National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Big Bend National Park

Natural Resource Condition Assessment

Natural Resource Report NPS/BIBE/NRR—2014/779

ON THE COVER
The Chisos Mountains as they rise out of the Chihuahuan Desert lowlands
Photograph by: Andy Nadeau, SMUMN GSS

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

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

This report is available from the Chihuahuan Desert Inventory and Monitoring Network (http://science.nature.nps.gov/im/units/chdn/index.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

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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 Big Bend National Park (BIBE) 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 BIBE. The final project framework contains 21 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 BIBE park resource managers and Chihuahuan Desert Inventory & Monitoring Network staff.

Existing literature, short- and long-term datasets, and input from NPS and other outside agency scientists support condition designations for components in this assessment. However, in a number of cases, data were unavailable or insufficient for several 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 4 of the 21 components (19%) due to these data gaps. The components that were not assigned conditions were spring habitats, black bear, mountain lion, and soundscape.

For those components with sufficient available data, the overall condition varied. Six components were determined to be of low concern: desert grasslands, birds, amphibians, reptiles, viewscape, and dark night skies. These components showed a stable (birds, viewscape, dark night skies) or unknown (desert grasslands, amphibians, and reptiles) trend. Three components were of moderate concern: montane forests/sky islands, bats, and fish. All three of these

components exhibited declining trends in recent years. Lastly, six components were of significant concern to park managers: fire, Rio Grande riparian community, desert bighorn sheep, macroinvertebrates, air quality, and water quality. Trends for these components were either declining or unknown, with the exception of air quality which was assigned a stable trend. A 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 BIBE. Those of primary concern include climate change, the presence of non-native species, habitat loss due to human activity, and alterations to the Rio Grande’s flow and water quality. Understanding these threats, and how they relate to the condition of these resources, can help the NPS prioritize management objectives and better focus conservation strategies to maintain the health and integrity of park ecosystems.

Acknowledgments

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Acronyms and Abbreviations

ARD – NPS Air Resources Division

BBS – Breeding Bird Survey

BBRSP – Big Bend Ranch State Park

BCMP – Backcountry Management Plan

BCR – Bird Conservation Region

BGWMA - Black Gap Wildlife Management Area

BIBE – Big Bend National Park

BRAVO – Big Bend Regional Aerosol and Visibility Observational

BRBIBI – Benthic Macroinvertebrate Rapid Bioassessment Index of Biotic Integrity

CAA – Clean Air Act of 1977

CASTNet – Clean Air Status and Trends Network

CBC – Christmas Bird Count

CCC – Civilian Conservation Corps

CCD – Charged-coupled device

CHDN – Chihuahuan Desert Network

CHLa – Chlorophyll a

CL – Condition Level

CLEAR – Connecticut's Center for Land Use Education and Research

dBA – A-Weighted decibel scale

DEM – Digital Elevation Model

DDE – Dichlorodiphenyldichloroethylene

DDT – Dichlorodiphenyltrichloroethane

DMTNC – Davis Mountains Preserve of the Nature Conservancy

dNBR – Differenced Normalized Burn Ratio

Acronyms and Abbreviations (continued)

DO – Dissolved Oxygen

Dv – deciviews

E&T –Ephemeroptera and Tricoptera

EMWMA – Elephant Mountain Wildlife Management Area

EPA – United States Environmental Protection Agency

EPT – Ephemeroptera, Plecoptera, Trichoptera

ESA – Endangered Species Act

FBPS – Fire Behavior Prediction System

FCCS – Fuel Characteristic Classification System

FLM – Fuel Loading Model

FMP – Fire Management Plan

FMU – Fire Management Units

GMP – General Management Plan

GPMP – NPS Gaseous Pollutant Monitoring Program

GPRA – Government Performance and Results Act

GRTS – Generalized Random-Tessellation Stratification

IDA – International Dark-Sky Association

IMBCR – Integrated Monitoring in Bird Conservation Regions

IMPROVE – Interagency Monitoring of Protected Visual Environments Program

IRMA – Integrated Resource Management Application

IUCN – International Union of Conservation of Nature

LFT – Landscape Fragment Tool

LiDAR – Light Detection and Ranging

Ma – Megaannum (Millions of Years Ago)

Acronyms and Abbreviations (continued)

MCL – Maximum Contaminant Levels

MCPA – Maderas del Carmen Protected Area

MFRI – Mean Fire Return Interval

MIST – Minimum Impact Suppression Tactics

MTBS – Monitoring Trends in Burn Severity

NAAQS – National Ambient Air Quality Standards

NADP – National Atmospheric Deposition Program

NH_4 – Ammonium

NO_3 – Nitrate

NPS – National Park Service

NRCA – Natural Resource Condition Assessment

NST – NPS Night Sky Team

PM – Particulate Matter

Ppb – parts per billion

QMH – Qualitative Multihabitat

RMBO – Rocky Mountain Bird Observatory

RRUMP – Recreational River Use Management Plan

RSS – Resource Stewardship Strategy

RTH – Richest Targeted Habitat

SAC – Strategic Air Command

SL – Significance Level

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

TCEQ – Texas Commission on Environmental Quality

TDS – Total Dissolved Solids

Acronyms and Abbreviations (continued)

TPWD – Texas Parks and Wildlife Department

TWDB – Texas Water Development Board

USFS – United States Forest Service

USFWS – United States Fish and Wildlife Service

USGS – United States Geological Survey

VIEWS – Visibility Information Exchange Web System

VOCs – Volatile Organic Compounds

WCS – Weighted Condition Score

WRMP – Water Resource Management Plan

WSR – Wild and Scenic River

WWF – World Wildlife Fund

ZLM – Zenithal Limiting Magnitude

Chapter 1 NRCA Background Information

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

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

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

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

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e.,

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

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

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

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

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

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

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

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

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

Important NRCA Success Factors

Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

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

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

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

NRCA Reporting Products…
Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:
Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations
(near-term operational planning and management)
Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values
(longer-term strategic planning)
Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public
("resource condition status" reporting)

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

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

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

Chapter 2 Introduction and Resource Setting

2.1 Introduction

2.1.1 Enabling Legislation

Big Bend National Park (BIBE) was authorized on 20 June 1935 when President Franklin Roosevelt and Congress passed the Establishment-Authorization Act (49 Stat. 393, appended) into law (NPS 2004). This Act states

> That when title to such lands as may be determined by the Secretary of the Interior as necessary for recreational park purposes within the boundaries to be determined by him within the area of approximately one million five hundred thousand acres, in the counties of Brewster and Presidio, in the State of Texas, known as the 'Big Bend' area, shall have been vested in the United States, such lands shall be, and are hereby, established, dedicated, and set apart as a public park for the benefit and enjoyment of the people and shall be known as the 'Big Bend National Park' (NPS 2004).

The park was officially established on 12 June 1944. On 30 August 1949, Congress passed into law (63 Stat. 679) an Act to authorize the addition of land, which stated

> That the Secretary of the Interior is authorized to acquire…land situated within sections 15, 22, 27, 34, block 234, Brewster County, Texas…considered to be suitable for addition to the Big Bend National Park.

Finally, on 8 August 1953, Congress passed into law (67 Stat. 497) an Act to authorize the acquisition by the United States of the remaining non-Federal lands within BIBE (NPS 2004). The North Rosillos Ranch (22,953 ha [56,719ac]) was added to the park by Public Law 100-201 on 22 December 1987. Approximately 9,712 ha (24,000 ac) of the southern Rosillos Mountains, encompassing the Pitcock-Rosillos Mountains Ranch, was authorized for addition to the park by act of Congress on 28 December 1980 (94 Stat. 3539), yet funds for purchase were not appropriated. It remains a private inholding.

2.1.2 Geographic Setting

BIBE is located in south Brewster County in southwest Texas. Brewster County (16,068 km^2 [6,204 mi^2]) has approximately 13,000 people, most of whom reside in the towns of Marathon and Alpine, which are 111 km (69 mi) to the north and 160 km (100 mi) to the northwest of park headquarters, respectively (NPS 2004).

The park covers more than 324,000 ha (801,000 ac). The Rio Grande runs adjacent to the park's southern boundary for 190 km (118 mi), and also forms the border between the United States and Mexico. The name "Big Bend" originated from the abrupt change of the Rio Grande's channel from southeasterly to northeast. BIBE also oversees the management of the 315 km (196 mi) Rio Grande Wild and Scenic River, which lies outside park boundaries (NPS 2004).

The BIBE boundary includes the northern portion of the Chihuahuan Desert, which is the wettest of all four deserts located in North America, receiving more than 25 cm (10 in) of rainfall annually (NPS 2010a). The rainy season usually lasts from mid-July through late-September.

However, it is common for certain areas to remain relatively dry during the rainy season (NPS 2010a).

BIBE encompasses diverse, complex geologic features that represent a variety of different depositional processes spanning a large interval of time. The Ordovician Maravillas Formation, Silurian-Mississippian Caballos Novaculite, and the Mississippian-Pennsylvanian Tesnus Formation are the oldest rocks present within BIBE. Major events of volcanism began in BIBE approximately 47 Ma, when the Chisos Formation was deposited. Prominent features of volcanism that formed during this period include volcanic flows extruding from a complex of vents and lava domes in the western region of the park and Mexico, and the Pine Canyon caldera complex (32 Ma) located in the upper region of the Chisos Mountains. The eruption of the Burro Mesa Formation marked the end of volcanism in the region (29 Ma) (Turner et al. 2011).

From approximately 25 to 2 Ma, BIBE experienced a period of continental extension and rifting. The last major tectonic event caused basin and range faulting, and created high-angle normal and oblique-slip faults. Movement of some of the major faults formed fault-controlled depositional basins; these depositional basins (e.g., the Delaho and Estufa bolson) now surround the Chisos Mountains (Turner et al. 2011). The last major event that modified the landscape in BIBE was basin and ranges faulting.

Extensive erosion occurred during the Quaternary period (2.6 Ma to present), caused by down cutting and some aggradation related to the Rio Grande River. This period contributed to the destabilization of bedrock slopes and resulted in large multi-event landslides, including those located at the Chilicotal and Talley Mountains, and the northwest flanks of the Chisos and Rosillos Mountains (Turner et al. 2011). Turner et al. (2011) updated the geological map of Maxwell et al. (1967) and included new research with the purpose of producing a new digital map that can be utilized by the NPS and the public.

The climate of BIBE exhibits extreme contrast due to the range in elevation, which causes wide variation in moisture and temperature. Along the Rio Grande River, the elevation is approximately 548 m (1,800 ft), while the Chisos Mountains reach 2,377 m (7,800 ft). In the late spring and early summer, the climate is hot and dry with temperatures often exceeding 37.8 ºC (100 ºF) in the lower elevations. During the winter, the climate is mild. However, sub-freezing temperatures occur sporadically. This variation in climate contributes to the extraordinary diversity in plant and animal habitats present in BIBE (NPS 2004). Table 1 summarizes average monthly temperature and precipitation for BIBE.

Table 1. Monthly climate summary (1943-2010) for BIBE (Station 411715, Chisos Basin) (Western Region Climatic Data Center 2011).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Temperature (°C)													
Max	14.7	16.6	20.3	24.5	28.2	30.3	29.3	28.7	26.3	23.2	18.4	15.2	23.0
Min	2.7	4.0	6.7	10.8	14.7	17.3	17.6	17.0	14.7	11.0	6.2	3.3	10.5
Average Precipitation (cm)													
Total	1.67	1.47	1.04	1.57	4.01	5.69	8.66	8.00	6.38	3.91	1.45	1.32	45.2

2.1.3 Visitation Statistics

BIBE is one of the least visited National Parks in the lower 48 states; from 2000 to 2010, BIBE averaged 340,909 visitors a year (NPS 2011a), with the busiest months being November through April (NPS 2011b). BIBE offers over 482 km (300 mi) of scenic roads across various landscapes, such as canyons, mountains, deserts, and the Rio Grande. The park contains more than 241 km (150 mi) of hiking trails, and BIBE has the largest area of roadless public land in Texas (NPS 2011b). Visitors can also float the Rio Grande or utilize the backcountry for horseback riding, biking, and rock climbing.

Backcountry hiking and camping are also popular activities in BIBE, particularly during the winter months. Turner et al. (2009) analyzed the backcountry use in the park, paying particular attention to the number of permits issued for backcountry camping in the park from 2000-2009 (visitors who travelled via water craft were excluded from the analysis). The study found that most backcountry permits were issued in from November-April (Figure 1), and that the overall number of backcountry permits has been declining since 2002 (Figure 2). The number of permits issued from 2000-2009 ranged from 3,973 (2007) to 5,920 (2002).

Figure 1. Average number of backcountry permits issued by month in BIBE from 2000 through 2009 (reproduced from Turner et al. 2009).

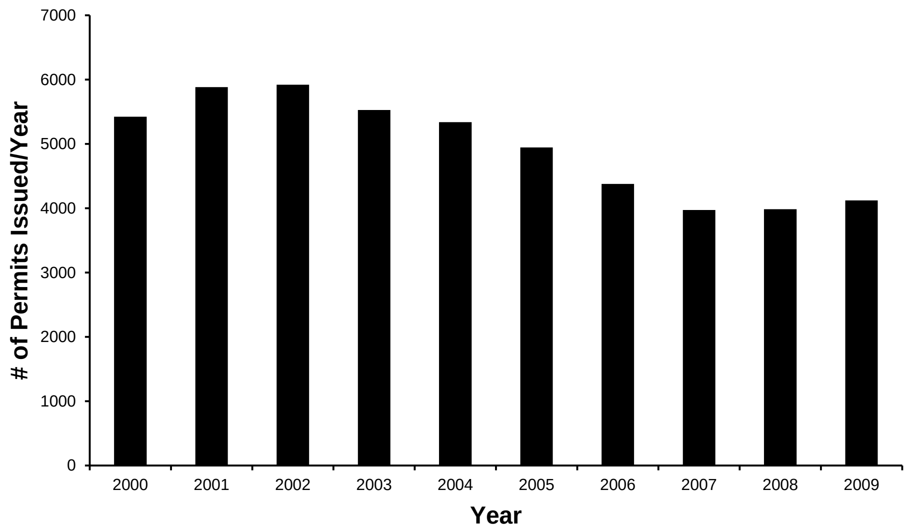

Figure 2. Number of permits issued for backcountry camping in BIBE from 2000 through 2009 (reproduced from Turner et al. 2009).

BIBE also offers a unique opportunity for birding because it is located at a bottleneck of several migration routes. During the winter months, northern species are visible, while spring brings birds from the tropics (NPS 2011b). Forty percent of visitors participate in bird watching (Littlejohn 1992).

2.2 Natural Resources

2.2.1 Ecological Units and Watersheds

BIBE is part of the Environmental Protection Agency's (EPA) Chihuahuan Deserts Level III Ecoregion. The following is a description of this ecoregion from EPA (2010):

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

The EPA divides Level III Ecoregions into smaller Level IV Ecoregions. In BIBE, the Chihuahuan Deserts Ecoregion consists of three Level IV Ecoregions: the Chihuahuan Desert Grasslands, Chihuahuan Montane, and Low Mountains and Bajadas Ecoregions (Plate 1) (EPA 2010). BIBE is located in region 13 of the Rio Grande watershed. Locally, the park encompasses five watershed cataloging units (Table 2; Texas NRCS State Office 2008)

Table 2. Watershed cataloging units located within BIBE.

Hydrologic Unit Code	Name	Area (ha) contained within BIBE
13040203	Black Hills – Fresno	6,550.89
13040204	Terlingua	26,593.26
13040205	Big Bend	245,082.05
13040206	Maravillas	4,850.24
13040207	Santiago Draw	46,012.93

2.2.2 Resource Descriptions

BIBE encompasses a wide variety of habitats, including deep canyons, grasslands, riparian habitats, and wetland areas found along the Rio Grande River. BIBE is also home to numerous natural springs that are spread throughout the park (NPCA 2003).

The Chihuahuan Desert is the easternmost arid environment in North America (Plumb 1992). The vegetation varies with the changes in elevation and precipitation across the park (Plumb 1992). The Chihuahuan Desert shrubland is located at the lowest elevations and supports low-water plants such as creosotebush (*Larrea tridentata*), yucca (*Yucca* spp.), ocotillo (*Fouquieria splendens*), lechuguilla (*Agave lechuguilla*), and numerous cacti (Cactaceae family). As the elevation increases, the shrubland vegetative zone gives way to the sotol grassland area. Named after the common sotol plant (*Dasylirion* spp.), the grassland is dominated by grama grasses (*Bouteloua* spp.) and succulent plants. At the park's highest elevations are the woodland areas, situated in the Chisos Mountains. The woodland vegetation located above 1,100 m (3,700 ft) is dominated by piñon pine (*Pinus cembroides*), junipers (*Juniperus* spp.), and oaks (*Quercus* spp.).

The park supports numerous reptile and amphibian species. BIBE has documented 39 species of snakes, 23 lizard species (NPS 2010c), and six turtle species (including the non-native red-eared [elegant] slider [*Trachemys scripta elegans*]), (Schmidly et al. 1996). Twelve species of amphibians are present in BIBE, all of which are anurans (frogs or toads) (NPS 2010c). Two of the amphibian species in the park are non-native species (American bullfrog [*Rana catesbeiana*], and green treefrog [*Hyla cinerea*]). The amphibian population in the park is unique in its diversity, as only 3% of anuran species worldwide exist in desert ecosystems due to the harsh conditions and limited water sources (Dayton et al. 2004). Adequate water sources are required for successful reproduction; amphibians in a desert ecosystem likely go for years without a successful breeding event (Dayton 2005). Amphibians are particularly susceptible to ecological changes due to their permeable skin, which absorbs toxins that can quickly spread throughout the ecosystem as amphibians are important prey for many species. For this reason, amphibians can act as a key indicator of ecosystem health (Smith and Keinath 2007).

Over half of the bat species in the United States occur in the BIBE area (Bryan 1989). Bat populations are critically important indicators of an ecosystem's overall health because they possess ecological and economic value as ecosystem components and are exceptionally vulnerable to rapid population declines (O'Shea et al. 2003). One bat species in BIBE, the Mexican long-nosed bat (*Leptonycteris nivalis*), is listed as endangered by the International Union for Conservation of Nature (IUCN), the state of Texas, and the United States Fish and Wildlife Service (USFWS) (USFWS 1994).

Before the park's establishment, black bears (*Ursus americanus*) were common in the Chisos Mountains (Borell and Bryant 1942). However, by the time the park was established, the species had been extirpated from the area (NPS 2009). In 1988, black bears recolonized the park, due in part to the natural restoration and preservation of habitat. Black bears in BIBE are unique in that they do not enter a true hibernation, and are dormant for just three to four months (January-March or April) a year. Food is very limited for bears in the park (which is a major reason for the small population in the park), and when they emerge from their dens in the spring they are very challenged to find adequate nourishment. Approximately 8-12 black bears reside in the park. However, researchers believe that park habitat supported 25 to 30 bears in the past (NPS 2009).

Mountain lions (*Felis concolor*) are vital in maintaining the biological diversity of BIBE (NPS 2002). The species plays a critical role in ensuring that herbivore populations stay within the food resource limits of the ecosystem. In BIBE, mountain lions primarily prey on deer (*Odocoileus* spp.) and javelina (*Dicotyles tajacu*) (NPS 2002). They range throughout the park, inhabiting the river flood plain, shrub desert, sotol grassland, woodland, and Chisos Mountains. The population was estimated at 30 mountain lions in 1984. However, it decreased to approximately 20-25 by 1985 (Pence et al. 1986).

In 1905, desert bighorn sheep (*Ovis canadensis mexicana*) were present in the Chisos Mountains and the Santa Elena Canyon (Bailey 1905, Cook 1991). However, prior to the establishment of BIBE in 1944 (NPS 2006), they were extirpated from the area by hunting and disease (transmitted by domestic livestock). Populations have established adjacent to BIBE, most notably the Elephant Mountain Wildlife Management Area (EMWMA) and the BGWMA (Froylan Hernandez, TPWD Desert Bighorn Sheep Program Leader, pers. communication, 2011). Bighorn restored to BGWMA have ranged into the northern Deadhorse Mountains of BIBE since 1995. TPWD also began restoring bighorn to Big Bend Ranch State Park in 2010. South of BIBE, the CEMEX corporation has for a number of years conducted a program to restore bighorn to the Sierra del Carmen of Mexico's Maderas del Carmen protected area.

Currently, the bighorn population in the park is small, and Roemer and Schwenke (2003) consider their presence in the park "rare". Important habitat requirements for the species include open landscapes next to steep mountains or canyons with slopes greater than 60% (TPWD 2010). Depending on the season, desert bighorn sheep forage primarily on shrubs and different plants; water is required year round and is a limiting factor in home range selection (TPWD 2010).

Over 400 species of birds, about 40% of which are migratory species, have been confirmed in BIBE (LCAS 2010), making the park a destination location for bird watchers from across the world. BIBE is also home to several unique species whose home ranges only extend into the U.S. near the U.S./Mexico border, with perhaps the best example being the Colima warbler (*Oreothlypis crissalis*). The Colima warbler's breeding range in the United States is restricted to the Chisos Mountains found within BIBE (Chipley et al. 2003, NABCI 2011). BIBE is also home to several species of conservation concern; perhaps most notable of these species is the black-capped vireo (*Vireo atricapilla*), which is federally listed as endangered (USFWS 2007). The yellow-billed cuckoo, also found in the park, is currently a candidate species to be listed as threatened under the Endangered Species Act.

Due to BIBE's remote location, infrequent cloud cover, and low humidity, BIBE provides some of the darkest night skies in the continental United States. On clear nights, visitors can see thousands of stars, as well as planets, meteorites, zodiacal light, and the Andromeda Galaxy (NPS 2011b). In 2012, BIBE was designated as a Gold Tier International Dark Sky Park by the International Dark-Sky Association (IDA) (NPS 2012); only three other National Park units (Natural Bridges National Monument, Death Valley National Park, and Chaco Culture National Historic Park) have been classified as Gold Tier parks, and BIBE has the darkest recorded night skies of those three parks (NPS 2012, IDA 2013).

2.2.3. Resource Issues Overview

<u>Historic Grazing Practices</u>
Prior to park establishment, independent farmers and the ranching industry brought herds of cattle, sheep, and goats to the area and overgrazed the park's grassland and woodland areas; the effects of this overgrazing are still present in the basin (Whitson 1974). Broomweed (*Gutierrezia sarothrae*) is prevalent, and has been found to increase and persist for long periods after grazing (Cottle 1931, Whitson 1974). Other effects of overgrazing include dense stands of prickly pear (*Opuntia* spp.) that were not obvious in 1935 (Warnock 1967, Whitson 1974), over-browsing of older trees, the establishment of lechuguilla in the lower basin, and scattered stands of creosotebush near eroded sites in BIBE (Whitson 1974).

<u>Air and Water Quality</u>
Pollution is having a significant effect on air quality, despite the remoteness of the park. Generally, most days are moderately hazy and have poor visibility. Conditions of less than 48.3 km (30 mi) visibility occur only 6% of the time (NPS 2011c). Depending on the season, air quality conditions vary significantly in BIBE. On a few days of the year, BIBE experiences the worst air quality of any western national park (NPS 2011c). Sulfate compounds are the largest contributing factor to particulate haze (accounting for approximately 50% in BIBE, annually), with the remaining particulate haze comprised of dust and carbonaceous compounds (Pitchford et al. 2004). Pollution sources from coal burning power plants and other industrial operations in northeastern and central Mexico, eastern Texas, along the Gulf coast (Houston, TX, and Galveston, TX), and other parts of the southern and eastern U.S. particularly affect visibility in the park, and contribute to deposition of nitrogen and sulfur onto park lands (Malm 1999, Pitchford et al. 2004, NPS 2011d).

Water quality and supply are constant issues for BIBE, due to the desert climate (Gray et al. 2007). Communities in both the United States and Mexico influence the water quality of the Rio Grande (NPS 2010d). The projected increase in the population near the Rio Grande's watershed in both Mexico and the United States is expected to put additional pressure on the already overburdened river system. Due to major impoundments and diversion, peak flow has significantly decreased just upstream of the park (NPCA 2003) Generally, BIBE water sources were below the EPA's maximum contaminant levels (MCL) for heavy metals and other chemical pollutants (Gray et al. 2007). However, Glenn Spring and an additional, unnamed spring west of Rio Grande Village were over MCL for arsenic, and water samples from Croton Spring indicated that fluoride levels were above MCL (Gray et al. 2007).

