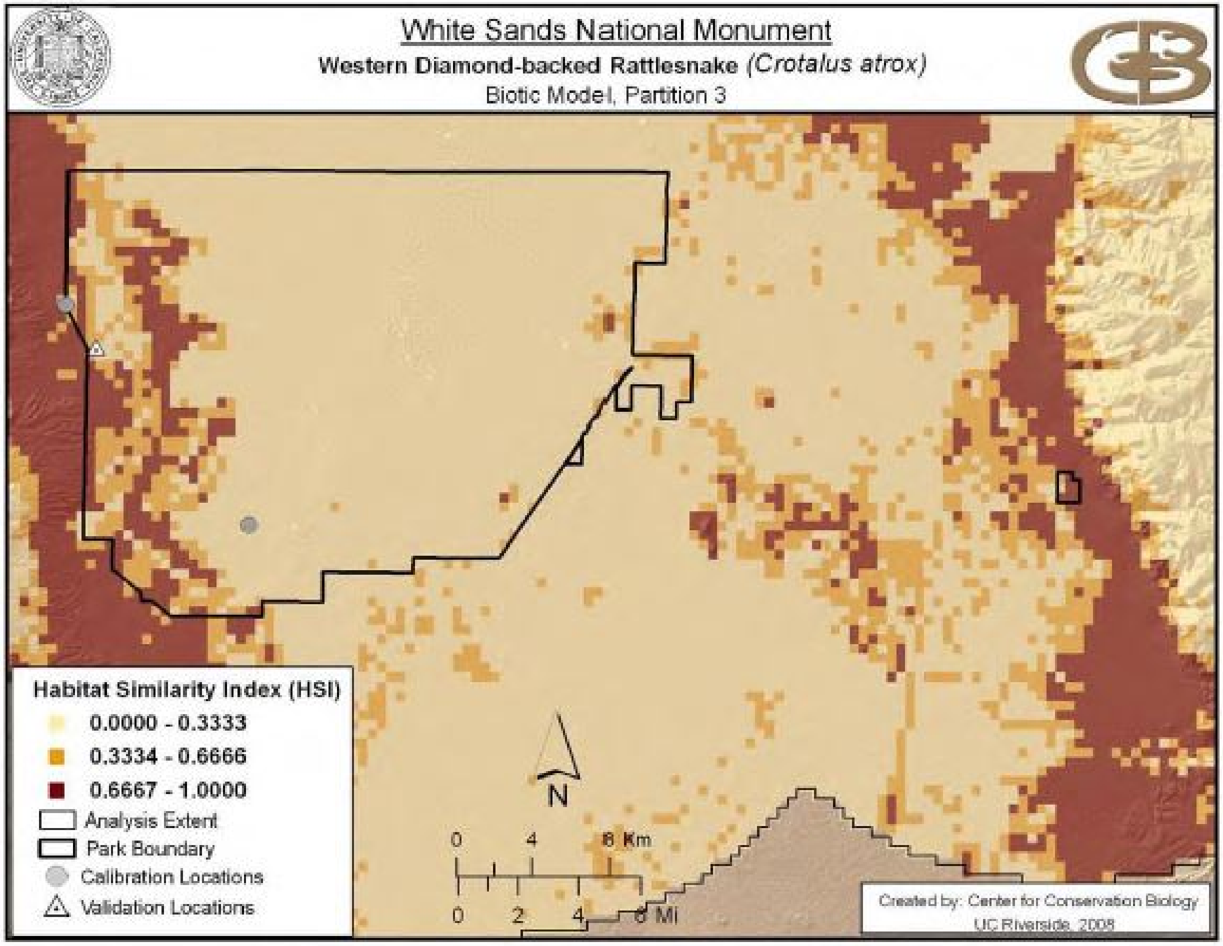


**Figure 40.** The niche model developed from the Rotenberry et al. (2008) for the western diamond-backed rattlesnake. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The niche model for the northern black-tailed rattlesnake (*Crotalus molossus molossus*) shows scattered moderate to highly suitable habitat along the east, south, and western edges of the park (Figure 41; Rotenberry 2008). There are no observations of this species recorded at the park.

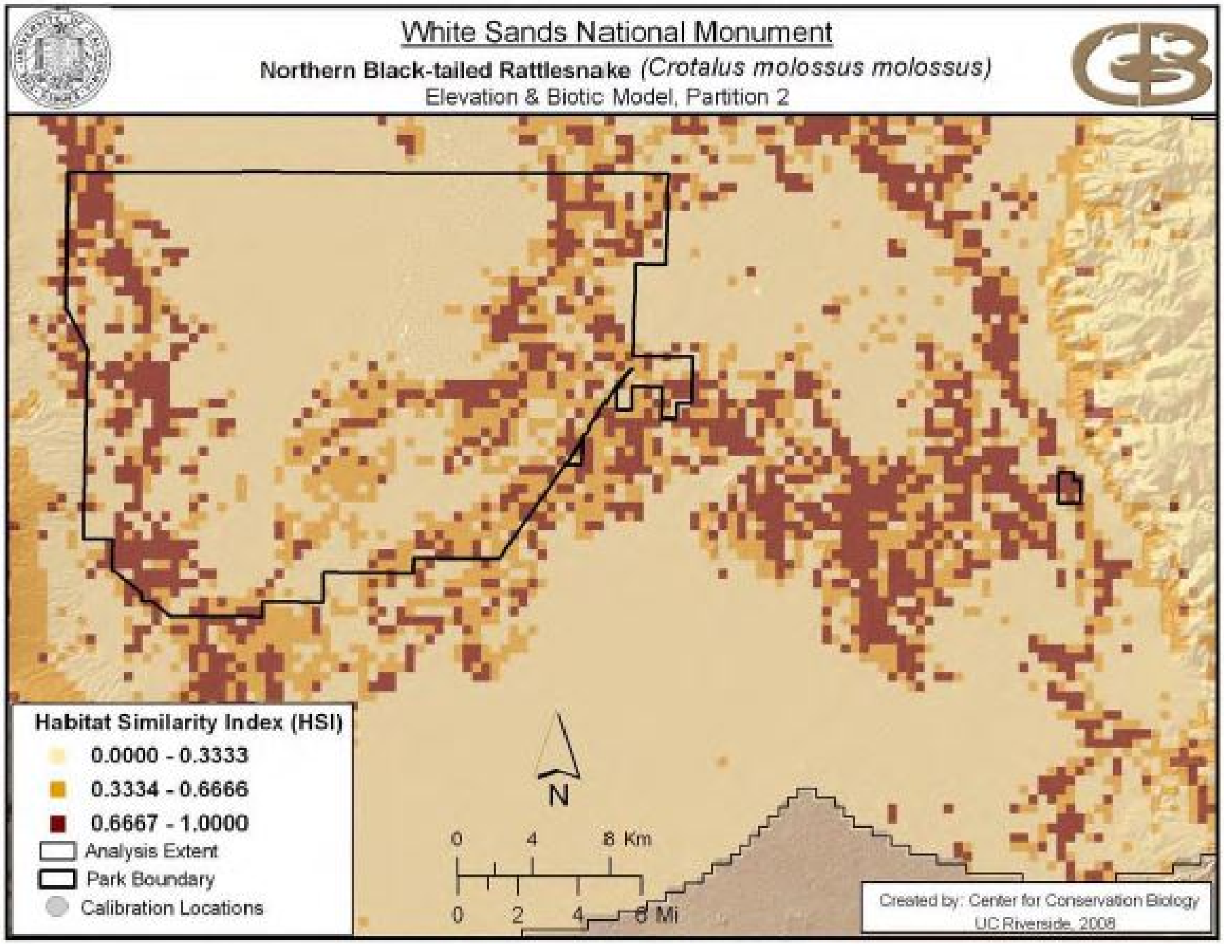


**Figure 41.** The niche model developed from the Rotenberry et al. (2008) for the northern black-tailed rattlesnake. The higher the HSI value, the more suitable the habitat is to the particular species (Reproduced from Rotenberry et al. 2008).

The models created by Rotenberry et al. (2008) indicate that some species may have gone undetected at the park, and may possibly reside in the areas that the niche model show as suitable habitat. Future monitoring efforts could benefit from using these HSI models as a guide for focusing survey efforts in the future to obtain observations of species that were not previously recorded at the park as well as more accurately describe relative abundance of species that have been confirmed, but that are not well documented.

McKeever (2009b) recorded snake observations from 1971 through 1977; four habitat categories within the park and the number of each species observed in each are listed in Table 24. The habitats in Table 24 are delineated by the author in Figure 42.

**Table 24.** Number of snakes encountered by habitat type (recreated from McKeever 2009b).

| Common name | Saltbush | Marginal Dunes | Gypsum Outcrop | Mesquite-Creosote |
|---|---|---|---|---|
| green prairie rattlesnake | 115 | 16 | 2 | 8 |
| Sonoran gophersnake | 113 | 15 | 6 | 3 |
| western coachwhip | 64 | 13 | 2 | 14 |
| Texas night snake | 21 | 6 | 0 | 5 |
| western diamond-backed rattlesnake | 10 | 0 | 9 | 8 |
| plains black-headed snake | 9 | 7 | 0 | 3 |
| desert massasauga | 2 | 16 | 0 | 0 |
| western hog-nosed snake | 13 | 0 | 0 | 0 |
| painted desert glossy snake | 8 | 2 | 0 | 3 |
| long-nosed snake | 11 | 0 | 0 | 0 |
| desert king snake | 4 | 0 | 0 | 0 |
| variable ground snake | 2 | 0 | 0 | 0 |
| Chihuahaun hook-nosed snake | 2 | 0 | 0 | 0 |

The saltbush association is found on the southeastern and eastern margins of the park and is typical Chihuahuan Desert basin ecology, or desert grassland (Figure 42). Saltbush habitat was the only source of the western hog-nosed snake observations during the time period (McKeever 2009b). Saltbush was also where the highest frequency of little striped whiptail, southwestern fence lizard, round-tailed horned lizard, Sonoran gopher snake, and prairie rattlesnake observations were made in the park; a total of 23 reptile species were observed in this habitat type, including the 13 snake species listed in Table 24 (McKeever 2009b).

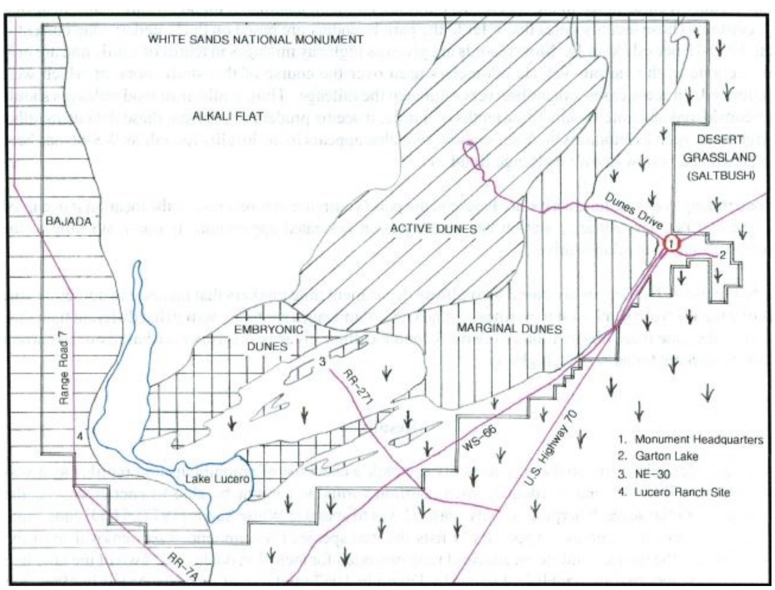


**Figure 42.** A map showing habitat categories in WHSA (reproduced from McKeever 2009b).

The marginal dunes area has interdune habitat and parabolic dunes that have been semi-stabilized by sparse vegetation that has adapted to the driving gypsum sand dunes McKeever 2009b). It is encountered in the inner, eastern area of the park just outside the saltbush areas. This is where the unique, color-morph lizard community was first encountered during the surveys (McKeever 2009b). Twelve reptile species were observed in the marginal dune habitat, including the seven snake species listed in Table 24.

The active dunes gradually become the dominant land feature towards the western center of the park (McKeever 2009b). In the active dunes area, there are very few, if any, plants; the area is completely devoid of vegetation on the eastern margin, adjacent to the alkali flat (Figure 42; McKeever 2009b). There were only three reptile species encountered in the dune field, the bleached earless lizard, the southwestern fence lizard, and the little white whiptail (*Aspidoscelis gypsi*) (McKeever 2009). The observation frequency of the southwestern fence lizard and the little white whiptail declined as the number of soaptree yucca declined in an east-to-west gradient through the active dunes; the bleached earless lizard was found anywhere there was even the slightest bit of vegetation of any kind (McKeever 2009).

The alkali flat covers much of the mid-northern area with the western edge adjacent to the bajada on the eastern margin of the park (Figure 42; McKeever 2009b). The only plant described was pickleweed (*Allenrolfea occidentalis*), which was increasingly sparse from north to south in the flat. One species was encountered here, the bleached earless lizard (McKeever 2009b).

The gypsum outcrop was described in McKeever (2009b) to have a combination of marginal dune and saltbush; the locality being the south-central area of the park. The New Mexico whiptail (*Aspidoscelis neomexicana*) was frequently observed here, unlike other habitats (McKeever 2009b). There were also little white whiptails observed commonly in this area and the western marbled whiptail (*Aspidoscelis marmorata marmorata*) was observed here, but not in the saltbush association. Species that were encountered in this habitat type, more so than other areas of the park, were the desert box turtle and the western diamond-backed rattlesnake; overall this area had a reptile community similar to that of the saltbrush association described above, including the four snake species listed in Table 24 (McKeever 2009b).

The mesquite-creosotebush area is basic desert shrubland along the western margin of the park, flanking the eastern edge of the alkali flat; within the park it is dominated by mesquite with some areas co-dominated by creosotebush (McKeever 2009b). Here the most frequently encountered reptiles were western marbled whiptails, Texas horned lizards (*Phrynosoma cornutum*), twin-spotted spiny lizards (*Sceloporus magister*), long-nosed leopard lizards (*Gambelia wislizenii*), and western coachwhips (*Masticophis flagellum testaceus*); the Chihuahuan greater earless lizard (*Cophosaurus texanus*) was observed exclusively in this area of the park (McKeever 2009b). Overall, 16 reptile species were observed, including the seven snake species listed in Table 24.

In 2009, Des Roches et al. (2011) conducted reptile surveys at WHSA and also found the park to be species poor within the dune field and the number of species found in the dark soil habitat of the park much larger. This survey also demonstrated reduced species richness and abundance of potential competitors and predators in the dune field habitat compared to the surrounding dark soil habitats.

Relatively few studies have documented the distribution of reptiles in WHSA. Prival and Goode (2011) completed foot, funnel trap, and pitfall surveys at the park from 2003-2004. Figure 43, Figure 44, and Figure 45 indicate the locations where reptiles were encountered in WHSA in 2003 and 2004. Prival and Goode (2011) had difficulties reaching the western portion of the park due to restrictions from WSMR Many of the species that were not observed at the park during these surveys are species that are likely to occur on the west side of the park only, which explains their absence from the surveys (Prival and Goode 2011).

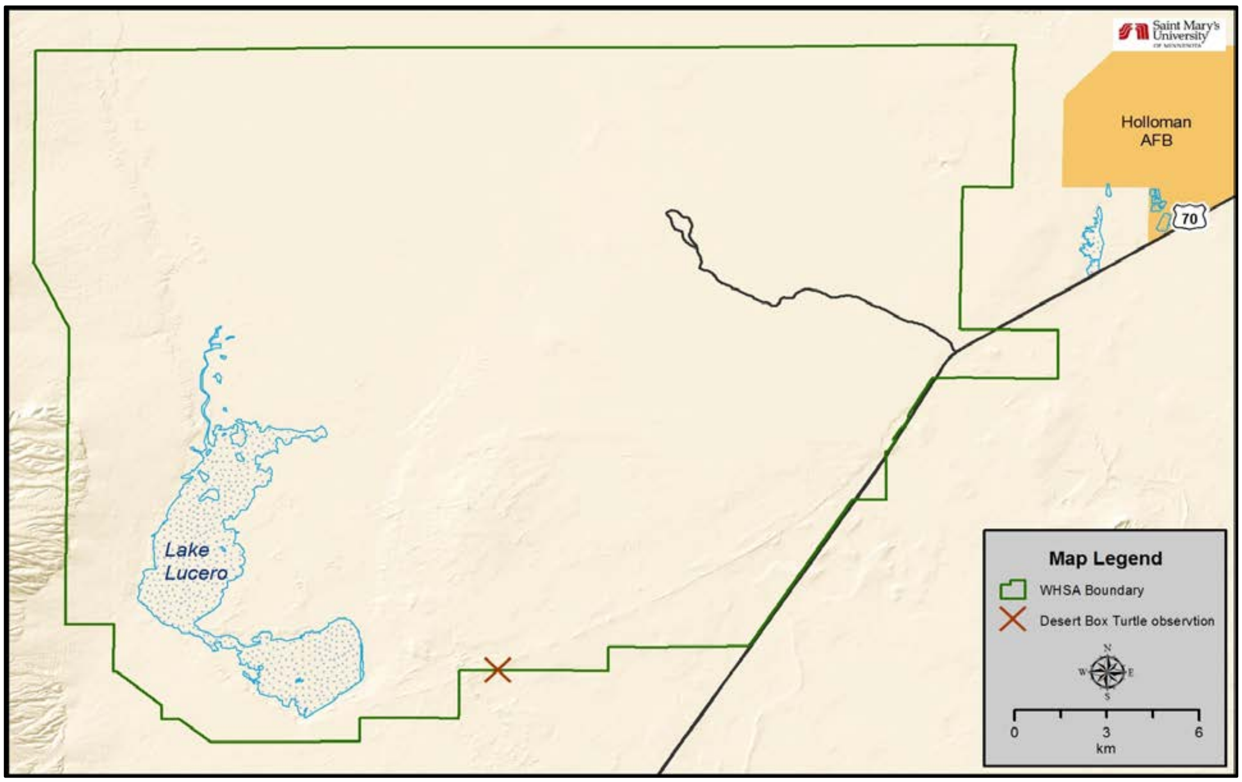


**Figure 43.** Only one turtle, the desert box turtle, was observed during the inventory surveys conducted in 2003 and 2004 (Prival and Goode 2011).

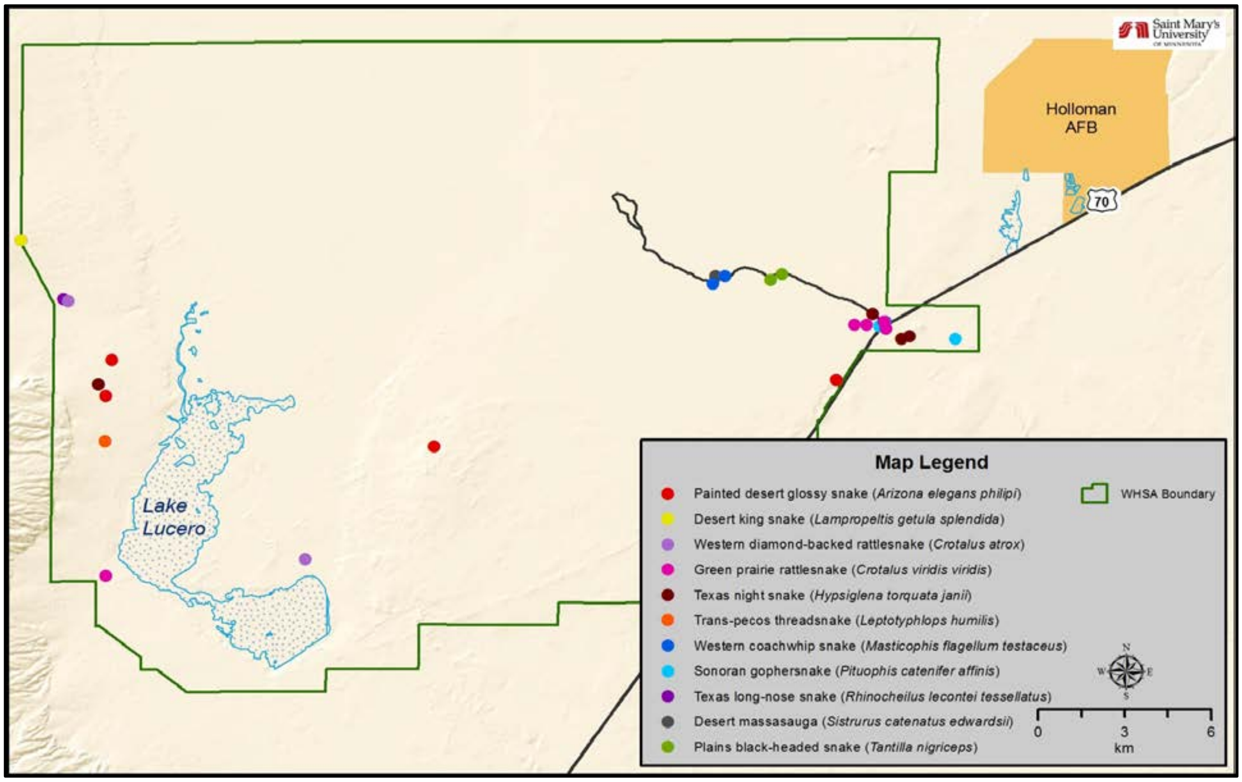


**Figure 44.** Species of snakes that were observed during the Prival and Goode (2011) inventory in 2003 and 2004.Several observations were in close proximity, which resulted in overlapping circles on this figure. Abundance estimates may be slightly inaccurate due to these overlaps.

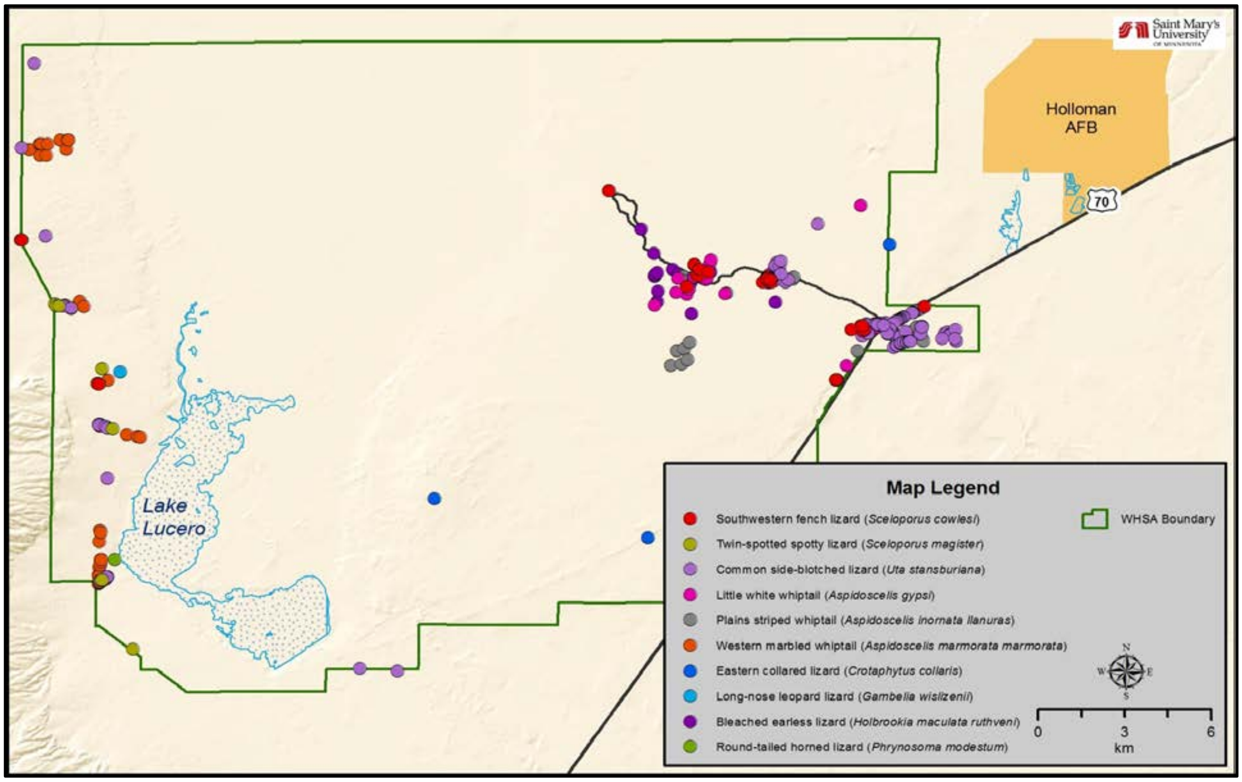


**Figure 45.** Species of lizards that were observed during the Prival and Goode (2011) inventory in 2003 and 2004. Several observations were in close proximity, which resulted in overlapping circles on this figure. Abundance estimates may be slightly inaccurate due to these overlaps.

Species Diversity

Species diversity is a specific metric that combines species evenness (the general abundance of each species) and species richness. Species diversity is measured by analyzing the total known number of species present in an area, and the general abundance of each species present. In WHSA, few studies have focused specifically on the species diversity metric.

McKeever (2009a, b) observed that areas outside the active dune field were more diverse in herpetofauna species than the dune field itself. During the survey efforts, there were 330 lizards, 261 snakes, and one turtle observed (McKeever 2009a). Reptiles found in the highest numbers were the western diamond-backed rattlesnake, little striped whiptail, and the eastern side-blotched lizard, 86, 84, and 77 individuals were encountered, respectively. Two species were not encountered, but are known to inhabit the park; the southwestern earless lizard and the Trans-Pecos blind snake.

As mentioned previously, species abundance is a component of species diversity. While Prival and Goode (2011) did not report a metric for species diversity, the report did record the number of individuals observed during surveys from 2003-2004. The species abundance values reported by Prival and Goode (2011) are included in Table 25.

**Table 25.** The number of each species encountered in the Prival et al. (2011) survey at WHSA.

| Scientific name | Common name | Number observed |
|---|---|---|
| *Arizona elegans philipi* | painted desert glossy snake | 4 |
| *Aspidoscelis gypsi* | little white whiptail | 60 |
| *Aspidoscelis inonata llanuras* | plains striped whiptail | 48 |
| *Aspidoscelis marmorata marmorata* | western marbled whiptail | 93 |
| *Crotalus atrox* | western diamond backed rattlesnake | 3 |
| *Crotalus viridis viridis* | green prairie rattlesnake | 5 |
| *Crotaphytus collaris* | eastern collared lizard | 4 |
| *Gambelia wislizenii* | long-nosed leopard lizard | 5 |
| *Holbrookia maculata ruthveni* | bleached earless lizard | 26 |
| *Hypsiglena torquata janii* | Texas nightsnake | 4 |
| *Lampropeltis getula splendida* | desert kingsnake | 1 |
| *Leptotyphlops humilis segregus* | Trans-Pecos threadsnake | 4 |
| *Masticophis flagellum testaceus* | western coachwhip | 5 |
| *Phrynosoma modestum* | round-tailed horned lizard | 2 |
| *Pituophis catenifer affinus* | sonoran gophersnake | 2 |
| *Rhinocheilus lecontei tessellatus* | Texas long-nosed snake | 3 |
| *Sceloporus cowlesi* | southwestern fence lizard | 53 |
| *Sceloporus magister* | twin spotted spotty lizard | 18 |
| *Sistrusus catenatus edwardsii* | desert massassauga | 1 |
| *Tantilla nigriceps* | plains black-headed snake | 5 |
| *Terrapene ornata luteola* | desert box turtle | 1 |
| *Uto stansburiana* | common side-blotched lizard | 214 |

Des Roches et al. (2011) computed the diversity of lizard populations in order to compare the lizard diversity inside the gypsum dune field and outside the dune field (referred to as the dark soil area). Although results showed that the species richness of lizards was significantly higher outside the dune field, there was no difference in general abundance (Figure 46; Des Roches et al. 2011).

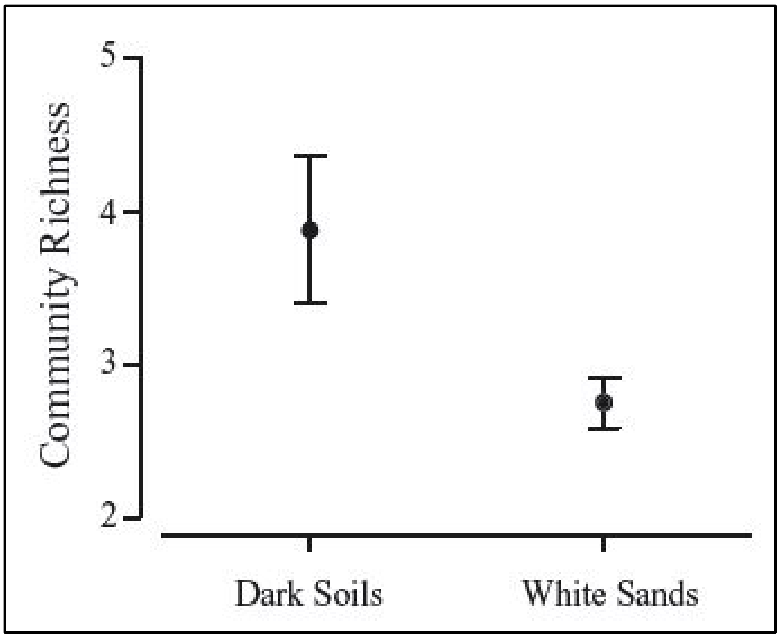


**Figure 46.** Mean lizard community richness (Shannon's H) in dark soils and white sands habitat. Circles represent the mean and error bars represent the standard error of the mean (reproduced from Des Roches et al. 2011).

Threats and Stressor Factors

WHSA staff identified existing roadways, roadway development, energy development (wind and solar), changes in landcover, habitat fragmentation, poaching, shifts in predators (roadrunners and shrikes), and climate change as potential threats and stressors to the reptile community at the park.

*Roadway Mortality*

Reptiles are affected by roadways in a variety of ways, the most common being direct mortality (Ehmann and Cogger 1985, Kline and Swann 1998, Seigel and Pilgrim 2002, Jochimsen et al. 2004), and habitat fragmentation (Jochimsen et al. 2004). Forman and Alexander (1998, p. 212) state that "Sometime during the last three decades, roads with vehicles probably overtook hunting as the leading direct human cause of vertebrate mortality on land." Reptiles in and near WHSA are susceptible to roadway mortality, as State Highway 70 runs adjacent to the southeastern boundary of the park. Road traffic within the park may impact reptile communities as well, as the daily plowing of the park entrance road is a possible source of reptile mortalities and disturbance. Many of the reptile species observed by Prival and Goode (2011) from 2004-2004 occurred near the entrance road into the park (Figure 47). McKeever (2009b) took notes on snake road mortalities whenever possible and found some differences among species as well as road type. The species of snakes that tend to reach longer body lengths were more often encountered dead-on-road (DOR); a higher frequency of alive-on-road (AOR) encounters was observed in the shorter bodied species of snakes (McKeever 2009b). The behavior of snakes was considered a possible factor in road mortality rates as well as average travel speeds and traffic volume; the highest rate of snake road mortality was found on U.S. Highway 70 (McKeever 2009b). This road experiences high volumes of traffic and is in close proximity to the southern boundary of the park (Figure 47).

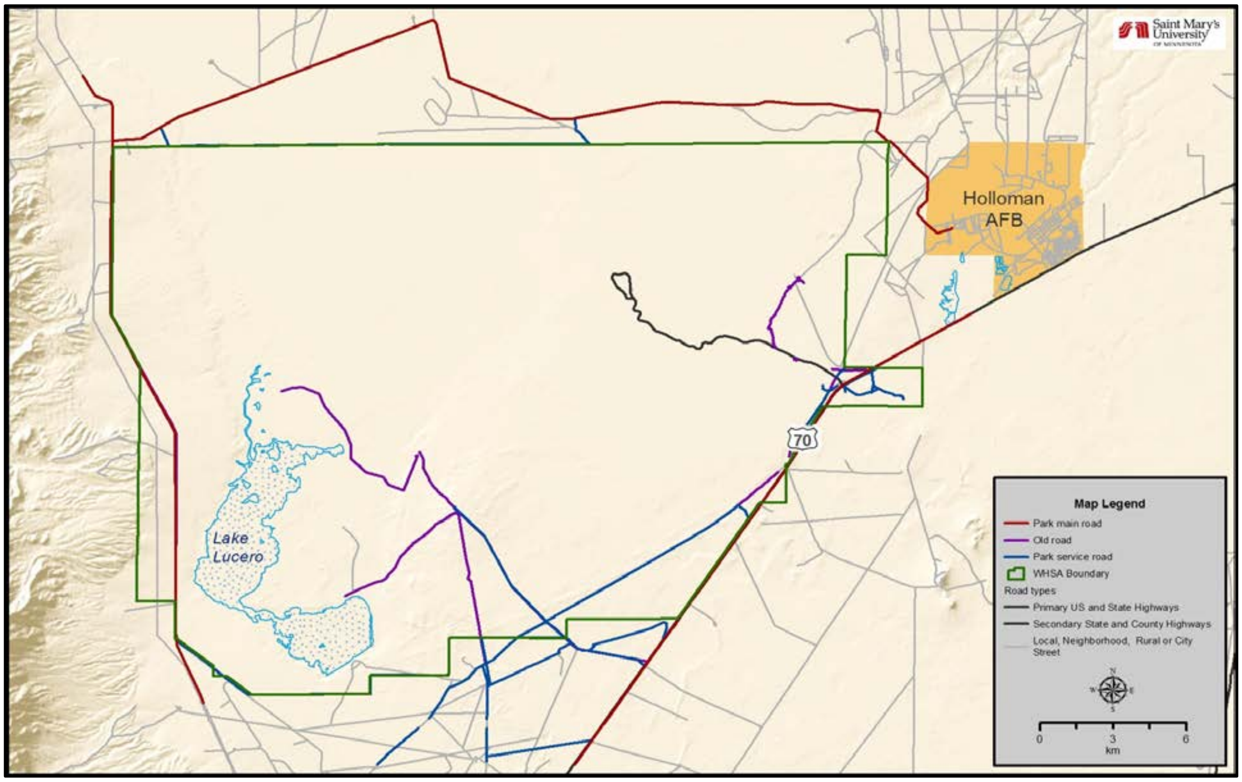


**Figure 47.** The roadways that may pose a threat or that may be a stressor to reptiles at the park are shown, state highway 70 is of particular concern since it is located at the edge of the park boundary and experiences heavy traffic.

The indirect effects that roadways have on herpetofauna have been poorly studied; much of the research on this topic has been dedicated to mammalian and avian species (Jochimsen et al. 2004). However, roads often serve as a boundary between habitat types, sometimes separating breeding areas from foraging areas (Palta 1997), and fragment normally continuous habitats. Furthermore, certain species may use roads as corridors for movement, and may increase the risk of vehicular strike, or exotic/invasive species establishment. Seabrook and Dettmann (1996) observed that the roads and trails across Australia allowed for the range expansion of an introduced toad species. The fragmentation of habitat by roads is thought to have contributed to altered distribution patterns in reptiles (Rudolph et al 1998), lower recolonization rates and increased extinction risks in local reptile populations (Vos and Chardon 1998), and lowered species richness in snakes (Kjoss and Litvaitis 2001).

*Poaching/Illegal Collection*

Although poaching has not been a major concern for park managers, a few isolated incidents have occurred at the park. There have been a few instances of rattlesnake mortalities, presumed to have been killed by visitors were observed between 1971 and 1977 (Bob McKeever, former National Park Service Law Enforcement Ranger, written communication, 16 July 2014). During a herpetological survey in 2009, a visitor was encountered in the act or poaching a Sonoran gopher snake along the Dunes Drive, and one rattlesnake was found killed as well (McKeever, written communication, 16

July 2014). McKeever (2009b) noted the discovery of rattlesnakes with rattles removed, chopped into pieces, and decapitated.

According to a study on the collection, trade, and regulation of herpetofauna of the Chihuahuan Desert ecoregion (Fitzerald et al. 2004), there are many accounts of reptile exploitation in the United States, including New Mexico. Herptiles are sought out by poachers to supply the demand for food, pets, leather, curios (trinkets), and other reasons (Fitzgerald et al. 2004). New Mexico state laws prohibit the collection of native, free-ranging herptiles without possession of a valid commercial collecting permit, though collection of wildlife on park property is explicitly prohibited (Title 36 Code of the Federal Regulations). The impact of illegal harvest of reptiles at WHSA is largely unknown, though dozens of reptile species that inhabit the Chihuahuan Desert are targeted by poachers

*Shifts in Predators*

Predation of reptiles at WHSA occurs, and common predators found at the park include: the loggerhead shrike (*Lanius ludovicianus*), American kestrel (*Falco sparverius*), and greater roadrunner (*Geococcyx californianus*). Des Roches et al. (2011) conducted analysis on the abundance and number of species of predatory avian fauna inside and outside of the dune field and found higher abundance of avian predators outside of the dune field. The study noted that the key avian predators of lizards, the loggerhead shrike, American kestrel and the greater roadrunner, were not observed in either habitat (Des Roches et al. 2011).

*Climate Change*

Precipitation patterns in the desert tend to be pulse driven; the rain events are often sporadic and create ephemeral water sources that are quickly utilized by flora and fauna for reproductive requirements (Noble et al. 1995). A change in frequency, duration, and timing is likely to heavily impact the arid desert ecology because of its adaptations to the complex reliance on these pulse events (Noble et al. 1995). As explained by Noble et al. (1995), pulse adapted species may be at a greater disadvantage with changes in climate; alternately there are also advantages to pulse adapted species when considering that they are adapted to extreme conditions.

The White Sands Dune Field has been interpreted as a wet aeolian system where soil moisture plays an important role in the sediment dynamics (Crabaugh 1994, Kocurek and Havholm 1994, Kocurek et al. 2007, Langford et al. 2009). As the sediment dries it can be move exponentially with a giving velocity of wind (Allmendinger 1972). The vast majority of habits east of the western mountain bajada are susceptible to climate change and drought. If the soil moisture that stabilizes the system were to change the dune systems grassland, cottonwood stands and surrounding scrubland would all likely be directly affected by shifting dunes.

Data Needs/Gaps

No survey at the park has examined the species diversity of WHSA. A long-term survey of the reptile community in the park is needed to assess the current species diversity of the park. While Prival and Goode (2011) surveyed much of WHSA, the western portion of the park was not surveyed. Expansion of past survey efforts is needed to better understand the species richness and diversity of the entire park. Rotenberry et al. (2008) suggests that some species not previously documented may exist within the park.

At the conclusion of the Prival and Goode (2011), the authors have several recommendations for future surveys and data needs within the park. These suggestions were:

> *Of the four monitoring strategies outlined, we recommend creating a monitoring program that will emphasize the ability to detect changes in distribution and relative abundance rather than species composition or species richness, because distribution and relative abundance are more likely to provide information on important community-level changes in time to take conservation measures. Species composition and richness should be recorded also; however, these parameters are less likely to indicate that something bad is happening until it is too late* (Prival and Goode 2011, p. 85).

Developing monitoring plans to track roadway mortalities in and outside of the park should be considered to quantify roadway impacts on the reptile communities at WHSA. Additionally, continued study of the unique reptile species in the dune field area, especially those species with unique color morphology and speciation events is recommended.

Overall Condition

*Distribution of Species*

The *Significance Level* for distribution of species was assigned a 2. Since the most recent distribution data on reptiles is outdated and incomplete, and previous studies have not specifically recorded distributions of the entire reptile community, a *Condition Level* cannot be assigned at this time.

*Distribution of Color Phase Species*

The *Significance Level* for distribution of color phase species was assigned a 1. The C*ondition Level* was assigned a 0 since historic and recent studies have not indicated any changes in the distribution of the color morph reptile species (Lewis 1950, Bugbee 1942, McKeever 2009b, Prival and Goode 2011).

*Species Richness*

The *Significance Level* for species richness was assigned a 3. The *Condition Level* was assigned a 0 since recent studies, compared to historical literature, have not indicated a decline in species richness at the park (Lewis 1950, McKeever 2009b, Prival and Goode 2011).

*Species Diversity*

The *Significance Level* for species diversity was assigned a 3. This measure cannot be assigned a *Condition Level* at this time due to the lack of data that assess this measure. There are differences in richness and abundance, which are the two components of diversity, between the dune field and areas outside the dune field, but there are not any indications that there are any increases or declines in the abundances of reptile species (McKeever 2009a, Prival and Goode 2011, Des Roches et al. 2011).

*Weighted Condition Score*

Due to the lack of data to assess the condition of species diversity and species distribution, it is not possible to assign a *Weighted Condition Score* at this time. Future monitoring and inventory efforts should pursue the collection of distribution and diversity data, and continue to collect data for species richness and the distribution of color phase species in the park. These future efforts should also focus on the west side of the park if possible since researchers have indicated that there may be species inhabiting this area that have not been previously documented and also that documented species may be there in more abundance (Rotenberry et al. 2008, McKeever 2009a,b, Prival and Goode 2011, Des Roches et al. 2011).

| Reptiles | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = N/A** |
| Color Phase Species Distribution | 2 | n/a | |
| Species Richness | 1 | 0 | |
| Species Distribution | 3 | 0 | |
| Species Diversity | 3 | n/a | |

#### *4.5.6. Sources of Expertise*

- David Bustos, Resource Program Manager, WHSA
- Hildy Reiser, Science Advisor, CHDN (Retired)
- Bob McKeever, former NPS Law Enforcement Ranger

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## 4.6. Desert Faunal Community

### *4.6.1. Description*

The Chihuahuan Desert is a unique ecosystem that has a tremendous diversity of habitat types and species. The desert is a difficult ecosystem for animals to survive and thrive in, however, as summer temperatures are very warm, and winters are short and mild (Schmidt 1979). Rainfall is sparse and sporadic, with the majority of rainfall events occurring in the late summer and early fall in the form of monsoonal rain; average precipitation in the WHSA region is 25 cm (9.8 in), but between-year variability is high (Robinson et al. 2014). Consequently, many of the faunal species in WHSA (and the Chihuahuan Desert as a whole) have unique adaptations that allow them to survive and persist under conditions of limited water availability. Species such as Merriam's kangaroo rat (*Dipodomys merriami*) (Schmidt-Neilson 1964, Yousef and Dill 1970) and kit fox (*Vulpes macrotis*; Photo 18) (Golightly and Ohmart 1984, Robinson et al. 2014) have unique physiological adaptations that allow them to retain high levels of water and meet almost all of their water requirements from foraging on prey or plant species.

**Photo 18.** A kit fox roaming the gypsum dunes of WHSA at night time (NPS photo).

In WHSA, the gypsum dune fields and desert scrublands are of particular importance to the various faunal species in the park, as they provide critical areas for foraging and shelter. The large expanse of gypsum dunes in WHSA is less than 10,000 years old and has provided a unique opportunity for researchers to observe the evolution and adaptation of several faunal species. Species of lizards, snakes, rodents, and insects have developed a unique white coloration that helps camouflage themselves in the white dunes (Benson 1932, Blair 1941, Stroud and Strohecker 1949, Hager 2002, Rosenblum 2005; 2006, NPS and CHDN 2010). The invertebrate community of WHSA, particularly those species that inhabit the dune fields of the park, is vast, and over 600 species of Lepidoptera (butterflies and moths) have been documented within WHSA (Metzler 2014b). Several new species to science have been documented in recent years in the gypsum dunes of WHSA (Metzler 2014b). According to Metzler (2014a, p. 83), "The number of endemic species of moths to White Sands National Monument compared to all of North America is the highest for a single location." The dune fields also provide refuge for several species; for example, the kit fox will often seek out and utilize areas of the dunes that are relatively prey-poor, likely in an effort to avoid competition and predation from its interspecific predator the coyote (*Canis latrans*; Photo 19) (Robinson et al. 2014).

**Photo 19.** A coyote with a prey item in the gypsum dune field of WHSA (NPS photo).

Unlike the barren gypsum dunes, the desert scrub community in WHSA is characterized by several plant species, most notably fourwing saltbush, mesquite, spiny allthorn (*Koeberlinia spinosa*), creosotebush, pickleweed and tarbush (Muldavin et al. 2000, Robinson al. 2014). This desert community is particularly important for the faunal species in WHSA, as it provides plant material for forage, shelter for burrowing (e.g., heteromyid rodents) and denning (e.g., American badger [*Taxidea taxus*]), and provides a forage habitat for predatory species such as coyotes, kit foxes, and badgers. The heteromyid community of the desert scrub is critical, as heteromyids are responsible for creating feedback mechanisms in this ecosystem through their burrowing, herbivory, and granivory (Brown and Heske 1990, Guo et al. 1995, Whitford and Bestelmeyer 2006, NPS and CHDN 2010). Furthermore, this mammalian group represents an important prey base for secondary and tertiary consumers (NPS and CHDN 2010).

The park's desert faunal community is incredibly diverse and impossible to summarize in a single component; WHSA is home to over 50 species of mammals (Appendix I), 160 species of birds, 35 species of herpetofauna, and well over 1,000 species of invertebrates. For this reason, focal groups of fauna have been identified for discussion in their own components. Birds are discussed in Chapter 4.3 and 4.4, reptiles are discussed in Chapter 4.5, and terrestrial and aquatic invertebrates are discussed in Chapter 4.7. This component will give primary focus to the mesocarnivore community of WHSA (Appendix J), with particular emphasis given to the predator-prey dynamics of this community. Interpretation of the measures below should keep this mesocarnivore focus in mind. Mesocarnivores include species in the order Carnivora that are small and mid-sized (i.e., <15 kg [33 lbs]), and typically have higher species richness numbers and more diverse behaviors and ecology than the large carnivore species (Roemer et al. 2009). Because of the relatively small size of mesocarnivores, and the fact that they can survive and thrive in a variety of habitat types, mesocarnivores are typically more abundant in a given habitat type when compared to larger carnivores (Roemer et al. 2009).

#### *4.6.2. Measures*

- Species richness in habitat types
- Species distribution
- Species abundance

#### *4.6.3. Reference Conditions/Values*

The ideal reference condition for the desert faunal community in WHSA is the time period before ranching and Anglo settlement (ca. 1850s). However, data from this time period are not available. For this assessment, species richness will use the NPS Certified Species List (NPS 2015) as a reference condition of species richness; all other metrics will operate without a reference condition and will rely upon the best professional judgment of NPS staff.

NPS (2015) represents the Certified Species list for WHSA, and identifies 11 mesocarnivore species (Table 26). Observations of only these species, as reported by different sources and studies, are included in this assessment.

**Table 26.** Mesocarnivore species in WHSA as identified by NPS (2015).

| Scientific name | Common name |
|---|---|
| *Canis latrans* | coyote |
| *Urocyon cinereoargenteus* | common gray fox |
| *Vulpes macrotis* | kit fox |
| *Lynx rufus* | bobcat |
| *Conepatus leuconotus* | white-backed hog-nosed skunk |
| *Mephitis mephitis* | striped skunk |
| *Spilogale gracilis* | western spotted skunk* |
| *Mustela frenata* | long-tailed weasel |
| *Taxidea taxus* | American badger |
| *Bassariscus astutus* | ringtail |
| *Procyon lotor* | northern raccoon |

* Species defined as “probably present” in the park; all other species are confirmed as present

#### *4.6.4. Data and Methods*

The NPS Certified Species List (NPS 2015) identifies all of the accepted mammalian species in WHSA. For this assessment, only the mesocarnivore species are discussed. The complete list of mammals in WHSA is presented in Appendix I, while the list of present and probably present mesocarnivore species is presented in Table 26.

There have been relatively few studies of the mammalian species in the WHSA area, and even fewer studies focused exclusively on the mesocarnivores. One of the earliest records for the area is Bailey (1913), which represents a summary of the characteristic species for each zone in New Mexico. Bailey (1913) identified six life zones in the state, and WHSA fell into the Lower Sonoran Zone (see Figure 1 in Bailey [1913]). Final species lists for each zone were created using a combination of field work and local communities’ species lists. Some of the very common species that ranged across almost every zone were excluded from each life zone’s list, due to the fact that their distribution had little zonal significance. However, the absence of common species from WHSA’s life zone list makes it impossible to say for certain which species were omitted. Due to the age of the publication, some of the mammalian Latin and common names were out of date. These names have been adjusted in this document and should now represent the most currently accepted taxonomic name.

Halloran (1946) discussed accounts of carnivores in the nearby San Andres National Wildlife Refuge (SANWR) from 1941-1944. Field observations were primarily achieved as part of a trapping effort, as refuge managers were trapping cat species in an effort to protect the resident desert bighorn sheep (*Ovis canadensis nelsoni*) population. Records of carnivore species are discussed in Halloran (1946), and when applicable, trapping records for each species or anecdotal historical observations were briefly summarized for the area. In 1965, SANWR released a mammal list for the refuge (USFWS 1965); Appendix I displays all mammalian species on this list, although this assessment will focus only on the mesocarnivore species. This list was prepared by refuge staff, and also had contributions from New Mexico State University. Similar to Bailey (1913), some of the mammalian Latin and common names were out of date. These names have been adjusted in this document and should now represent the most currently accepted taxonomic name.

Robinson (2013) and Robinson et al. (2014) investigated an occupancy model to better understand the intraguild predation dynamic in WHSA between the kit fox and coyote. Intraguild predation is when two species compete for the same basic prey resources, and sometimes consume each other (Robinson 2013). Typically, the larger dominant species (coyote) will kill the smaller species (kit fox) that may be better suited or more efficient at killing the shared prey resources. These two studies (Robinson 2013, Robinson et al. 2014) selected 86 locations across six major habitat types (Table 27) in WHSA and placed remote cameras at each site. In 2011, 43 sites were sampled, and in 2012 an additional, independent, 43 sites were also sampled. Sampling surveys were split into 24 10-day intervals, with 13 surveys in 2011 and 11 surveys in 2012. All detections of coyotes and kit foxes were recorded in order to create a site-specific detection history for the two species (Robinson 2013).

**Table 27.** Area and number of camera sites used in the six major habitat types in WHSA during Robinson (2013) (Table reproduced from Robinson 2013). These six major habitat types are used in the species richness measure of this assessment.

| Habitat type | Area (km$^2$) | Proportion of study area | Camera sites |
|---|---:|---:|---:|
| Interdunal Grassland | 122.8 | 0.29 | 24 |
| Gypsum Duneland | 83.7 | 0.19 | 16 |
| Pickleweed Playa | 68.9 | 0.16 | 14 |
| Fourwing Saltbush Shrubland | 63.1 | 0.15 | 12 |
| Gypsum Outcrop Shrubland | 54.1 | 0.13 | 12 |
| Mesquite Shrubland | 37.7 | 0.09 | 8 |
| **Total** | **430.1** | **-** | **86** |

### *4.6.5. Current Condition and Trend*

Species Richness in Six Priority Habitat Types

WHSA preserves a variety of habitat types, with each being utilized at varying intensities by the various mesocarnivore species of the park. The prominent gypsum dome, barchan, and transverse dunelands in the park are almost devoid of plant life, indicative of the harsh physical conditions that prevail in that ecosystem. Conversely, the parabolic dunes and shrublands and grasslands of the park (desert scrub communities) offer refuge for many mesocarnivores, and provide habitat for burrowing rodents and foraging predators. In understanding the overall ecology of the park (including species richness of mesocarnivores) it is important to look at each individual ecosystem that is present in the park. For this reason, WHSA managers have elected to look at mesocarnivore species richness as it pertains to the six priority habitat types as identified in Robinson (2013) and Robinson et al. (2014) (Table 27).

Mesocarnivore data in WHSA are extremely limited, and few, if any, species richness data are available for the individual habitat types in the park. This does not underscore the importance of this measure, however, as this data gap represents a vital need for the park going forward if managers are to fully understand the complexity of this resource. Species richness data are presented below, and are separated by habitat type when possible.

*NPS (2015)*

The NPS Certified Species List identifies 53 mammalian species for the park, 11 of which (20%) are mesocarnivores (Appendix I, Table 26). This list, however, does not allow for a specific analysis of species richness, as no annual data are collected other than the presence (or historic presence) of the identified species in the park. No dates are provided in NPS (2015) to indicate when a species was confirmed as being present in the park.

*Bailey (1913)*

Bailey (1913) represents the earliest mammalian species account for the WHSA area. While Bailey (1913) did not collect in the park, the authors did describe the unique mammalian species of the Lower Sonoran Zone in New Mexico (a zone that includes WHSA). Final species lists for each zone were created using a combination of field work and local communities' species lists. Species were not identified to specific habitat types, so a classification of mesocarnivores into the six priority habitat types in the park is not possible. In the Lower Sonoran Zone, Bailey (1913) identified nine mesocarnivore species (Appendix I).

*Halloran (1946)*

While Halloran (1946) did not report on mesocarnivore richness within WHSA boundaries, the study did identify mesocarnivore species on the nearby SANWR. Accounts of carnivore observations from 1941-1944 indicated 10 unique mesocarnivore species in the SANWR area, but did not indicate which habitat priority habitat type the species may use (Appendix I).

*Robinson (2013) and Robinson et al. (2014)*

Robinson (2013) and Robinson et al. (2014) focused observations on coyotes and kit foxes in WHSA. American badgers (detected on 22 days at 19 camera sites) (Photo 20) and bobcats (detected on 14 days at 10 camera sites) were documented during the study, but the habitat location of those trail cameras was not provided. Coyotes were most commonly observed in the shrubland habitats of the park, while kit foxes were more frequently observed in the dunelands and pickleweed playa. The distribution of the species in the park is discussed in more detail later in this assessment.

**Photo 20.** An American badger in WHSA; this species was detected sporadically during Robinson (2013) and Robinson et al.'s (2014) study in the park (NPS photo).

<u>Species Distribution</u>

Few data exist in WHSA that document the distribution of mesocarnivores. The variety of habitat types in the park provide foraging and denning sites for many species, and several areas are of high priority for mesocarnivore species (e.g., desert scrublands). As discussed in Robinson et al. (2014), competition and predation often influence the distribution patterns of several mammalian species; this trend is particularly evident among intraguild predators. To date, the only studies to document the distribution of mesocarnivores in WHSA are Robinson (2013) and Robinson et al. (2014). These studies focused only on the distribution patterns/occupancy patterns of two species in WHSA: the kit fox and the coyote. This measure will represent a data gap for the park, but a discussion and summary of the results of Robinson (2013) and Robinson et al. (2014) are still provided below.

*Robinson (2013) and Robinson et al. (2014)*

Coyotes and kit foxes were observed in all habitat types (Table 27; Figure 48) during the course of the study, with coyotes being documented on 324 days at 55 different camera sites (Robinson 2013). Coyotes were almost 21 times more likely to be observed in the shrubland habitat types (fourwing saltbush, gypsum outcrop, and mesquite) when compared to the gypsum dunelands and pickleweed playa (Figure 49). Coyote occupancy in a habitat type was strongly correlated with the presence and abundance of prey species in that habtiat type (Robinson et al. 2014); the odds of a coyote being observed at a shrubland habitat that was rich in prey species was 332:1 (Robinson et al. 2014). Conversely, the odds of observing a coyote at a prey-poor habitat site (such as the gypsum dunelands) were 1:4 (Robinson et al. 2014).

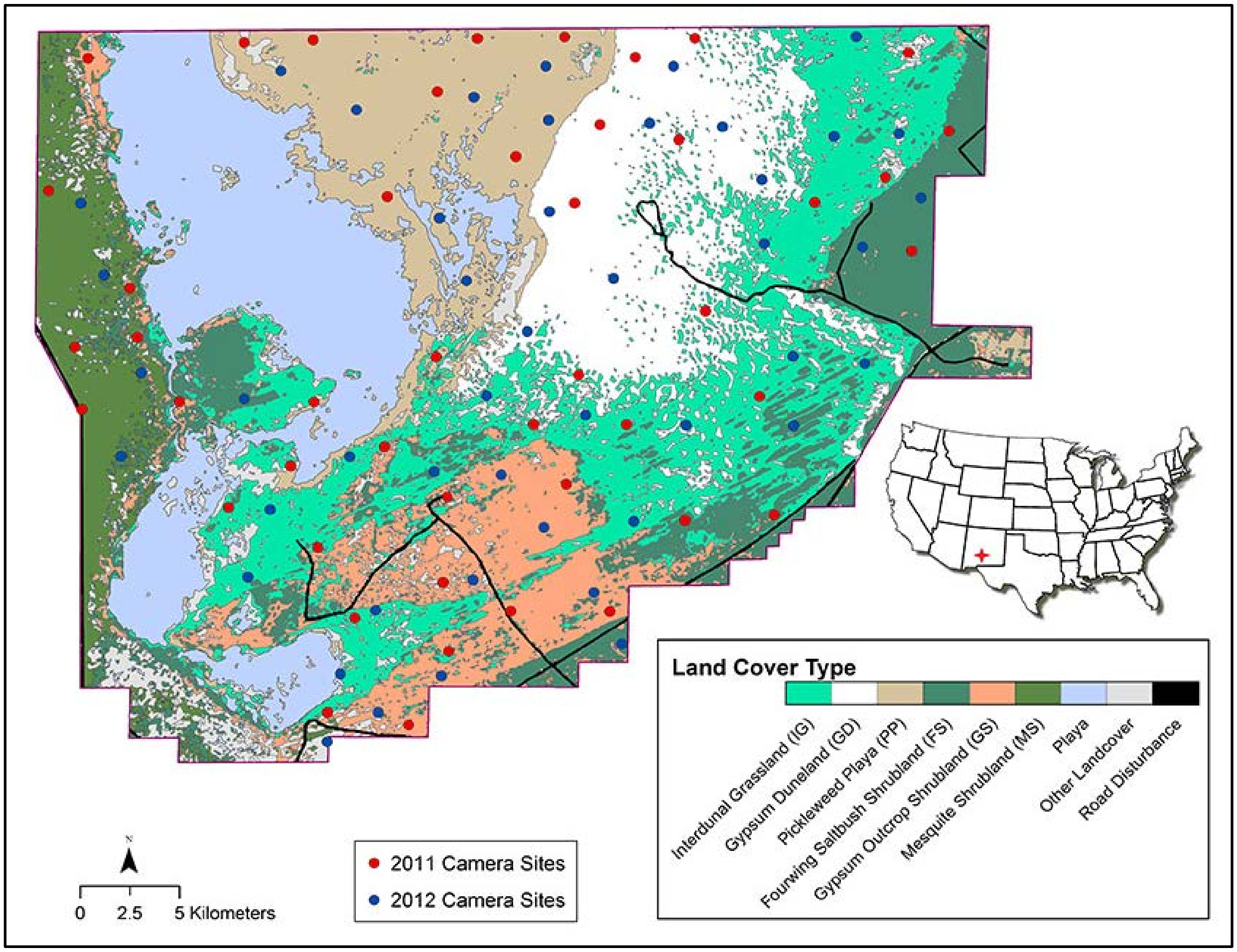


**Figure 48.** The distribution of cameras and photographs of land cover types in WHSA during Robinson et al. (2014).

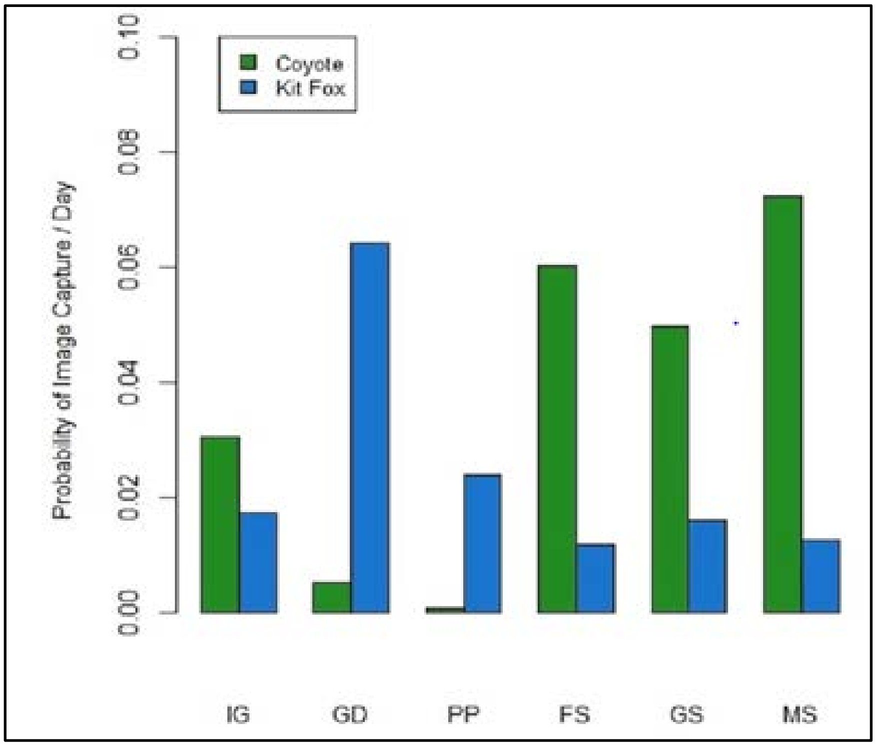


**Figure 49.** Total coyote and kit fox detection days at 86 remote camera sites across the six major habitat types in WHSA (reproduced from Robinson 2013). Abbreviations follow the same definitions as defined in Figure 49.

Kit foxes exhibited distribution patterns inverse of the coyotes, as the species was approximately five times more likely to be observed in the gypsum dunelands than the shrubland habitat types (Figure 49). Robinson et al. (2014) found that kit fox occupancy was approximately the same between prey-rich (i.e., desertscrub) and prey-poor (i.e., dunelands) habitats, although the likelihood of observing a kit fox at a camera site was higher at sites where coyotes were absent. At sites where coyotes were not present, the odds of observing a kit fox were 7.9:1, while the odds of observing a kit fox at sites where coyotes were present were 2.2:1 (Robinson et al. 2014).

The distribution patterns observed in Robinson (2013) and Robinson et al. (2014) indicate that the kit fox is able to avoid coyotes in the park by occupying prey-poor habitat types that the coyote cannot utilize, despite sharing several prey species with the coyote. The kit fox is an exploitative competitor and, due to unique physiological adaptations (e.g., large ears, smaller body size) and nutrition/water requirements, can persist in areas where prey species are less abundant. The coyote cannot occupy these areas for long durations, as the habitats fail to provide the coyote with adequate resources to satisfy metabolic and water requirements of the species (Robinson 2013).

Species Abundance

The species abundance measure investigates and discusses the total number of mesocarnivore individuals observed in a habitat type, study year, or the park as a whole. This measure is typically used to estimate population size in a park or specific habitat type, and is useful for managers to detect changes in a species' overall population size or frequency of detection. Unfortunately, no data exist that specifically relate to mesocarnivore species abundance for WHSA. Robinson (2013) and Robinson et al. (2014) discuss the detection probability of kit foxes and coyotes in the various habitat types in the park, which are discussed above in the species distribution measure. However, this study did not document species abundance (i.e., the number of individuals observed), as abundance was difficult to document using trail cameras alone. It is often not possible to determine total species abundance using trail cameras alone, as it becomes uncertain if individuals observed are unique individuals, or just repeated observations of the same individual over a longer time period.

Threats and Stressor Factors

During project scoping, WHSA staff identified several threats to the mesocarnivore species in the park, one of which dealt with the roads that ran along and within the park. The two major impacts that roads have on animal species are direct mortality through vehicle strikes, and fragmentation due to roads acting as movement barriers (Forman and Alexander 1998). Fragmentation, while certainly a concern, is likely to be minimal in WHSA as there are only a few roads in the park, many of which are primitive (i.e., the primitive Dunes Drive). The presence of the oryx exclosure fence that surrounds the entire park boundary certainly has the potential to fragment the landscape. The presence of this fence may alter home range expansion of some species, and may factor in to the distribution of prey species within and outside of the park. Additional research into the effects that this fence has on fragmentation and distribution of mesocarnivores is needed.

Traffic related mortality represents a threat to the mesocarnivore population of WHSA. U.S. Highway 70 passes along the southeastern boundary of the park and traverses through primarily fourwing saltbush shrublands (Figure 49). This habitat type is highly utilized by mesocarnivore species (Figure 49). Additionally, small mammal and lagomorph species are also likely to be struck by cars, which could impact the prey availability for mesocarnivore species in the park.

Typically, discussion of disease and mesocarnivores centers on the threat of human exposure, and not necessarily on the impacts to the mesocarnivores themselves. According to Ray (2000, p. 12), the main conservation issues posed by diseases in mesocarnivores are two-fold:

> *First, transmission of diseases among mesocarnivore species remains ill-understood, and evidence suggests that this phenomenon is occurring to an increasing extent as land use changes bring about more inter-specific contacts between species that previously did not share ranges. Second, the financial costs associated with protection of human populations can be quite substantial, and may take away from the conservation and management of the mesocarnivore themselves.*

Disease is a threat to WHSA’s mesocarnivore population, and is a conservation topic that is frequently overlooked. Parasites are a common problem for mesocarnivores, and the species can be hosts to a number of lethal parasite species (Appel 1987). Additionally, there exists a threat of disease transmission from domestic animals (Murray et al. 1999), and a wide variety of diseases have been documented as being transferred to wild carnivorous species (Fox 1983, Daoust and McBurney 1995, Harder and Osterhaus 1997, McBurney et al. 1997). The most recognizable disease that affects both humans and mammals is perhaps rabies; however, the ecology of the rabies virus and its impact on population dynamics of North American mesocarnivores is poorly understood. Regular sampling of mesocarnivores, or necropsies of deceased mesocarnivores, may help managers more fully understand the prevalence of disease in the mesocarnivores of the WHSA area.

Data Needs/Gaps

A comprehensive survey of the mesocarnivore community in WHSA is needed in order to assess the current condition of this component. While detailed work has been completed in the past regarding interactions between the kit fox and coyote, surveys and inventories of other mesocarnivore species are lacking. The establishment of a baseline for the measures identified in this report would allow a point-in-time comparison to gauge the overall health and condition of this community. Monitoring of the park's important desert scrub community is also needed, as this community supports a wide array of faunal species in the park. Additionally, if condition is to be reported for the species richness in the six priority habitat types, monitoring efforts will need to be distributed based on the locales of those habitat types.

Overall Condition

*Species Richness in Six Priority Habitat Types*

The project team defined the *Significance Level* for the species richness in six priority habitat types as a 3. The six priority habitat types were identified by Robinson (2013) and Robinson et al. (2014) during a study of the park's kit fox and coyote interactions (Table 27). However, there exists a significant data gap in regards to both the species richness of the park's mesocarnivores and in the habitat use of those species. Until a more comprehensive survey or inventory takes place in the park, a *Condition Level* cannot be assigned to this measure.