Climate Change

Desert and mountain climates are some of the most complex and variable in the world, and their response to climate change may be equally as complex (Barry 1992, Whiteman 2000, Warner 2004, Herbert 2006). Predictions suggest that Texas will warm at relatively the same rate as the global average (Herbert 2006). However, changes in precipitation levels are expected to be complex, most likely increasing in the eastern parts of the state, and remaining the same or decreasing in the west (Griffiths 1995, North 1995, Mellilo et al. 2001, Herbert 2006). Climate change in BIBE is expected to follow this same pattern (Herbert 2006).

The aquatic ecosystems of the arid southwest are regarded as biodiversity hotspots. Precipitation is critical to ensure that seeps and springs continue to flow and supply surface water to the most restricted habitats. Climate change could alter the size, frequency, and duration of precipitation events that would alter surface water quantity and seasonal patterns of flooding and droughts (NPS 2013). Changes in temperature and precipitation patterns may affect vegetation cover (abundance, type, and distribution) in watersheds, which would likely affect the magnitude and duration of flood events, sediment loads, and water chemistry (NPS 2013). Therefore, changes in climate patterns have the potential to shift the distribution of some plant communities, and threaten the continued existence for others (NPS 2013).

Exotic Species

Exotic plant species and invasive species can cause fragmentation of native habitat, displacement of animals, and may alter the fire regime (Young et al. 2007, NPS 2013). While the exact number of invasive plant species in BIBE is unknown, it is estimated that over 200 invasive plants have the potential to threaten park resources. In a study conducted in 1998, two species, saltcedar (*Tamarix* spp.) and buffelgrass (*Pennisetum ciliare)* were identified as having the greatest negative impact on the park's resources, outside of the Rio Grande corridor. Bermudagrass (*Cynodon dactylon*), Lehmann's lovegrass (*Eragrostis lehmanniana*), and Johnson grass (*Sorghum halepense*) also have the potential to negatively impact the park (Young et al. 2007).

In recent years, the park has begun more active management of exotic vegetation in the Rio Grande corridor. Since 2005, bi-national projects to reduce dominance of both saltcedar and giant cane (*Arundo donax*) have been successful ,and areas of the Rio Grande in the east side of the park are largely free of dense exotic vegetation. Saltcedar leaf beetles (*Diorhabda* spp.) were introduced in 2009 (NPS 2007) and have significantly reduced saltcedar dominance throughout the Big Bend reach of the Rio Grande.

Many exotic vertebrate species have the potential to disrupt the ecosystem and the native species that inhabit it by competing for food and water resources, competing for territories, introducing foreign diseases, and creating the potential for hybridization (NPS 2006).

Twenty-five non-native animal species currently inhabit BIBE, including birds, mammals, fish, amphibians, reptiles, and clams (Reiser et al. 2012)

The water requirement of feral hogs (*Sus scrofa*) restricts their habitat to close proximity of riparian areas and springs (Choquenot and Ruscoe 2003). They often degrade these critical habitats by rooting, causing erosion, and spreading disease to native species (NPS 2006). The feral hog population is believed to be limited to the northeastern section of the park (NPS 2006).

Barbary sheep (*Ammotragus lervia*), also known as aoudad, are a non-native species that have several well-established populations throughout Texas. Barbary sheep have inhabited BIBE for about 20 years, however the population size is unknown (NPS 2006). They are a socially dominant species and limit resources for native desert bighorn sheep (Mungall and Sheffield 1994, NPS 2006). Barbary sheep also have the potential to harbor diseases that desert bighorn sheep are susceptible to (Simpson et al. 1978, Richomme et al. 2005, NPS 2006).

<u>Development and Related Issues</u>
Development and activities associated with it are an obvious concern in any national park, where the primary goal is to protect natural resources in a largely natural setting. In an arid region such as BIBE, development is a particular threat due to the demand it can place on an already limited water supply. There are three main developed areas within the park providing interpretive facilities, lodging, and/or other services: Panther Junction, the Chisos Basin, and Rio Grande Village (Alex et al. 2005, Plate 2). Smaller developments (e.g., ranger or entrance stations) are found at Castolon and Persimmon Gap. The main visitor center and park offices, along with the majority of staff housing and maintenance facilities, are located at Panther Junction (Alex et al. 2005). Facilities at Chisos Basin include a lodge, restaurant, and shop for visitors (NPS 2011e).

The park faces a dilemma, as current facilities may not meet visitor and staff needs (e.g., housing shortages, crowded campgrounds and parking lots, deteriorating water and wastewater systems), but the areas and resources available for development within BIBE are limited (NPS 2004). Power lines and structures are already obstructing scenic views along roads and trails and in key resource areas (NPS 2004). Developments such as roads can also alter water regimes (e.g., increased runoff and ponding) and facilitate exotic plant invasion and establishment (Whitson 1974, Alex et al. 2005).

Number of Acres(or Hectares) Affected by Development
The five developments within the park are shown in Plate 2. A total of 1,281.6 ha (3,167 ac) are affected by these developments, which is less than 1% of the total park area. The area covered by each individual development is shown in Table 3 below.

Table 3. Area of developments within BIBE. Note that the Panther Junction area also includes the nearby sewage treatment plant.

Development	Area (ha)
Rio Grande Village	654.9
Panther Junction	212.3
Castolon	209.9
Chisos Basin	193.3
Persimmon Gap	11.2
Total	1,281.6

Water Use
Water in BIBE's developed areas is supplied by groundwater. The Chisos Basin's water is pumped from Oak Springs, 3.2 km (2 mi) to the west (NPS 2004). During high visitor use, the spring supply is barely sufficient to meet visitor and staff needs, leaving little water for vegetation and wildlife at the spring itself (NPS 2004).

Acres of Roadside Affected by Exotics
Soil disturbance from development and human activity make roadsides particularly vulnerable to exotic plant species invasion. In the past, exotic species may have been intentionally planted to stabilize roadsides (Alex et al. 2005) or in the landscaping around park developments (e.g., Chisos Basin visitor facilities) (Whitson 1974). Some of the species currently of the most concern include Lehmann's lovegrass, buffelgrass, and Johnson grass (Sirotnak 1998, Leavitt et al. 2010). Two exotic species in the park - saltcedar and giant cane - are on the Texas noxious weed list (NRCS 2012)

The earliest study to focus on exotic plant species along BIBE's roads and developed areas took place in 1998 (Sirotnak 1998). At that time, 60 exotic plant species had been documented in the park. Researchers identified and mapped 870 individual exotic plant patches occupying a total of 64 ha within the park (Sirotnak 1998, Plate 3). The areas covered by individual species are presented in Table 4.

Table 4. Number of patches and total area covered by exotic species during the 1998 roadside survey (Sirotnak 1998).

Species	Number of patches	Total area (ha)
Bermudagrass	91	11.53
Lehmann's lovegrass	338	9.53
buffelgrass	264	8.89
Russian thistle	11	4.47
Johnson grass	122	28.64
saltcedar spp.	28	1.35
other exotics	16	0.02
Total	**870**	**64.43**

Since this initial survey, park staff have monitored and treated various sections of the park roads and developed areas for exotic species every year. In 2008, the most recent year for which exotic plant data have been analyzed, staff treated three different species (saltcedar, buffelgrass, and giant cane) covering 6.7 ha (16.6 ac) and 6.6 km (3.1 mi) of roadside (Plate 4). In 2007, 21 ha (52 ac) of exotic plants were treated ,while in 2006 treatment occurred on just 2.6 ha (6.5 ac). However, these numbers do not represent a full park-wide survey of the total roadside and developed area impacted by exotics within the park.

In 2010-2011, the CHDN conducted a pilot exotic plant monitoring study throughout its network parks, which included surveying along 29.9 km (18.6 mi) of BIBE roads, trails, and other developed areas (Reiser et al. 2012). Survey areas in BIBE were divided into 1,195 50-m blocks; approximately 82% of these were located along paved roads, including paved roads in developed campgrounds, lodging areas, and visitor centers, as well as the two entrance roads and the road from the primary visitor center to Rio Grande Village (Reiser et al. 2012). A total of 24 exotic species were detected along roads and other developed areas; approximately 29% of surveyed blocks contained exotics. The percent of blocks with exotics, sorted by use and/or surface type are shown in Table 5; individual species and their prevalence are presented in Table 6.

Table 5. Number and percent of surveyed blocks containing exotic plant species (Reiser et al. 2012)

	Total blocks	Paved roads	Trails		Other[1]
			Paved	Unpaved	
Total blocks sampled	1195	977	12	176	30
Blocks with exotics	344	279	0	35	30
% blocks with exotics	28.8%	28.6%	--	19.9%	100.0%

[1] = areas around park facilities (e.g., visitor center, parking lots, sidewalks, motel)

Table 6. Exotic species documented in CHDN surveys and their prevalence (Reiser et al. 2012).

Scientific name	Common Name	# of blocks	% of blocks
Eragrostis lehmanniana	Lehmann lovegrass	233	19.5
Bothriochloa ischaemum	King Ranch bluestem	134	11.2
Cynodon dactylon	Bermudagrass	61	5.1
Sorghum halepense	Johnsongrass	26	2.2
Marrubium vulgare	horehound	25	2.1
Calyptocarpus vialis	straggler daisy	21	1.8
Paspalum dilatatum	dallisgrass	17	1.4
Pennisetum ciliare	buffelgrass	17	1.4
Tribulus terrestris	puncturevine	14	1.2
Digitaria sanguinalis	hairy crabgrass	9	0.8
Echinochloa colona	jungle rice	7	0.6
Salsola tragus	prickly Russian thistle	7	0.6
Eragrostis cilianensis	stinkgrass	5	0.4
Taraxacum officinale	common dandelion	5	0.4
Verbena brasiliensis	Brazilian vervain	5	0.4
Amaranthus blitoides	mat amaranth	3	0.3
Bromus catharticus	rescuegrass	3	0.3
Medicago polymorpha	burclover	3	0.3
Erodium cicutarium	redstem stork's bill	2	0.2
Portulaca oleracea	little hogweed	2	0.2
Digitaria ciliaris	southern crabgrass	1	0.1
Nicotiana glauca	tree tobacco	1	0.1
Solanum lycopersicum	garden tomato	1	0.1
Tamarix species	tamarisk or saltcedar	1	0.1

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

BIBE's General Management Plan (GMP) (NPS 2004) provides park staff guidance for decisions regarding management of natural and cultural resources, visitation, and development for the next 15 to 20 years. Based on the park's mission and mandate statements, the main purposes of the park are to:

- maintain and protect cultural resources and values;

- encourage understanding and appreciation of natural and human history for the region by providing educational opportunities;

- provide recreational opportunities to various groups interested in park appreciation and protection.

The BIBE Water Resources Management Plan (WRMP; NPS 1996) is complimentary to the park's General Management Plan, and provides a thorough review of existing water resource information. The WRMP overviews existing water resource conditions and issues, and provides alternative management strategies for addressing these areas. This report was prepared to address several specific issues, among these were:

- the assurance of adequate and safe water supplies for present and future needs of all facilities located in the park;

- transboundary water resource issues stemming from the reach of the Rio Grande river that comprises both the southern boundary of the park and the international boundary between the United States and Mexico;

- flood hazards and flood plain management;

- fisheries and biological resource management;

- back country water resource monitoring and management.

The purpose of the Fire Management Plan (FMP) (NPS 2005) is to protect people, property, and resources within the park, as well as provide a transition from fire suppression to allowing natural fires to shape and structure the park's vegetation. Specific goals of the fire management program are outlined below in the order of priority.

Goal 1: Protecting people and property.

- protect the public, staff and fire personnel by preventing injury;

- reduce the use of fuels which may negatively affect life and property;

- provide public education to prevent fires caused by humans;

- maintain safe emergency exits from all park areas in case of fire.

Goal 2: Accomplish natural resource management objectives by applying wildland fire use, prescribed fire, non-fire fuel reduction measures, and fire suppression.

- establish the range of variability of the natural fire-return intervals;

- determine desired conditions and condition classes for vegetation categories;

- fire is to be used as a restoration or maintenance tool;

- adjust fire management as new knowledge becomes available and monitor results.

Goal 3: Accomplish cultural resource management objectives by applying wildland fire use, prescribed fire, non-fire fuel reduction measures, and fire suppression.

- reduce fuels around sensitive sites by utilizing prescribed fire or non-fire fuel reductions tools;

- cultural landscapes will be restored and/or maintained;

- after fire operations take advantage of surveying opportunities.

Goal 4: Minimize fire program activities that cause unacceptable environmental impacts on park resources.

- conduct pre-action surveys and properly plan fire management activities;

- determine prescriptions carefully;

- Fires that fail to meet management objective will be suppressed;

- use minimum impact suppression tactics (MIST);

- discuss with resource advisors.

Goal 5: Cooperate with adjacent landowners in fire management practices conducted near the park's boundaries.

- maintain communication and provide fire program education to neighbors;

- conduct joint fire management activities and formalize relationships with park neighbors.

Goal 6: Fire activities shall be coordinated with all park divisions, concessionaires, and the public.

- maintain communication using the daily briefing sheet, website, and interpretive programs will all parties;

- bring together structural and wildland fire planning operations;

- all park divisions will cooperate appropriate tasks for fire management.

The goals of the Recreational River Use Management Plan (RRUMP) (NPS 1997) are to provide a long-term plan for recreational river use activities that preserves environmental processes and the park resources of the river corridor, while maintaining the visitors' expectations. To achieve these goals, the main objectives outlined in the RRUMP are to

- provide a variety of sociological experiences for river users;

- distribute river use between various groups;
- provide visitors of most ages, abilities, and physical limitations access to the river corridor for recreational use;
- establish guidelines for motorized watercraft;
- define procedures to dispose of human waste;
- establish fishing guidelines within the river corridor;
- create a program to educate the public about the RRUMP;
- create management policies based on sound data and encourage inventory and monitoring of natural, cultural and recreational resources.

The Backcountry Management Plan (BCMP) (NPS 1995) was created to serve multiple purposes. It is intended to address strategies for meeting legislative and policy mandates to provide recreational opportunities while preserving the natural and cultural resources of the park, to provide continuity for management, and to serve as a forum for the public, other agencies, and interested organizations. To ensure these purposes are achieved, the following are specific objectives listed in the BCMP:

- provide a wide variety of appropriate visitor activities to ensure a quality backcountry experience;
- preserve the environmental integrity, solitude, and primitiveness of the backcountry by establishing impact limits;
- manage natural and cultural resources while protecting sensitive resources and allow the function of natural processes;
- implement NPS policies regarding recommended and potential wilderness management;
- provide the appropriate level of public safety;
- provide visitors with information for a successful experience that also maintains the integrity of park resources.

2.3.2 Status of Supporting Science

The Chihuahuan Desert Network (CHDN) Inventory and Monitoring Program 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 2010b). Table 7 shows the network vital signs selected for monitoring in BIBE.

Table 7. CHDN Vital Signs selected for monitoring in BIBE (NPS 2010b). 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 in concert with other networks, using funding from the Vital Signs or water quality monitoring programs.

Category	CHDN Vital Signs
Air and Climate	**Ozone**, **wet and dry deposition**, **visibility and particulate matter**, **and basic meteorology**
Geology & Soils	**River channel characteristics**, *soil hydrologic function, biological soil crusts, and soil erosion (wind and water)*
Water	*Groundwater quantity, surface water dynamics*, *persistence of springs, surface water quality, and aquatic invertebrates*
Biological Integrity	*Invasive/non-native plants, plant community composition, and bird communities*

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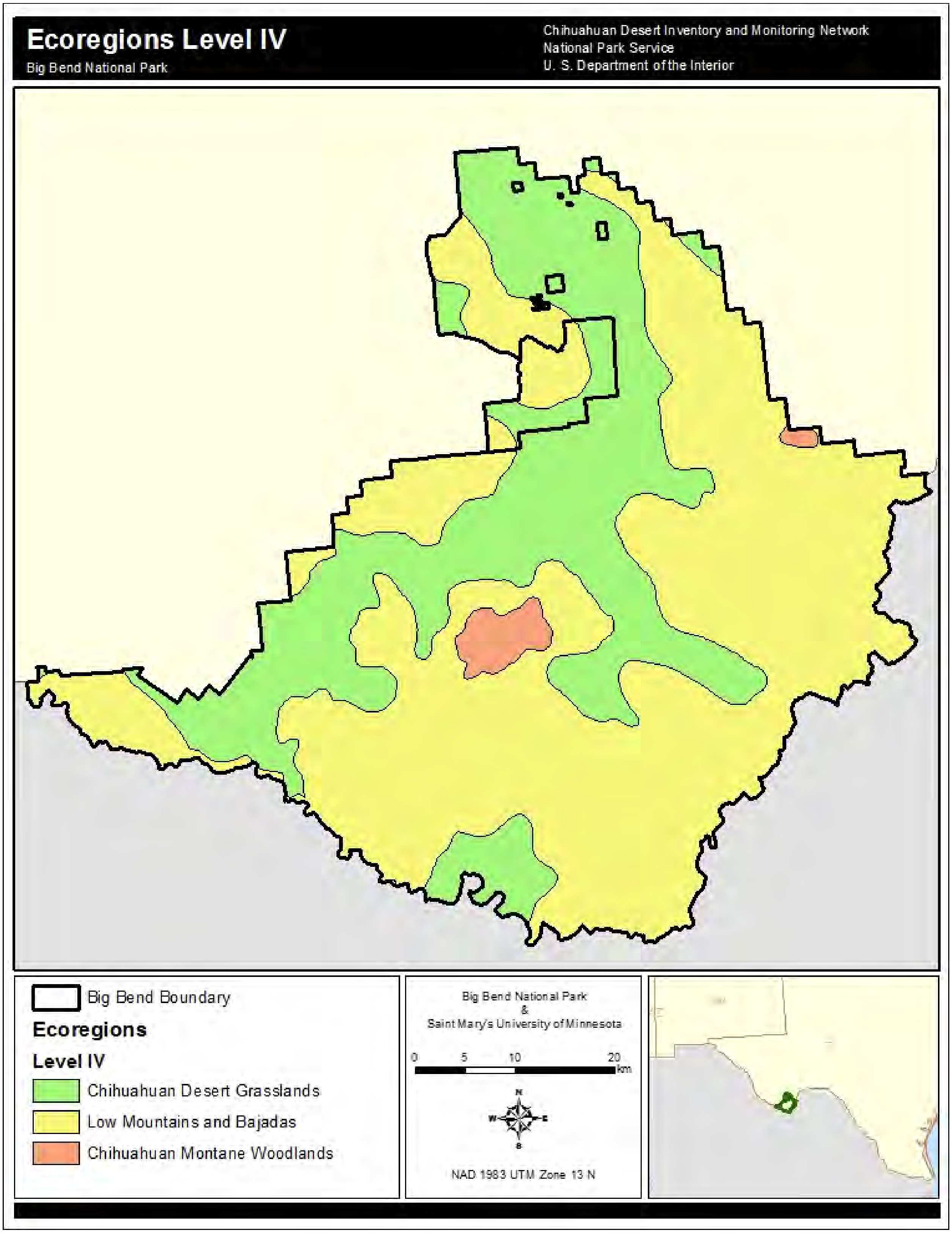


Plate 1. Regional EPA Level IV Ecoregions (EPA 2011).

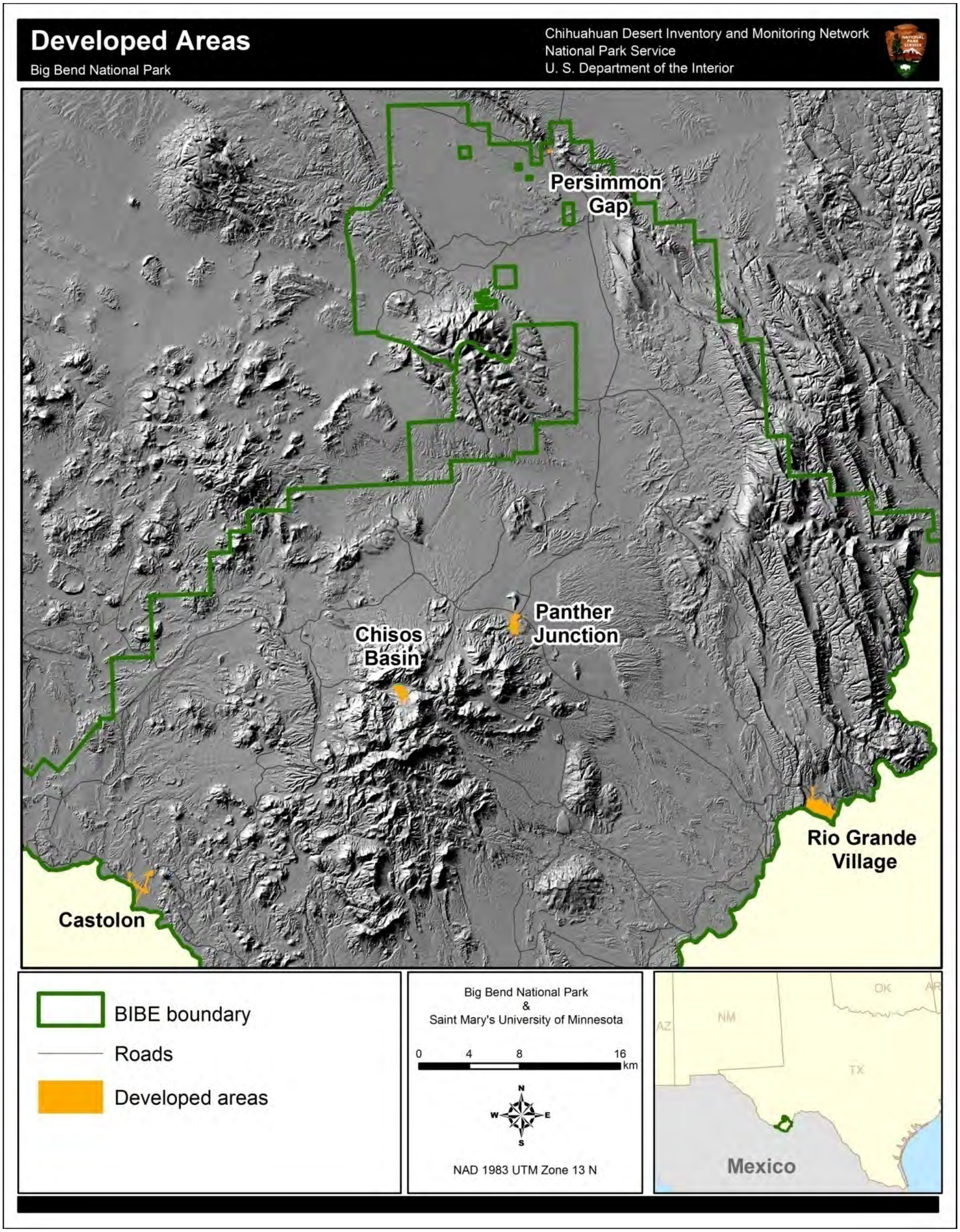


Plate 2. Developed areas within BIBE.

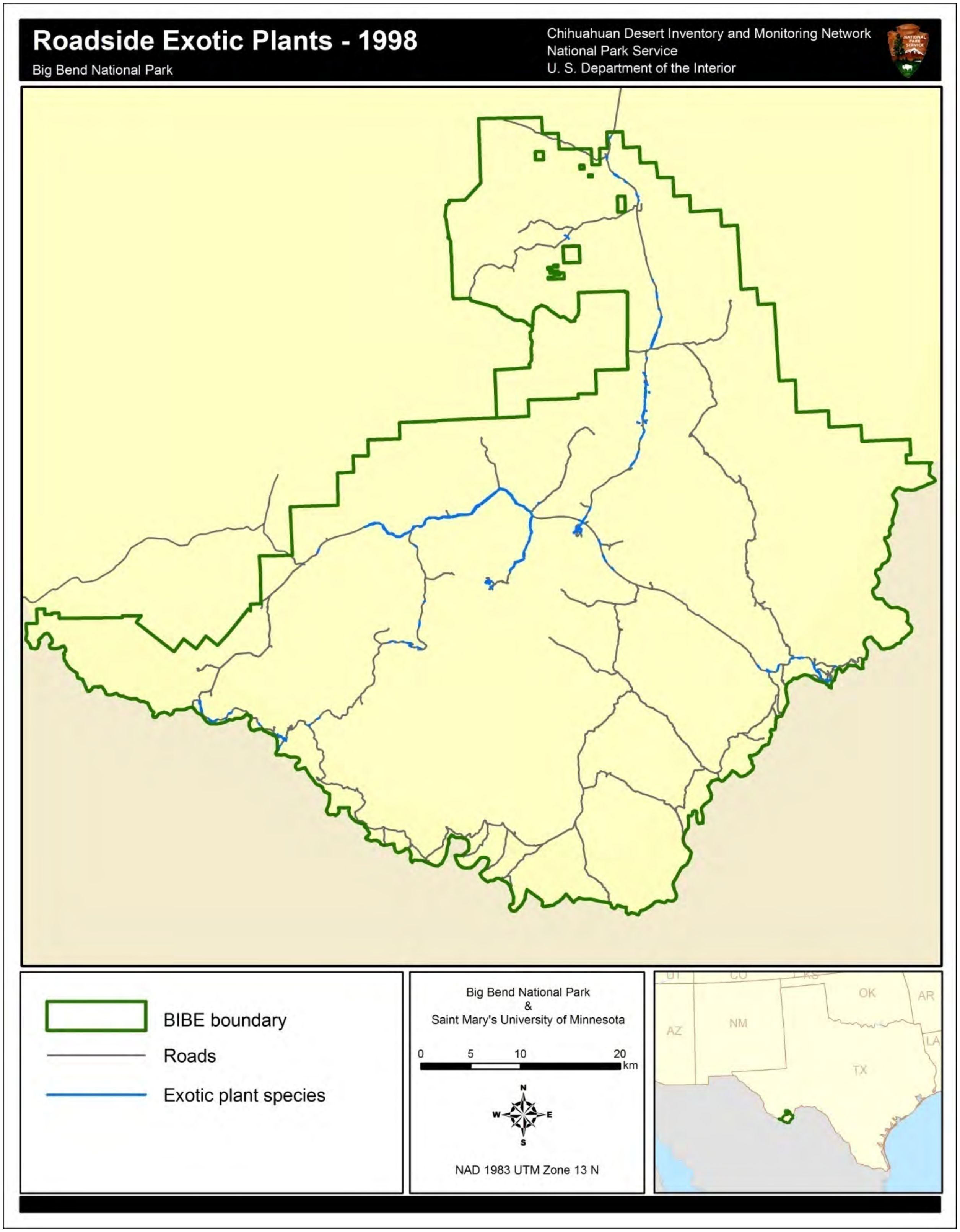


Plate 3. Extent of exotic plant species along roads and developed areas within the park in 1998.

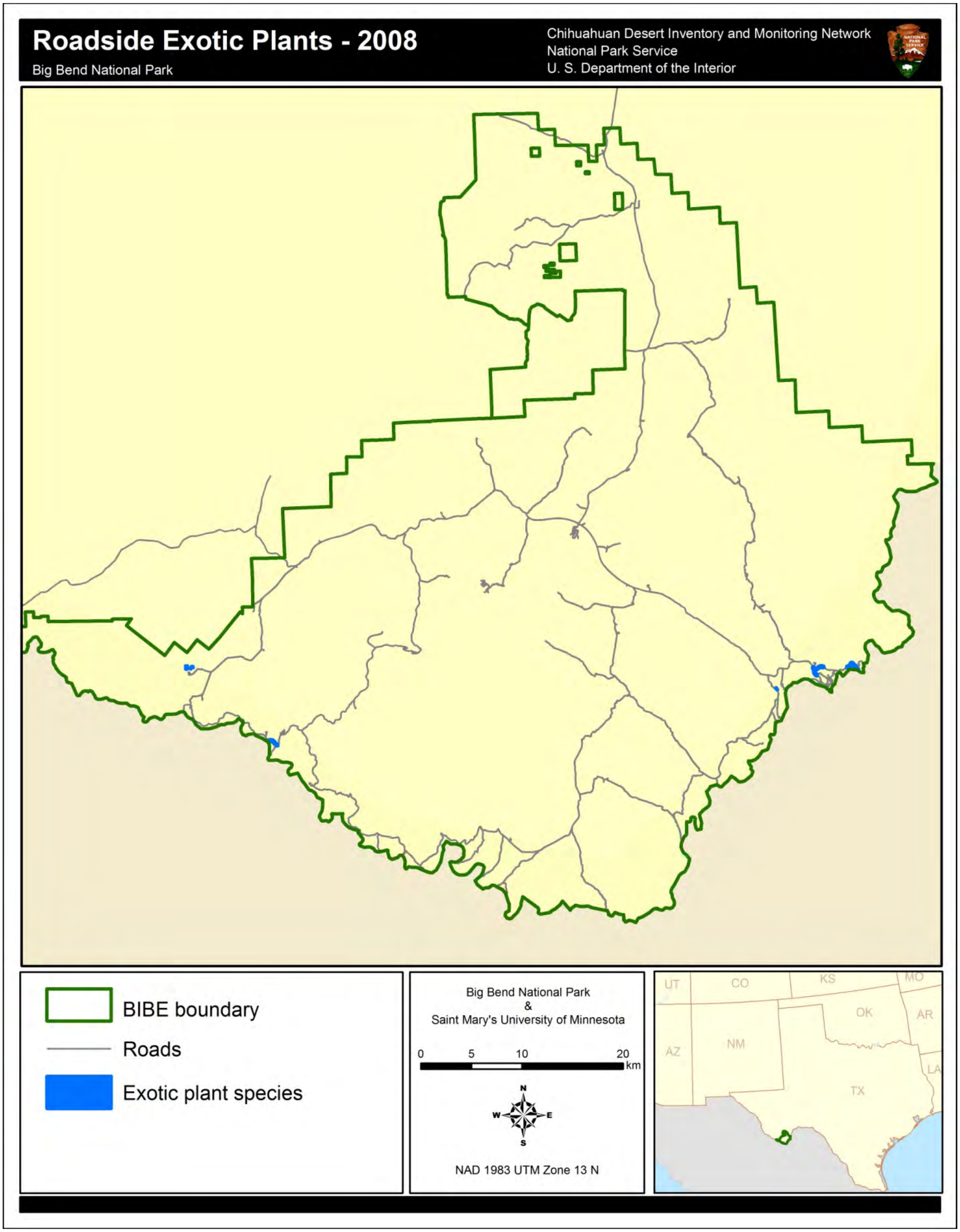


Plate 4. Exotic plants treated along roads and developed areas in 2008. Note that these numbers do not represent a full park-wide survey of the total roadside and developed area impacted by exotics within the park.

Chapter 3 Study Scoping and Design

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

3.1 Preliminary Scoping

A preliminary scoping meeting was held on 29 June 2010. At this meeting, SMUMN GSS (via phone link) and NPS, CHDN ,and park staff confirmed that the purpose of the BIBE 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 BIBE managers. A draft framework (that was provided before the meeting) was also discussed. There were several follow-up conference calls through December 2010. 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 BIBE resource management;

This condition assessment provides a “snapshot-in-time” evaluation of the condition of a select set of park natural resources that were identified and agreed upon by the project team. Project findings will aid BIBE 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 BIBE resource staff, the NPS Integrated Resource Management Application (IRMA) website, Inventory and Monitoring Vital Signs, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project;

- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point;

- Clearly identify "management critical" data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process;

- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually;

- Utilize "gray literature" and reports from third party research to the extent practicable.

3.2 Study Design

3.2.1 Indicator Framework, Focal Study Resources and Indicators

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

"Components" in this process are defined as natural resources (e.g., birds), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current park management. Each key resource component has one or more "measures" that best define the current condition of a component being assessed in the NRCA. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of a component. In addition to measures, current condition of components may be influenced by certain "stressors," which are also considered during assessment. A "stressor" is defined as any 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 BIBE NRCA scoping process, key resource components were identified by NPS staff and are represented as "components" in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the park, it includes resources and processes that are unique to the park in some way, or are of greatest concern or highest management priority in BIBE. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

<u>Selection of Reference Conditions</u>
A "reference condition" is a benchmark to which current values of a given component's measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an

established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., a bison herd of at least 200 individuals) (adapted from Stoddard et al. 2006).

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

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science’s “State of Our Nation’s Ecosystems 2008” (Heinz Center 2008). 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 the end of January 2011 following a post-scoping workshop 4-6 January 2011, and acceptance from NPS resource staff. The framework was amended the end of October 2012 to reflect the deletion of three components (Flooding, Landcover, and Development and Related Activities). The amended framework contains a total of 21components (Table 8) and was used to drive analysis in this NRCA. This framework outlines the components (resources), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each component for comparison to current conditions.

Table 8. Big Bend National Park natural resource condition assessment framework.

BIBE Framework
Natural Resource Condition Assessment Framework

Component	Measures (Significance Level)	Stressors	Reference Condition
Ecosystem Extent and Function			
Disturbance Regimes			
Fire	Frequency (2), Severity (3), Fuel Loading and Distribution (3), Location (1), Intensity (1)	Climate change, exotic plant species, past management practices, fire regime shifted from frequent low intensity to large more severe starting in 1900s; past fire suppression; past grazing practices & other land use & past natural climate patterns	Pre-Anglo settlement (from Helen Mills-Poulos for Chisos area)
Biotic Composition			
Ecological Communities			
Spring Habitats	Plant Community Composition (3), Species Richness of Macro/microinvertebrates (3), Groundwater Levels (3),	Precipitation amounts and seasonal timing of rainfall events, watershed management as relates to recharge, overuse, contaminants, fire	Earlier spring condition reports (varies from 1976 to present). See Betty's comments
Montane Forest/Sky Islands	Forest Community Structure (3), Carmen White-tailed Deer Population Size (2), Acorn Woodpecker Abundance (2), Eastern Cottontail Abundance (2), Canyon Treefrog Abundance (2), Guadalupe Fescue Abundance (1)	Fire, higher temperatures (drying conditions), change in seasonal rainfall/timing, overuse.	Pre-Anglo settlement
Desert Grasslands	Total Acreage (1), Fragmentation (3), Patch Size (3), Grassland Bird Diversity (2)	Invasive plant species, grassland degradation and erosion, altered fire regime, climate change	Pre-Anglo settlement
Rio Grande Riparian Community	Size and distribution of riparian species (2), aquatic inverts metrics (maybe IBI is done) (2), Width/depth ratio of river channel (3), water quality (3)	Channel narrowing, sediment balance, upstream diversion, invasive species	"Pre-river regulation, or post reset events";
Birds			
Birds	Grassland Species Diversity (3), Breeding Bird Diversity (3), Migratory Species Diversity (3), Peregrine Falcon Population Size (1), Black-capped Vireo Breeding pairs (2)	Grassland degradation, degradation of wintering/migratory habitat; modern alterations fostering non-native competition; seliunum & mercury contaminanation	Pre-agricultural US/Mexico conditions
Mammals			
Black Bear	Population Size (abundance) (3), Genetic Conservation (1), Regional Population Size (2), Quality of Mast Production (3)	Poor mast conditions due to climatic variation, lack of connectivity to historic (outside BIBE) populations, high visitor use of critical bear habitat (high density trail network, Chisos Basin), genetic isolation	Intact regional metapopulation of the late 19th/early 20th centuries
Mountain Lion	Population Size (3), Genetic Conservation (1)	Persistence of populations outside of park (genetic integrity), agricultural predator-control practices (killing of lions), consistent visitor-use of the high-density Chisos trail network, and the Chisos Basin visitor-use development within the small high value lion habitat (Chisos Mountains)	Pre-Agricultural US/Mexico conditions

Table 8. Big Bend National Park natural resource condition assessment framework (continued).

BIBE Framework

Natural Resource Condition Assessment Framework

	Component	Measures (Significance Level)	Stressors	Reference Condition
Biotic Composition				
Mammals				
	Desert Bighorn Sheep	Population Size (3), Barbary Sheep Distribution (3)	Disease from domestic sheep, habitat alteration, small population size, Barbary sheep (food/territory competition, diseases, social dominance).	Sites outside of park where Texas Parks and Wildlife Dept. have restored bighorn to near stable populations
	Bats	Species Diversity (3), Mexican Long-Nose Bat roosting colony size (2), Paniculate Agave Abundance (2), Metapopulation size of Mexican Long-Nose Bat (2)	Cave roost disturbance (particularly migrant sp.), extermination south of border (perception of rabies/vampire bats)	Pre-Agricultural US/Mexico conditions
Aquatics				
	Macroinvertebrates	Species Richness (3), Species Abundance (2), Species Distribution (3)	Water chemistry; toxics; exotics & non-natives (competitors); stream channel condition and characteristics; altered flow regimes; episodic oxygen defieciency & their anthropogenic influence as related to oxygen def.; parasites & diseases because of previous stressors - those stressors could increase incidents of p & d; exteripation or status of larva fish host	Pre-dam conditions on both the Rio Conchos & the upper Rio Grande
	Fish	Inventory (3), Big Bend Mosquito Fish Population Size (2), Big Bend Mosquito Fish Genetic Conservation (1)	Water chemistry; toxics; exotics & non-natives (competitors); stream channel condition and characteristics; altered flow regimes; episodic oxygen defieciency & their anthropogenic influence as related to oxygen def.; parasites & diseases because of previous stressors - those stressors could increase incidents of p & d	Pre-dam conditions on both the Rio Conchos & the upper Rio Grande
Herptiles				
	Amphibians	Species Diversity (3), Species Distribution (2)	Precipitation amounts and seasonal timing of rainfall events, overuse, contaminants, fire	Pre-Rio Grande alteration conditions
	Reptiles	Species Diversity (3), Species Distribution (2)	Poaching, road-kill	Unknown
Environmental Quality				
	Air Quality	Ozone (2), Mercury (2), Visibility (3), Sulfate (3), Nitrogen (1), PM 2.5 (3)	Smog and pollution from industrial and transportation sources	Pre-Anglo settlement
	Water Quality	Total Dissolved Solids (TDS) (3), Chloride (3), Sulfate (3), Dissolved Oxygen (3), Coliform Bacteria (1), Macroinvertebrates (2)	Water diversions upstream, groundwater extractions, non point sources and point sources (water treatment and disposal)	Pre river regulation

Table 8. Big Bend National Park natural resource condition assessment framework (continued).

BIBE Framework
Natural Resource Condition Assessment Framework

Component	Measures (Significance Level)	Stressors	Reference Condition
Environmental Quality			
Soundscape	Occurrence of Human-caused Sound (3), Natural Ambient Sound Level (3)	Vehicular road noises, park construction activities, recreational vehicle generators (campgrounds), aircraft overflights	All vehicles meet NPS decibel maximum standards, all generators are best-available technology, and non-essential overflights are not allowed over NPS lands
Viewshed	Change since 1997 integral vista photography (3)	Development within and outside of park, light pollution, visibility	Undeveloped and natural park setting (Integral Vistas will be helpful here)
Dark night skies	V-Magnitude (3)	Long-range air pollution, improperly shielded NPS lighting, long-distance light domes	Park, local communities, and distant cities meet International Dark Sky Association night sky lighting standards
Physical Characteristics			
Geologic & Hydrologic			
Hydrology/Spring Hydrology	Quantity of Discharge (3), Quality of Discharge (3)	Watershed alterations as relates to recharge, changes to characteristics of precipitation, atmosheric deposition of pollution	Pre development
Soils	Soil Texture (1), Soil Structure (3), Organic Matter Content (2), Infiltration (2), Soil Aggregate Stability (3), Inorganic Nitrogen Accumulation (2), % Cover of Soil Crusts (3)	Alterations to hydrologic patterns (i.e. roads, fences), legacy management activities (grasslands restoration efforts of the 1950s and 1960s), soil erosion (grasslands), climate change, atmospheric deposition of nutrients/pollutants	Pre-Anglo settlement

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.

<u>Data Mining</u>

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

<u>Data Development and Analysis</u>

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available for the component and recommendations from NPS reviewers and sources of expertise including NPS staff from BIBE 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.

<u>Scoring Methods and Assigning Condition</u>

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 9. This categorization allows measures that are more important for determining condition of a component (higher significance level) to be more heavily weighted in calculating an overall condition. If a measure is given a Significance Level of 1, it is thought to be of low importance when determining the overall condition of the component. For this reason, measures with a Significance Level of 1 are not discussed in detail in the Current Condition and Trends section of a component’s chapter. Significance Levels were determined for each component measure in this assessment through discussions with park staff and/or outside resource experts.

Table 9. 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 10). This is based on all the available literature and data reviewed for the component, as well as communications with park and outside experts.

Table 10. Scale for Condition Level of individual measures.

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

Weighted Condition Score

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

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

The resulting WCS value is placed into one of three possible categories: condition of low concern (WCS = 0.0 – 0.33); condition of moderate concern (WCS = 0.34 - 0.66); and condition of significant concern (WCS = 0.67 to 1.00). Figure 3 displays all of the potential graphics used to represent a component's condition in this assessment. The colored circles represent the categorized WCS; red circles signify a significant concern, yellow circles a moderate concern and green circles a condition of low concern. Gray circles are used to represent situations in which SMUMN GSS analysts and park staff felt there was currently insufficient data to make a statement about the condition of a component. The arrows inside the circles indicate the trend of the condition of a resource component, based on data and literature from the past 5-10 years, as well as expert opinion. An upward pointing arrow indicates the condition of the component has been improving in recent times. A right-pointing arrow indicates a stable condition or trend and an arrow pointing down indicates a decline in the condition of a component in recent times. These are only used when it is appropriate to comment on the trend of condition of a component. A gray, triple-pointed arrow is reserved for situations in which the trend of the component's condition is currently unknown.

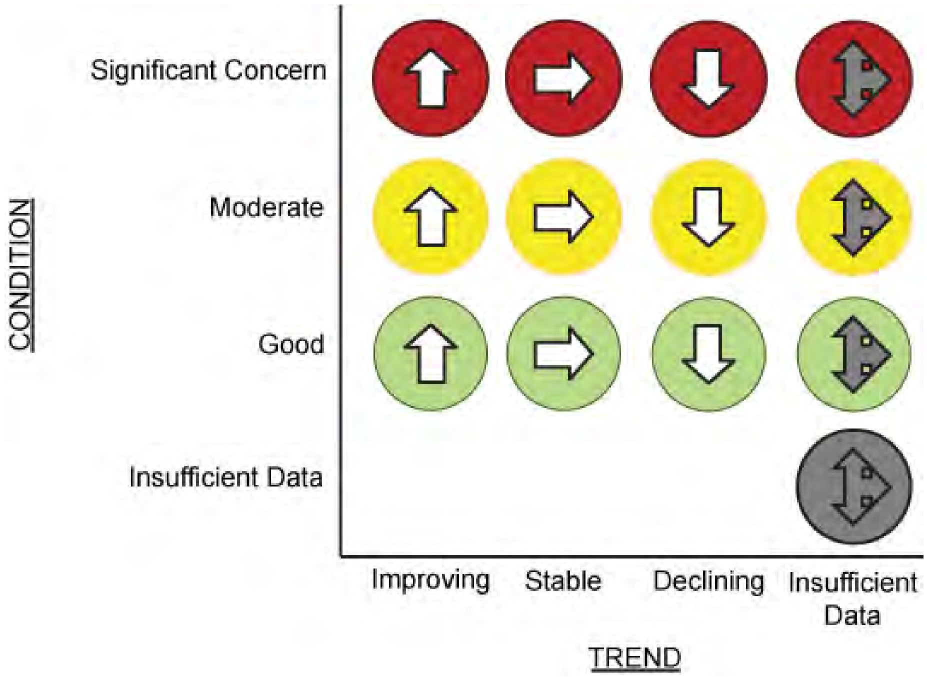


Figure 3. Symbols used for individual component assessments with condition or concern designations along the vertical axis and trend designations along the horizontal.

<u>Preparation and Review of Component Draft Assessments</u>

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

<u>Development and Review of Final Component Assessments</u>

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 BIBE resource staff and other experts, the final component assessments represent the most relevant and current data available for each component and the sentiments of park resource staff and resource experts.

Format of Component Assessment Documents

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

Description

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

Measures

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

Reference Conditions/Values

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

Data and Methods

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

Current Condition and Trend

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

Threats and Stressor Factors

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

Data Needs/Gaps

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

Overall Condition

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

Sources of Expertise

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

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 section'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).

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 21 key resource components in the project framework. The following sections discuss the key resources and their measures, stressors, and reference conditions. The summary for each component is arranged around the following sections:

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

The order of components follows the project framework (Table 8):

4.1 Fire
4.2 Spring Habitats
4.3 Montane Forest/ Sky Islands
4.4 Desert Grasslands
4.5 Rio Grande Riparian Community
4.6 Birds
4.7 Black Bear
4.8 Mountain Lion
4.9 Desert Bighorn Sheep
4.10 Bats
4.11 Macroinvertebrates
4.12 Fish
4.13 Amphibians
4.14 Reptiles
4.15 Air Quality
4.16 Water Quality
4.17 Soundscape
4.18 Viewscape
4.19 Dark Night Skies
4.20 Hydrology/Spring Hydrology
4.21 Soils

4.1 Fire Regime

4.1.1 Description

A common definition of fire regime is the frequency, size, seasonality, intensity and type of fire occurrence in a given area over a specified period of time (Krebs et al. 2010). However, Krebs et al. (2010, p. 61-62) state that “at the highest level of complexity, i.e. reality, a fire regime is a sequence of fire events with some stable, recurrent cyclic characteristics or properties (with all the conditions and consequences directly involved in burning processes) affecting a specified spatial and temporal window.” Although not as frequent as in many western U.S. forests, fire in BIBE is an important natural disturbance and ecosystem driver; fire helps to maintain grasses in the understories of piñon-oak woodlands of the Chisos Mountains, curbing the encroachment of shrubs (Photo 1). Historic (before 1937) fire regime in these vegetation communities was fairly typical of ponderosa pine and southwestern white pine of the southwest United States (Poulos et al. 2013). However, the fire regime of BIBE has been altered by humans beginning with fires set by Native Americans during pre-Anglo settlement times, then indirectly through livestock grazing beginning with Anglo settlement around 1890 (first cattle, then sheep and goats). From 1934 to 1980, fires were actively suppressed by the Civilian Conservation Corps (CCC) and later by the NPS. Livestock grazing, namely improper grazing practices, resulted in passive fire exclusion in the southwestern United States because of reductions in or even complete elimination of fine herbaceous fuels (Swetnam and Baisan 1996). Direct fire suppression was first initiated by a CCC camp in 1934 in what is now BIBE (NPS 2005) and continued with NPS fire suppression policies during approximately the first 36 years of the park’s existence (the park was established in 1944). These suppression activities removed fire from the landscape for many decades and caused changes in forest stand structure and fuel loads (Camp et al. 2006). Additional indirect, human effects on fire regime in the park have occurred through the introduction of non-native invasive plants (e.g., *Tamarix* spp. and several non-native grasses), and from other land uses (e.g., development), which have altered vegetation composition and fuel distribution, and resulted in unnatural fuel loading.

Photo 1. Telephone Canyon Fire, March 2006, in the Chisos Basin of BIBE (Photo by Tom Alex, BIBE).

Hazard fuels have accumulated in the park as a result of past fire exclusion (NPS 2005). The park's FMP is designed to address this by using prescribed fire and non-fire fuel treatments to reduce the risk of severe, un-planned fires. According to the most recent FMP, the park has three primary categories related to fire management in the park : 1) unplanned ignitions; 2) planned ignitions (prescribed fire); and 3) non-fire fuel treatments.

The NPS can allow fires caused by natural fire ignitions to burn or suppress them depending on conditions, whereas fires from all unplanned human-caused ignitions are to be suppressed. Management of naturally caused wildland fires is based on prevailing management objectives. If the issue is mitigating risk to human health and safety, the fire is generally suppressed. If achieving some resource (cultural or natural) objective is the issue, the fire will be managed to meet those objectives. The fire can be managed to meet multiple objectives and they can change as the fire moves across the landscape. The NPS can manage naturally ignited fires in a number of ways depending upon the objectives to be met. First and foremost of these objectives is to protect human health and safety of fire fighters, the public and park staff, followed generally by the protection of the park infrastructure and cultural and natural resources. Achieving these objectives will dictate how the fire is managed.