*Species Distribution*

Species distribution was assigned a *Significance Level* of 3 during project scoping. This measure represents a data gap for the park, as no survey has taken place in recent years that has documented the distribution of *all* mesocarnivore species. Robinson (2013) and Robinson et al. (2014) observed coyotes and kit foxes in all habitat types of the park. Coyotes were almost 21 times more likely to be observed in the shurbland habitat types (fourwing saltbush, gypsum outcrop, and mesquite) when compared to the gypsum dunelands and pickleweed playa. Kit foxes exhibited distribution patterns inverse of the coyotes, as the species was approximately five times more likely to be observed in the gypsum dunelands than the shrubland habitat types. Without distribution data for all mesocarnivore species, a *Condition Level* cannot be assigned to this measure.

*Species Abundance*

The species abundance measure was assigned a *Significance Level* of 2. No data exist relating to species abundance (number of individuals) for mesocarnivores in WHSA. Because of this, a *Condition Level* was not assigned to this measure at this time.

*Weighted Condition Score*

A *Weighted Condition Score* for the desert faunal community was unable to be determined due to a lack of data for all of the measures. The current condition and any trends in this resource are unknown.

| Desert Faunal Community | | | |
|---|---|---|---|
| Measures | Significance Level | Condition Level | WCS = N/A |
| Species Richness in Six Priority Habitats | 3 | n/a | |
| Species Distribution | 3 | n/a | |
| Species Abundance | 2 | n/a | |

#### *4.6.6. Sources of Expertise*

- David Bustos, WHSA Resource Program Manager

#### *4.6.7. Literature Cited*


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## 4.7. Terrestrial and Aquatic Invertebrates

### *4.7.1. Description*

WHSA has a highly diverse invertebrate community that plays an integral role in the trophic web of the floral and faunal communities as both prey and pollinators (NPS 2010). Specialized aquatic invertebrates, such as fairy shrimp (*Branchinecta coloradensis*) and seed shrimp (*Herpetocypris* sp.), are an important source of food for larger animals (specifically migratory waterfowl) and are found in the desert playas and Lake Lucero in WHSA (Patrick et al. 1977, NPS 2010). Subterranean and terrestrial invertebrates are important primary consumers that perform nutrient cycling of detritus and animal scat in xeric environments and also are the main food source of many reptile and avian inhabitants (NPS 2010). Unfortunately, there is a significant lack of historic and recent research regarding the invertebrate fauna in WHSA, specifically in the dune fields.

The unique environments of WHSA have resulted in some remarkable speciation events and habitat associations not seen elsewhere in the U.S. According to recent research relating to moths and butterflies, WHSA is home to several hundred species belonging to the order Lepidoptera, and many of these species are endemic to WHSA (e.g., Photo 21; Metzler 2014). Additionally, there is a mutualistic relationship between yucca moths and yucca plants (Powell 1992). The moths pollinate yucca and the yucca serve as a host for the moth larvae, which hatch from eggs that were laid on or in the yucca. There are also two endemic camel cricket species at WHSA: *Ammobaenetes arenicolus*, and *Daininoides larvale* that were identified during field collections in 1945 (Strohecker 1947, Stroud 1950, Eades et al. 2016).

**Photo 21.** Endemic moth species, from top to bottom: *Protogygia whitesandsensis* and *Euxoa lafontainei* (Metzler et al. 2009).

#### *4.7.2. Measures*

- Species Richness
- Precipitation (Timing and Amount)

#### *4.7.3. Reference Conditions/Values*

The reference condition of terrestrial and aquatic invertebrates was identified as the invertebrate community as it would have appeared at the time of park establishment. This reference condition can only be partly described due to a data gap; the earliest publications regarding invertebrate species richness after the 1933 proclamation are from 1942, 1950, 1975, and 1977. There haven't been any drastic environmental changes to the WHSA area since 1977, and more appropriate reference condition may be to look at the current climatic conditions in the area in order to compare them to future conditions as they are likely to change due to climate change (Bustos, written communication, 23 September, 2016).

Bugbee (1942) spent two nights in WHSA in 1940 and 1941, respectively, and recorded notes on invertebrate species and behavior that were encountered during those overnight stays. This report discusses only casual encounters of invertebrate species, and it does not serve as an effective reference condition of invertebrate species richness. The invertebrates noted by Bugbee (1942) include unidentified members of nine taxonomic orders: Coleoptera (beetles), Hemiptera (true bugs), Orthoptera (e.g., grasshoppers, crickets), Lepidoptera (butterflies and moths), Hymenoptera (wasps, bees, and ants), Diptera (flies), Araneae (spiders), Solifugae (sun-spiders, camel-spiders, wind scorpions, and solifuges) and Scorpiones (scorpions).

The species list provided in Stroud (1950) will serve as the reference condition for the terrestrial invertebrate species richness measure, as it is the most extensive list of insect species specific to WHSA. There are 451 species included in the list from nine orders of insects: Coleoptera, Diptera, Hemiptera, Hymenoptera, Isoptera (termites), Lepidoptera, Odonata (dragonflies), Orthoptera, Neuroptera (net-winged insects) (Appendix K). Although, it should be noted that this survey deviates slightly from the reference condition period, as it was published 17 years after WHSA was formed.

Muma (1975) conducted the earliest study that documented Araneae (spiders) in the park dune field and will serve as the reference condition of subsequently documented spider species. Muma (1975) investigated spider populations to determine if any species had developed lighter coloration that has been observed in other WHSA organisms that inhabit the dune field. There were 23 spider species documented in the park during the investigation. In addition, two species of solpugids (wind scorpions) and one species of Scorpiones (scorpions) were recorded.

Patrick et al. (1977) conducted sampling in the ephemeral Lake Lucero to identify the aquatic life in the lake and areas where water stands after rainfall events. This study resulted in the identification of 20 species of invertebrate taxa with presumptive conclusions of the existence of many more species being highly likely (Patrick et al. 1977). The species listed in the report will serve as a reference condition for the aquatic invertebrates at WHSA.

#### *4.7.4. Data and Methods*

Bugbee (1942) collected notes on animal occurrence and activity during two overnight stays in WHSA during the summers of 1940 and 1941. The purpose of the visits was to record notes on the behavior and identification of animals as encountered. Although it was not a formal or intensive inventory of invertebrates, it provides a small sample of invertebrates that were present at that time, just less than 10 years after the park was officially established in 1933.

Stroud (1950) collected insects in and around WHSA in 1946 and 1947 as part of a survey. The survey was conducted from 20-21 June in 1946 and from 5 June to 9 August in 1947. The insect survey includes a few collections made by others and brief descriptions of the associated flora where insects were collected.

Muma (1975) sampled at WHSA from 1 June through 4 September of 1972 in order to study the effects the unique gypsum dune field environment had on the vernal ground-surface spider population. This sampling effort resulted in a list with identified several invertebrate species. An area of salt flats 8 km (5 mi) north of the park was sampled simultaneously. Specimens were collected with can-traps continuously during the sampling effort; each of the 10 can-traps contained ethylene glycol and 70% isopropyl alcohol to kill and preserve specimens between the bi-weekly trap collections (Muma 1975). Five traps were set up in a line 10 m (33 ft) apart in an interdune flat. The other five traps were set up on the southeast face of the barchan dune adjacent to the interdune trap line (Muma 1975).

Patrick et al. (1977) sampled areas in the park where there was periodic standing water. First, soil samples were collected in several areas during normal, dry conditions and wetted with distilled water in beakers or covered dishes. The samples were lighted to simulate 12-hour day and night and aerated with a bubbler while being periodically checked for activity such as algal growth and organisms.

NPS (1992, 1993) produced unpublished lists of known insect orders, families, and species that occur at WHSA (Appendix L). The Lepidoptera species are listed separately due to the large volume of species in this order.

Lightfoot et al. (2014) inventoried and surveyed the arthropods of WHSA and Cuatrocienegas Protected Area (Coahuila, Mexico) from 2010-2012. The primary objective of this effort was to inventory the undescribed to science and potentially endemic species in these areas. The project sampled many locations in WHSA, but prioritized areas in gypsum dunes and interdune swales, gypsum outcrops, surface springs that originated in gypsum substrate, alkali flats, and pickleweed shrublands (Figure 50); there were 24 arthropod sampling sites in WHSA. There were several arthropod sampling methodologies utilized in Lightfoot et al. (2014), examples of active collection methods included: general collection, aerial net collecting, vegetation sweep net collecting, vegetation beating sheets, aquatic dip net collecting, pedestrian UV light collecting for scorpions, and sand sifting. Trapping and bait attraction collection techniques include: aquatic drift nets, pitfall traps, UV light traps, oatmeal bait traps, and bee/pollinator traps.

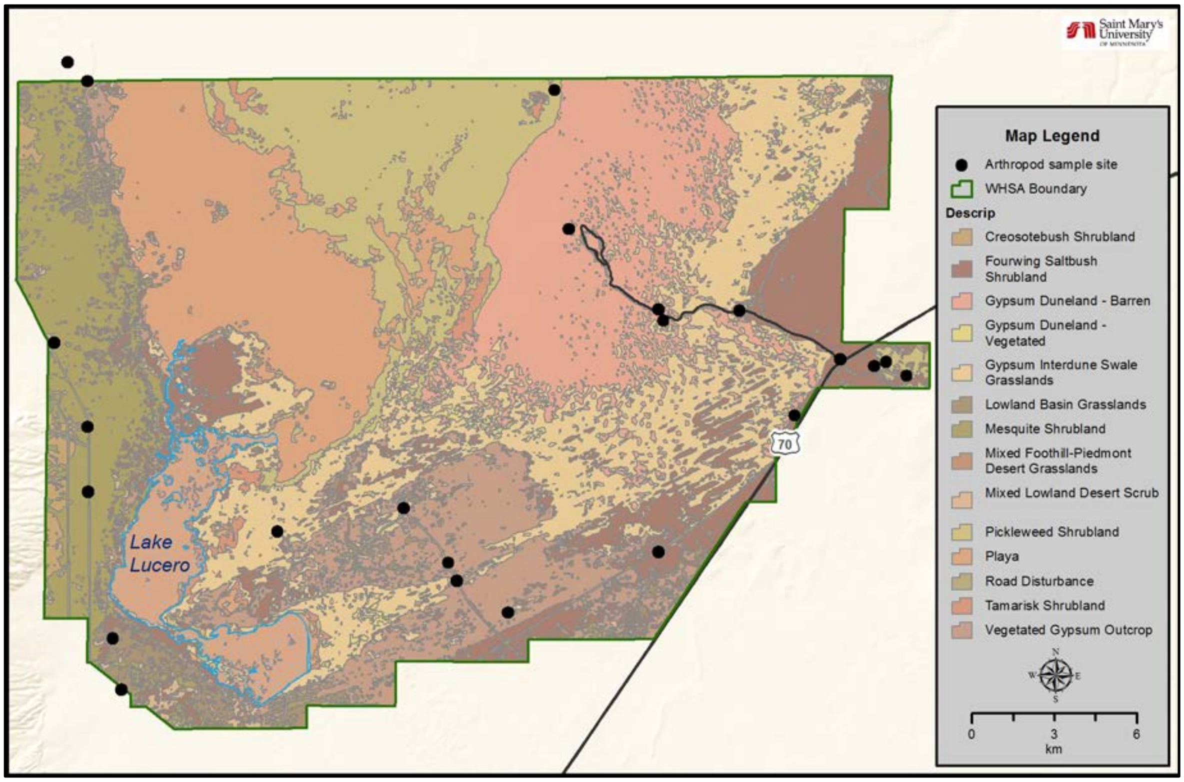


**Figure 50.** Arthropod survey sites sampled during both early and late summer of 2010 and 2011. Sample sites obtained from Lightfoot et al. (2014).

<u>Long-term Lepidoptera Studies</u>

Metzler et al. (2009), Metzler and Forbes (2011), and Metzler (2014 a, b) collected moths at WHSA as part of a long-term study on the Lepidoptera community that was initiated in 2006. Moths were collected using bucket-type-black-light traps and black light and sheet methods (Photo 22; Metzler et al. 2009). Identification processes were conducted on adults by dissecting and mounting genital structures on microscope slides; both the whole bodies and chemically-stained and preserved genitals were photographed using a macro-lens (Metzler et al. 2009, Metzler 2014a, b). Some rear legs were removed from some of the pinned adults for submission to the Barcode of Life Data System and used to create cladograms which were used to help delineate and define Lepidoptera species (Metzler 2014b). The forewings were measured and described along with genital descriptions to assist in identification. Select specimens were preserved by pinning with the wings spread and were labeled with the appropriate identification (Metzeler et al. 2009). Caterpillars were also gathered off of plants and raised to adults in laboratory conditions; representative caterpillars were preserved in 95% ethanol (Metzler 2014b). Metzler and Forbes (2011) stated that preserved adults and caterpillars collected for this long-term study are to be integrated into permanent collections at:

- **EHM** Eric H. Metzler, Alamogordo, New Mexico, for subsequent transfer to MSU
- **MSU** Albert J. Cook Arthropod Research Collection, Department of Entomology, Michigan State University, East Lansing, MI
- **UNM** Museum of Southwestern Biology, University of New Mexico, Albuquerque, New Mexico

- **USNM** United States Museum of Natural History (Smithsonian Institution), Washington, DC pending mutual resolution and agreement with the NPS regarding specimen deposition.

**Photo 22.** Bucket-type blacklight trap (Metzler 2014).

### *4.7.5. Current Condition and Trend*

Species Richness

There are two endemic camel cricket species in WHSA: *Ammobaenetes arenicolus* and *Daihiniodes larvale* (Strohecker 1947, Stroud 1950, Eades et al. 2016). The discovery of these two endemic camel cricket species occurred at WHSA in 1945 and 1946.

In total, Stroud (1950) collected and identified 371 taxa, with 352 of specimens being identified to species (Appendix K). The species richness decreased toward the dune field's center, while and the highest species richness values at WHSA were associated with soaptree yucca. Additionally, Stroud (1950) identified eight previously undescribed species; however, those eight species were never subsequently described and there is no evidence of a follow up publication or description as was originally indicated in Stroud (1950). As noted by Lightfoot et al. (2014), the lack of a subsequent description of these species prevents validation that these previously undescribed species were in fact unique.

Muma (1975) focused on the spider community of WHSA, and identified several species of Araneae, one Scorpiones (scorpion) species, and three genera of Solifugae (sun-spiders, camel-spiders, wind-scorpions, and solifuges) (Table 28). In total, 210 individuals of 23 spider species were observed from June-August 1972. Additionally, Muma (1975) observed a lone scorpion (Scorpiones) species, *Paruroctonus utahensis* (formerly *aquilonalis*), during sampling; this species had previously been studied for its cold hardiness by Riddle and Pugach (1976). Two species of Solifugids were also observed during sampling. The spiders listed in Muma (1975) are the earliest record available for WHSA and serves as the reference condition of WHSA spider and other invertebrates.

**Table 28.** The results of the Muma (1975) spider study conducted at WHSA.

| Taxonomic order | Species name |
|---|---|
| Aranae | *Scaphiella hespera* |
| | *Filistata arizonica* |
| | *Filistatoides* new sp. |
| | *Lycosa coloradensis* |
| | *Argennina* sp. (undetermined) |
| | *Dictyna personata* |
| | *Callilepis gosoga* |
| | *Callilepsis* new sp., nr. *Gosoga* |
| | *Herpyllus propinquus* |
| | *Herpyllus hesperolus* |
| | *Cicurina parma* |
| | *Castianeira occidens* |
| | *Piabuna brevispina* |
| | *Psilochorus imitatus* |
| | *Steatoda fulva* |
| | *Apollophanes texanus* |
| | *Apollophanes margareta* |
| | *Pellenes arizonensis* |
| | *Marpissa lineata* |
| | *Micaria longipes* |
| | *Micaria* new species #2 |
| | *Zelotes tuobus* |
| Scorpiones | *Paruroctonus aquilonalis* |
| Solifugae | *Eremobates* sp. (Immature) |
| | *Eremochelis* sp. (Immature) |

Patrick et al. (1977) identified 20 species of aquatic invertebrates, but does not list them by name. There were two crustacean taxa mentioned as “substantially abundant” which were seed shrimp and fairy shrimp. Patrick et al. (1977) indicated that there are likely many other species that exist in the playas, Lake Lucero, and the alkali flat, as these areas become active only when standing water is present.

Lightfoot et al. (2014) was able to identify the majority of their collected specimens to only the family taxonomic level. Inventory efforts varied by year, 1,648 specimens from 15 orders and over 65 families were collected in 2010. In 2011, 933 specimens were collected in WHSA, with specimens coming from 15 orders and over 38 families. Collections in 2012 were less intensive, and Lightfoot et al. (2014) did not report specific results to taxonomic levels. The primary objective of Lightfoot et al. (2014) was to document species of arthropods that were undescribed to science, and during one of the less intense 2012 surveys, the authors documented a small species of moth that was new to science (*Areniscythris whitesands*), and appears to be endemic to WHSA. In addition to this species, Lightfoot et al. (2014) documented four additional species that were previously undescribed (Table 29; Photos 23 and 24).

**Table 29.** List of five undescribed arthropod species and genera found as part of Lightfoot et al. (2014) inventory survey at WHSA. Taxa with species names were found during Lightfoot et al. (2014) and were formally described, other species remain to be formally described. Table modified from Lightfoot et al. (2014).

| Class | Order | Family | Genus | Identifier |
|---|---|---|---|---|
| Hexapoda | Orthoptera | Acrididae | *Cibolacris* | D. C. Lightfoot |
| Hexapoda | Orthoptera | Acrididae | *Trimeroptropis* 1 | D. C. Lightfoot |
| Hexapoda | Orthoptera | Acrididae | *Trimeroptropis* 2 | D. C. Lightfoot |
| Hexapoda | Lepidoptera | Scythrididae | *Areniscythris whitesands* | E. Metzler |
| Hexapoda | Diptera | Asilidae | *Efferia* | G. S. Forbes |

**Photo 23.** *Cibolacris* sp., a previously undescribed Orthopteran species that was observed by Lightfoot et al. (2014). (Photo from Lightfoot and Miller nd).

**Photo 24.** *Efferia* sp., a previously undescribed Dipteran species that was observed by Lightfoot et al. (2014). (Photo from Lightfoot and Miller nd).

*Long-term Lepidoptera Studies at WHSA*

The long-term Lepidoptera study in the park began in 2006, and has resulted in 14 publications. Since 2006, over 600 species of moths have been identified in the park (Metzler 2014, citing unpublished data). In comparison, Stroud (1950) reported only 20 species of Lepidoptera in a 1950 inventory. Additionally, the long-term study in the park has resulted in the identification of approximately 30 species that are new to science (Metzler 2014a, citing unpublished data); several of these new species are described in the studies many publications (e.g., Metzler et al. 2009, Metzler and Forbes 2011, Metzler and Lightfoot 2014). Many of the new species are amelanistic species, which is a coloration variant frequently observed in the park's invertebrate and reptilian species. According to Metzler (2014a, p. 83), "The number of endemic species of moths to White Sands National Monument compared to all of North America is the highest for a single location." The rate of endemism for moth species in the park has been identified as nearly 5% (Metzler 2014b).

Precipitation

Average monthly precipitation for the park is based on records from 1971 through 2011; the late winter, early spring (Feb-Apr) averages are the lowest through the year (Table 30) (NPS 2015).

**Table 30.** Average monthly precipitation in WHSA (NPS 2015).

| Month | Inches | Centimeters |
|---|---|---|
| Jan | 0.60 | 1.52 |
| Feb | 0.39 | 0.99 |
| Mar | 0.27 | 0.69 |
| Apr | 0.29 | 0.74 |
| May | 0.49 | 1.24 |
| Jun | 0.89 | 2.26 |
| Jul | 1.41 | 3.58 |
| Aug | 2.07 | 5.26 |
| Sep | 1.44 | 3.66 |
| Oct | 1.09 | 2.77 |
| Nov | 0.68 | 1.73 |
| Dec | 0.79 | 2.01 |
| **Total** | **10.41** | **26.45** |

There have been some exceptional periods of drought in recent years. In 2011 nearly the entire lower half of New Mexico was in “exceptional” drought for a few weeks in June and July (USDM 2015). Nearly the entire state of New Mexico has been experiencing some level of drought for the past several years. Predominantly warm and dry conditions seem to be the new normal for the state. According to the National Weather Service (NWS) (2013) New Mexico is experiencing below average precipitation regularly, particularly for 12 and 24 month periods ending in April. The 2013 precipitation averages for the Tularosa area, where the park is situated, are not even half of what is considered normal (Table 31; NWS 2013).

**Table 31.** The 2013 (water year) precipitation data for the Tularosa Area (NWS 2013).

| Period | Observed mm (inches) | Normal mm (inches) | Percent of normal |
|---|---|---|---|
| October 2012-April 2013 | 8.64 (0.34) | 35.05 (1.38) | 25% |
| January 2013-April 2013 | 33.02 (1.3) | 89.41 (3.52) | 37% |

WHSA is considered a desert environment with already, very low annual precipitation. Periods of drought can still have an adverse impact on the invertebrate community and the floral and faunal communities that rely upon them for pollination and sustenance. According to Enquist and Gori (2008) there are numerous drought and climate change-linked ecological changes that have been observed in New Mexico; conservation priorities have been focused on widespread forest dieback, declines in endemic species, and exotic species invasions. Results of Enquist et al. (2008) analysis indicated increasing water deficits in 69 out of 74 watersheds (HUC-8 level) that were increasing from 1970 to 2006; the intensity of drying observed was greater in areas with the lowest elevation as well as the driest. This indicates that low laying areas where it is already very dry (such as WHSA) are only getting drier with the changing climate.

Threats and Stressor Factors

Drought and climate change are contributing to broad ecological changes occurring in and around WHSA and is discussed in the section above for the precipitation measure (Enquist and Gori 2008). The presence of exotic plant species is a threat to invertebrates since it can result in the loss of native plant species by altering the dune field; loss of native plants may result in the loss of specialized pollinators and other invertebrate species that are reliant on specific plant community members (NPS 2010).

Habitat fragmentation is a concern to the invertebrates at WHSA. For example, the presence of water in Lake Lucero and the playas in WHSA provides the necessary resource for aquatic invertebrates to carry out their often short-lived life cycle and for species that rely on water for a portion of their life cycle (e.g., dragonflies, mayflies, midges, and stoneflies). However, the availability of this habitat fluctuates widely, as the lake level depends on the precipitation in the Tularosa Basin which has been declining in the last few decades (Enquist and Gori 2008, NWS 2013, USDM 2015). Situated in a low depression in the basin, Lake Lucero is dry most of the year and only contains water after sustained rain events, at which time the dormant organisms reactivate and reproduce before the water dries up again. The lake has no river outlet, so water will remain in Lake Lucero until it has evaporated. Shifts in precipitation in the area could result in sustained periods where the lake is dry. Many of the aquatic invertebrates are highly tolerant of these dry periods as they simply lay dormant in the sediment until water is again present. The lack of water is more problematic for the migratory birds, mainly waterfowl, which rely on the presence of the aquatic invertebrates for food during long-distance migrations.

Data Needs/Gaps

As stated by Metzler et al. (2009) there is a dearth of research regarding the invertebrate community of WHSA. Recent publications that were part of the long-term Lepidoptera study indicate that WHSA is home to a vast number of moth and butterfly species, and several species that are new to science have been described as part of this effort. It is reasonable to infer that similar patterns may be observed in other invertebrate species if expanded research efforts and inventories were to occur in the park. Continuation of the long-term Lepidoptera study is needed to ensure as many species are documented as is possible.

The dune fields of WHSA represent a unique ecosystem, and with the speciation events that have been observed in the moths and reptiles of the park these areas need additional research to identify all the species (unique to science or not) that may occur in these areas. With the last formal invertebrate survey occurring in the 1940s, this represents a significant data gap for WHSA.

Overall Condition

*Species Richness*

The assessment team assigned the *Significance Level* for species richness as a 3. The majority of the recent publications involve the ongoing, long-term Lepidoptera study and do not include aquatic and other terrestrial invertebrate species in the park. While the results of the long-term Lepidoptera studies appear to indicate low or no concern regarding species richness, a park-wide inventory is needed to determine the species richness of the entire park/insect community. Lightfoot et al. (2014) focused on the arthropod species of the park, but prioritized orders for which they could have a dedicated expert available. Because of this, the study did not inventory the invertebrate as a whole, and prioritized identifying undescribed or endemic species. It is suspected that this measure is currently of good condition, due to the lack of community wide data a *Condition Level* was not assigned.

*Precipitation*

The assessment team assigned the *Significance Level* for precipitation as a 3. Trends in precipitation are declining in New Mexico (Enquist et al. 2008, Enquist and Gori 2008, NWS 2013, USDM 2015). Studies have also indicated these declines are more severe at lower elevations and where precipitation is already low (desert) (Enquist et al. 2008). Considering this trend in precipitation the *Condition Level* has been assigned a 2, or of moderate concern.

*Weighted Condition Score*

The *Weighted Condition Score* could not be calculated due to the data gap for species richness. The precipitation *Condition Level*, however, is of moderate concern. The species richness of invertebrates globally is ranked number one (Metzler 2012, GIGA 2014). That is not to say that the local invertebrate communities of WHSA and other areas are not in danger of decreases in diversity due to these regional precipitation deficits; particularly in regard to endemic species that could be lost if trends in precipitation fragment or destroy critical habitats (i.e. vegetation loss, decline in water availability/timing). It is of concern to managers since the desert invertebrates are highly sensitive, pulse-driven organisms that are vulnerable to climatic shifts that are being documented on a global scale (Schwinning and Sala 2004, Enquist and Gori 2008).

| Terrestrial and Aquatic Invertebrates | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = N/A** |
| Species Richness | 3 | n/a | |
| Precipitation | 3 | 2 | |

### *4.7.6. Sources of Expertise*

- David Bustos, WHSA Resource Program Manager
- Liz Walsh, Department of Biological Sciences, University of Texas at El Paso

### *4.7.7. Literature Cited*


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## 4.8. Soil Faunal Community

### *4.8.1. Description*

Soil faunal communities make up a portion of the soil ecosystem in WHSA. Soils usually contain a large diversity of soil fauna that can be split into three divisions according to size: microfauna (20 µm – 200 µm), mesofauna (200 µm – 2 mm), and macrofauna (2 mm – 20 mm) (Menta 2012). Microfauna include protozoa, small mites, nematodes, and rotifers (Photo 25). Mesofauna includes larger species of mites, nematodes, and rotifers, and additionally springtails. Macrofauna include earthworms, gastropods, isopods, and most insects (e.g., beetles, spiders, diplopods, and chilopods) (Photo 26; Menta 2012). Other mechanisms for classifying soil fauna include time spent in the soil, location in the soil profile, feeding strategies, and method of movement (Wallwork 1970).

**Photo 25.** Examples of soil microfauna found in WHSA: a springtail (*Folsomides parvulus,* left) and an orbatid trash mite (*Orbitada* spp., right) (Photo from Bernard 2014).

**Photo 26.** Examples of soil macrofauna found in WHSA: a wingless wasp (*Ceraphronid* spp., top) and a short-winged barklouse (*Psocopteran* spp., bottom) (Photo form Bernard 2014).

Soil fauna, nematodes in particular, are considered biotic indicators of ecosystem health. They are not only sensitive to changes in habitat, but also to changes in food source abundance. Nematodes are also key organisms in the food web because they consume living material (Unc et al. 2014). For instance, there are nematodes that feed on bacteria (bacteriovores), fungi (fungivores), plants (herbivores), insects (entomopathogens), other nematodes (predators), and algae and other organisms (omnivores) (Thomas and Beacham 2014). Due to the wide variety of trophic levels in nematodes species, it's possible to determine the other components of the soil community by comparing the proportions of the various species present at a site (Thomas and Beacham 2014).

WHSA is located in the Tularosa Basin, and the arid climate and a wet active dune field result in limited habitat type. According to Santos and Whitford (1983), WHSA has densities and taxonomic diversity of microarthropods that are similar to other CHDN units, despite the active dunes and chemical composition of the soils.

#### *4.8.2. Measures*

- Species diversity
- Species diversity for species associated with carbon sequestration

### 4.8.3. Reference Conditions/Values

A reference condition has not been defined for soil faunal community for WHSA. The seasonal and spatial variation in the soil microarthropod fauna observed by Santos and Whitford (1983) between 1977 and 1979 is the most dated study that investigated and identified soil faunal communities. There have not been subsequent studies conducted in the same fashion, so a comparison isn't possible to assess any trends at this time.

### 4.8.4. Data and Methods

Santos and Whitford (1983) conducted a study on the seasonal and spatial variation in the soil microarthropod fauna of WHSA. This study was intended to document the relationship between plant litter accumulations, organic matter content of soil, and the density and diversity of soil microarthropod fauna. Sixteen soil core samples were collected between November 1977 and February 1979. The core samples were taken from different strata including at the edge of dune fields, on dunes, and under shrubs.

Thomas and Beacham (2014) conducted an inventory of soil nematode fauna in WHSA. This inventory was conducted to assess the soil nematode populations in the park, and to compare those populations to others in different ecological sites within the park. The six sites that were chosen were mesquite coppice dunes site, a barren site associated with Lake Lucero, an interdune cottonwood site, an atriplex-grassland site, an intermittent playa site, and an active barchan dune site (Figure 51). Samples were collected post-monsoon season from the six sites between 16 November and 19 December 2011(the seventh site, W7, was sampled on 3 October 2012), and resampling occurred between June 20$^{th}$ and 25$^{th}$ of 2012. Resampling efforts allowed for a comparison of wet and dry season community compositions (Thomas and Beacham 2014).

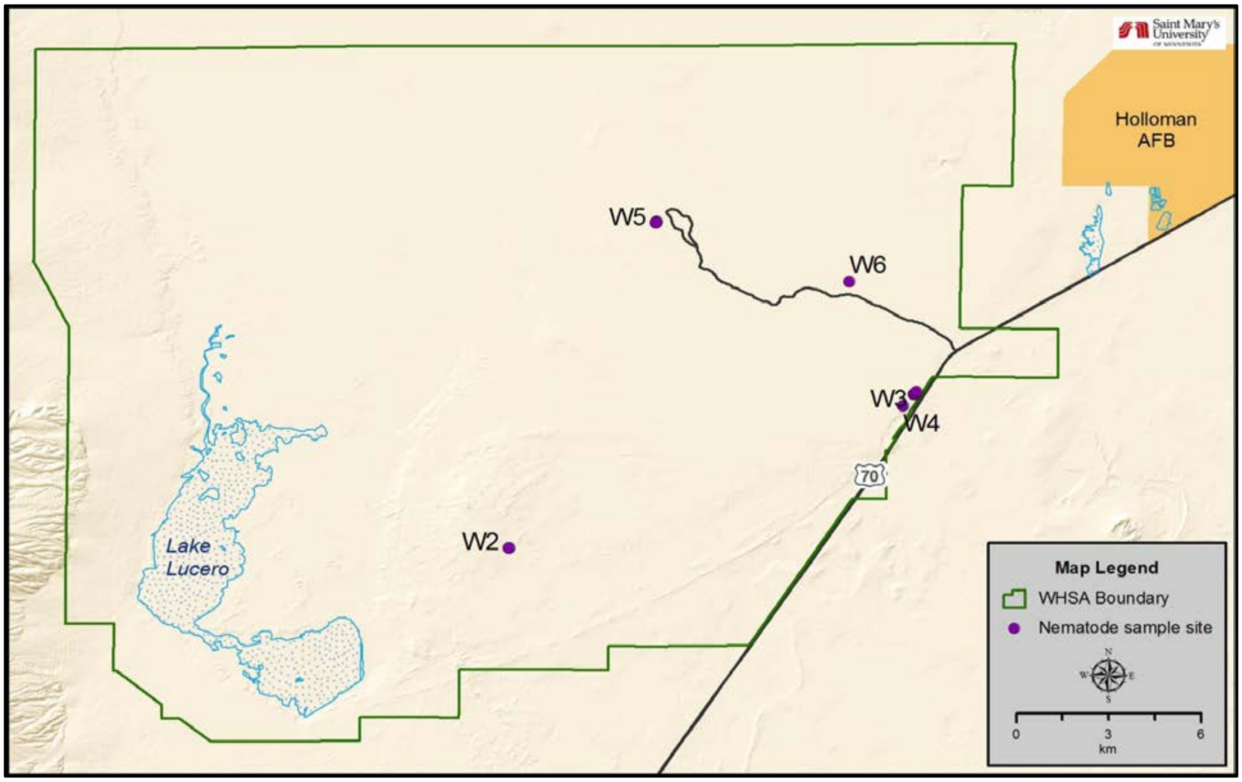


**Figure 51.** Areas where samples were collected during Thomas and Beacham (2014) nematode inventory.

Lightfoot and Miller (2012) conducted an arthropod inventory in WHSA in 2010 and attempted to inventory the WHSA endemic arthropod species as well as to document any undiscovered arthropod species in the park. This inventory targeted certain arthropod taxa including isopods, millipedes, centipedes, spiders, solifuges, and scorpions. Active collection methods were used as well as trapping and bait attraction methods. Active collecting methods included aerial net collecting, vegetation sweep net collecting, vegetation beating sheets, aquatic dip net collecting, pedestrian UV light collecting for scorpions, and sand sifting. Trapping and baiting attraction methods included aquatic drift nets, ultraviolet light traps, UV/mercury vapor lamp sheet lighting, oatmeal bait trails, and bee/pollinator traps.

Unc et al (2014) conducted an inventory on the soil microbial and other soil faunal ecosystem components at WHSA in November 2011. The main purpose of this study was to determine the diversity of bacteria and fungi in the park's soils. There were seven sampling locations, each representing a unique ecological site within the gypsum dune ecosystem, throughout the park. The name/descriptors of those locations include: W1 (Lake Lucero), W2 (interior quartzose sand sheet), W3 (atriplex/alkali sacaton), W4 (cottonwood site), W5 (barchans interdune "islands") W6 (small playa site), and W7 (alkali flat site) (Figure 52).

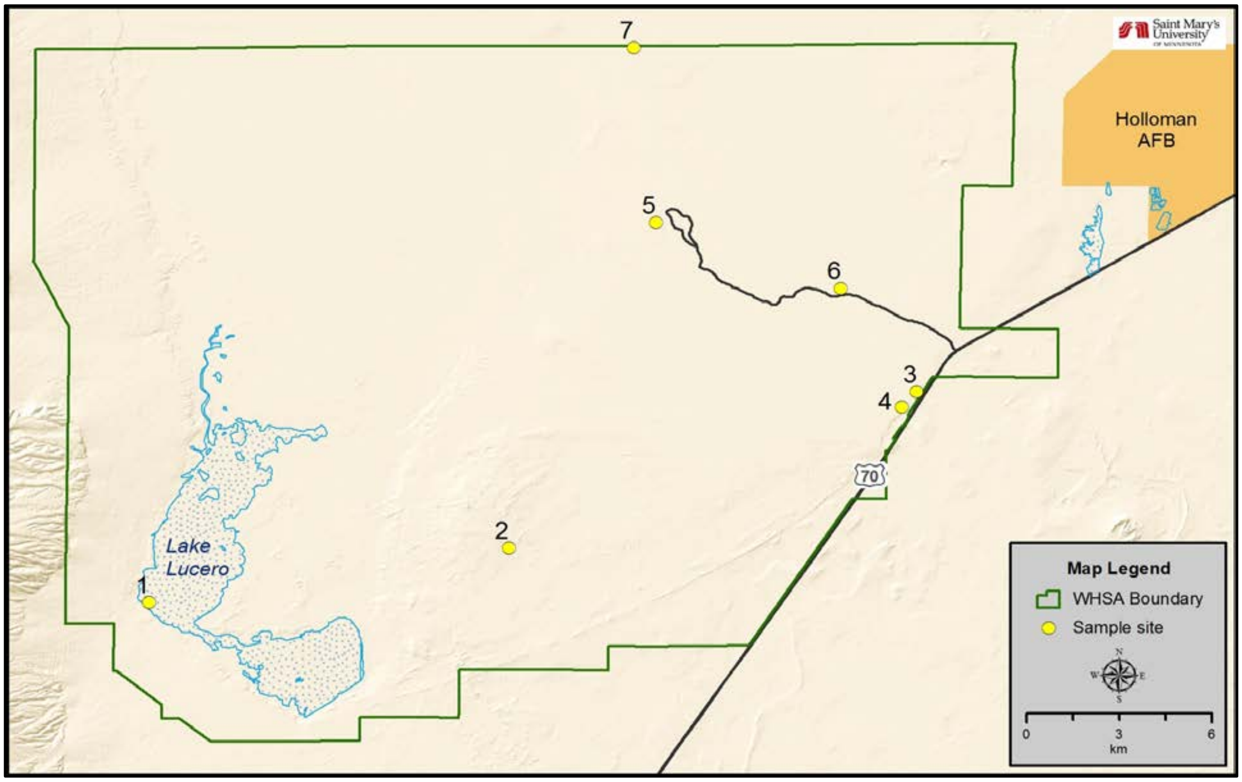


**Figure 52.** Sampling sites used during inventory of soil microbial and soil fauna ecosystems in WHSA in 2011 (Unc et al. 2014).

Bernard (2014) conducted a soil arthropod study as a part of the Unc et al. (2014) inventory in WHSA. Sandy terrestrial samples were rehydrated and scanned for arthropod activity. An aerator was used for samples that may have contained aquatic arthropods. Arthropod species were than identified and recorded.

Monger et al. (2014) conducted an inventory of carbon sequestration organisms in WHSA in 2012. Samples were collected in May 2012. Four sites were chosen, each from an area with different biotic influences in the park. Those sites were described as playa (barren), interdune (primarily barren with sparse areas of vegetation), cottonwood (dune fields with cottonwood trees and other vegetation), and grassland (dense grass and saltbrush) (Figure 53). Large exposures were excavated, soil horizons were described, samples were collected from the horizons, and samples were analyzed by a lab in the Soil Survey Center located in Lincoln, Nebraska.

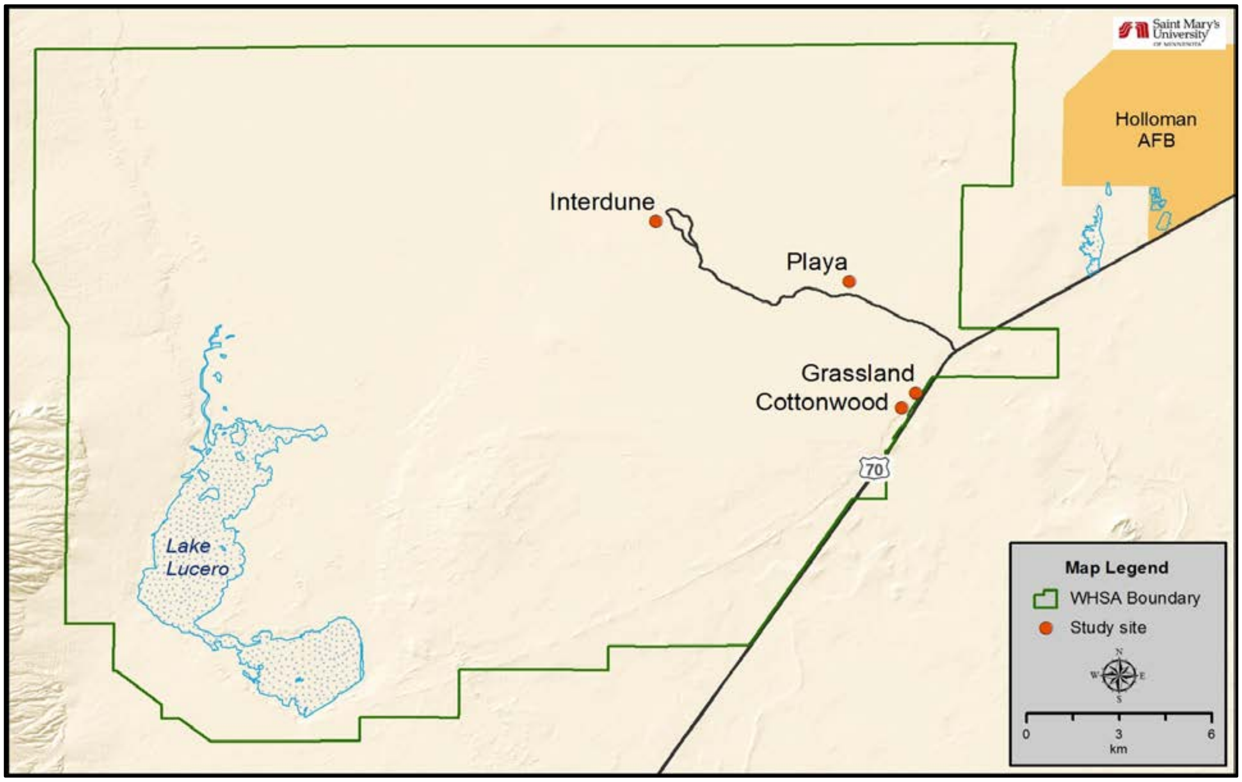


**Figure 53.** The locations of the four study sites used by Monger et al. (2014).

### *4.8.5. Current Condition and Trend*

Species Diversity

Santos and Whitford (1983) documented 20 microarthropod taxa from soil samples in WHSA between 1977 and 1979. A majority of the taxa (19) were part of the Prostigmata suborder (Table 32). Santos and Whitford (1983) noted seasonal changes in soil microarthropod diversity. Temperature and moisture were directly related to microarthropod diversity. For example, during the summer months diversity was higher under shrubs on dunes and interdunes, and little to no microarthropods were observed in unvegetated areas. The most abundant taxa throughout the study were Nanorchestidae, Tarsonemidae, Tydeidae, and Pyemotidae.

**Table 32.** Seasonal variation in relative abundance and diversity of microarthropod taxa in WHSA between 1977 and 1979 (Santos and Whitford 1983). An x indicates the taxon was present, xx indicates the taxon was abundant, xxx indicates the taxon was very abundant (>100 individuals), and a – indicates the taxon was not observed.

| Suborder | Family | November | January | March | May | July | October | February |
|---|---|---|---|---|---|---|---|---|
| Prostigmata | Nanorchestidae | xx | xxx | xxx | xxx | xx | xxx | xxx |
| | Tarsonemidae | xxx | xxx | x | xxx | xxx | xxx | xxx |
| | Anystidae | xx | x | x | x | - | - | x |
| | Tetranychidae | x | x | x | x | x | - | x |
| | Tydeide | x | xx | x | xxx | xx | xxx | xx |
| | Stigmaeidae | x | xx | - | x | xx | x | - |
| | Scutacaidae | x | - | x | - | - | - | - |
| | Paratydeidae | x | x | x | x | - | - | x |
| | Chyletidae | - | x | - | - | - | - | x |
| | Cunaxidae | - | x | - | - | - | - | x |
| | Bdellidae | - | x | x | - | - | x | - |
| | Pyemotidae | - | x | xxx | xxx | xxx | xxx | xxx |
| | Caeculidae | - | - | x | x | x | - | - |
| | Neophyllobiidae | - | - | x | - | - | x | x |
| | Raphignathidae | - | - | x | x | - | - | - |
| | Erythraeidae | - | - | x | x | - | - | - |
| | Teneriffidae | - | - | - | x | - | - | - |
| | Trombiculidae | - | - | - | x | x | - | - |
| | Nematalycidae | - | - | x | - | - | - | - |
| Mesostigmata | Ascidae | x | x | x | x | x | xx | x |

Thomas and Beacham (2014) documented several differences in nematode populations among the study sites in WHSA. Table 33 lists the nine genera and two species of nematodes identified in the study. Thomas and Beacham (2014) did not document any living nematodes at the Lake Lucero site or the interdune cottonwood site (Figure 52). There were only a few nematodes collected from the interdune cottonwood site, which was thought to be low due to the abundance of roots at the sample site. The mesquite coppice dune site had the highest number of fungivore, herbivore, and bacterivore nematode species (53 species: three fungivore species, seven herbivore species, and 43 bacteriovore species, at a depth of 0-10 cm) found at bare-soil sites during the wet season. The artiplex grassland site had a high abundance of herbivore nematode species (383) during the dry season. The active barchan dune site had a prevalence of fungivores (313) during the wet season.

**Table 33.** Genera (and species) of nematodes identified in Thomas and Beacham (2014) inventory at WHSA.

| Genera/Species | Trophic level | Location |
|---|---|---|
| *Acrobeles* spp. | bacterivore | cottonwood rhizosphere |
| *Aphelenchoides* spp. | fungivore | non-vegetated interdunal floor between barchans dunes |
| *Aphelenchus* avenae | fungivore | honey mesquite (Prosopis glandulosa) rhizosphere |
| *Dorylaimid* spp. | omnivore | interior siliceous sand sheet; bare, plant-free soil |
| *Gracilacus* spp. | plant-parasitic | Site 4 alkali sacaton rhizosphere |
| *Hoplolaimus* spp. | plant-parasitic | Site 6 alkali sacaton rhizosphere |
| *Meloidogyne* spp. | plant-parasitic | Site 3 alkali sacaton rhizosphere |
| *Pratylenchus* spp. | plant-parasitic | Site 4 alkali sacaton rhizosphere |
| *Quinisulcius* acutus | plant-parasitic | Site 3 and 4 alkali sacaton rhizosphere |
| *Tylenchida* spp. | fungivore | non-vegetated interdunal floor between barchans dunes |
| *Tylenchorhynchus* spp. | plant-parasitic | Site 3 alkali sacaton rhizosphere |

Communities of nematodes were recovered from the all plant rhizosphere regions that were sampled during Thomas and Beacham (2014). The fourwing saltbush/alkali sacaton vegetation association rhizosphere region supported the most diverse nematode communities, followed by pickleweed collected from site W5 (Figure 52). The fungivores were much more prevalent during the wet season than during the dry season within non-vegetated sites; during the wet season over half of the total species were fungivores, while less than a quarter were present in samples during the dry season (Thomas and Beacham 2014).

The overall soil biotic community is reflected by the nematode community that is present in soils at WHSA. The results of Thomas and Beacham (2014) indicated that there is a fairly robust source of living organisms within each sampled trophic category in WHSA. These trophic zones appear to be adequately supporting the nematode communities that were identified during the study (i.e., bacteria, fungi, plants, algae, and other nematodes) (Thomas and Beacham 2014). Thomas and Beacham (2014) provides excellent baseline data on the nematode community in WHSA and will be very useful for comparing future inventories to assess trends in the health of soil faunal communities.

Lightfoot and Miller (2012) documented 1,668 specimens of arthropod soil faunal species (e.g., isopod, centipede, spider, and scorpion) in WHSA during the 2010 field season. During this study, arthropod specimens were identified to order and family and are presented in Appendix N. Additionally, four arthropod species endemic to WHSA were collected during the study. Those species include: *Euxoa lafontainei*, *Protogygia whitesandsesis*, *Ammobaenetes arenicolous*, and *Daihiniodes larvale*. Lightfoot and Miller (2012) also documented five new species of arthropods collected during this 2010-2011 study. Those species include a *Cibolacris* sp., two *Trimerotropis* spp., *Efferia* sp, and a species from the Gelechiidae family.

Unc et al. (2014) assessed the diversity of bacteria between sites where soil samples were collected. The results indicated that endophyte diversity was minimally controlled by plant species present, and were rather a function of primarily biogeographical location (Unc et al. 2014). The microbial community was identified to the genus level, and a checklist of those microbes detected, summarized by sampling location, are shown in Appendix O.

A total of 297 distinct genera were identified in WHSA during Unc et al. (2014) (Appendix O). The largest number of genera observed at a single collection location (including soil, leaf, rhizosphere, and seed analyses) was at the alkali flat site (W7) where 137 genera where identified (Appendix O; Figure 52; Unc et al. 2014). For the most part, similar bacterial diversity profiles were found at each site, with the largest bacterial diversity at the cottonwood (W4) and quartzose sand sheet (W2) sites (Figure 52; Unc et al. 2014). Within the W4 site samples, proximity of poplar (*Populus wislizenii*) roots led to dramatically decreased bacterial diversity, which was unique in comparison to most other plant taxa at all other sites (Unc et al. 2014). Root endophyte communities were distinct between sites and strikingly similar between co-located plants, which is what alluded to the diversity of endophytes is a function of biogeographical location, as stated above (Unc et al. 2014). Leaf bacterial endophyte diversity were similar in roots and leaves of spike dropseed (*Sporobolus contractus*) and morman tea (*Ephedra torreyana*), and of soaptree yucca and four-wing saltbush. There was a high number of two *Xanthomonadales* species, which are a gram-negative, non-spore forming, catalase-positive, aerobic, rod-shaped bacteria within the class Gammaproteobacteria. The *Pseudomonas fluorescens*, another gram-negative bacteria species from the same class, was the other species found in high numbers at two sites, the playas (W6) and barchans dune (W5) (Unc et al. 2014, MEMS 2015). This suggests that species profiles are dependent upon environmental conditions and are a consequence of biogeography, while population level profiles are very distinct between spatially separate locations (Unc et al. 2014).

Bernard (2014) documented several arthropods from rehydrated soil samples that were collected from the rhizosphere of plants; only six arthropods were identified to the species level (Table 34). Two dominant species, both of the Order Collembola (i.e., springtails), were *Folomides marchicus* and *F. parvulus*. These species are typical of drought-prone and desert soils throughout the world and are specialized for anhydrobiosis (i.e., an almost completely desiccated state which stabilizes membranes and other cellular structures, preventing otherwise lethal damage cause by environmental extremes), which allows them to survive extreme conditions that are typical of the park (Klok 2009, Bernard 2014). Other springtails were also collected, but in small numbers. Examples of species collected in low numbers included *Hypogastura* spp., which represents an undescribed species, and *Brachystomella* spp. and *Sphaeridia pumilis*.

**Table 34.** The six species identified to the species level during the Bernard (2014) soil study.

| Species | Plant association | Site description |
|---|---|---|
| *Sphaeridia pumilis* | n/a | n/a |
| *Folsomides parvulus* | n/a | n/a |
| *Folsomides marchicus* | Cottonwood (*Populus fremontii var. wislizenii*) | Cottonwood Site |
| *Brachystomella parvula* | Alkali sacaton (*Sporobolus airoides*) | Atriplex-Grassland |
| *Proisotoma minuta* | n/a | n/a |
| *Folsomides parvulus* | Alkali sacaton (*Sporobolus airoides*) | Atriplex-Grassland |

Other arthropods included two species of booklice, also called barklice. Oribatid mites (Oribatida) were also collected, but neither has been identified to Genus or species; however, the specimens were sent to specialists for identification. There were also fly larvae frequently within samples, but these larvae were difficult to identify to which family they belonged due to their life stage (Bernard 2014). Other organisms included unidentified beetle larvae (Coleoptera), parasitoid wasps (Ceraphronidae), scorpion relatives (Pseudocorpions), and spiders (Araneae) (Photo 25, Photo 26, and Photo 27; Bernard 2014).

**Photo 27.** A sample of unidentified soil fauna from studies conducted in WHSA (Photo from Bernard 2014).

There are likely hundreds, if not thousands or tens of thousands, of other species of fauna living or lying dormant in the soil at WHSA. Further investigations would help complete a baseline list to use for future inventories and monitoring activities. The level of diversity of organisms in soil affects the trophic cascade at the very top, and is heavily reliant upon the soil biota to function efficiently (Belnap 2001). This is increasingly clear for desert environments, where living soil crust plays a crucial role in ecological functions (Belnap 2001). Soil faunal communities (e.g., bacteria, microbes, and invertebrates) in conjunction with living soil crusts (e.g., cyanobacteria, fungi, lichens, and mosses) recycle organic material in a manner that fixes nitrogen and carbon, and stabilizes and balances soil in terms of structure and function (Belnap 2001). These living soil organisms are resilient to the regional conditions found at WHSA. However, they can also be sensitive to prolonged or repeated periods of abnormal conditions (e.g., moisture, salinity, atmospheric carbon increases, and temperature levels), disturbance (e.g., foot/vehicle traffic, landuse activities/development, invasive species), and contaminants (e.g., fuel spills, explosive debris).

Although this measure is lacking baseline or reference condition for identifying any trends, there are clearly many more soil faunal species than have been documented at this time. There will be continued interest in the soil faunal communities in WHSA where there is high potential of endemism and additional species to document.

<u>Species Diversity for Species Associated with Carbon Sequestration</u>

As a result of human activities, in particular burning fossil fuels, atmospheric carbon dioxide is progressively increasing (Monger et al. 2014). The desert soils are capable of sequestering large quantities of atmospheric carbon, the subterranean ecosystem include microorganisms that produce calcite via biomineralization (WSSS 2012). This process is directly linked to the above ground ecosystem and the subterranean soil faunal community (WSSS 2012). Investigations into which taxon are linked to this process are necessary to determine the diversity of species involved with biomineralization.

Monger et al. (2014) conducted experiments in WHSA and Guadalupe Mountains National Park (GUMO) and found that numerous microbes (bacteria and fungi) were able to generate carbonate crystals (e.g., rods, spheres, aggregates, and bipyramids) when cultured on a calcium-rich medium (Table 35). This showed that microbial biomineralization does occur in arid and semiarid soils, which cover a third of the earth’s land surface (Monger et al. 2014).

**Table 35.** The genera shown to generate carbonate crystals (Monger et al 2014).

| Group | Genus |
|---|---|
| Bacteria | *Arthrobacter* |
| | *Bacillales* |
| | *Bacillaceae* |
| | *Bacillus* |
| | *Cellulomonas* |
| | *Delftia* |
| | *Promicromonospora* |
| | *Streptomyces* |
| | *Fontibacillus* |
| | *Microbacterium* |
| | *Microbacterium* |
| | *Paenibacillus* |
| Fungi | *Ascomycota* |
| | *Emericella* |
| | *Fusarium* |
| | *Penicillium* |
| | *Phoma* |
| | *Pleosporales (Coniotrichum, Phoma)* |
| Mold | *Aspergillus* |

According to Monger et al. (2014) there are microbial gypsophiles that biomineralize via two chemical reactions:

Reaction one: $CO_2+H_2O \rightarrow H_2CO_3 \rightarrow H^++HCO_3^-$

Reaction two: $Ca^{2+}+2HCO_3^- \rightarrow CaCO_3+CO_2+H_2O$

To varying degrees, the below ground environment in WHSA has the ability to biomineralize calcium carbonate. In regard to carbon sequestration, there is heterogeneous respiration across the landscape. This reflects biological activity occurring throughout the area, and is measured as the amount of $CO_2$ in the soil, which is the source of $HCO_3^-$ that is the precursor to $CaCO_3$ as shown in reaction one (Monger et al. 2014). Monger et al. (2014) concludes that the microbes in the soil at WHSA should be explored further to determine the level of atmospheric carbon sequestration potential of the area. Unfortunately, neither a current condition nor a trend can be assessed at this time, as there not only lacks a reference condition, but there are also very limited data are available related to carbon sequestration in the area.

Threats and Stressor Factors

WHSA staff identified several threats to the soil faunal communities in the park. Those threats included low soil moisture, salinity, contaminants, and invasive species. Low soil moisture is a major threat to soil fauna in WHSA. Although most of the fauna are adapted to the extreme environmental conditions found in the Chihuahuan Desert, not all soil fauna have a well-developed mechanism for encystment or excystment (Killham 1994). Those soil faunal species with exposed soft tissue are less resistant to low soil moisture (e.g., earthworms, gastropods) (Killham 1994). Protozoa, in particular, are sensitive to low soil moisture because they require a constant film of water for movement. Currently, the soils tend to have much higher soil moisture when compared to the adjacent lands of the area, and most of the soils within the dunes are at 100% humidity or fully saturated year round (David Bustos, WHSA Resource Program Manager, written communication, 4 April 2016). According to Killham (1994), increased negative soil potential can reduce numbers of organisms as well as restrict movement until a rain event occurs.

Salinity levels increasing in the soil are a concern for the soil faunal community in WHSA. Soil salinity is considered natural, particularly in arid and semi-arid regions such as the Chihuahuan Desert. However, salinization has become a worldwide problem and consists of the accumulation of water soluble salts (e.g., potassium, magnesium, calcium, chloride, sulfate, carbonate, bicarbonate, and sodium ions) in the soil (Silva and Fay 2012). Salinization of soil in WHSA may be the result of a combination of anthropogenic and natural factors. Soil faunal communities inhabiting saline soils experience high bio-energetic taxation as they must maintain osmotic equilibrium and effects are pronounced within the rhizosphere where the majority of soil fauna reside (Silva and Fay 2012). An impact on organisms in soil as a result of salinization may include shifts in soil faunal community composition, decreased spore germination and growth of hyphae in fungi, and overall reduction in activity (Silva and Fay 2012).

Contaminants are also a threat to the soil faunal community in WHSA. In particular, debris and fuels left behind following incidences originating from the WSMR and the Holloman Air Force Base (HAFB) nearby are a contamination concern for soil faunal communities. Testing of missiles and rockets occur within close proximity to WHSA and are a point source of contamination from metals, solvents, and explosives, many of which are hazardous and toxic to all living organisms in the park (Bricka et al. 1994). Heavy metals are a particularly persistent material that tends to linger until physically removed or immobilized (Bricka et al. 1994). The most common removal practice for soils contaminated with heavy metals is to “dig and haul” since they are considered permanent and immutable once soil has been contaminated (Bricka et al. 1994).

Invasive species threaten soil fauna in WHSA in a couple ways. Pritekel et al. (2005) documented a significant correlation in microarthropod abundance and presence of invasive species. There were low numbers of microarthropods in plots with invasive plants (Pritekel et al. 2005). The lower number of microarthropods may have been due to the increased bare ground found in the invasive plant plots, which would have decreased litter layer and lower food availability.

Data Needs/Gaps

Overall, there have been few studies that provide a baseline inventory of many genera of soil fauna. However, without a reference condition to compare them to, assessment in trend of species diversity for either measure isn’t possible at this time. Since there do appear to be continually added species to those already collected at the park, it seems that there is not a need for great concern at this time. The relationship between soil faunal communities and vegetation is considered a crucial component of desert ecology and lacks a reference condition for the area. The studies that have been conducted in the area provide some limited baseline information on the composition of soil fauna, but further study will likely identify many more species. Impacts on soil faunal communities from salinization, contaminants, and other activities that disturb soil strata has not been investigated thoroughly, and is considered a data gap. Identification of invertebrate, bacterial, and fungal communities to the species level would also be useful in future assessments to determine any trends in community composition and diversity.

Overall Condition

*Species Diversity*

The project team defined the *Significance Level* for species diversity as a 3. At this time, there is a baseline started on the diversity of soil fauna (e.g., Thomas and Beacham 2014), but the overall understanding of this component is likely incomplete and lacks a reference condition. With the studies and inventories included in the discussion, there are sufficient baseline data for future assessment of soil faunal communities. Due to data gaps for a reference condition to compare as well as variability in the existing studies (e.g., study focus, methodology, location, timing/duration), it is not possible to identify a trend in the diversity of soil fauna. This also has not been fully assessed in the park in terms of species identification, but it would seem that the constantly growing list of species from subsequent studies does not merit any concerns for species diversity at this time. Considering these factors, a *Condition Level* of 0 has been assigned at this time.

*Species Diversity for Species Associated with Carbon Sequestration*

The project team defined the *Significance Level* for species diversity for species associated with carbon sequestration as a 3. There is only a small amount of information collected on species that may play a role in sequestering carbon, and more data are needed regarding this biologically important group of organisms. Without baseline information and an established reference condition it is currently not possible to identify trends in these soil fauna beyond the observation that soil moisture and temperature were seen to be a major driver in microbial activity (Bustos, written communication, 4 April 2016). Due to this data gap, a *Condition Level* was not assigned.

*Weighted Condition Score*

A *Weighted Condition Score* cannot be calculated at this time due to data gaps. The data that is available at this time will be excellent baseline data for future assessments. Soil faunal communities are fundamental to the environmental health of WHSA since they are the primary mechanism of nutrient cycling in soil.

| Soil Faunal Community | | | |
|---|---|---|---|
| Measures | Significance Level | Condition Level | WCS = N/A |
| Species Diversity | 3 | 0 | |
| Species Diversity for species associated with carbon sequestration | 3 | n/a | |

#### *4.8.6. Sources of Expertise*

- David Bustos, WHSA Resource Program Manager

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## 4.9. Soundscape and Acoustic Environment

### *4.9.1. Description*

Acoustic resources are physical sound sources, including both natural sounds (wind, water, wildlife, vegetation) and cultural and historic sounds (living history events, tribal ceremonies, quiet reverence) (NPS 2014). The acoustic environment is the combination of all the acoustic resources within a given area, natural sounds and human-caused sounds (NPS 2014). The acoustic environment includes sound pressure variations made by geological processes, biological activity, and even sounds that are inaudible to most humans, such as bat echolocation calls (Krause 2002, NPS 2014). Soundscape is the component of the acoustic environment that can be perceived by humans (NPS 2014). It is an important part of the natural environment (Photo 28) that influences human perceptions of an area, providing a sense of place that differentiates from other places (Krause 2002, NPS 2014).

**Photo 28.** The wide open landscape of WHSA (Photo: Andy Nadeau, SMUMN GSS).

Visitors to national parks often indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. In a 1998 survey of the American public, 72% of respondents identified opportunities to experience natural quiet and the sounds of nature as an important reason for having national parks (Haas and Wakefield 1998). Additionally, 91% of NPS visitors consider enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald et al. 1995). Thus, an important part of the NPS mission is to maintain or restore the natural and biological soundscape of parks, as well as to provide for positive visitor experiences of the natural soundscape (Krause 2002, NPS 2014).

Overly intrusive or inappropriate human-caused sounds are of concern to park managers, as they can impact wildlife as well as detract from visitors' natural and cultural resource experiences (NPS 2000). Wildlife activities such as avoiding predators, attracting mates, finding adequate habitat, establishing territories, and protecting young are all dependent upon the acoustic environment (NPS 2016). Recent research suggests that many species of wildlife are increasingly stressed by a noisy environment (beyond the natural soundscape), and will change their behavior or leave the area if consistently intrusive noise persists (NPS 2016a). Repeated noise can cause chronic stress to animals, possibly affecting their energy use, reproductive success, and long-term survival (Radle 2007).

The natural soundscape is an inherent component of "the scenery and the natural and historic objects and the wildlife" protected by the Organic Act of 1916. NPS Management Policies (§ 4.9) require the NPS to preserve the park's natural soundscape and restore any degraded soundscapes to the natural condition wherever possible. Additionally, NPS is required to prevent or minimize degradation of the natural soundscape from noise (i.e., inappropriate/undesirable human-caused sound).

The WHSA Foundation Document (NPS 2016b) states that one of seven significances of the park is its soundscape and viewscape, as described below:

> *As the Tularosa Basin is almost exclusively held in public trust, White Sands National Monument provides an opportunity for visitors to experience unimpeded panoramic views of the horizon, which is largely devoid of human presence. Visitors enjoy extraordinary views of the white sand dune field and exceptional night skies. This vast undeveloped landscape allows for natural quiet and solitude supporting a high quality visitor experience.*

Although WHSA is located in rural southern New Mexico, it is situated on U.S. Highway 70, which connects rural towns across the state. US-70 is the only direct road from Las Cruces, NM (the state's second large city) to WHSA, Alamogordo, NM, and HAFB. In addition, it serves as the main entrance to WSMR. In 1970, US-70 was paved in order to provide improved vehicular access across the basin.

Additionally, the park is approximately 16 km (10 mi) west of HAFB, a major training base for U.S. Air Force military aircraft and flight personnel (Figure 54). Heavy highway traffic can be heard at the park's visitor center, and WHSA can experience approximately 100-150 overflights per day by a variety of military aircraft originating from HAFB (Miller et al. 1999).

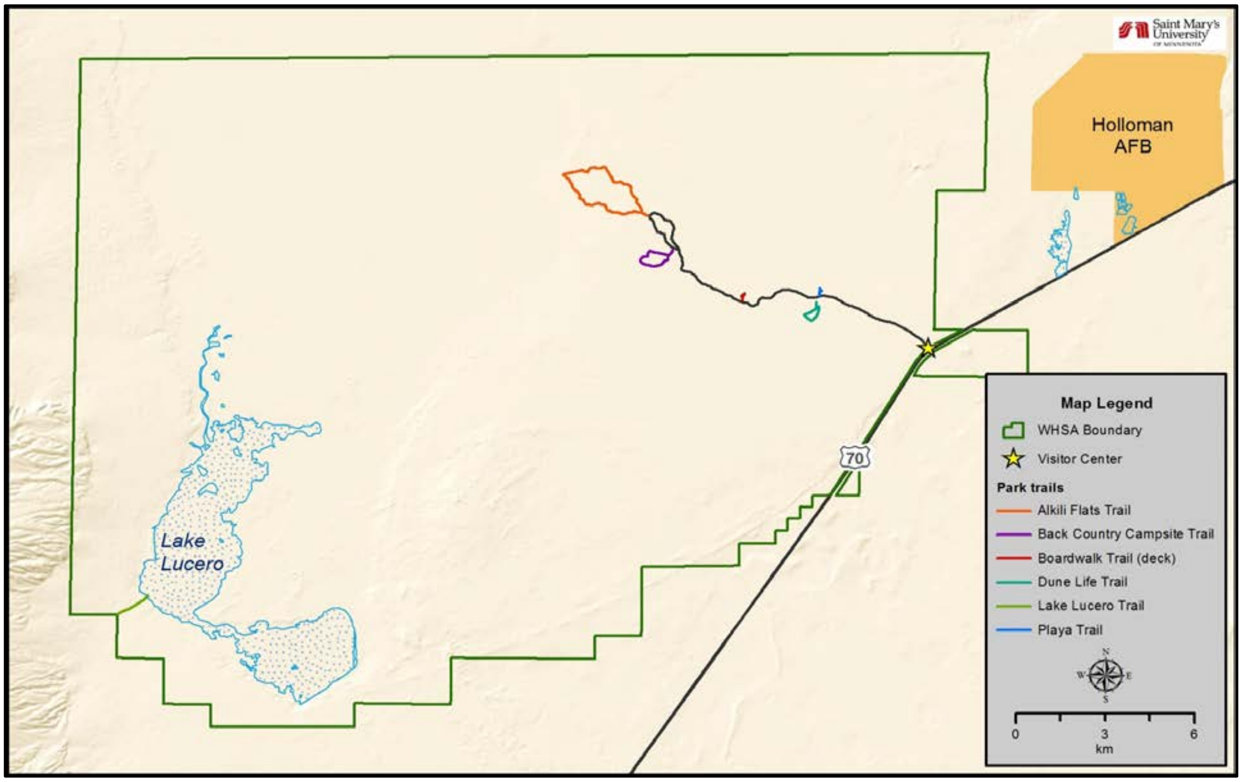


**Figure 54.** Location of the Holloman AFB and WHSA visitor center, roads, and trails.

A recent concern was introduced with an expansion of supersonic airspace in a 2006 Environmental Assessment at HAFB. To accommodate larger supersonic maneuvering ellipses and flying area for F-22A aircraft, the existing supersonic airspace was enlarged to cover a large area of the park that had not previous been subjected to regular supersonic aircraft overflights (Figure 55). This has resulted in an increased number of sonic booms that is a concern for historic structures and other cultural resources.