Prescribed fires, or planned ignitions, are used to achieve a variety of resource management goals; fires can be set to reduce hazard fuels, conduct fire and vegetation research, and restore and or maintain fire adapted ecosystems (NPS 2005). While the FMP is designed to address fire in the park as a natural disturbance regime, the park must also incorporate fire prevention and suppression strategies in order to protect at-risk developments, prevent spread to adjacent privately-owned lands, ensure visitor and employee safety, and protect cultural and natural resources from fire impacts (NPS 2005).

According to the NPS (2005), differing fire management strategies are applied to each of three park-established fire management units (FMUs) (NPS 2005). It is especially important in the Chihuahuan Desert that fire be characterized by geographic or vegetative unit because of factors such as episodic drought and large variations in topography, elevation, and climatic variables (Reiser et al. 2006). This assessment will focus on FMU #3, the Chisos Mountains. This unit contains the majority of the forest vegetation types listed in NPS (2005), grassy woodlands, and montane forests. It's boundary in the park is shown with a dashed outline in Plate 5. It also contains some shrub desert, high desert grasslands, and shrub woodlands (Figure 4; NPS 2005). FMU #3 is a special fire treatment zone where prescribed fires are being evaluated to achieve a variety of management objectives (NPS 2005). The grassy woodlands and forests in this FMU include the piñon-juniper vegetation type and several other diverse, mixed conifer forest types that have received recent research attention regarding fire regime and forest stand dynamics (e.g., Camp et al. 2006 and Poulos et al. 2009). This FMU encompasses approximately 15,783 ha (39,000 ac) (NPS 2005), and it contains the isolated montane forest areas referred to as "sky islands", known for high floral biodiversity and species richness (Camp et al. 2006).

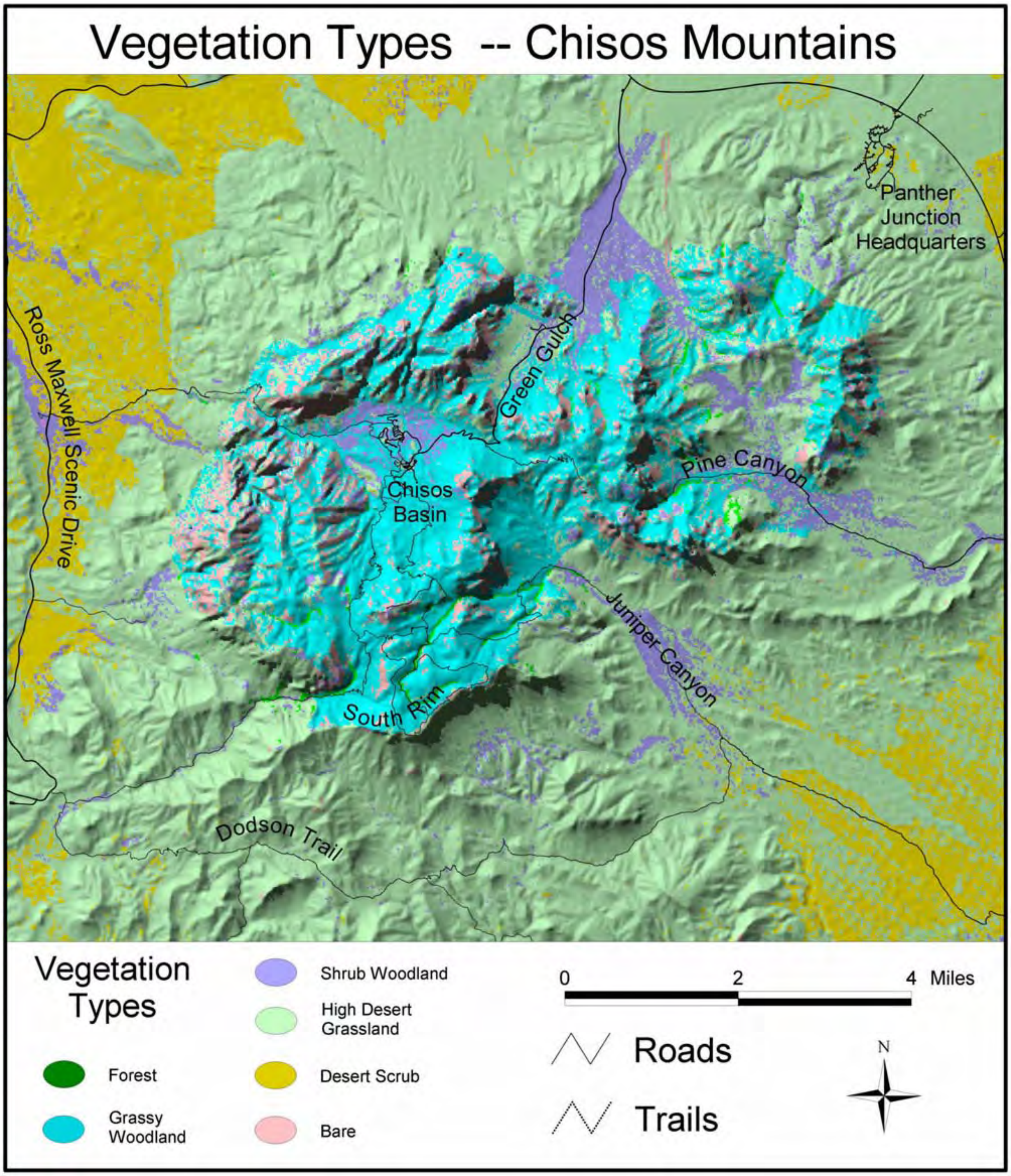


Figure 4. Vegetation types in the Chisos Mountains (FMU #3). Reproduced from NPS (2005). Vegetation types from Plumb (1992).

Piñon pine – juniper woodland, a fire-adapted vegetation community in the park, is composed of Mexican piñon, juniper, oak, and mixed-conifer tree species with the following dominant species: *Juniperus deppeana*, *Quercus grisea*, *Q. gravesii*, *Q. emoryi*, and *J. flaccida* (Poulus et al. 2009). An example of a Piñon–oak-juniper vegetation community is shown in the foreground of Photo 2.

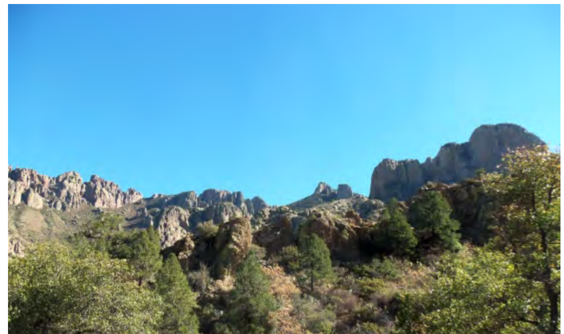


Photo 2. Piñon-oak juniper woodland in BIBE (NPS Photo).

Fires also occur in other plant communities of BIBE, particularly high desert scrub areas and high desert grasslands such as sotol grasslands. Historic fire frequencies are difficult to determine in the mosaic of grasslands, shrublands, and savannas. This is due in part to the fact that fire's effects (at least those measured by vegetative cover, vigor, and composition) do not persist in grasslands for more than a few years (Wright and Bailey 1982, Poulos et al. 2009). Another confounding factor in determining grassland fire frequency is evidence of the pre-Anglo settlement fires set by Native Americans (Humphrey 1958, Hastings and Turner 1966). According to the mean fire return interval layer, a modeled GIS output of LANDFIRE (Landscape Fire and Resource Management Planning Tools), much of the park's surface has indeterminate fire regime characteristics (i.e., fire return intervals are not known and therefore are not represented in this GIS product) (Plate 6). According to the LANDFIRE fire regime GIS layer, areas with indeterminate fire regime characteristics generally coincide with grassland areas of the park, as identified by the Plumb (1992) vegetation classification. Joe Sirotnak (BIBE Botanist/Ecologist, email communication, 23 January 2013) asserts that fires were likely infrequent in these grasslands, and that it may not be appropriate to assume that the introduction of fire would stimulate the remaining grasslands in BIBE (i.e., those that were either not grazed or those that eventually became re-vegetated with grasses), as it does in more mesic grasslands. Likewise, Hastings and Turner (1965) and York and Dick-Peddie (1969) state that desert grasslands may not have experienced frequent fire, and when they did, they may have been relatively small because of discontinuous fine fuels and low biomass.

Richard Gatewood (Fire Ecologist, Southwest Texas, Permian and Southern Plains Fire Groups, written communication, 2 May 2013) suggests that contemporary fire occurrence in these grasslands is likely determined by the amount of precipitation that occurred during approximately one to five preceding years, especially for large fires. Analysis of precipitation patterns at BIBE and Carlsbad Caverns National Park suggest that there may be a threshold precipitation level required before enough fine fuel has accumulated to sustain fire spread over large areas. Thus, short-term precipitation patterns may be a determinant to fire occurrence in desert grasslands in the absence of grazing. However, compounding this are the effects that heavy grazing may have had in altering the fine fuel matrix from pre-settlement condition. Most suppositions regarding fire occurrence are based on these altered desert grasslands, which are likely at some stage of "recovery". The frequency of fire going forward will, in Richard Gatewood's assessment (written communication, 2 May 2013), be determined by fine fuel accumulation, largely in response to variation in precipitation patterns. Lastly, Richard Gatewood (written communication, 2 May 2013) suggests that fine fuel accumulation could also be augmented by an increased presence of non-native grasses such as Lehmann's lovegrass or buffelgrass.

4.1.2 Measures

- Fire frequency

- Fire location
- Fire severity
- Fuel loading and distribution

4.1.3 Reference Conditions/Values

The ideal reference condition for this component would be the fire regime that existed in the region prior to Anglo settlement. Unfortunately, information is not available from this time period for all of the above measures. The following subsections (fire frequency, intensity and severity, and fuel loading and distribution) report reference conditions related to each measure. However, Poulos (2009, p. 1925) suggests that "restoration of vegetation and fuels to conditions that resemble conditions prior to fire suppression may not be a feasible goal on all forestlands." In these cases, the Poulos (2009) research, and other similar research, can be used to inform fire management decisions that are intended to maintain ecosystem structure and function.

Fire Frequency

Fire frequency is often expressed as mean fire return interval (MFRI), defined as the arithmetic average of all fire intervals, determined in years, for a designated area during a specified time period (McPherson et al. 1990). The reference condition for this measure is the pre-Anglo-settlement fire frequency. For much of the park this historic (pre-Anglo-settlement) fire return interval is difficult to determine, especially in the lower elevation systems of the Chihuahuan Desert (Dick-Peddie 1993). In fact, much of the land outside of the Chisos Mountains in BIBE is represented as undetermined MFRIs in a modeled GIS layer created by LANDFIRE (LANDFIRE MFRI 2006). Instead, the reference condition for this measure will focus on the fire scar and forest structure research in the Chihuahuan Borderlands, specifically the high Chisos Mountains of BIBE which are encompassed by FMU #3.

FMU #3

Moir (1982) conservatively estimated a 70-year fire-return interval in examining fire-scarred trees in Boot Canyon and the Southeast Rim in the high Chisos Mountains of the park (within FMU #3). The author recommended that fuel-reduction fires be set approximately every 50 years as a way to maintain natural population structures of piñon savannas (woodlands) and canyon cypress forests. Later, Camp et al. (2006) examined piñon pine fire history and forest structure, and determined a 7.5-year MFRI (range 2-34 years) prior to fire exclusion in BIBE (1786-1900) for fires scarring 10% or more of the total trees in their samples.

Poulos et al. (2009) examined Mexican piñon pine trees in a 75 m (146 ft) radius around 65 vegetation plots (a larger sample size than that of Moir [1982]) and calculated a pre-fire exclusion (i.e., pre-Anglo settlement, approximately 1700 to 1930) MFRI of 36.5 yrs (range 9-74 yrs) in BIBE. Major fire years were 1880, 1903, 1916, and 1926, with most fires (76.5%, N = 450) occurring during spring time (Poulos et al. 2009). In contrasting this MFRI with some other contemporary research results (Floyd et al. 2000, 2004, 2008; Huffman et al. 2008), Poulos et al. (2009) found that in BIBE, fires occur more frequently and the High Chisos Mountains may also experience fewer stand-replacing fires than in areas examined by those studies. However, to explain these differing results, the authors note the study areas in the comparative research are less topographically complex than within BIBE and suggest that steep slopes in BIBE may have helped fires move from lower grasslands to up-slope forests. The steeper slopes may also have caused fires to move more rapidly, allowing older tree cohorts to survive fires.

<u>Location</u>

A basic piece of information for understanding fire regimes is the geographic location of a fire event. The NPS now maintains two GIS datasets, a point fire occurrence dataset and a fire perimeter polygon dataset, which contain location and several other attributes of fires in the park. These GIS datasets begin with the earliest recorded fire event in 1946 and are current through 2003 for this assessment. The sources of this information range from Department of Interior Individual Fire Reports (DI-1202), the park's GIS, strategic air command (SAC) reports, and various burn plans and pre-existing GIS datasets. The fire perimeter dataset contains fires 4 ha (10 ac) and larger, whereas the fire occurrence point dataset contains all known fires. While redundancy exists between these two datasets, fire perimeters are intended for fires greater than 4 ha (10 ac).

There is no reference condition for this measure (i.e., no desired condition); however, where fires occur on the landscape and how they relate to a multitude of geographic and environmental variables (e.g., slope, aspect, vegetation type, topographic complexity) are of great interest to fire researchers.

<u>Fire Severity</u>

For this assessment, information on fire severity is reported, but not fire intensity because intensity is a determinant of fire severity and because no specific, direct information is available for fire intensity in the park.

Keeley (2009) discusses some of the common confusion surrounding the terms fire intensity and fire severity as they relate to fire research, and provides an illustration of the relationships between the two terms and two fire outcome categories, ecosystem responses and societal impacts (Figure 5). Richard Gatewood (written communication, 2 May 2013) defines fireline intensity as the rate of energy (heat) released per a unit of time per linear unit of the flaming fire front, coupled with the rate of energy released per unit of time per unit area after the passing of the flaming front. That is, fireline intensity is a particular type of fire intensity measure commonly used to address the energy output of a fire in forest ecosystems (Keeley 2009). However, to measure this directly would require some form of instrumentation and measurements from such instrumentation are most likely to be found in experimental settings (Gatewood, written communication, 2 May 2013). Direct measurements of fireline intensity are not collected for BIBE fires. Fire or burn severity, on the other hand, is a term used to describe the physical and chemical changes to the soil, the conversion of vegetation and fuels to inorganic carbon, and structural or compositional transformations that create new microclimates and species assemblages (Key and Benson 2006). Fire severity can be measured by the amount of organic matter loss both above and below the surface of the ground after a fire, and fire severity has a strong influence over ecosystem responses to fires such as soil erosion, vegetative regeneration, restoration of community structure, faunal recolonization, or many other similar responses (Keeley 2009).

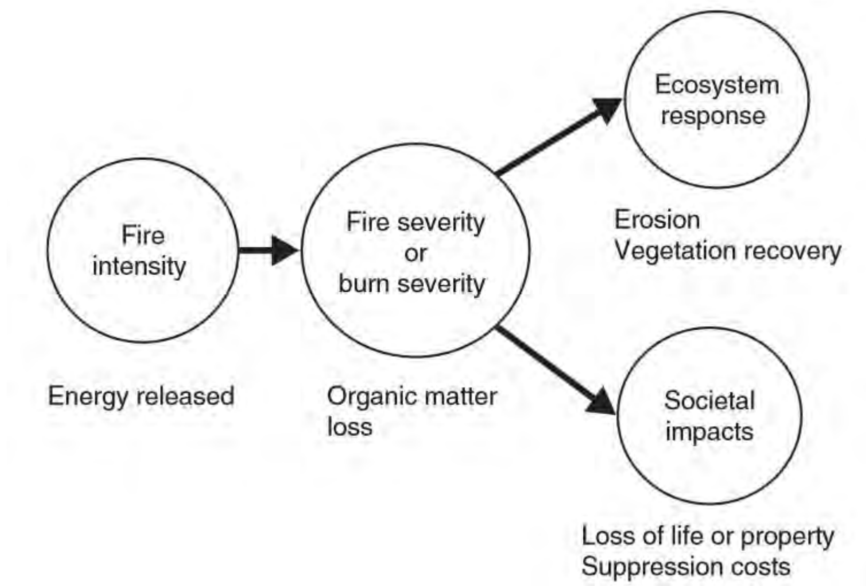


Figure 5. Schematic representation relating the energy output from a fire (fire intensity), the impact as measure by organic matter loss (fire or burn severity), and ecosystem responses and societal impacts. Reproduced from Keeley (2009).

Fire or burn severity is used as an "indicator" to infer how intense (level of fire intensity) a particular fire was in a particular area (Gatewood, written communication, 2 May 2013) or, conversely, fire intensity is measured or estimated during a fire as a "predictive tool for anticipating post-fire effects" (Keeley 2009, p. 116). Even though fire intensity acts as a determinant of fire severity, it is not necessarily true that low fire intensity will always result in low fire severity. Gatewood (written communication, 2 May 2013) notes that it is problematic when, during a fire, burning establishes in thick litter and duff layers and results in high burn severity, even though the fireline intensity may have been low. Therefore, fire intensity can act, along with other information such as fuel loading measures, as an indicator to fire managers of the potential effects a particular fire may have on soil and vegetation.

FMU #3

Moir (1982) found Mexican piñon pines to be resistant to low to moderate-severity fires. Similarly, Camp et al. (2006) and Poulos et al. (2009) suggest that piñon-juniper woodlands in BIBE historically experienced a low-intensity fire regime (presumably meant as a synonym to low-severity) because multiple fire scars were found in sampled trees (typically between one and four scars in each tree). The presence of multi-cohort stands of piñon pine also suggests fires were of low enough severity that trees were able to survive multiple fires. Generally, differences in fire regime characteristics between the Poulus et al. (2009) study site and other piñon-juniper woodlands in related fire research (e.g., less topographically diverse areas were often over 200-yr MFRI) suggest that across the southwestern U.S., these woodlands are adapted to mixed-severity fire regimes (Poulos et al. 2009). Along with fire frequency, Poulos et al. (2009) suggest that fire intensities are likely influenced by topography, but that more research on how topography may affect fire intensity and severity in these vegetation types is needed. NPS (2005) states that in the grassy woodlands of the High Chisos Mountains in FMU #3, fires were likely fast-moving and of low intensity.

Fuel Loading and Distribution

According to NPS (2005), determining the desirable conditions in terms of the types, amounts, and relative locations of fuels on the landscape represent important topics for continued fire research in BIBE. There is not a specific reference condition for this measure. Rather, fuels data are collected by on-the-ground sampling and, in many cases, are modeled in a GIS. Fuel maps can be created from vegetation maps, where each vegetation type has an associated fuel type. However, Camp et al. (2006) found that the fuel maps generated by their study differed greatly from the vegetation type fuel maps, because the fuels distribution varied more with the local physical environment than the vegetation type alone.

The process of determining desired fuel load conditions and condition classes for each vegetation category is ongoing. In relation to the fuel load conditions, the management plan does not specify how fuels will be assessed, rather it states the objective to reduce fuels in order to reduce threats on human life and property and generally to achieve natural resource management goals. The fire management plan (NPS 2005) lists several goals for the park and objectives for achieving each goal. Two primary goals related, broadly, to fire safety and to natural resource management in BIBE are as follows:

GOAL 1: Protecting people and property is the highest priority of every fire management activity.

Objectives to achieve goal:

- Prevent injuries to the public, staff, and fire personnel.
- Reduce fuels that could threaten life and property using prescribed fire and mechanical or other non-fire fuel reduction methods.
- Prevent human-caused wildland fires through public education.
- Maintain safe egress from all areas of the park in case of fire.

GOAL 2*:* Apply wildland fire use, prescribed fire, non-fire fuel reduction measures, and fire suppression to accomplish natural resource management objectives.

Objectives to achieve goal:

- Determine the natural range of variability of the fire-return intervals.
- Determine desired conditions and condition classes for vegetation categories.
- Use fire as a restoration tool and/or as a maintenance tool.
- Monitor results of fire program activities and adjust management based on new knowledge.
- Where possible, ultimately allow fire to resume its natural role in park ecosystems

NOTE: The above goals and objectives will be reevaluated and the current fire management plan will be rewritten. Specifically, the management alternatives will be reevaluated to incorporate the most current research (e.g., Camp et al. 2006, Poulos et al. 2009) for FMU #3 (Gatewood, written communication, 2 May 2013).

4.1.4 Data and Methods

Fire-related GIS datasets available from the NPS for BIBE used in this assessment include the following: a fire perimeter dataset (polygon), a fire occurrence dataset (point), and a fire management unit dataset (polygon). These data are used to report descriptive fire statistics in the current condition section of this assessment, summarized park-wide to provide a context for the park and by FMU #3, an area for which several published fire research articles are available. Areas reported for the fire occurrence points are not consistent across all fire points. For example, several fire occurrences from 1997 and 1998 were extinguished naturally and the 'CNTRL_ACRE' field for each was reported as 0.1 acre.

Additional GIS data regarding fire regime characteristics, as modeled by LANDFIRE, were downloaded from the LANDFIRE website. As of 2012, available GIS products regarding fire severity are primarily applicable to some areas of the park outside of FMU #3. Modeled GIS data relevant to BIBE include a MFRI continuous raster GIS dataset, a fuel characteristic classification system (FCCS) raster, a fuel loading model (FLM) raster, and a 2004 edition of fuels classification raster following the fire behavior prediction system (FBPS) made with input from NPS vegetation and fire experts familiar with BIBE fire and vegetation.

Vegetation GIS polygon data from Plumb (1992) is used to overlay existing fire GIS data, to report descriptive statistics of fire occurrences by vegetation form (a broad or coarse-level vegetation classification of the dataset), vegetation category (a finer level of the classification), and by elevation using an available 10 m (32.8 ft) digital elevation model (DEM).

4.1.5 Current Condition and Trend

<u>Fire Frequency</u>

Parkwide

Examination of the fire frequency (all general causes) for the entire park using existing NPS GIS fire occurrence point data, reveals that fire has occurred somewhere in the park every year from 1948 to 2003. However, in partitioning data into two time periods (before and after the initiation of the park's prescribed fire program in 1980), there were approximately four fires recorded each year from 1946 to 1979, and approximately 15 fires recorded each year from 1980 to 2003 (Figure 6). Over the 24-year period (1980 to 2003), the total number of fires increased nearly three-fold over the previous 34-year period (1946 to 1979). However, this increase in fire numbers was not only due to prescribed burns, but also due to an increase in lightning- and human-caused fires. It is also theorized that greater efforts may have been made to document fires in the park in recent decades and this may have contributed to the increase in the number of fires (Gatewood, written communication, 2 May 2013).

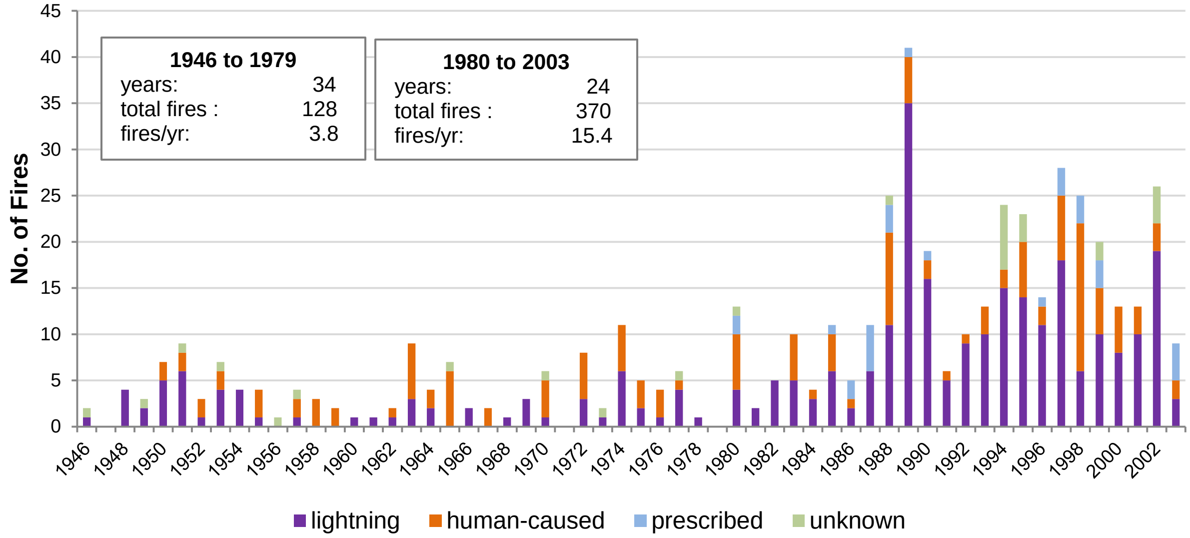


Figure 6. Number of park-wide fires by year and fire cause in BIBE; data from the fire occurrence GIS point dataset.