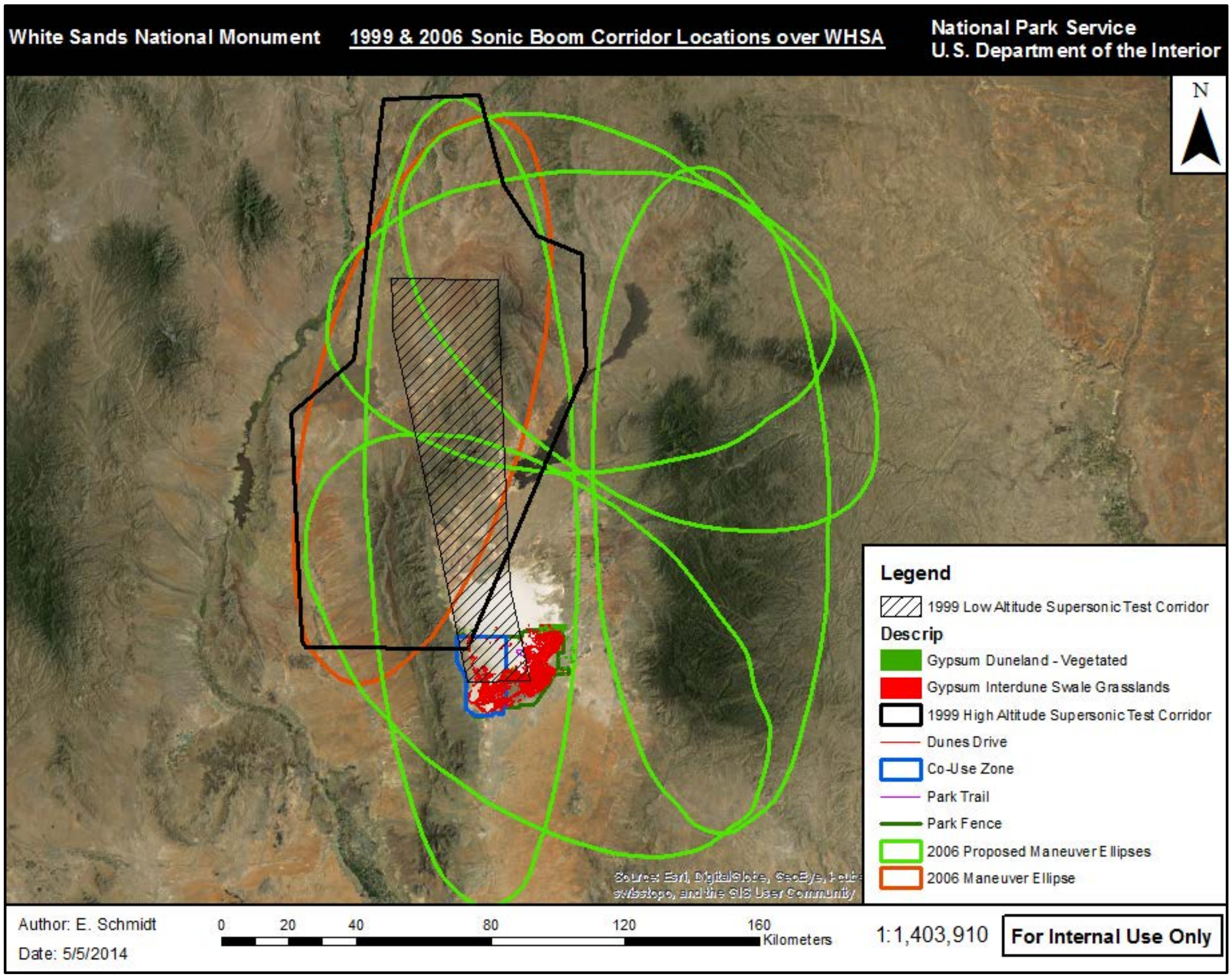


**Figure 55.** Supersonic Airspace Boundaries and Maneuvering Ellipses near WHSA (NPS).

Even with these human-caused noise sources, it can be extremely quiet and still in the dunes or on the flats in WHSA. In these areas, it is often easy to hear the sound of your breath or the footsteps of a small lizard running across the ground. As one drops down into interdunal areas, all sound is hushed, and peace and solitude can readily be found. To help preserve these opportunities for solitude and to prevent noise pollution from negatively impacting visitors to the park, the NPS audio disturbance rules in 36 CFR 2.12 have been included in the Superintendent's compendium.

#### *4.9.2. Measures*

Sound measures may be classified in terms of amplitude, frequency, or duration, as described below. Additional details are provided in Chapter 4.9.4.

- Sound pressure levels (in decibels [dB], a logarithmic unit) are the most common measure of sound amplitude, and especially A-weighted sound levels (in A-weighted decibels [dBA]).
- Frequency is a measure of the repetition rate of a sound wave component (in hertz [Hz] or less commonly, cycles per second [cps]); it may be perceived as pitch by an auditory system.

- Duration of sounds; examples include Time Above Ambient [TAA], Time Above 35 dBA (or other level) [TA35], Noise Free Interval [NFI], Time Audible [TAud], in hours, minutes, or seconds, and Percent Time Audible [%TAud], in percent.

#### *4.9.3. Reference Conditions/Values*

Acoustic reference conditions should address the effects of noise on human health and physiology, the effects of noise on wildlife, the effects of noise on the quality of the visitor experience, and finally, how noise impacts the acoustic environment itself. NPS policy states that the natural ambient sound level is the baseline condition, and the standard against which current conditions in a soundscape will be measured and evaluated (NPS 2006). The NPS defines natural ambient sound level as the environment of sound that exists in the absence of human-caused noise (NPS 2006).

In line with NPS policies, the ideal reference condition for WHSA would be the natural ambient sound level in the absence of human-caused noise. However, given existing park visitation and continued development around WHSA, it could be difficult to achieve in all parts of the park. This reference condition would be analogous to the soundscape prior to the advent of military installations in the Tularosa Basin in the 1940s.

#### *4.9.4. Data and Methods*

Sound Science

Humans and wildlife perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air. Sound is measured in terms of frequency (pitch) and volume (amplitude), or sound level (Templeton and Sacre 1997, Harris 1998). Noise, essentially the negative evaluation of sound, is defined as extraneous or undesired sound (Morfey 2001).

Frequency, measured in Hertz (Hz), describes the cycles per second of a sound wave (NPS 2014). Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and are most sensitive to frequencies between 1,000 Hz and 6,000 Hz (NPS 2014). High frequency sounds are more readily absorbed by the atmosphere or scattered by obstructions than low frequency sounds. Low frequency sounds diffract more effectively around obstructions. Therefore, low frequency sounds travel farther.

In addition to the pitch of a sound, humans also perceive the amplitude (or level) of a sound (NPS 2014). This metric is described in decibels (dB). The decibel scale is logarithmic, meaning that every 10 dB increase in sound pressure level (SPL) represents a tenfold increase in sound energy (NPS 2014). This also means that small variations in sound pressure level can have significant effects on the acoustic environment (NPS 2014). Sound pressure level is commonly summarized in terms of dBA (A-weighted decibles) (NPS 2014). Table 36 provides examples of A-weighted sound levels measured in national parks.

**Table 36.** Examples of sound levels measured in national parks

| Park sound sources | Common sound sources | dBA |
|---|---|---|
| Volcano crater (Haleakala National Park) | Human breathing at 3m | 10 |
| Leaves rustling (Canyonlands NP) | Whispering | 20 |
| Crickets at 5m (Zion NP) | Residential area at night | 40 |
| Conversation at 5m (Whitman Mission National Historic Site) | Busy restaurant | 60 |
| Snowcoach at 30m (Yellowstone National Park) | Curbside of busy street | 80 |
| Thunder (Arches National Park) | Jackhammer at 2m | 100 |
| Military jet at 100m AGL (Yukon-Charley Rivers National Preserve) | Train horn at 1m | 120 |

The natural acoustic environment is vital to the function and character of a national park. Natural sounds include those sounds upon which ecological processes and interactions depend. Examples of natural sounds in parks include:

- Sounds produced by birds, frogs, or insects to define territories to attract mates;
- Sounds produced by bats to navigate or locate prey;
- Sounds produced by physical processes such as wind in trees, flowing water, or thunder.

Although natural sounds often dominate the acoustic environment of a park, human-caused noise has the potential to mask these sounds. Noise impacts the acoustic environment much like smog impacts the visual environment; obscuring the listening horizon for both wildlife and visitors.

### *4.9.5. Current Condition and Trend*

Unlike other components within this NRCA, the specified measures for this component are discussed in conjunction with each other below. Measure-specific subheadings were not used in this assessment.

Because it is difficult to collect acoustic data across all landscapes, NPS developed a novel geospatial sound model that predicts natural and existing sound levels with 270 m (886 ft) resolution (see Figure 56). The model is based on acoustic data collected at 244 sites and 109 spatial explanatory layers (such as location, landcover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports) (Mennitt et al. 2013).

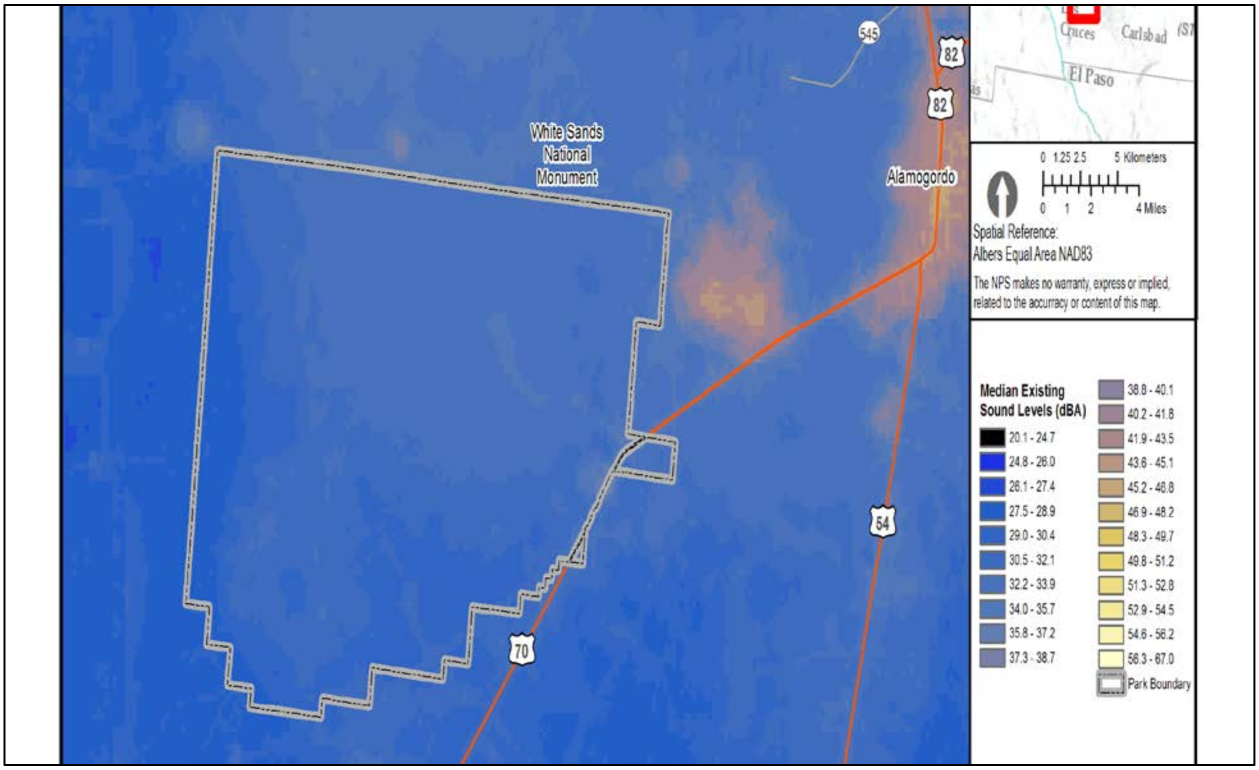


**Figure 56.** Map displaying predicted median existing sound levels ($L_{50}$) in dBA (figure provided by NPS).

The model shows that predicted median existing daytime sound levels within the park are fairly low, ranging from 26 to 30 dBA. These modeled sound levels are supported by acoustic data from a cooperative study by U.S. Air Force and the NPS to better understand the potential impacts of military aircraft overflights on the soundscape and visitor experiences within the park (Miller et al. 1999).

During the cooperative study, data were collected during weekday daytime hours from 14-25 July 1997, at a location along the Big Dune Nature Trail. Although about 28% of visitors experienced no overflights, roughly 2/3 of visitors experienced one to 10 aircraft overflights. The maximum A-weighted sound levels for the overflights ranged from a low of 40-45 dBA, to a high of 90-95 dBA. Most visitors experienced non-aircraft equivalent continuous sound levels ranging from 16 dBA to about 28 dBA, with a median level of about 22-23 dBA. Although non-aircraft levels, including road vehicle sound levels, were mostly between 15 and 25 dBA at this location, the median existing sound level for the entire period was 25 dBA, which compares closely to the predicted values in Figure 56.

The measured and modeled sound level data for WHSA indicate that between infrequent high noise levels from military flyovers, sound levels within the park are often extremely quiet.

<u>Threats and Stressor Factors</u>

Sound plays a critical role in intraspecies communication, courtship and mating, predation and predator avoidance, and effective use of habitat. Studies have shown that wildlife can be adversely affected by sounds that intrude on their habitats. While the severity of the impacts varies depending on the species being studied and other conditions, research strongly supports the fact that wildlife can suffer adverse behavioral and physiological changes from intrusive sounds (noise) and other human disturbances. Documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, and separation of mothers and young (Selye 1956, Clough 1982, USDA 1992, Anderssen et al. 1993, NPS 1994,).

WHSA managers have identified several sources of human-caused sound that threaten the park's soundscape, including noise and vibrations from heavy highway traffic, visitor traffic on the dune road, flights and air traffic originating from HAFB (including sonic booms), and noise and vibration from low-flying aircraft such as helicopters conducting unexploded ordinance (UXO) recovery activities.

King et al. (1988) conducted a vibration study for the historic buildings at WHSA. King et al. (1988) determined the vibration response parameters of the museum (visitor center) building and made a visual assessment of the building's existing cracking damage. A maximum vibration level of 2 mm/sec was recommended for the historic, irreplaceable adobe-masonry structures at WHSA (King et al. 1988). With this vibration level, normal aircraft take-off patterns would be acceptable, but low-flying helicopters, and low-flying, high-speed jet aircraft within a few thousand feet of the structures would not be acceptable (King et al. 1988).

Data Needs/Gaps

With the exception of the 1999 cooperative study by U.S. Air Force and the NPS, and a new system intended to measure sonic booms within the park, there is a lack of measured sound data available to assess the effects military operations and flights. Further recording efforts are warranted since the military activities are not likely to decrease and will likely continue to increase in future years.

Overall Condition

*Sound Pressure Levels*

A *Significance Level* of 3 was assigned to this measure by the project team. Considering the addition of the sonic boom from aircraft operations at HAFB, this measure warrants a *Condition Level* of 2, or of moderate concern.

*Frequency*

This measure was also assigned a *Significance Level* of 3 by the project team. Data on sound frequencies within WHSA are limited. Since this is considered a data gap, a *Condition Level* cannot be assigned at this time.

*Duration of Sounds*

The *Significance Level* for this measure was assigned a 3. This measure is a data gap, as there are no recent data on the duration of sounds from military operations and flights that occur in close proximity to WHSA. The survey of WHSA visitors conducted by Miller et al. (1999) was comprehensive but limited to weekday daytime hours. Due to this data gap, a *Condition Level* was not assigned.

*Weighted Condition Score*

A *WCS* has not been calculated for this component due to data gaps for two of the three measures defined by WHSA management. Future assessments that investigate the soundscape condition would need to include all three of the above listed measure in analysis in order to determine any trends.

| Soundscape | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = N/A** |
| Sound Pressure Levels | 3 | 2 | |
| Frequency | 3 | n/a | |
| Duration of sounds | 3 | n/a | |

#### *4.9.6. Sources of Expertise*

- Randy Stanley, Natural Sounds and Night Skies Coordinator, Natural Resources Division
- David Bustos, WHSA Resource Program Manager

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## 4.10. Viewscape

### *4.10.1. Description*

A viewscape analysis can help determine which features can be seen from a selected set of observation points (e.g., what the view will be from the road) (Esri 2014a). It can help document changes over time in the view an observer might see (e.g., natural vs. developed landscapes). Multiple studies indicate that people prefer natural compared to developed landscapes (Sheppard 2001, Kearney et al. 2008, Han 2010). The NPS Organic Act (16 U.S.C. l) implies the need to protect the viewscapes of national parks, monuments, and reservations (Prenni et al. 2015). Specifically, the enabling legislation for WHSA states the park should "preserve the unique geology of the gypsum sand dunes and to protect all of its other scenic, scientific and educational values" (NPS 1981, p. 2) (Photo 29). However, defining a desirable viewscape is widely regarded as a subjective and difficult process, because what is preferable is intrinsically humanistic and varies by individual. Development within the park and in the immediate vicinity is minimal compared to many areas in the conterminous United States. Some anthropogenic features are present within WHSA; many of these, such as the visitor center, campgrounds, and parking areas, enable recreational access to the park's resources, which is a primary purpose for the park (NPS 1981).

**Photo 29.** The rolling dune fields of WHSA as visible from the Alkali Flats trail (Photo by Andy Nadeau SMUMN GSS).

### *4.10.2. Measures*

- Change in internal viewscape
- Change in external viewscape
- Visibility

### *4.10.3. Reference Conditions/Values*

The reference conditions for WHSA viewscape identified by park resource managers were the natural views that existed prior to the establishment of HAFB and WSMR. Landcover data were not available for this time period; however it is assumed based on available photographs from the NPS that there was minimal development at that time (1939) and the landcover was primarily sparse shrub/scrub except for the dune areas (Photo 30).

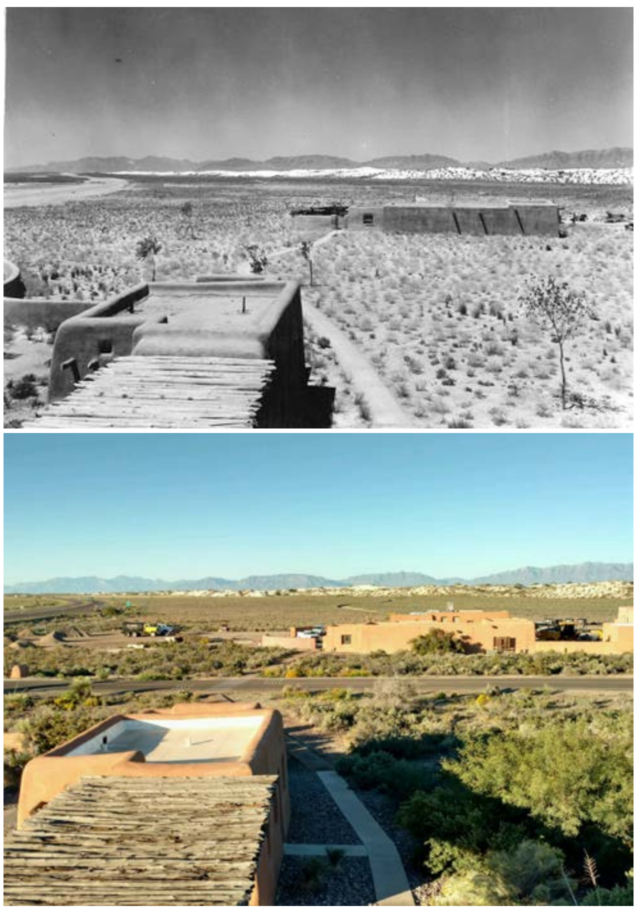


**Photo 30.** Except for dune areas, landcover in WHSA was primarily sparse shrub/scrub, as seen in the view from the roof the visitor center in 1939 (top photo; NPS photo). The bottom image is of the view from the same location in 2016 (NPS photo).

Visibility conditions can be assessed in terms of a Haze Index (NPS 2013). This index (reported in deciviews [dv]) is derived from calculated light extinction and represents the minimal perceptible change in visibility to the human eye (NPS 2013). The NPS Air Resources Division (ARD) has developed an approach for rating air quality conditions based on current National Ambient Air

Quality Standards (NAAQS), ecosystem thresholds, and visibility improvement goals (Prenni et al. 2015). The NPS ARD considers visibility to be in “good condition” when the air quality index is less than 2 dv (Table 37). This condition will be used as the reference condition for visibility at WHSA.

**Table 37.** National Park Service Air Resources Division air quality index values for visibility (NPS 2013).

| Condition | Visibility (dv*) |
|---|---:|
| Significant Concern | >8 |
| Moderate Condition | 2-8 |
| Good Condition | <2 |

*a unit of visibility proportional to the logarithm of the atmospheric extinction; one deciview (dv) represents the minimal perceptible change in visibility to the human eye (Environmental Protection Agency (EPA) 2003).

#### *4.10.4. Data and Methods*

In order to assess the condition of the park’s viewscape (both internal and external), a number of GIS analyses were conducted. These involved creating a viewshed from select observation points within the park and then analyzing the change in landcover over the period 2006–2011. This period was selected rather than change from the reference condition date, mainly due to the availability of a landcover change (2001–2011) dataset.

A visibility analysis determines the area that can be seen from a set of observation points (Esri 2014b). This resultant area is referred to as a viewshed. A viewshed was created for WHSA using Environmental Systems Research Institute’s (ESRI) ArcGIS Spatial Analyst 10.2 Visibility tool. This tool requires two data inputs, a digital elevation model (DEM) and point or polyline data defining points in which a person would be observing the landscape.

Visitors frequently observe the landscape in and around the park from four main observation points: the Visitor Center, Interdune Boardwalk, Backcountry Campground, and Alkali Flats Trail (Figure 57). These four areas were chosen as the observation point inputs for the Visibility tool. For each location, a point shapefile was created to represent the approximate location. The second input for the Visibility tool, the DEM, was obtained from the National Elevation Dataset (NED) website (http://www.mrlc.gov/nlcd2011.php). This elevation surface had a resolution of approximately 10 m (32.8 ft). In order to replicate the view as seen by a person standing at these points as accurately as possible, a 1.7 m (5.5 ft) observer offset was applied to each observation point shapefile to account for average human height (CDC 2012). The curvature of the earth was also taken into consideration during the analysis. This analysis resulted in a theoretical surface layer (that represents the visible area or viewshed) from a point(s) without correcting for visibility factors (e.g., vegetation, smoke, humidity, or heat shimmer) (Figure 58). For purposes of the analysis in this report, the internal viewscape is defined as those areas within the park boundary that are visible from any of the observation points and the external viewscape includes those areas outside the park boundary that are visible from any of the selected observation points.

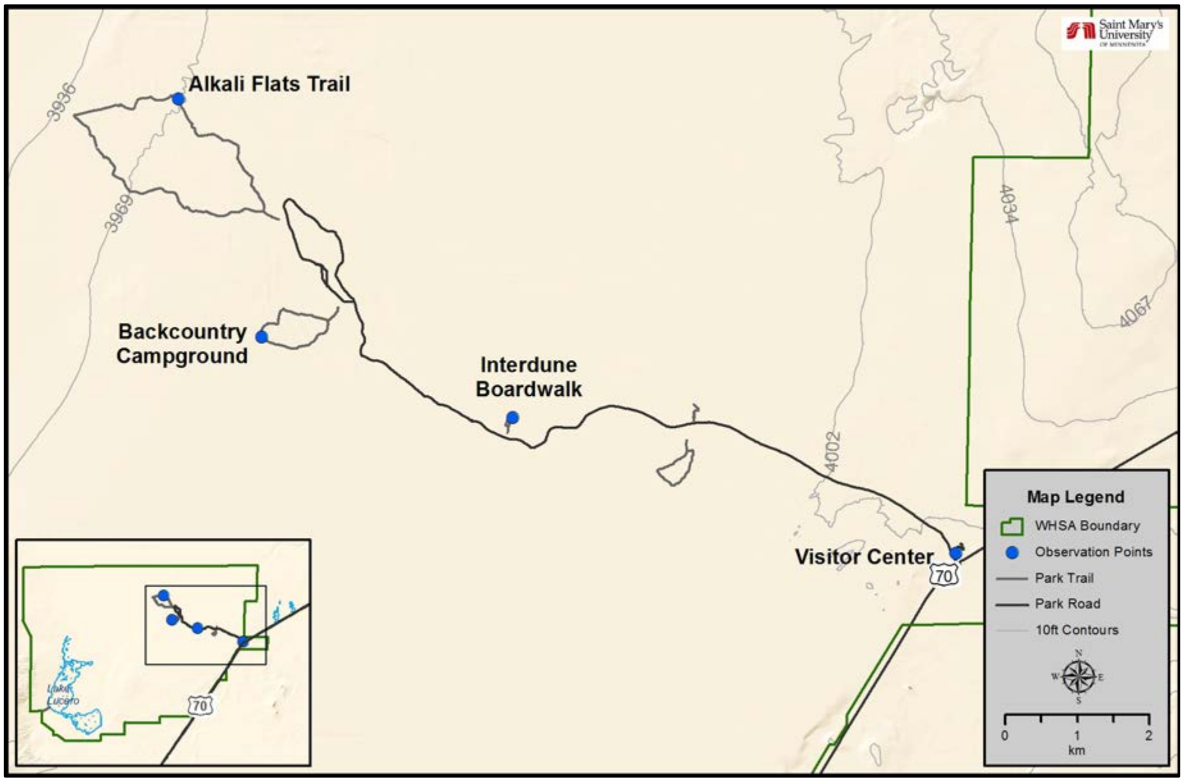



**Figure 57.** The four observation points used in the WHSA viewscape analysis include the Visitor Center, Interdune Boardwalk, Backcountry Campground, Alkali Flats Trail.

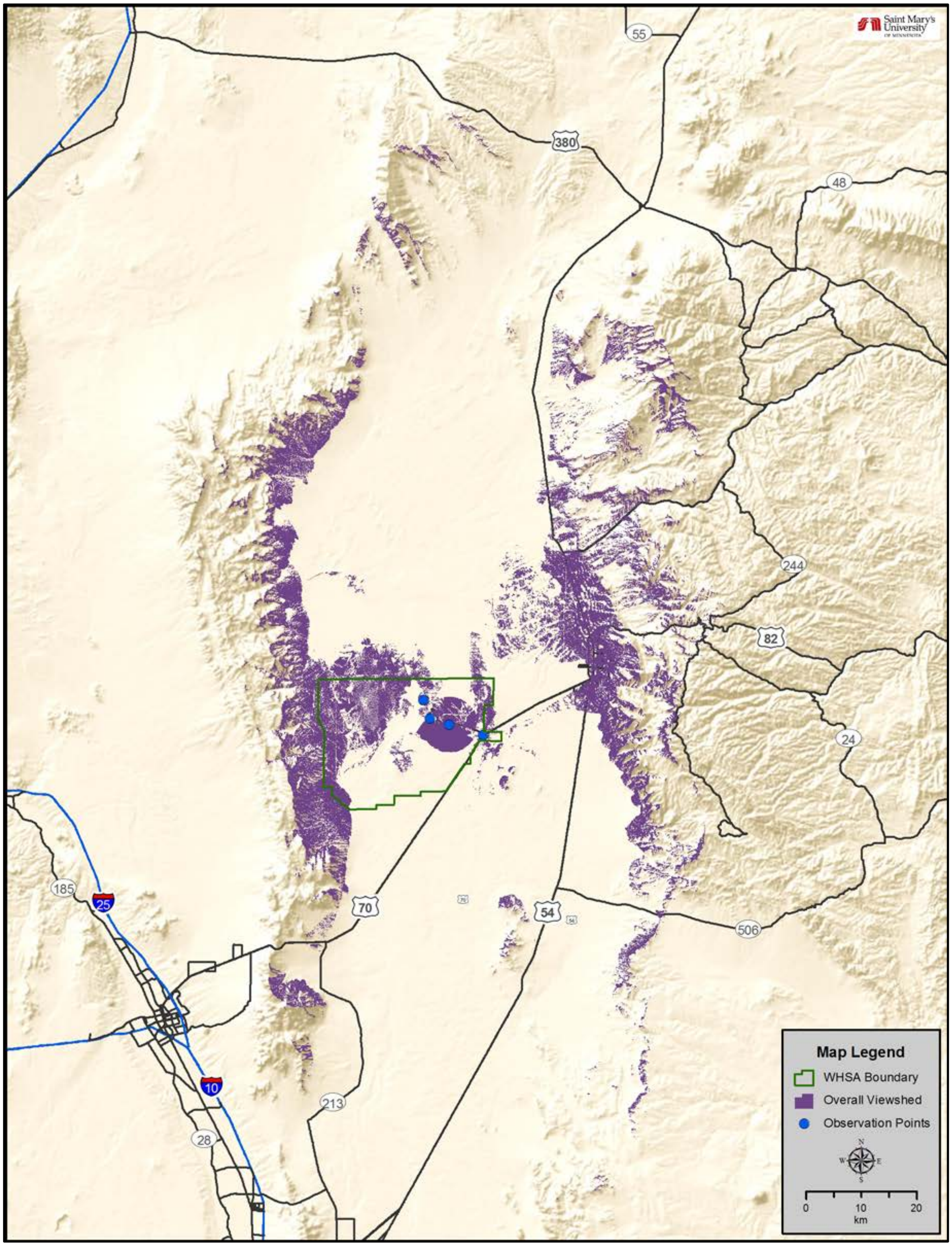



**Figure 58.** The overall viewscape output for WHSA. The areas in purple represent the features that are visible from one or more of the four observation points inside the park.

The landcover change dataset used in the change analysis was obtained from the U.S. Geological Survey (USGS). The USGS, in cooperation with the Multi-Resolution Land Characteristics (MRLC) Consortium, produces the National Land Cover Dataset (NLCD). This raster dataset is considered to be the most up to date land cover product for the United States, with updates every five years (USGS 2011a). This dataset contains a variety of attribute information including: 2011 land cover data, 2006–2011 land cover change, 2001–2011 land cover change, 2011 percent developed impervious surface, 2006–2011 percent developed impervious surface change, and 2011 tree canopy cover (USGS 2011a). The landcover is classified as: unclassified, open water, developed-open space, developed-low intensity, developed-medium intensity, developed-high intensity, barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, pasture/hay, cultivated crops, woody wetlands, herbaceous wetlands (USGS 2011a). The NLCD 2001–2011 landcover change classifications were used to determine changes in the internal and external viewscapes. Specifically, analysis was conducted to identify areas where landcover has changed and to compare the type of landcover change (e.g., shrub/scrub to grassland/herbaceous or developed, open space to developed, low intensity). This provided a 10-year record of change occurring in and around the park.

The NPS ARD provides estimates of visibility, based on interpolations of data from air quality monitoring stations operated by the NPS, EPA, states, and other entities, averaged over the most recent five years (2009–2013). These estimates are available online from the Air Quality Conditions and Trends by Park website (NPS 2015b). On-site or nearby data are needed for a statistically valid trends analysis, while a 5-year average interpolated estimate is preferred for the condition assessment. The most up-to-date visibility data for WHSA are collected by the IMPROVE monitoring station (ID BOAP1) (NPS 2015b) located in the Bosque del Apache National Wildlife Refuge, which is approximately 241 km (150 mi) northwest of WHSA (NPS and USFS 2015).

The U.S. Forest Service Air Resource Management Division has developed a visibility “conversion calculator” that will convert a haze index (dv) value to a standard visual range in miles. This calculator was used to determine the standard visual range for this WHSA visibility analysis (USFS 2016).

A published attempt at a semi-quantitative method of visual observations is described in the Bortle Dark Sky Scale (Bortle 2006). 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 2006).

### *4.10.5. Current Condition and Trend*

Change in internal viewscape

The internal viewscape area from all observation points covers 2,553.84 ha (6,310.65 ac) (Figure 59). The chance of interdune areas becoming covered or filled in is highly likely because of the actively migrating dunes (KellerLynn 2012), thus causing the internal landscape of WHSA to change over time. For more information about dune morphology, please refer to Chapter 4.1 of the document.

Very little change in landcover has occurred within the internal viewscape (less than1%) from 2001 to 2011. A total of 4.2 ha (10.5 ac) has been converted from some type of vegetated cover (e.g., grassland or shrub/scrub) to barren land and 6.6 ha (16.3 ac) has stayed at some level of development (open, low, medium, or high density) (Figure 60). The landcover classes are defined as follows (USGS 2011b):

- Barren = areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
- Developed, Open Space = areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
- Developed, Low Intensity = areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% of total cover. These areas most commonly include single-family housing units.
- Developed, Medium Intensity = areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
- Developed, High Intensity = highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.

<u>Change in external viewscape</u>

The external viewscape area from all observation points covers 134,487 ha (332,325 ac) (Figure 61). Approximately 1% of the external viewscape as seen from WHSA has undergone some type of small landcover change between 2001 and 2011 (Figure 62, Figure 63). A portion of this change has occurred around the urban areas of Alamogordo and Tularosa, New Mexico, while the majority was related to natural vegetation change (Table 38) near headwaters of the South Fort Rio Ruidoso stream.

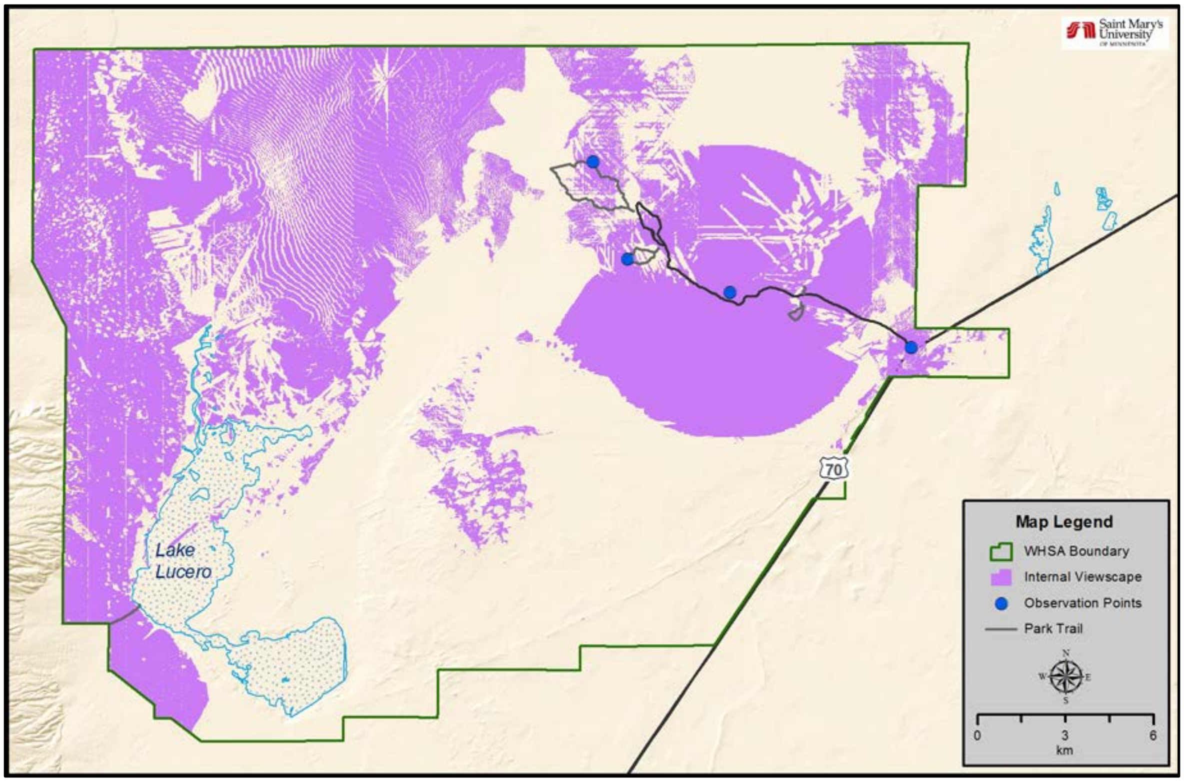



**Figure 59.** The internal viewscape analysis output displays which features inside the park can be seen from the observation points.

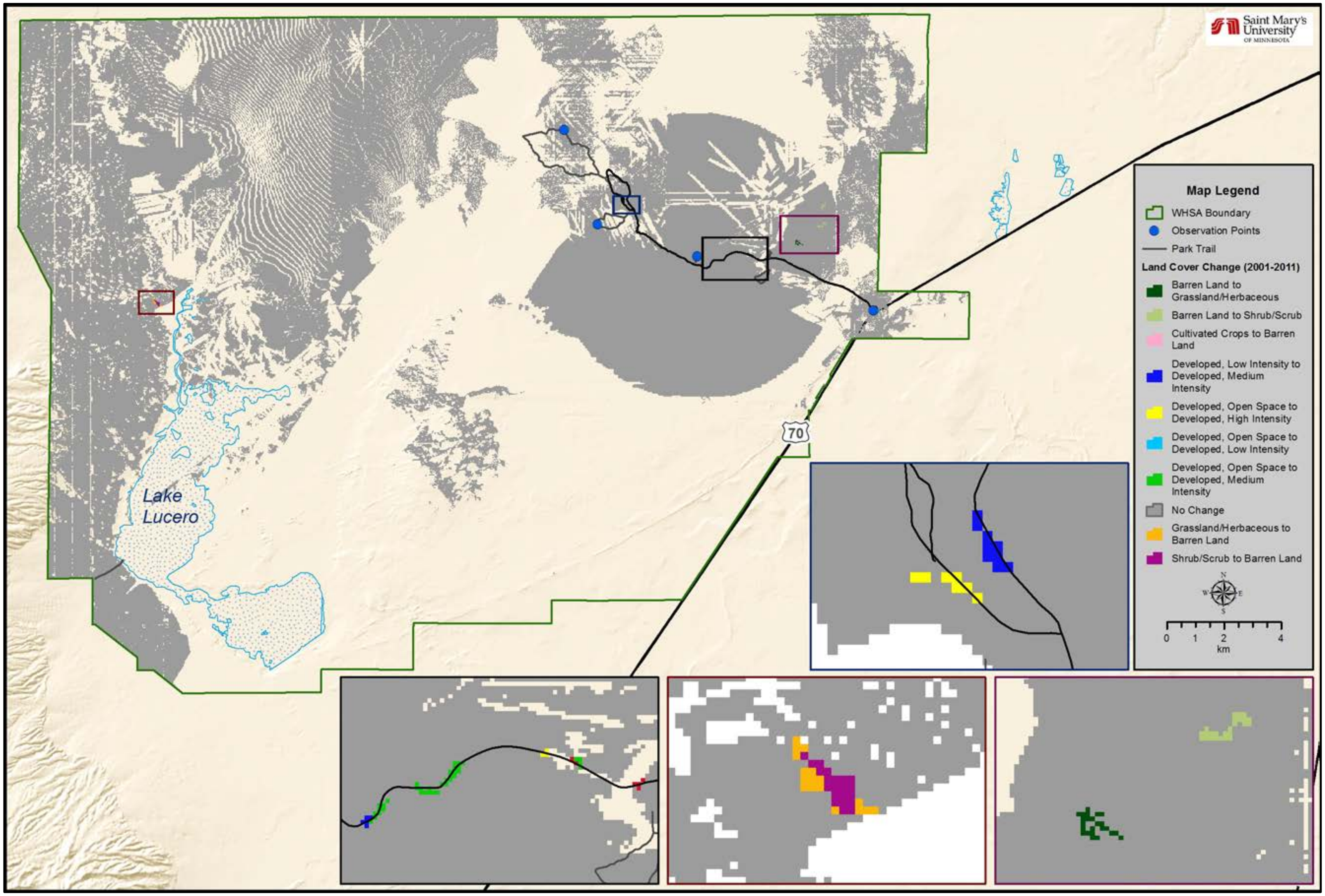



**Figure 60.** There was little landcover change within WHSA between 2001 and 2011 that could be seen from the observation points; no more than 1%. The majority of the change was due to some level of development for park infrastructure (USGS 2011a).

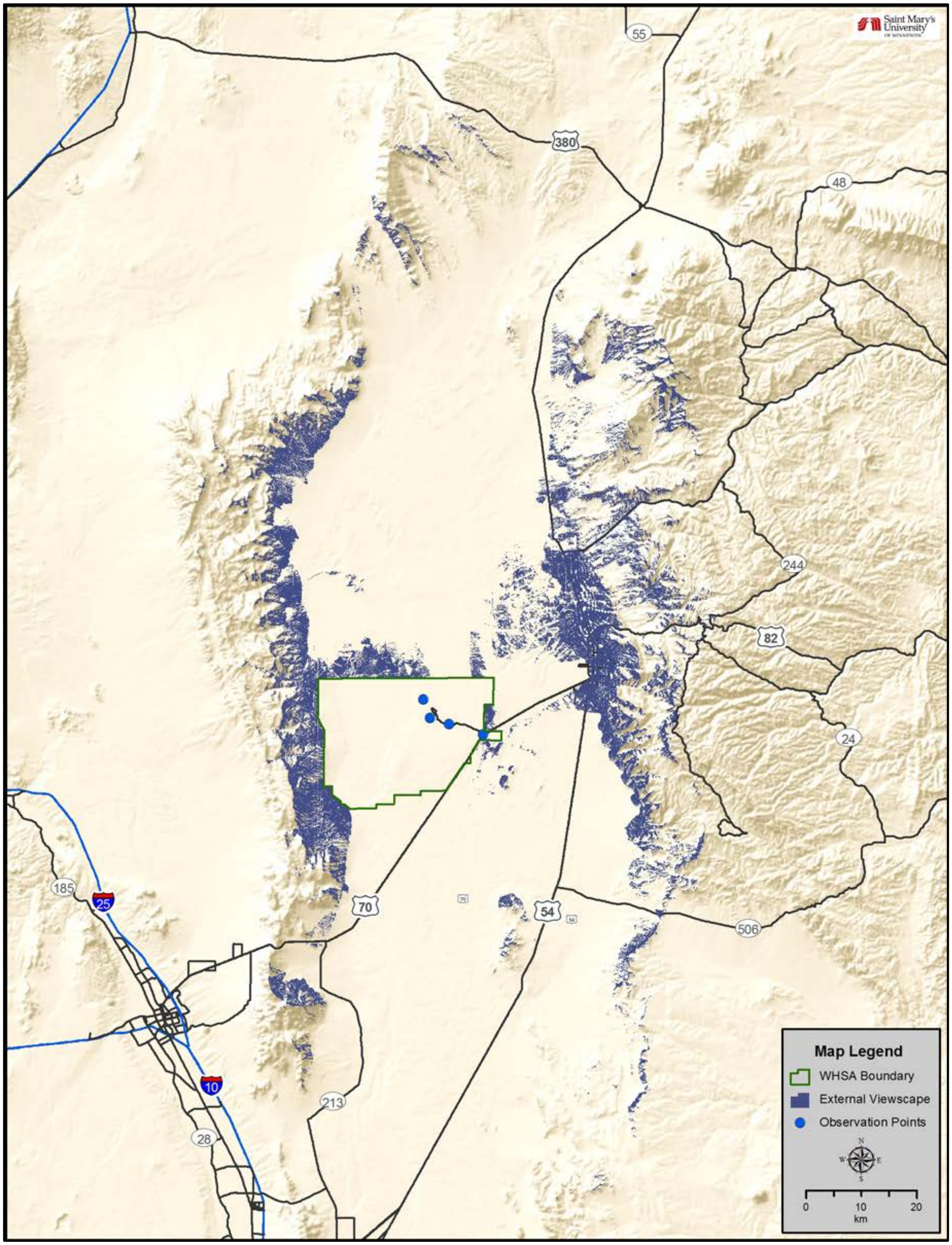



**Figure 61.** The external viewscape analysis output displays what features outside the park can be seen from one or more of the selected observation points.

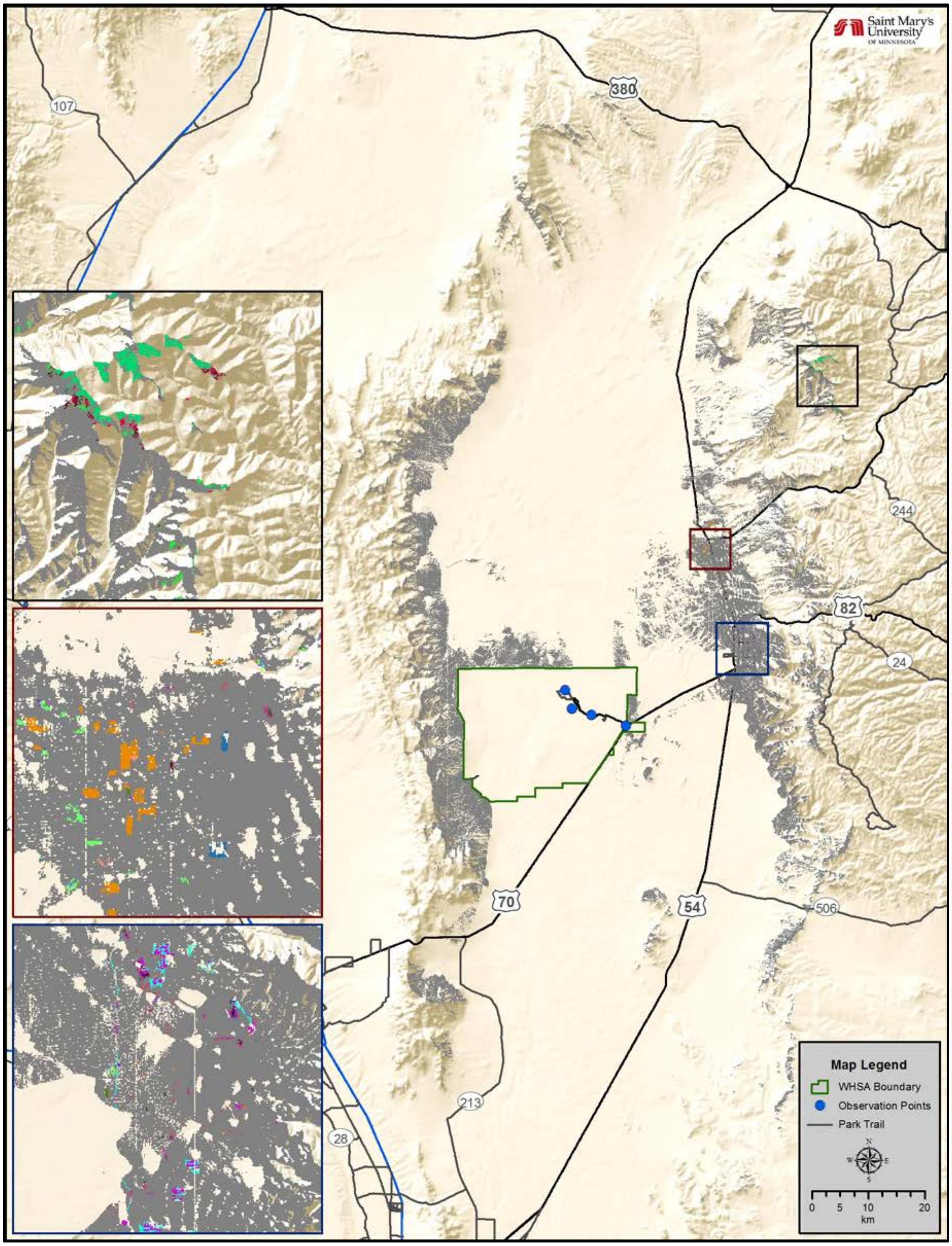



**Figure 62.** The external landcover change that can be seen from inside WHSA is minimal (less than 1%). The majority of the change occurred around the urban areas of Alamogordo (blue frame) and Tularosa (red frame), New Mexico (USGS 2011a). The legend for this map is located on the next page (Figure 63).

**Land Cover Change (2001-2011)**

- Barren Land to Developed, Medium Intensity
- Barren Land to Shrub/Scrub
- Cultivated Crops to Developed, Low Intensity
- Cultivated Crops to Emergent Herbaceous Wetlands
- Cultivated Crops to Evergreen Forest
- Cultivated Crops to Shrub/Scrub
- Cultivated Crops to Woody Wetlands
- Deciduous Forest to Evergreen Forest
- Deciduous Forest to Shrub/Scrub
- Developed, High Intensity to Developed, Medium Intensity
- Developed, Low Intensity to Developed, High Intensity
- Developed, Low Intensity to Developed, Medium Intensity
- Developed, Low Intensity to Developed, Open Space
- Developed, Medium Intensity to Developed, High Intensity
- Developed, Medium Intensity to Developed, Low Intensity
- Developed, Open Space to Developed, High Intensity
- Developed, Open Space to Developed, Low Intensity
- Developed, Open Space to Developed, Medium Intensity
- Evergreen Forest to Deciduous Forest
- Evergreen Forest to Grassland/Herbaceous
- Evergreen Forest to Pasture/Hay
- Evergreen Forest to Shrub/Scrub
- Evergreen Forest to Woody Wetlands
- Grassland/Herbaceous to Deciduous Forest
- Grassland/Herbaceous to Developed, High Intensity
- Grassland/Herbaceous to Developed, Medium Intensity
- Grassland/Herbaceous to Developed, Open Space
- Grassland/Herbaceous to Evergreen Forest
- Grassland/Herbaceous to Open Water
- Grassland/Herbaceous to Pasture/Hay
- Grassland/Herbaceous to Shrub/Scrub
- Grassland/Herbaceous to Woody Wetlands
- Open Water to Evergreen Forest
- No Change
- Open Water to Woody Wetlands
- Pasture/Hay to Emergent Herbaceous Wetlands
- Pasture/Hay to Shrub/Scrub
- Pasture/Hay to Woody Wetlands
- Shrub/Scrub to Barren Land
- Shrub/Scrub to Cultivated Crops
- Shrub/Scrub to Deciduous Forest
- Shrub/Scrub to Developed, High Intensity
- Shrub/Scrub to Developed, Low Intensity
- Shrub/Scrub to Developed, Medium Intensity
- Shrub/Scrub to Developed, Open Space
- Shrub/Scrub to Emergent Herbaceous Wetlands
- Shrub/Scrub to Evergreen Forest
- Shrub/Scrub to Grassland/Herbaceous
- Shrub/Scrub to Open Water
- Shrub/Scrub to Pasture/Hay
- Shrub/Scrub to Woody Wetlands

**Figure 63.** Legend for the external land cover change viewscape analysis (located on previous page).

**Table 38.** Percent of land cover change for each land cover change class found in the WHSA external viewscape.

| Land cover change (2001-2011) | % of total land cover change | Land cover change (2001-2011) | % of total land cover change |
|---|---|---|---|
| No change in landcover | 99.3 | Grassland/Herbaceous to Woody Wetlands | <0.01 |
| Shrub/Scrub to Open Water | 0.06 | Grassland/Herbaceous to Pasture/Hay | <0.01 |
| Shrub/Scrub to Pasture/Hay | 0.01 | Grassland/Herbaceous to Open Water | <0.01 |
| Shrub/Scrub to Grassland/Herbaceous | 0.01 | Grassland/Herbaceous to Developed, Open Space | <0.01 |
| Shrub/Scrub to Developed, Open Space | 0.01 | Grassland/Herbaceous to Developed, Medium Intensity | <0.01 |
| Shrub/Scrub to Developed, Medium Intensity | 0.01 | Grassland/Herbaceous to Developed, High Intensity | <0.01 |
| Shrub/Scrub to Deciduous Forest | 0.01 | Evergreen Forest to Woody Wetlands | <0.01 |
| Shrub/Scrub to Cultivated Crops | 0.01 | Evergreen Forest to Pasture/Hay | <0.01 |
| Grassland/Herbaceous to Evergreen Forest | 0.01 | Evergreen Forest to Grassland/Herbaceous | <0.01 |
| Grassland/Herbaceous to Deciduous Forest | 0.01 | Evergreen Forest to Deciduous Forest | <0.01 |
| Evergreen Forest to Shrub/Scrub | 0.01 | Developed, Open Space to Developed, Low Intensity | <0.01 |
| Developed, Open Space to Developed, Medium Intensity | 0.01 | Developed, Open Space to Developed, High Intensity | <0.01 |
| Developed, Low Intensity to Developed, Medium Intensity | 0.01 | Developed, Medium Intensity to Developed, Low Intensity | <0.01 |
| Developed, Low Intensity to Developed, High Intensity | 0.01 | Developed, Medium Intensity to Developed, High Intensity | <0.01 |
| Cultivated Crops to Shrub/Scrub | 0.01 | Developed, Low Intensity to Developed, Open Space | <0.01 |
| Shrub/Scrub to Woody Wetlands | 0.01 | Developed, High Intensity to Developed, Medium Intensity | <0.01 |
| Shrub/Scrub to Evergreen Forest | <0.01 | Deciduous Forest to Shrub/Scrub | <0.01 |
| Shrub/Scrub to Emergent Herbaceous Wetlands | <0.01 | Deciduous Forest to Evergreen Forest | <0.01 |
| Shrub/Scrub to Developed, Low Intensity | <0.01 | Cultivated Crops to Woody Wetlands | <0.01 |
| Shrub/Scrub to Developed, High Intensity | <0.01 | Cultivated Crops to Evergreen Forest | <0.01 |
| Shrub/Scrub to Barren Land | <0.01 | Cultivated Crops to Emergent Herbaceous Wetlands | <0.01 |
| Pasture/Hay to Woody Wetlands | <0.01 | Cultivated Crops to Developed, Low Intensity | <0.01 |
| Pasture/Hay to Shrub/Scrub | <0.01 | Barren Land to Shrub/Scrub | <0.01 |
| Pasture/Hay to Emergent Herbaceous Wetlands | <0.01 | Barren Land to Developed, Medium Intensity | <0.01 |
| Open Water to Woody Wetlands | <0.01 | Grassland/Herbaceous to Shrub/Scrub | <0.01 |

Visibility

Visibility is generally defined as the greatest distance, or visual range, at which a dark object can be seen (Pitchford and Malm 1994). Visibility impairment occurs when airborne particles and gases scatter and absorb light; the net effect of this is called “light extinction” (EPA 2003). The Environmental Protection Agency (EPA) defines light extinction as the reduction in the amount of light from a view that is returned to an observer (EPA 2003). In response to the mandates of the Clean Air Act of 1977, federal and regional organizations established the Interagency Monitoring of Protected Visual Environments (IMPROVE) program in 1985 to aid in monitoring of visibility conditions in Class I areas. The goals of IMPROVE are to:

- Establish current visibility and aerosol conditions in 156 mandatory Class I areas (CIAs);
- Identify chemical species and emission sources responsible for existing anthropogenic visibility impairment;
- Document long-term trends for assessing progress towards the national visibility goal;
- and with the enactment of the Regional Haze Rule, provide regional haze monitoring representing all visibility-protected federal CIAs where practical (Hand et al. 2011).

WHSA is not considered to be a Class I area, and certain standards of air quality do not pertain to the park (EPA 2015). The most current 5-year average (2009–2013) data from the IMPROVE monitoring station (IP BOAP1) estimates the average visibility in WHSA to be 5.5 dv above average natural conditions (NPS 2015b). This can be translated to a 225 km (140.1 mi) range of sight for the human eye (not accounting for earth curvature) (USFS 2016). This estimate falls into the *Moderate Condition* category based on NPS criteria for air quality assessment (EPA 2003).

The 20% clearest days (least impairment) and the 20% haziest days (most impairment) each year are another measure used by states and the EPA to assess progress towards meeting the national visibility goal (EPA 2003). In assessing this measure, conditions measured near zero dv are clear and provide excellent visibility, and as dv measurements increase, visibility conditions become hazier. The most current 5-year average (2006–2010), according to NPS Air Atlas (2015a), estimates visibility at WHSA as 4.3 dv on the 20% clearest days and 13.2 dv on the 20% haziest days. This translates to a standard visual range of 254 km (158 mi) on the clearest days and 104 km (65 mi) on the haziest days (Figure 64) (USFS 2016). These estimates fall into the *Moderate Condition* and *Significant Concern* categories, respectively (EPA 2003).

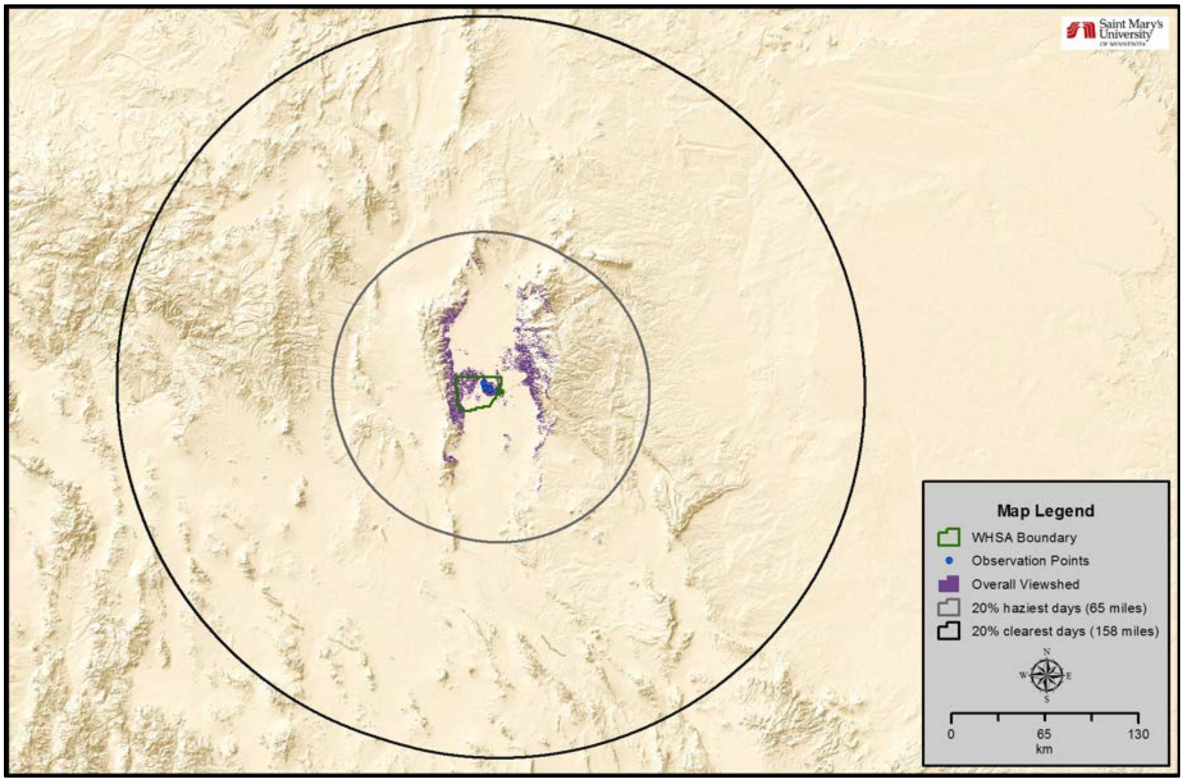



**Figure 64.** According to NPS Air Atlas (2015a), visibility at WHSA is 104 km (65 mi) (13.2 deciviews) on the 20% haziest days and 254 km (158 mi) (4.3 deciviews) on the 20% clearest days. The distance in miles is translated through a visibility calculator provided by the U.S. Forest Service Air Resource Management Regions 8 and 9 (USFS 2016).

Threats and Stressor Factors

The WHSA park staff identified several on-going and potential threats to park visitors' views of the surrounding landscape. These include the lighting at HAB and base expansion, air pollution, wind and solar energy development, a desalinization plant, traffic and road use, and climate change.

An NPS study was conducted in 2013 that surveyed visitor's nation-wide on their perceptions and values of clean air, scenic views, and dark night skies. In this survey, 62% of visitor groups felt that it was *extremely important* or *very important* that national parks have a dark night sky (Kulesza et al. 2013). Light pollution coming from the air force base is a potential threat to the WHSA viewscape at night (Figure 65). As of 2006, the light coming from HAB ranges from 2-4.5 on the Bortle Scale; typical truly dark site to rural/suburban transition (Bortle 2006). If development at HAB continues expanding, it could create additional light pollution for WHSA.

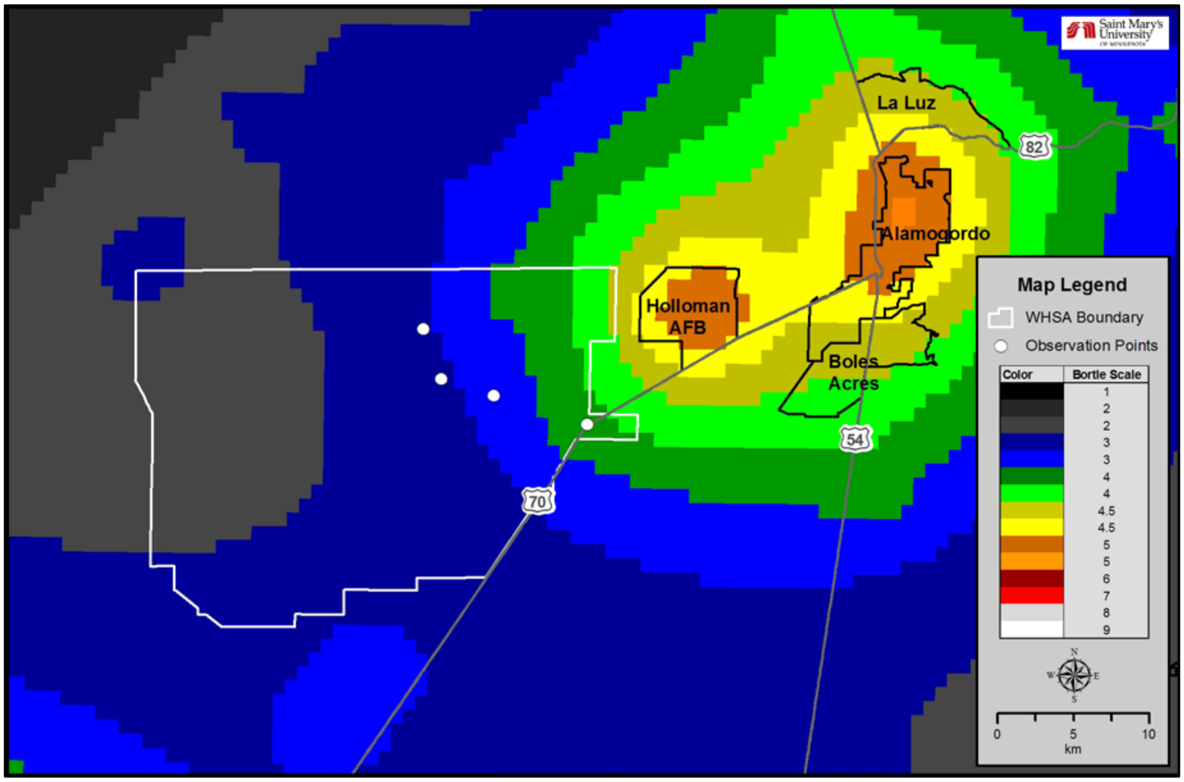



**Figure 65.** The light pollution coming from the Holloman Air Force Base is minimal at this time; ranging from 2-4.5 on the Bortle Scale (Bortle 2006, Lorenz 2006).

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 2014). Particulate matter largely consists of acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (EPA 2013, 2014). Fine particles are a major cause of reduced visibility (haze) in many national parks and wildernesses (EPA 2012). $PM_{2.5}$ 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 with air (EPA 2012, 2014). Particulate matter either absorbs light or scatters light. As a result, the clarity, color, and distance that humans can see decreases. Water in the atmosphere causes particles like nitrates and sulfates to expand, increasing their light scattering efficiency (EPA 2012, 2013).

Pollution from particulate matter is sensitive to shifts in weather (EPA 2012). Higher temperatures tend to trap more particulate in the air, thus increasing pollution and reducing visibility (IPCC 2001b). The EPA projects that climate change could cause particulate pollution to increase in some regions and decrease in others (EPA 2012). Climate change also increases the rate of water evaporation because as temperatures increase, the water-holding capacity of air increases (IPCC 2001a). This is important for WHSA because the stability of the dunes depend on the underground shallow water table (Bourret 2015). With higher temperatures causing higher evaporation rates, the potential for dust in the air increases at WHSA and the potential for dust particles to stay in the air is heightened because of those warmer temperatures.

The proposed new well field for the Brackish Groundwater National Desalinization Research Facility will have an indirect effect on the amount of dust in the air at WHSA. It has been determined that the new well field will consume groundwater from the Tularosa Basin where WHSA is located (Bourret 2015). Lowering of the groundwater table can increase the activity and movement of the dunes, while also decreasing vegetation and creating more wind erosion (KellerLynn 2003)

Currently, no solar and wind facilities are located in the vicinity of WHSA. However, as of 2015, New Mexico had 264 operating solar projects and 451 under development (Solar Energy Industries Association (SELA) 2015). Wind energy has been a proven cost-effective form of energy in New Mexico and is gaining interest (Velarde 2016). With both solar and wind industries gaining popularity in New Mexico, new construction near WHSA is possible.

Higher traffic counts are likely to occur during peak visitor season, which is June and July (Begly et al. 2013). These are also the months with the highest temperatures (NCDC 2015). High temperatures can lead to increased dust on the roads and with air pollution from traffic, the potential for the particulate matter to be moved around increases.

Data Needs/Gaps

While this assessment provides some baseline information regarding the park's visual resources, it should not be considered comprehensive. Incorporation of different and new GIS data sets, such as a higher resolution DEMs, additional or different land cover classes, or updated air quality data will enable accurate and up-to-date viewshed assessments of the metrics examined in this analysis. Also, establishing photo points throughout the park could provide photographic evidence of the changes in viewshed over time.

Overall Condition

*Change in Internal Viewscape*

The *Significance Level* for change in internal viewscape was assigned a 2. The natural landscape within WHSA has remained relatively intact from 2001 to 2011, with only a slight (< 1 %) change. The majority of that change consists of development for park infrastructure and only a small amount of change from one natural vegetation type to another. From the viewpoint of the observation points, the internal viewshed consists of mainly natural cover types and very little change has taken place. Therefore, the *Condition Level* for this measure was assigned a 1, indicating low concern.

*Change in External Viewscape*

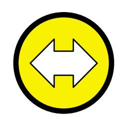
The *Significance Level* for change in external viewscape was assigned a 3. From the viewpoint at the selected observation points within WHSA, the external viewscape for park visitors is much more expansive and diverse than the internal viewscape. A visitor has the potential to view over 13,355 ha (33,000 ac) of land around the park. The majority of this external viewscape consists of the natural landscape (i.e., mountains, dunes, natural vegetation). Some areas where the land cover has changed are visible from the park; however, most of the change has occurred in the urban areas of Alamagordo and Tularosa, New Mexico. These cities are expected to continue to expand, but it is unknown if this expansion will occur in areas that can be seen from the park. Due to these factors, the *Condition Level* for this measure was assigned a 2, meaning moderate concern.

*Visibility*

The *Significance Level* for visibility was assigned a 2. The natural tendencies of sand dunes are to ever-evolve and migrate downwind (Fryberger 2001, KellerLynn 2012). Multiple factors can influence sand movement such as increased wind, a change to a more flat land cover, or increased evaporation rates or a lowered water table (KellerLynn 2012). For more detailed information on dune morphology and movements, please refer to Chapter 4.1. The movement of sand and dust in the air can affect visibility, through increased amounts of particles (or haze) in the air. Climate change and surrounding development can increase the level of haze for certain areas through increased temperatures and lower water tables. Lower water tables allow for more sand and dust particles to be swept into the air and warmer air temperatures tend to trap those particles, thus decreasing visibility. At this time, visibility in WHSA does not seem to be a major concern, with the average visibility at 5.5 dv above average natural visibility conditions (NPS 2015b). Therefore, a *Condition Level* of 2 was assigned for this, meaning moderate concern.

*Weighted Condition Score (WCS)*

The *Weighted Condition Score* for this component is 0.57, indicating viewscape is of moderate concern, and the current trend is considered stable. This is driven mainly by the impact of urban development and haze on visibility. Very little change has occurred to landcover inside the park that would affect internal viewscape. Although impacted by dust and other airborne pollutants, the majority of natural features inside and outside the park are in view.

| Viewscape | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = 0.57** |
| Change in Internal Viewscape | 2 | 1 |  |
| Change in External Viewscape | 3 | 2 | |
| Visibility | 2 | 2 | |

#### *4.10.6. Sources of Expertise*

- David Bustos, WHSA Resource Program Manager
- Jeremy White, NPS Natural Sounds and Night Sky Division, Physical Science Technician

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## 4.11. Surface Water Hydrology

### *4.11.1. Description*

Watershed

WHSA is part of the Tularosa Valley Watershed, which covers 44,996 $km^2$ (17, 373 $mi^2$) of land area (Figure 66), with 17,252 km (10,720 mi) of intermittently flowing water course. The park is part of an internally drained or closed geologic and topographic basin where surface water travels to and accumulates in the Lake Lucero wholly within WHSA and Alkali flats within WHSA and WSMR.

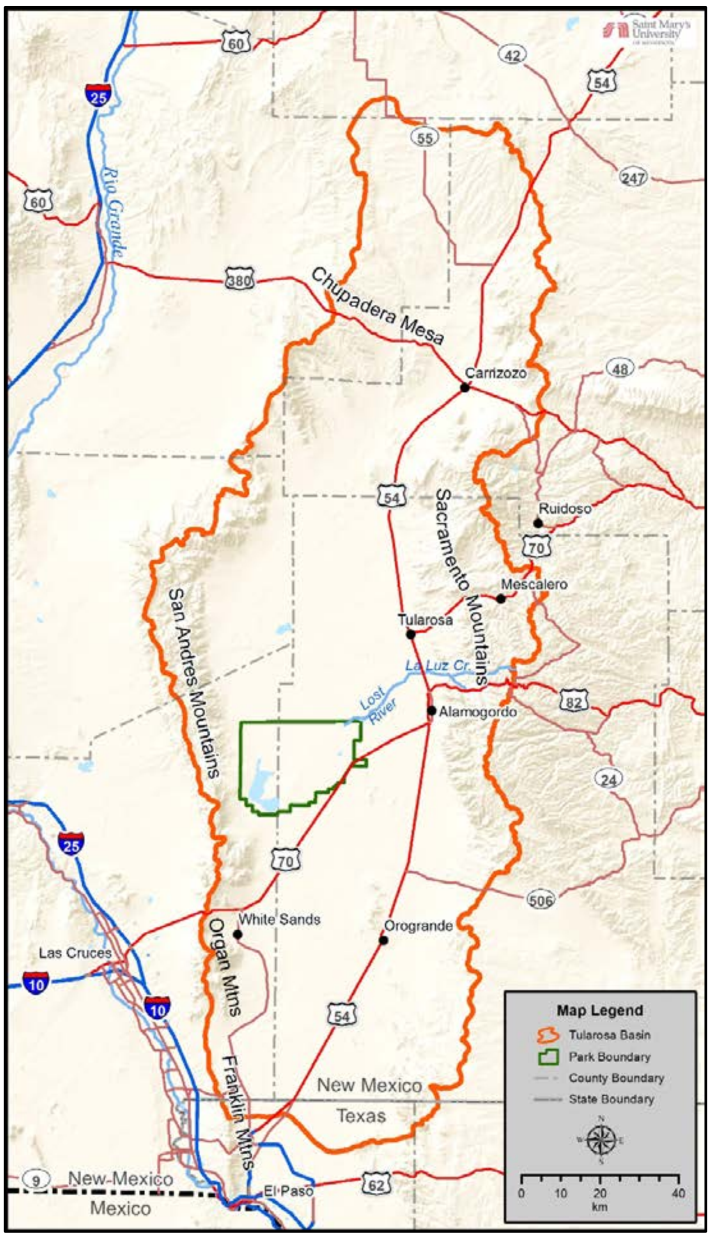


**Figure 66.** Location of WHSA within the Tularosa Basin in Southern New Mexico.

The topography of the region isolates the Tularosa Basin; its eastern boundary is provided by the Sacramento Mountains while the San Andres, Organ, and Franklin Mountains provide the western boundary. The northern end of the basin is bounded by the Chupadera Mesa and a gently inclining landscape separates the Tularosa Basin from the Hueco Bolson to the south (Newton and Allen 2014). The surrounding mountains consist of Paleozoic sedimentary rocks which impact the regional geochemistry (KellerLynn 2007, Jonathan Knapp, WHSA Physical Scientist, written communication, 28 June 2016). Groundwater and surface waters (Photo 31) are highly integrated within this environment and are closely tied to the geological processes that created and sustain the White Sands gypsum dune fields (Conrad 2005b, KellerLynn 2007, NPS 2016).

**Photo 31.** Lake Lucero with water and shorebirds after 2006 flood (NPS Photo).

Geologic Setting, Major Hydrologic Processes, and Climate

WHSA is situated within a closed drainage system formed as part of the Rio Grande Rift System. Normal faulting has created a series of half grabens resulting in an asymmetrical topographic and structural basin. Paleozoic sedimentary rocks, including carbonates and evaporates, are exposed in rift valley walls and deeply buried in the basin floor. A thick but unevenly distributed recent accumulation of sediment has filled the basin since the initiation of rifting. This accumulation includes fluvial (river) sediments related to the Rio Grande River, past lake sediments that include evaporates and carbonates, eolian (wind blown) deposits, paleosols (fossil soils), alluvial fans, and fluvial sediments resulting from the internally drained basin. The basin is bounded and dissected by large and unmapped normal faults occurring as fault zones with swarms of associated reverse faults. Tertiary ingenious intrusions from early rifting processes create large granitic monoliths in Saria Blanca and the Organ Mountains. Basaltic lava flows within the last 7000 years have occurred at the surface in the basin, indicating that this rift may not entirely tectonically quiescent.

The topographic Tularosa Basin is an underfilled type basin resulting in an evaporative sedimentary lithofacies assemblage. Groundwater becomes enriched in ions such as calcium ($Ca^{2+}$) and sulfate ($SO_4^{2-}$) as it moves through Paleozoic sedimentary rocks and recent basin fill containing evaporates. Surface water may accumulate some ions as it passes over gypsum exposed at the surface and accumulate $SO_4$ from acid rain and dryfall deposition. The groundwater and surface water all generally flow towards the lowest topographic point the in the basin.

Surface water accumulations are directly tied to meteoric water inputs by: 1) rise in groundwater associated with precipitation events, 2) riverine inputs to the system (i.e., Lost River), and 3) flash flooding and overland un-channelized flow. Surface water accumulates in the lowest part of the basin (Lake Lucero and Alkali Flats), the interdunal areas, and several smaller isolated playas in the park. In the interdunal areas, groundwater quickly drops in the highly porous and elevated sediment, allowing the lakes to lose their surface water to the groundwater system. On the Alkali flats and Lake Lucero, the groundwater is slower to recede, resulting in a longer resident time for surface water and subjecting this water to evaporation.

The Tularosa Basin is a semi-arid region within the Chihuahuan Desert. Total precipitation is less than 25 cm (10 in) per year, while evaporation exceeded 137 cm (54 in) per year. The standing bodies of water are enriched in $SO_4$, Ca, and other dissolved solids or ions as water ($H_2O$) molecules are evaporated and transferred into the atmosphere; a process called evapoconcentration. As the waters become supersaturated in $SO_4^{2-}$ and Ca they will combine with two waters to form gypsum ($CaSo_4•2H_2O$). From standing bodies of water, gypsum can directly precipitate from the water and accumulate in the bottom of the lake as small cumulate crystals or grow from the bottom of the lake as larger bottom growth gypsum crystals. Through this process, the lake may become completely dry and enter the desiccation stage with groundwater wicking through the surface results in efflorescent gypsum crusts. Gypsum can also precipitate directly from groundwater to create displasive gypsum crystals (see Chapter 4.12.1 for a discussion of groundwater at WHSA). Once the lake desiccates, strong winds erode the sediment into the dunes (see Chapter 4.1.1).

At present, surface water resources within WHSA include Lake Lucero, Garton Pond, Lost River, intermittent streams, and several springs (Figure 67). Additional surface water features in the immediate vicinity include Holloman Lake, along with other intermittent and perennial lakes/ponds, playas and several springs (USGS 2000). With the exception of Lost River (which originates in the Sacramento Mountains) the surface water features found within WHSA originate in the San Andres Mountains (Newton and Allen 2014).

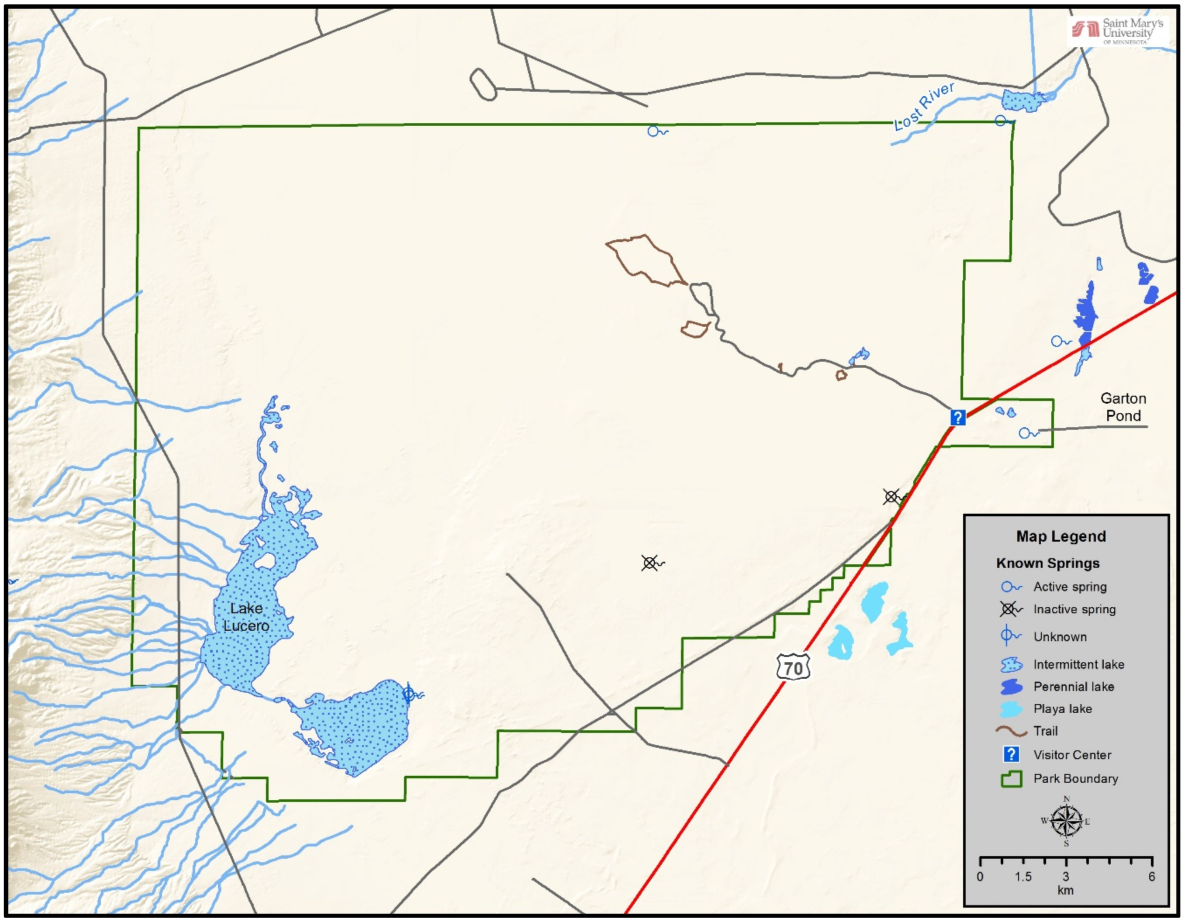


**Figure 67.** Surface water resources within WHSA and the immediate area.

### *4.11.2. Measures*

- Frequency of surface water
- Geochemistry of surface water
- Persistence of surface water
- Timing and amount of precipitation
- Groundwater recharge and discharge

### *4.11.3. Reference Conditions/Values*

The reference condition selected by the project team was the pre-water diversion conditions (pre-1950s) of the parks surface water features. In general, over recent history surface water features have been scarce within the Tularosa Basin and there is very little stream gauge information available (Sprester 1980). Based on anecdotal evidence, the section of the Lost River within the park has always been an ephemeral stream (Dr. Hildy Reiser, retired CHDN Science Advisor, pers. Communication, as cited by Conrad 2005b). However, during the reference condition period defined above, upstream of HAFB, Lost River was free-flowing, with only occasional periods of dry channel (Reiser, pers. Communication, as cited by Conrad 2005b). The only perennial surface water feature within the park during the reference condition was Garton Pond (Martin 2009). This is not a natural feature, but rather a surface pond created after an exploratory oil drilling rig experienced an uncontrolled blowout of over pressurized hot water in 1916 (Martin 2009). Other surface water features within the park included a number of ephemeral and intermittent streams, the ephemeral lake system of Lake Lucero and Alkali Flat, and a number of small playa lakes (Figure 67) (WHSA 1992).

Weather data are available for the WHSA NWS Cooperative weather station, located near the visitor center and park headquarters, dating back to 1939. In an effort to match the same time period as the reference condition for surface water features, the 1961–1990 climate normal data will be used for the reference condition for the timing and amount of precipitation measure. This 30-year normal is available from the Western Regional Climate Center (WRCC) and the monthly and yearly averages are given in Table 39 (WRCC 2016c).

**Table 39.** Mean precipitation for WHSA Cooperative Weather Station for the period of 1961–1990 (WRCC 2016c). Measurements are in centimeters with the inch equivalent in parenthesis.

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.17 | 0.97 | 0.71 | 0.58 | 0.89 | 2.13 | 3.84 | 5.21 | 3.40 | 2.41 | 1.50 | 1.75 | 24.56 |
| (0.46) | (0.38) | (0.28) | (0.23) | (0.35) | (0.84) | (1.51) | (2.05) | (1.34) | (0.95) | (0.59) | (0.69) | (9.67) |

#### *4.11.4. Data and Methods*

Hydrologic studies have been conducted on the surface water and groundwater resources within the Tularosa Basin beginning as early as 1915 (Meinzer and Hare 1915). This study focused on the variability of precipitation in the Tularosa Basin, both spatially and temporally, and how that impacted the regional groundwater recharge rates. Due to the lack of surface water features in the Tularosa Basin, only a few surface water studies were available for developing an overall view of the surface hydrology of the region. However, due to the importance of groundwater as a drinking water source is this region, there have been many groundwater studies conducted. Most of these studies do cover the surface water features and hydrology of the region. Knowles and Kennedy (1958) conducted a groundwater study of the Northern Hueco Bolson, which forms the southern boundary of the Tularosa Basin. Herrick and Davis (1965) reported on groundwater resources in the Tularosa Basin, McLean (1970) conducted research focused on the saline and fresh groundwater supply, and Orr and Myers (1986) studied the available freshwater and saline water supply within the basin.

More recent regional hydrologic studies utilized by this assessment include; Waltemeyer (2001) who estimated annual stream-flow and groundwater recharge for the Tularosa Basin, Huff (2002a) who studied the direction of groundwater flow and geochemical data to interpret the age of the groundwater, Allen (2005) who estimated the surface area, drainage area and the evaporation and precipitation rates for select ice age lakes in New Mexico, Porter et al. (2009) who reported on the surface and groundwater resources within CHDN parks, and Mamer et al. (2014) who identified groundwater recharge areas and recharge estimates along with groundwater flow rates, direction and residence time for the northeastern portion of the Tularosa Basin.

A number of hydrologic studies have been conducted in an attempt to understand the surface and groundwater systems within WHSA. Allmendinger (1971) researched the source of gypsum sands deposited through the evaporation of Lake Lucero. Sprester (1980) and Martin (2009) provided an overview of the formation of Garton Pond along with an evaluation of several water quality parameters. Barud-Zubillaga (2000) conducted a thesis research project on the hydrogeology of the WHSA area in order to determine groundwater flow characteristics. Barud-Zubillaga and Schulze-Makuch (2001) conducted research on the hydrogeology of WHSA using satellite imagery. Schulze-Makuch (2002) conducted research on the groundwater and soils from beneath Lake Lucero. Newton and Allen (2014) conducted a hydrologic study at WHSA to identify the source of the shallow aquifer beneath the dune field and the interaction between this and the larger regional aquifer. Bourret (2015) conducted a thesis research project to model the source of water supplying the shallow dune aquifer and updated an existing conceptual model of the relationship between the regional hydrologic system and the shallow dune aquifer at WHSA.

Additional information on the surface water features, hydrology, and geology of WHSA and HAFB was obtained from several published and unpublished NPS and USGS reports (e.g., McDougall 1939, Basabukvazo et al. 1994, Fryberger 2001, KellerLynn 2003, Conrad 2005b, KellerLynn 2007). Perchlorate data were obtained from a USGS study that collected groundwater, soil and organic matter (salt cedar leaves) for testing along the Lost River and near Garton Pond (Huff 2002b).

### *4.11.5. Current Condition and Trend*

Frequency of Surface Water

A few small perennial streams are located within the Tularosa Basin (Sprester 1980). These originate on the west side of the Sacramento Mountains in the area of Sierra Blanca; however, none flow through WHSA (Sprester 1980). The park does have several ephemeral streams, comprised of several arroyos in the western portion of the park and Lost River in the northeast corner of the park (Figure 67). Flow in these streams originates mainly from surface water runoff from precipitation events in the surrounding mountains (Bourret 2015). The arroyos on the west side of the park originate on the east slopes of the San Andres Mountains and drain into Alkali Flats or Lake Lucero where the majority of the surface water is lost through evaporation or infiltration (Fryberger 2001, Myers and Langman 2008). Lost River originates to the northeast of the park in the Sacramento Mountains near La Luz (Figure 66).

The ephemeral flow of the Lost River decreased within the park (and overall) over time due to water diversion by the City of Alamogordo, rural homes, and irrigated field crops upstream from the park (Conrad 2005b). Flow into the park was further interrupted by a large dune that formed in the early 1990s, damming the channel about 200–300 m (656–984 ft) upstream of the parks boundary (Conrad 2005b). On only a few occasions since 1996 has surface water been observed flowing around this dam, usually occurring during periods associated with heavy rains (Conrad 2005b). Currently within the park, the Lost River has only ephemeral flow, although portions of the Lost River, including a small reach in the northeast corner of the park, have permanent water. Recent studies indicate that this is due to regional groundwater (Newton and Allen 2014).

The ephemeral streams found within the park normally have sustained flow only during precipitation events (Basabukvazo et al. 1994, Fryberger 2001). Typically, these rainfall events occur during the monsoon season or in the winter (Newton and Allen 2014). In general, the flow from these streams fill the ephemeral lakes and playas found within the park (Basabukvazo et al. 1994, Fryberger 2001). Heavy rainfall events can create periods of flash flooding (Newton and Allen 2014). An example of this flooding occurred during the winter of 1992–1993 when a large portion of the north-central portion of the park was inundated after an above average rain event (Figure 68) (Conrad 2005b). On 17 May 2016, park staff experienced a flash flood event while working on Lake Lucero. Water flowed at high speed in an unconfined manner over the alluvial fan surface and onto Lake Lucero after a heavy precipitation and hail event. Flood water reached the ephemeral lake flat and caused a short period of inundation over small areas (Knapp, written communication 17 June 2016).

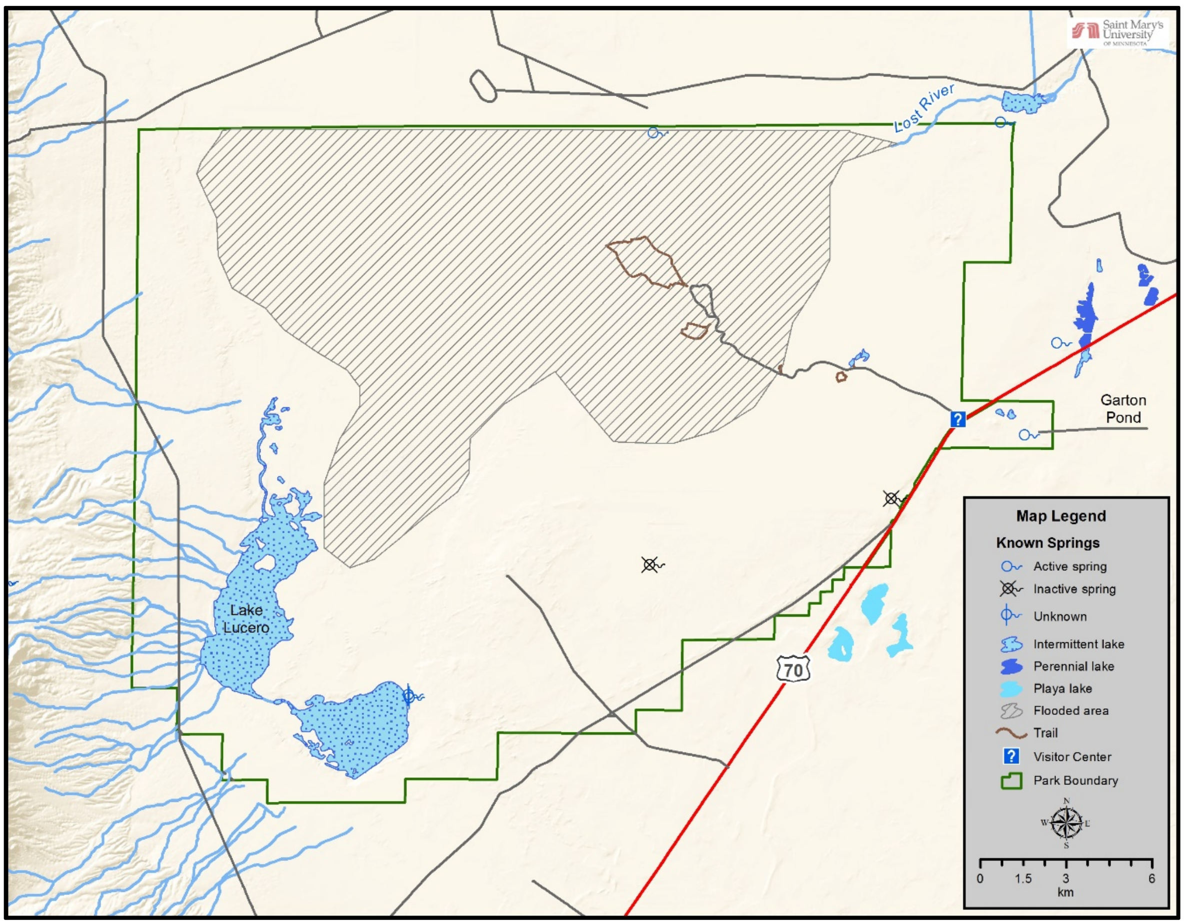


**Figure 68**. Extent of the flooding in the winter of 1992-1993.

Several ephemeral water bodies are found within the park (Figure 67). The ephemeral lake and saline mudflat system of Lake Lucero and Alkali Flats is the largest of the park’s playa lakes (Bourret 2015). Lake Lucero is the portion of the system that floods most often, but Alkali Flats experiences flooding and exhibits bottom growth gypsum crystals and other features that justify grouping it with Lake Lucero as part of a unified ephemeral lake system. The ephemeral lake system is dry most of the year. Waters are supplied into this system by highly seasonal surface water runoff transported by the arroyos to the west or from groundwater discharge (Barud-Zubillaga 2000, Schulze-Makuch 2002). The Lake Lucero-Alkali Flats ephemeral lake system is considered the park's second-most important asset, as it is part of the overall dune system and the regional groundwater system (KellerLynn 2003). Several smaller playa lakes are located on the park's eastern side; some of these rely on flood waters from the Lost River as their water source (Newton and Allen 2014).

The only perennial surface water feature found in historic times within the park is Garton Pond (Newton and Allen 2014). As stated earlier, this is not a naturally occurring body of water. Garton Pond is located approximately a mile to the southwest of the Visitor Center (Figure 67). After the artesian flow began, the landowner at the time constructed a circular dike 0.9–1.2 m (3–4 ft) high with a radius of 15.2 m (50 ft) around the wellhead (Sprester 1980, Martin 2009). The initial flow rates into the pond were measured at 4,164 liters per minute (1,100 gallons per minute) and the water eventually formed a small pond (approximately 1.6 ha [4 ac]) surrounded by a marshy area (Sprester 1980). Originally outside the boundary of WHSA on the south side of the highway, the NPS acquired the pond and the land in the 1930s for use in educational and recreational purposes (Conrad 2005b, Newton and Allen 2014). Flow rates declined over the years, and today Garton Pond is considered a large marsh with little standing water (Newton and Allen 2014).

Anecdotal evidence suggests that wetlands were present in the 1980s and early 1990s. This assumption is based on observations from park personnel of hearing the sounds of frogs near the housing area (KellerLynn 2007). It should be noted that the period from the 1970s to the early 1990s were an unusually wet period (Conrad 2005b). While neither a comprehensive wetlands inventory nor scientific wetland delineations have been conducted, on the basis of the anecdotal evidence it can be assumed that wetlands were present during this time period (Conrad 2005b, KellerLynn 2007). Recently, a wet microbial mat was observed within the park, and park staff have undertaken efforts to remove salt cedar in areas along the parks south boundary in an attempt to create wet areas (Knapp, written communication, 28 June 2016).

<u>Persistence of Surface Water</u>

As stated above, the only two perennial water features within the park are Garton Pond and a small reach of Lost River, and the source of the water for each of these features is groundwater (Newton and Allen 2014). Due to the ephemeral nature of the park's remaining water features, in general the duration of inundation is largely determined by climatic factors. Streamflow within the park's arroyos is dependent on precipitation, surface temperature, and other climatic factors (KellerLynn 2003).

No weather observation stations are located in the San Andres Mountains to the west, but data are available for National Oceanic and Atmospheric Administration (NOAA) cooperative stations at Alamogordo (Coop ID 290199), Mountain Park (Coop ID 295960) and WHSA (Coop ID 299686). Average annual rainfall for these stations ranges from 22.89 cm (9.01 in) at the park to 27.81 cm (10.95 in) in Alamogordo, and 48.87 cm (19.24 in) in the mountains at Mountain Park, near Cloudcroft, New Mexico (WRCC 2016a, b, c). These low precipitation rates, coupled with the high temperatures and low humidity on the basin floor, result in a condition where evaporation is greater than precipitation (Allen 2005, Bourret 2015).

The park has many ephemeral lakes and saline pans. The rate of evaporation within the park has been estimated at 203–254 cm (80–100 in) per year (WHSA 1992). Ephemeral lakes and saline pans often occur when evaporation and infiltration exceeds inputs from runoff, precipitation, and groundwater seeps. Lake Lucero and the other ephemeral lakes within the park are dry most of the year, except for a short period of time following heavy precipitation events (Photo 32) (WHSA 1971, 1992).

**Photo 32.** During the flood of 2006 the Dunes Drive remained closed for 8 months (NPS Photo).

Within the dune field, the depth to groundwater is shallow (Newton and Allen 2014). During the monsoon season or in the winter, it is somewhat common for a rising water table level to result in areas of interdunal flooding (Newton and Allen 2014). The rising groundwater levels are due to the heavy rains and low evaporation rates during these periods of the year (Newton and Allen 2014). But overall, the high annual aridity eventually evaporates these surface water (WHSA1992).

The availability of surface water and soil moisture is critical to the survivability of the spadefoot toad species that inhabit the park. Three species of spadefoot toad are present within the park, Couch's spadefoot (*Scaphiopus couchii*), plains spadefoot (*Spea bombifrons*), and Mexican spadefoot (*Spea multiplicata)* (Photo 33) (NPS 2015). These species have specialized habitat requirements and have adapted to the arid environment present at WHSA (Naish 2015). The spadefoot is nocturnal and is generally only seen during and immediately after precipitation events. In order to avoid the heat of the surface, the spadefoot digs a burrow below the surface or inhabits an existing burrow. Normally these burrows extend only a few inches below the surface, but when surface temperatures are high and soil moisture is low, they can extend several feet below the surface. The body chemistry of the spadefoot allows for them to absorb water through their semi-permeable skin from the surrounding moist soil. They can stay below ground for months at a time and emerge during the monsoon season and winter when the nighttime temperatures are lower and the rains provide ephemeral pools for breeding (RGNC 2016). These ephemeral surface features normally persisting for a relatively short period of time (a few weeks or days) and the spadefoot has adapted to the short wet phase (Naish 2015). The eggs have a short incubation period and once hatched, the tadpoles undergo rapid development (Naish 2015). Another adaptation is that during periods of drought or low precipitation, they can remain dormant in the ground for several years until sufficient rainfall is present (Boeing et al. 2014).

**Photo 33.** Couch's (left), Plains (center), and Mexican (right) spadefoot toads (NPS Photos).

Geochemistry of surface water

Water chemistry, particularly major ions, is a primary control on mineral production in saline lakes (Hardie et al. 2009), and thus directly connected to the availability of gypsum to be supplies to the dunes. Little information and data are currently available in regard to the geochemistry of surface waters within WHSA. Newton and Allen (2014) collected samples from one surface water locality, the reach of Lost River where perennial water is present. One well, WS23, was sampled from a well near Lake Lucero’s southeast tip. Laboratory and field geochemical analysis of this sample was complete, but was only a single sample with no spatial or temporal information. Results identified a pH of 7, dissolved oxygen of 0.04 mg/L, $SO_4^{2-}$ concentrations of 88, 000 ppm, and chlorine (Cl) levels of 81,000 ppm. The Lost River sample is taken from a location considered to be with the next highest being the 19,800 ppm measured at the Lost River. This should not be considered an adequate characterization of the surface water chemistry within WHSA (Knapp, written communication, 27 June 2016).

Timing and Amount of Precipitation

The primary drivers of ecological processes in desert ecosystems (like those found at WHSA) are precipitation and solar radiation (NPS 2010). Precipitation at WHSA is highly seasonal, with the majority of the precipitation received during the summer months of July–September (monsoon season) or in the winter (January–March) (Figure 69). The maximum amounts of the rainfall occur during the summer months, but this is also when evaporation rates are highest, due to the higher average temperatures (McLean 1970, Fryberger 2001). Winter precipitation events are the primary source of groundwater recharge in the surrounding mountains. With lower temperatures, less water is lost through evaporation and more infiltration takes place (McLean 1970). The driest months are from March through May, which coincide with the windy season in the area (McKee and Douglass 1971).

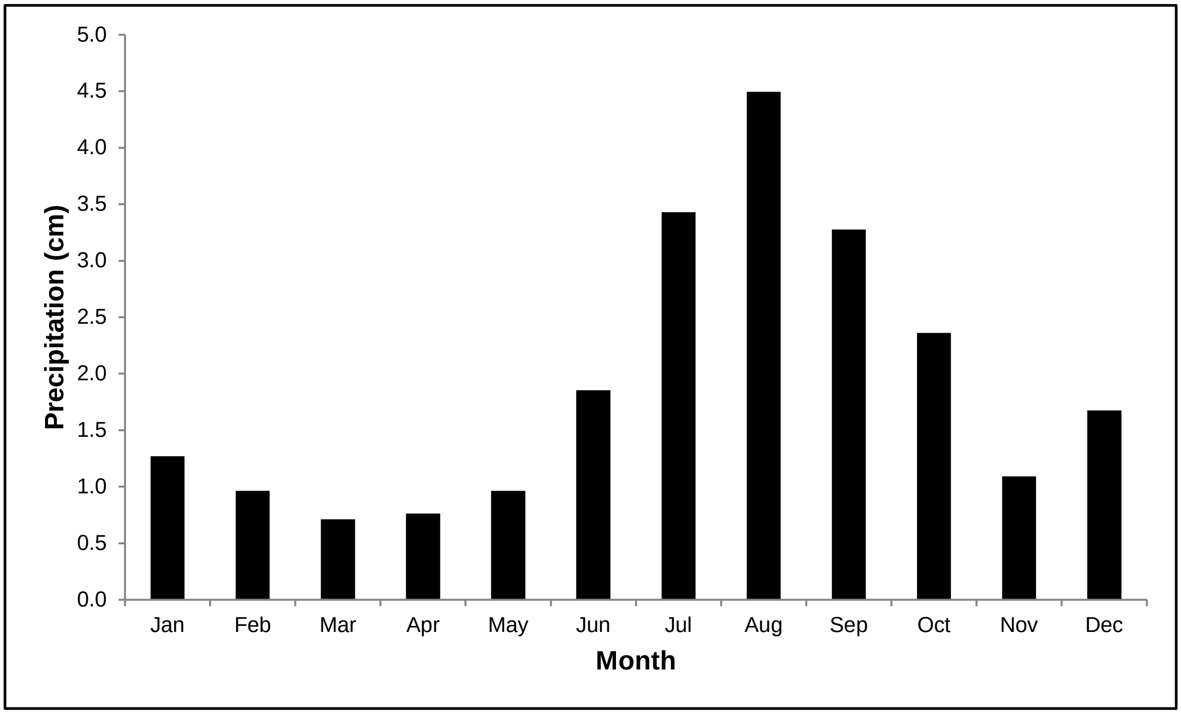


**Figure 69.** Average monthly precipitation recorded at WHSA weather station. Data are for the period 1939–2012 (WRCC 2016c).

The weather systems that produce the precipitation events in the Tularosa Basin originate in the Gulf of Mexico, Gulf of California, and the Pacific Ocean, and most summer storms that occur in the region are part of the North American monsoon system. As these saturated air masses move across the San Andres and Sacramento Mountains, an orographic effect causes precipitation. This effect is greater in the Sacramento Mountains due to generally higher elevations (Bourret 2015). In the San Andres Mountains, nearly all precipitation is in the form of rain, while the Sacramento Mountains receive approximately 180 cm (71 in) of snowfall annually (Waltemeyer 2001, Bourret 2015).

In general, mean annual precipitation within the Tularosa Basin ranges from approximately 25.4 cm (10 in) in the central portion to approximately 63.5 cm (25 in) in the higher mountain elevations (McLean 1970, WRCC 2016a, b, c). The latest 30 year monthly average (1981–2010) for the weather stations in and around WHSA showed mean annual precipitation ranging from 27.36 cm (10.77 in) at WHSA, to 29.8 cm (11.73 in) in Alamogordo, to 51.74 cm (20.37 in) at Mountain Park in the Sacramento Mountains (WRCC 2016a, b, c). Figure 70 shows the monthly mean precipitation values for WHSA for the last 4 years, as well as 30 year monthly averages for the periods 1961–1990 and 1981–2010. The peak in precipitation during the summer months can clearly be seen. The variation in the amount of precipitation from month to month and year to year is also evident. In terms of the 30 year averages, except for the months of March and November, the mean monthly precipitation for the latest 30 year period (981–2010) has increased over the previous 30 year average (1961–1990) (Figure 70).

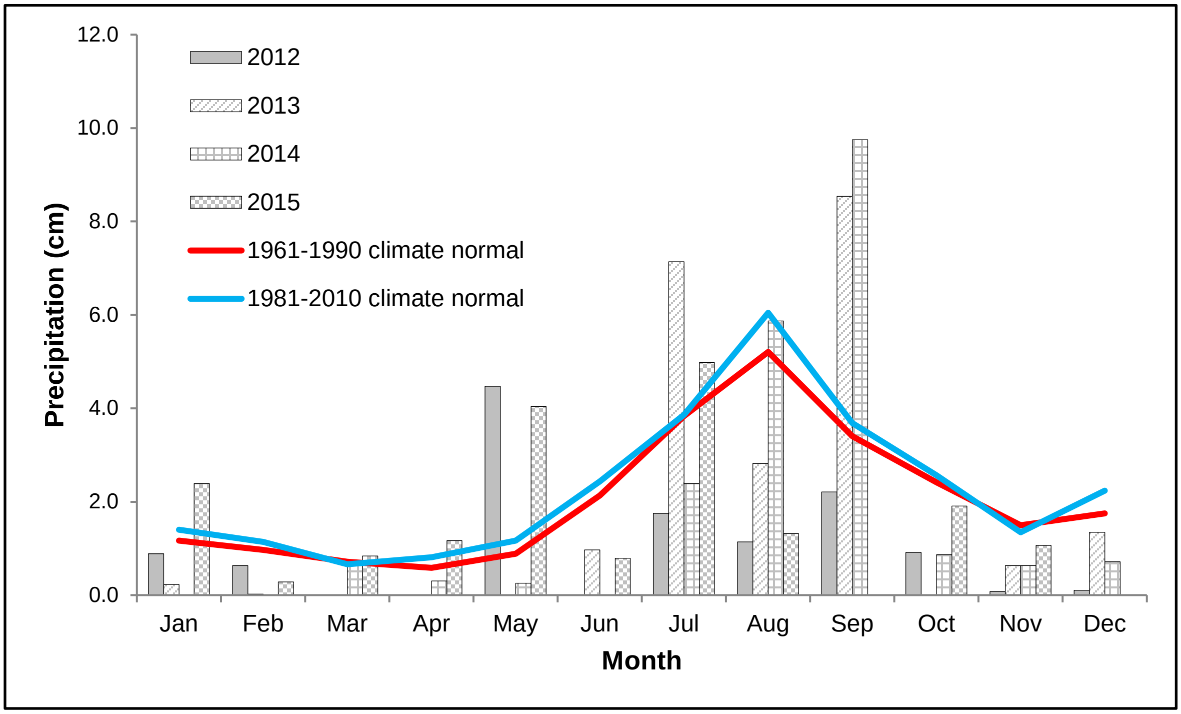


**Figure 70.** Monthly mean precipitation for the last 4 years compared to the last two 30 year periods (1961–1990 and 1981–2010) (WHSA 2016c).

<u>Groundwater Recharge and Discharge</u>

The flux between groundwater and surface is poorly understood at WHSA. In conjunction with the park's ephemeral streams and playa lakes, springs (i.e., areas of groundwater discharge) are an important component of this desert ecosystem. Springs provide specialized habitats and are an important source of water for the plant communities they support and the park's wildlife (NPS 2010). The source of the brines that feed the lake can either be from runoff or from rising groundwater tables after storm events. The chemical pathways of evapoconcentration will differ between the two endmembers, resulting in different mineral assemblages (Eugster and Hardie 1978).

Though recharge and groundwater-surface water interactions are not currently monitored in the park, the CHDN I&M currently monitors three active springs with the park (McIntyre, written communication, 5 January 2016) (Figure 71). These springs are EC 50, Garton Pond, and Salt Spring. Another spring identified from old park maps by Newton and Allen (2014) is no longer present, but was located in the vicinity of monitoring well WS-003 (Figure 71). Figure 71 also shows the location of four additional springs (two inactive and two of unknown flow) known to be within the park. A summary of the flow regimes for all seven springs is given in Table 40.

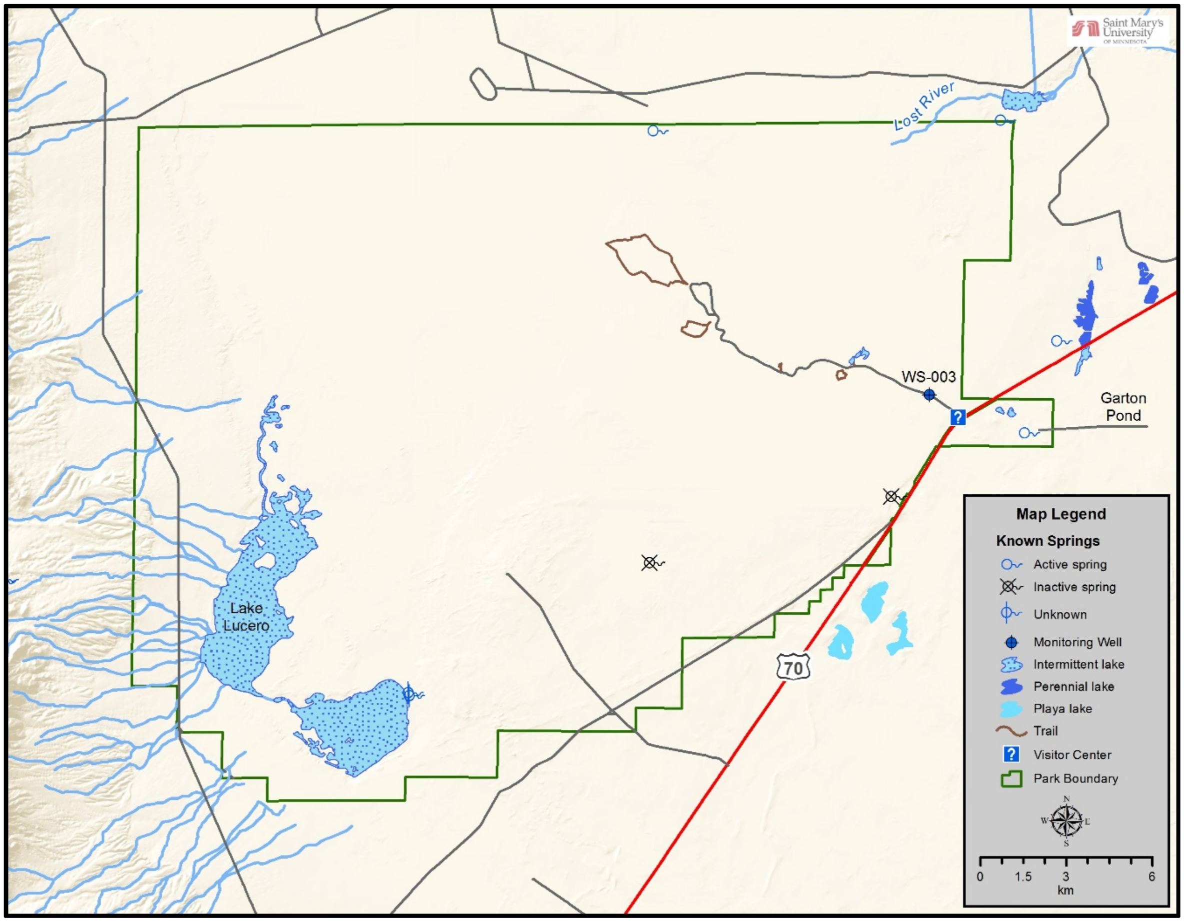


**Figure 71**. Current and historical location of springs within WHSA.

**Table 40.** Flow regimes and notes on the currently known springs within WHSA.

| Name | Flow regime | Comments |
|---|---|---|
| EC 50 | Active | - |
| Garton Pond | Active | - |
| Salt Spring | Active | - |
| Adobe well | Inactive | - |
| Un-named spring 1 | Unknown | Dried up approximately 8 years ago |
| Un-named spring 2 | Unknown | Active in February 2011 |
| Un-named spring 3 | Unknown | Active in February 2011 |

Threats and Stressor Factors

Located within a hydrologically closed basin, WHSA relies on precipitation in the surrounding mountains to produce the ephemeral flows that supply water to the park's playa lakes and provide groundwater recharge (Myers and Langman 2008). These ephemeral streams also carry dissolved gypsum from the Paleozoic sedimentary rocks in the mountains (Newton and Allen 2014). This stream water, along with contributions from groundwater, is than concentrated in the ephemeral lake/saline mudflats in the basin through evapoconcentration of solutes. Minerals will precipitate from the water column and nucleate from the saline pan floor as the brines concentrate in species such as $SO_4^{2-}$, Cl, calcium carbonate ($CaCO_3$) and Ca. In the final stages of evaporation, groundwater may be wicked through saline mineral crusts or sediment to create efflorescent crusts (Eugster and Hardie 1978). After desiccation the sediments are available for transport by wind. The prevailing southwest winds have transported these deposits to the east to form the White Sands dune field (Newton and Allen 2014).

WHSA and CHDN staff have identified several threats to these ephemeral surface water features that are important to the ecosystems found within the park and the formation of the gypsum crystals that form the sand (KellerLynn 2003, NPS 2010). These threats include processes such as perturbations of the climate systems such as drought and the changing precipitation patterns associated with climate change, the impact of invasive species (specifically salt cedar), increased use of groundwater and surface water for municipal and agricultural water supplies and surface water contamination.

The majority of the surface water is associated with precipitation events in the mountains to the west of the park, as surface flow from the east and south is restricted by sand dunes and flow from the north is intercepted by small playas or is regulated/restricted by anthropogenic features (Allmendinger 1971, KellerLynn 2003). The role of groundwater in providing surface water to the park is poorly understood. In general, most surface water runoff is lost to infiltration and evaporation before reaching the park. Precipitation events of sufficient intensity, duration, and frequency are needed to produce a volume of surface runoff sufficient enough to reach the park (Allmendinger 1971), though sustained precipitation events may also raise the groundwater table and flood the ephemeral lake/saline mudflat system. Ephemeral surface features and associated groundwater is extremely vulnerable to climate change and drought (Bull 1997). Loss of ephemeral flows due to periods of drought, coupled with the high evaporation rates in the region, would cause a drop in the available surface water in the park. The loss of surface water and high evaporation rates would also negatively impact groundwater recharge, increasing the depth to groundwater and groundwater supplies (McLean 1970). More information on the effects of drought on groundwater supplies can be found in Chapter 4.12.5, but in general, prolonged periods of drought could result in destabilization of the parks dune field (NPS 2010).

The climate at WHSA is typical of the arid to semi-arid conditions found throughout the southwestern United States (Sprester 1980). Currently, the park experiences hot summer temperatures and cool dry winters (Bennett and Wilder 2009). Seasonal rains occur in the winter and summer, with the majority of the precipitation occurring during the summer (Bennett and Wilder 2009). Winter precipitation in the mountains and monsoon season precipitation at lower elevations are an important component of groundwater recharge in the region, as even though the rainfall amounts are lower, the associated lower temperatures result in low evaporation rates (Mamer et al. 2014). Climate change projections for the southwestern US predict an increase in annual temperature of 1.5–3.6 °C (2.7–6.5 °F) by 2050, and 2.5–5.4°C (4.5–9.7 °F) by 2100 (Garfin et al. 2010). The temperature change predictions vary, dependent on the models and emission scenarios used (Garfin et al. 2010). The model results for projected changes in the amount and timing of precipitation are less clear. A conservative evaluation suggests a slight increase in mean annual precipitation by 2100 (Garfin et al. 2010). The models consistently predict a decrease (11–25%) in precipitation during May–June (Garfin et al. 2010). Overall, the results of climate change modeling show a trend toward an increase in aridity for the southwestern United States (Seager et al. 2007, Garfin et al. 2010).

The invasion and expansion of salt cedar has become a serious problem in arid regions such as the southwestern US. Early studies (pre-1990) indicated that salt cedar was a prolific water user as compared to native riparian species. More recent studies have shown that salt cedar on average uses less than 122 liters per day (32.2 gallons per day) (Owens and Moore 2007). While this value is similar to native woody species, salt cedar uses the water less efficiently and is capable of surviving for extended periods without access to saturated soil (Howard 1983). This allows for them to outcompete and replace cottonwoods and other species with similar soil moisture requirements. Ideal conditions for salt cedar infestation are found throughout the park, due to the high groundwater table, especially along the dune field edges and around Lake Lucero, Alkali Flats (ephemeral lake/saline mudflat system), and Lost River (Photo 34, Figure 72). With the climate change models predicting a drier and warmer climate resulting in a dropping water table, an increase in salt cedar infestations within the park may become more realistic (Conrad 2005a). Currently, salt cedar is found in discrete isolated patches within WHSA. The park began herbicide treatment of salt cedar infestations in 1997 and spraying and mechanized removal continues to be maintained by the NPS Exotic Plant Management Team (EPMT) and WHSA staff.

As in many deserts, the local population and industry of the Tularosa Basin competes with the natural systems for water. Local municipalities of Alamogordo, Tularosa, La Luz and other small communities in the area, along with WHSA, WSMR, and HAFB all rely on the limited surface water and saline or brackish groundwater resources of the Tularosa Basin. Even with modest development in the area, water demands have increased (NPS 2010). To meet the growing water needs, municipalities are looking at increased pumping of potable groundwater and also building desalinization plants to treat the brackish groundwater (Newton and Allen 2014). Increases in groundwater pumping and projected higher aridity rates and lower precipitation have the potential to impact regional groundwater levels and the surface water features that are supported by groundwater. More detailed information on the impacts of increased water demand on groundwater can be found in Chapter 4.12.5.

**Photo 34.** Lost River overgrown with salt cedar flowing into park after 2006 flood (NPS Photo).

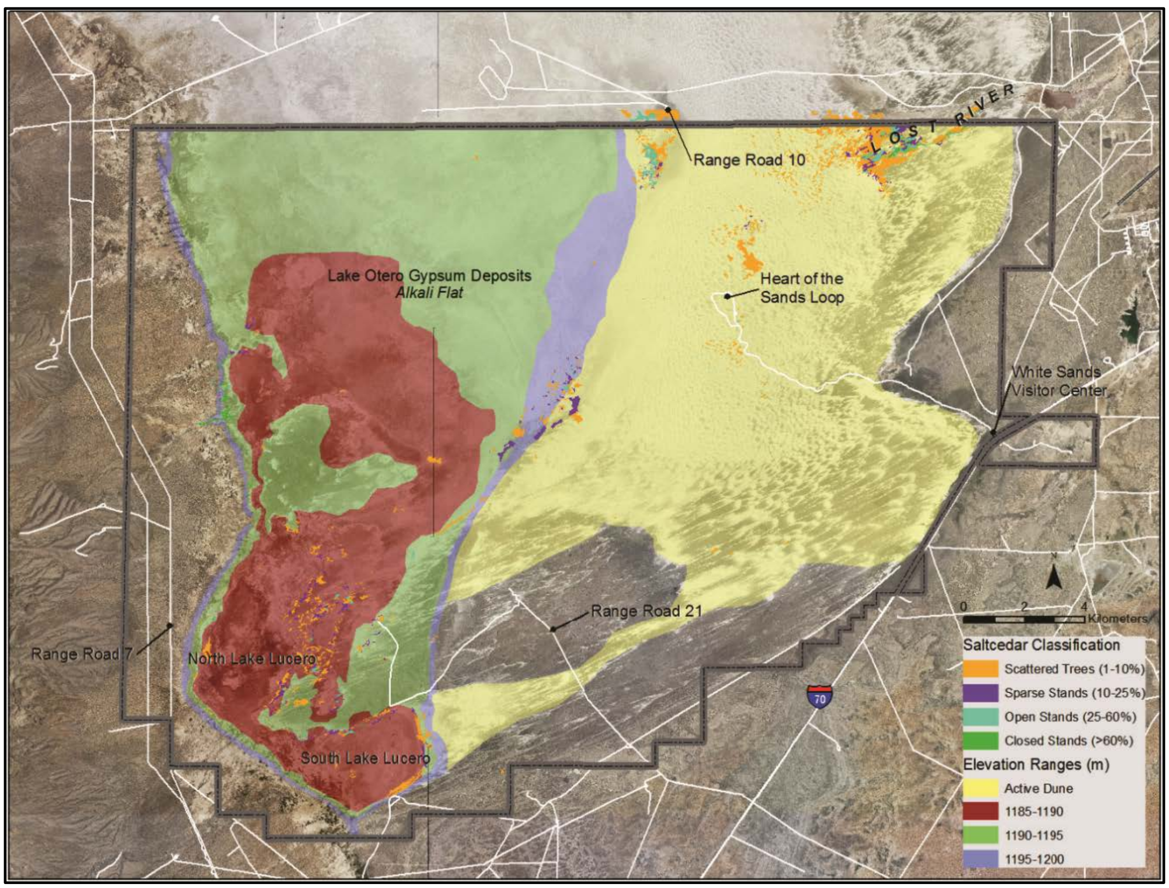


**Figure 72**. Distribution by stand cover value of salt cedar within the park (reproduced from Muldavin et al. 2010)

WHSA is surrounded by military neighbors. WHSA has a strong working relationship with the military, but this does cause an increased risk associated with its location within the flight path of HAFB and directly in the middle of WSMR. Risk to surface water from the associated military operations include: 1) introduction of contaminates from UXO and missile/rocket parts, 2) introduction of contaminates from aircraft incidents (crashes), 3) impacts to the hydrological system through engineering or construction along the alluvial fans, and 4) groundwater contamination from point source pollution on the military base entering the park through groundwater plume migration or surface runoff. Resource managers at WHSA report that over 300 incidents concerning UXO or aircraft have occurred within the park since the military started operations. Contaminants in surface water or groundwater could represent a risk to the health of park visitors and wildlife (WHSA 1992). Visitors, especially children, could be exposed through contact with interdunal lakes. Contaminants in the surface and groundwater may also become incorporated in the sands, as they precipitate out of solution or through evaporation. When these sands become airborne, low levels of these contaminants could be inhaled as fine dust (WHSA 1992).

WSMR dominates the Tularosa Basin. By one estimate, WSMR is one of 10,444 operational munitions ranges in the US contaminated, with cleanup costs of $125 billion worth of UXO containing contaminates such as lead, trinitrotoluene, ammonium perchlorate salt, and hydrazine (UGAO 2004). Workers in the backcountry at WHSA are required to watch a UXO safety video due to the large number of UXO in the park. Many unexploded missile parts, including rockets from before the introduction of solid fuel, can be seen protruding from the flats. WSMR is an active range and represents on ongoing threat to surface water resources.

WHSA lies within Accident Potential Zone (APZ) 1 for runway 25 of HAFB. A 2011 environmental assessment (EA) identified five aircraft to be stationed at HAFB: three piloted fighters (F-16, F-22, and the German Tornado), one piloted training aircraft (T-38A), and three unmanned fighters (QF4, MQ-1, and MQ-9) (Garcia et al. 2009, Austin et al. 2011). According to the 2011 EA the F-16 carries hydrazine, jet fuel, grease, and other hydrocarbons that may be released upon an “aircraft mishap” within the park. The fuel capacity for fighter jets remains classified, but many fighter jets have crashed within the boundaries of WHSA with enough residual fuel to threaten soil and water resources. Future crashes could result in significant impairment of the resource.

Natural resource managers at WHSA have expressed concerns over the potential threat of contamination to the parks surface water and groundwater resources from hazardous materials used and stored on the adjacent military lands. Several potential contaminants, including VOCs, fuels, PCBs, dioxins, nitrates, heavy metals, radioactive compounds, and pesticides, are stored at over 50 hazardous waste sites on WSMR and HAFB (WHSA 1992, USGS 2000, KellerLynn 2007). In addition to these storage facilities, another potential source of surface or groundwater contamination is the evaporation ponds on HAFB and WSMR. Accidental spills of fuels or other industrial products during normal operations at HAFB and WSMR are also potential sources of surface water and groundwater contamination.

These chemicals can enter the parks surface and groundwater systems through surface runoff or infiltration through migration of groundwater plumes. The Lost River flows through a portion of

HAFB that contains groundwater and soils that potentially have been contaminated by VOCs and semi-volatile compounds (SVOCs). Surface runoff and groundwater could introduce these contaminants into the river (USGS 2000, KellerLynn 2007). If the waters of the Lost River become contaminated, since there is no flow within the park, any contaminants within these waters have the potential to enter the groundwater.

Perchlorate is both a naturally occurring and manufactured chemical compound. It is commonly used as an oxidizer in a variety of products, such as solid fuels, munitions, signal flares, matches, and airbag initiators. Ammonium perchlorate (AP) has been in use as an oxidizer in solid rocket fuel at the HAFB high speed test track since the 1950's (Conrad 2005b). During tests at this facility, the rocket sled exhaust is directed towards Red Playa on the Lost River. AP is highly soluble in water and it can quickly be absorbed from the soil into the groundwater. Perchlorate is relatively inert in groundwater and surface water conditions, allowing for it to remain in solution for extended periods of time. The primary pathways for human exposure are through contact or ingestion of contaminated water or food. Acute health effects can be very hazardous from skin or eye contact to perchlorate (Sciencelab.com 2013). Extended periods of exposure can result in skin burns and ulceration. Ingestion or inhalation also poses a serious health risk. Over-exposure through inhalation can result in respiratory irritation. Exposure to perchlorate can also lead to chronic health effects. Perchlorate may be toxic to the blood, kidneys, liver and thyroid. Repeated or prolonged exposure can result in permanent damage to these organs. Other effects include coughing, nausea, vomiting and diarrhea (EPA 2014).

Perchlorate was placed on the EPA's Contaminant Candidate List in 1998 for possible regulation (EPA 2015). In 1999, the EPA required the monitoring of drinking water for perchlorate and in 2005 an official reference dose (RfD) of 0.00007 ppm was established (EPA IRIS 2005). In 2011, the EPA determined that perchlorate met the criteria for regulation as a contaminant under the Safe Drinking Water Act, and in 2012 established an interim lifetime drinking water health advisory of 15 ppb (EPA 2014). Initial grab samples collected from the Lost River, collected within HAFB approximately 2 km (1.2 mi) upstream of the park boundary, had AP concentrations of 18 ppm, over 1,200 times the 2012 EPA drinking water standard of 15 ppb (Conrad 2005b). The results of this sampling led to a research study whose objective was to determine if perchlorate was being transported to the park from HAFB by the Lost River. This study collected samples from the evaporite mineral crusts, soils and shallow groundwater associated with the streambed of the Lost River and also from salt cedar plants along the streambed and from Garton Pond (Huff 2002b, 2004). Results from this project are given in Table 41. This study found high levels of perchlorate was accumulating in the salt cedar, most likely from uptake of groundwater by these plants.

<u>Data Needs/Gaps</u>

WHSA contains a unique set of resources. It is a geologic park with a resource being actively created and modified by natural processes. Despite a long tradition of science, the dynamics of hydrologic and geologic processes remain relatively poorly understood in comparison to the eolian processes in the dunes. The source of brines that feed mineral productions is unknown. Insufficient work has been published on the distribution of modern sedimentary facies, the spatial distribution of production of gypsum in the park, or interactions between the hydrologic system and the dunes. Information on the hydrologic system and the past hydrology of the park is largely in reports that are hard to access and have not been peer-reviewed. There is an overall lack of information regarding the effects of surface water quality on the ecosystems of the park.

The Tularosa Basin offers many challenges to the study of its hydrology. The dependence on precipitation events for sustained stream flow and the loss of water through evaporation makes it difficult to collect stream flow and water quality samples using typical surface water sampling techniques. Installations of crest gauges or surface flow modeling could provide more information on the volume and duration of the ephemeral flows into the park. However, the nature of the ephemeral flows makes logistics more complicated. Access through military parameters requires researchers to be escorted by park staff. The UXO hazard also requires significant additional training.

**Table 41.** Results of 2003 perchlorate sampling at WHSA. (Table was reproduced from Huff 2004). ND = No detection

| Sample site | Sample medium | Sample date | Perchlorate concentration (ppb) |
|---|---|---|---|
| Lost River Site 1 | Salt cedar leaves | 4 April 2003 | 4.3 |
| - | Salt cedar leaves | 15 July 2003 | 7.9 |
| - | Groundwater | 27 August 2003 | ND |
| - | Soil | 28 Aug 2003 | ND |
| Lost River Site 2 | Salt cedar leaves | 2 April 2003 | 19.0 |
| - | Salt cedar leaves | 15 July 2003 | 29.0 |
| - | Groundwater | 27 August 2003 | 0.81 |
| - | Soil | 27 Aug 2003 | ND |
| Lost River Site 3 | Salt cedar leaves | 3 April 2003 | 3.0 |
| - | Salt cedar leaves | 16 July 2003 | 6.6 |
| - | Groundwater | 27 August 2003 | ND |
| - | Soil | 27 Aug 2003 | ND |
| Lost River Site 4 | Salt cedar leaves | 2 April 2003 | 3.1 |
| - | Salt cedar leaves | 16 July 2003 | 5.3 |
| Lost River Site 5 | Salt cedar leaves | 2 April 2003 | 2.5 |
| - | Salt cedar leaves | 16 July 2003 | 14.0 |
| Garton Pond Site | Salt cedar leaves | 2 April 2003 | ND |
| - | Salt cedar leaves | 16 July 2003 | 4.0 |

The ephemeral pan/saline lake system of Lake Lucero and Alkali Flats remains poorly understood. The physical chemistry factors that influence saline minerals are pH, salinity, temperature, and the chemical composition of the brine. Saline Brines are normally dominated by a few major solutes: silicon dioxide ($SiO_2$), Ca, magnesium (Mg), sodium (Na), potassium (K), nitric acid ($HCO_3$), carbon trioxide ($CO_3$), $SO_4$, and Cl. (Eugster and Hardie 1978). A monitoring program that tracks these physical chemical parameters in conjunction with mapping of the resulting minerals will allow managers to track the most important factors governing mineral production through space and time. The chemistry reported from Lost River and the Lake Lucero well qualifies as saline brine. Concentrations of $SO_4$ is consistent with levels reported from other betters studied saline systems at Carson's Sink in Nevada, Hot Lake in Washington, and Deep Springs Lake in California (Eugster and Hardie 1978 and references therein). The relative contributions of groundwater verses surface water into the ephemeral lake/ saline mudflat system are unknown. Further chemical analysis sustained through a flooding-evapoconcentration-desiccation cycle is required. This should be accompanied by detailed sedimentological observations and mapping of lake facies.

A comprehensive wetland study has not been performed at WHSA, but anecdotal evidence suggests that there has been some loss of wetlands within the park. A previous review of research needs identified the need for a park-wide survey for current and historical wetlands within the park (KellerLynn 2007). That review recommended any wetlands inventory undertaken should use the same protocols and classification used for a nine-year study at WSMR. Historical imagery for the park in the park archives and remote sensing images date back to the 1980s. This information could be useful in identifying previous wetland areas and other baseline hydrological information.

Continued study of Lake Lucero has also been previously recommended (KellerLynn 2007). This study should include the entire ephemeral lake/saline mudflat system that includes Lake Lucero and Alkali flat. Monitoring flooding events, major ions, salinity, pH, alkalinity, water temperature, dissolved oxygen, sediment facies, and perhaps isotopes within the ephemeral lake/saline mudflat system would provide resource managers with information on how the lake is integrated into the dune processes and ground water system. These data sets could provide additional information on several important processes, including; how and when salts are produced in the system, and what are the surface water to groundwater interactions in the lake. Overall, more in-depth study of this resource would provide resource managers with the information to better understand, manage, and interpret the dynamics of this system that covers a large portion of the park and in key to sediment supply to the dunes.

Overall Condition

*Frequency of Surface Water*

The project team defined the *Significance Level* for the frequency of surface water as a 3. The number and extent of the surface water features has declined as compared to the pre-1950's development reference condition. As late as the 1990s, there were periods of time when the Lost River did exhibit flow within the park (John Mangimeli, WHSA Chief of Interpretation 1989-2004 as cited by Conrad 2005b). Water diversion to supply drinking water to Alamogordo and other cities up gradient from the park, along with the installation of groundwater wells to supply rural homes and irrigation have contributed to the loss of flow within the park (KellerLynn 2003).

Garton Pond was the only other perennial surface water feature present within the park during the 1950's pre-development reference period. This is an artificial feature created when an oil and gas well encountered an artesian aquifer. It initially encompassed a 1.6 ha (4 ac) and was surrounded by a marshy area (Sprester 1980). Over time, the artesian flow diminished and currently it is a large marsh with little to no observable standing water. Though not officially documented, it has been speculated that additional wetland resources have also been lost as compared to the reference condition, based on anecdotal evidence (Porter et al. 2009).

The majority of the surface water features within the park are ephemeral streams and playa lakes. These are dependent on the timing, intensity, and duration of precipitation events in surrounding mountains or height of the water table. Development within the area has impacted and redirected the natural flow regime of the ephemeral streams, particularly to the west of the park (KellerLynn 2003). Roads, culverts, drainage ditches, and buried utility cables all have contributed to changes to the natural flow regime within the park and the surrounding lands (KellerLynn 2003). The parks playa lakes are dependent on these ephemeral streams and local precipitation events for their water supply.

Due primarily to the loss of flow in the Lost River, the projected changes in the climate conditions, (particularly the increased aridity), and increased pumping of groundwater, a *Condition Leve*l of 2, indicating moderate concern, has been assigned to this measure.

*Persistence of Surface Water*

The project team defined the *Significance Level* for the persistence of surface water as a 3. At the time of the reference condition, two perennial surface water features were present within the park, Lost River and Garton Pond. Neither of these exists as a perennial feature today. While the water in Garton Pond has always been dependent on artesian groundwater, the water currently present in the Lost River channel within the park is the result of groundwater inflow (Newton and Allen 2014).

While standing water is present at times in the Lost River, very little if any standing water is currently present at Garton Pond (Newton and Allen 2014, McIntyre, written communication, 5 January 2016). The duration of standing water in these two features and the park's other ephemeral streams and playa lakes is dependent on climatic conditions within the Tularosa Basin (Bourret 2015). Currently, potential evaporation rates within the region exceed the precipitation rates. The climate models project conditions of higher summer temperatures with slightly lower precipitation rates (Garfin et al. 2010). These conditions will cause an increase in the evaporation rates creating a condition where there is the potential for even less surface water runoff to reach to the park than what is currently supplied by the ephemeral flows. Due to these factors, a *Condition Level* of 3, indicating high concern has been assigned.

*Geochemistry of Surface Water*

The geochemistry of surface water measure was assigned a *Significance Level* of 3. Limited information is available on the physical chemistry of the parks surface waters and this measure is considered to be a data gap. Due to this, a *Condition Level* cannot be assigned at this time

*Timing and Amount of Precipitation*

The project team defined the *Significance Level* for the frequency of surface water as a 3. Under the current climate conditions, the park receives the majority of its precipitation as rain during the summer and winter months. When comparing the monthly precipitation totals for the last two 30-year periods (1961–1990 and 1981–2010), with the exception of the month of November, monthly precipitation during the latest 30-year period (1981–2010) has been equal or slightly greater than the corresponding monthly totals for the 1961–1990 period (Figure 70). The climate model projections vary depending on the model and emission scenario, but in general the models predict a 6% decrease in annual precipitation by the period 2070–2100 (Garfin et al. 2010). The models also predict the potential for a 25% decrease in precipitation during the months of May and June (Garfin et al. 2010). While it appears that the timing of the precipitation patterns remains the same, the changing climate could also produce extended periods of drought (Garfin et al. 2010). Due to the decreasing annual precipitation predicted by the climate models, a *Condition Level* of 2, indicating moderate concern was assigned.