Similarly, more area in the park was burned after the initiation of the NPS prescribed fire program in 1980. From 1946 to 1979, a total of 3,495 ha (8,636 ac) burned, annualized at 103 ha/yr (255 ac/yr), according to the CNTRL_ACRE field in the GIS dataset. From 1980 to 2003, a total of 10,557 ha (26,136 ac) burned, or an average of 439 ha/yr (1,085 ac/yr) (Figure 7). The prescribed fire program has increased fire frequency across the park as a whole. With the exception of the 1974 Big Brushy fire that burned approximately 2,962 ha (7,320 ac), fire was largely absent from the park in terms of actual area burned from when record-keeping began (1946) to 1980 when NPS fire policies changed. Note, some fires reported in Figure 6 and Figure 7 are of unknown size and some lightning-caused fires noted to have extinguished naturally are reported as 0.1 acre fires according to the ‘CNTRL_ACRE’ field in the fire occurrence point GIS dataset.

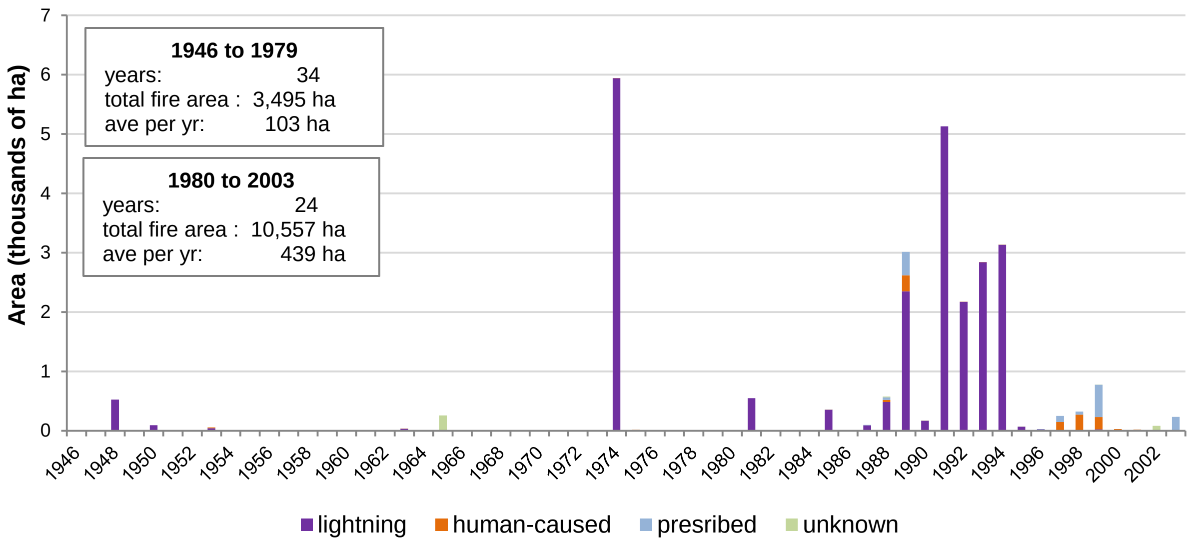


Figure 7. Area of fires by year and fire cause park-wide in BIBE, 1946-2003; data from the fire occurrence GIS point dataset.

FMU #3

Poulos et al. (2009) suggest that, historically, steep slopes in BIBE may have helped fires to move from lower elevation grasslands to up-slope forests, and fires may have traveled more rapidly on steep slopes than in other piñon pine forests and woodlands in the Chihuahuan Desert, allowing older cohorts of trees to survive. In a study area within FMU #3, based on fire-scarred piñon pines, the interval since the last fire was 16 years as of 2005 (Poulus et al. 2009). Fires occurred in spring or early summer, as evidenced by the majority of fire scars examined in this study being found in the earlywood of trees. From 1900 to 2003, Camp et al. (2006) calculated a MFRI (10% scarred) of 20.3 years (range 9-46).

According to the BIBE fire occurrence point GIS dataset, fire frequency in FMU #3 more than doubled for the period of time since prescribed fire was introduced. From 1980 to 2003, fire frequency in FMU #3 was 4.2 fires/year, compared with the period of record before prescribed fire (1946 to 1979) with a fire frequency of 1.6 fires/year (Figure 8). However, many of the fires recorded from 1946 to 1979 were very small, as most of the fires were quickly suppressed.

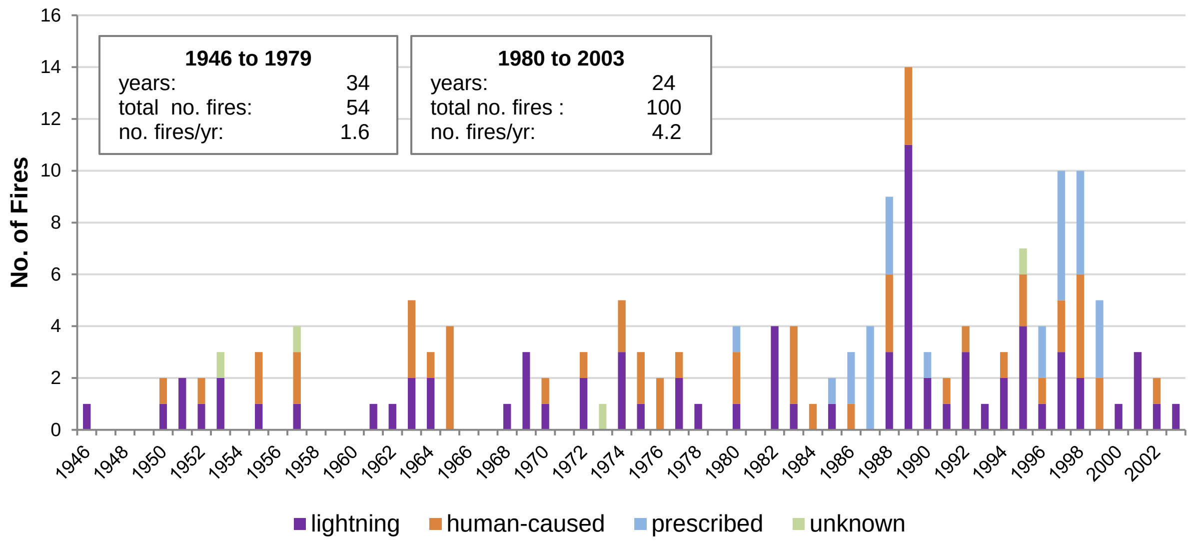


Figure 8. Number of fires by year and fire cause within FMU #3 of BIBE, 1946 to 2003; data from the fire occurrence GIS point dataset.

Perhaps more importantly, the total area burned in FMU #3 increased substantially after the beginning of the prescribed fire program. A comparison of area burned between these two time periods using the 'CNTL_AC' fields in both the BIBE fire occurrence point GIS dataset and the fire perimeter (polygon) dataset reveals the average area burned per year increased after the change of policies (i.e., the introduction of prescribed fire and the use of wildland fire), from approximately less than 1 ha/yr (2.5 ac/yr) to 49 ha/yr (121 ac/yr) (Figure 9). The reason for this large increase in total burn area was in part due to the use of prescribed fires, but to a greater extent because of large fire years in 1982, 1988, 1993, 1994, 1995, 1997, and 1998. During these years, human- or lightning-caused fires were allowed to burn larger areas than they might have burned under suppression policies prior to 1980.

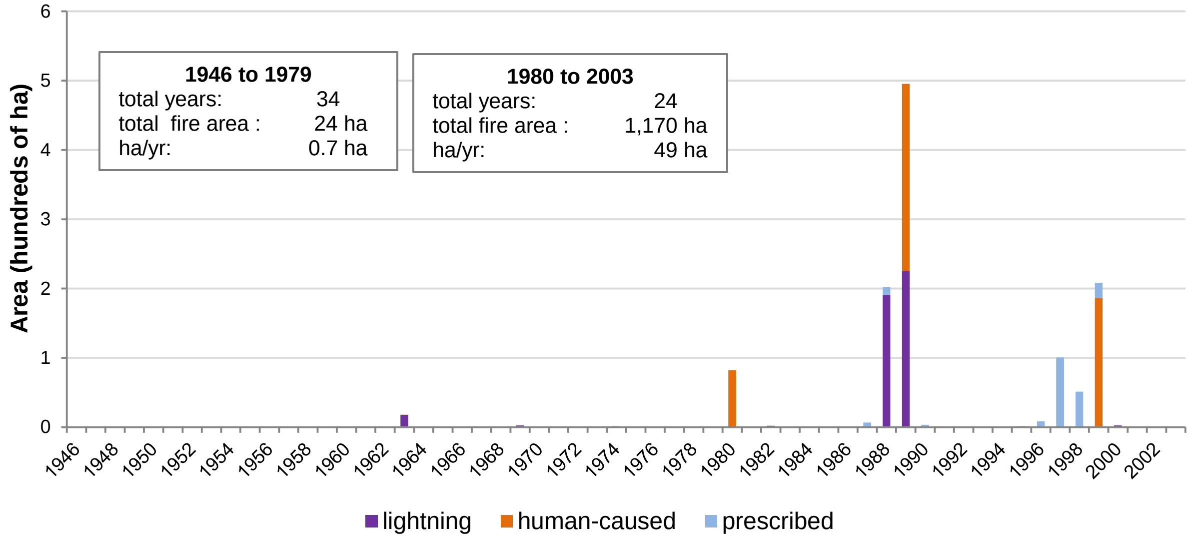


Figure 9. Fire area by year and fire cause within FMU #3 of BIBE, 1946 to 2003, data from the fire occurrence GIS point dataset.

<u>Fire Location</u>

Fires by Vegetation Type - Park-wide

A spatial join (ESRI ArcGIS 10.0 analysis tool) between the BIBE fire occurrence point GIS dataset and the Plumb (1992) vegetation polygon GIS dataset results in an estimation of the relative proportion of fire area (as determined by the 'CNTRL_ACR' field in the fire point dataset) and number of fires by vegetation-form and vegetation category. This analysis assumes that each fire point accurately corresponds with the major vegetation from the Plumb (1992) dataset and that this vegetation type is the primary vegetation type burned by each fire represented in the GIS point dataset. According to this analysis, the majority of fires across the park (63.6% by total area) coincide with the Sotol-Grassland vegetation form, with 28.4% by area in the Shrub Desert vegetation form, 2.7% in Floodplain-Arroyo, and 2.7% in Woodland; 2.5% are associated with a spatial error such as missing spatial coverage or spatial accuracy error (Table 11).

Table 11. Number of fires, total area of fires, and proportions of total fires and total fire area by vegetation form and category park-wide in BIBE. The Plumb (1992) vegetation polygon GIS dataset and the BIBE fire occurrence point GIS datasets were used for this analysis.

Vegetation Form	Vegetation Category (Plumb 1992)	Sum of Area (ha)	% of Total Burn Area	Sum No. of Fires	% of Total Fires
Sotol-Grassland		8,996.2	63.6	196	39.5
	Yucca-Sotol	6,432.0	45.5	48	9.7
	Lechuguilla-Grass-Viguiera	1,446.5	10.2	51	10.3
	Sotol-Lechuguilla-Grass	607.5	4.3	65	13.1
	Lechuguilla-Grass	458.1	3.2	19	3.8
	Sotol-Nolina-Grass	52.1	0.4	13	2.6
Shrub Desert		4,022.4	28.4	129	26.0
	Lechuguilla-Grass-Candelilla	2,170.1	15.3	37	7.5
	Creosote-Grass	1,534.4	10.8	12	2.4
	Creosote-Lechuguilla	298.4	2.1	35	7.1
	Creosote Flats	8.0	0.1	10	2.0
	Creosote-Tarbush	7.6	0.1	10	2.0
	Lechuguilla-Grass-Hechtia	3.8	0.0	21	4.2
	Creosote-Yucca-Grass	0.1	0.0	3	0.6
	Creosote-Lech-Prickly Pear	0.0	0.0	1	0.2
Floodplain-Arroyo		384.5	2.7	39	7.9
	Mesquite thicket	195.0	1.4	16	3.2
	Mixed Riparian	132.8	0.9	4	0.8
	Cane Grass	28.7	0.2	6	1.2
	Cottonwood Grove	28.0	0.2	11	2.2
	Desert Willow	0.1	0.0	2	0.4
Woodland		381.9	2.7	85	17.1
	Pinyon-Oak-Juniper	254.6	1.8	21	4.2
	Pinyon-Juniper-Grass	93.6	0.7	16	3.2
	Mixed Scrub	29.2	0.2	32	6.5
	Pinyon-Talus	3.8	0.0	7	1.4
	Oak Scrub	0.6	0.0	6	1.2
	Mixed Oak	0.1	0.0	2	0.4
	Forest Meadow	0.1	0.0	1	0.2
Coverage Discrepancy or Error*		358.7	2.5	47	9.5
	No Data	275.6	1.9	28	5.6
	Bare	45.5	0.3	5	1.0
	(blank)	34.6	0.2	10	2.0
	Water	3.0	0.0	4	0.8
	Totals:	**14,143.7**	**100.0**	**496**	**100.0**

*The coverage discrepancy/erroneous categorization includes fires occurring in unmapped vegetation areas (No Data) or those that erroneously coincide with bare, blank, or water polygons in the Plumb (1992) dataset. This may be due to slight spatial inaccuracy between the two GIS datasets.

Fires by Vegetation Type - FMU #3
The vast majority of fire occurrences in FMU #3 by area or total number of fires are either associated with Woodlands (57.5% of total FMU #3 burn area, as determined by the CNTRL_ACR field in the fire point dataset) or with Sotol-Grasslands vegetation forms (42.3% by area). Primary Plumb (1992) woodland vegetation categories that experienced fire are Pinyon-Oak-Juniper (38.6% by total burn area in FMU #3), Pinyon-Juniper-Grass (14.2%), and Mixed Scrub (4.1%) (Table 12).

Table 12. Number of fires, total area of fires, and proportions of total fires and total fire area by vegetation form and categories in FMU #3. The Plumb (1992) vegetation polygon GIS dataset and the fire occurrence point GIS dataset were used for this analysis.

Vegetation Form	Vegetation Category (Plumb 1992)	Sum of Area (ha)	% of total FMU #3 burn area	Sum No. of Fires	% of Total FMU #3 Fires
Woodland		379.01	57.48	71	49.7
	Pinyon-Oak-Juniper	254.60	38.61	21	14.7
	Pinyon-Juniper-Grass	93.56	14.19	16	11.2
	Mixed Scrub	26.91	4.08	23	16.1
	Pinyon-Talus	3.77	0.57	7	4.9
	Mixed Oak	0.08	0.01	2	1.4
	Forest Meadow	0.08	0.01	1	0.7
	Oak Scrub	0.00	0.00	1	0.7
Sotol-Grassland		278.88	42.30	62	43.4
	Sotol-Lechuguilla-Grass	138.33	20.98	25	17.5
	Lechuguilla-Grass	103.07	15.63	7	4.9
	Lechuguilla-Grass-Viguiera	33.55	5.09	19	13.3
	Sotol-Nolina-Grass	3.93	0.60	11	7.7
Shrub Desert		1.42	0.21	9	6.3
	Creosote-Tarbush	1.25	0.19	5	3.5
	Creosote-Grass	0.12	0.02	3	2.1
	Creosote-Lechuguilla	0.04	0.01	1	0.7
Bare		0.04	0.01	1	0.7
	Bare	0.04	0.01	1	0.7
	Totals:	**659.35**		**143**	

Fires by Elevation - Park-wide
A GIS analysis reveals an elevation range for documented fires in BIBE (those contained within the park's GIS datasets). According to the BIBE fire occurrence point GIS dataset, fire occurrence points one acre or larger (according to the CNTRL_ACRE field) from 1946-2003 occurred across an elevation range of 500 to 2,335 m mean sea level (1,640 to 7,660 ft msl), with most fire occurrence points (~90% by area) occurring within 900 – 1,600 m msl (2,953 to 5,429

ft msl), a 755 m (2,476 ft) range (Figure 10, Figure 11). From 1946 to 2003, many small fires occurred between 500 and 900 m (1,640 to 2,953 ft). This may be due, in part, to a relatively high percentage of small, unintentionally human-caused fires. Of the 496 fires in the park's point GIS dataset, 41% were human caused. In examining only fires between 500-900 m in elevation, 65% were human-caused. These fires may be of smaller size because many were suppressed before they were allowed to spread; according to the NPS (2005), unintentional human-caused fires are to be suppressed, and the majority of human-caused ignitions were reported as less than 0.1 acre each from 1980 to 2004.

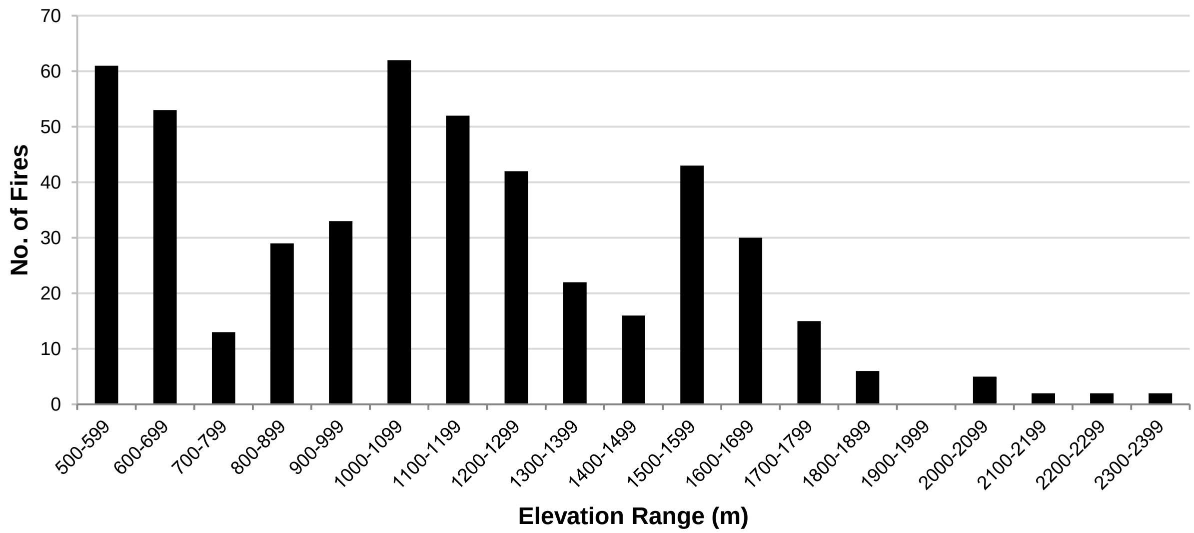


Figure 10. Number of fires by elevation range in BIBE according to the park's fire point GIS dataset. Eight fires totaling 28 ha fell outside the available 10m DEM and therefore were not included in this analysis.

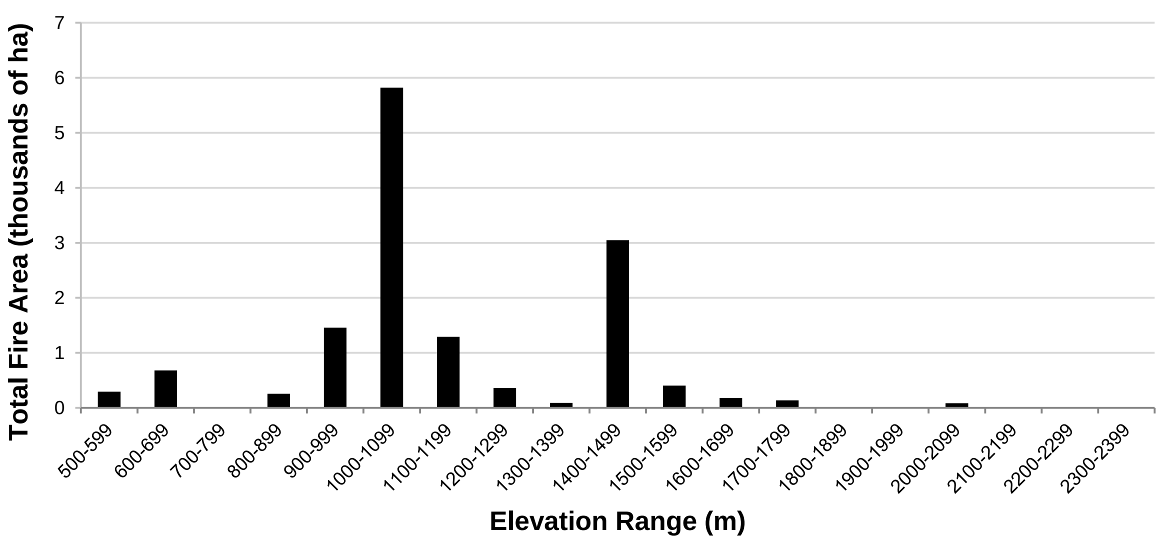


Figure 11. Total area of fires by elevation range within the park according to the BIBE fire occurrence point GIS dataset. Eight fires totaling 28 ha fell outside the available 10m DEM and therefore were not included in this analysis. The 'CNTRL_ACRE' was used for reporting area.

Fires by Elevation – FMU #3

The piñon-juniper woodlands in BIBE occur between 1,411 and 2,352 m msl (4,630 to 7,717 ft), whereas grasslands are more prevalent at lower elevations (Poulus et al. 2009). Poulus et al. (2009) suggest that lightning-caused fires may begin in the lower elevation grasslands and carry into upslope forests. A GIS analysis extracts the elevation values from a 10m DEM (the grid cells coincident with the BIBE fire history polygon GIS dataset), revealing an approximate range and proportion of elevations for larger fires, those ≥ 4.04 ha (10 ac) within FMU #3. According to this analysis, fires occurred over an elevation range of 1,060 to 2,246 m (3,478 to 7,369 ft), with larger relative proportions of burn area occurring around elevations of approximately 1,145 m and 2,229 m (3,757 and 7,313 ft) (Figure 12).

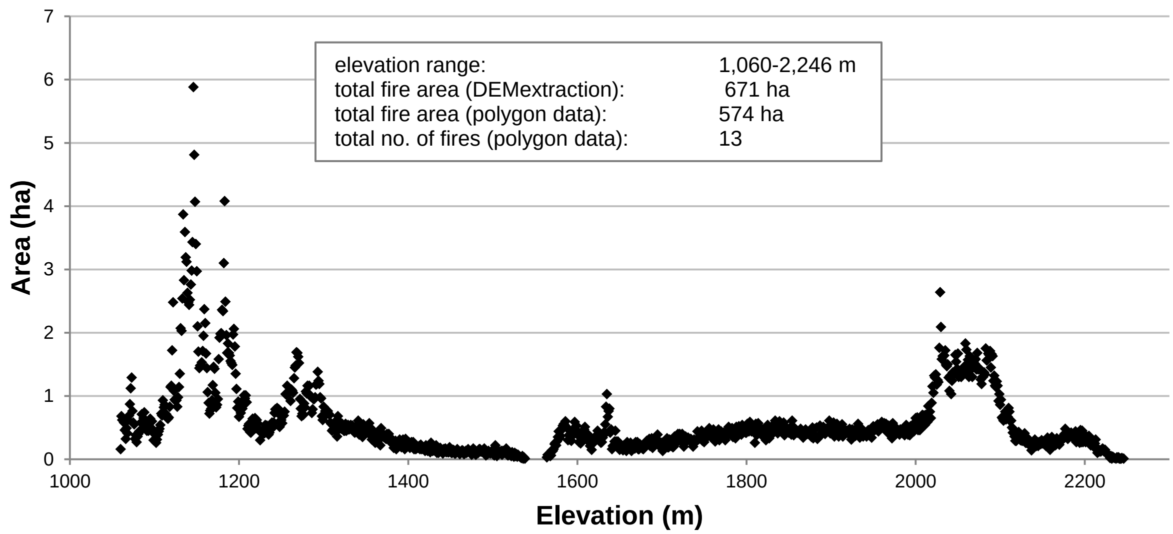


Figure 12. Fire area by elevation in FMU #3 according to the BIBE fire perimeter (polygon) GIS dataset, 1946 to 2003 (all fires ≥ 10 acres according to the CNTRL_ACRE field in the dataset). Area by elevation was determined by using the BIBE fire perimeter polygon dataset to extract 10m DEM grid cells; each 10x10m cell equals 100m^2 multiplied by the cell count for each elevation.