*Groundwater Recharge and Discharge*

The project team defined the *Significance Level* for the groundwater recharge and discharge as a 2. The only documented evidence of springs present during or prior to the 1950's pre-development period were references to a spring at the old ranch headquarters and Garton Pond (McDougall 1939). According to park GIS data, as many as seven springs were active within the park as of the early 2000's. Currently there are only three active springs within the parks boundary. While the exact number of springs during the reference condition is not known, old maps and anecdotal evidence of more wetland areas within the park suggest that there has been an overall decline in the number of springs. The projected changes to the park's climate, in particular the increase aridity, along with increased demands on the regions groundwater are likely to have an impact the parks springs. Due to these factors a *Condition Level* of 2, indicating moderate concern, has been assigned.

*Weighted Condition Score*

The *Weighted Condition Score* for this component is 0.77, indicating high concern. The surface water features within the park are dependent on surface runoff from precipitation reaching the park in the form of ephemeral flows or groundwater. The effects of climate change and water use by the surrounding communities has impacted this resource and will continue to impact it in the future. For this reason a declining trend has also been assigned to this measure.

| Surface Water Hydrology | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = 0.77** |
| Frequency of Surface Water | 3 | 2 | |
| Persistence of Surface Water | 3 | 3 | |
| Geochemistry of Surface Water | 3 | n/a | |
| Timing and Amount of Precipitation | 2 | 2 | |
| Groundwater Recharge and Discharge | 2 | 2 | |

### *4.11.6. Sources of Expertise*

- Cheryl McIntyre, CHDN Physical Scientist
- Jonathan Knapp, WHSA Physical Scientist
- Talon Newton, New Mexico Bureau of Geology and Mineral Resources Hydrogeologist
- David Bustos, WHSA Resource Program Manager

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## 4.12. Groundwater Hydrology

### *4.12.1. Description*

In semi-arid regions such as the Chihuahuan Desert, surface water and groundwater systems are closely tied. Within the Middle Rio Grande Basin, groundwater recharge occurs primarily in the surrounding mountain ranges through ephemeral streams while little to no recharge occurs in inter-stream basin-floor settings (Scanlon et al. 2006). Climate variability can also have an impact on groundwater recharge rates. Recharge rates can be up to three times higher during periods of frequent El Niños (Photo 35; Scanlon et al. 2006). With water being the limiting factor for ecosystem productivity in the Chihuahuan Desert, and the scarcity of surface water features, groundwater is a critical component of the hydrologic cycle. Groundwater recharge is the most important component of this cycle (Knapp, written communication, 6 July 2016). In order to understand ecosystem function and integrity in this environment, an understanding of groundwater dynamics is crucial. Groundwater is the primary source for solutes that contribute to gypsum formation and the dunes. Groundwater plays an important role in the stabilization of dune features from the past, impacting movement of dune features in the modern, and generating the gypsum crusts that form an important part of landscapes and soils. Overall, long-termed groundwater monitoring can lead to a better understanding of surface water dynamics.

**Photo 35.** During periods of extended high precipitation water may pool above ground level providing a source of groundwater recharge (NPS photo).

The groundwater within the Tularosa Basin has significantly different flow behavior than the surface water. In general, groundwater flows from the drainage divides created by the surrounding mountains toward the basin floor, then southward toward the Hueco Bolson (Figure 73). The closed contour lines (in the Lake Lucero, Alkali Flat and dune field area) indicate that discharge is through evaporation (Allmendinger and Titus 1973, Szynkiewicz et al. 2009, Newton and Allen 2014). However, it is generally believed that the majority of the groundwater in the basin discharges into the Rio Grande near El Paso, Texas. Groundwater flow is slower than the surface water, and while residence times are unknown, sampling indicates that most of the groundwater is on the order of hundreds to thousands of years old (Mamer et al. 2014). This old water can be found at both high elevations in the mountains and lower elevations in the basin. The presence of old water in the sedimentary and volcanic rocks in the mountains (which have high hydraulic gradients) indicates that the groundwater is moving slowly. This is likely due to flow barriers that restrict groundwater in the mountains from flowing directly into the basin. It is likely that there is a wide variety in groundwater flow velocities due to the variety of lithologies and structures that are crossed by the groundwater flow paths (Mamer et al. 2014). In contrast the hydraulic gradient in the center of the basin is likely very constant (Talon Newton, Hydrologist, New Mexico Institute of Mining and Technology, written communication 6 July 2016).

Field observations and groundwater geochemistry provide evidence that significant fluid movement is occurring along faults and/or fracture systems in the basins and on WHSA. Garton Pond was created when oil well drilling struck an overpressure thermally elevated aquifer. This indicated transport of deeper and hotter fluids along a subsurface fluid pathway. Additionally, the location of this artificial lake coincided with the suspect location of a major basin normal fault system later imaged on seismic. Crystal pedestals in the lake contain altered gypsum (selenite) crystals. This is a chemical precipitate from spring discharge. The physical location of the pedestals indicates they form along a fault system antithetic to the master basin normal fault (Knapp, written communication, 6 July 2016). Additionally, work by Szynkiewicz et al. (2009) indicated a hydrothermal source. Additionally, the widespread alteration of gypsum at the near surface can been seen to indicate exotic fluid flow, likely hydrothermal, through WHSA. The crystals were deposited at primary bottom growth gypsum sometime after before 30,000 years BP and alteration must have occurred after deposition. This alteration did not occur through interaction with “normal” groundwater (Knapp, written communication, 6 July 2016).

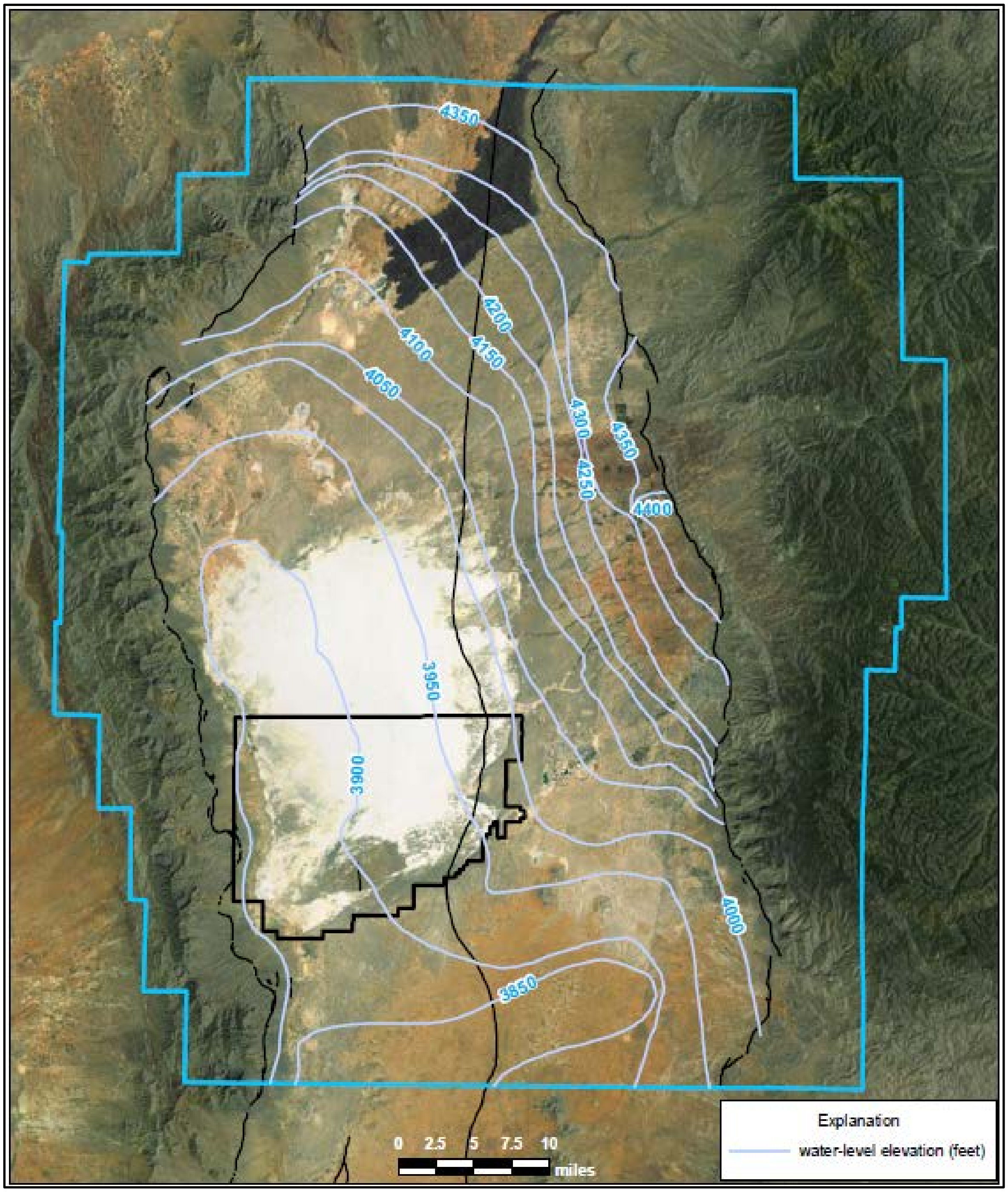


**Figure 73.** Water-level elevation contours for a portion of the Tularosa Basin in the vicinity of WHSA (outlined in black). Groundwater flow is primarily from northeast to southwest. The closed contours on the western side of the basin indicate that groundwater is discharging through evaporation. Figure was reproduced from JS&A (2011).

In the area of the dune field, the groundwater table is relatively shallow (within 1m [3ft] of the surface) during most of the year (Fryberger 2001). To a certain extent, the present level of the dune field has been controlled by water table levels (Allmendinger 1971, Fryberger 2001). The area of the dune field that is available for movement and the creation of topography is located above the water table. Below the water table the sand is stabilized. As a result, a flat interdunal area is present. If the water table rises, then the parts of the dunes that are left behind will increase, becoming sediment that is taken out of the active eolian system. The movement and speed of movement of the dunes, as well as dune morphology, is controlled by the soil moisture content of the dunes. This is the area that is wet and saturated to the capacity gravity flow out of the dune system. This moisture will restrict the transport of sediment by wind, but the wind and evaporation will remove the moisture, freeing part of the dune surface for movement, although at a retarded rate. If this sediment moisture is less then active dunes (above the water table) will be more active, larger, and may change shape. Cementation is the process where the crystal cement forms between grains. This process may: stabilize the core of the dune preventing the active dune from migrating as fast, create a crust that prevents dry sediment from moving, or create rock from sediment deposits (this mostly occurs below the water table in water supersaturated in gypsum, halite, calcite, or silica) (Schenck and Fryberger 1988, Fryberger 2001).

The specific role that groundwater hydrology has played and continues to play in controlling the dune field has been:

- to accumulate ions from surround rocks or hydrothermal sources and transport them to the basin;
- to regulate sediment dynamics within the dune field and capture sediment before it can be exported from the system as dust;
- to control vegetation growth (in conjunction with surface water) in terms of type and abundance through changes to available moisture and salinity brought on by seasonal or long-term fluctuations in precipitation. This sediment moisture is also utilized by burrowing animals and microbial mats (Fryberger 2001, Conrad 2005).

The primary aquifer within the Tularosa Basin is located within an assortment of basin-fill deposits of Tertiary to Holocene age (Huff 2005, Newton and Allen 2014). The thickness of this aquifer depends on the geology of the underlying formations and can vary from less than 30.5 m (<100 ft) over areas of uplifted bedrock to 1,219 m (4,000 ft) in other areas (Porter et al. 2009). In the Tularosa Basin, the groundwater is controlled by a generally horizontal, regional northeast to southwest flow through basin fill and playa deposits (Newton and Allen 2014, Bourret 2015). Recharge to the groundwater systems is primarily from streams flowing out of the Sacramento Mountains to the east (McLean 1970). This recharge is limited by the seasonal variations in precipitation patterns and the high evaporation rates (Porter et al. 2009).

Throughout the Tularosa Basin the groundwater is saline, with total dissolved solids (TDS) greater than 1,000 ppm (Newton and Allen 2014). Large portions of the saturated deposits are actually considered to be brines, with TDS >35,000 ppm (Newton and Allen 2014). Prior studies have estimated that less than 0.2% of the groundwater would be considered freshwater (TDS <1,000 ppm) and 85% of the groundwater deposits are saline with TDS of greater than 3,000 ppm (McLean 1970, Orr and Myers 1986, Newton and Allen 2014).

#### *4.12.2. Measures*

- Depth to groundwater
- Regional aquifer flow rate and direction
- Lost River stream flow
- Soil moisture

#### *4.12.3. Reference Conditions/Values*

The reference condition selected by the project team was the pre-water diversion conditions (pre-1950s) of the parks groundwater features. Groundwater monitoring data are available from the network of monitoring wells and piezometers located within the park for the period of 2009–2012 (Newton and Allen 2014). Groundwater levels reported by various groundwater studies conducted during the reference period will be used to define the groundwater conditions for the reference period.

#### *4.12.4. Data and Methods*

The hydrology of the Tularosa Basin has been studied since the early 1900s. The earliest report on record studied the variability of precipitation in the Tularosa Basin and included a regional water table map and groundwater recharge estimates (Meinzer and Hare 1915). The methodology of Meinzer and Hare (1915) and several other surface and groundwater studies completed since that first report were discussed in detail in Chapter 4.11.4 of this document. Over the last 100 years, many studies have focused on various aspects of the region's hydrology, including some that were particularly focused on the quality and quantity of the groundwater. These included Herrick and Davis (1965), who described the groundwater resources in the Tularosa Basin, McLean (1970), which focused on the saline and fresh groundwater supply, and Orr and Myers (1986) who discussed the water resources stored in the basin fill.

The analysis of the current condition of the deep regional aquifer and the shallow aquifer beneath the dune field in this document primarily relied on three studies that created conceptual models of the groundwater system at WHSA. Barud-Zubillaga (2000) developed a conceptual model of the hydrogeology of WHSA to determine the characteristics of the groundwater flow in the subsurface of WHSA. Newton and Allen (2014) conducted a hydrologic study of the groundwater resources at WHSA and attempted to identify the water sources that contributed to the shallow aquifer beneath the dune field and to assess the interactions between this shallow aquifer and the deeper regional aquifer. Figure 74 is the conceptual hydrogeologic model that was developed for WHSA by Newton and Allen (2014). Bourret (2015) characterized the relative importance of the source of groundwater in the shallow aquifer using both a 1-dimensional and 3-dimensional models.

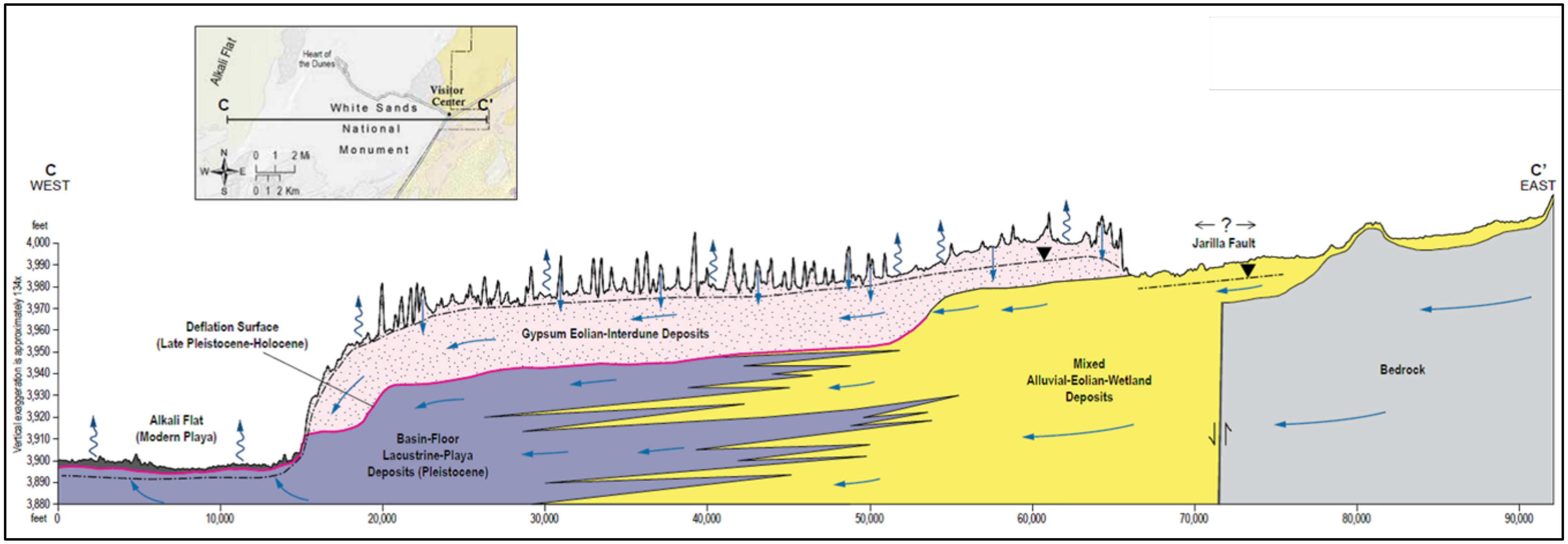


**Figure 74.** Conceptual hydrogeologic model for WHSA developed by Newton and Allen (2014). Figure is reproduced from Newton and Allen (2014).

Information on soil moisture within WHSA is limited. Scheidt et al. (2010) explored the relationships among soil moisture, potential soil erosion, and thermal inertia. Reid (1979, 1980) conducted a natural resources inventory and ecosystem analyses at WHSA. These reports focused on vegetation and soil properties.

### *4.12.5. Current Condition and Trend*

Depth to Groundwater

WHSA has a shallow groundwater regime below the dune field that resulted from the formation of the dune field. Within the dune field, a perched aquifer is located above the lake bed of Lake Otero, a Pleistocene lake or ephemeral lake/saline pan that formed within the basin (Conrad 2005, Porter et al. 2009). The clay sediments of the lakebed isolate this aquifer from the regional basin-fill aquifer (Conrad 2005, Porter et al. 2009). This water table in the shallow aquifer is located within approximately 3 m (10 ft) of the surface, and more commonly is found within 0.1–0.5 m (0.5–1.5 ft) of the surface (NPS 2016).

This shallow aquifer is recharged by meteoric and fluvial water within the dune field (Allmendinger 1971, Porter et al. 2009, Newton and Allen 2014, NPS 2016). The groundwater levels within the dune field quickly respond to local precipitation events (Newton and Allen 2014). Within the dunes, hydraulic gradients in the unsaturated zone exhibit a fairly constant downward gradient (Newton and Allen 2014). The pore spaces between the dune sand grains are usually at their maximum field capacity (the total amount of water that can be held against gravitational pull) (Newton and Allen 2014). As a result, when precipitation events occur the water stored in the dune sands are quickly flushed downward (Newton and Allen 2014). During the driest and warmest part of the year when evaporation rates are highest (March–June), there is an upward gradient in the top 0.3–0.9 m (1–3 ft) of the shallow unsaturated sands (Newton and Allen 2014). This condition is reversed in the monsoon season (July–September), when abundant water returns the hydraulic gradient in the upper portion of the unsaturated zone back to a downward gradient (Newton and Allen 2014). Evaporation rates play a major role in the hydrology of this shallow aquifer (Allmendinger 1971, Fryberger 2001). The depth to water in this shallow aquifer is largely controlled by evaporation through the unsaturated zone (Allmendinger 1971, Fryberger 2001, Newton and Allen 2014). Water table levels are higher (smaller depth to water) during the winter when evaporation rates are low, and are lower (larger depth to water) when evaporation rates are high (Allmendinger 1971, Fryberger 2001). The depth to water has an impact on both the movement, overall spatial extent and the thickness of the dune field (Allmendinger 1971, KellerLynn 2003, Conrad 2005, Bourret 2015). The depth to the water table controls the formation of the gypsum and the mobility of the sand by the wind (Allmendinger 1971, KellerLynn 2003, Conrad 2005). With a lowered water table, the dunes will become more active (Allmendinger 1971, KellerLynn 2003, Conrad 2005).

Newton and Allen (2014) represents the most recent groundwater study reviewed for this analysis, and was conducted from 2010–2012. Depth to water measurements were taken hourly from a variety of monitoring wells and piezometers over this period (Newton and Allen 2014). These monitoring sites were located on the eastern end of the dune field (WS-009, WS-010, WS-011, WS-014), within the dune field (WS-007, WS-008, WS-012, WS-020, WS-021, WS-022), and west of the dune field and near Lake Lucero (WS-015, WS-019, WS-023) (Figure 75). Newton and Allen (2014) found that the depths to water level in the wells to the west and within the dune field are shallower than those to the east of the dune field (Figure 76).

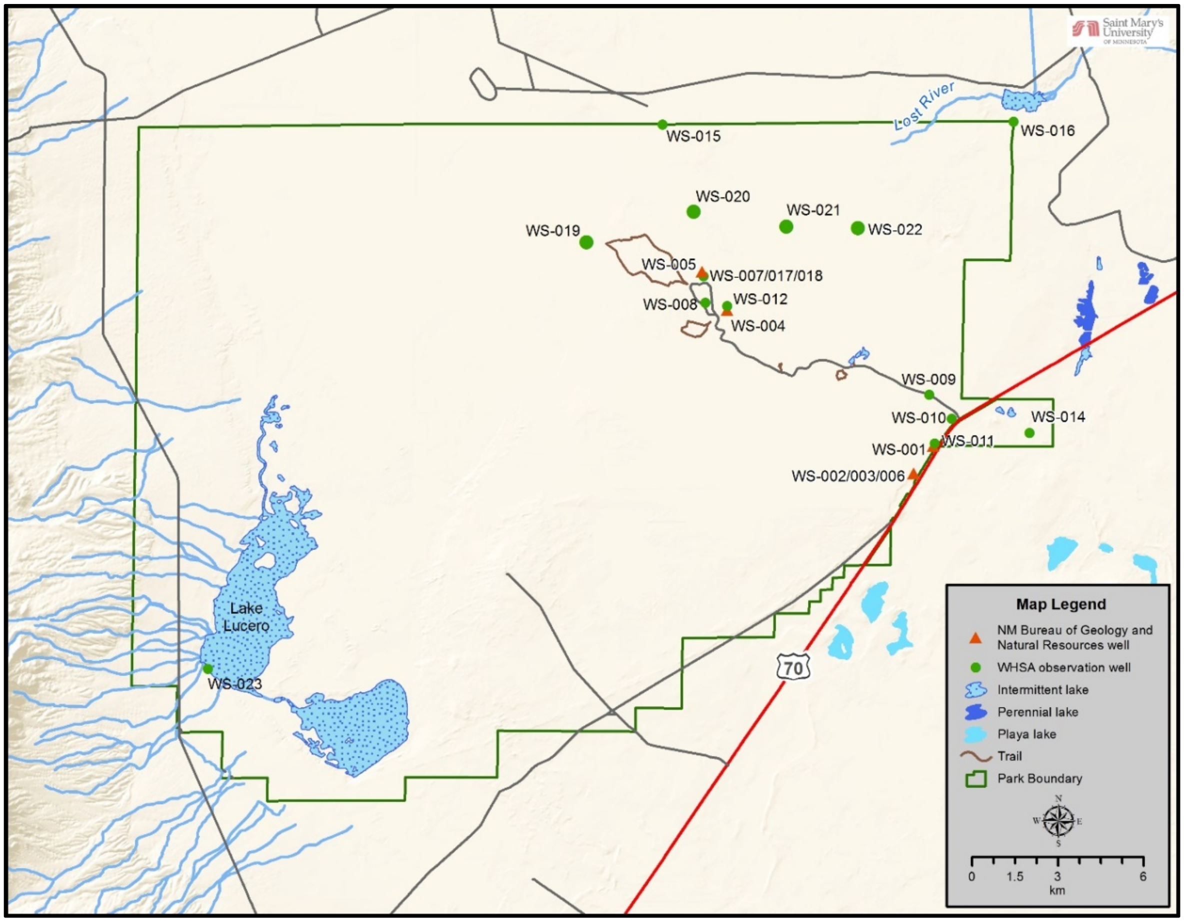


**Figure 75.** Location of select groundwater monitoring sites within WHSA. Figure from Newton and Allen (2014).

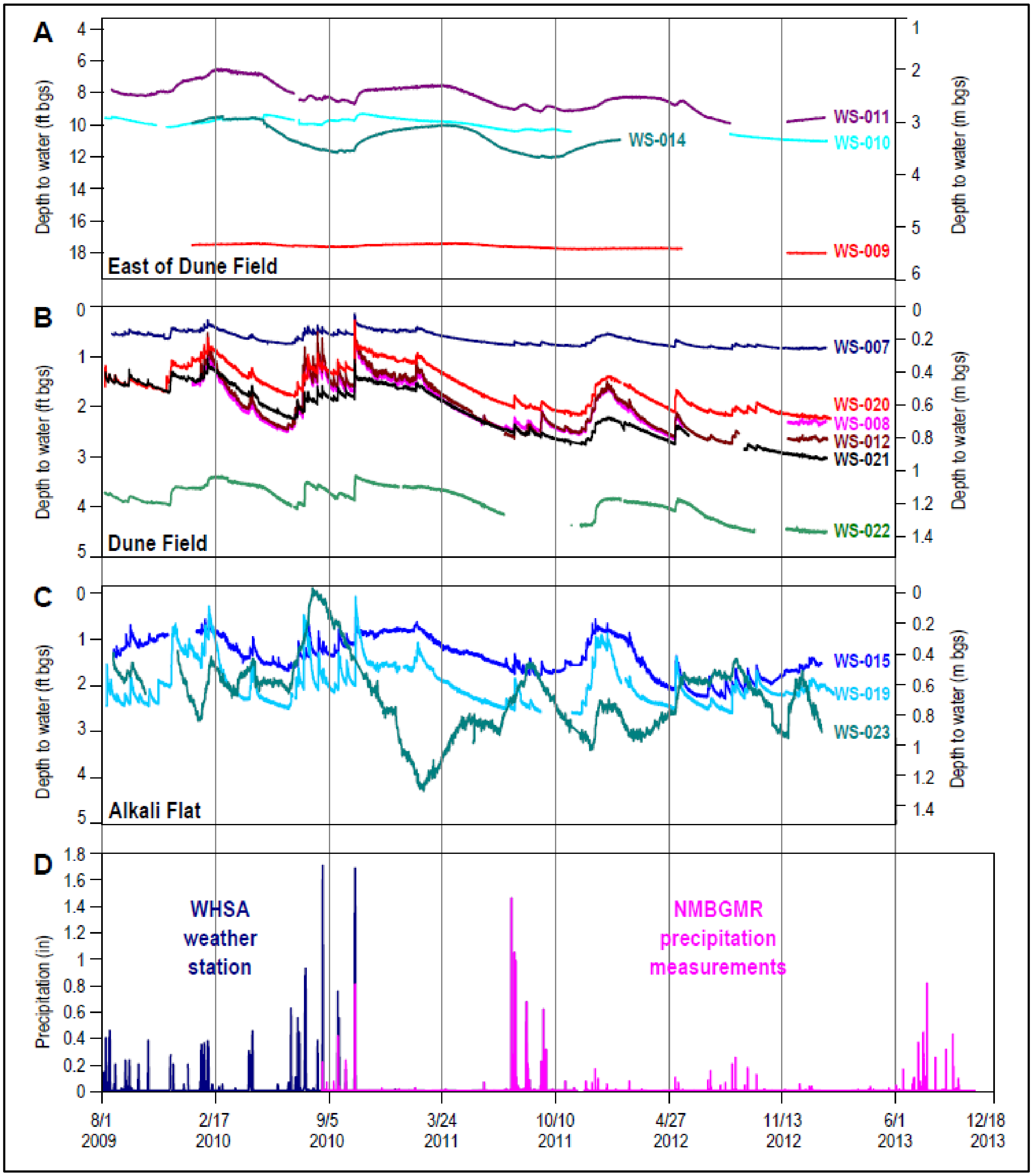


**Figure 76.** Continuous water level depths for (A) wells east of the dune field, (B) wells within the dune field, and (C) wells to the west of the dune field, (D) Represents precipitation measurements within WHSA. Figure reproduced from Newton and Allen (2014).

Analysis of the depth to water for the wells within the dune field revealed both short- and long-term trends. The short-term trend was tied to local, individual storm events, where the water levels rise by less than 0.3 m (<1 ft) then return to previous levels within hours to days (Newton and Allen 2014).

The long-term trend was represented by water level increases of greater than 0.3 m (<1 ft), but the lag time until the water levels returned to previous levels could be several months (Newton and Allen 2014).

The short-term response represents local recharge of the shallow water aquifer through the dunes (Newton and Allen 2014). The short-term responses generally occur in groups and are superimposed on a long-term fluctuation (Figure 76) (Newton and Allen 2014). The wells to the east and west of the dune field (with one exception) only exhibited the long-term fluctuation pattern (Figure 76) (Newton and Allen 2014). The well near Lake Lucero did not conform exactly to this single long-term fluctuation pattern (Figure 76) (Newton and Allen 2014). Newton and Allen (2014) stated that some of the water fluctuations in this well matched the long-term trend, while other water level changes appear to be unrelated to recharge events in the dune field. Newton and Allen (2014) suggest that the groundwater near Lake Lucero may be responding to a different or more regional hydrologic regime.

Lost River Stream Flow

The Lost River is an ephemeral stream that begins on the east side of the Tularosa Basin in the Sacramento Mountains (Figure 66). It flows southeasterly from its headwaters, through HAFB before entering WHSA. Approximately 1.6 km (1 mi) upstream of the park boundary, the river's channel widens to form Red Playa. The channel outlet of this evaporate lake was dammed by a northeast migrating sand dune (Conrad 2005), in 2006 with heavy rains. The channel continues into the park for approximately 3.2 km (2 mi) before it terminates in the dune field (Huff 2002). There is no sustained discharge in the Lost River within the park, but heavy flow can occur in relation to flash flood events during the summer monsoon season (Photo 36) (Bourret 2015). Some perennial water does exist in topographically low portions of the channel, but ion water chemistry and isotope data identifies this water as regional groundwater (Newton and Allen 2014).

**Photo 36.** Lost River flow within WHSA following 2006 storm (NPS photo).

Portions of the Lost River within HAFB, and WHSA, are the only known habitat for the White Sands pupfish, a state-listed endangered species (Newton and Allen 2014). Pupfish continue to flow into the park with flash flood events and high flow periods (Photo 37).

**Photo 37.** White Sands Pupfish in Lost River at edge of dune field in 2007 (NPS photo).

The Lost River flowed into the park until the early 1990s when the channel was dammed by a migrating dune approximately 200–300 m (656–984 ft) upstream of the parks boundary (Conrad 2005). In 2006, Lost River broke through the dune and continues to flow in to the park boundary once again with high flow events. There are no baseline flow records for the Lost River within WHSA, however anecdotal evidence shows the river did flow nearly year-round, with only occasional periods of dry channel, prior to 1950 above HAFB (Conrad 2005). The river began to be dewatered as water was diverted for the city of Alamogordo, agricultural purposes, and rural water supplies (Conrad 2005). Anecdotal evidence suggests that during the 1950-1960's the Lost River did at times have flow into the park (Conrad 2005).

Soil Moisture

The White Sands Dune Field has been interpreted as a wet aeolian system where soil moisture plays an important role in the sediment dynamics (Kocurek and Havholm 1993, Kocurek et al. 2007, Langford et al. 2009, Newton and Allen 2014, NPS 2016). In a wet aeolian system, accumulation and other processes are primarily controlled by water table depth (Figure 77) (Fryberger 2001, Kocurek et al. 2007). In these systems, the capillary fringe of the water table is at or near the surface (Figure 78). The moist soil conditions result in the accumulation of evaporite minerals, which commonly corresponds to a relative rise of the groundwater table (Scheidt et al. 2010). Under dry conditions, coupled with a falling water table, deflation can occur which mobilizes sediments that become the source of gypsum for the White Sands Dune Field (Scheidt et al. 2010).

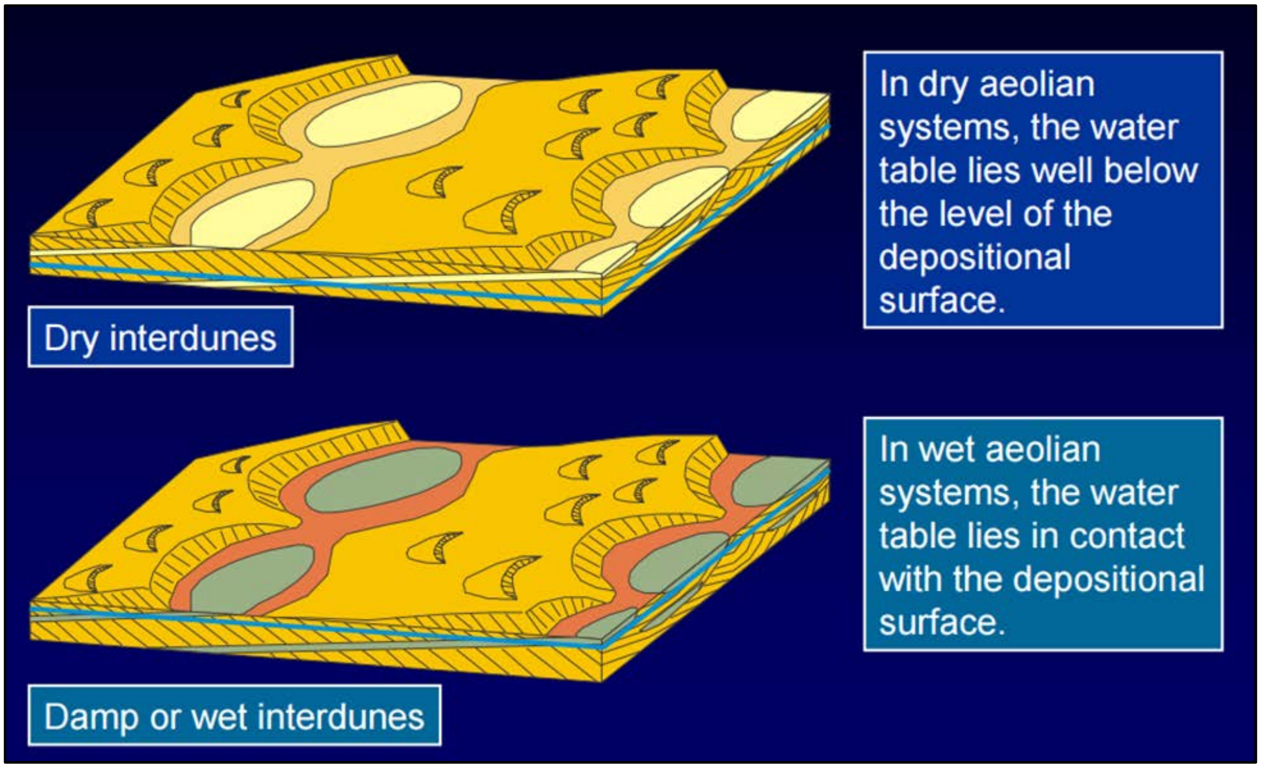


**Figure 77.** Graphical comparison of dry and wet aeolian systems (figure courtesy of NPS).

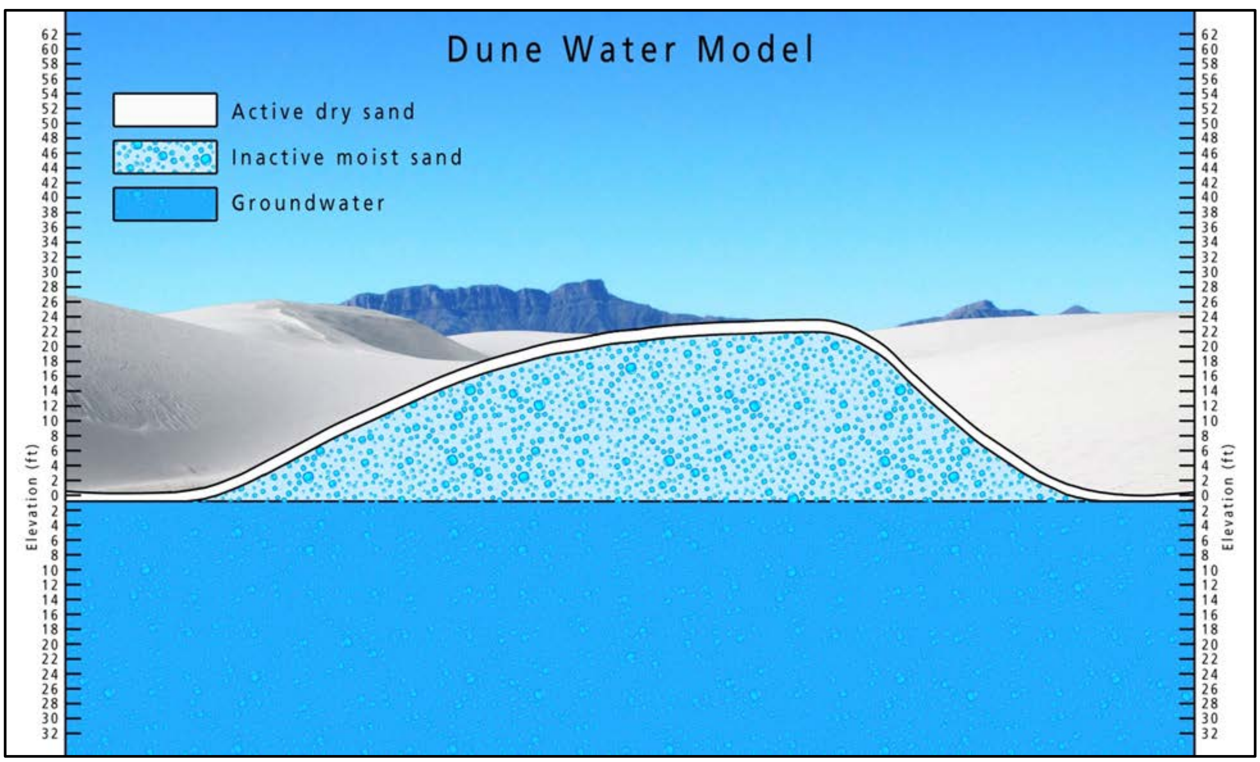


**Figure 78.** A model showing the importance of groundwater table depth to dune morphology and processes (figure courtesy of NPS).

Soil moisture differs from depth to groundwater, in that soil moisture of the dunes defines the depth of the dune that can be transported by wind. Soil moisture also precipitates crusts that stabilizes dunes and other surfaces. The measurement of soil moisture in arid environments, especially over large geographic areas, while important to hydrologic and aeolian studies, is often difficult (Scheidt et al. 2010). Soil moisture is an extremely important component in determining the erosion potential of sediment. Within aeolian environments, soil composition and textural characteristics change in response to hydrologic and climatologic conditions, such as the flux of rainfall, soil moisture and groundwater (Scheidt et al. 2010). In general, within a playa environment these changes can occur rapidly on the scale of minutes to days (Scheidt et al. 2010).

The capacity of the soil to store water can also vary spatially with the periodic inundation and drying of playa lake beds, the influx of fine sediments and the crusting of evaporite minerals (Langer and Kerr 1966, Reheis 2006). As soil moisture increases, sediment availability decreases due to the adhesive and capillary forces that bind wet sediment particles together. This binding makes the sediment more resistant to wind erosion (Kocurek et al. 2007, Scheidt et al. 2010). Areas with lower soil moisture are more susceptible to wind erosion (Figure 79 and Figure 80).

Data on soil moisture within WHSA are limited. Studies that have been completed have focused primarily on the moisture content within the dune field. Reid (1979) reported soil moisture ranged from 14-16% in the top 30 cm (11.8 in) of a vegetated interdune to 23-26% in a unvegetated Heart of the Dunes interdune. Scheidt et al. (2010) estimated soil moisture using remote sensed data collected between 2002 and 2008 (Figure 79). Differences in trends of soil moisture across WHSA were expected and observed in the analysis of the remotely sensed data. Large playa lakes, like Lake Lucero, which are periodically inundated exhibited complete saturation at times as well as complete desiccation at other times. Other playa and interdune areas that did not reach complete saturation, showed similar trends. Scheidt et al. (2010) estimated that alluvial fan (6%) and dune areas (8%) had the lowest levels of soil moisture variation. In general dune areas had lower soil moisture that the adjacent interdune areas. The parabolic dunes at the southern end of the dune field had lower estimated soil moisture levels and less variability than the crescent dunes within the central portion of the dune field. A more detailed discussion of dune moisture can be found in Chapter 4.1 of this document.

Below WHSA's interdunal areas, up to 9.1 m (30 ft) of gypsum sand is stored (Newton and Allen 2014). Currently, dune migration occurs for the active dunes on top of the accumulation surface, while the base remains stable due to the grain cohesion, phreatic cementation and root stability provided by the wetted and saturated sands (Bourret 2015). The availability of groundwater in the unsaturated zone, and the associated water holding capacity of the dunes is also important for the vegetation and wildlife communities found within the dune field (KellerLynn 2007, Newton and Allen 2014). Any long-term decrease in the water levels would likely result in some portion of the accumulated sand becoming more available for transport by wind (Newton and Allen 2014). This change, whether natural or anthropogenic, would change dune dynamics as well as the local ecosystems and habitats that rely on the moist sand conditions (Newton and Allen 2014).

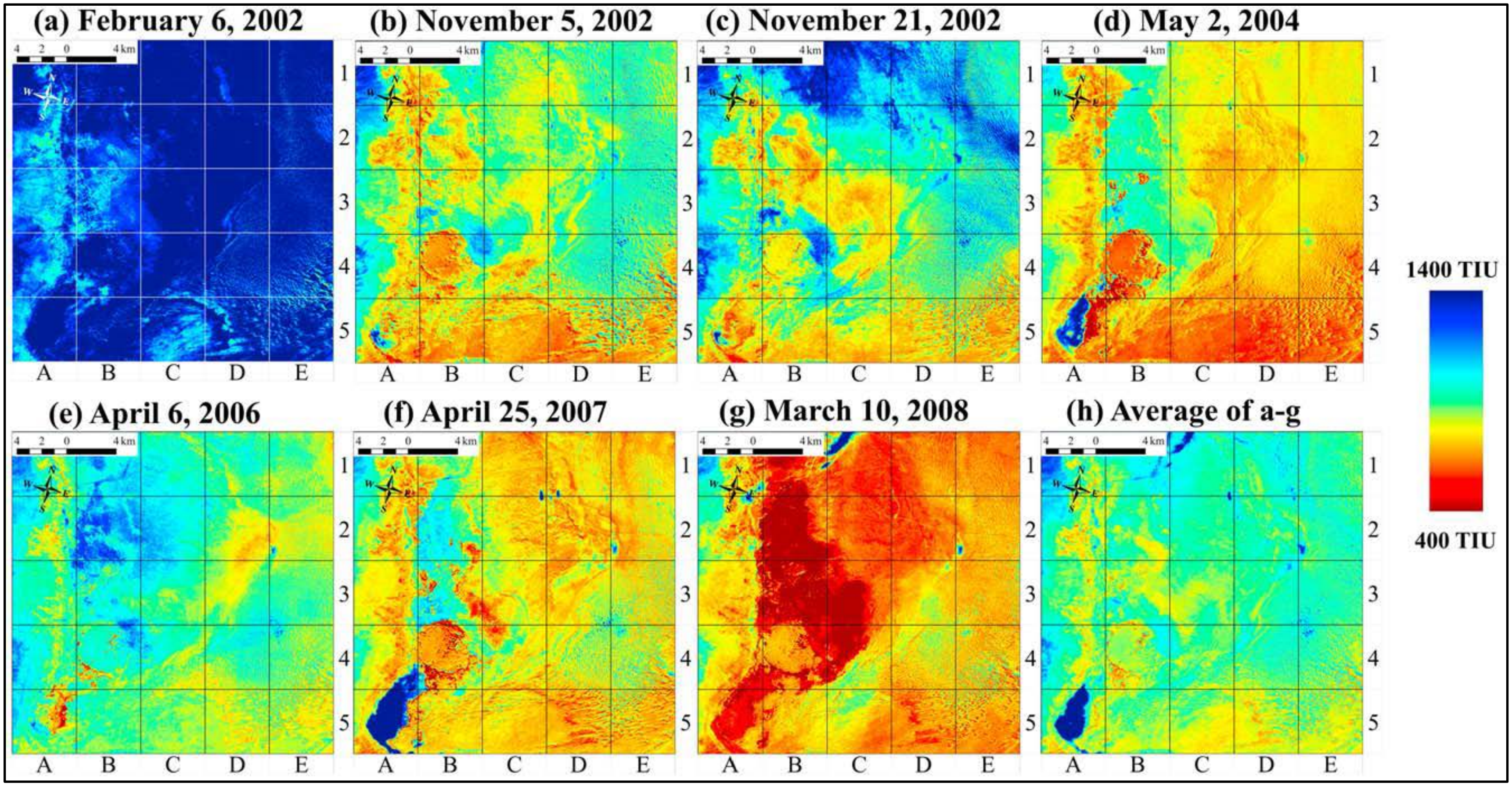


**Figure 79.** Thermal Inertia (TI) derived from the ASTER data, which corresponds to a range of soil moisture from 9% to 25%. Regions in blue are surfaces with higher soil moisture and therefore immobile sediment, whereas area red shows dry. (figure courtesy of Scheidt et al. 2010).

**Figure 80.** Image of significant dust storm (Acquired on March 14, 2008 by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua) showing sand being broken down to dust carried beyond the east margin of the White Sands dune field. The dust storm is centered on the quadrant A-5 in Figure 79g. (image courtesy of NPS)

Threats and Stressor Factors

WHSA and CHDN staff have identified several threats to the groundwater resources present within WHSA. These threats include physical processes such as drought and climate change and the increased demands of the regional aquifer for municipal and agricultural water supplies. NPS (2010) identifies the key degradation processes that are predicted to affect dune ecosystems as being: climatic change, local groundwater withdrawal, and exotic plants. All three of these are predicted to increase the salinity of the groundwater and the depth of the groundwater (NPS 2010).

Hydrologic models of the basin show that climate factors provide the greatest threat to the groundwater near WHSA (Bourret 2015). Regional groundwater, recharged by precipitation and surface water, is the largest component of the shallow water aquifer at WHSA (Newton and Allen 2014). The current climate is considered to be typical of the semi-arid conditions found throughout the southwestern U.S. (Sprester 1980). The park experiences hot summers with cool dry winters. Precipitation comes in the form of seasonal rains in the winter and summer, with the majority of the precipitation falling in the summer (Bennett and Wilder 2009). Winter rains are more important in terms of groundwater recharge for the regional basin-fill aquifer due to the lower temperatures and lower evaporation rates offset the lower precipitation rates (McLean 1970). Projected increases in annual temperature, along with projected decreases in monsoonal precipitation will affect the availability and timing of these precipitation events critical for groundwater recharge (Seager et al. 2007, Garfin et al. 2010).

Along with the increased levels of aridity, the climate models also predict frequent, extended periods of drought (Seager et al. 2007). Periods of extended drought can have significant impact on the water table level of the shallow aquifer underneath the dune field (NPS 2010). These prolonged periods of drought will also have an effect on the depth to groundwater for the deeper regional aquifer, especially when coupled with greater pumping demands on adjacent lands (NPS 2010). Various portions of the dune field were rapidly formed during short, hyper-arid events (NPS 2010). Prolonged periods of drought could cause a drop in the water table and an associated loss of dune moisture due to evaporation (NPS 2010). This could result in the mobilization of the parabolic interdunes in addition to other areas that are stable under the current conditions (NPS 2010).

WHSA is located in proximity to several localities that depend on the limited surface water and groundwater features for their drinking water supplies (Bourret 2015). This included the cities of Alamogordo, Tularosa, La Luz and several smaller communities along with the military installations of WSMR and HAFB (Bourret 2015). Increased demands for water have led to increased groundwater pumping for drinking water and also for use in desalinization efforts (Bourret 2015). As an example, Alamogordo's current water rights rely heavily on surface water resources for municipal use (Bourret 2015). As a result, the city is vulnerable to water shortages from prolonged periods of drought or low snowfall (Bourret 2015). The city is in the process of developing a new well field and desalinization plant to decrease its reliability on surface water (Bourret 2015). The current projections estimate that pumping at this well field, along with increased pumping at the city's other well fields, will result in an increase in groundwater use by approximately 1,110 hectare–meter/year (9,000 acre–feet/year) (JS&A and L&A 2005). Based on estimates of groundwater recharge for the eastern portion on the Tularosa Basin by Mamer et al. (2014), this increase represents nearly 10% of the annual recharge in the eastern portion of the basin, significantly impacting the water balance of the currently over-drafted groundwater system (Bourret 2015). The projected increase in groundwater extraction by the city of Alamogordo will have impacts on the down-gradient regions, including WHSA (Bourret 2015). Other entities in the region have similar plans for increased pumping of groundwater resources; including a planned desalinization plant at HAFB will also have an impact on the availability of groundwater at WHSA.

Resource managers at WHSA are concerned that the predicted changes to the regional climate due to climate change coupled with the expected increased pumping pressure on groundwater resources for drinking water supplies will have an adverse effect on the shallow aquifer that supports the dune field (NPS 2010, Bourret 2015). WHSA resource managers are actively facilitating and participating in research that is aimed at gaining a better understanding of the geologic, hydrologic, and biological factors that control the dune system (Fryberger 2001, Kocurek et al. 2007, Newton and Allen 2014). One recent research effort constructed a 3-dimensional, finite difference, hydrologic model of the Tularosa Basin for the purpose of estimating the impact on the regional groundwater system that would result from the projected increased pumping demands (Bourret 2015). The model was calibrated using computed and observed groundwater residence times and water table elevations (Bourret 2015). The model conservatively predicted that increased groundwater pumping would result in a lowering of the regional groundwater table in the vicinity of WHSA of up to 1.5 m (approximately 5 ft) (Bourret 2015). The lowering of the water table at WHSA is an indirect response to the predicted change in the balance between groundwater recharge and extraction on the eastern side of the Tularosa Basin creating an altered, steady-state, regional water balance (Bourret 2015). The model results also showed the degree of sensitivity that the groundwater levels in the basin have to the evapotranspiration rate (Bourret 2015).

Data Needs/Gaps

A number of the measures could not be assessed a condition level due to data gaps in the measures, reference condition, or both. Many hydrologic studies have been conducted within WHSA on the shallow aquifer due to its importance to the formation of the dunes, however little research or literature was available for the deeper regional aquifer. The regional aquifer system is critical to the shallow aquifer system under the dune field (Knapp, written communication 6 July 2016). Future study of this system including its water chemistry would be beneficial to WHSA resource managers. Currently, due to the lack of information the measure regarding the regional aquifer flow rate is considered to be a data gap. However, in the studies that were available, there are indications that there is some interaction between the shallow and regional aquifer even though they are separated by an aquitard (Newton and Allen 2014, Bourret 2015). Additional study on this interaction is important due to the effects that projected climate change will have on the shallow aquifer due to increase evaporation rates and the projected increase demands on the regional groundwater for drinking water supplies. The soil moisture measure was also considered to be a data gap based on the limited amount of data available. Inclusion of evaporation rates and groundwater levels could lead to a better understanding of the soil moisture estimated by Scheidt et al. (2010) using remotely sensed data.

Due to the importance of groundwater to the ecosystems present at WHSA, continued research is needed on hydrologic, geologic, and biological factors that control the dune systems (Fryberger 2001, Kocurek et al. 2007, Newton and Allen 2014). Continued monitoring of groundwater levels in existing wells along with the establishment of additional groundwater monitoring wells (Photo 38) would provide a better basis for understanding the mechanics and processes at work within the groundwater systems at WHSA (KellerLynn 2007). The monitoring system in place at Great Sand Dunes National Park could serve as a model for such a system at WHSA (KellerLynn 2007). With the projected increase in demand on groundwater for use as drinking water, these data will also help distinguish whether drawdown in the groundwater table is due to human use or from natural (seasonal and annual) fluctuations (KellerLynn 2007). Other groundwater research needs in the area includes the transmissibility of groundwater across the fault system, the source and geochemistry of the groundwater, and the role of rift tectonic and deep formation or hydrothermal water (Knapp, written communication, 6 July 2016).

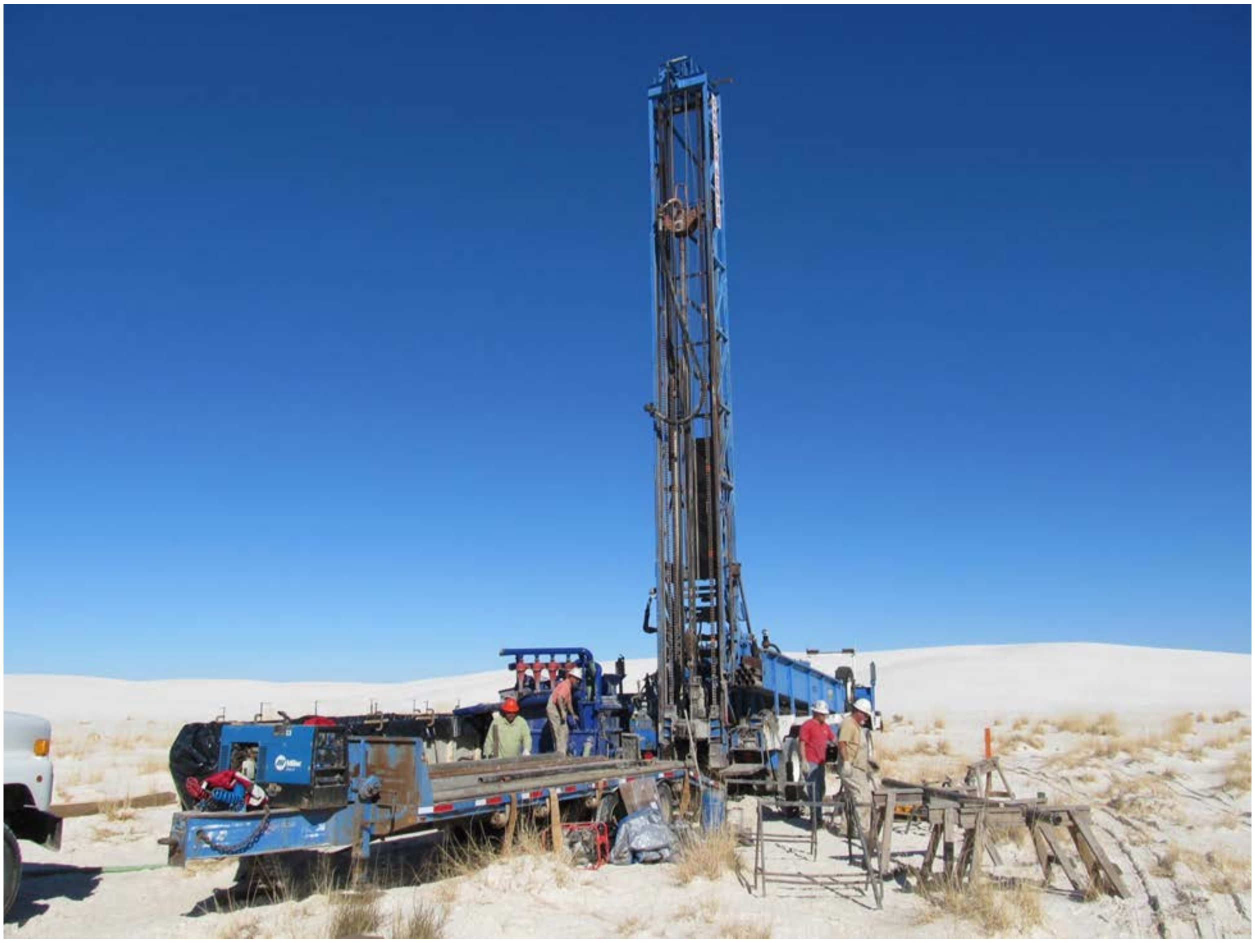

**Photo 38.** Installation of a groundwater monitoring well at WHSA (NPS photo).

Depth to groundwater in the majority of the park is critical for understanding the sediment supply to the dunes. This measure has been extensively studied and monitored, however the sediment supply has not been as extensively studied. In an aeolian system is as important as the water table in the dunes for dune morphology, preservation, persistence, etc. (Knapp, written communication, 6 July 2016). Additional research on the source of sediments within the system is recommended.

A systematic study of the saline pan system is needed (Knapp, written communication, 6 July 2016). This type of research could provide information on questions such as:

- What minerals and sediments are produced by Lake Lucero and Alkali Flats?
  - How much gypsum is the actively produced today, how will this change in the future?
    - Lake Lucero and Alkali Flats have active lacustrine processes that are creating bottom growth gypsum. They may also make cumulate (from the water column) gypsum. They are both active ephemeral lakes and/or saline pans.
    - Gypsum can be created by groundwater. This can take the form of displasive crystals, ephemeral crusts (a surface feature created through groundwater wicking that is common at WHSN), and alteration of existing crystals.

        - Cements may form around clastic gypsum grains from groundwater.
    - All of the above processes may have occurred in paleo Lake Otero and be eroded by the wind (deflation) into the current dune field. No study has attempted to understand the source of the gypsum (what environment it formed in) the source of the brines that created the gypsum (groundwater, surface water, hydrothermal, volcanogenic, etc).
- When are they produced?
    - Is production of bottom growth gypsum a process that is occurring in modern environments, or is all gypsum sourced from previous conditions?
    - Is the dolomite observed in the saline pan system formed in modern environments?
    - Will gypsum form from evapoconcentration of surface runoff, groundwater, or a combination or both?
    - How much time does it take for bottom growth gypsum crystals observed in the dunes required to form?
    - How much surface water and what residence time is required for gypsum to form?
- What are the relative amounts of surface- and groundwater that contribute to the brines that form surface minerals within the saline pan system?
- How does changes in water levels in the saline pan system affect salinity?
- How does the water levels in the saline pan system correspond to the regional water table aquifer and shallow aquifer of the dune field at WHSA? (KellerLynn 2007).
- What is the current and past geochemistry of the groundwater, surface water, and source brines for minerals in the saline pan system?
- What minerals are produced by groundwater? Specifically:
    - What is the source of groundwater and has this changed over time,
    - What minerals are altered by groundwater and what processes resulted in this alterations, and
    - Do groundwater produced or altered minerals feed the dunes?
- How has mineral production and brine source into the surface saline pans changed over time?
- How is the gypsum produced in the modern saline pan system related to the dunes? Specifically:
    - What is the amount of gypsum and other minerals produced in the saline pan system and exported to the dunes?
    - What is the spatial distribution of mineral production in the system and where is that mineral production transported through eolian processes? and
    - Do differences in hydrology between Alkali Flats and Lake Lucero effect mineral production, form, and distribution?
- Do hydrothermal waters, volcanogenic waters, and deep formation waters transported through fault and fracture systems contribute to the regional and/or local groundwater system?

- What is the hydrologic transmissibility of local and regional fault systems? Are local fault and fracture systems acting as regional or local flow systems?
- What is the role of microorganisms in the hydrologic system? Specifically:
    - Do microorganisms and the production of photosynthetic microbial mats influence landscape stability (i.e., biological sediment cementation)?
    - What is the phylogentic diversity of the endogenous microbial communities within the Tularosa Basin?
    - Are microorganisms being preserved within the gypsum crystal structures within fluid inclusions?
- Are we able to observe a change or evolution of microbial communities over time?
- What role or influence do microorganisms play in sulfur cycling, carbon cycling, and biotransformation of chemical sediments between the lithosphere, hydrosphere, and biosphere?

The ephemeral lake system is also a critical part of the resources at WHSA. This system covers a large portion of WHSA. Ephemeral lakes are not only the source of the gypsum, but are also a critical and unique ecosystem. This is a seemingly unique geologic feature and provides an area of superb vistas and natural beauty. Fossil trackways can be found within the ephemeral lake system and it is an area of keen scientific investigation and interest. Additional research on this system would also be beneficial to WHSA resource managers.

Further analysis and refinement of the regional 3-dimentional concept model of the basin's groundwater dynamics and its relationship to the overall eolian system will enable resource managers to develop scenarios of the possible effects that increased demands on groundwater in the basin would have on the groundwater at WHSA (KellerLynn 2007, Newton and Allen 2014). Additional research is also needed to determine the exact interaction between the regional groundwater system and the shallow groundwater system beneath the dune field (KellerLynn 2007, Newton and Allen 2014). A mathematical model is being developed to estimate the volume of regional groundwater that enters the shallow dune aquifer and also to assess the timescale on which changes in regional groundwater levels will affect the water levels in the shallow dune field aquifer (Newton and Allen 2014). The results of this model were not available at the time of this writing.

Lastly, the effect of the Jarilla Fault on the groundwater system is also not very well understood (Newton and Allen 2014). However, significant evidence indicates that this fault is critical to the dune/saline pan system. Conducting more geophysical surveys to better understand this structure and its interaction with the groundwater is crucial.

Overall Condition

*Depth to Groundwater*

The project team assigned a *Significance Level* of 3 to the depth to groundwater measure. The dune field at WHSA is considered to be a wet eolian system (Newton and Allen 2014). Studies have shown that this type of dune system is very sensitive to the level of the groundwater table (Fryberger

2001, Newton and Allen 2014). The lowering of the water table may lead to changes in the dune dynamics present at WHSA (Kocurek et al. 2007, Newton and Allen 2014, Bourret 2015). A long-term (± 50 year) change in the water table of 1 m (3.3 ft) is enough to initiate major changes in dune dynamics (Fryberger 2001). Data is not available for the depth to groundwater in the dune field aquifer over the period of time for the shallow aquifer below the dune field. The monitoring data that are available do not have a long enough period of record to accurately determine any trend. There are some data that do show a long-term decrease in groundwater levels in some areas of the basin.

The potential future of the WHSA dune field under a lowered water table condition could be evidenced by a sister dune field to WHSA located near the town of Cuatro Cienegas in the Mexican state of Coahuila (NPS 2014, Bourret 2015). This is the second largest gypsum field in the world, and while not currently considered to be a wet eolian system, there is evidence that suggests it was previously (Bourret 2015; Newton, written communication, 6 July 2016). Due to the climate change projections and potential impact from groundwater pumping of the regional aquifer a *Condition Level* of 2 has been assigned. The current state of knowledge regarding the interaction between the shallow aquifer and regional aquifer is not sufficient to warrant assignment of a *Condition Level* of 3, however as research improves the understanding of this interaction, the *Condition Level* should be reassessed.

*Regional Aquifer Flow Rate and Direction*

The project team defined the *Significance Level* for the frequency of surface water as a 1. Measures with a *Significance Level* of 1 are not discussed in depth in the current condition section of this assessment, but available information is summarized here in the overall condition section. A regional aquifer composed of rif-fill sediment, unconsolidated sediment and deeper bedrock is located below the surficial aquifer present within WHSA (McLean 1970). The deeper regional aquifer ranges in thickness from 30–1,200 m (98–3,937 ft) depending on location within the Tularosa Basin (Huff 2005). Clay layers separating the shallow aquifer from the deeper regional aquifer greatly limit vertical flow between these two resources (McLean 1970, Huff 2005).

Aquifer pumping tests and computer modeling have indicated that some vertical flow does exist between these two aquifers (Bourret 2015). The direction of this flow and its magnitude are important components of the water balance equation at WHSA (Bourret 2015). An aquifer pumping test was conducted by Newton and Allen (2014) using well WS-018 (Figure 75). Water levels for this well and two observation wells (WS-007 and WS-017) were recorded during the pump test and recovery period (Newton and Allen 2014). Analysis of the data showed the expected decrease in water levels for the wells in the regional system (WS-017 and WS-018), but no draw-down was observed in the shallow dune field aquifer (WS-007). This indicated that there was no vertical movement from the shallow system to the deeper regional system, as the clay layer limited movement (Newton and Allen 2014).

While no vertical flow was measured over the time-frame of the pumping test, there is evidence of some vertical flow over a much larger time scale (Newton and Allen 2014, Bourret 2015). It is assumed that the regional groundwater enters the shallow groundwater system in the dune field from the east and by localized vertical flow from below (Newton and Allen 2014, Bourret 2015). Bourret

(2015) estimated this vertical flow rate to be on the order of 66–120 cm/yr (26–47 in/yr), which is similar to estimated evapotranspiration rates (30–95 cm/yr [12–37 in/yr]). Additional research is needed to better understand the relationship between these two groundwater resources (Newton and Allen 2014).

In general, the flow in the regional aquifer is from east to west, with the potential of some north to south flow (Newton and Allen 2014). An important aspect that has to be considered in terms of the regional groundwater and the shallow aquifer system is the effect that the Jarilla Fault has on groundwater flow (Newton and Allen 2014). The exact location of this feature is not known, and is represented on geologic maps as a dashed line (Figure 81). Newton and Allen (2014) were able to locate a section of the fault line within the park through various means. On the eastern side of the park, the fault is evident by the exposed bedrock to the east of the Visitor's Center near the water tower on the east side of Highway 70 (Newton and Allen 2014). Efforts by Newton and Allen (2014) to locate the fault in the northern portion of the park were not as conclusive, indicating the fault may be spatially complex in this area. A conceptual hydrological model of groundwater flow within WHSA has been recently developed by Newton and Allen (2014) and a copy of this model is shown in Figure 74. This representation has been intentionally exaggerated in order to show the flow in the shallow water system and the regional system. Groundwater flow in the regional aquifer is represented by the blue arrows in Figure 74 (Newton and Allen 2014).

A *Condition Level* could not be assigned at this time due to a number of factors. While the direction of flow of the regional aquifer within WHSA is the same as for the Tularosa Basin, specific information on the direction of flow was unavailable at this time. The majority of the research on groundwater within WHSA has focused on the shallow aquifer that is important to the formation of the dunes, and little is known about how the deeper regional aquifer interacts with the shallow aquifer. In addition, the effect of the Jarilla Fault on the groundwater system is also not well defined.

*Lost River Flow Rate and Direction*

The project team defined the *Significance Level* for this measure as a 2. While there is no flow within the portion of the Lost River within WHSA, anecdotal evidence suggests that during the reference period flow was present at times during the year. With no baseline flow records available for this period, the amount of flow or the persistence of water is unknown. It is most likely that this flow did correspond to the precipitation pattern of the region. Small portions of the channel do exhibit perennial water, but this is sustained by groundwater (Newton and Allen 2014). Due to projected changes in the evaporation rates due to climate change, the regional groundwater may no longer be able to supply water to the Lost River within WHSA. Due to this, and the fact that there is evidence of greater flow during the reference period a *Condition Level* of 2, meaning moderate concern has been assigned.

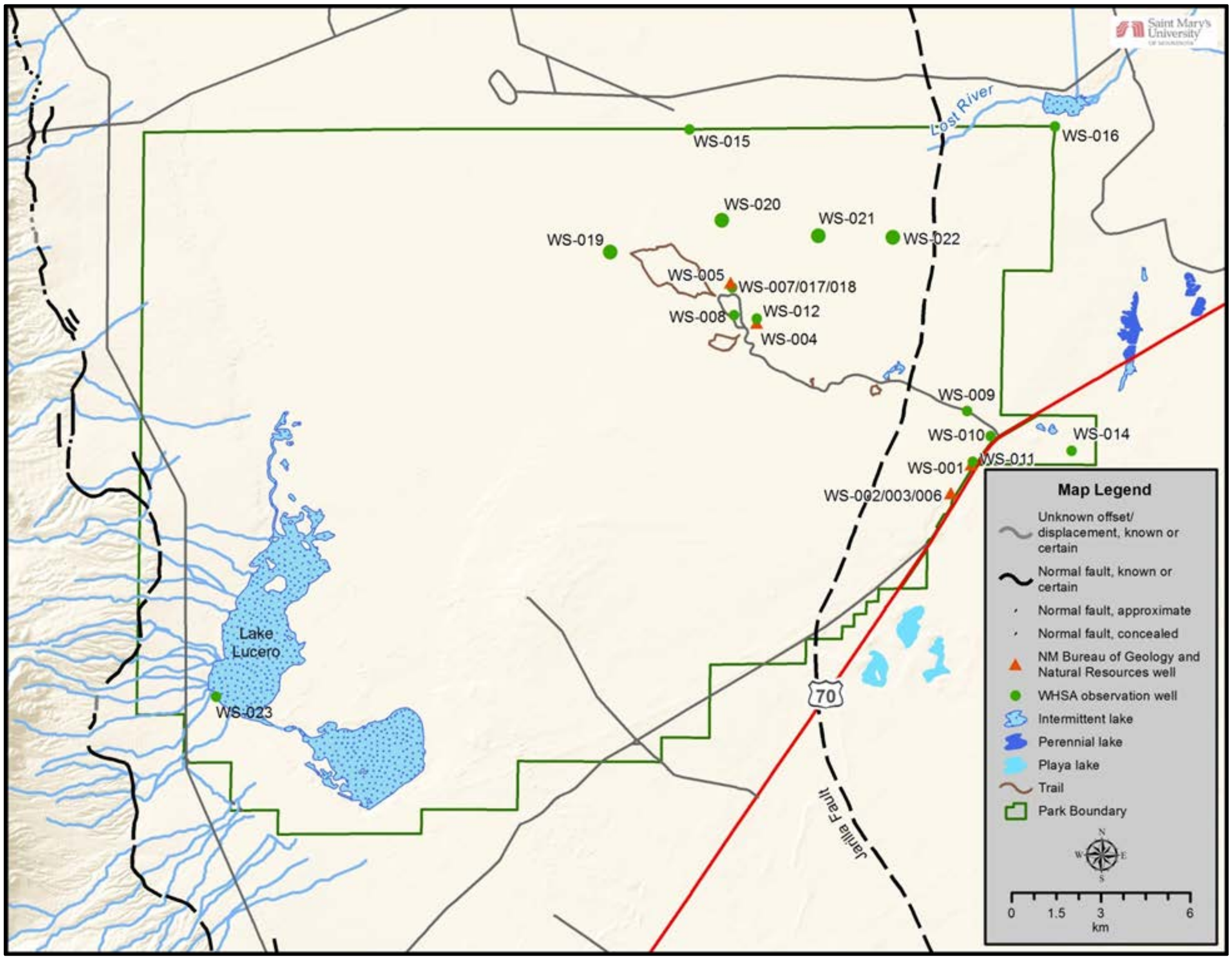


**Figure 81.** Approximate location of the Jarilla Fault within WHSA and immediate vicinity.

*Soil Moisture*

The project team assigned this measure a *Significance Level* of 3. Limited data is available for this measure. Within the dune field, Scheidt et al. (2010) found that interdunes consistently have higher moisture levels than the surrounding dunes and that barchan dune moisture is typically higher than parabolic dune moisture levels. Playa areas ranged from complete saturation to complete desiccation. Scheidt et al. (2010) estimated that alluvial fan areas had the lowest levels of soil moisture within WHSA. Soil moisture and the shallow aquifer under the dune field are recharged by precipitation events (Newton and Allen 2014). Soil moisture results from the downward infiltration of precipitation and from the capillary action drawing moisture into the upper levels of the sand from the saturated areas below, and is lost through evapotranspiration (Newton and Allen 2014). The increased evaporation rates predicted by the global climate models have the potential to affect soil moisture levels and lower the water table within the dune field. This could be compounded by the increased pumping of the regional aquifer for drinking water supplies. However, due to a lack of data, a *Condition Level* could not be assigned. The information presented in this report may serve as a baseline for future assessments.

*Weighted Condition Score*

The *Weighted Condition Score* for this component is 0.67, indicating high concern. The groundwater features within the park are dependent on surface runoff and precipitation. The regional groundwater and shallow groundwater aquifers are integral components of the dune system at WHSA. The effects of climate change and to some degree water use by the surrounding communities has impacted this resource and will continue to impact it in the future. For this reason, a declining trend has also been assigned to this measure.

| Groundwater Hydrology | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = 0.67** |
| Depth to Groundwater | 3 | 2 | |
| Regional Aquifer Flow Rate and Direction | 1 | n/a | |
| Lost River Stream Flow | 2 | 2 | |
| Soil Moisture | 3 | n/a | |

#### *4.12.6. Sources of Expertise*

- David Bustos, WHSA Resource Program Manager
- Jonathan Knapp, WHSA Physical Scientist
- Talon Newton, Hydrologist, New Mexico Institute of Mining and Technology

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## 4.13. Cenozoic Trackways

### *4.13.1. Description*

WHSA is situated in the Tularosa Basin where the vast Lake Otero formed during the late Pleistocene epoch, approximately 45,000-28,000 years ago (Allen et al. 2009). This vast lake expanded and receded over time, and with these changes came periods of deposition and deflation of sediment (Allen et al. 2009). Research has indicated that Lake Otero expanded several times between 24,500 and 15,500 years BP, prior to an extended period of drought (Allen et al. 2009). At its high point, Lake Otero's surface was approximately 1,204 m (3,950 ft) above sea level (Allen et al. 2009). Research on the ancient lithofacies (i.e., sediment or rock layers) indicate conditions of shallow water along the shorelines where terrestrial megafauna walked, leaving behind trace fossil trackways of footprints which have recently been discovered in WHSA (Photo 39 and Figure 82) (Lucas et al. 2007, Allen et al. 2009).

**Photo 39.** Example of what fossil trackways look like in WHSA. These tracks are proboscidean, and most likely mammoth prints (digital mammoth added to show scale, print stride suggest mammoth would have stood 4 m (13 ft) tall at the shoulders) (NPS photo).

**Figure 82.** An artistic rendition of what the ancient lakeshore landscape may have looked like and the creatures that have left behind the fossil trackways visible today in WHSA (reproduced from NPS 2015).

Trackways recently discovered within WHSA include prints thought to be left behind by the saber-toothed tiger (*Smilodon fatalis*), dire wolf, camelids (*Camelops hesternus*), and two species of mammoth, the wooly and the Columbian (*Mammuthus primigenius* and *M. columbi*) (Photo 40; NPS 2013). These fossil records are snapshots in time that help in understanding the ancient climate, landscape, and inhabitants of the Tularosa Basin (Santucci et al. 2009). The animal trackways around on the west side of WHSA are estimated to have been produced before 30,000 B.P. (Lucas et al. 2007), and are found in sedimentary material deposited by the Pleistocene Lake Otero within the Tularosa Basin (Figure 83; NPS 2015). On the eastern side along the L2 lake margin the dates range from 18,000 to 23,000 B.P. (Figure 84; Allen et al. 2014)


**Photo 40.** Trackways discovered within WHSA. Photo A is of a dire wolf, Photo B is of a camelid, Photo C is of a sabre-toothed tiger, and Photo D is of a species of mammoth (NPS photos).

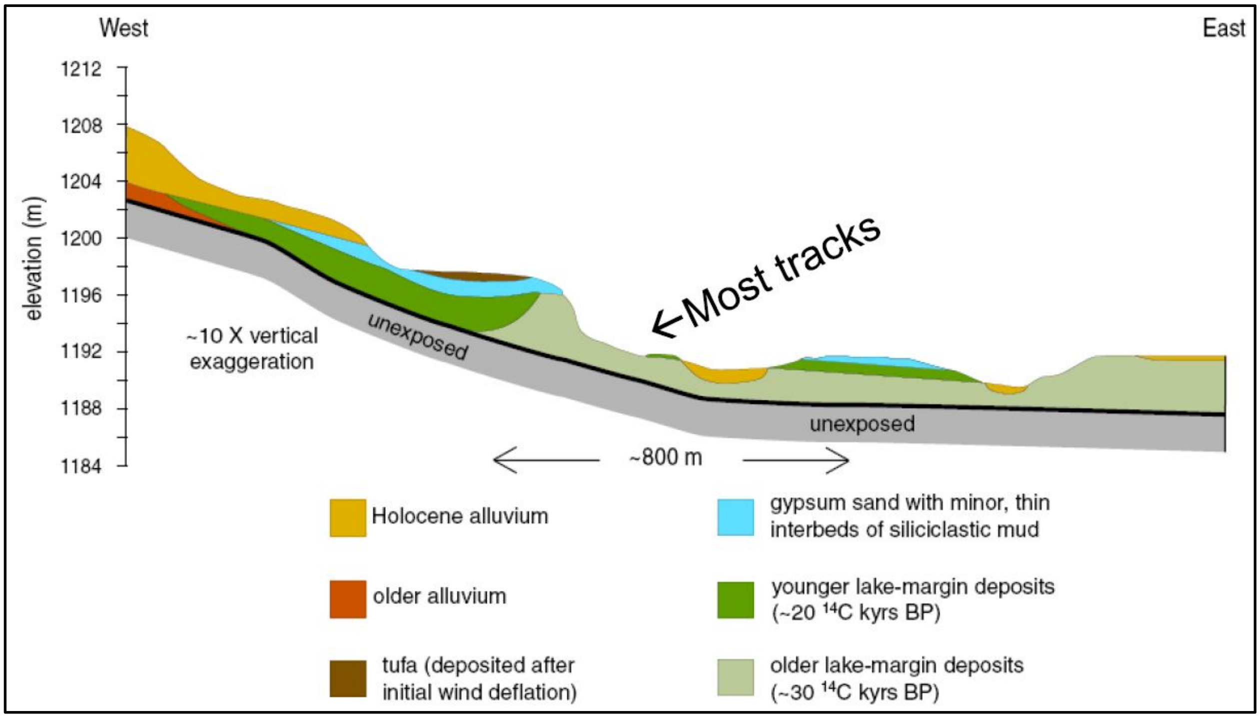



**Figure 83.** Depiction of the ancient layers of sediment in the Tularosa Basin where Cenozoic trackways have been discovered from the west side of Lake Otero (schematic cross section reproduced from Allen et al. 2009).

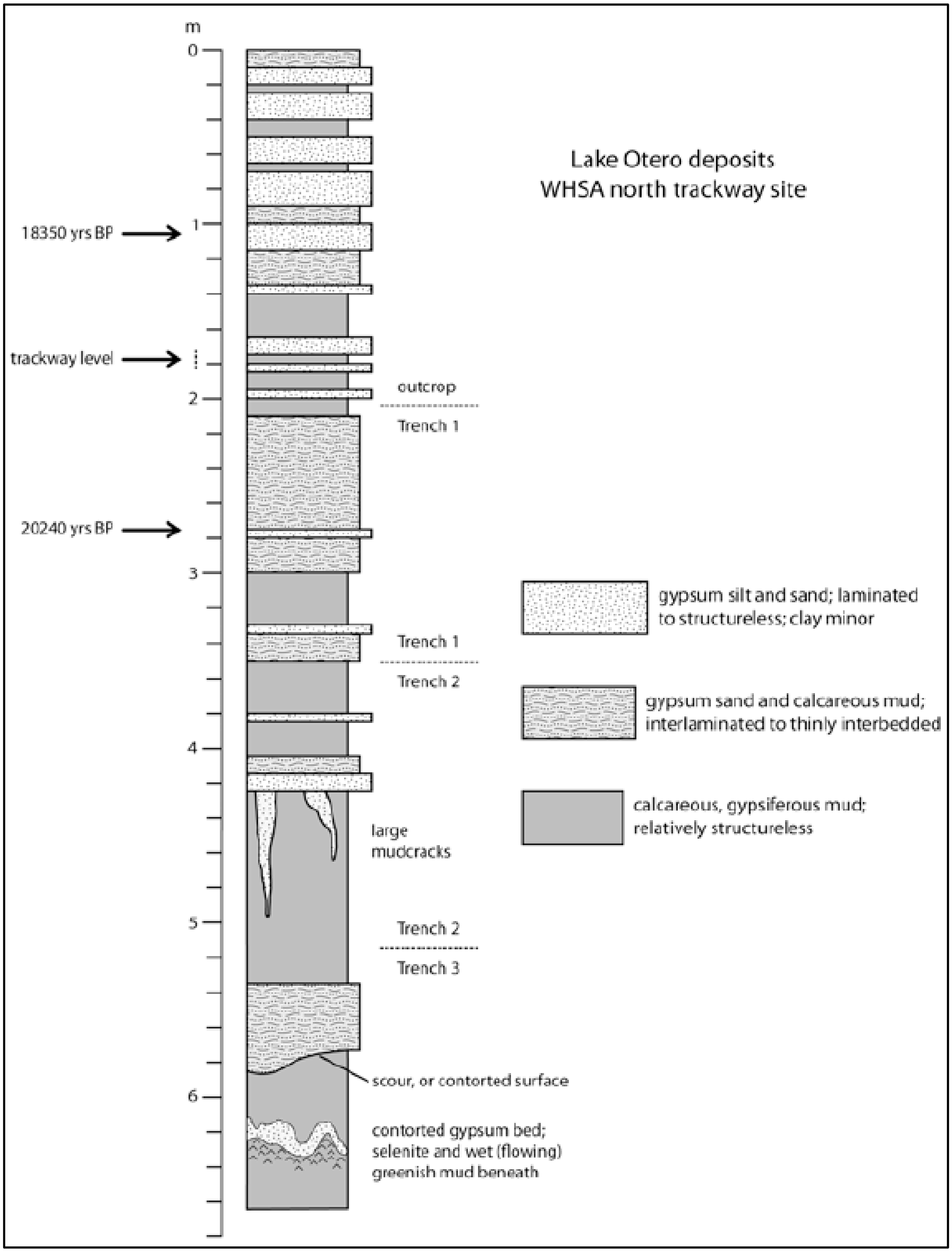



**Figure 84.** Depiction of the ancient layers of sediment in the Tularosa Basin where Cenozoic trackways have been discovered on the east side of Lake Otero (reproduced from Allen et al. 2014).

#### 4.13.2. Measures

- Condition of prints in trackway
- Number of prints in trackway, length, width, stride, pace, type of track maker
- Rate of erosion of the trackways

#### 4.13.3. Reference Conditions/Values

A reference condition for the Cenozoic trackways in WHSA has not been defined, as records of their existence prior to the establishment of the park do not exist. The first discovery of Cenozoic trackways occurred in 1932 just outside the western boundary of WHSA (Lucas et al. 2007). At first mistaken for human tracks, they were later identified (in 1981) as mammoth tracks (Lucas et al. 2007). The rate of erosion, number of prints, and condition of those first prints are not known.

#### 4.13.4. Data and Methods

Lucas et al. (2002) described the Cenozoic trackways in and near WHSA with a brief history and descriptions of locality, stratigraphy, and age. Photos, time of discovery, and general descriptions of the identified trackways are included in this publication. Trackway descriptions include the identity of the animal; size, shape, and number of prints; the site location coordinates (NAD 1927 zone 13); and the New Mexico Museum of Natural History and Science (NMMNHS) identification number assigned to each site (Lucas et al. 2002).

Lucas et al. (2007) described the trackways and associated prints found at five sites in the Tularosa Basin, some of which were located inside the WHSA boundary. One of the tracksites was previously described in Lucas et al. (2002). Lucas et al. (2007) described the structural appearance of the prints and included the measurements that were taken during the documentation process. Measurements included length and width of prints, stride distances, number of prints, and location and strata in which the prints were preserved.

Gentry et al. (2011) conducted a survey to document fossilized trackways, plant material, and treefalls at WHSA that were discovered post-Lucas et al. (2002, 2007). Documentation included radio-carbon dating of deposits in which trace fossils were preserved in order to estimate their age. Date estimates were also derived from preserved plant material, including plant fibers and seeds found in the gypsiferous clay deposits in close proximity to trackways. Photographs were taken of full trackways, individual prints, and the general area as documentation took place. Trackway data were recorded for each print (e.g., diameter, width, stride length, number of prints), and some trackways were "collected" by tracing the trackways onto clear Mylar sheeting. Ichnotaxonomy (identification of species) was documented for each trackway when possible.

#### 4.13.5. Current Condition and Trend

Condition of Prints in Trackway

The trackways discovered to date in WHSA exist in varied conditions, and some have already been worn away by natural processes. The first trackway discovery in the area of the current park extent occurred in 1932 by Ellis Wright. The gypsum layers in which the trackways are preserved are fragile, and once exposed to the elements they are quickly worn away. Documentation is a crucial management strategy, considering that the majority of recently discovered trackways were gone within a year of their first documentation (Gentry et al. 2011). All the trackways preserved in WHSA are considered temporary for two primary reasons. First, the substrate they are preserved in is soft and water-soluble, making them highly vulnerable to the elements. Second, the windswept environment at the park is constantly wearing away at exposed surfaces, so all the trackways exposed in this manner are also eventually worn away completely. Due to the fragile state of the trackways, the exact locations will not be provided in this document. Instead, references will only be made to the NMMNHS tracksite number along with a brief description of an approximate location. Although the general appearance of these trackways is described, the actual condition hasn't been explicitly assessed.

*Lucas et al. (2002, 2007)*

Tracksite NMMNHS 4979 was not actually within the WHSA boundary, but was in close proximity to the western edge and was the first known discovery of trace fossils in the area (Lucas et al. 2002). Mammoth and camelid prints were identified at this site in 1981. The mammoth prints identified in 1981 were exposed over an area of about 75,000 $m^2$ (810,000 $ft^2$) and were preserved in convex relief. The soft gypsite matrix surrounding the prints had eroded away, and the actual prints were preserved in a pinkish-gray gypsite layer of the Otero Formation, which consists of lacustrine deposits from the late Pleistocene epoch. These prints were large (diameter of 430-620 mm [16.9-24.4 in]), round to ovoid, and lacked separate toe impressions, with an estimated stride length of 2-3 m (6.6-9.8 ft) (Lucas et al. 2002). The camelid prints at this site were heart-shaped with two distinct digits and a diameter of 160-180 mm (6.3-7.1 in). Stride length was about 1.3 m (4.3 ft), which is compatible with a large Pleistocene *Camelops* species (Lucas et al. 2002). The camelid prints were also preserved in convex relief on the surface of the Alkali Flat, similar to the mammoth prints.

Tracksites NMMNHS 7142 and 7144 both consisted of shallow depressions in the sediment surface (Lucas et al. 2007). Tracksite 7142 was a single mammoth trackway, while tracksite 7144 consisted of several mammoth trackways with each print appearing as a halo-shaped imprint on the surface. The mammoth prints varied in diameter between 38 and 89 cm (15 and 35 in) (Lucas et al. 2007). At that time, these tracksites were only recently discovered and were only minimally described in Lucas et al. (2007).

Tracksites NMMNHS 7139 and 7140 consisted of mammoth trackways that were similar to those at NMMNHS 4979. At these locations, preserved gypsite casts of ovoid prints stood out from the surrounding substrata in color and texture (Lucas et al. 2007). These were found along the southern shoreline of Lake Lucero with patterns suggesting undertracks (i.e., smaller prints beneath larger ones), incomplete overstepping (one print partly over the other), and altered shapes and sizes from differential erosion and cementation (Lucas et al. 2007). The prints at site 7139 varied in size, with lengths from 15 to 50 cm (6 to 20 in) and widths from 25 to 43 cm (9.8 to 17 in). These prints were thought to be footprints from a juvenile mammoth (Lucas et al. 2007). At site 7140, another set of 10 prints were measured and ranged in length from 38 to 70 cm (15 to 27.5 in), with widths between 33 and 65 cm (13 and 25.6 in); strides ranged from 105 to 230 cm (41.3 to 90.5 in) in distance (Lucas et al. 2007).

*Gentry et al. (2011)*

Three major areas were surveyed in WHSA during research conducted by Gentry et al. (2011) in order to document 16 recently discovered trackways that consisted of over 700 individual prints. Areas where these trackways were discovered were simply referred to as sites 1, 2, and 3 to protect the specific locality information in accordance with federal laws pertaining to the sensitive nature of the information recorded (Gentry et al. 2011). A total of 20 trackways were documented during the Gentry et al. (2011) surveys, including new and existing discoveries.

Site 1, the Lake Lucero Site, consisted of shallow circular to ovoid depressions with diameters of 45 to 144 cm (17.7 to 56.7 in), and appeared to be of one type (Gentry et al. 2011). Gentry et al. (2011) noted that the prints visible at this locality were visually similar and in close spatial proximity to those described in Lucas et al. (2007). The average stride length of one mammoth trackway at this site was between 2.5 and 3.5 m (8 to 9.8 ft) and prints were 45 cm to 120 cm (17.7 to 47.2 in) wide (Gentry et al. 2011).

Site 2, the Garton Pond Site, had hundreds to thousands of what appeared to be camelid foot prints, as well as several mammoth prints and six unknown felid (large cat) prints. This site was thought to be from a more recent period of time when researchers suspect that mammoths were on the decline in the Tularosa Basin, following a period of abundance (Gentry et al. 2011). The average length and width of mammoth prints from site 2 were 45 cm (17.7 in) and 47 cm (18.5 in), respectively (Gentry et al. 2011). The stride length was 220 cm (86.6 in), an average falling short of those measured at sites 1 and 3, which suggests a smaller animal (i.e., juvenile) (Gentry et al. 2011). The camelid trackways at this locality were shallow (1-2 cm [0.4-0.8 in]) heart-shaped depressions and averaged 21 cm (8.3 in) in length and 18 cm (7.1 in) in width (Gentry et al. 2011). Stride length was an average of 150 cm (59 in), with trackways predominantly oriented in a north- south direction that suggests they traveled to and from the lakeshore to drink (Gentry et al. 2011). There were *Felipeda* prints at this site as well, with four anteriorly pointed digits and rounded digit pads (Gentry et al. 2011). The *Felipeda* prints at site 2 were 9 cm (3.5 in) long and 6.5 cm (2.6 in) wide and were thought to have originated from either a saber-toothed tiger or an American lion (*Panthera atrox*) (Gentry et al. 2011). An additional single print, seemingly fitting the *Felipeda* track characteristics, was around 19 cm (7.5 in) wide and 15 cm (5.9 in) long (Gentry et al. 2011). This single track was preserved in pedestaled, convex relief, sticking 1-2 cm (0.4-0.8 in) up from the surrounding surface (Gentry et al. 2011). The large size and digit position of this single print (Photo 41) has led researchers to believe it is most likely that of a giant short-faced bear (*Arctodus simus*), which roamed this region during the late Pleistocene (Schubert et al. 2010, as cited by Gentry et al. 2011).

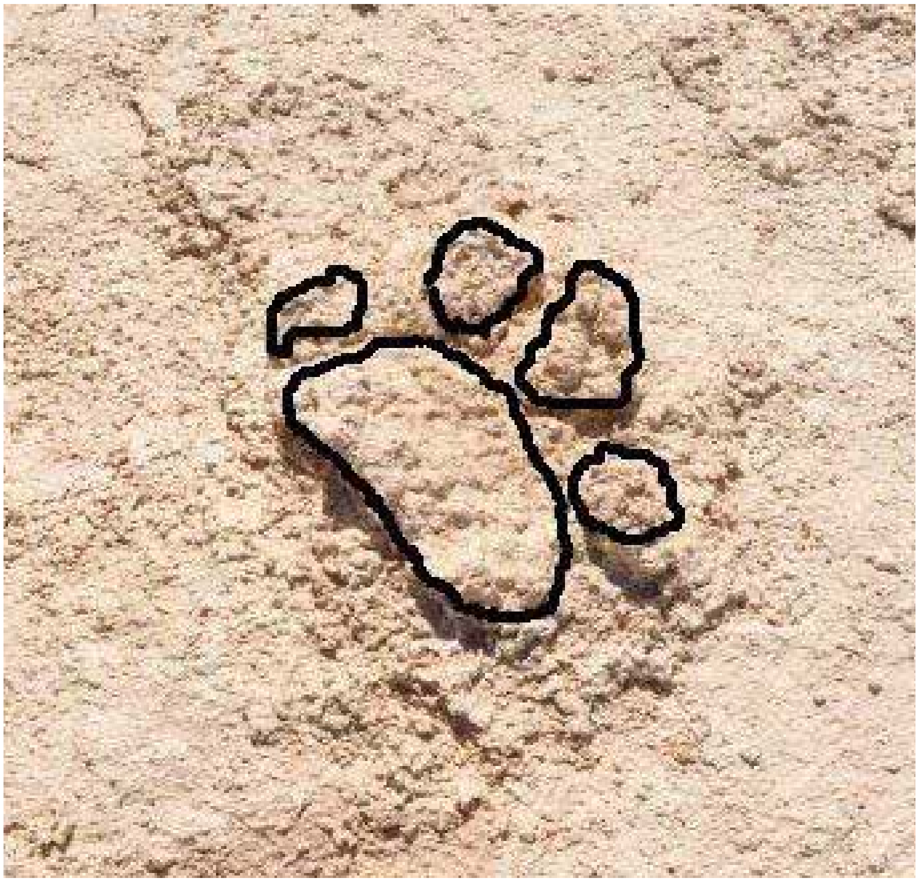


**Photo 41.** A single print photographed at site 2 in WHSA is most likely that of a giant short-face bear (*Arctodus simus*) that once roamed the Tularosa Basin area (Photo: Gentry et al. 2011).

Site 2 also had a trackway from the ichnogenus *Canipeda*, which was previously discovered by WHSA staff in 2010, but has since been eliminated via deflation (Gentry et al. 2011). The tracks were, on average, 7.8 cm (3.1 in) long and 8.5 cm (3.3 in) wide for the manus (paw of front limb) and 10 cm (3.9 in) long and 6.35 cm (2.5 in) wide for the pes (paw of rear limb), with circular to elliptical-shaped digits (Gentry et al. 2011).

Site 3, the Alkali Flats Site, held the most extensive trackway assemblage that was documented during the survey (Gentry et al. 2011). This trackway consisted of mammoth, camelid, cat, canine, and tridactyl (three-toed) prints amongst what were thought to be tree-falls (Gentry et al. 2011). The prints at site 3 were preserved in convex relief, and were pedestaled above the surface anywhere from 1 cm to 4 cm (0.4 in to 1.6 in) (Gentry et al. 2011). The dozens of mammoth trackways consisted of pedestaled, disc-like prints between 31 cm and 88 cm (12.2 in and 34.6 in) in length (Gentry et al. 2011). Stride length averages were variable, suggesting the presence of several animals of various stages of development (i.e., juvenile to adult) (Gentry et al. 2011). Researchers have interpreted these variations in stride lengths and print sizes to be indicative of the presence of mammoth family units traveling to and from the ancient shores of Lake Otero (Gentry et al. 2011).

Number of Prints in Trackway

Not every trackway was a good candidate for determining the number of tracks. Some trackway sites were trample sites, with numerous tracks overlapping each other, and in some cases more than one type of animal track. Hundreds, and in some cases thousands, of prints have been found for each of the flowing camelid, probocian, *Felipeda*, *Canipeda*, and Harlan's ground sloth.

*Lucas et al. (2002, 2007)*

The number of prints observed during Lucas et al. (2007) differed among the five NMMNHS tracksites in the WHSA area, although only the number of prints was documented for only two of the five tracksites. Tracksite 4979 had the highest number of prints, with 64 camelid prints and 25 mammoth prints. Tracksites NMMNHS 7144 and NMMNHS 7139 had multiple trackways, and one trackways at the 7139 site consisted of 10 prints from what was thought to be a juvenile mammoth (Lucas et al. 2007).

*Gentry et al. 2011*

The trackways documented most recently had hundreds to thousands of individual footprints that were mainly from mammoths and camelids (Gentry et al. 2011). One trackway at site 1 had 57 individual prints that showed bidirectional movement of one large adult mammoth (Gentry et al. 2011). At site 2, with the largest number of individual tracks on record, there were nine camelid trackways with a total of 503 individual camelid prints, 24 *Felipeda* prints, one giant short-faced bear print, 16 *Canipeda* prints, and five mammoth prints (Gentry et al. 2011). There were additional trackways with prints at all sites, but only the prints that were clearly discernable from others were counted individually.

Rate of Erosion of the Trackways

Trackways are worn away in a similar fashion as to how they become exposed. In WHSA, this is a natural process of weathering via aeolian and fluvial deflation which unearths the trackways as the surrounding material blows away or is eroded by runoff (Photo 42; Gentry et al. 2011). Wind deflation alone has exposed footprints and associated deposits in the Tularosa Basin and at WHSA (Gentry et al. 2011).

**Photo 42.** An example of the rate of erosion that the Cenozoic trackways in WHSA experience. The photo on the left was taken on 2/26/2009, the photo in the middle on 3/10/2010, and the photo on the right on 5/26/2011 (NPS photos).

Trackway NMMNHS 4947 has weathered away over time; according to Lucas et al. (2007), many of the tracks that had been documented in 1981 were gone at the time when the Lake Lucero trackways were discovered (NMMNHS 7139 and 7140). This is typical of the trackways in WHSA as they are preserved in soft, gypsiferous clay in the harsh New Mexico desert where winds deflate the surface materials constantly (Gentry et al. 2011). The time frame available to document the trackways is relatively short. This merits substantial need for regular and systematic survey, inventory, and documentation of these important resources at WHSA (Gentry et al. 2011). There are documented examples of very rapid erosion of trackways (< 6 months) when exposed to rain (Gentry et al. 2011). Not all trackways erode away this quickly, but most are short-lived and need to be documented in a timely matter in order to preserve the natural history of the region (Gentry et al. 2011). There is not an actual rate of erosion calculated for the trackways, but there are general notes on the general environment and substrate making all tracksites temporary to some degree. A gradient such as fast, medium, or slow rates of erosion is not defined for trackways at WHSA at this time.

<u>Threats and Stressor Factors</u>

Trampling of trackways is a concern, since these types of fossils are largely kept in situ and are difficult to preserve, collect, and protect (Santucci et al. 2014). The trackways, particularly in WHSA, are fragile and could easily be trampled by humans or other animals. This makes management and protection of trackway sites a priority in WHSA.

Erosion by wind (i.e., deflation) and water exposes these trackways naturally but also eventually wears them away (Allen et al. 2009). Trackways are most vulnerable when exposed to the elements, particularly after having a protective cover of lacustrine deposits for the last 10,000 to 30,000 years; they often disappear nearly as fast as they emerge (Lucas et al. 2007, Gentry et al. 2011). Water is, for the most part, ephemeral in WHSA, even for Lake Lucero, which contracts and recedes with the availability of precipitation. Flooding could damage the trackways, considering their fragility and the solubility of the gypsiferous clay medium in which they are preserved. If inundated, trackways may be partially or completely destroyed.

Missile impacts and recovery efforts occur within and in close proximity to the park, originating from the WSMR and HAFB to the north and east of WHSA. It is not known if any of these occurrences have affected trackways, although if such activities were to occur near or upon trackways, they would likely be destroyed.

Climate change is a concern in WHSA since it may alter the direction, velocity, and general pattern of winds, which play a prominent role in soil transport and moisture content (NPS 2010). Climate change may also impact water availability, both in-ground and meteorological (NPS 2010). Currently, WHSA is included in ongoing climatic monitoring as part of the CHDN Vital Signs Monitoring Plan, which considers climate change to be an issue of moderate importance (NPS 2010). Changes in the global and regional climate can cause a shift in the local disturbance regime (NPS 2010). This could involve an increase in extreme weather events such as drought and flooding (NPS 2010). In the event of heavy rains, Cenozoic trackways can be rapidly eroded, as observed by Gentry et al. (2011).

Data Needs/Gaps

In order to monitor and track the condition of the fossil trackways in WHSA, detailed documentation must occur. Important strategies include mapping the locations of trackways at the time of or immediately after discovery in order to document their spatial and surficial distribution. It is also important to record a site description and take photographs, since these tracks often only exist for a limited period of time before being weathered away forever (Santucci et al. 2009). Protecting these valuable resources by managing the sites is important, but it is also critical to conduct timely track site inventories, site mapping, photo documentation, track replication, specimen collection, site stabilization, site closure, construction of maintenance barriers, and a variety of site monitoring strategies (Santucci et al. 2014). According to Santucci et al. (2014), field documentation of trackways was scheduled to begin in a systematic fashion starting in 2011. However, none of these records were available for assessment at the time this NRCA was prepared. Completion of the NPS-led trackway cataloging and preservation effort will also help to better inform the current condition of this resource.

Overall Condition

*Condition of Prints in Trackways*

The condition of prints in trackways was assigned a *Significance Level* of 3. The condition of some prints has been recorded in terms of general size and shape, with some identifications of the type of animal that most likely left them. It is clear that these are delicate fossil relics that are not long-lasting due to the softness and fragility of the gypsiferous clay matrix in which they are preserved. This is the primary reason why documentation with photographs and measurements must be done in a timely manner once a trackway or print has been discovered. Since many of the previously discovered trackways have already been worn away by completely natural processes, the *Condition*

*Level* for this measure is a 3, or of high concern. In additional the fossil prints are located in a precious location within the co-use area of a military use area and under one of the most active missile test ranges in the country.

*Number of Prints in Trackways*

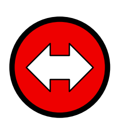
The number of prints in trackways was also assigned a *Significance Level* of 3 by the project team. The number of prints has been documented in trackways where it was discernable that one animal was leaving a particular trackway of prints. However, many areas where trackways were documented were heavily trampled areas where discerning a single animal's path to count the number of prints was not feasible. The prints previously documented are in many cases already gone or worn away to the point of no longer being intact trackways. Due to this waning nature of prints in the trackways at WHSA, the *Condition Level* is assigned a 2.

*Rate of Erosion of the Trackways*

Rate of erosion of the trackways was assigned a *Significance Level* of 3. Although not officially measured, the rate of erosion is relatively high at WHSA due to combined factors including constant blowing wind and the softness and general solubility of the gypsiferous clay matrix in which the trackways are preserved (Gentry et al. 2011). As Gentry et al. (2011) noted in the survey of trackways at WHSA, a set of prints that was photographed early in the project had been completely eroded away between June and August 2011 (< 6 months) by meteorological activity (i.e., rain and wind). Since trackways are experiencing high rates of erosion, a *Condition Level* of 3 has been assigned.

*Weighted Condition Score*

The *Weighted Condition Score* for WHSA's Cenozoic trackways is a 0.89, indicating high concern. This is based on available literature stating that these ancient trackways, while abundant in WHSA, are fragile and temporary, meriting the importance of ongoing and regular survey and monitoring efforts to record these constantly emerging and quickly fading resources. However, park managers have little or no control over the factors that make these features vulnerable to erosion. Considering that new trackways are being revealed as others are fading away, this resource is likely to remain in WHSA for the near future, but should be carefully managed and inventoried to capture trackways and other fossil assets as they come to the surface.

| **Cenozoic Trackways** | | | |
|---|---|---|---|
| **Measures** | **Significance Level** | **Condition Level** | **WCS = 0.89** |
| Condition of Trackways | 3 | 3 |  |
| Number of Prints in Trackways | 3 | 2 | |
| Rate of Erosion of the Trackways | 3 | 3 | |

### *4.13.6. Sources of Expertise*

- David Bustos, WHSA Resource Program Manager

### *4.13.7. 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 42 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 42.** Identified data gaps or needs for the featured components.

| Component | Data gaps/needs |
|---|---|
| Dune Communities | ➢ Updated information regarding dune areal extent and plant species composition is needed. An updated vegetation classification/mapping project is slated for completion in 2016 to help address these needs.<br>➢ Additional research into the dune dynamics (e.g., mobilization and transport/flow of sediments) is needed.<br>➢ Further study of evaporation rates is needed to better understand dune moisture and other parameters.<br>➢ An inventory of yardangs (i.e., locations and conditions) and additional LiDAR data collection are both needed in this community. |
| Semidesert Grasslands | ➢ An updated vegetation classification map is needed to accurately document the extent of grasslands in WHSA. A vegetation classification/mapping project is slated for completion in 2016 to help address these needs.<br>➢ The grasslands of WHSA have not been comprehensively surveyed for plant species richness. Additionally, winter grassland bird surveys are needed within park boundaries.<br>➢ Further research is needed into the historical role of fire in the Tularosa Basin. |
| Migratory Birds | ➢ Continued monitoring of the WHSA bird population is needed to establish baseline values for species richness and species diversity.<br>➢ Additional monitoring during the migratory season is needed to accurately assess the current condition of this avian assemblage.<br>➢ Monitoring/inventorying of WHSA's avian species of conservation concern is needed, especially in the isolated cottonwood stands. |
| Breeding Birds | ➢ Continued monitoring of the WHSA bird population is needed to establish baseline values for species richness and species diversity. Trend analysis is needed after 5-10 years of data have been collected.<br>➢ Monitoring/inventorying of WHSA's avian species of conservation concern is needed, especially in the isolated cottonwood stands.asdf |

**Table 42 (continued).** Identified data gaps or needs for the featured components.

| Component | Data gaps/needs |
|---|---|
| Reptiles | ➢ No survey at the park has examined the species diversity of WHSA. A long-term survey of the reptile community in the park is needed to assess the current species diversity of the park.<br>➢ Expansion of past survey efforts is needed to better understand the species richness and diversity of the entire park. Rotenberry et al. (2008) suggests that some species not previously documented may exist within the park.<br>➢ Developing monitoring plans to track roadway mortalities in and outside of the park should be considered to quantify roadway impacts on the reptile communities at WHSA. Additionally, continued study of the unique reptile species in the dune field area, especially those species with unique color morphology and speciation events is recommended. |
| Desert Faunal Community | ➢ A comprehensive survey of the mesocarnivore community in WHSA is needed in order to assess the current condition of this component.<br>➢ Monitoring of the park's important desert scrub community is also needed, as this community supports a wide array of faunal species in the park.<br>➢ Monitoring of the six priority habitat types identified by Robinson et al. (2014) is needed to assess the distribution of mammals in the park. |
| Terrestrial and Aquatic Invertebrates | ➢ Additional, formal invertebrate research is needed in WHSA to ensure that as many species are documented as possible. This is especially important in the park due to the high endemism rates observed in WHSA. |
| Soil Faunal Community | ➢ Monitoring (e.g., annual surveys, species inventories, area searches) is needed to more accurately assess the current condition of this community.<br>➢ Greater study regarding the potential impacts that salinization, contaminants, and other soil-disturbance regimes is needed.<br>➢ Further identification of community members to the species classification level would benefit researchers and park managers. |
| Soundscape and Acoustical Environment | ➢ There is a lack of measured sound data available to assess the effects military operations and flights have on the park's soundscape. Additional monitoring is needed as military sounds are likely to increase in the future.<br>➢ WHSA and the Natural Sounds and Night Skies program recently began monitoring the sonic booms in the area, continued monitoring of this threat is needed. |
| Viewscape | ➢ Incorporation of different and new GIS data sets, such as a higher resolution DEMs, additional or different land cover classes, or updated air quality data will enable accurate and up-to-date viewshed assessments of the metrics examined in this analysis.<br>➢ Establishing photo points throughout the park could provide photographic evidence of the changes in viewshed over time. |

**Table 42 (continued).** Identified data gaps or needs for the featured components.

| Component | Data gaps/needs |
|---|---|
| Surface Water Hydrology | ➢ The source of brines that feed mineral productions is unknown, and insufficient work has been published on the distribution of modern sedimentary facies, the spatial distribution of production of gypsum in the park, or interactions between the hydrologic system and the dunes.<br>➢ There is an overall lack of information regarding the effects of surface water quality on the ecosystems of the park.<br>➢ The relative contributions of groundwater verses surface water into the ephemeral lake/ saline mudflat system are unknown and further chemical analysis sustained through a flooding-evapoconcentration-desiccation cycle is required. This should be accompanied by detailed sedimentological observations and mapping of lake facies.<br>➢ A comprehensive wetland study has not been performed at WHSA.<br>➢ Continued study of Lake Lucero is needed, and study should include the entire ephemeral lake/saline mudflat system that includes Lake Lucero and Alkali flat. Monitoring flooding events, major ions, salinity, pH, alkalinity, water temperature, dissolved oxygen, sediment facies, and perhaps isotopes within the ephemeral lake/saline mudflat system would provide resource managers with information on how the lake is integrated into the dune processes and ground water system. |
| Ground Water Hydrology | ➢ Additional study of the regional deep aquifer system, as well as how this system interacts with the shallow aquifer in the area, is needed.<br>➢ Further study of soil moisture, evaporation rates, and ground water levels are needed in WHSA.<br>➢ Continued research is needed on hydrologic, geologic, and biological factors that control the dune systems. Additional monitoring of groundwater levels in existing wells along with the establishment of additional groundwater monitoring wells would provide a better basis for understanding the mechanics and processes at work within the groundwater systems at WHSA.<br>➢ A systematic study of the saline pan system is needed.<br>➢ Further analysis and refinement of the regional 3-dimentional concept model of the basin's groundwater dynamics and its relationship to the overall eolian system is needed to enable resource managers to develop scenarios of the possible effects that increased demands on groundwater in the basin would have on the groundwater at WHSA.<br>➢ Additional geophysical surveys are needed to better understand the effect that the Jarilla Fault has on the park's groundwater system. |
| Cenozoic Trackways | ➢ Detailed documentation and tracking of the fossil trackways in WHSA is needed.<br>➢ Mapping of trackways at the time of discovery, or immediately following, is needed to document their spatial and surficial distribution. Photographs of these sites are also needed.<br>➢ Various sources have suggested that the park conduct timely track site inventories, site mapping, photo documentation, track replication, specimen collection, site stabilization, site closure, construction of maintenance barriers, and a variety of site monitoring strategies. |

The majority of the park's data needs focus on establishing, or in some instances continuing, annual monitoring efforts. WHSA represents a combination of unique ecological habitats and niches, and a great deal of research is needed to better understand the complex relationships that exist between these habitats and the plant, animal, and hydrological regimes/communities of the park. Many of the data gaps relate to expanding previous monitoring efforts to include broader parameters to determine how species richness may vary depending on habitat type in the park (e.g., mesocarnivores, breeding and migratory birds, and reptiles), or how the component may interact with its ecosystem. With several documented ecological adaptations found in species that inhabit the dune field habitats of the park, particular attention needs to be paid to better document and understand this region; this need is particularly evident for the reptile, aquatic and terrestrial invertebrate, and soil and microbial communities.

Situated in the Chihuahuan Desert, water is a critical resource for many of the biological communities in WHSA. There is a significant need for a better understanding of how the quality of park's limited surface water affects the quality and success of the communities that depend on that water. The biotic communities of WHSA are not the only ones tied to water, however, as the dune fields of WHSA are closely interrelated to the regional water table and deep water aquifer. Further study of the groundwater dynamics in the region is needed; particularly important is further study of soil moisture, evaporation rates, and ground water levels in the park.

With over half of the selected components in this NRCA having substantial data gaps that prevented an assessment of current condition, the establishment and expansion of monitoring efforts for these components will be vital for park managers to gather a better understanding of the current health and condition of these resources.

## 5.2 Component Condition Designations

Table 43 displays the conditions assigned to each resource component presented in Chapter 4 (definitions of condition graphics and examples of how indicator symbols should be interpreted are located in Tables 44 and 45 following Table 43). It is important to remember that the graphics represented are simple symbols for the overall condition and trend assigned to each component. Because the assigned condition of a component (as represented by the symbols in Table 43) 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) for some measures, or even current information. Condition could not be determined for eight of the 13 selected components: dune communities, semidesert grasslands, migratory birds, reptiles, desert faunal communities, terrestrial and aquatic invertebrates, soil faunal communities, and the soundscape and acoustical environment.

For featured components with available data and fewer information gaps, assigned conditions varied. One component is considered in good condition (breeding birds), one component is considered of moderate concern (viewscape), and three components are considered of high concern (surface water hydrology, ground water hydrology, Cenozoic trackways; Table 43). Of the components determined to be of high concern, both of the hydrology-related components exhibited declining trends. The Cenozoic trackways component appears to be stable currently, largely due to the erratic nature of when and where trackways are revealed.

**Table 43.** Summary of current condition and condition trend for featured NRCA components.

| Component | WCS | Condition |
|---|---|---|
| **Biotic Composition** | | |
| *Ecological Communities* | | |
| Dune Communities | n/a | |
| Semidesert Grasslands | n/a | |
| *Birds* | | |
| Migratory Birds | n/a | |
| Breeding Birds | 0.33 | |
| *Herpetofauna* | | |
| Reptiles | n/a | |
| *Mammals* | | |
| Desert Faunal Community | n/a | |
| *Microbiota* | | |
| Terrestrial and Aquatic Invertebrates | n/a | |
| Soil Faunal Community | n/a | |

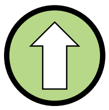
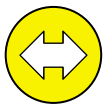
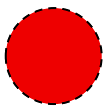
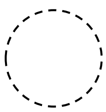
**Table 43 (continued).** Summary of current condition and condition trend for featured NRCA components.

| Component | WCS | Condition |
|---|---|---|
| **Environmental Quality** | | |
| Soundscape and Acoustical Environment | n/a | |
| Viewscape | 0.57 | |
| **Physical Characteristics** | | |
| *Geologic & Hydrologic* | | |
| Surface Water Hydrology | 0.77 | |
| Ground Water Hydrology | 0.67 | |
| Cenozoic Trackways | 0.89 | |

**Table 44.** Description of symbology used for individual component assessments.

| Condition Status | | Trend in Condition | | Confidence in Assessment | |
|---|---|---|---|---|---|
| | Resource is in Good Condition | | Condition is Improving | | High |
| | Resource warrants Moderate Concern | | Condition is Unchanging | | Medium |
| | Resource warrants Significant Concern | | Condition is Deteriorating | | Low |

**Table 45.** Examples of how indicator symbols should be interpreted.

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

## 5.3. Park-wide Condition Observations

Despite the wide variety of habitats, harsh conditions, and unique species that occupy WHSA, many of the resources discussed in this report are interrelated and share similar management concerns that directly and indirectly affected their current condition designation (e.g., data gaps, threats from outside the park, critical communities). The park represents a unique environment in the American Southwest, and the threats/stressors, data needs, and priority habitats of WHSA are critical to park managers in order to fully understand this ecosystem.

### *5.3.1. Need for Additional Research*

The need for further and expanded research in the focal resources discussed in this NRCA is perhaps the most striking observation of this report. As has been stated throughout, WHSA is one of the most unique landscapes in the Western U.S. and is home to ecological processes, formations, and species' adaptations unlike anywhere else on the planet. There are few ecosystems quite like WHSA on the planet, and this is further evidenced by the fact that NASA has used WHSA as a research area that is perhaps analogous to what may be found on Mars.

The need for additional research was expressed in nearly every component of this NRCA (see Tables 42 and 43), and significant data gaps were the primary reason that current condition could not be assessed for eight of the 13 components in this report. Even for components that have had a great deal of research (e.g., reptiles, terrestrial and aquatic invertebrates, hydrologic components), there is still the need for further, expanded efforts in order to fully grasp the complex nature of these resources in the harsh WHSA habitats. Components such as the breeding birds of WHSA, semidesert grasslands, and dune communities all have ongoing research and monitoring efforts and continuation of these will provide park managers with a more accurate picture of what the current condition of these focal resources is. However, long-term monitoring is needed for *all* components in order to assess any trends or shifts in resource condition. This is a common trend for NPS units with small resource management staff sizes and relatively small acreage. Often times there are simply not enough staff hours available to accommodate all of the necessary day-to-day operational needs and the research/data needs of the critical resources. Further complicating this issue is the fact that funding to fill in these research needs and gaps often is difficult to obtain.

#### *5.3.2. Climate Change*

Climate change represents one of the largest and most significant threat and stressor to the priority resources within WHSA. It also represents an area that needs a tremendous amount of research in the future; this will be particularly useful as managers attempt to more fully understand how it may be affecting the priority resources in the WHSA area. In the Chihuahuan Desert, climate is constantly fluctuating on multiple temporal scales, including natural cycles such as the wet monsoon season and El Nino events (when the tropical Pacific Ocean brings wet weather to the desert). There is a scientific consensus that human activities, particularly those that produce greenhouse gases, have contributed to a general warming trend in global climate (IPCC 2007). Current warming has accelerated processes that release greenhouse gases into the atmosphere, further contributing to global warming (Anisimov 2007, Walter et al. 2007).

There has been a consistent, statistically significant, increase in temperature in WHSA since 1930, and major temperature increases have been observed in the park since 1950 (NPS 2016a). The mean annual temperature in WHSA is approximately 15.4°C (59.7°F) (WRCC 2016), and a warming trend of 3-5°F, and a reduction in precipitation of 1-4% annually is expected to occur over the next 50-100 years (NPS 2016a). At larger scales, New Mexico's Agency Technical Working Group (ATWG 2005) estimated that the state's mean temperatures could increase 3.3-6.7°C (6-12°F) by 2100, and Garfin et al. (2010) projected that the Southwestern U.S. could experience an increase in annual temperature of 1.5-3.6°C by 2050 and 2.5-5.4°C by 2100. The model results for projected changes in the amount and timing of precipitation are less clear, but overall the results of climate change modeling appear to show a trend toward an increase in aridity for the southwestern United States (Seager et al. 2007, Garfin et al. 2010).

With water being such a limiting resource in the Chihuahuan Desert, a reduction in precipitation and an increase in drought conditions will have significant impacts on several communities in WHSA. The projected warmer temperatures will accelerate water loss through evapotranspiration, contributing to overall drier conditions and water stress for plants. Long dry periods, especially those accompanied by hot, dry winds, can cause significant perennial grass mortality (NPS 2010). In desert environments, plants are often already stressed by limited water availability, and any change in the amount or timing of precipitation can have a large impact (Munson and Reiser 2013). Further, a loss of vegetative cover may destabilize dunes, particularly the more vegetated parabolic dunes on the downwind side of the field (Bennet and Wilder 2009, NPS 2010). The dunes themselves are also influenced by soil moisture and the depth to groundwater (Kocurek et al. 2007, Scheidt et al. 2010) and could be impacted by shifts in precipitation, particularly if the frequency and duration of droughts increases (KellerLynn 2012). According to Fryberger (2001), a long-term rise or fall in the groundwater table of only a meter would trigger major changes in the dune dynamics at WHSA.

Climate change will also likely impact the timing and amount of surface runoff/recharge into the low-lying areas south and east of the White Sands dune field (ATWG 2005, Spera 2011). If the water table in these areas drops, more sediment will dry up and be available for deflation/transportation into the dune field (Bennet and Wilder 2009, Spera 2011). If this occurs, the overall extent of the dune field may increase (Spera 2011).

The majority of the surface water in WHSA is associated with precipitation events in the mountains to the west of the park, as surface flow from the east and south is restricted by sand dunes and flow from the north is intercepted by small playas or is regulated/restricted by anthropogenic features (Allmendinger 1971, KellerLynn 2003). In general, most surface water runoff is lost to infiltration and evaporation before reaching the park. However, ephemeral surface features and associated groundwater are extremely vulnerable to climate change and drought (Bull 1997). Loss of ephemeral flows due to periods of drought, coupled with the high evaporation rates in the region, would cause a drop in the available surface water in the park. The loss of surface water and high evaporation rates would also negatively impact groundwater recharge, increasing the depth to groundwater and groundwater supplies (McLean 1970); prolonged periods of drought could result in destabilization of the parks dune field (NPS 2010).

Periods of extended drought can have significant impact on the water table level of the shallow aquifer underneath the dune field (NPS 2010). These prolonged periods of drought will also have an effect on the depth to groundwater for the deeper regional aquifer, especially when coupled with greater pumping demands on adjacent lands (NPS 2010). Various portions of the dune field were rapidly formed during short, hyper-arid events (NPS 2010). Prolonged periods of drought could cause a drop in the water table and an associated loss of dune moisture due to evaporation (NPS 2010). This could result in the mobilization of the parabolic interdunes in addition to other areas that are stable under the current conditions (NPS 2010).

#### *5.3.3. Presence of Invasive Plant Species*

The presence of invasive species in WHSA is of high concern to park managers, as their presence directly threatens several of the highlighted resource communities in this NRCA. The invasive salt cedar has become established in several dune areas due to the high water table, particularly in some interdunes, along the dune field edges, and around Lake Lucero (Conrod 2005, KellerLynn 2012). The species is able to tolerate saline groundwater conditions, and its roots can stabilize dune sands, creating pedestals as the surrounding sands are blown away (Bennet and Wilder 2009, KellerLynn 2012). The presence of these pedestals or the plants alone can alter wind patterns, influencing dune patterns and movement (Bennett and Wilder 2009, KellerLynn 2012). In WHSA, salt cedar has the ability to outcompete and replace cottonwoods and other species with similar soil moisture requirements. Ideal conditions for salt cedar infestation are found throughout the park, due to the high groundwater table, especially along the dune field edges and around Lake Lucero, Alkali Flats (ephemeral lake/saline mudflat system), and Lost River. Removing or controlling the species is difficult at WHSA, due to the remote, roadless nature of much of the park and the dispersed distribution of the plants (Conrod 2005).

Salt cedar is not the only invasive plant species currently causing issues in WHSA, as the desert grassland and desert scrub habitats are also dealing with the presence of invasives. Since the mid- to late 1800s, many southwestern grasslands have been invaded by desert scrub species such as creosote bush, mesquite, and tarbush (Humphrey 1953, Branscomb 1958, Buffington and Herbel 1965). The invasion appears to coincide with the beginning of livestock ranching in the region (Martin 1975). Scrub/shrub encroachment affects nutrient cycling and habitat structure, which impacts both the plant community and the associated wildlife (NPS 2010). The loss of grasslands has been documented at the Jornada Experimental Range, approximately 30 km (19 mi) southwest of WHSA. Between 1915 and 1946, grassland area on the Jornada mesa decreased 28%, from 25,167 ha (62,189 ac) to 18,076 ha (44,666 ac) (Branscomb 1958). The most likely drivers of shrub invasion are livestock grazing and reduced fire occurrence (Humphrey 1953, Branscomb 1958, Boykin 2008).

In addition to altering the species composition of the native grasslands, invasive species also degrade the overall composition and function of desert grasslands; grassland degradation represents one of the major threats to bird species in WHSA. Species that depend on the Chihuahuan Desert grasslands (including the grasslands of Mexico) are likely to be greatly affected by changes in grassland composition. Over 97% of the native grasslands in the United States have been lost, primarily due to land conversion to agricultural fields (NABCI 2011). In the Chihuahuan Desert alone, more than one million acres of grasslands have been converted to agricultural lands in the last 5 years (NABCI 2009). Drought conditions, desertification, and overgrazing of ranch lands all contribute to the degradation of grasslands in the Chihuahuan Desert. As mentioned previously, the Chihuahuan Desert grasslands are expected to become drier due to higher temperatures and lower precipitation levels (NABCI 2010); the loss of a continuous grassland habitat across WHSA and the Chihuahuan Desert could greatly influence the breeding success and population size of the park's grassland bird species.

#### 5.3.4. Anthropogenic Threats

The roads in the WHSA area (primarily U.S. Highway 70 and Dunes Drive) pose threats to the various ecological communities in WHSA in several ways. While reptiles are affected by roads in various ways, the most common threat posed to this community by roadways is direct mortality (Ehmann and Cogger 1985, Kline and Swann 1998, Seigal and Pilgrim 2002, Jochimsen et al. 2004). Past surveys of reptiles in the park have documented high numbers of reptiles near the entrance to the park, and McKeever (2009b) documented snake mortality to be highest along Highway 70. Vehicle strikes are not limited to reptiles, however, as many bird and mammal species are also affected. Forman and Alexander (1998, p. 212) state that "Sometime during the last three decades, roads with vehicles probably overtook hunting as the leading direct human cause of vertebrate mortality on land." Highway 70 passes through fourwing saltbrush shrublands along the southeastern boundary of WHSA; this habitat type is highly utilized by the mesocarnivore and lagomorph communities of the park. Vehicle strikes of foxes, coyotes, small rodents, greater roadrunners, and rabbits along this corridor is certainly a threat to these communities.

Direct mortality is not the only consequence of traffic along these roads, as it also has several indirect impacts on several resources in the area. Passing vehicles detrimentally affect the park's natural soundscape by contributing non-natural sounds to the area at nearly all hours of the day. While Dunes Drive has a much lower daily traffic load and a lower speed limit than Highway 70, the cars that traverse this road also contribute to noise pollution. Nighttime traffic, specifically the headlights of passing vehicles, contributes to slightly lower dark night skies conditions in the area. Further, the very presence of the roads in the area detrimentally affects the park's viewshed, as these features are considered 'non-natural'. Higher traffic counts are likely to occur during peak visitor season, which is June and July (Begly et al. 2013). These are also the months with the highest temperatures (NCDC 2015). High temperatures can lead to increased dust on the roads and with air pollution from traffic, the potential for the particulate matter to be moved around increases.

Fragmentation in landscapes, often the result of roadways or other human-created structures, is also a common threat in the WHSA area. Roads often serve as a boundary between habitat types, and can sometimes separate breeding areas from foraging areas (Palta 1997) or serve as a boundary between what is normally a continuous habitat. Furthermore, certain species (e.g., snakes, roadrunners, small to mid-sized mammals) may use roads as corridors for movement. This behavior not only increases the risk of vehicular strike, but also may allow for a corridor for invasive species establishment. The fragmentation of landscapes by roads is thought to have altered the distribution patterns in reptiles (a priority community in WHSA), lowered the recolonization rates, and increased extinction rates in local reptile populations (Rudolph et al. 1998, Vos and Chardon 1998). With several endemic reptile and invertebrate species in WHSA, this is a threat that should be monitored in the future.

#### *5.3.5. Military-Related Impacts*

WHSA is surrounded by military neighbors, with WSMR bordering much of the park and sharing the Zone of Cooperative Use in the northwest portion of the park in Alkali Flats. The park has a strong working relationship with the military, but there is an increased risk to the park's natural resources with WHSA being situated in such close proximity to military operations. The many flights and air traffic originating from HAFB (including sonic booms), combined with noise and vibration from low flying aircraft (e.g., helicopters conducting UXO recovery efforts), pose threats to the park's soundscapes and dark night skies. Additionally, the development of the HAFB and surrounding facilities are a detriment to the natural viewscape of the area.

Risk to the park's surface water from the associated military operations include: introduction of contaminants from UXO and missile/rocket parts, introduction of contaminants from aircraft incidents (crashes), impacts to the hydrological system through engineering or construction along the alluvial fans, and groundwater contamination from point source pollution on the military base entering the park through groundwater plume migration or surface runoff. Resource managers at WHSA report that over 300 incidents concerning UXO or aircraft have occurred within the park since the military started operations. Contaminants in surface water or groundwater could represent a risk to the health of park visitors and wildlife (WHSA 1992). Natural resource managers at WHSA have expressed concerns over the potential threat of contamination to the parks surface water and groundwater resources from hazardous materials used and stored on the adjacent military lands. Several potential contaminants, including VOCs, fuels, PCBs, dioxins, nitrates, heavy metals, radioactive compounds, and pesticides, are stored at over 50 hazardous waste sites on WSMR and HAFB (WHSA 1992, USGS 2000, KellerLynn 2007).

Contaminants are also a threat to the soil faunal community in WHSA. In particular, debris and fuels left behind following incidences originating from the nearby military operations are a contamination concern. Testing of missiles and rockets occurs within close proximity to WHSA and represent a point source of contamination for metals, solvents, and explosives, many of which are hazardous and toxic to all living organisms in the park (Bricka et al. 1994). Heavy metals are a particularly persistent material that tends to linger until physically removed or immobilized (Bricka et al. 1994). The most common removal practice for soils contaminated with heavy metals is to “dig and haul” since they are considered permanent and immutable once soil has been contaminated (Bricka et al. 1994).

#### *5.3.6. Water Demands in the WHSA Region*

WHSA is located in close proximity to several localities (i.e., Alamogordo, Tularosa, La Luz and several smaller communities along with the military installations of WSMR and HAFB) that depend on the limited surface water and groundwater features for their drinking water supplies (Bourret 2015). When demands for water increase, so too does groundwater pumping efforts for drinking water (Bourret 2015). Alamogordo’s current water rights rely heavily on surface water resources for municipal use, and leave the city vulnerable to water shortages during periods of drought or low surface water. Because of this, the city is in the process of developing a well field and desalinization plant to decrease its reliance on surface water (Bourret 2015). The pumping from this well and other nearby wells could increase the city’s ground water use by 1,110 hectare–meter/year (9,000 acre–feet/year) (JS&A and L&A 2005). This pumping represents a threat to the regional ground water system, as projections estimate that the increase in groundwater pumping represents nearly 10% of the annual recharge in the eastern portion of the Tularosa Basin (Mamer et al. 2014). Other cities and entities in the WHSA region have similar plans for increased ground water pumping, and the construction and utilization of these pumps and desalinization plants will have impacts on the already over-drafted groundwater system of the WHSA area.

Resource managers at WHSA are concerned that the predicted changes to the regional climate due to climate change coupled with the expected increased pumping pressure on groundwater resources for drinking water supplies will have an adverse effect on the shallow aquifer that supports the dune field (NPS 2010, Bourret 2015). Park staff are actively facilitating and participating in research aimed at gaining a better understanding of the geologic, hydrologic, and biological factors that control the dune system (e.g., Fryberger 2001, Kocurek et al. 2007, Newton and Allen 2014). A recent research effort constructed a three-dimensional, finite difference, hydrologic model of the Tularosa Basin for the purpose of estimating the impact on the regional groundwater system that would result from the projected increased pumping demands (Bourret 2015). The model conservatively predicted that increased groundwater pumping would result in a lowering of the regional groundwater table in the vicinity of WHSA of up to 1.5 m (approximately 5 ft) (Bourret 2015). The lowering of the water table at WHSA is an indirect response to the predicted change in the balance between groundwater recharge and extraction on the eastern side of the Tularosa Basin creating an altered, steady-state, regional water balance (Bourret 2015).

#### *5.3.7. Overall Conclusions*

WHSA represents one of the most ecologically diverse and scientifically important areas in the Chihuahuan Desert. Several park-wide threats and stressors are certainly present in the park, and the threat of climate change still looms; however, until additional and expanded research efforts are initiated, a complete understanding of the health of the priority resources in the park cannot be determined. The scientific significance of the dune fields, particularly how they interact with the water table, how they may be influencing species' adaptations or even speciation events, and how they form and migrate across the Tularosa Basin, cannot be emphasized enough. Management efforts to increase monitoring in the park will allow for park managers to obtain a better current understanding of the many unique resources in the park. Continuing advancements in the scientific understanding of WHSA's resources will not only provide park managers with an estimate of current condition, but it will also help to inform the scientific community on the intricate inner-workings of this ecologically unique area.

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# Appendix A. Plant species list for the White Sands dune communities, according to Emerson (1935).

The far right column indicates those species included on the current WHSA certified species list (NPS 2015). Some scientific and common names were updated to match USDA (http://plants.usda.gov/java/) and/or ITIS (http://www.itis.gov/) nomenclature. Species in bold have the ability to grow upward through encroaching sand dunes (Emerson 1935).

| Scientific Name | Common Name | NPS (2015) |
|---|---|---|
| ***Ephedra torreyana*** | **Torrey's jointfir** | X |
| *Schizachyrium scoparium* | little bluestem | X |
| *Aristida adscensionis* | sixweeks threeawn | X |
| *Muhlenbergia pungens* | sandhill muhly | X |
| *Achnatherum hymenoides* | Indian ricegrass | X |
| *Sporobolus giganteus* | giant dropseed | X |
| *Muhlenbergia arenacea* | ear muhly | X |
| *Sporobolus asperifolius* | scratchgrass | X |
| *Sporobolus airoides* | alkali sacaton | X |
| *Sporobolus nealleyi* | gyp dropseed | X |
| *Sporobolus flexuosus* | mesa dropseed | X |
| *Bouteloua barbata* | sixweeks grama | X |
| *Bouteloua breviseta* | gypsum grama | X |
| *Distichlis spicata* | saltgrass | X |
| *Juncus mexicanus* | Mexican rush | X |
| ***Yucca elata*** | **soaptree yucca** | X |
| ***Populus deltoides* ssp. *wislizeni*** | **Rio Grande cottonwood** | X |
| *Salix nigra** | black willow | - |
| *Suaeda suffrutescens* | desert seepweed | X |
| *Suaeda moquinii* | Torrey’s seepweed; Mojave seablite | X |
| *Allenrolfea occidentalis* | iodinebush; pickleweed | X |
| ***Atriplex canescens*** | **fourwing saltbush** | X |
| *Abronia angustifolia* | purple sand verbena | X |
| *Selinocarpus lanceolatus* | lanceleaf moonpod | X |
| *Nerisyrenia linearifolia* | White Sands fanmustard | X |
| *Chamaesyce serrula* | sawtooth sandmat | X |
| ***Rhus trilobata*** | **skunkbush sumac** | X |
| *Sphaeralcea arenaria* | globemallow | X |

*This was likely *Salix gooddingii*, as *S. gooddingii* is on the current WHSA certified species list and has sometimes been considered a variety of *S. nigra*.

| Scientific Name | Common Name | NPS (2015) |
|---|---|---|
| *Sphaeralcea angustifolia* | copper globemallow | X |
| *Sphaeralcea incana* | gray globemallow | X |
| *Malvella lepidota* | scurfymallow | X |
| *Frankenia jamesii* | James' seaheath | X |
| *Mentzelia pumila* var. *pumila* | dwarf mentzelia; golden blazingstar | X |
| *Mentzelia multiflora* var. *integra* | Adonis blazingstar | X |
| *Echinocereus triglochidiatus* | kingcup cactus; claretcup hedgehog | X |
| *Calylophus hartwegii* | Hartweg's sundrops | X |
| *Oenothera pallida* ssp. *gypsophila* | whitepole evening primrose | X |
| *Centaurium texense* | Lady Bird's centaury | X |
| *Eustoma exaltatum* ssp. *russellianum* | showy prairie gentain | X |
| *Asclepias arenaria* | sand milkweed | X |
| *Ipomoea purpurea* | tall morning-glory | X |
| *Ipomopsis pumila* | dwarf ipomopsis | X |
| *Phacelia crenulata* var. *corrugata* | cleftleaf wildheliotrope | X |
| *Tiquilia hispidissima* | hairy crinklemat | X |
| *Phyla nodiflora* | turkey tangle frogfruit | X |
| ***Poliomintha incana*** | **frosted mint; hoary rosemarymint** | X |
| *Lycium berlandieri* var. *parviflorum* | Berlandier's wolfberry | X |
| *Cucurbita foetidissima* | Missouri gourd | X |
| *Acourtia nana* | dwarf desertpeony | X |
| *Chrysothamnus pulchellus* | southwestern rabbitbrush | X |
| ***Ericameria nauseosa*** | **rubber rabbitbrush** | X |
| *Machaeranthera pinnatifida* ssp. *pinnatifida* | lacy tansyaster | X |
| *Isocoma pluriflora* | southern goldenbush; jimmyweed | X |
| *Machaeranthera parviflora* | smallflower tansyaster | X |
| *Machaeranthera canescens* | hoary tansyaster | X |
| *Dicranocarpus parviflorus* | pitchfork | X |
| *Zinnia grandiflora* | Rocky Mountain zinnia | X |
| *Thelesperma megapotamicum* | greenthread | X |
| *Psilostrophe tagetina* | wooly paperflower | X |
| *Clappia suaedifolia* | fleshy clapdaisy | X |
| *Hymenopappus filifolius* var. *cinereus* | fineleaf hymenopappus | X |
| *Sartwellia flaveriae* | threadleaf glowwort | X |

# Appendix B. Difference maps for five different areas within the WHSA dune field, based on June 2007 and 2008 LiDAR imagery (Kocurek et al. 2012).