From fire occurrence point GIS data for all fires ≥ 0.404 ha (1 ac) in size (according to the CNTRL_ACRE field in the dataset), 43 fire occurrence points (43 fires) coincide with an elevation range of 1,060-2,307 m (3,478-7,569 ft), representing a total of 654 ha (265 ac) of total burn area (Figure 13).

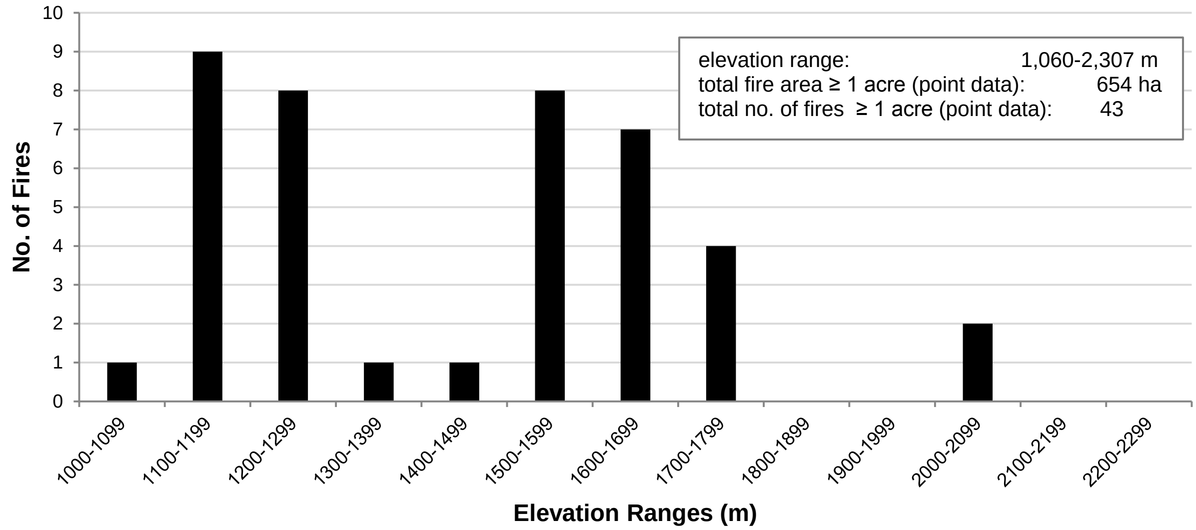


Figure 13. Number of fire occurrences ≥ one acre by 100m elevation range in FMU #3, according to the BIBE fire occurrence point GIS dataset, 1946 to 2003 (all fires ≥ 1 acre according to the CNTRL_ACRE field in the dataset).

The fire occurrence point GIS dataset also contains 92 fire occurrences less than 0.4 ha (1 ac) within FMU #3 and eight listed as 0 acres in the CNTRL_ACR field. Following the same extraction of point elevations from all of the 143 fire occurrences (including those <1 ac), a similar elevation range is revealed (995 to 2,335 m). The average elevation is 1,505 m, with similar, high relative fire occurrence elevation ranges at 1,100-1,999 m and 1,500-1,699 m) (Figure 14).

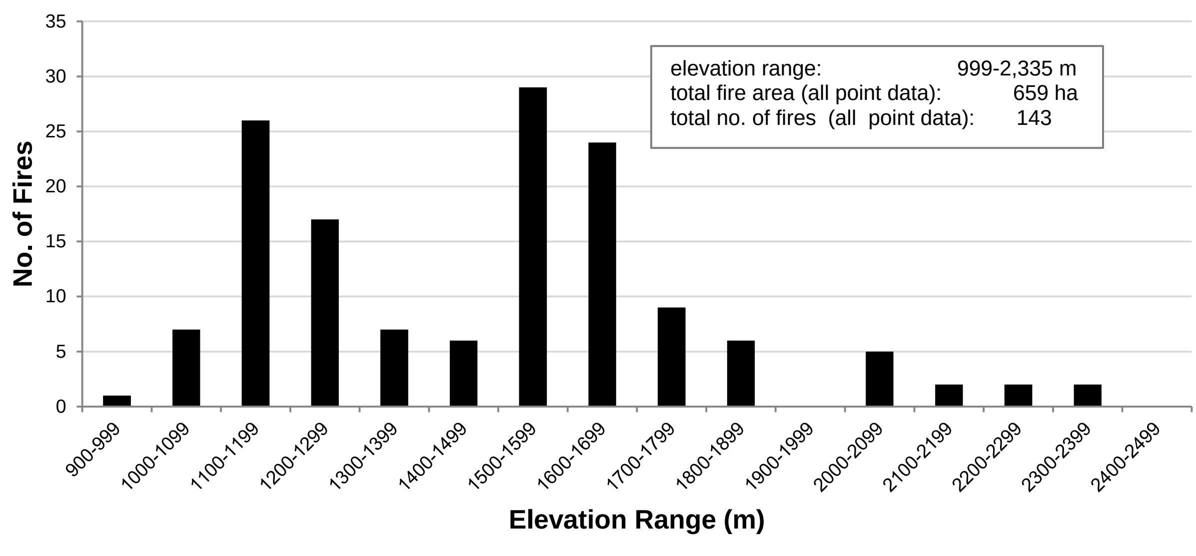


Figure 14. Number of fires by elevation range in FMU #3 of BIBE according to the BIBE fire occurrence point GIS data, 1946 to 2003 (all fires ≥ 0.1 acre according to CNTRL_ACR field).

In examining the fire area reported for each fire point by elevation for all fires within FMU #3, (again, the "CNRL_ACRE" field is used for fire area) a range of elevation of 900 to 2,400m (2,953 to 7,874 ft) is revealed. However, the vast majority of burn area is associated with an elevation range of 1,100-2,099m (3,609-6,886 ft) (Figure 15).

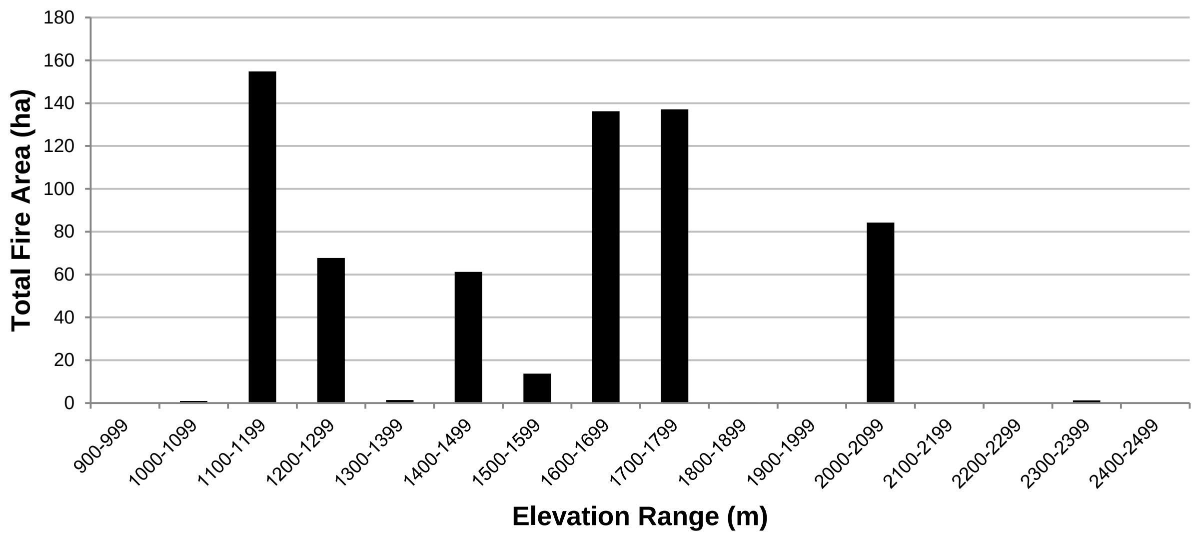


Figure 15. Total fire area for all fires in FMU #3 by elevation range according to the BIBE fire occurrence point GIS data, 1946 to 2003 (all fires ≥ 0.1 acre according to CNTRL_ACRE field).

Fire Severity

Fire severity can be measured through various methodologies, but generally refers to measureable effects on ecosystem properties. Fire (or burn) severity is a term used to describe the physical and chemical changes to the soil, the conversion of vegetation and fuels to inorganic carbon, and structural or compositional transformations that create new microclimates and species assemblages (Key and Benson 2006). Similarly, severity can be measured by amount of organic matter loss both above and below the surface of the ground after a fire (Keeley 2009).

One method for measuring burn severity as it relates to fire effects in above-ground biomass on a landscape scale, is to compare LandSat imagery prior to and after a fire to determine a Differenced Normalized Burn Ratio (dNBR). dNBR raster GIS data, which represent continuous values, are separated into six categories. The Monitoring Trends in Burn Severity (MTBS) project classifies the six severity categories as unburned to low, low, moderate, high, increased greenness, and no data (MTBS 2011b). According to MTBS (2011a), an analyst evaluates the dNBR data range and determines where significant thresholds exist to discriminate between severity categories. Richard Gatewood (written communication, 2 May 2013) suggests that data typically requires field validation to ensure accuracy before it is appropriate for use in mapping burn severity locally. It may be especially important that initial unsupervised image classifications be validated in BIBE where little data are available.

Park-wide

MTBS (2011b) provided burn severity data in which acreage of severity categories were derived for the 1993 Mayday fire and the 1994 Estufa fire within BIBE. Both of these large fires resulted in primarily low-level severity effects (65-67% of total area) as determined by MTBS (2012b) (Table 13), a generally desirable result under the NPS fire management goals. Both of these fires are outside of the FMU #3 boundaries; their locations are represented in Plate 5.

Table 13. Area of three burn severity classes for two fires (Mayday and Estufa) in BIBE (MTBS 2012b).

Fire Name	Severity Level						Totals
	Unburned to Low		Low		Moderate		
	area (ac)	% of total fire area	area (ac)	% of total fire area	area (ac)	% of total fire area	
Mayday	404	12	2,240	67	821	24	3,465
Estufa	0	0	2821	65	1,533	35	4,354
Totals	404	--	5,062	--	2,353	--	--

FMU #3
No information is available that characterizes recent fire severities in FMU #3. However, since the fire occurrence GIS data indicates that much of the FMU #3 area did not burn from 1946 to 2003, it is likely that high severity fires have not burned in this area during this period of record. With continued fuel loading, some areas in FMU #3 may be at risk for high severity fires.

Fuel Loading and Distribution
Fuel loading is defined as the weight per area of fuel, often expressed in tons per acre or tonnes per hectare. Dead woody fuel loadings are commonly described for small material in diameter classes of 0 to 1/4-, 1/4 to 1-, and 1 to 3 inches, and for large material in one class greater than 3 inches (Brown 2000). Fuel loading and distribution have strong influences on the frequency, intensity, and severity of fires. Generally, when fuels accumulate, fire intensity and severity increase.

Park-wide
The only information for park-wide fuel loading and distribution is fuel maps created by applying fuel types to vegetation types mapped by Plumb (1992). A representation of this is available in Plate 7.

FMU #3
NPS (2005) describes most of FMU #3 as following fuel model 2, in which fire is primarily carried by fine fuels (grasses) and some litter and downed stemwood. However, the forested areas of this FMU contain heavier than average fuel loading as indicated by the model because of high densities of sapling pinion pine and juniper (NPS 2005). Until a recent prescribed burn (Southeast Rim Rx in 2006), the area had not experienced a large scale fire since 1903 (NPS 2005, Poulus et al. 2009).

Camp et al. (2006) quantified fuel distribution patterns using measured variables at vegetation plots in BIBE and in two other Chihuahuan Desert borderland study sites, the Davis Mountains Preserve of the Nature Conservancy (DMTNC) in Texas and the Maderas del Carmen Protected Area (MCPA) in Mexico. In the High Chisos Mountains (within FMU #3), Camp et al. (2006) found fuel types 1, 3, and 4 in BIBE and described fuel load and environmental characteristics for each (Table 14). Camp et al. (2006) also tabulate dominant species by average density in sample plots (Table 15).

Table 14. Fuel load characteristics for each fuel load type in BIBE. Adapted from Camp et al. (2006).

Fuel Load Type*	Fuel Load Characteristics	Environmental Characteristics
1	• Low live fuels • Low standing dead fuel • Low dead and downed fuel • Low snag density	• Middle elevations • Steep slopes • Exposed sites • Upper topographic position • Dry sites
3	• Low live and standing dead tree density • Low snag density	• Middle elevations
4	• High live fuels • High snag density • Abundant large dead and downed fuels • High intermediate-sized (20-25 cm) snag density	• High elevation valley bottoms • Mesic sites • High sediment accumulation

*Original source (Camp et al. 2006) presented fuel types 1-5; fuel types 2 and 5 were not found in BIBE, only in other sites in study (DMTNC, TX, and MCPA in Mexico).

Table 15. Species dominance by average density in BIBE plots (Camp et al. 2006).

Vegetation Type	Sample Size (n)	Dominant Species 1	Dominant Species 2	Dominant Species 3	Dominant Species 4
Gray oak	38	*Quercus grisea*	*Pinus cembroides*	*Quercus arizonica*	*Juniperus deppeana*
Graves oak	18	*Quercus gravesii*	*Acer grandidentata*	*Quercus laceyi*	*Pinus ponderosa*
Emory oak	20	*Quercus emoryi*	*Pinus cembroides*	*Juniperus deppeana*	*Quercus gravesii*
Piñon pine	65	*Pinus cembroides*	*Quercus grisea*	*Quercus arizonica*	*Juniperus deppeana*
Oak piñon juniper	14	*Quercus grisea*	*Juniperus deppeana*	*Pinus cembroides*	*Quercus arizonica*
Alligator juniper	13	*Juniperus deppeana*	*Pinus cembroides*	*Quercus grisea*	*Quercus arizonica*

Fire fuels and fire behavior are also often modeled and simulated in a GIS using a variety of different fuel models. For example, the NPS often uses FARSITE, a fire behavior and growth simulator that uses spatial and temporal data regarding topography, fuels, and weather. A landscape file (a FARSITE specific file type) was developed in 2005 and updated in 2007 with further refinements (e.g., new fuel models, changes due to previous fires) and incorporating vegetation and fuels information specific to the Chisos Basin area (Stephen 2007). The landscape file contains GIS layers including fuel model, canopy cover, tree height, canopy base height, canopy bulk density, elevation, slope, and aspect.

Poulos (2009) identified and mapped four fuel types for a piñon-juniper woodland study area within FMU #3 of BIBE and a study area in the MCPA in Mexico. The author sampled 200 sites in BIBE and 200 in MCPA in which live fuel structure and dead and downed fuels were measured and data were analyzed for a fuel-type classification. To understand fuel distribution patterns, a set of explanatory variables were analyzed against the sampled fuel characteristics

(Poulos 2009); these variables and their definitions are available in Appendix B. Using a cluster analysis, mean fire characteristics and environmental and Landsat spectral characteristics by fuel type found in BIBE are presented in Appendix C; the average fuel characteristics are available in Appendix D. Areas with fuel type 1 were represented by dense forests found in valley bottoms and drier, high-elevation sites. Fuel type 2 areas, also dense forests, were found on high-elevation, wet sites with low incident solar radiation. Fuel type 3 areas were open savanna woodlands found on lower topographic positions with high incident solar radiation Lastly, fuel type 4 areas were shrublands found in upper topographic positions (Poulos 2009).

Poulos (2009) concludes that fuel maps generated from this study provide fire managers with more accurate, spatially explicit information from the relationships of environmental, spectral, and field data. In respect to the amounts of standing dead and downed fuels, the piñon-juniper woodlands of the study area were similar to other fire-suppressed sites in the southwestern U.S., suggesting that these woodlands may be at risk for high-intensity (high severity) fires in the future. The map outputs produced by Poulus (2009) may be used to target high fire-risk areas for tree thinning and prescribed fuel-reduction fires. Figure 16 shows a fuel map of the Poulus (2009) study area in BIBE. The study area's general location within the park is indicated in Plate 6 and Plate 7.

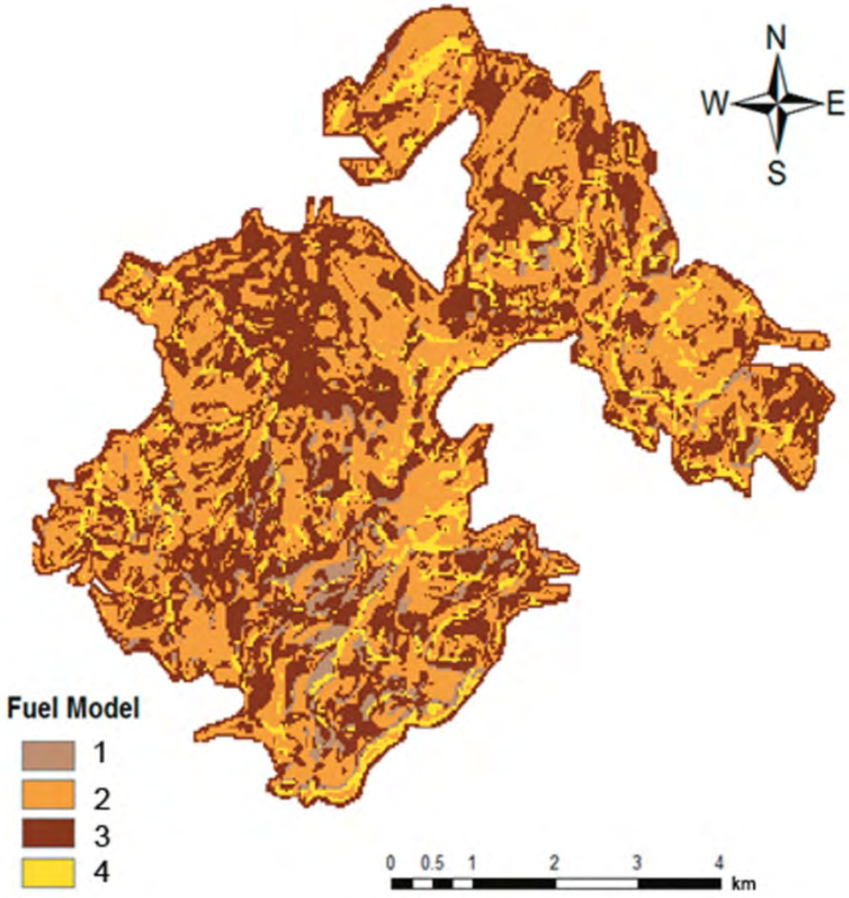


Figure 16. Fuel map for BIBE produced via a decision-tree analysis of fuels, environmental, and spectral data. Adapted from Figure 3 in Poulos (2009). Refer to Plate 6 for general location of this study area within BIBE.

Threats and Stressor Factors

Past land management practices such as fire suppression and livestock grazing have altered vegetation, fuel, and fire patterns; cattle, sheep and goat ranching was prevalent in the park prior to its establishment in 1944 (Poulus et al. 2009). Areas such as Green Gulch and Oak Canyon were heavily impacted by grazing (NPS 2005); their general locations in the park are indicated in Plate 5. Some of these areas in and around homesteads and where livestock was concentrated now contain dense thickets of bee brush (*Aloysia gratissima*) and catclaw acacia (*Acacia greggii*). Generally, in homesteads (areas that were intensely grazed, or where livestock was concentrated) fires were suppressed and densities of juniper, piñon, and oaks increased, canopies closed, and the once common fine herbaceous understories were excluded. Muldavin et al. (2001, as cited in NPS 2005) estimated that over-grazed sites in the lower elevation desert grasslands of BIBE took 25-40 years to recover with comparable species assemblages.

In the 1940s and 1960s, park assessments suggested bringing fire back to the landscape to combat noted vegetation changes resulting from fire exclusion practices (NPS 2005). However, early park policies resulted in the suppression of natural ignition fires, allowing continued fire fuel accumulation. Long-term fire exclusion can create excessive amounts of dead and dried vegetation, leading to large, high severity fire events and introductions of disease or non-native species invasions. Drought may increase the intensity of fire events, especially following decades of fire suppression (Camp et al. 2006). NPS (2012b) suggests that grazing from the 1880s to the 1940s, drought from the 1890s to the 1950s, and fire suppression since the 1940s, have led to higher stand densities in the forests of the Chisos Mountains. With high fuel loading and recent drought years, the risk of high severity fires is of high concern for BIBE.

Brooks and Pyke (2001) note that invasion by non-native invasive grasses could increase fine fuel biomass and continuity, elevating the risk of fire and burn intensity in the region. For example, Lehmann lovegrass became a dominant grass at locations in the foothills of the Chisos Mountains in BIBE over approximately a 50-year period from the mid-1950s to the mid-2000s (Leavitt et al. 2010). Brooks and Pyke (2001) suggest that Lehmann's lovegrass is the primary invasive plant threat in the region. However, Leavitt et al. (2010) documented other plant species in BIBE including buffelgrass, King Ranch bluestem (*Bothriochloa ischaemum*), and Johnson grass. Leavitt et al. (2010) found that two locations, Tornillo Flats and Green Gulch 2, had high invasive plant densities (Leavitt et al. 2010).

Human-caused wildfires pose a continued threat to the fire regime of BIBE and other CHDN network parks. All of these fires are to be suppressed according to the park's FMP (NPS 2005). While BIBE conducts prescribed burns when conditions are suitable, strong winds are common in BIBE, and they can present a challenge in executing safe prescribed fires. However, the primary concern for implementing prescribed fires in BIBE is the elevated fuel loading; this poses control issues during prescribed fires (Gatewood, written communication, 2 May 2013).

Climate change may alter the park's vegetation (fuels) and, therefore, fire regime. Multiple climate models predict more frequent, extreme droughts, and drought is directly connected to fire frequency and intensity (Davey et al. 2007). In the future, the southwest U.S. will have fewer frost days, warmer temperatures, and greater water demand by plants (i.e., higher evapotranspiration rates) (Archer and Predick 2008). In 2011, the Big Bend region experienced the driest year on record (NOAA 2012). Effects of this drought were seen in both desert and montane habitats, with significant overstory and understory tree mortality occurring in the Chisos Mountains (within FMU #3) (Poulos, *in press*). Across all tree species and size classes, approximately 17% of trees living before the drought were dead in 2012, with overstory tree mortality most pronounced in Mexican piñon (Poulos, unpublished data). If such dry periods become more frequent or severe in the coming decades, natural vegetation communities and the role of fire may be significantly altered.

<u>Data Needs/Gaps</u>
A vegetation mapping project is currently underway in the park through the NPS Vegetation Mapping Program. This will result in higher resolution data (map scale 1:24,000 with a 0.5 ha minimum mapping unit) and a more contemporary understanding of plant communities across the entire park that can be used by resource managers and fire researchers.

Muldavin et al. (2010) report the results of an ongoing, long-term effort monitoring vegetation dynamics in desert grasslands, shrublands, and woodlands of BIBE, expanding on the Ecological

Survey of the Big Bend Area by Barton Warnock and others (Warnock 1970). Using pre-existing, permanent vegetation transects with individual plant charts, species cover estimates, and repeat photography, the authors intend to create an understanding of ecosystem recovery and how the ecosystems will respond to various, future management practices (Muldavin et al. 2010). Future reported results of the ongoing monitoring effort will continue to help NPS fire managers understand trends in vegetation change and may inform fire management decisions in these areas.

Poulos et al. (2009) suggest that topographic complexity may have an important influence over fire regimes in piñon-juniper woodlands. Additional research that can incorporate topographic variables such as slope, aspect, and patch dynamics may provide further insight to potential relationships with vegetation, fuels, fire return intervals, and fire severity.