Note that red represents areas of deposition (e.g., dune building) and blue represents areas of erosion. The location of each mapped area within the dune field study area is shown in Figure 12 (Chapter 4.1).

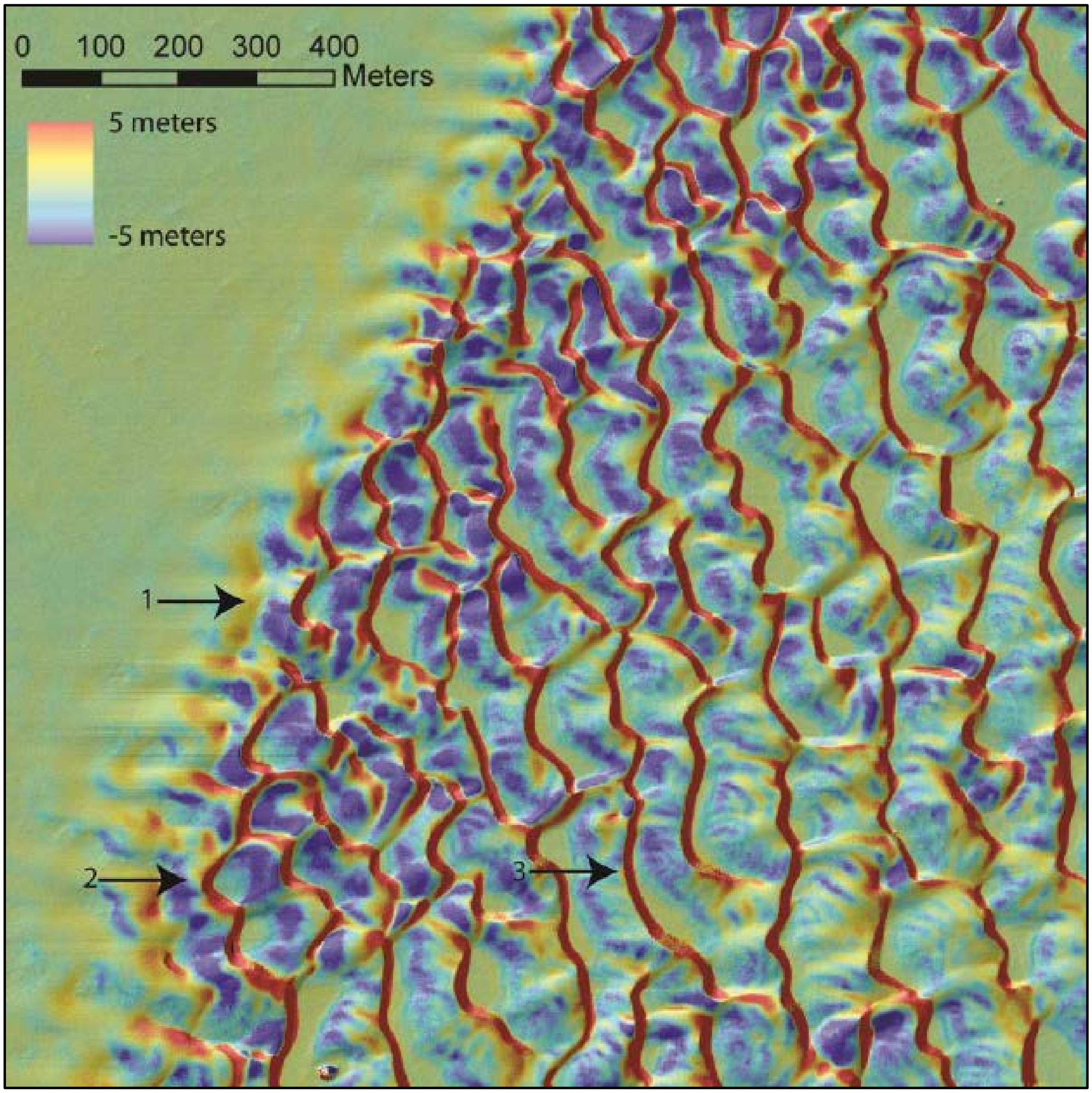


**Figure B-1.** Difference map for the upwind edge of the dune field (the “Figure 12” box in the full difference map). Arrow 1 shows initial vertical growth of dunes. Arrow 2 shows more well-defined dunes with erosion on the upwind (stoss) side and deposition on the downwind (lee) side. Arrow 3 shows more well-defined dunes (reproduced from Kocurek et al. 2012).

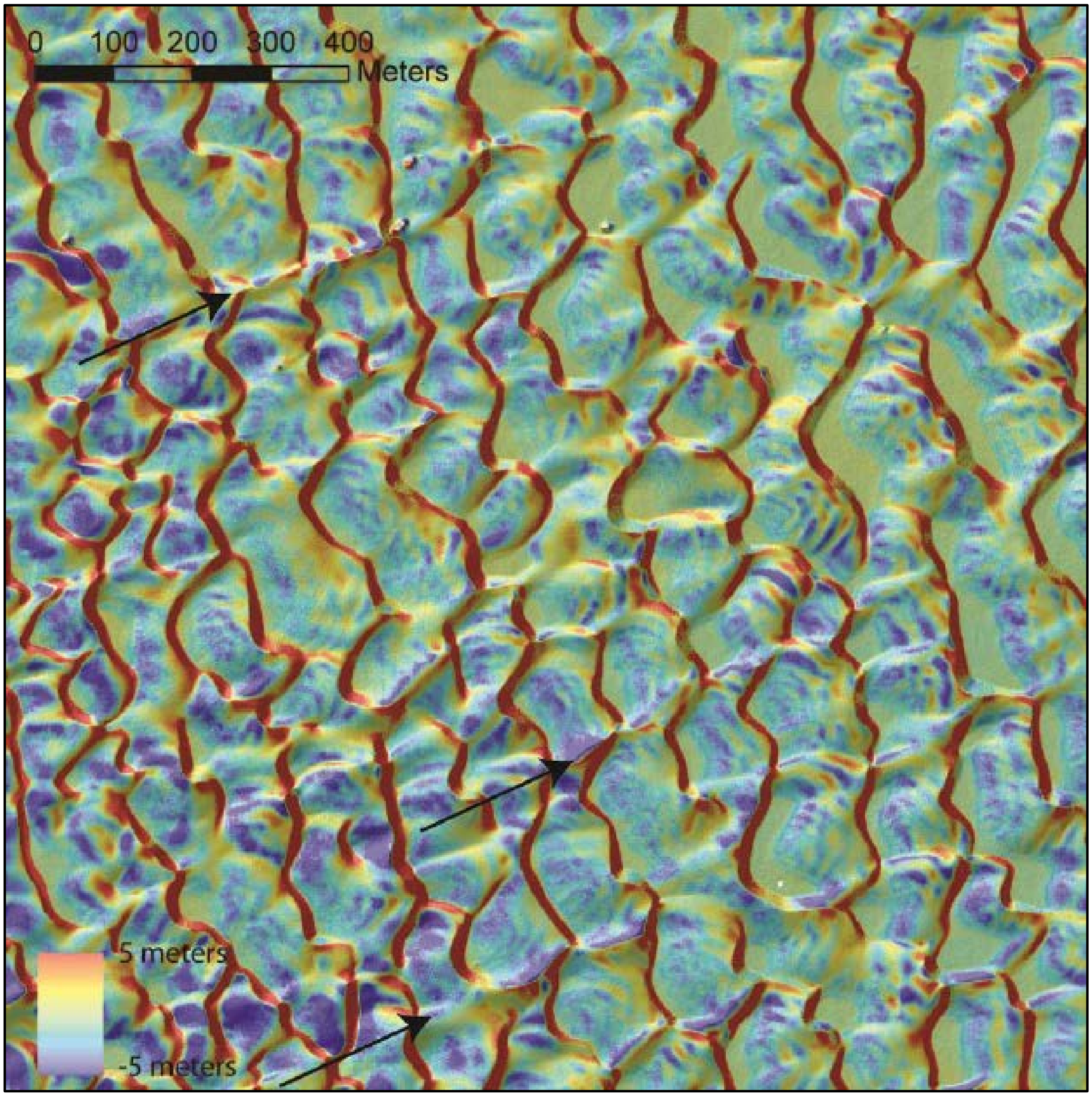


**Figure B-2.** Difference map for an area near the upwind edge of the WHSA dune field ("Figure 13" in full map) showing closely spaced dunes and minimal interdune areas. Arrows highlight areas that show southward migration as a result of northern winter winds (reproduced from Kocurek et al. 2012).

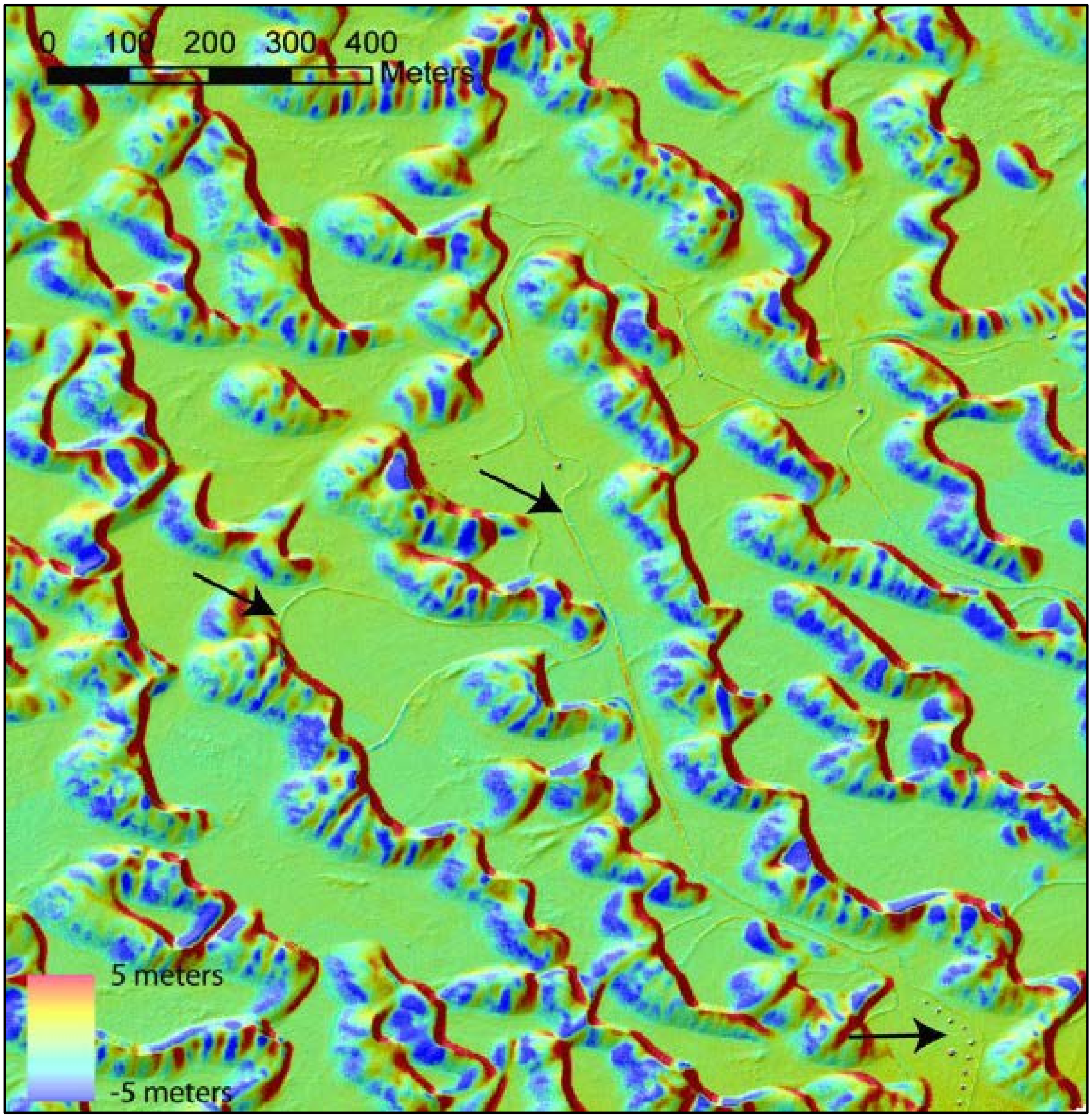


**Figure B-3.** Difference map showing widely spaced dunes and broad interdune areas towards the middle of the WHSA dune field ("Figure 14" in full map). Arrows point out picnic structures (lower right) and roads that are kept clear of sand by park maintenance crews (reproduced from Kocurek et al. 2012).

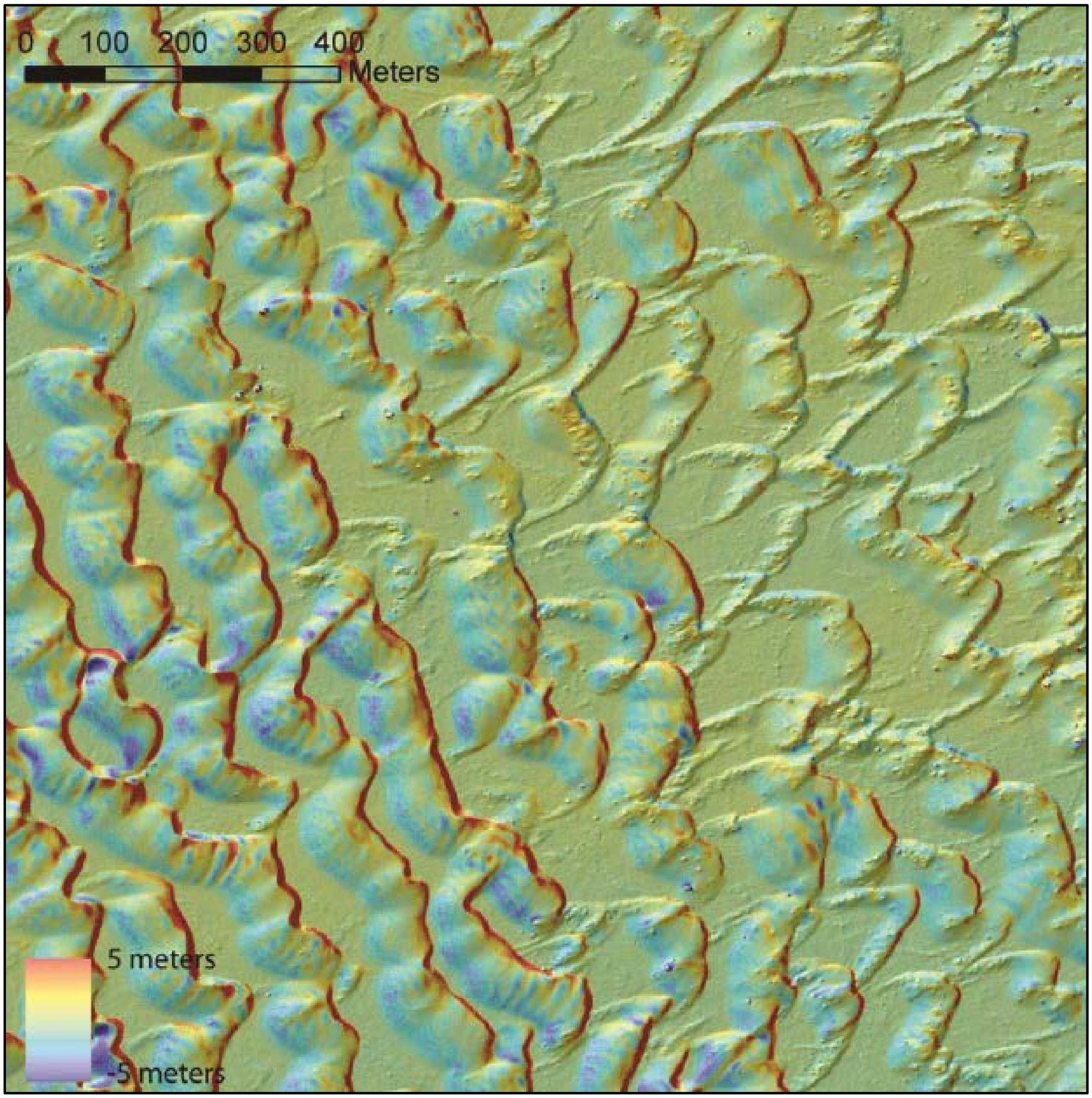


**Figure B-4.** Difference map showing the downwind area of the WHSA dune field where dunes transition from crescentic to parabolic ("Figure 15" in full map). Note the decrease in dune activity (i.e., less color) in the parabolic dune area on the right (reproduced from Kocurek et al. 2012).

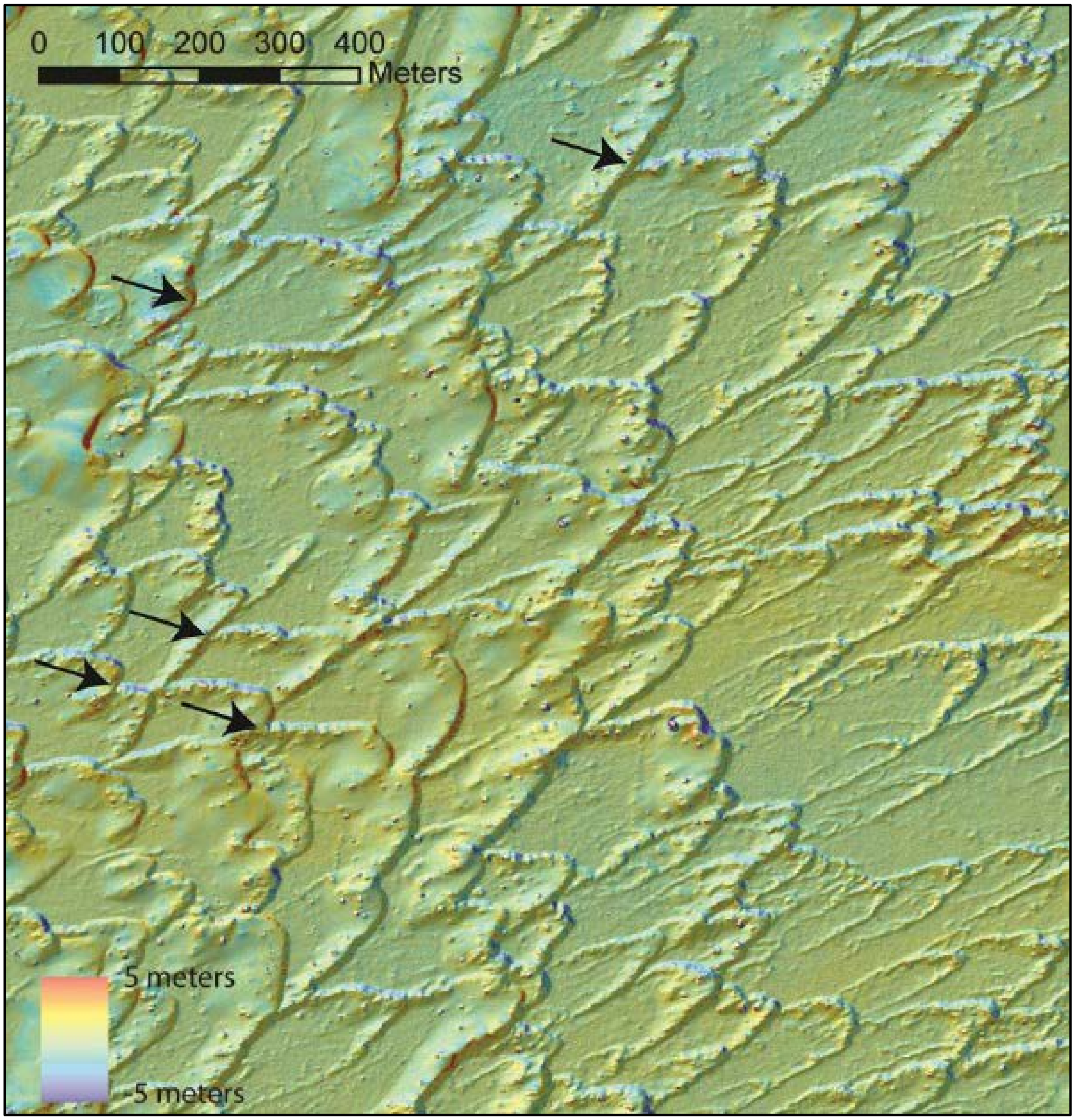


**Figure B-5.** Difference map of parabolic dunes in the eastern part of the dune field ("Figure 16" box), showing little activity relative to previous maps. Arrows highlight areas where the south dune arm is migrating over the northern arm of an adjacent dune (reproduced from Kocurek et al. 2012).

# Appendix C. Plant species documented during CHDN upland vegetation monitoring in areas identified as semidesert grassland by Muldavin et al. (2000b).

| Scientific Name | Common Name |
|---|---|
| *Allionia incarnata* | trailing windmills |
| *Comandra umbellata* | bastard toadflax |
| *Cryptantha fulvocanescens* | tawny cryptantha |
| *Hymenopappus filifolius* | fineleaf hymenopappus |
| *Machaeranthera pinnatifida* (*Xanthisma spinulosum*) | lacy tansyaster, spiny goldenweed |
| *Mentzelia multiflora* | Adonis blazingstar |
| *Nama carnosa* | sand fiddleleaf |
| *Nerisyrenia linearifolia* | White Sands fanmustard |
| *Oenothera pallida* | pale evening primrose |
| *Phacelia* sp. | phacelia |
| *Psilostrophe tagetina* | woolly paperflower |
| *Salsola kali** | Russian thistle |
| *Sartwellia flaveriae* | threadleaf glowwort |
| *Thelesperma megapotamicum* | Hopi tea greenthread |
| *Achnatherum hymenoides* | Indian rice grass |
| *Bouteloua hirsuta* | hairy grama |
| *Muhlenbergia porteri* | bush muhly |
| *Muhlenbergia torreyi* | ring muhly |
| *Schizachyrium scoparium* | little bluestem |
| *Sporobolus airoides* | alkali sacaton |
| *Sporobolus contractus* | spike dropseed |
| *Sporobolus flexuosus* | mesa dropseed |
| *Sporobolus nealleyi* | gyp dropseed |
| *Lepidium* sp. | pepperweed |
| *Mentzelia* sp. | blazingstar |
| *Artemisia filifolia* | sand sagebrush |
| *Atriplex canescens* | fourwing saltbush |
| *Chrysothamnus pulchellus* (*Lorandersonia pulchella*) | southwestern rabbitbrush |
| *Ephedra torreyana* | Torrey's jointfir |
| *Ericameria nauseosa* | rubber rabbitbrush |
| *Frankenia jamesii* | James' seaheath |
| *Koeberlinia spinosa* | crown of thorns |

*Exotic species

| Scientific Name | Common Name |
|---|---|
| *Lycium berlandieri* | Berlandier’s wolfberry |
| *Poliomintha incana* | frosted mint |
| *Acleisanthes lanceolata* | lanceleaf moonpod |
| *Oenothera hartwegii* ssp. *hartwegii* (*Calylophus hartwegii*) | Hartweg's sundrops |
| *Gutierrezia microcephala* | threadleaf snakeweed |
| *Gutierrezia sarothrae* | broom snakeweed |
| *Isocoma pluriflora* | southern goldenbush |
| *Porophyllum scoparium* | Trans-Pecos poreleaf |
| *Pseudoclappia arenaria* | Trans-Pecos false clapdaisy |
| *Psorothamnus scoparius* | broom dalea |
| *Senecio riddellii* | Riddell's ragwort |
| *Senecio spartioides* | broom-like ragwort |
| *Sphaeralcea angustifolia* | copper globemallow |
| *Sphaeralcea hastulata* | spear globemallow |
| *Tiquilia hispidissima* | hairy crinklemat |
| *Coryphantha macromeris* | nipple beehive cactus |
| *Cylindropuntia imbricata* | tree cholla |
| *Cylindropuntia leptocaulis* | Christmas cactus |
| *Echinocereus fendleri* | pinkflower hedgehog cactus |
| *Mammillaria meiacantha* | little nipple cactus |
| *Opuntia* sp. | pricklypear |
| *Opuntia macrocentra* | purple pricklypear |
| *Opuntia phaeacantha* | tulip pricklypear |
| *Yucca elata* | soaptree yucca |
| *Ariocarpus fissuratus* | chautle livingrock |

*Exotic species

# Appendix D. Migratory bird species observed in WHSA from 1935-2013.

V = vagrant

| Species | NPS (2013) | MVAS (1996) | Borell (1937) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| Acorn Woodpecker | V | - | - | - | - | - | - | - | - |
| American avocet | X | X | X | X | - | - | - | - | - |
| American golden-plover | - | X | - | - | - | - | - | - | - |
| American goldfinch | X | - | - | - | - | - | - | - | - |
| American pipit | X | X | X | - | - | - | - | - | - |
| American redstart | X | X | - | - | - | - | - | - | - |
| American robin | X | X | X | X | - | - | - | - | - |
| American tree sparrow | - | - | X | - | - | - | - | - | - |
| American white pelican | - | X | X | - | - | - | - | - | - |
| American wigeon | - | X | X | - | - | - | - | - | - |
| Baird's sandpiper | - | X | - | - | - | - | - | - | - |
| Baird's sparrow | - | X | X | - | - | - | - | - | - |
| bank swallow | - | X | X | - | - | - | - | X | X |
| belted kingfisher | - | X | X | - | - | - | - | - | - |
| black phoebe | X | X | X | - | - | - | - | - | - |
| black tern | - | X | X | - | - | - | - | - | - |
| black-and-white warbler | X | - | - | - | - | - | - | - | - |
| black-bellied plover | - | V | - | - | - | - | - | - | - |
| black-headed grosbeak | X | X | - | X | - | - | - | - | X |
| black-throated blue warbler | X | - | - | - | - | - | - | - | - |
| Bonaparte's gull | - | X | - | - | - | - | - | - | - |
| Brewer's blackbird | X | X | X | X | - | - | - | - | - |
| Brewer's sparrow | X | X | X | X | X | X | - | X | X |

| Species | NPS (2013) | MVAS (1996) | Borell (1937) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| broad-tailed hummingbird | X | X | - | X | - | - | - | X | X |
| bronzed cowbird | X | X | - | X | - | - | - | X | - |
| brown creeper | X | - | - | - | - | - | - | - | - |
| brown thrasher | V | - | - | - | - | - | - | - | - |
| brown-headed cowbird | X | X | X | X | - | X | X | - | X |
| bufflehead | - | X | X | - | - | - | - | - | - |
| California gull | - | X | - | - | - | - | - | - | - |
| Canada goose | - | X | - | - | - | - | - | - | - |
| canvasback | - | X | X | - | - | - | - | - | - |
| Caspian tern | - | V | - | - | - | - | - | - | - |
| Cassin's finch | X | - | - | - | - | - | - | - | - |
| cattle egret | X | X | - | - | - | - | - | - | - |
| cedar waxwing | X | X | X | - | - | - | - | - | - |
| chestnut-collared longspur | X | X | X | X | - | - | - | - | - |
| chestnut-sided warbler | V | - | - | - | - | - | - | - | - |
| chipping sparrow | X | X | X | X | - | X | - | X | X |
| Clark's grebe | - | V | - | - | - | - | - | - | - |
| clay-colored sparrow | X | X | X | X | - | - | - | - | - |
| common goldeneye | - | X | - | - | - | - | - | - | - |
| common grackle | X | - | - | X | - | - | - | - | - |
| common loon | - | X | - | - | - | - | - | - | - |
| common merganser | X | X | X | - | - | - | - | - | - |
| common snipe (Wilson's snipe) | - | X | - | - | - | - | - | - | - |
| common tern | - | V | - | - | - | - | - | - | - |
| common yellowthroat | X | X | X | - | - | - | - | - | - |

| Species | NPS (2013) | MVAS (1996) | Borell (1937) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| Cooper's hawk | X | X | X | - | - | - | - | - | - |
| dark-eyed junco | X | X | X | - | - | - | - | - | - |
| dickcissel | X | X | X | - | - | - | - | - | - |
| double-crested cormorant | - | X | - | - | - | - | - | - | - |
| dunlin | - | V | - | - | - | - | - | - | - |
| dusky flycatcher | X | - | X | X | - | X | - | - | - |
| eared grebe | - | X | X | - | - | - | - | - | - |
| Eurasian wigeon | - | X | - | - | - | - | - | - | - |
| evening grosbeak | X | - | - | - | - | - | - | - | - |
| ferruginous hawk | - | X | X | - | - | - | - | - | - |
| Forster's tern | - | X | - | - | - | - | - | - | - |
| Franklin's gull | X | X | - | - | - | - | - | - | - |
| gadwall | - | X | X | - | - | - | - | - | - |
| gila woodpecker | - | - | V | - | - | - | - | - | - |
| gray-cheeked thrush | V | - | - | - | - | - | - | - | - |
| gray flycatcher | X | - | X | X | - | - | - | - | X |
| gray hawk | - | V | - | - | - | - | - | - | - |
| great egret | - | X | - | - | - | - | - | - | - |
| greater yellowlegs | - | X | X | - | - | - | - | - | - |
| great-tailed grackle | X | X | - | X | - | - | - | - | - |
| green heron | X | X | - | - | - | - | - | - | - |
| green-tailed towhee | X | X | X | X | - | X | - | X | X |
| green-winged teal | - | X | X | - | - | - | - | - | - |
| Harris's sparrow | V | - | - | - | - | - | - | - | - |
| hepatic tanager | X | - | - | - | - | - | - | - | - |

| Species | NPS (2013) | MVAS (1996) | Borell (1937) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| hermit thrush | X | X | X | X | - | - | - | - | X |
| herring gull | - | X | - | - | - | - | - | - | - |
| hooded merganser | - | X | - | - | - | - | - | - | - |
| hooded oriole | V | - | - | - | - | - | - | - | - |
| hooded warbler | V | - | - | - | - | - | - | - | - |
| horned grebe | - | V | - | - | - | - | - | - | - |
| house wren | X | X | X | X | - | - | - | - | - |
| Hudsonian godwit | - | V | - | - | - | - | - | - | - |
| indigo bunting | X | X | - | - | - | - | - | - | - |
| Kentucky warbler | V | - | - | - | - | - | - | - | - |
| lark bunting | X | X | X | - | - | - | - | - | X |
| lark sparrow | X | X | X | X | - | X | X | - | X |
| lazuli bunting | X | - | X | - | - | - | - | - | - |
| least sandpiper | - | X | X | - | - | - | - | - | - |
| least tern | - | V | - | - | - | - | - | - | - |
| lesser goldfinch | X | X | - | X | - | X | X | - | X |
| lesser scaup | - | X | X | - | - | - | - | - | - |
| lesser yellowlegs | - | X | X | - | - | - | - | - | - |
| Lincoln's sparrow | X | X | X | X | - | - | - | - | - |
| little blue heron | - | V | - | - | - | - | - | - | - |
| little gull | - | V | - | - | - | - | - | - | - |
| long-billed curlew | - | X | X | - | - | - | - | - | - |
| long-billed dowitcher | X | X | X | - | - | - | - | - | - |
| MacGillivray's warbler | X | X | X | X | - | X | - | X | X |
| marbled godwit | X | X | X | - | - | - | - | - | - |

| Species | NPS (2013) | MVAS (1996) | Borell (1937) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| marsh wren | - | X | X | - | - | - | - | - | - |
| McCown's longspur | - | X | - | - | - | - | - | - | - |
| merlin | - | X | - | - | - | - | - | - | - |
| mountain plover | - | X | - | - | - | - | - | - | - |
| Nashville warbler | V | - | - | - | - | - | - | - | - |
| Neotropic cormorant | - | X | - | - | - | - | - | - | - |
| northern parula | V | - | - | - | - | - | - | - | - |
| northern pintail | - | X | X | - | - | - | - | - | - |
| northern shoveler | - | X | X | - | - | - | - | - | - |
| northern waterthrush | X | X | - | - | - | - | - | - | - |
| oldsquaw (long-tailed duck) | - | V | - | - | - | - | - | - | - |
| orange-crowned warbler | X | X | X | X | - | - | - | - | - |
| orchard oriole | X | X | - | X | - | - | - | - | - |
| osprey | - | X | - | - | - | - | - | - | - |
| ovenbird | X | - | - | - | - | - | - | - | - |
| palm warbler | - | V | - | - | - | - | - | - | - |
| pectoral sandpiper | - | X | - | - | - | - | - | - | - |
| pine siskin | X | X | - | X | - | - | - | - | - |
| purple martin | - | - | X | - | - | - | - | - | - |
| red knot | - | V | - | - | - | - | - | - | - |
| red phalarope | - | V | - | - | - | - | - | - | - |
| red-breasted merganser | - | X | - | - | - | - | - | - | - |
| red-breasted nuthatch | X | - | - | - | - | - | - | - | - |
| red-eyed vireo | V | - | - | - | - | - | - | - | - |
| redhead | - | X | X | - | - | - | - | - | - |

| Species | NPS (2013) | MVAS (1996) | Borell (1937) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| red-naped sapsucker | X | X | X | X | - | - | - | - | - |
| red-necked phalarope | - | X | - | - | - | - | - | - | - |
| red-winged blackbird | X | X | X | X | - | - | - | - | - |
| ring-billed gull | X | X | X | - | - | - | - | - | - |
| ring-necked duck | - | X | - | - | - | - | - | - | - |
| rose-breasted grosbeak | V | - | - | - | - | - | - | - | - |
| ruby-crowned kinglet | X | X | X | X | - | - | - | - | - |
| ruddy duck | - | X | X | - | - | - | - | - | - |
| ruddy turnstone | - | V | - | - | - | - | - | - | - |
| ruff | - | V | - | - | - | - | - | - | - |
| rufous hummingbird | X | X | - | - | - | - | - | - | - |
| Sabine's gull | - | V | - | - | - | - | - | - | - |
| sage sparrow | X | X | X | - | - | - | - | - | - |
| sage thrasher | X | X | X | X | - | - | - | - | - |
| sanderling | - | V | V | - | - | - | - | - | - |
| sandhill crane | X | X | - | - | - | - | - | - | - |
| savannah sparrow | X | X | X | X | - | - | - | - | - |
| scarlet tanager | V | - | - | - | - | - | - | - | - |
| semipalmated plover | - | V | - | - | - | - | - | - | - |
| semipalmated sandpiper | - | X | - | - | - | - | - | - | - |
| sharp-shinned hawk | X | X | X | X | - | - | - | - | X |
| short-billed dowitcher | - | V | - | - | - | - | - | - | - |
| short-eared owl | - | - | X | - | - | - | - | - | - |
| snow goose | - | X | X | - | - | - | - | - | - |
| snowy egret | X | X | X | - | - | - | - | - | - |

| Species | NPS (2013) | MVAS (1996) | Borell (1937) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| solitary sandpiper | - | X | X | - | - | - | - | - | - |
| solitary vireo | - | X | - | - | - | - | - | - | - |
| song sparrow | X | X | - | - | - | - | - | - | - |
| sora | X | X | X | - | - | - | - | - | - |
| spotted sandpiper | - | X | X | - | - | - | - | - | - |
| Sprague's pipit | - | X | - | - | - | - | - | - | - |
| stilt sandpiper | - | X | - | - | - | - | - | - | - |
| Swainson's thrush | X | - | - | - | - | - | - | - | - |
| swamp sparrow | - | X | - | - | - | - | - | - | - |
| Tennessee warbler | - | X | - | - | - | - | - | - | - |
| Townsend's solitaire | X | - | - | - | - | - | - | - | - |
| Townsend's warbler | X | X | - | - | - | X | - | - | - |
| tree swallow | - | X | X | - | - | - | - | - | - |
| tricolored heron | - | V | - | - | - | - | - | - | - |
| vesper sparrow | X | X | X | X | - | - | - | - | - |
| Virginia's warbler | X | X | - | - | - | - | - | - | - |
| Virginia rail | - | - | X | - | - | - | - | - | - |
| warbling vireo | X | X | - | X | - | - | X | X | X |
| western grebe | - | X | - | - | - | - | - | - | - |
| western palm warbler | - | - | V | - | - | - | - | - | - |
| western sandpiper | X | X | X | - | - | - | - | - | - |
| western tanager | X | X | - | - | - | - | - | - | X |
| whimbrel | - | V | - | - | - | - | - | - | - |
| white-faced ibis | - | X | X | - | - | - | - | - | - |
| white-rumped sandpiper | - | V | V | - | - | - | - | - | - |

| Species | NPS (2013) | MVAS (1996) | Borell (1937) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| white-throated sparrow | X | - | - | - | - | - | - | - | - |
| white-winged scoter | - | V | - | - | - | - | - | - | - |
| willet | - | V | V | - | - | - | - | - | - |
| Williamson's sapsucker | X | - | - | - | - | - | - | - | - |
| Wilson's snipe | - | - | X | - | - | - | - | - | - |
| Wilson's phalarope | - | X | X | - | - | - | - | - | - |
| Wilson's warbler | X | X | X | X | - | X | - | - | X |
| wood duck | - | X | - | - | - | - | - | - | - |
| worm-eating warbler | V | - | - | - | - | - | - | - | - |
| yellow warbler | X | X | X | X | - | - | - | X | - |
| yellow-headed blackbird | X | X | X | X | - | - | - | - | - |
| yellow-rumped warbler | X | X | X | X | - | X | X | X | X |
| **Total Species** | **161** | **228** | **138** | **37** | **14** | **51** | **33** | **37** | **53** |
| **Migratory/Vagrant Species** | **93** | **147** | **83** | **37** | **1** | **11** | **5** | **10** | **18** |
| **% Migratory** | **58** | **64** | **60** | **46** | **7** | **20** | **15** | **27** | **34** |

# Appendix E. Migratory species of conservation concern that have been documented in WHSA. List compiled by Hildy Reiser, CHDN Science Advisor.

IA = immediate action is the recommended conservation action (Rich et al. 2004)

M = continued active management is the recommended conservation action (Rich et al. 2004)

LPR = long-term planning and responsibility is the recommended conservation action (Rich et al. 2004)

T = Threatened, Federal and State listing category (Rich et al. 2004)

DL = Delisted, but being monitored, Federal listing category

Tri-National = Temperate breeders of high tri-national concern (Berlanga et al. 2010)

Steep Decline = % population loss based on BBS or CBC trend since mid 1960s, or on PT score (>50%) if no reliable trend data

SOC = Species of Concern, Federal listing category

| | | USFWS (2008); BCR 35 | Rich et al. (2004) | | Federal/State Listings | | NMDGF (2006) |
|---|---|---|---|---|---|---|---|
| **Common Name** | **Park Status** | **Chihuahuan Desert** | **NA LCP** | **Saving our Shared Birds (SOS)** | **New Mexico Listed** | **Federal Listed** | **Chihuahuan Desert** |
| Baird's sparrow | Documented in Park | X | IA | TRI-NATIONAL | T | SOC | X |
| bank swallow | Historic | - | - | STEEP DECLINE | - | - | X |
| belted kingfisher | Documented in Park | - | - | STEEP DECLINE | - | - | - |
| black tern | Documented in Park | - | - | - | - | SOC | - |
| black-throated blue warbler | Documented in Park | - | - | - | - | - | X |
| Brewer's sparrow | Documented in Park | - | M[A] | STEEP DECLINE[B] | - | - | - |
| brown pelican | Not on NPSpecies | - | - | - | E | - | - |
| Cassin’s finch | Documented in Park | - | - | STEEP DECLINE[B] | - | - | - |
| chestnut-collared longspur | Documented in Park | X | - | TRI-NATIONAL | - | - | - |
| eared grebe | Documented in Park | - | - | - | - | - | X |
| ferruginous hawk | Documented in Park | X | - | - | - | - | X |

A = Stewardship species with > 75% of population found in BCRs 20, 35, and 36

B = species endemic to the Tri-National area (Berlanga et al. 2010).

| Common Name | Park Status | USFWS (2008); BCR 35 | Rich et al. (2004) | | Federal/State Listings | | NMDGF (2006) |
|---|---|---|---|---|---|---|---|
| | | Chihuahuan Desert | NA LCP | Saving our Shared Birds (SOS) | New Mexico Listed | Federal Listed | Chihuahuan Desert |
| green-tailed towhee | Documented in Park | - | LPR[A] | - | - | - | - |
| Harris’s sparrow | Documented in Park | - | - | STEEP DECLINE[B] | - | - | - |
| hooded oriole | Documented in Park | - | - | - | - | - | X |
| lark bunting | Documented in Park | X | - | STEEP DECLINE[B] | - | - | - |
| least tern | Documented in Park | - | - | - | E | E | X |
| long-billed curlew | Documented in Park | X | - | - | - | - | X |
| northern pintail | Documented in Park | - | - | - | - | - | X |
| pine siskin | Documented in Park | - | - | STEEP DECLINE | - | - | - |
| rose-breasted grosbeak | Documented in Park | - | - | STEEP DECLINE | - | - | - |
| rufous hummingbird | Documented in Park | - | - | STEEP DECLINE[B] | - | - | - |
| sage sparrow | Documented in Park | - | - | - | - | - | X |
| sage thrasher | Documented in Park | - | - | - | - | - | X |
| sandhill crane | Documented in Park | - | - | - | - | - | X |
| short-eared owl | Not on NPSpecies | - | - | STEEP DECLINE | - | - | - |
| Virginia’s warbler | Documented in Park | X | LPR | - | - | - | - |
| white-faced ibis | Documented in Park | - | - | - | - | - | X |
| Williamson’s sapsucker | Documented in Park | - | - | - | - | - | X |
| Wilson's phalarope | Documented in Park | - | - | - | - | - | X |
| Wilson's warbler | Documented in Park | - | - | STEEP DECLINE | - | - | - |
| wood thrush | Not on NPSpecies | - | - | TRI-NATIONAL | - | - | - |
| yellow warbler | Documented in Park | X | - | - | - | - | X |
| yellow-headed blackbird | Documented in Park | - | LPR[A] | - | - | - | - |

A = Stewardship species with > 75% of population found in BCRs 20, 35, and 36

B = species endemic to the Tri-National area (Berlanga et al. 2010).

| Common Name | Park Status | USFWS (2008); BCR 35 | Rich et al. (2004) | | Federal/State Listings | | NMDGF (2006) |
|---|---|---|---|---|---|---|---|
| | | Chihuahuan Desert | NA LCP | Saving our Shared Birds (SOS) | New Mexico Listed | Federal Listed | Chihuahuan Desert |
| - | **TOTAL:** | **7** | **5** | **14** | **3** | **3** | **16** |
| - | **IA:** | - | **1** | - | - | - | - |
| - | **M/SS:** | - | **1/1** | - | - | - | - |
| - | **LPR/SS:** | - | **3/2** | - | - | - | - |
| - | **STEEP DECLINE/ ENDEMIC:** | - | - | **11/5** | - | - | - |
| - | **TRI-NATIONAL:** | - | - | **3/0** | - | - | - |

A = Stewardship species with > 75% of population found in BCRs 20, 35, and 36

B = species endemic to the Tri-National area (Berlanga et al. 2010).

# Appendix F. Breeding bird species observed in WHSA from 1935-2013.

| Species | NPS (2013) | MVAS (1996) | Borell (1938) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| American coot | - | X | X | - | - | - | - | - | - |
| American kestrel | - | - | X | X | - | - | - | - | - |
| Ash-throated flycatcher | - | - | X | X | X | X | X | X | X |
| barn owl | - | X | - | - | - | - | - | X | - |
| barn swallow | X | X | X | X | - | X | X | - | X |
| Bell's vireo | - | - | - | - | - | X | - | - | - |
| Bewick's wren | X | X | X | X | - | X | - | - | - |
| black-chinned hummingbird | X | X | - | - | - | X | - | - | - |
| black-crowned night heron | - | X | X | - | - | - | - | - | - |
| black-necked stilt | - | X | X | - | - | - | - | - | - |
| black-tailed gnatcatcher | X | X | - | X | X | X | - | X | - |
| black-throated sparrow | X | X | X | X | X | X | X | X | X |
| blue grosbeak | X | X | X | X | X | X | X | X | X |
| blue-gray gnatcatcher | X | X | X | X | - | - | - | - | - |
| blue-winged teal | - | X | X | - | - | - | - | - | - |
| Bullock's oriole | X | X | X | X | - | - | - | X | X |
| burrowing owl | X | X | - | X | - | - | - | - | X |
| bushtit | - | X | - | - | - | - | - | - | - |
| cactus wren | X | X | X | X | - | X | - | X | X |
| canyon towhee | - | X | - | - | - | - | - | - | - |
| canyon wren | - | - | - | - | - | - | - | X | - |
| Cassin's kingbird | X | X | - | X | - | X | X | X | X |
| Cassin's sparrow | X | X | X | X | X | X | X | - | X |
| Chihuahuan raven | X | X | - | - | X | X | - | X | X |

| Species | NPS (2013) | MVAS (1996) | Borell (1938) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| cinnamon teal | - | X | X | - | - | - | - | - | - |
| cliff swallow | X | X | X | - | - | X | - | - | - |
| common moorhen | - | X | - | - | - | - | - | - | - |
| common nighthawk | - | X | - | - | - | - | X | - | - |
| common poorwill | - | X | - | - | - | - | - | - | X |
| common raven | X | X | - | X | - | - | X | - | - |
| Cordilleran flycatcher | X | X | - | X | - | - | - | - | - |
| crissal thrasher | X | X | X | X | - | X | - | X | X |
| curve-billed thrasher | X | X | - | X | - | X | X | - | X |
| eastern meadowlark | X | X | - | - | - | X | X | X | X |
| Eurasian collared-dove | X | - | - | X | - | - | - | - | - |
| European starling | X | X | - | X | - | - | - | - | - |
| Gambel's quail | X | X | - | X | - | X | X | X | X |
| golden eagle | X | X | X | - | - | - | - | - | - |
| great blue heron | - | X | X | - | - | - | - | - | - |
| great horned owl | X | X | X | - | - | - | - | - | - |
| greater roadrunner | X | X | X | X | - | X | X | - | X |
| hairy woodpecker | - | X | - | - | - | - | - | - | - |
| Harris's hawk | - | X | - | - | - | - | - | - | - |
| horned lark | X | X | X | - | - | X | X | X | X |
| house finch | X | X | X | X | - | X | X | X | X |
| house sparrow | X | X | X | X | - | - | - | - | - |
| Inca dove | X | - | - | - | - | - | - | - | - |
| killdeer | X | X | X | X | - | - | - | - | - |
| ladder-backed woodpecker | X | X | - | X | - | X | X | X | X |

| Species | NPS (2013) | MVAS (1996) | Borell (1938) | Meyer and Griffin (2011) | White (2011) | White and Valentine-Darby (2012) | White and Valentine-Darby (2013) | White and Valentine-Darby (2014) | Ali and Valentine-Darby (2014) |
|---|---|---|---|---|---|---|---|---|---|
| lesser nighthawk | X | X | X | X | X | X | X | X | X |
| loggerhead shrike | X | X | X | X | - | - | X | X | X |
| long-eared owl | - | X | - | - | - | - | - | - | - |
| Lucy's warbler | X | - | - | - | - | - | - | - | - |
| mallard | - | X | X | - | - | - | - | - | - |
| mountain bluebird | X | X | X | - | - | - | - | - | - |
| mountain chickadee | X | X | - | - | - | - | - | - | - |
| mourning dove | X | X | X | X | X | X | X | X | X |
| northern cardinal | - | - | - | - | - | - | - | - | X |
| northern flicker | X | X | X | X | - | - | - | - | - |
| northern harrier | X | X | X | X | - | - | - | - | - |
| northern mockingbird | X | X | X | X | X | X | X | X | X |
| northern rough-winged swallow | X | X | X | - | - | X | - | - | - |
| olive-sided flycatcher | - | X | - | - | - | - | - | - | - |
| peregrine falcon | - | X | X | - | - | - | - | - | - |
| phainopepla | - | - | - | X | - | X | - | - | - |
| pied-billed grebe | - | X | - | - | - | - | - | - | - |
| prairie falcon | X | X | X | - | - | - | - | - | - |
| pyrrhuloxia | X | X | - | - | X | X | - | - | - |
| red-tailed hawk | X | X | X | - | - | - | - | - | X |
| rock dove | X | X | - | - | - | - | - | - | - |
| rock wren | X | X | X | X | - | X | - | - | - |
| Say's phoebe | X | X | X | X | - | X | X | - | - |
| scaled quail | X | X | X | - | X | - | X | - | X |
| Scott's oriole | X | X | - | X | X | X | X | X | X |

| **Species** | **NPS (2013)** | **MVAS (1996)** | **Borell (1938)** | **Meyer and Griffin (2011)** | **White (2011)** | **White and Valentine-Darby (2012)** | **White and Valentine-Darby (2013)** | **White and Valentine-Darby (2014)** | **Ali and Valentine-Darby (2014)** |
|---|---|---|---|---|---|---|---|---|---|
| short-eared owl | - | - | - | - | - | - | - | - | - |
| snowy plover | X | X | X | - | - | - | - | - | - |
| spotted towhee | X | X | X | - | - | - | - | - | - |
| summer tanager | X | - | X | - | - | X | - | - | - |
| Swainson's hawk | X | X | X | X | - | X | X | - | X |
| turkey vulture | X | X | - | X | - | - | - | - | X |
| verdin | X | X | X | X | X | X | X | X | X |
| violet-green swallow | X | X | X | - | - | X | - | X | X |
| western bluebird | X | X | - | - | - | - | - | - | - |
| western kingbird | X | X | X | X | - | X | X | X | X |
| western meadowlark | X | X | X | - | - | X | - | X | - |
| western scrub jay | - | X | X | - | - | - | - | - | - |
| western wood-pewee | X | X | X | X | - | X | X | X | X |
| white-crowned sparrow | X | X | X | X | - | X | X | - | X |
| white-throated swift | X | X | X | - | - | - | - | - | - |
| white-winged dove | X | X | - | X | - | X | X | X | X |
| willow flycatcher | - | - | X | - | - | - | - | - | - |
| **Total Species** | **156** | **226** | **137** | **81** | **14** | **51** | **33** | **37** | **53** |
| **Breeders** | **63** | **79** | **53** | **42** | **13** | **39** | **28** | **27** | **35** |
| **% of total Breeders** | **40%** | **35%** | **39%** | **52%** | **93%** | **76%** | **85%** | **73%** | **66%** |

# Appendix G. Breeding species of conservation concern that have been documented in WHSA. List compiled by Hildy Reiser, retired CHDN Science Advisor.

IA = immediate action is the recommended conservation action (Rich et al. 2004)

M = continued active management is the recommended conservation action (Rich et al. 2004)

LPR = long-term planning and responsibility is the recommended conservation action (Rich et al. 2004)

T = Threatened, Federal and State listing category (Rich et al. 2004)

DL = Delisted, but being monitored, Federal listing category

Tri-National = Temperate breeders of high tri-national concern (Berlanga et al. 2010)

Steep Decline = % population loss based on BBS or CBC trend since mid 1960s, or on PT score (>50%) if no reliable trend data

SOC = Species of Concern, Federal listing category

| | | USFWS (2008); BCR 35 | Rich et al. (2004) | | Federal/State Listings | | NMDGF (2006) |
|---|---|---|---|---|---|---|---|
| **Common Name** | **Park Status** | **Chihuahuan Desert** | **NA LCP** | **Saving our Shared Birds (SOS)** | **New Mexico Listed** | **Federal Listed** | **Chihuahuan Desert** |
| Bell's vireo | Documented in Park | X | IA | TRI-NATIONAL | T | SOC | X |
| black-chinned sparrow | Documented in Park | X | M[A] | STEEP DECLINE[B] | - | - | - |
| black-tailed gnatcatcher | Documented in Park | - | LPR[A] | - | - | - | - |
| black-throated sparrow | Documented in Park | - | M[A] | - | - | - | - |
| burrowing owl | Documented in Park | X | - | - | - | SOC | X |
| cactus wren | Documented in Park | - | LPR[A] | - | - | - | - |
| canyon towhee | Documented in Park | - | LPR[A] | - | - | - | - |
| Cassin's sparrow | Documented in Park | X | M[A] | - | - | - | - |
| common nighthawk | Documented in Park | - | - | STEEP DECLINE | - | - | - |
| crissal thrasher | Documented in Park | - | LPR[A] | - | - | - | - |
| curve-billed thrasher | Documented in Park | - | LPR[A] | - | - | - | - |
| eastern meadowlark | Documented in Park | - | - | STEEP DECLINE | - | - | - |

A = Stewardship species with > 75% of population found in BCRs 20, 35, and 36

B = species endemic to the Tri-National area (Berlanga et al. 2010).

| Common Name | Park Status | USFWS (2008); BCR 35 | Rich et al. (2004) | | Federal/State Listings | | NMDGF (2006) |
|---|---|---|---|---|---|---|---|
| | | Chihuahuan Desert | NA LCP | Saving our Shared Birds (SOS) | New Mexico Listed | Federal Listed | Chihuahuan Desert |
| Gambel's quail | Documented in Park | - | LPR[A] | - | - | - | - |
| golden eagle | Documented in Park | X | - | - | - | - | X |
| gray vireo | Documented in Park | X | LPR | - | T | - | X |
| horned lark | Documented in Park | - | - | STEEP DECLINE | - | - | - |
| loggerhead shrike | Documented in Park | X | - | STEEP DECLINE[B] | - | - | X |
| Lucy’s warbler | Documented in Park | - | M[A] | - | - | - | X |
| mourning dove | Documented in Park | - | - | - | - | - | X |
| northern flicker | Documented in Park | - | - | STEEP DECLINE | - | - | - |
| northern harrier | Documented in Park | - | - | - | - | - | X |
| olive-sided flycatcher | Documented in Park | - | - | TRI-NATIONAL | - | - | X |
| painted bunting | Documented in Park | X | M | - | - | - | X |
| peregrine falcon | Documented in Park | X | - | - | T | DL | X |
| phainopepla | Documented in Park | - | LPR[A] | - | - | SOC | - |
| pyrrhuloxia | Documented in Park | - | M[A] | - | - | - | - |
| red-headed woodpecker | Documented in Park | - | - | STEEP DECLINE[B] | - | - | X |
| scaled quail | Documented in Park | - | M[A] | - | - | - | X |
| Scott's oriole | Documented in Park | - | LPR[A] | - | - | - | - |
| snowy plover | Documented in Park | X | - | - | - | - | X |
| Swainson's hawk | Documented in Park | - | M | - | - | - | - |
| verdin | Documented in Park | - | M[A] | STEEP DECLINE[B] | - | - | - |
| white-throated swift | Documented in Park | - | M | - | - | - | - |

A = Stewardship species with > 75% of population found in BCRs 20, 35, and 36

B = species endemic to the Tri-National area (Berlanga et al. 2010).

| | | USFWS (2008); BCR 35 | Rich et al. (2004) | | Federal/State Listings | | NMDGF (2006) |
|---|---|---|---|---|---|---|---|
| **Common Name** | **Park Status** | **Chihuahuan Desert** | **NA LCP** | **Saving our Shared Birds (SOS)** | **New Mexico Listed** | **Federal Listed** | **Chihuahuan Desert** |
| **TOTAL:** | | **10** | **20** | **10** | **3** | **1** | **30** |
| **IA:** | | - | **1** | - | - | - | - |
| **M/SS:** | | - | **11/8** | - | - | - | - |
| **LPR/SS:** | | - | **9/8** | - | - | - | - |
| **STEEP DECLINE/ ENDEMIC:** | | - | - | **8/4** | - | - | - |
| **TRI-NATIONAL:** | | - | - | **2** | - | - | - |

A = Stewardship species with > 75% of population found in BCRs 20, 35, and 36

B = species endemic to the Tri-National area (Berlanga et al. 2010).

# Appendix H. Reptile species observed in WHSA during various monitoring efforts from 1943-present.

Note that NPS (2014) represents a checklist and is not the result of an active monitoring project.

X = confirmed

P = probably present

| Scientific Name | Common Names | NPS (2014) | Prival and Goode (2011) | McKeever (2009) | Dixon (1967) | Lewis (1950) | Smith (1943) |
|---|---|---|---|---|---|---|---|
| *Arizona elegans* | painted desert glossy snake | X | X | X | - | X | - |
| *Aspidoscelis exsanguis* | Chihuahuan spotted whiptail | X | - | - | - | - | - |
| *Aspidoscelis gypsi* | little white whiptail | X | X | - | - | - | - |
| *Aspidoscelis inornata* | plains striped whiptail | X | X | X | X | - | X |
| *Aspidoscelis marmorata* | western marbled whiptail | X | X | X | - | - | - |
| *Aspidoscelis neomexicana* | New Mexico whiptail | X | - | X | X | - | X |
| *Cophosaurus texanus* | Chihuahuan greater earless lizard | X | - | - | - | - | - |
| *Crotalus atrox* | western diamond-backed rattlesnake | X | X | X | - | X | - |
| *Crotalus viridis* | green prairie rattlesnake | X | X | X | - | X | - |
| *Crotaphytus collaris* | eastern collared lizard | X | X | X | X | X | - |
| *Diadophis punctatus* | ring-necked snake | - | P | - | - | - | - |
| *Eumeces obsoletus* | great plains skink | - | P | - | - | - | - |
| *Gambelia wislizenii* | long-nosed leopard lizard | X | X | X | - | X | - |
| *Gyalopion canum* | Chihuahuan hook-nosed snake | X | - | X | - | - | - |
| *Heterodon nasicus* | western hog-nosed snake | X | - | X | - | X | - |
| *Holbrookia maculata ruthveni* | bleached earless lizard | X | X | X | X | - | X |
| *Hypsiglena torquata* | Texas nightsnake | X | X | X | - | - | - |
| *Lampropeltis getula* | desert kingsnake | X | X | X | - | X | - |
| *Leptotyphlops humilis* | Trans-Pecos threadsnake | X | X | - | - | - | - |
| *Masticophis flagellum* | western coachwhip | X | X | X | - | X | - |

| Scientific Name | Common Names | NPS (2014) | Prival and Goode (2011) | McKeever (2009) | Dixon (1967) | Lewis (1950) | Smith (1943) |
|---|---|---|---|---|---|---|---|
| *Masticophis taeniatus* | desert striped whipsnake | X | - | - | - | X | - |
| *Phrynosoma cornutum* | Texas horned lizard | X | - | X | - | X | - |
| *Phrynosoma modestum* | round-tailed horned lizard | X | X | X | - | X | - |
| *Pituophis catenifer* | Sonoran gophersnake | X | X | X | - | X | - |
| *Rhinocheilus lecontei* | Texas long-nosed snake | X | X | X | - | X | - |
| *Salvadora hexalepis* | Big Bend patch-nosed snake | X | - | - | - | X | - |
| *Sceloporus cowlesi* | southwestern fence lizard | X | X | X | ? | - | - |
| *Sceloporus magister* | twin-spotted spiny lizard | X | X | X | X | X | - |
| *Sceloporus undulatus* | eastern fence lizard | X | - | - | X | X | X |
| *Sistrurus catenatus* | desert massasauga | X | X | X | - | - | - |
| *Sonora semiannulata* | variable groundsnake | X | - | X | - | - | - |
| *Tantilla hobartsmithi* | Smith's black-headed snake | - | P | - | - | - | - |
| *Tantilla nigriceps* | plains black-headed snake | X | X | X | - | - | - |
| *Terrapene ornata* | desert box turtle | X | X | X | - | X | - |
| *Thamnophis cyrtopsis* | western black-necked gartersnake | X | - | - | - | - | - |
| *Urosaurus ornatus* | Big Bend tree lizard | - | - | - | - | - | - |
| *Uta stansburiana* | common side-blotched lizard | X | X | X | X | X | X |

# Appendix I. All mammalian species observed or suspected to occur in the WHSA area.

P = probably present

N = no longer present.

Bolded species indicate mesocarnivore species.

| Species Name | Common Name | NPS (2015) | Bailey (1913) | Halloran (1946) | USFWS (1965) | Robinson (2013) |
|---|---|---|---|---|---|---|
| *Antilocapra americana* | pronghorn | X | - | - | - | - |
| *Oryx gazella* | gemsbok | X | - | - | - | - |
| *Ovis canadensis nelsoni* | desert bighorn sheep | - | - | - | X | - |
| *Odocoileus hemionus* | mule deer | X | - | - | X | - |
| *Canis latrans* | coyote | X | X | X | X | X |
| *Urocyon cinereoargenteus* | common gray fox | X | - | X | X | - |
| *Vulpes vulpes macroura* | red fox | - | - | X | X | - |
| *Vulpes macrotis* | kit fox | X | X | X | X | X |
| *Lynx rufus* | bobcat | X | - | X | X | X |
| *Puma concolor* | mountain lion | X | - | - | - | X |
| *Conepatus leuconotus* | white-backed hog-nosed skunk | X | - | X | X | - |
| *Mephitis mephitis* | striped skunk | X | - | - | X | - |
| *Mephitis macroura* | hooded skunk | - | - | X | - | - |
| *Spilogale gracilis* | western spotted skunk | P | X | - | X | - |
| *Spilogale gracilis leucoparia* | Rio Grande spotted skunk | - | X | X | - | - |
| *Mustela frenata* | long-tailed weasel | X | X | - | - | - |
| *Taxidea taxus* | American badger | X | X | X | X | X |
| *Bassariscus astutus* | ringtail | X | - | X | X | - |
| *Procyon lotor* | common raccoon | X | X | - | X | - |
| *Nasua narica* | white-nosed coati | - | X | - | - | - |

| Species Name | Common Name | NPS (2015) | Bailey (1913) | Halloran (1946) | USFWS (1965) | Robinson (2013) |
|---|---|---|---|---|---|---|
| *Nyctinomops macrotis* | big free-tailed bat | P | - | - | - | - |
| *Tadarida brasiliensis* | Mexican free-tailed bat | X | - | - | X | - |
| *Antrozous pallidus* | pallid bat | X | - | - | - | - |
| *Corynorhinus townsendii* | Townsend's big-eared bat | P | - | - | X | - |
| *Eptesicus fuscus* | big brown bat | P | - | - | - | - |
| *Lasionycteris noctivagans* | silver-haired bat | P | - | - | - | - |
| *Lasiurus cinereus* | hoary bat | P | - | - | X | - |
| *Myotis californicus* | California myotis | P | - | - | X | - |
| *Myotis ciliolabrum* | western small-footed myotis | P | - | - | X | - |
| *Myotis thysanodes* | fringed myotis | P | - | - | - | - |
| *Myotis velifer* | cave myotis | P | - | - | - | - |
| *Parastrellus hesperus* | western pipistrelle | P | - | - | - | - |
| *Lepus californicus* | black-tailed jackrabbit | X | - | - | X | - |
| *Sylvilagus audubonii* | desert cottontail | X | - | - | X | - |
| *Erethizon dorsatum* | north american porcupine | X | - | - | X | - |
| *Cratogeomys castanops* | yellow-faced pocket gopher | X | - | - | - | - |
| *Geomys arenarius* | desert pocket gopher | X | - | - | - | - |
| *Thomomys bottae* | Botta's pocket gopher | X | - | - | - | - |
| *Thomomys umbrinus* | pigmy pocket gopher | - | - | - | X | - |
| *Chaetodipus hispidus* | hispid pocket mouse | P | - | - | - | - |
| *Chaetodipus penicillatus* | Sonoran Desert pocket mouse | X | - | - | X | - |
| *Dipodomys merriami* | Merriam's kangaroo rat | X | - | - | X | - |
| *Dipodomys ordii* | Ord's kangaroo rat | X | - | - | X | - |
| *Dipodomys spectabilis* | banner-tailed kangaroo rat | P | - | - | X | - |
| *Perognathus flavescens* | plains pocket mouse | X | - | - | - | - |
| *Perognathus flavus* | silky pocket mouse | X | - | - | X | - |
| *Mus musculus* | house mouse | P | - | - | - | - |

| Species Name | Common Name | NPS (2015) | Bailey (1913) | Halloran (1946) | USFWS (1965) | Robinson (2013) |
|---|---|---|---|---|---|---|
| *Neotoma leucodon* | eastern white-throated woodrat | X | - | - | X | - |
| *Neotoma micropus* | southern plains woodrat | X | - | - | - | - |
| *Onychomys arenicola* | Mearns's grasshopper mouse | X | - | - | - | - |
| *Onychomys leucogaster* | northern grasshopper mouse | X | - | - | - | - |
| *Onychomys torridus* | southern grasshopper mouse | - | - | - | X | - |
| *Peromyscus eremicus* | cactus mouse | X | - | - | - | - |
| *Peromyscus leucopus* | white-footed mouse | X | - | - | X | - |
| *Peromyscus maniculatus* | deer mouse | X | - | - | X | - |
| *Peromyscus boylii* | brush mouse | - | - | - | X | - |
| *Peromyscus truei* | pinyon mouse | - | - | - | X | - |
| *Reithrodontomys megalotis* | western harvest mouse | X | - | - | X | - |
| *Sigmodon hispidus* | hispid cotton rat | X | - | - | X | - |
| *Cynomys ludovicianus* | black-tailed prairie dog | N | - | - | - | - |
| *Xerospermophilus spilosoma* | spotted ground squirrel | X | - | - | - | - |
| *Ammospermophilus leucurus* | white-tailed antelope squirrel | - | - | - | X | - |
| *Otospermophilus variegatus grammurus* | rock squirrel | - | - | - | X | - |
| *Notiosorex crawfordi* | Crawford's desert shrew | X | - | - | - | - |

# Appendix J. Mesocarnivore species that occur, or are expected to occur in the WHSA region, as determined by the various checklists and surveys that have occurred in the region.