Camp et al. (2006) suggests that fire effects on vegetation are not well understood in the Chihuahuan Desert Borderlands that exist in BIBE. Fire effects monitoring is ongoing by the CHDN and the Fire Management Program of the NPS.

GIS fire occurrence data available for this assessment are current through 2003; updated fire GIS datasets would allow for a more contemporary understanding of fire in BIBE. In addition, an estimate of spatial accuracy of fire occurrence points could make for more accurate analyses of fire occurrence by a multitude of factors (slope, aspect, etc.).

Lastly, more research is needed to understand how the timing of burns may affect vegetation structure and composition in BIBE, specifically in regards to the seasonality of prescribed fires and non-fire fuel treatments. Poulos et al. (2009) found that most fire-scars occurred in the earlywood of trees, indicating that historic fires typically occurred in spring.

Overall Condition

The condition scores assigned to each measure below apply only to FMU #3 of BIBE, as most of the available data indicating current conditions and research providing a basis for reference conditions used in this assessment are primarily applicable to forest and woodland vegetation within this FMU. As discussed previously, reference conditions for fire regime characteristics in other areas of the park are not well understood.

Fire Frequency

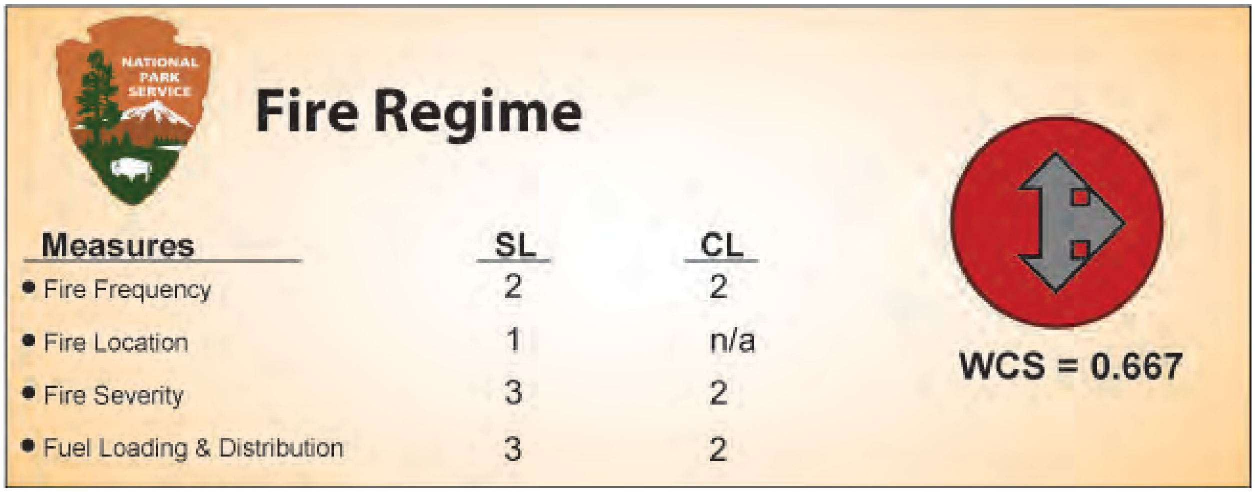
The project team defined the *Significance Level* for fire frequency as a 2, as this is an important fire regime measure that shapes vegetation structure and composition over time. Poulos et al. (2009) reported an historic MFRI of 36 years from approximately 1700 to 1930 for a study area within FMU #3. According to the park's fire occurrence point GIS dataset, it appears that much of FMU #3 has not burned in at least 50 years. Similarly, until a prescribed burn in 2006 (Southeast Rim Rx), one area in FMU #3 had not experienced a large scale fire since 1903 (NPS 2005, Poulus et al. 2009). Fire frequency is assigned a *Condition Level* of 2, indicating that it is currently of moderate concern. However, Camp et al. (2006, p. 60) suggest that a historic MFRI shouldn't necessarily translate to a pattern to be explicitly repeated by managers; rather, fire should be used to maintain sustainable forest stand structures on a "more or less frequent basis". In addition, Camp et al. (2006) suggest that prescribed fires be small in size, reflecting the historic fire sizes found in their study.

Fire Location
The *Significance Level* for fire location is a 1. Location is a basic piece of information important for managing fire and studying its effects. There is not a specific reference condition established for this measure; however, locations are currently captured in the available park fire occurrence GIS dataset. The actual locations (geographic coordinates) are developed from varying sources including Department of the Interior 1202 Individual Fire reports (DI-1202), burn plans, the park's GIS, and Strategic Air Command (SAC) reports. Locations derived from DI-1202 reports vary from hand-drawn maps to topo-maps or maps with GPS coordinates. Therefore, the level of spatial accuracy across all fire points is unclear. However, as expected, most of the fires in FMU #3 are associated with woodlands, as identified by the Plumb (1982) dataset (57.5% by total fire area within FMU #3), and most of these occurrences are associated with Pinyon-Oak-Juniper (38.6% by total FMU #3 burn area), Pinyon-Juniper-Grass (14.2%) or Mixed Scrub (4.1%) vegetation types. In terms of elevation, fires in FMU #3 occur across a wide elevation range, 1,060-2,246 m (3,478-7,369 ft), with clusters of fire area occurring from approximately 1,100-1,300 m (3,609-4265 ft) and 2,000-2,100 m (6,562-6,890 ft). This 2,000-2,100 m cluster tends to coincide with the average elevations for fuel models developed by Poulos (2009). A *Condition Level* was not assigned to this measure.

Fire Severity
Fire severity was assigned a *Significance Level* of 3 by the project team, as fire severity has a large influence on ecosystem response to fire. Only two fires were examined by MTBS, the Mayday and Estufa fires. Most of the area burned by these mid-1990s fires was characterized by the MTBS as low or moderate fire severity. Therefore, with respect to these fires alone, fire severity would be of low concern. Neither of these fires occurred within FMU #3, an area for which there is historic fire severity research to base reference conditions upon. However, based upon the GIS data, much of FMU #3 has not burned in several decades, well over the fire return intervals reported by Poulos et al. (2009) for Piñon woodlands. Poulos (2009) asserts that, based upon comparative fuel characteristics in other fire suppressed areas, the risk of severe fires still exists in this area. In addition, the 2011 drought that the park experienced caused some plant mortality and likely increased fuels and therefore risk of severe fires in the future. As a result, this measure is assigned a *Condition Level* of 2, indicating a moderate concern in FMU #3.

Fuel Loading and Distribution
The project team assigned this measure a *Significance Level* of 3, as it is consequential to fire frequency, severity, and ultimately vegetation response to fires. Camp et al. (2006) suggest that areas with heavy live, dead, and down fuel loads may be more vulnerable to high intensity fires and that, with future warmer and drier climate change scenarios, areas with these fuel loads in upper elevations and valley bottoms may be under threat of high severity fires. This measure is assigned a *Condition Level* of 2, indicating it as a moderate concern in FMU #3.

Weighted Condition Score
The *Weighted Condition Score* for fire regime in FMU#3 is 0.667, indicating a condition of high concern. Due to limited available data, a trend was not determined for this component.



4.1.6 Sources of Expertise

Richard Gatewood, Fire Ecologist, Southwest Texas, Permian and Southern Plains Fire Groups

Joe Sirotnak, BIBE Botanist/Ecologist

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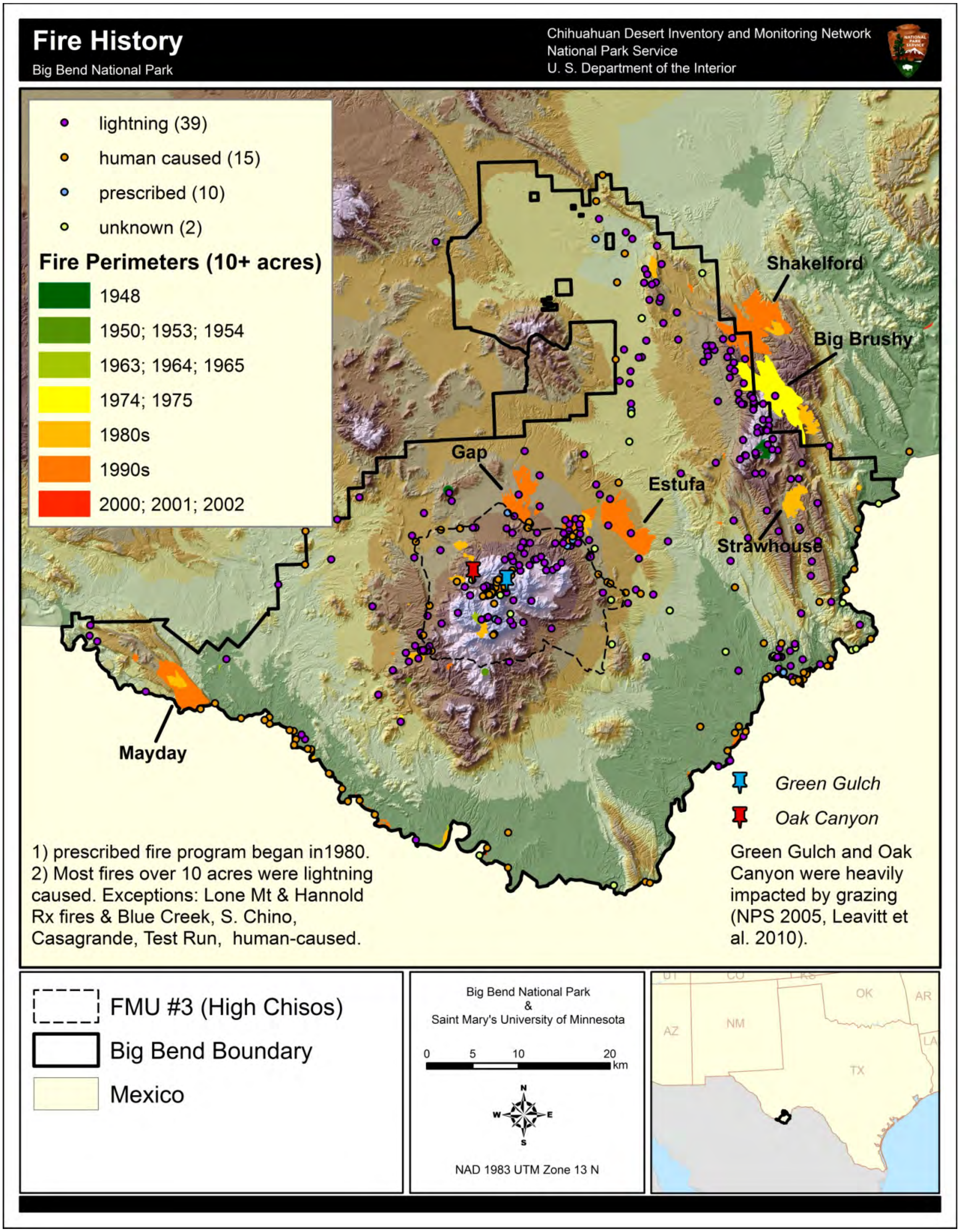


Plate 5. Fire history in BIBE 1948 to 2003 (NPS GIS polygon and point data).

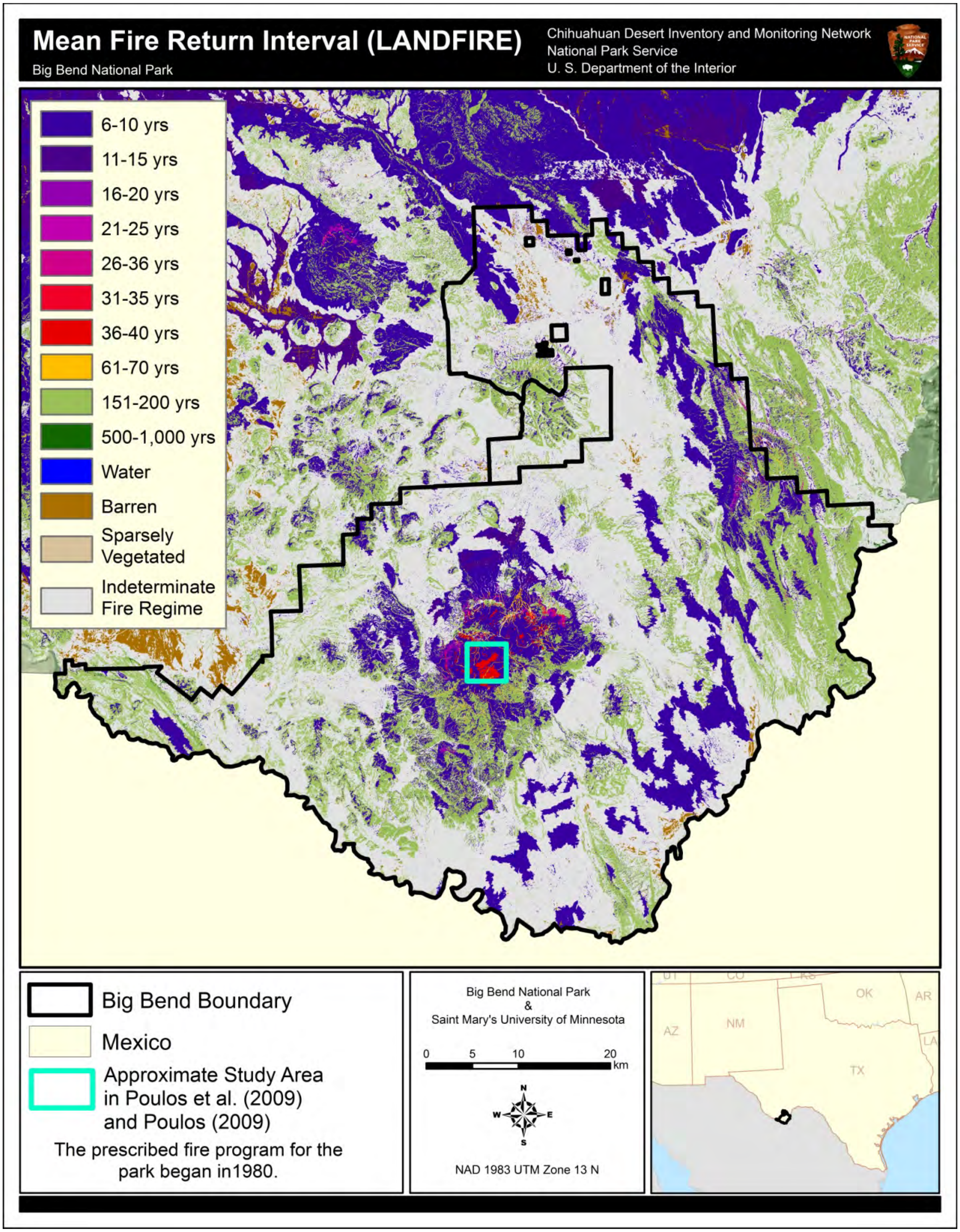


Plate 6. Mean fire return intervals in BIBE (LANDFIRE MFRI 2006).

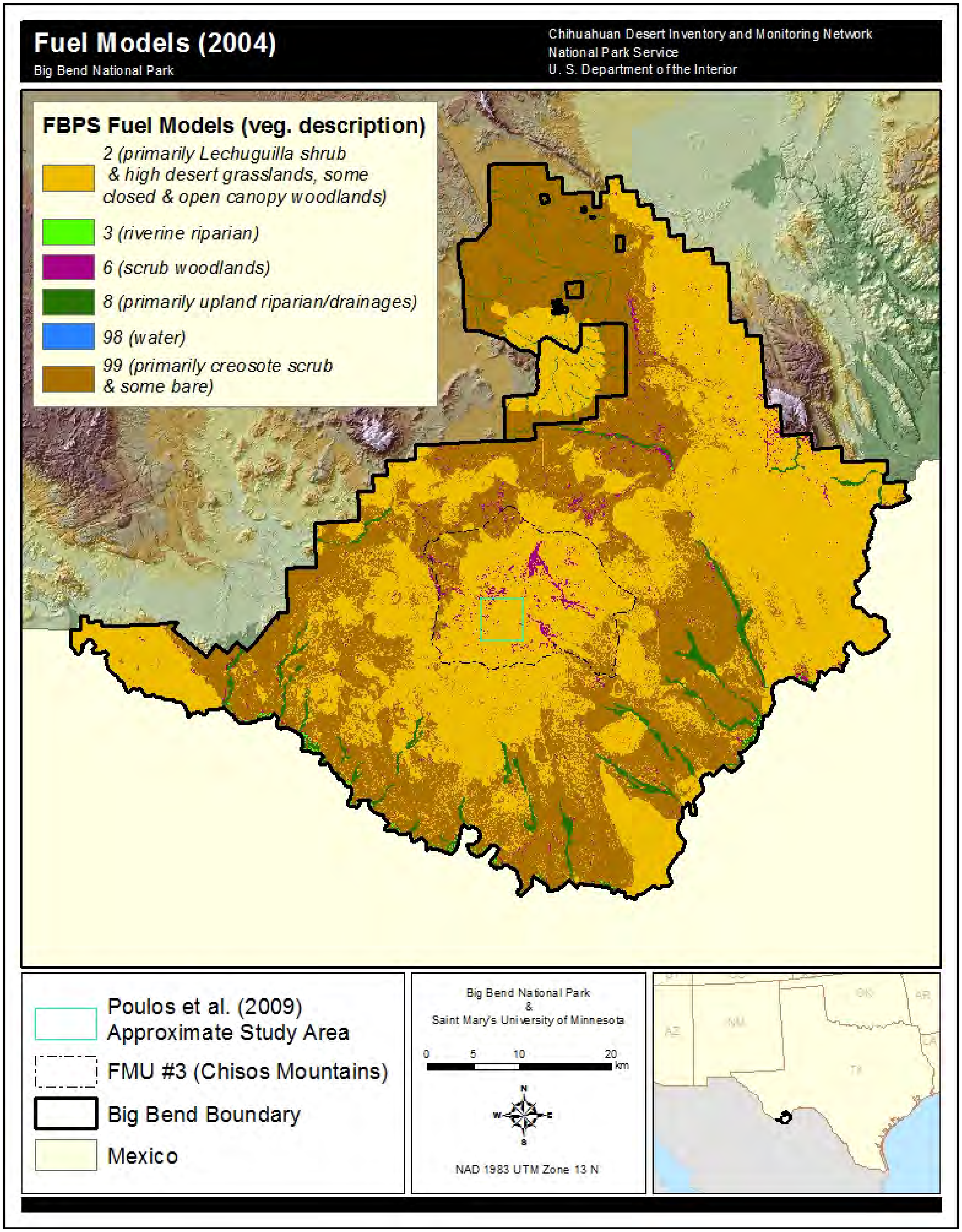


Plate 7. Fire Behavior Prediction Systems (FBPS) fuel models and primary vegetation descriptions in BIBE as of 2004. Refer to Appendix A for a list of assigned fule models and canopy characteristics.

4.2 Spring Habitats

4.2.1 Description

Springs are important water sources in the arid environment of BIBE, supporting vegetation and wildlife wherever they occur (MacNish et al. 1996). Animals that commonly utilize these areas include deer, javelina, mountain lions, and frogs (Bartel 2002). Several springs near the Rio Grande provide vital habitat for the Big Bend gambusia, a federally endangered fish species (NPS 1992). These springs provide warm water to help the gambusia survive during cold weather. According to Porter et al. (2009, p. 71), "Much of the aesthetic beauty and biological diversity within the park and along downstream reaches of the Rio Grande Wild and Scenic River (RIGR) depends on the temporal and spatial distribution of these springs and seeps." Flows from BIBE's springs and seeps also contribute substantially to the recharge of the Rio Grande, supporting the only river section with reliable flows for nearly 1,500 km (900 mi) (Reid and Reiser 2005, as cited by Huff et al. 2006; Bennett et al. 2012). Due to their importance in the Chihuahuan Desert's arid environment, the CHDN has identified the persistence of springs as a network Vital Sign (NPS 2010).

In BIBE, springs may be fed by small aquifers recharged by local precipitation or by large regional aquifers, with water travelling long distances before being discharged (MacNish et al. 1996). Discharge from locally fed springs, such as those in the Chisos Mountains, generally fluctuates with changes in precipitation, while discharge from springs fed by large aquifers (e.g., warm springs near the Rio Grande) does not fluctuate with precipitation variation, even during droughts or several wet years in a row (MacNish et al. 1996).

More than 300 upland water sources have been documented in BIBE (Alex 2008, Plate 8). However, less than 25% of these are perennial, meaning they produce water year-round; the remaining springs are seasonal (Alex 2008). Some of the park's springs are in remote locations and remain in relatively pristine condition; others are easily accessible and, prior to the park's establishment, experienced intense grazing pressure from livestock and significant human modification (Bartel 2002). During this time, cottonwoods (*Populus* sp.) were removed from some sites to provide timber and fuel for nearby mining operations (Ragsdale 1995, as cited in Bartel 2002). Currently, the park's springs are threatened by invasive species, recreational use, climate change, and increasing groundwater withdrawals (Bartel 2002, Porter et al. 2009).

4.2.2 Measures

- Plant community composition
- Species richness of macro/microinvertebrates
- Groundwater levels

4.2.3 Reference Conditions/Values

The first attempt to survey the park's springs occurred during the mid-1970s, with additional information gathered in the mid-1980s. Comprehensive, park-wide surveys were performed in 1990 and 1995, and approximately 60% of mapped springs were surveyed again in 2007. Unfortunately, these data are inconsistent, as each survey recorded different parameters and used different methods. The level of expertise of the surveyors also varied (Alex 2008).

Inconsistencies in the historic records and conflicts between written reports and associated photos suggest that there may be errors in the data (Alex 2008). Therefore, it is difficult to establish a park-wide reference condition for the selected measures. The information presented in this assessment represents the best available data for the park's spring habitats and can be considered a baseline or reference condition for future assessments.

4.2.4 Data and Methods

Bartel (2002) documented the vegetation and water chemistry at four relatively pristine (i.e., little to no human use since park establishment) BIBE springs that could potentially serve as "reference springs" for the park: Claro 2 Spring, Desert Spring, Grigsby Spring, and Serendipity Spring (Plate 9). These four springs are in different areas of the park with varying geology, and observations are likely to be more representative of conditions in the park as a whole than if several springs in close proximity were sampled. The selected springs were also chosen because they can be easily accessed in one day by a single person carrying the necessary sampling equipment. Bartel (2002) visited these sites monthly from June 2000 through July 2001 to conduct plant inventories and note changes in water flow; water quality and quantitative vegetation samples were taken quarterly.

Wallace et al. (2005) and Walsh et al. (2007) present the results of aquatic invertebrate (rotifers) sampling in BIBE from 2001-2005. Samples were taken from planktonic, littoral, and benthic habitats using a variety of techniques. The Wallace et al. (2005) analysis focused on species richness at 92 sites (springs and other aquatic habitats) throughout the park. Walsh et al. (2007) explored temporal and geographic variation in rotifer communities from 10 aquatic habitats, including four springs.

Alex (2008) analyzed existing spring data from the BIBE database to develop a potential method for "valuing" surface water sources in the park. Variables explored included reliability of flow (perennial or seasonal), flow rate, and presence of riparian vegetation. Lastly, Porter et al. (2009) described the hydrology of parks in the CHDN and included available data on depth to groundwater for several wells and springs in BIBE. Groundwater levels for the Panther Junction observation well were obtained from the Texas Water Development Board (TWDB 2012).

4.2.5 Current Condition and Trend

<u>Plant Community Composition</u>

The habitat around springs in BIBE can vary greatly over time and between locations. According to Bartel (2002, p. 1), "high temperatures, aridity and the isolated nature of precipitation events lead to difficulties in stating with certainty what a visitor to a desert spring may find on any given day." Water levels, flow rates, and vegetation can differ by season and during very wet or dry years (Alex 2008).

Over 150 vascular plant taxa have been documented in BIBE's spring habitats (Appendix F). Bartel (2002) observed 135 of these taxa, representing 45 families, across four sample sites. The most dominant families were Asteraceae (sunflower family) with 25 taxa, and Poaceae (grasses) with 23 taxa. Perennial herbaceous plants were the most common lifeform, comprising 57.8% of all taxa, followed by shrubs with 11.9% of taxa. Other lifeforms included winter and summer annuals (9.6% and 7.4%), perennial vines (4.4%), and trees (3.7%). Seven exotic species were collected at springs throughout the park (mostly grasses); at least one exotic species was collected at each of the four study sites (Bartel 2002).