X = confirmed

P = probably present

| Species Name | Common Name | NPS (2015) | Bailey (1913) | Halloran (1946) | USFWS (1965) | Robinson (2013) |
|---|---|---|---|---|---|---|
| *Canis latrans* | coyote | X | X | X | X | X |
| *Urocyon cinereoargenteus* | common gray fox | X | - | X | X | - |
| *Vulpes vulpes macroura* | red fox | - | - | X | X | - |
| *Vulpes macrotis* | kit fox | X | X | X | X | X |
| *Lynx rufus* | bobcat | X | - | X | X | X |
| *Conepatus leuconotus* | white-backed hog-nosed skunk | X | - | X | X | - |
| *Mephitis mephitis* | striped skunk | X | - | - | X | - |
| *Mephitis macroura* | hooded skunk | - | - | X | - | - |
| *Spilogale gracilis* | western spotted skunk | P | X | - | X | - |
| *Spilogale gracilis leucoparia* | Rio grande spotted skunk | - | X | X | - | - |
| *Mustela frenata* | long-tailed weasel | X | X | - | - | - |
| *Taxidea taxus* | American badger | X | X | X | X | X |
| *Bassariscus astutus* | ringtail | X | - | X | X | - |
| *Procyon lotor* | common raccoon | X | X | - | X | - |
| *Nasua narica* | white-nosed coati | - | X | - | - | - |

# Appendix K. Insects collected at WHSA (Stroud 1950).

| Order/Family | Species Name |
|---|---|
| **Orthoptera** | - |
| Locustidae | *Aeoloplides elegans* |
| Locustidae | *Anconia hebardi* |
| Locustidae | *Aulocara elliotti* |
| Locustidae | *Bootettix argentatus* |
| Locustidae | *Cibolacris parviceps arida* |
| Locustidae | *Cordillacris occipitalis cinerea* |
| Locustidae | *Derotmena haydeni laticinctum* |
| Locustidae | *Eremiacris acris* |
| Locustidae | *E. virgata* |
| Locustidae | *Goniatron planum* |
| Locustidae | *Melanoplus bowditchi* |
| Locustidae | *Paropomala wyomingensis* |
| Locustidae | *Pedioscirtetes maculipennis* |
| Locustidae | *Psoloessa d. delicatula* |
| Locustidae | *Schistocerca lineata* |
| Locustidae | *Spharagemon collare* |
| Locustidae | *Trimerotropis citrina* |
| Locustidae | *T. p. pallidipennis* |
| Locustidae | *T. Pistrinaria* |
| Locustidae | *T. strenua* |
| Locustidae | *T. texana* |
| Locustidae | *Xanthippus c. corallipes* |
| Tettigoniidae | *Eremopedes scudderi* |
| Tettigoniidae | *Insara e. elegans* |
| Gryllacrididae | *Ammobaenetes phrixocnemoides* |
| Gryllacrididae | *A. p. arenicolus* |
| Gryllacrididae | *Ceuthophilus n.* sp. |
| Gryllacrididae | *C.* sp. |
| Gryllacrididae | *Daihiniodes hastiferum* |
| Gryllacrididae | *D. h. larvale* |
| Gryllidae | *Acheta assimilis* |
| Blattaria/Corydiidae | *Arenivaga erratica* |
| Blattaria/Corydiidae | *Eremoblatta subdiaphana* |
| Phasimida/Phasmidae | *Diapheromera velii eucnemis* |
| Mantodea/Mantidae | *Stagmomantis californica* |
| Isopetera | - |

| **Order/Family** | **Species Name** |
|---|---|
| Rhinotermitedae | *Reticulitermes tibialis* |
| **Odonata** | - |
| Coenagriidae | *Argia alberta* |
| Coenagriidae | *Enallagma civile* |
| Aeschnidae | *Ischnura barberi* |
| **Hemiptera** | - |
| Cydnidae | *Aeschna multicolor* |
| Pentatomidae | *Chlorochroa sayi* |
| Pentatomidae | *C. ubleri* |
| Pentatomidae | *Murgantia histrionica* |
| Pentatomidae | *Penibalus limbolarius* |
| Pentatomidae | *Frionnosoma podopiodes* |
| Pentatomidae | *Thyanto brevis* |
| Pentatomidae | *T. custator* |
| Pentatomidae | *Zicrona caerulea* |
| Coreidae | *Chariesterus cuspidatus* |
| Coreidae | *Chelinidea* sp. |
| Corizidae | *Leptoglossus clypealis* |
| Corizidae | *Harmostes reflexus* |
| Corizidae | *Mecidea minor* |
| Lygaeidae | *Geocoris pallens* |
| Lygaeidae | *Ligyrocoris nitidula* |
| Lygaeidae | *Liorhyssus hyalinus* |
| Lygaeidae | *Lygaeus kalmii* |
| Lygaeidae | *L. lateralis* |
| Lygaeidae | *Nysius californicus* |
| Lygaeidae | *N. monticola* |
| Lygaeidae | *N. raphanus* |
| Tingidae | *Corythucha morrilla* |
| Nabidae | *Nobis alternatus* |
| Arthocoridae | *Orius latulus* ? |
| Arthocoridae | *O. tristicolor* |
| Miridae | *Chlamydatus* sp. |
| Miridae | *Hadronema* sp. |
| Miridae | *Halticus bractatus* |
| Miridae | *Lygus eli sus* |
| Miridae | *Orthotylus* sp. |
| Miridae | *Polymerus basalis var* |

| **Order/Family** | **Species Name** |
|---|---|
| Miridae | *Phytocoris ramosus* |
| Miridae | *P. vividus* |
| Miridae | *Rhinocloa forticornis* |
| Miridae | *unidentified* |
| Notonectidae | *Notonecta* sp.? |
| Fulgoridae | *Acanatonia parva* |
| Fulgoridae | *Hysteropterum unum* |
| Fulgoridae | *Orgerius foliafus* |
| Delphacidae | *Prokelisia salina* |
| Cixiidae | *Cixius* sp. |
| Cixiidae | Unidentified sp. |
| Cicadidae | *Beameria wheeleri* |
| Cicadidae | *Diceroprocta Yitripennis* |
| Cicadidae | *Tibiceri townsendi* |
| Membracidae | *Centrodontus atlas* |
| Cercopidae | *Clastoptera* |
| Cicadellidae | *Aceratagallia abrupta* |
| Cicadellidae | *Acinopterus* sp. |
| Cicadellidae | *Atahysanella (Gladioneura) concava* |
| Cicadellidae | *Cuerna* sp. |
| Cicadellidae | *Doleramus* sp. |
| Cicadellidae | *Empoasca* sp. |
| Cicadellidae | *Exitianus obscurinervis* |
| Cicadellidae | *Lonatura salsura* |
| Cicadellidae | *Nesosteles* sp. |
| Cicadellidae | *Ollarianus* sp. |
| Cicadellidae | *Opsius stetogalus* |
| Cicadellidae | *Parabolocratus viridis* |
| Cicadellidae | *Paraphlepsius denudatus* |
| Cicadellidae | *Stragania (Penestragania) robusta* |
| Cicadellidae | *Sigara alternata* |
| Aphididae | *Aphis helianthi* |
| Aphididae | *Capitophorus stroudi* |
| **Neuroptera** | - |
| Chrysopidae | *Chrysopa excepta* |
| Chrysopidae | *C. harrisii* |
| Chrysopidae | *C. nigricornis* |
| Chrysopidae | *Chrysopiella sabulosa* |

| Order/Family | Species Name |
|---|---|
| Chrysopidae | *Eremochrysa punctinervis* |
| Myrmeleonidae | *Hesperoleon abdominalis* |
| Myrmeleonidae | *H. minusculus* |
| Myrmeleonidae | *H. tenuis* |
| Myrmeleonidae | *Myrmeleon crudelis* |
| Myrmeleonidae | *Paranthaclisis hageni* |
| Myrmeleonidae | *Puren inscriptus* |
| Myrmeleonidae | *Scotoleon longipalpus* |
| **Lepidoptera** | - |
| Coleophoridae | Unidentified sp. |
| Prodoxidae | *Tegeticula alba* |
| Euchromiidae | *Ctenucha venosa* |
| Noctuidae | *Bulia deducta* |
| Noctuidae | *B. d. fm. yulpina* |
| Noctuidae | *Ercbus odora* |
| Sphingidae | *Celerio lineata* |
| Sphingidae | *Pachysphinx modesta imperator* |
| Sphingidae | *Phlegethontius quinquemaculata* |
| Hesperiidae | *Hesperia neskei* |
| Hesperiidae | *Pyrgus communis* |
| Hesperiidae | *Papilio bairdii* |
| Hesperiidae | *Colias eu rytheme fm. amphidosa* |
| Hesperiidae | *Eurema nicippe* |
| Hesperiidae | *Pieris protodice* |
| Danaidae | *Danaus berenice strigosa* |
| Nymphalidae | *Euptoieta claudia* |
| Nymphalidae | *Phyciodes picta* |
| Lycaenidae | *Hemiargus isola* |
| Lycaenidae | *Leptotes marina* |
| Lycaenidae | *Strymon melinus* |
| **Coleoptera** | - |
| Cicindelidae | *Cicindela chihuahuae* |
| Cicindelidae | *C.knausi* |
| Cicindelidae | *C. lemniscata* |
| Cicindelidae | *C. lepida* |
| Cicindelidae | *C. praetextata* |
| Cicindelidae | *C. togata* |
| Carabidae | *Bembidion bifossulatum* |

| Order/Family | Species Name |
|---|---|
| Carabidae | *B. nr. striola* |
| Carabidae | *Diplochaetus lecontei* |
| Hydrophilidae | *Berosus infuscatus* |
| Hydrophilidae | *Hydrous triangularis* |
| Silphidae | *Necrophorus marginatus* |
| Histeridae | Unidentified sp. |
| Lycidae | *Lycus fernandezi* |
| Melyridae | *Attalus nr. demissus* |
| Melyridae | *Collops limbellus* |
| Melyridae | *C. Yittatus* |
| Melyridae | *Trichochrous* sp. |
| Cleridae | *Cymatodera brunnea* |
| Cleridae | *C.* sp. |
| Cleridae | *Enoclerus abdominalis var. spinolae* |
| Elateridae | *Agrypnus scotti* |
| Elateridae | *Conoderus yespertinus* |
| Elateridae | *Drasterius* sp. |
| Elateridae | *Erthesopus* sp. |
| Elateridae | *Lacon rectangularis* |
| Elateridae | *Melanotus* sp. |
| Elateridae | *Neotrichophorus arizonensis* |
| Elateridae | Unidentified sp. |
| Buprestidae | *Acmacodera delumbris* |
| Buprestidae | *Chrysobothris ulkei* |
| Buprestidae | *Hippomelas planicosta* |
| Dermestidae | *Dermestes marmoratus* |
| Dermestidae | *Trogoderma obsolcscens* |
| Lathridiidae | Unidentified sp. |
| Coccinellidae | *Chilocorus cacti* |
| Coccinellidae | *Hippodamia convergens* |
| Coccinellidae | *H. 5-signata* |
| Coccinellidae | *Hyperaspis nr annexa* |
| Coccinellidae | *H. fimbriolata* |
| Coccinellidae | *H. nr. Gemma* |
| Coccinellidae | *Olla abdominalis* |
| Oedemeridae | *Oxacis sonoria* |
| Oedemeridae | *O.* sp. |
| Oedemeridae | Unidentified sp. |

| Order/Family | Species Name |
| --- | --- |
| Mordellidae | *Anthobates fusculus* |
| Mordellidae | *A. pallens* |
| Mordellidae | *A. pallidus* |
| Mordellidae | *Mordellistena* sp. |
| Meloidae | *Cysteodemus wislizeni* |
| Meloidae | *Epicauta atri-vitiata* |
| Meloidae | *E. funebris* |
| Meloidae | *E. nogales* |
| Meloidae | *E. pardalis* |
| Meloidae | *E. tenella* |
| Meloidae | *E. virgulata* |
| Meloidae | *E.* sp. |
| Meloidae | *Pleuropompha costata* |
| Meloidae | *Pyrota akhurstiana* |
| Meloidae | *P. myabrina* |
| Meloidae | *Zonitis n.* sp. |
| Anthicidae | *Anthicus nr. obliquus* |
| Anthicidae | *A.* sp. |
| Anthicidae | *Mecynotarsus candidus* |
| Anthicidae | *Notoxus apicalis* |
| Anthicidae | *Tanarthrus* sp. |
| Alleculidae | Unidentified sp. |
| Tenebrionidae | *Blapstinus* |
| Tenebrionidae | *nr. Cnemodinus* |
| Tenebrionidae | *Discodemus reticulatus* |
| Tenebrionidae | *Eleodes acuta* |
| Tenebrionidae | *E. caudifera* |
| Tenebrionidae | *E. hispilabris* |
| Tenebrionidae | *E. longicollis* |
| Tenebrionidae | *E. obsoleta* |
| Tenebrionidae | *Embaphion contusum* |
| Tenebrionidae | *Glyptasida sordida* |
| Tenebrionidae | *Metoponium* sp. |
| Tenebrionidae | *Zopherinus* sp. |
| Monommatidae | *Hyporhagus gilensis* |
| Bostrichidae | *Amphicerus bicaudatus* |
| Scarabaeidae | *Aegialia* sp. |
| Scarabaeidae | *Coenonycha* sp. |

| Order/Family | Species Name |
|---|---|
| Scarabaeidae | *Cotinis texana* |
| Scarabaeidae | *Dichromina dimidiata* |
| Scarabaeidae | *Diplotaxis belfragei var. sinuata* |
| Scarabaeidae | *D.* sp. *nr. sinuata* |
| Scarabaeidae | *D. subangulata var. californica* |
| Scarabaeidae | *D.* sp. |
| Scarabaeidae | *Euetheola rugiceps* |
| Scarabaeidae | *Ochrosidia* sp. |
| Scarabaeidae | *Podolasia ferruginea* |
| Scarabaeidae | *Thyce squamicollis* |
| Trogidae | *Trox punctatus* |
| Trogidae | *T. scutellaris* |
| Cerambycidae | *Aneflus cochisensis* |
| Cerambycidae | *Anetlomorpha* sp. |
| Cerambycidae | *Batyleoma pearsalli* |
| Cerambycidae | *Crossidius intermedius* |
| Cerambycidae | *Derobrachus geminatus* |
| Cerambycidae | *Moneilema* sp. |
| Cerambycidae | *Prionus curvatus* |
| Cerambycidae | *Stenaspis solitaria* |
| Cerambycidae | *Tragidion armatllm* |
| Chrysimelidae | *Diabrotica tricincta* |
| Chrysimelidae | *Haltica foliacea* |
| Chrysimelidae | *Luperodes nr. nigrovirescens* |
| Chrysimelidae | *Monoxia consputa* |
| Chrysimelidae | *Myochrus longulus* |
| Chrysimelidae | *Pachybrachys nr. minor* |
| Bruchidae | Unidentified sp. |
| Curculionidae | *Calendra* sp. |
| Curculionidae | *Cleonaspis* sp. |
| Curculionidae | *Dyslobus* sp. |
| Curculionidae | *Eupagoderes cretaceus* |
| Curculionidae | *E. decipiens* |
| Curculionidae | *E. wickhami* |
| Curculionidae | *E.* sp. |
| Curculionidae | *Panscopus* sp. |
| Curculionidae | *Scyphophorus yuccae* |
| Curculionidae | Unidentified sp. |

| Order/Family | Species Name |
|---|---|
| **Hymenoptera** | - |
| Ichneumonidae | *Cremastus n.* sp. |
| Ichneumonidae | *Ophion n* sp. |
| Braconidae | *Bassus gibbosus* |
| Braconidae | *Chelonus n.* sp. |
| Braconidae | *Hormius* sp. |
| Braconidae | *Iphiaulax* sp. |
| Braconidae | *Orgilus* sp. |
| Braconidae | *Zelomorpha arizonensis* |
| Chalcididae | *Catolaccus aeneoviridis* |
| Chalcididae | *Spilochalcis side* |
| Callimomidae | *Torymus* sp. |
| Tetrastichidae | *Tetrastichus* sp. |
| Elachertidae | *(Elachertini) Genus·?* sp.? |
| Formicidae | *Aphaenogaster (A.) boulderensis* |
| Formicidae | *Camponotus acutirostnis* |
| Formicidae | *C. vafer* |
| Formicidae | *Crematogaster punctulata depilis* |
| Formicidae | *C.* sp. |
| Formicidae | *Dorymyrmex pyramicus* |
| Formicidae | *D. p. bicolor* |
| Formicidae | *D. p. niger* |
| Formicidae | *Forelius maccooki* |
| Formicidae | *F.* sp. |
| Formicidae | *Formica perpilosa* |
| Formicidae | *F.* sp. |
| Formicidae | *Iridomyrmex pruinosus* |
| Formicidae | *I. p. analis* |
| Formicidae | *I. p. testaceus* |
| Formicidae | *I.* sp. |
| Formicidae | *Lasius niger neorlliger* |
| Formicidae | *Liometopum apiculatum* |
| Formicidae | *Myrmecocystus melliger* |
| Formicidae | *M. m. mendax* |
| Formicidae | *M. m. semirufus* |
| Formicidae | *M. mexicanus navajo* |
| Formicidae | *Novomessor cockerelli* |
| Formicidae | *Pheidole (Ceratopheidole)* |

| Order/Family | Species Name |
|---|---|
| Formicidae | *P. desertorum* |
| Formicidae | *P. hyatti* |
| Formicidae | *P.* sp. |
| Formicidae | *Pogonomyrmex barbatus marfensis* |
| Formicidae | *P. californicus* |
| Formicidae | *P. c. estebanius* |
| Formicidae | *P. c. longinodis* |
| Formicidae | *P. c. maricopa* |
| Formicidae | *P. ocoidentalis* |
| Formicidae | *P.* sp. |
| Formicidae | *Solenopsis molesta* |
| Formicidae | *S.* sp. |
| Sphecidae | *Cerceris argyrotricha* |
| Sphecidae | *C. rufinoda* |
| Sphecidae | *C.* sp. |
| Sphecidae | *Chlorion ashmeadi* |
| Sphecidae | *C. atratum* |
| Sphecidae | *C. aztecum* |
| Sphecidae | *C. cyaneum* |
| Sphecidae | *C. thomae* |
| Sphecidae | *Eucerceris bitruncata* |
| Sphecidae | *E. canaliculata* |
| Sphecidae | *E. montana* |
| Sphecidae | *E. tricolor* |
| Sphecidae | *Hoplisoides confertus* |
| Sphecidae | *H. spilopterus* |
| Sphecidae | *Microbembex hirsuta* |
| Sphecidae | *Oxybelus abdominalis* |
| Sphecidae | *O.* sp. |
| Sphecidae | *Philanthus albopilosus* |
| Sphecidae | *P. anna* |
| Sphecidae | *P. politus psyche* |
| Sphecidae | *Sceliphron caementarium* |
| Sphecidae | *Sphecius grandis* |
| Sphecidae | *Sphex ferruginosus* |
| Sphecidae | *S. pruinosus* |
| Sphecidae | *S. wrightii* |
| Sphecidae | *S.* sp. |

| Order/Family | Species Name |
|---|---|
| Sphecidae | *Stizus unicinctus* |
| Sphecidae | *Tachytes elongatus* |
| Sphecidae | *T. fulviventris* |
| Sphecidae | *T. obscurus* |
| Mutillidae | *Dasymutilla gordon* |
| Mutillidae | *D. klugii* |
| Mutillidae | *Micromutilla bicolor* |
| Mutillidae | *Photopsis halcyone* |
| Mutillidae | *P.* sp. |
| Scoliidae | *Campsomeris octomaculata race texensis* |
| Scoliidae | *Scalia lecontei* |
| Tiphiidae | *Drachycistis dentata* |
| Tiphiidae | *B. indiscreta* |
| Tiphiidae | *B. normalis* |
| Tiphiidae | *B.* sp. |
| Tiphiidae | *Glyptacros angustior* |
| Tiphiidae | *Myzine dubiosa* |
| Tiphiidae | *Paratiphia* sp. |
| Eumenidae | *Eumenes bollii* |
| Pompilidae | *Cryptocheilus cressoni* |
| Pompilidae | *C. terminates* |
| Pompilidae | *Pepsis bequaerti* |
| Pompilidae | *P. formosa* |
| Pompilidae | *P. nephele* |
| Pompilidae | *P. obliquerugosa* |
| Pompilidae | *Pompilus fabricii* |
| Pompilidae | *P. relativus* |
| Pompilidae | *P. spp* |
| Vespidae | *Polistes fuscallts var. flayus* |
| Vespidae | *Stenodynerus taos* |
| Vespidae | *S. toltecus* |
| Halticidae | *Agapostemon cockerelli* |
| Halticidae | *A. melliventris* |
| Halticidae | *A. texanus* |
| Halticidae | *Halictus ligatus* |
| Halticidae | *Lasioglossum* spp. |
| Halticidae | *Sphecodes* sp. |
| Megachilidae | *Ashmeadiella bigeloviae* |

| Order/Family | Species Name |
|---|---|
| Apidae | *Anthophora californica* |
| Apidae | *Diadasia rinconis* |
| Apidae | *Martinapis luteicornis* |
| Apidae | *Melissodes comanche* |
| Apidae | *M.* spp. |
| **Diptera** | - |
| Itonididae | *Lasioptera* sp. |
| Apioceratidae | *Apiocera bilineata* |
| Bombyliidae | *Anthrax* sp. |
| Bombyliidae | *Exeprosopa eremita* |
| Bombyliidae | *Geron* sp. |
| Bombyliidae | *Phthiria* sp. |
| Asilidae | *Dizonias tristis* |
| Asilidae | *Erax bicolor* |
| Asilidae | *E. pilosus* |
| Asilidae | *Proctacanthella leucopogon* |
| Asilidae | *Proctacanthus occidentalis* |
| Asilidae | *P.* sp. |
| Asilidae | *Promachus giganteus* |
| Asilidae | *Stenopogon langulus* |
| Dolichopodidae | *Asyndetus* sp. |
| Dolichopodidae | *Diaphorus* sp. |
| Dolichopodidae | *Hydrophorus cerutias* |
| Dolichopodidae | *Medeters californiensis* |
| Dolichopodidae | *Parasyntormon occidentale* |
| Syrphidae | *Mesogramma marginata* |
| Otitidae | *Euxesta abana* |
| Otitidae | *E. knowltoni* |
| Otitidae | *E. scutellaris* |
| Otitidae | *E. xeres* |
| Otitidae | *Mclieria occidentalis* |
| Trypetidae | *Trypanea bisetosa* |
| Sapromyzidae | *Homoneura harti* |
| Sapromyzidae | *H.* sp. |
| Sapromyzidae | *Lauxania* sp. |
| Sapromyzidae | *Pseudocalliope n.* sp. |
| Chamaemyiidae | *Leucopis* spp. |
| Helomyzidae | *Pseudoleria pectinata* |

| Order/Family | Species Name |
|---|---|
| Ephydridae | *Notiphila olivacea* |
| Chloropidae | *Diplotoxa pulcripes* |
| Chloropidae | *Hippelates pusio* |
| Anthomyiidae | *Coenosia ovata* |
| Anthomyiidae | *Fannia scalaris* |
| Anthomyiidae | *F.* sp. *conspicua* |
| Anthomyiidae | *Hylemya cilicrura* |
| Anthomyiidae | *Lispe nasoni* |
| Anthomyiidae | *L. tentaculata* |
| Anthomyiidae | *Pegomya* sp. |
| Anthomyiidae | *Schoenomyza litorella* |
| Calliphoridae | *Calliphora coloradensis* |
| Sarcophagidae | *Eumacronychia decens* |
| Sarcophagidae | *E. montana* |
| Sarcophagidae | *E.* sp. |
| Sarcophagidae | *E.* sp. |
| Sarcophagidae | *Hilarella hilarella* |
| Sarcophagidae | *Sarcophaga eleodis* |
| Sarcophagidae | *S. kellyi* |
| Sarcophagidae | *S. l'herminieri* |
| Sarcophagidae | *S. reinhardii* |
| Sarcophagidae | *S. rob usta* |
| Sarcophagidae | *S. sarracenioides* |
| Sarcophagidae | *S. sulculata* |
| Sarcophagidae | *S.* sp. *nr. masculina* |
| Sarcophagidae | *S.* spp. |
| Sarcophagidae | *Senotainia flavicornis* |
| Sarcophagidae | *S. trilineata* |
| Tachinidae | *Cloacina filialis* |
| Tachinidae | *Distichona varia* |
| Tachinidae | *Doryphorophaga doryphorae* |
| Tachinidae | *Drepramoglossa lucens* |
| Tachinidae | *Euphorocera tachinomoides* |
| Tachinidae | *Goniochaeta plagioides* |
| Tachinidae | *Hyalomyopsis aldrichi* |
| Tachinidae | *Neophorocera claripennis* |
| Tachinidae | *Oestrophasia signifera* |
| Tachinidae | *Phorocera* sp. |

| **Order/Family** | **Species Name** |
|---|---|
| Tachinidae | *Schizotachina convecta* |
| Tachinidae | *S. vitinervis* |
| Tachinidae | *Viviania* sp. |

# Appendix L. List of invertebrate orders, families, and some species that have been observed at WHSA.

| Order/Family | Common Name | Genus species |
|---|---|---|
| **Thysanura** | **Bristletails** | **-** |
| Lepismatidae | silverfish | - |
| Machilidae | jumping bristletails | - |
| **Collembola** | **springtails** | **-** |
| Entomobryidae | common springtails | - |
| **Odonata** | **dragonflies and damselflies** | **-** |
| Aeshnidae | darners | - |
| Libellulidae | common skimmers | - |
| Coenagrionidae | narrow-winged damselflies | - |
| **Isoptera** | **termites** | **-** |
| Rhinotermitidae | subterraenian termites | - |
| **Orthoptera** | **grasshoppers, crickets, etc** | **-** |
| Acrididae | short-horned grasshoppers | - |
| Tettigoniidae | long-horned grasshoppers | - |
| Gryllacrididae | camel crickets | - |
| Gryllidae | crickets | - |
| Mantidae | mantids | - |
| Phasmatidae | walking sticks | - |
| Blattidae | cockroaches | - |
| **Dermaptera** | **earwigs** | **-** |
| Forficulidae | common earwigs | - |
| Labiidae | little earwigs | - |
| **Hemiptera** | **bugs** | **-** |
| Corixidae | water boatmen | - |
| Notonectidae | backswimmers | - |
| Belostomatidae | giant waterbugs | - |
| Gerridae | water striders | - |
| Miridae | leaf/plant bugs | - |
| Nabidae | damsel bugs | - |
| Lygaeidae | seed bugs | - |
| Pyrrhocoridae | red bugs | - |
| Coreidae | leaf-footed bugs | - |
| Corizidae | scentless plant bugs | - |
| Scutelleridae | sheild-backed bugs | - |
| Pentatomidae | stink bugs | - |

| Order/Family | Common Name | Genus species |
|---|---|---|
| Homoptera | - | - |
| Cicadidae | cicadas | - |
| Cercopidae | spittlebugs or froghoppers | - |
| Cicadellidae | leafhoppers | - |
| Flatidae | planthoppers | - |
| Dictyopharidae | planthoppers | - |
| Aphididae | aphids | - |
| **Neuroptera** | **Net-winged insects** | **-** |
| Chrysopidae | green lacewings | - |
| Myrmeleontidae | antlions | - |
| **Thysanoptera** | **thrips** | **-** |
| **Megaloptera** | **alderflies, dobsonflies, and fishflies** | **-** |
| Corydalidae | dobsonflies and fishflies | - |
| **Coleoptera** | **beetles** | **-** |
| Cicindelidae | tiger beetles | - |
| Carabidae | Ground Beetles | - |
| Dytiscidae | Predaceous Diving Beetles | - |
| Histeridae | Hister Beetles | - |
| Hydrophilidae | Water Scavenger Beetles | - |
| Silphidae | Carrion Beetles | - |
| Dermestidae | Dermestid Beetles | - |
| Malachiidae | Soft-Winged Flower Beetles | - |
| Cleridae | Checkered Beetles | - |
| Elateridae | Click Beetles | - |
| Bupresitidae | Metallic Wood-Boring Beetles | - |
| Coccinellidae | Ladybird Beetles | - |
| Anthicidae | Antlike Flower Beetles | - |
| Oedermeridae | False Blister Beetles | - |
| Meloidae | Blister Beetles | - |
| Tenebrionidae | Darkling Beetles | - |
| Bostrichidae | Branch and Twig Borers | - |
| Scarabaeidae | Scarab Beetles | - |
| Cerambycidae | Long-Horned Beetles | - |
| Chrysomelidae | Leaf Beetles | - |
| Curculionidae | Snout Beetles | - |
| Lampyridae | Fireflies/Lightning Bugs | - |
| **Siphonaptera** | **fleas** | **-** |
| Pulicidae | Common Fleas | - |

| Order/Family | Common Name | Genus species |
|---|---|---|
| **Diptera** | **Flies** | **-** |
| Tipulidae | Flies | - |
| Culicidae | Crane Flies | - |
| Tabanidae | Mosquitos | - |
| Asilidae | Horse and Deer Flies | - |
| Bombyliidae | Robber Flies | - |
| Dolichopodidae | Bee Flies | - |
| Syrphidae | Long-legged Flies | - |
| Otitidae | Flower Flies | - |
| Ephydridae | Picture-Winged Flies | - |
| Sarcophagidae | Shore Flies | - |
| Tachinidae | Flesh Flies | - |
| Calliphoridae | Tachinid Flies | - |
| Muscidae | Blow Flies | - |
| **Hymenoptera** | **House Flies** | **-** |
| Ichneumonidae | Ants, Bees, Wasps | - |
| Cynipidae | Ichneumons | - |
| Tiphiidae | Gall Wasps and others | - |
| Scoliidae | Tiphiid Wasps and others | - |
| Mutillidae | Scollid Wasps | - |
| Mutillidae | Velvet Ants | *Dasymutilla gorgonaa* |
| Mutillidae | Velvet Ants | *D. snoworuma* |
| Mutillidae | Velvet Ants | *Pseudomethoca propinqua* |
| Mutillidae | Velvet Ants | *P. nudulaa* |
| Mutillidae | Velvet Ants | *P. paludataa* |
| Mutillidae | Velvet Ants | *P. propinquaa* |
| Mutillidae | Velvet Ants | *P. scaevolellaa* |
| Formicidae | Ants | *Lasius xerophilus* |
| Pompilidae | Spider Wasps | - |
| Vespidae | Vespid Wasps | - |
| Sphecidae | Sphecid Wasps | - |
| SuperFamily: Apoidea | Bees | - |
| Colletidae | Yellow-faced and Plasterer Bees | - |
| Apidae | Digger, Carpenter, Bumble, and Honey Bees | - |
| Halictidae | Green Metalic Bees, mining bees | - |
| Megachilidae | Leafcutting Bees | - |
| **CLASS: Chilopida** | **centipedes** | **-** |
| Scholopendridae | Giant Desert Centipede | - |

| Order/Family | Common Name | Genus species |
|---|---|---|
| **CLASS: Arachnida** | **Arachnids** | **-** |
| **Pedipalpida** | **Whip-Scorpions** | **-** |
| **Scorpionida** | **Scorpions** | **-** |
| **Solpugida** | **Wind-Scorpions or Solpugids** | **-** |
| **Chelonethida** | **Pseudoscorpions** | **-** |
| **Acarina** | **Mites and Ticks** | **-** |
| **Araneida** | **Spiders** | **-** |
| Salticidae | Jumping Spiders | - |
| Thomisidae | Crab Spiders | - |
| Lycosidae | Wolf or Ground Spiders | - |
| Araneidae | Orb-Weavers | - |
| Theridiidae | Comb-Footed Spiders (Black Widows) | - |
| Theraphosidae | Tarantulas | - |

# Appendix M. Lepidoptera species grouped by family as documented in WHSA (284 species).

| Family | Species Name |
|---|---|
| Cossidae | *Givira lucretia* |
| Cossidae | *Comadia henrici* |
| Cossidae | *C. albistriga* |
| Cossidae | *C. manfredi* |
| Crambidae | *Petrophila jaliscalis* |
| Crambidae | *Microtheoris ophionalis* |
| Crambidae | *M. rufofascialis* |
| Crambidae | *Noctueliopsis brunnealis* |
| Crambidae | *Mojavia achemonalis* |
| Crambidae | *Abegesta concha* |
| Crambidae | *Hellula aqualis* |
| Crambidae | *H. rogatalis* |
| Crambidae | *Evergestis simulatilis* |
| Crambidae | *E. vinctalis* |
| Crambidae | *Hahncappsia* sp. *lighter fm* |
| Crambidae | *Prorasea fernaldi* |
| Crambidae | *Evergestis obliqualis* |
| Crambidae | *Hahncappsia alpinensis* |
| Crambidae | *H. mellinialis* |
| Crambidae | *Achyra rantalis* |
| Crambidae | *Loxostege albiceralis* |
| Crambidae | *L. kearfottalis* |
| Crambidae | *L. egregialis* |
| Crambidae | *Pyrausta napaealis* |
| Crambidae | *P. nexalis* |
| Crambidae | *Loxostege sticticalis* |
| Crambidae | *Pyrausta volupialis* |
| Crambidae | *P. pseudonythesalis* |
| Crambidae | *P. subsequalis* |
| Crambidae | *Nomophila nearctica* |
| Crambidae | *Hymenia perspectalis* |
| Crambidae | *Spoladea recurvalis* |
| Crambidae | *Lygropia octonalis* |
| Crambidae | *Diastictis fracturalis* |
| Crambidae | *Pilocrocis ramentalis* |

| Family | Species Name |
| --- | --- |
| Crambidae | *Pseudoschoenobius opalescalis* |
| Crambidae | *Euchromius ocelleus* |
| Geometridae | *Speranza pallipennata* |
| Geometridae | *Digrammia irrorata* |
| Geometridae | *Rindgea parcata* |
| Geometridae | *Digrammia pallidata* |
| Geometridae | *Rindgea cyda* |
| Geometridae | *Fernaldella fimetaria* |
| Geometridae | *Anacamptodes obliquaria* |
| Geometridae | *Chlorospilates bicoloraria* |
| Geometridae | *Pergama meskaria* |
| Geometridae | *Hemimorina dissociata* |
| Geometridae | *Eucaterva variaria* |
| Geometridae | *E. bonniwelli* |
| Geometridae | *Plataea trilinearia* |
| Geometridae | *Dichorda rectaria* |
| Geometridae | *Lobocleta ossularia* |
| Geometridae | *Euacidalia sericearia* |
| Geometridae | *Lobocleta sp. undescr* |
| Geometridae | *L. plemyraria* |
| Geometridae | *L. peralbata* |
| Geometridae | *Idaea eremiata* |
| Geometridae | *Haematopis grataria* |
| Geometridae | *Archirhoe neomexicana* |
| Geometridae | *Perizoma custodiata* |
| Geometridae | *Eubaphe unicolor* |
| Hesperiidae | *Pyrgus communis* |
| Hesperiidae | *P. albescens* |
| Hesperiidae | *Pholisora catullus* |
| Hesperiidae | *Hesperopsis alpheus* |
| Hesperiidae | *Copaeodes aurantiaca* |
| Hesperiidae | *Hesperia meskei* |
| Incurvariidae | *Tegeticula yuccasella* |
| Lycaenidae | *Strymon melinus* |
| Lycaenidae | *Brephidium exilis* |
| Lycaenidae | *Leptotes marina* |
| Lycaenidae | *Echinargus isola* |
| Lycaenidae | *Plebejus acmon* |

| Family | Species Name |
|---|---|
| Noctuidae | *Tetanolita floridana* |
| Noctuidae | *Rejectaria albisinuata* |
| Noctuidae | *Tathorhynchus exsiccatus* |
| Noctuidae | *Melipotis indomita* |
| Noctuidae | *M. jucunda* |
| Noctuidae | *M. novanda* |
| Noctuidae | *Forsebia perlaeta* |
| Noctuidae | *Bulia deducta* |
| Noctuidae | *Drasteria mirifica* |
| Noctuidae | *D. pallescens* |
| Noctuidae | *Ascalapha odorata* |
| Noctuidae | *Toxonprucha crudelis* |
| Noctuidae | *Heteranassa mima/minor/fraterna complex* |
| Noctuidae | *Toxonprucha volucris* |
| Noctuidae | *Lesmone griseipennis* |
| Noctuidae | *Matigramma inopinata* |
| Noctuidae | *Caenurgina erechtea* |
| Noctuidae | *Callistege intercalaris* |
| Noctuidae | *Mocis latipes* |
| Noctuidae | *Trichoplusia ni* |
| Noctuidae | *Rachiplusia ou* |
| Noctuidae | *Megalographa biloba* |
| Noctuidae | *Autographa californica* |
| Noctuidae | *Marathyssa inficita* |
| Noctuidae | *M. inficita* |
| Noctuidae | *Tripudia limbatus* |
| Noctuidae | *Characoma nilotica* |
| Noctuidae | *Ozarba propera/catalina species complex* |
| Noctuidae | *Amyna octo* |
| Noctuidae | *Aleptina inca* |
| Noctuidae | *Copibryophila angelica* |
| Noctuidae | *Metapopneumata rogenhoferi* |
| Noctuidae | *Tarachidia venustula* |
| Noctuidae | *T. binocula* |
| Noctuidae | *Conochares altera* |
| Noctuidae | *Tarachidia dorneri* |
| Noctuidae | *T. cuta* |
| Noctuidae | *T. libedis* |

| Family | Species Name |
|---|---|
| Noctuidae | *T. phecolisca* |
| Noctuidae | *Conochares arizonae* |
| Noctuidae | *Conochares arizonae/elegantulus species complex* |
| Noctuidae | *Tarachidia candefacta* |
| Noctuidae | *Therasea angustipennis* |
| Noctuidae | *Spragueia magnifica* |
| Noctuidae | *Spragueia funeralis* |
| Noctuidae | *Acontia quadriplaga* |
| Noctuidae | *A. n.* sp. *"deserticola" mss* |
| Noctuidae | *A. lucasi* |
| Noctuidae | *A. expolita* |
| Noctuidae | *A. arida* |
| Noctuidae | *A. lanceolata* |
| Noctuidae | *A. areli species group* |
| Noctuidae | *A. cretata* |
| Noctuidae | *A.* sp. *lks like unpub. Todd* |
| Noctuidae | *Bagisara repanda* |
| Noctuidae | *B. buxea* |
| Noctuidae | *Apamea devastator* |
| Noctuidae | *Euscirrhopterus cosyra* |
| Noctuidae | *E. gloveri* |
| Noctuidae | *Dypterygia patina* |
| Noctuidae | *Rhizagrotis cloanthoides* |
| Noctuidae | *Properigea continens* |
| Noctuidae | *Pseudanarta crocea* |
| Noctuidae | *P. singula* |
| Noctuidae | *Magusa orbifera* |
| Noctuidae | *Micrathetis costiplaga* |
| Noctuidae | *Spodoptera exigua* |
| Noctuidae | *S. frugiperda species* |
| Noctuidae | *S. ornithogalli* |
| Noctuidae | *Condica sp. Gray white reniform* |
| Noctuidae | *Galgula partita* |
| Noctuidae | *Condica mobilis* |
| Noctuidae | *C. leucorena* |
| Noctuidae | *Stiriodes perflava* |
| Noctuidae | *Azenia implora* |
| Noctuidae | *Lythrodes tripuncta* |

| Family | Species Name |
|---|---|
| Noctuidae | *Eulithosia papago* |
| Noctuidae | *Basilodes chrysopis* |
| Noctuidae | *Stiria blanchardi* |
| Noctuidae | *Acopa perpallida* |
| Noctuidae | *Redingtonia alba* |
| Noctuidae | *Paramiana marina* |
| Noctuidae | *Walterella ocellata* |
| Noctuidae | *Escaria clauda* |
| Noctuidae | *Homoglaea carbonaria* |
| Noctuidae | *Catabenoides terminellus* |
| Noctuidae | *Sympistis* sp. Undescribed redish forewing |
| Noctuidae | *S.* sp. Undescribed dark gray forewing |
| Noctuidae | *Sympistis laticosta* |
| Noctuidae | *Copanarta aurea* |
| Noctuidae | *Cucullia pulla* |
| Noctuidae | *C. strigata* |
| Noctuidae | *C. serraticornis* |
| Noctuidae | *C. styx* |
| Noctuidae | *C. charon* |
| Noctuidae | *C. antipoda* |
| Noctuidae | *Trichocosmia inornata* |
| Noctuidae | *Discestra trifolii* |
| Noctuidae | *D. mutata* |
| Noctuidae | *Scotogramma harnardi* |
| Noctuidae | *S. ptilodonta* |
| Noctuidae | *S. gatei* |
| Noctuidae | *Tridepia nova* |
| Noctuidae | *Trichoclea postica* |
| Noctuidae | *T. antica* |
| Noctuidae | *T. decepta* |
| Noctuidae | *Trichordestra prodeniformis* |
| Noctuidae | *Lacinipolia rodora* |
| Noctuidae | *L. martini* |
| Noctuidae | *L. vicina* |
| Noctuidae | *L. illaudabilis* |
| Noctuidae | *Protorthodes alfkeni* species complex |
| Noctuidae | *Faronta terrapictalis* |
| Noctuidae | *Mythimna unipuncta* |

| Family | Species Name |
|---|---|
| Noctuidae | *Faronta diffusa* |
| Noctuidae | *Trichopolia dentatella* |
| Noctuidae | *T. suspicionis* |
| Noctuidae | *Agrotis orthogonia* |
| Noctuidae | *A. malefida* |
| Noctuidae | *A. ipsilon* |
| Noctuidae | *Feltia subterranea* |
| Noctuidae | *Copablepharon grandis* |
| Noctuidae | *C. serratigrande* |
| Noctuidae | *Protogygia album* |
| Noctuidae | *Dichagyris dubitata* |
| Noctuidae | *Euxoa lafontainei* |
| Noctuidae | *E. messoria* |
| Noctuidae | *E. auxiliaris* |
| Noctuidae | *E. inconcinna* |
| Noctuidae | *E. misturata* |
| Noctuidae | *E. sculptilis* |
| Noctuidae | *E. tronellus* |
| Noctuidae | *Striacosta albicosta* |
| Noctuidae | *Protogygia lagena* |
| Noctuidae | *P. whitesandsensis* |
| Noctuidae | *Anicla exuberans* |
| Noctuidae | *A. expoetica* |
| Noctuidae | *Hemieuxoa rudens* |
| Noctuidae | *Peridroma saucia* |
| Noctuidae | *Noctua pronuba* |
| Noctuidae | *Abagrotis orbis* |
| Noctuidae | *Heliothis virescens* |
| Noctuidae | *Helicoverpa zea* |
| Noctuidae | *Ufeus plicatus* |
| Noctuidae | *Heliothis phloxiphaga* |
| Noctuidae | *Heliocheilus paradoxus* |
| Noctuidae | *Heliothis toralis* |
| Noctuidae | *Schinia roseitincta* |
| Noctuidae | *S. septentrionalis* |
| Noctuidae | *S. cupes* |
| Noctuidae | *S. sexplagiata* |
| Noctuidae | *S. niveicosta* |

| **Family** | **Species Name** |
|---|---|
| Noctuidae | *S. gaurae* |
| Noctuidae | *S. walsinghami* |
| Noctuidae | *S.* sp. undescr. white species |
| Noctuidae | *S. coercita* |
| Noctuidae | *S. hulstia* |
| Noctuidae | *S. ciliata* |
| Noctuidae | *S. luxa* |
| Noctuidae | *Grotella binda* |
| Noctuidae | *G. stretchi* |
| Noctuidae: Arctiinae | *Cisthene tenuifascia* |
| Noctuidae: Arctiinae | *Eudesmia arida* |
| Noctuidae: Arctiinae | *Estigmene acrea* |
| Noctuidae: Arctiinae | *Grammia incorrupta* |
| Noctuidae: Arctiinae | *Notarctia proxima* |
| Noctuidae: Arctiinae | *Ctenucha venosa* |
| Noctuidae: Arctiinae | *Pygarctia murina* |
| Notodontidae | *Datana perspicua* |
| Nymphalidae | *Euptoieta claudia* |
| Nymphalidae | *Phyciodes picta* |
| Nymphalidae | *Danaus gilippus* |
| Papilionidae | *Papilio polyxenes* |
| Pieridae | *Pontia protodice* |
| Pieridae | *Pieris rapae* |
| Pieridae | *Colias eurytheme* |
| Pieridae | *Nathalis iole* |
| Pieridae | *Abaeis nicippe* |
| Plutellidae | *Plutella xylostella* |
| Pyralidae | *Aglossa cuprina* |
| Pyralidae | *Toripalpis trabalis* |
| Pyralidae | *Pococera asperatella* |
| Pyralidae | *P. fuscolotella* |
| Pyralidae | *Galleria mellonella* |
| Pyralidae | *Arivaca ostreella* |
| Pyralidae | *Pima fosterella* |
| Saturniidae | *Hemileuca nevadensis* |
| Saturniidae | *H. juno* |
| Sphingidae | *Manduca sexta* |
| Sphingidae | *M. quinquemaculata* |

| Family | Species Name |
|---|---|
| Sphingidae | *M. rustica* |
| Sphingidae | *Sagenosoma elsa* |
| Sphingidae | *Hyles lineata* |
| Sphingidae | *Pachysphinx occidentalis* |
| Tineidae | *Hypoplesia busckiella* |
| Tineidae | *Acrolophus arizonellus* |
| Tineidae | *A. davisellus* |
| Tineidae | *A. kearfotti* |
| Tineidae | *A. popeanella* |
| Tineidae | *A. variabilis* |
| Tineidae | *A. sinclairi* |
| Tortricidae | *Phaneta bucephaloides* |
| Tortricidae | *Eucosma canariana* |
| Tortricidae | *E. ridingsana* |
| Tortricidae | *E. mirosignata* |
| Tortricidae | *Pelochrista corosana* |
| Tortricidae | *Ofatulena duodecemstriata* |
| Tortricidae | *Choristoneura occidentalis* |
| Tortricidae | *Rudenia leguminana* |
| Tortricidae | *Platphalonidia felix* |
| Tortricidae | *Carolella n.* sp. undescribed with gray fringe |

# Appendix N. Specimen counts of targeted arthropod taxa in 2010 (Lightfoot and Miller 2012).

| Order | Family | Number of Specimens |
|---|---|---|
| **Class Hexapoda** | | |
| Odonata | Coenagrionidae | 4 |
| Odonata | Cortiliidae | 7 |
| Odonata | Libellulidae | 9 |
| Orthoptera | Acrididae | 8 |
| Orthoptera | Gryllidae | 8 |
| Orthoptera | Raphidophoridae | 3 |
| Orthoptera | Tettigoniidae | 1 |
| Phasmatodea | all families | 19 |
| Dictyoptera | Blattodea | 4 |
| Dictyoptera | Mantodea | 4 |
| Dermaptera | all families | 1 |
| Heteroptera | Alydidae | 3 |
| Heteroptera | Coreidae | 1 |
| Heteroptera | Corixidae | 21 |
| Heteroptera | Cydnidae | 19 |
| Heteroptera | Lygaeidae | 55 |
| Heteroptera | Nabidae | 33 |
| Heteroptera | Notonectidae | 11 |
| Heteroptera | Pentatomidae | 43 |
| Heteroptera | Reduviidae | 15 |
| Heteroptera | Rhopalidae | 16 |
| Heteroptera | Saldidae | 3 |
| Heteroptera | Thyreocoridae | 4 |
| Coleoptera | Carabidae | 176 |
| Coleoptera | Dytiscidae | 57 |
| Coleoptera | Elateridae | 43 |
| Coleoptera | Hydrophilidae | 66 |
| Coleoptera | Meloidae | 24 |
| Coleoptera | Scarabaeidae | 54 |
| Coleoptera | Tenebrionidae | 144 |
| Lepidoptera | Gelechiidae | 4 |
| Lepidoptera | Incurvaridae | 2 |
| Lepidoptera | Noctuidae | 172 |
| Diptera | Asilidae | 49 |

| Order | Family | Number of Specimens |
|---|---|---|
| Hymenoptera | Andrenidae | 74 |
| Hymenoptera | Apidae | 69 |
| Hymenoptera | Bradynobaenidae | 7 |
| Hymenoptera | Colletidae | 3 |
| Hymenoptera | Halictidae | 112 |
| Hymenoptera | Megachilidae | 30 |
| Hymenoptera | Mutillidae | 18 |
| Hymenoptera | Pompilidae | 6 |
| **Class Arachnida (Spiders and scorpions)** | | |
| Aranea | Araneidae | 54 |
| Aranea | Dictynidae | 10 |
| Aranea | Diguetidae | 4 |
| Aranea | Dipluridae | 1 |
| Aranea | Filistatidae | 1 |
| Aranea | Gnaphosidae | 23 |
| Aranea | Linyphiidae | 7 |
| Aranea | Lycosidae | 22 |
| Aranea | Mimetidae | 2 |
| Aranea | Miturgidae | 1 |
| Aranea | Oxyopidae | 1 |
| Aranea | Philodromidae | 17 |
| Aranea | Pholcidae | 9 |
| Aranea | Salticidae | 32 |
| Aranea | Sicariidae | 1 |
| Aranea | Tetragnathidae | 5 |
| Aranea | Theraphosidae | 1 |
| Aranea | Theridiidae | 8 |
| Aranea | Thomisidae | 42 |
| Scorpiones | scorpions | 4 |
| Solifugae | wind scorpions | 10 |
| **Class Diplopoda** | | |
| - | Millipedes | 9 |
| **Class Chilopoda** | | |
| - | Centipedes | 2 |

## Appendix O. Soil microbial and other soil fauna from field samples at the seven WHSA sampling sites (Unc et al. 2014).

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Achromobacter | - | - | - | - | - | X | - |
| Aciditerrimonas | X | X | X | X | X | X | X |
| Acidovorax | - | - | - | - | - | X | X |
| Acinetobacter | - | - | X | - | X | X | X |
| Actinophytocola | - | - | X | - | - | - | - |
| Adhaeribacter | - | X | - | X | - | - | X |
| Aeromicrobium | - | - | X | - | - | - | X |
| Afifella | - | - | - | X | - | - | - |
| Afipia | X | - | - | - | - | - | - |
| Agrococcus | - | X | X | X | - | - | X |
| Alcanivorax | X | X | - | - | - | - | X |
| Alistipes | - | - | - | - | X | - | X |
| Alklalibacillus | - | - | - | - | X | - | - |
| Altererythrobacter | - | X | X | X | X | X | X |
| Amaricoccus | X | - | - | - | - | - | - |
| Amphibacillus | - | - | - | - | - | - | X |
| Ancylobacter | - | - | - | - | - | - | X |
| Anaerococcus | - | - | - | - | - | - | X |
| Anaerotruncus | - | - | - | - | - | - | X |
| Anaerobacter | - | - | - | - | X | - | - |
| Anaerobacillus | - | - | - | - | - | - | X |
| Anoxybacillus | - | X | - | - | - | X | X |
| Aquabacterium | - | - | - | - | - | X | X |
| Aquicella | X | - | - | - | - | - | - |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Aquincola | - | X | - | - | - | - | - |
| Arenimonas | X | - | - | - | - | - | - |
| Armatimonadetes | X | X | X | X | X | X | - |
| Armatimonas | X | X | - | X | X | - | - |
| Arthrobacter | - | X | - | X | - | - | - |
| Aspromonas | - | - | - | - | - | - | X |
| Bacillariophyta | - | X | - | X | - | - | - |
| Bacillus | X | - | X | X | - | X | X |
| Bacteroides | - | - | - | - | X | - | - |
| Balneimonas | X | X | - | X | - | - | - |
| Balneola | - | - | - | X | - | - | - |
| Barnesiella | - | - | - | - | - | - | X |
| Bauldia | X | - | - | - | - | - | - |
| Beijerinckia | X | X | X | - | X | X | - |
| Bifidobacterium | - | X | - | - | - | - | - |
| Blastococcus | - | X | X | X | X | - | X |
| Blastochloris | - | - | - | - | - | - | X |
| Blastopirellula | - | X | - | - | - | - | - |
| Bordetella | - | - | - | - | - | X | - |
| Bosea | - | - | X | - | - | X | - |
| Bradyrhizobium | - | - | - | - | X | X | - |
| Brevundimonas | - | X | X | X | X | X | X |
| Burkholderia | - | - | X | - | - | - | - |
| Byssovorax | - | - | X | X | - | - | X |
| Caldilinea | X | X | X | X | X | X | X |
| Caldithrix | - | - | - | X | X | - | - |
| Caulobacter | - | - | X | X | X | - | - |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Cellulomonas | - | - | - | - | - | - | X |
| Cellulosilyticum | - | - | - | - | - | X | - |
| Chelativorans | - | - | - | - | - | X | - |
| Chelatococcus | - | - | - | - | - | X | - |
| Chloroflexus | - | - | X | - | - | - | - |
| Chromohalobacter | - | X | - | - | - | - | - |
| Citricoccus | - | - | - | - | - | - | X |
| Cloacibacillus | - | - | - | - | - | - | X |
| Cloacibacterium | - | - | X | - | - | X | - |
| Clostridium sensu stricto | X | - | X | X | X | X | X |
| Clostridium III | - | - | - | - | - | - | X |
| Clostridium XI | - | - | - | - | X | X | - |
| Clostridium XIX | - | - | X | - | - | - | - |
| Comamonas | - | - | - | - | - | - | X |
| Conenaxibacter | - | - | - | - | - | X | - |
| Conexibacter | X | X | X | X | X | - | X |
| Corynebacterium | X | X | X | X | X | X | X |
| Coxiella | X | X | - | - | - | - | - |
| Cryptosporangium | - | X | X | X | - | - | X |
| Curtobacterium | - | - | - | - | - | X | X |
| Cystobacter | X | - | - | - | - | - | - |
| Daeguia | - | - | - | - | - | X | - |
| Deinococcus | - | - | - | X | X | - | X |
| Delftia | - | - | X | - | - | X | - |
| Desertibacter | - | - | - | - | - | X | - |
| Devosia | X | X | X | X | X | X | X |
| Dialister | - | - | X | - | - | - | - |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Diaphorobacter | - | - | - | - | - | X | - |
| Dolosigranulum | - | - | - | - | - | - | X |
| Dokdonella | - | - | - | X | - | - | - |
| Dongia | - | X | - | X | - | X | X |
| Duganella | - | - | X | X | X | X | X |
| Empedobacter | - | - | - | - | - | X | - |
| Ensifer | - | - | - | X | - | X | - |
| Erwinia | - | - | X | - | - | - | X |
| Erythrobacter | - | - | X | - | - | - | - |
| Escherichia/Shigella | - | - | X | - | X | X | X |
| Exiguobacterium | - | - | - | - | - | - | X |
| Euzebya | X | X | X | X | - | - | - |
| Faecalibacterium | - | - | X | - | X | X | X |
| Flavisolibacter | - | X | - | X | - | X | - |
| Flavobacterium | X | X | X | X | X | - | X |
| Fodinicurvata | - | - | - | - | X | - | - |
| Frigoribacterium | - | - | X | - | - | - | - |
| Friedmanniella | - | - | - | - | - | - | X |
| Fusobacterium | X | X | X | - | X | X | X |
| Gemella | - | - | - | X | - | - | X |
| Gemmata | X | - | X | - | - | - | - |
| Gemmatimonas | X | X | X | X | X | X | X |
| Globicatella | - | - | - | - | - | - | X |
| Geobacter | - | X | X | X | - | X | X |
| Geodermatophilus | - | X | X | X | - | - | - |
| Gp10 | X | X | - | - | - | - | X |
| Gp16 | X | X | X | X | X | X | X |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Gp21 | - | X | - | - | - | - | - |
| Gp4 | X | X | - | X | X | X | - |
| Gp6 | X | X | X | X | X | X | X |
| Gp7 | X | X | X | X | X | X | - |
| GpI | X | X | X | - | X | X | X |
| GpIV | X | X | X | X | X | X | X |
| GpV | - | X | - | - | - | - | - |
| GpVI | - | - | X | - | - | - | - |
| GpVII | - | X | - | X | - | - | - |
| GpX | X | - | - | - | - | - | - |
| GpXIII | X | X | - | X | X | X | - |
| Gracilibacillus | - | - | - | - | - | - | X |
| Gracilimonas | X | X | - | X | X | - | - |
| Haemophilus | - | - | X | - | - | - | - |
| Haliscomenobacter | X | - | X | X | X | - | - |
| Halobacillus | - | - | - | - | - | - | X |
| Halomonas | X | X | - | - | X | X | X |
| Haloplanus | X | - | - | - | - | - | - |
| Halorubrum | X | - | - | - | - | - | - |
| Heliothrix | X | - | - | - | - | - | - |
| Herbaspirillum | - | X | - | - | - | - | - |
| Herpetosiphon | - | - | X | - | - | - | - |
| Hoeflea | - | - | - | - | - | X | - |
| Hyalangium | X | - | - | - | X | X | X |
| Hyphomicrobium | - | - | - | - | - | - | X |
| Hydrogenobacter | X | - | - | - | - | - | - |
| Hydrogenophilus | - | - | X | X | X | X | X |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Hymenobacter | - | - | X | X | - | - | - |
| Idiomari | - | - | - | - | - | X | - |
| Idiomarina | - | X | - | - | X | - | X |
| Janthinobacterium | - | - | - | - | - | X | - |
| Jeotgalibacillus | - | - | - | - | - | - | X |
| Kamurella | - | - | - | - | - | X | - |
| Kushneria | - | - | - | - | - | - | X |
| Kocuria | - | - | - | X | - | X | X |
| Kribbella | - | - | - | X | - | - | - |
| Labrenzia | X | - | - | - | - | - | X |
| Lactobacillus | - | - | - | - | X | X | - |
| Lactococcus | - | - | X | - | - | - | - |
| Lamia | X | X | X | X | X | X | X |
| Lentzea | - | - | - | - | - | - | X |
| Lechevalieria | - | - | - | - | X | - | - |
| Legionella | X | - | - | - | - | - | - |
| Leifsonia | - | - | - | - | - | X | - |
| Levilinea | X | - | X | X | - | - | X |
| Luteimonas | - | - | X | - | X | - | - |
| Lysobacter | - | X | X | X | X | - | - |
| Mariniflexile | X | - | - | - | - | - | - |
| Marinimicrobium | X | X | - | - | X | X | - |
| Marinobacter | X | X | - | X | X | X | X |
| Marinococcus | - | X | - | - | - | - | - |
| Marinilactibacillus | - | - | - | - | - | - | X |
| Marinoscillum | - | - | - | X | - | - | - |
| Marmoricola | X | X | - | X | - | - | X |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Martelella | - | - | - | - | - | - | X |
| Massilia | - | X | - | X | X | X | - |
| Megamonas | - | - | - | - | X | - | - |
| Megasphaera | - | - | - | - | X | - | - |
| Mesorhizobium | - | - | X | - | - | - | - |
| Methylobacterium | - | - | X | X | - | - | - |
| Methylibium | - | - | - | - | - | - | X |
| Methylocystis | - | X | - | - | - | - | X |
| Microbacterium | X | - | X | X | X | - | X |
| Microlutus | - | - | - | - | - | X | - |
| Microvirga | X | X | X | X | X | X | X |
| Modestobacter | - | - | - | - | - | - | X |
| Modicisalibacter | - | X | - | - | - | - | X |
| Mucilaginibacter | - | - | - | X | - | - | - |
| Mycobacterium | X | X | X | X | X | X | X |
| Nakamurella | - | - | X | - | X | - | X |
| Natrinema | X | - | - | - | - | - | - |
| Naxibacter | - | - | - | - | X | X | - |
| Neisseria | - | - | - | - | - | - | X |
| Nitriliruptor | X | - | X | - | X | - | - |
| Nocardia | - | - | - | - | - | - | X |
| Nocardioides | - | X | X | X | X | - | X |
| Novosphingobium | X | X | X | X | X | X | - |
| Oceanobacillus | - | - | - | - | - | - | X |
| Ochrobactrum | - | - | - | - | - | - | X |
| Ohtaekwangia | - | X | X | X | X | - | X |
| Oscillibacter | - | - | - | - | - | - | X |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Olsenella | - | - | - | - | X | - | X |
| Opitutus | - | - | - | - | - | X | - |
| Oxalicibacterium | - | X | - | - | - | - | - |
| Paenibacillus | - | - | - | - | X | X | X |
| Palleronia | - | X | - | - | X | - | - |
| Pantoea | - | - | - | - | - | - | X |
| Parabacteroides | - | - | - | - | X | - | X |
| Parasutterella | - | - | - | - | - | - | X |
| Paracoccus | X | X | - | X | - | - | - |
| Parvularcula | - | X | - | - | - | - | - |
| Pasteuria | X | X | X | X | X | - | X |
| Patulibacter | X | X | X | X | X | X | X |
| Pedobacter | - | - | - | X | - | - | - |
| Pelagibius | - | X | - | - | X | - | - |
| Pelomonas | - | - | - | - | - | X | - |
| Phascolarctobacterium | - | - | - | - | - | - | X |
| Phenylobacterium | - | X | X | X | X | - | - |
| Phyllobacterium | - | - | - | - | - | - | X |
| Phycisphaera | X | X | - | X | X | - | X |
| Pimelobacter | - | - | X | - | - | - | - |
| Planctomyces | X | X | X | X | X | - | X |
| Planococcus | - | - | - | - | - | - | X |
| Planomicrobium | - | X | - | - | X | - | X |
| Polaromonas | - | - | X | - | - | - | - |
| Pontibacillus | - | - | - | - | X | - | X |
| Pontibacter | - | - | - | - | X | - | - |
| Porphyrobacter | X | X | X | X | X | X | X |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Prevotella | - | - | - | - | - | X | - |
| Propionibacterium | X | X | X | X | X | X | X |
| Pseudomonas | X | X | X | X | X | X | X |
| Pseudonocardia | X | X | X | X | - | X | X |
| Pseudoflavonifractor | - | - | - | - | - | - | X |
| Pseudoxanthomonas | - | - | - | X | X | X | - |
| Psychrobacter | - | X | - | - | - | - | - |
| Ralstonia | - | X | X | - | - | X | X |
| Rheinheimera | X | - | - | - | - | X | - |
| Rhizobium | X | - | X | X | X | X | X |
| Rhodobacter | - | - | - | - | - | X | - |
| Rhodococcus | - | X | X | - | - | - | - |
| Rhodopirellula | - | X | - | X | X | - | - |
| Rhodoplanes | - | - | - | - | - | X | X |
| Rhodothermus | X | - | - | - | - | - | - |
| Rothia | - | - | - | - | - | - | X |
| Roseburia | X | - | - | - | X | X | X |
| Roseiflexus | - | - | X | - | - | - | - |
| Roseomonas | - | X | - | - | - | - | X |
| Rubellimicrobium | X | X | - | X | X | X | X |
| Rubrobacter | X | X | X | X | X | X | - |
| Saccharomonospora | - | - | X | - | - | - | - |
| Saccharospirillum | X | - | - | - | - | - | X |
| Salarchaeum | X | - | - | - | - | - | - |
| Salengentibacter | - | X | - | - | X | - | - |
| Salimicrobium | - | X | - | - | - | - | - |
| Salinarimonas | - | X | - | - | - | - | - |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Salinicola | - | | - | - | - | - | X |
| Salinimicrobium | - | X | - | - | X | - | - |
| Salinisphaera | - | - | - | X | - | - | - |
| Salisaeta | - | - | - | X | - | - | - |
| Schlesneria | - | - | X | - | - | - | - |
| Sediminibacillus | - | - | - | - | - | - | X |
| Segetibacter | - | X | - | X | - | X | - |
| Shewanella | X | - | - | - | - | - | - |
| Shinella | - | - | - | - | - | X | - |
| Simplicispira | - | - | - | - | - | - | X |
| Singulisphaera | - | X | - | - | - | - | - |
| Sinorhizobium | - | - | - | - | - | X | - |
| Skermanella | X | X | - | - | - | X | - |
| Solirubrobacter | X | X | X | X | X | X | X |
| Sorangium | - | X | - | - | - | - | - |
| Spartobacteria general incertae sedis | X | - | - | X | - | - | - |
| Sphaerobacter | X | X | X | X | X | - | X |
| Sphingobacterium | X | - | X | X | X | X | X |
| Sphingomonas | X | X | X | X | X | X | X |
| Sphingopyxis | X | - | X | - | - | - | - |
| Sphingosinicella | - | X | X | X | X | X | X |
| Stappia | - | - | - | - | - | - | X |
| Staphylococcus | X | X | X | X | X | X | X |
| Stenotrophomonas | - | - | - | X | X | X | - |
| Steroidbacter | - | - | - | X | - | - | - |
| Streptococcus | X | - | X | - | X | X | X |
| Streptomyces | - | - | X | - | - | X | - |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Subdoligranulum | - | - | - | - | - | - | X |
| Succinatimonas | - | - | - | - | X | - | - |
| Sulfurospirillum | - | - | X | - | - | - | - |
| Sutterella | - | - | - | - | - | - | X |
| Syntrophobacter | - | X | - | - | - | - | - |
| Tepidimonas | - | - | - | - | - | X | X |
| Terribacillus | - | - | - | - | - | X | - |
| Thalassospira | X | - | - | - | - | X | X |
| Thauera | - | X | - | - | - | - | - |
| Thermocrinis | - | - | X | - | - | - | - |
| Thermogymnomonas | X | - | - | X | - | - | - |
| Thermoleophilum | X | X | X | X | - | - | - |
| Thermus | - | - | X | - | - | - | - |
| Thiobacillus | - | - | - | X | - | X | - |
| Thiomonas | - | - | - | X | - | - | X |
| Thiothrix | - | - | X | - | - | - | - |
| TM7 genera incertae sedis | X | X | X | X | X | X | X |
| Truepera | X | - | - | - | - | - | - |
| Tumebacillus | - | X | - | - | - | X | - |
| Turicibacter | - | - | - | - | X | X | - |
| Unknown | X | X | X | X | - | X | X |
| Vasilyavaea | X | X | X | X | - | X | X |
| Virgibacillus | - | - | - | - | - | - | X |
| Veillonella | - | - | X | - | - | - | - |
| Wenxinia | - | - | - | - | - | - | X |
| Weissella | - | - | - | - | - | - | X |
| Williamsia | - | - | - | - | - | X | - |

| Species | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| Xanthomonas | - | - | X | - | - | - | - |
| Zavarzinella | X | - | - | X | - | X | - |
| Zobellella | X | - | - | X | - | - | - |
| **Total Number of Genera: 297** | **91** | **103** | **101** | **100** | **96** | **106** | **137** |

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National Park Service
U.S. Department of the Interior

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