Species richness varied greatly between the four springs examined in Bartel (2002). Serendipity Spring supported just nine taxa, while Desert Spring had 21 taxa, and Claro 2 Spring had 59 taxa. Grigsby Spring, which was dry during the entire study year, supported 67 taxa (Bartel 2002). Appendix F shows the species present at each of these sites, while Table 16 displays the major vegetation type and plant species associated with each spring.

Table 16. Vegetation associated with four spring sites in BIBE (Bartel 2002).

Site	Vegetation Type	Major Plant Species
Claro 2 Spring	Sotol-Nolina	grasses & sedges (*Cladium mariscus*, *Carex microdonta*, *Fuirena* spp., *Eleocharis* spp.), cattail (*Typha domingensis*), black willow (*Salix nigra*)
Desert Spring	Creosote-Lechuguilla	Cattails (*Typha* spp.), seepwillow (*Baccharis salicifolia*), sedges (*Carex* spp.), mesquite (*Prosopis* spp.), creosote (*Larrea* spp.)
Grigsby Spring	Desert grassland	seepwillow, bushy bluestem (*Andropogon glomeratus*), rabbitfoot grass (*Polypogon monspeliensis*), Bermudagrass (*Cynodon dactylon*), evergreen sumac (*Rhus virens*), Apache plume (*Fallugia paradoxa*), persimmon (*Diospyros texana*), oak (*Quercus* spp.), monkeyflower (*Mimulus* spp.)
Serendipity Spring	Creosote-Grass	maidenhair fern (*Adiantum capillus-veneris*), seepwillow

According to the BIBE springs database, 116 of the park's springs (almost 35%) support cottonwood trees, while willows (*Salix* sp.) are present at 141 springs (over 42%) (Alex 2008). Saltcedar, an exotic tree or large shrub capable of outcompeting native species (Bartel 2002), has been documented at 146 springs (43.5%) (NPS 2008); however, park staff have been working to eradicate this species from spring habitats and it may no longer be present at all previously documented locations (Alex 2008). Seventy-eight springs (23%) are known to support other riparian vegetation (NPS 2008), such as cattails (*Typha* sp.), sedges (Family Cyperaceae), maidenhair fern (*Adiantum capillus-veneris*), poison oak (*Toxicodendron radicans*), California loosestrife (*Lythrum californicum*), and cardinal flower (*Lobelia cardinalis*) (Alex 2008).

<u>Species Richness of Macro/microinvertebrates</u>

Macro- and microinvertebrates are an important component of desert aquatic communities, as they provide a food source for larger invertebrates and small fish (Wallace et al. 2005). Little is known about the macro/microinvertebrate communities in BIBE's springs. Some data were gathered on macroinvertebrates by Maher (2009) and are discussed in section 4.14 of this assessment. From 2001-2005, various water sources throughout the park were sampled for rotifers, microinvertebrates from the phylum Rotifera. Wallace et al. (2005) documented 94 rotifer taxa (from 19 families; Appendix G) across 92 sites, representing 23 different aquatic systems (not just springs). Isolated springs reported some of the highest species richness values, with an average of 3.0-3.5 taxa per habitat. Pools in the Cattail Springs complex averaged 10.3 species per pool, while the single hot spring sampled supported seven species (Wallace et al. 2005).

During five years of sampling, Walsh et al. (2007) identified 54 rotifer taxa in four park springs. Species richness in springs varied between years, ranging from eight to 32 taxa with a mean of 19.4. Rotifer species also varied between aquatic habitat types. Springs supported the highest percentage of periphytic (attached to the bottom) species of any habitat sampled, but no planktonic (floating near the surface) species (Walsh et al. 2007). Rotifer community composition in each aquatic habitat type is presented by family and by microhabitat type in Figure 17 and Figure 18.

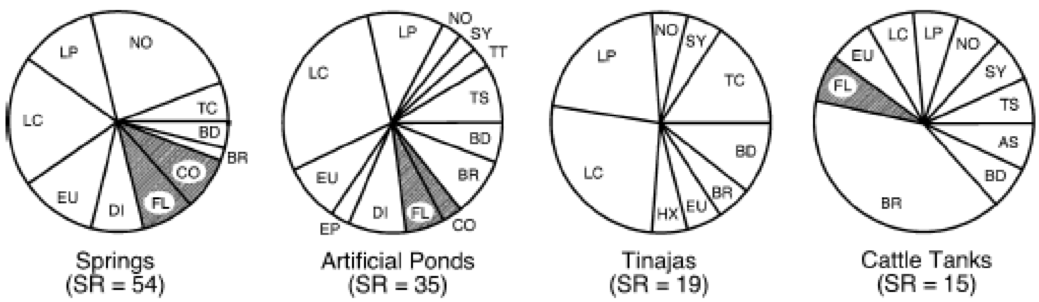


Figure 17. Summer rotifer community composition by family in four BIBE aquatic habitats. AS = Asplanchnidae, BR = Brachionidae, CO = Collothecidae, DI = Dicranophoridae, EP = Epiphanidae, EU = Euchlanidae, FL = Floscularidae, HX = Hexarthridae, LC = Lecanidae, LP = Lepadellidae, NO = Notommatidae, SY = Synchaetidae, TC = Trichocercidae, TT = Trichotriidae, TS = Trochosphaeridae, BD = Bdelloids. Shaded areas represent sessile families (Walsh et al. 2007).

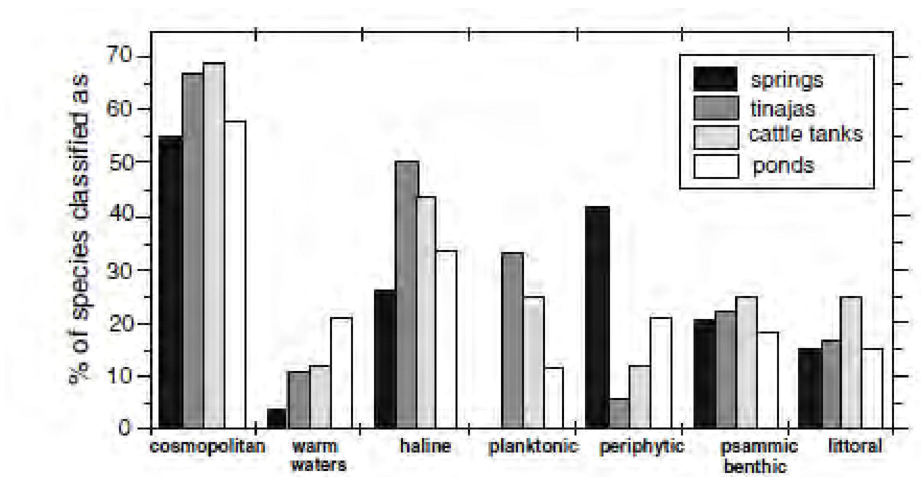


Figure 18. Percent of rotifer species by microhabitat type in four BIBE aquatic habitats (Walsh et al. 2007).

<u>Groundwater Levels</u>

Groundwater availability in the Chihuahuan Desert region is always changing based on weather, well withdrawals, and land use practices (Porter et al. 2009). Given the limited and unpredictable nature of precipitation in this region, groundwater supplies are vulnerable to both seasonal and long-term declines (Porter et al. 2009). If groundwater levels drop, spring flow may decrease or even cease, dramatically impacting the surrounding habitats.

Over the past century, more than 100 wells have been dug or drilled within the current boundaries of BIBE. However, groundwater levels essentially were not measured in the park prior to the mid-2000s. Since then, water levels have been measured at several wells throughout the park. In 2007, the TWDB established an observation well within BIBE in the Panther Junction area (identified as Brewster County Well 73-47-404) (Porter et al. 2009, Plate 8). This nearly 190 m (620 ft) deep well is the first site within the CHDN that can electronically track groundwater levels over time. Since data gathering began in May 2007, depth to groundwater has ranged from 53.1 to 33.9 m below ground level (TWDB 2012). These data are presented in Figure 19. While recent measurements (2011) are lower than in the two previous years, they are similar to 2008 levels. Due to the relatively short period of observations, it is not possible to determine if these low levels indicate a decline or are part of a natural cycle.

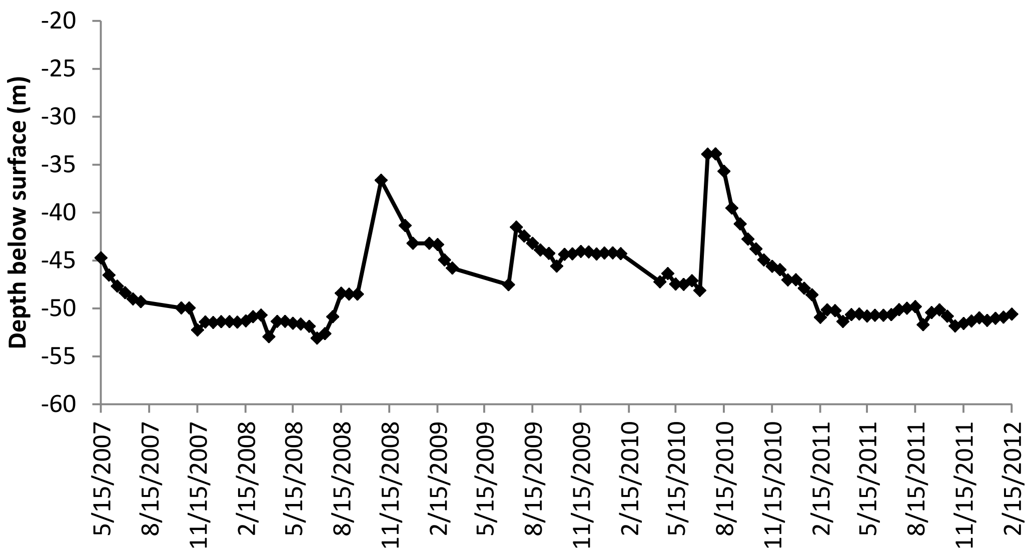


Figure 19. Depth to groundwater at BIBE's Panther Junction observation well (Brewster County Well 73-47-404), May 2007 – February 2012 (TWDB 2012).

Data from the four years with complete or nearly complete records were compared to look for seasonal trends (Figure 20). No clear patterns emerged, perhaps due to the limited amount of data.

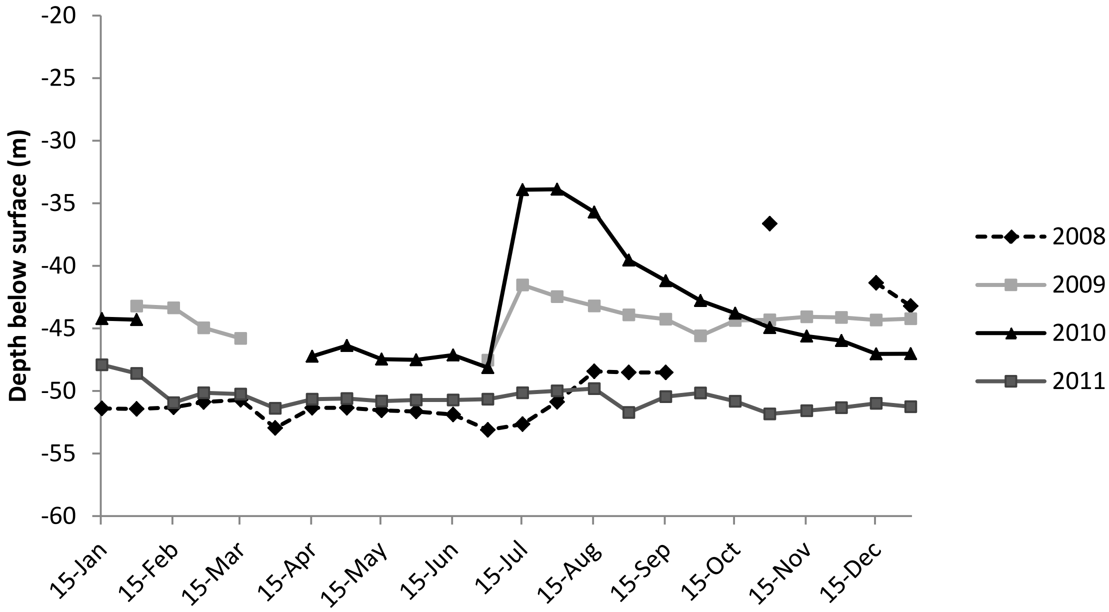


Figure 20. Depth to groundwater measurements by year, 2008-2011 (TWDB 2012).

Porter et al. (2009) reported groundwater depth data from additional wells in the park from 2004-2008 (Figure 21). While there is variation at some wells over time, groundwater depth has been stable at the majority of these wells. Ten observation wells have been selected in BIBE for inclusion in the long-term groundwater monitoring protocol for the CHDN (Filippone et al., *in prep.*). Long-term monitoring of these wells, listed in Table 17, began in June 2012 and will provide valuable data for future assessments.

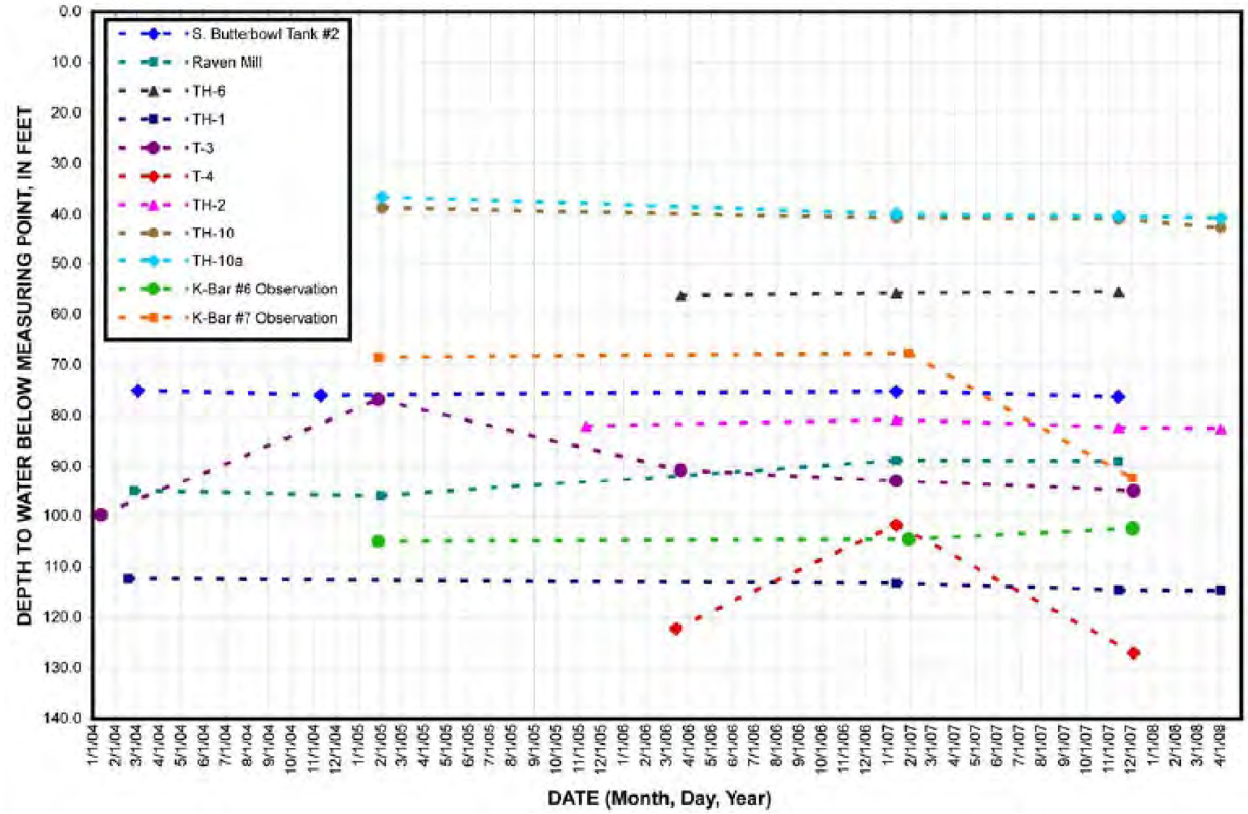


Figure 21. Depth to groundwater at multiple wells in BIBE, 2004-2008 (Porter et al. 2009).

Table 17. Summary of wells in BIBE selected for long-term monitoring by the CHDN (Porter et al. 2009, Filippone et al., *in prep.*).

Well Name	Well ID	Total Depth (ft)	Aquifer
Rio Grande Village Irrigation Well #1	72-49-499	27	
TH-2	73-47-103	600	Tertiary Volcanics
TH-10	73-47-201	455	Tertiary Volcanics
TH-10a	73-47-202	469	Tertiary Volcanics
K-Bar Number 3	73-47-503	234	Cretaceous limestone
K-Bar Number 6	73-47-507	145	Alluvial deposits
TH-7	73-47-507a	600	
Reynold's Well	73-47-799	90	
Lower Pine Canyon Well	73-47-899	250	
Gallery Well	73-52-905	26	

Threats and Stressor Factors

BIBE staff identified a number of potential threats and stressors to spring communities in the park, including climate change, visitor overuse, wildland fire, and human development (e.g., groundwater withdrawal, oil and gas development). Climate change could impact both the amount and timing of precipitation (NAST 2001, as cited by Davey et al. 2007), which would directly impact spring recharge. These changes could affect vegetation, invertebrate communities, and wildlife associated with spring habitats (Betty Alex, BIBE GIS Specialist, written communication, March 2011). Warmer temperatures will accelerate evaporation and transpiration, reducing the amount of standing water available at springs and potentially increasing vegetation's demand for water.

Visitor use threatens springs in a number of ways, including the trampling of vegetation, churning sediments in spring water, extraction of large amounts of water, disruption of wildlife, and contamination from pathogens (e.g., *Giardia*) or chemicals (e.g., sunscreen, water treatments) (B. Alex, written communication, March 2011).

Groundwater drawdowns due to increased well pumping also threaten some springs in the park. Excessive water removal through wells lowers groundwater levels, which can reduce or eliminate spring flow. Growing security concerns along the U.S.-Mexico border have increased the number of security personnel stationed within the park, placing greater demands on water supplies (Jeffery Bennett, BIBE Physical Scientist, written communication, 12 October 2012). Springs along the Rio Grande could be threatened by unregulated groundwater pumping for human developments outside the park (Porter et al. 2009).

Exotic plant invasion also threatens BIBE's spring habitats. These plants can displace native species (Bartel 2002), and some exotics, such as saltcedar, may reduce water availability by aggressively competing for this limited resource (NPS 1992). During 2010-2012 spring inventories in the park, 13 exotic plant species were detected at 157 or 45% of the 355 springs surveyed (Table 18, Reiser et al. 2012). Exotic animals (e.g., feral hogs) and trespass livestock (typically in the southern part of the park near the Rio Grande) can also impact springs by damaging vegetation, increasing erosion through streambank trampling, increasing sediment loading, and introducing fecal coliform bacteria or other contaminants (NPS 1992, Bartel 2002).

Table 18. Number and percentage of surveyed springs where exotic plant species were detected, 2010-2012 (Reiser et al. 2012).

Scientific name	Common name	# of springs	% of springs
Tamarix spp.	tamarisk or saltcedar	83[a]	23.9
Cynodon dactylon	Bermudagrass	42	12.1
Eragrostis lehmanniana	Lehmann's lovegrass	35	10.1
Sorghum halepense	Johnsongrass	18	5.2
Pennisetum ciliare	buffelgrass	5	1.4
Arundo donax	giant cane	4	1.2
Paspalum dilatatum	dallisgrass	3	0.9
Polypogon spp.	rabbitsfoot grass	3	0.9
Salsola tragus	prickly Russian thistle	3[b]	0.9
Marrubium vulgare	horehound	2	0.6
Sonchus oleraceus	common sowthistle	2	0.6
Nicotiana glauca	tree tobacco	1	0.3
Echinochloa crus-galli	barnyardgrass	1	0.3

[a] includes *Tamarix* spp. and *T. chinensis*
[b] includes *Salsola* spp. and *S. tragus*

<u>Data Needs/Gaps</u>

Little research has been done on small, isolated, often ephemeral springs in general. A better understanding of the typical processes, patterns, and ecological interactions at these unique sites would help managers in maintaining them and assessing their condition (Bartel 2002).

While a considerable amount of data has been collected regarding BIBE's springs, little information exists that relates spring data to season, precipitation, or "other environmental factors that could significantly influence the amount of water available at a water source" (Alex 2008, p. 2). MacNish et al. (1996) recommended studying the response of important springs in the park to climatic variation, so that spring flow at these locations could be estimated without actually visiting them. According to the authors, cumulative departure from monthly average precipitation is "a good index of the hydrologic driving mechanism for springflow" (MacNish et al. 1996, p. 27). Additional aquatic invertebrate data, consistent and comparable vegetation surveys, and continued groundwater level monitoring will help managers better assess the condition of spring habitats in the future.

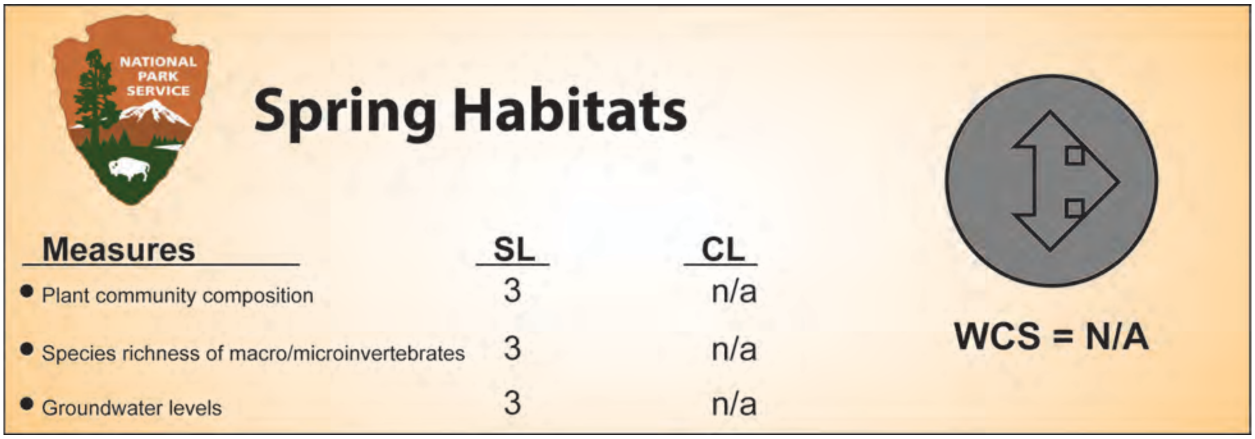
<u>Overall Condition</u>

Plant Community Composition
The project team defined the *Significance Level* for plant community composition as a 3. While spring habitat plant communities have been surveyed, very little of the available information is comparable, particularly over time. While the presence of exotic plants such as saltcedar and Bermudagrass is a cause for concern, it is not possible to assign a park-wide *Condition Level* at this time.

Species Richness of Macro/microinvertebrates
A *Significance Level* of 3 was assigned to the measure of species richness of macro/ microinvertebrates. Some data exists for rotifer species in the park's springs, but these represent just one part of the overall macro/microinvertebrate community, and macroinvertebrate sampling has been limited to just a few springs in the park. A more thorough study of aquatic invertebrates in BIBE springs is needed before this measure's condition can be accurately assessed. Therefore, a *Condition Level* was not assigned for this measure.

Groundwater Levels
A *Significance Level* of 3 was assigned to the measure of groundwater levels. Groundwater level data gathering in the park began relatively recently. With relatively little data, a *Condition Level* currently cannot be assigned.

Weighted Condition Score
Since *Condition Levels* could not be assigned for this component's measures, a *Weighted Condition Score* (WCS) was not calculated. The condition of BIBE's spring habitats is unknown.



4.2.6 Sources of Expertise

Betty Alex, BIBE GIS Specialist

Jeffery Bennett, BIBE Physical Scientist

Kirsten Gallo, CHDN Program Coordinator

Joe Sirotnak, BIBE Botanist/Ecologist

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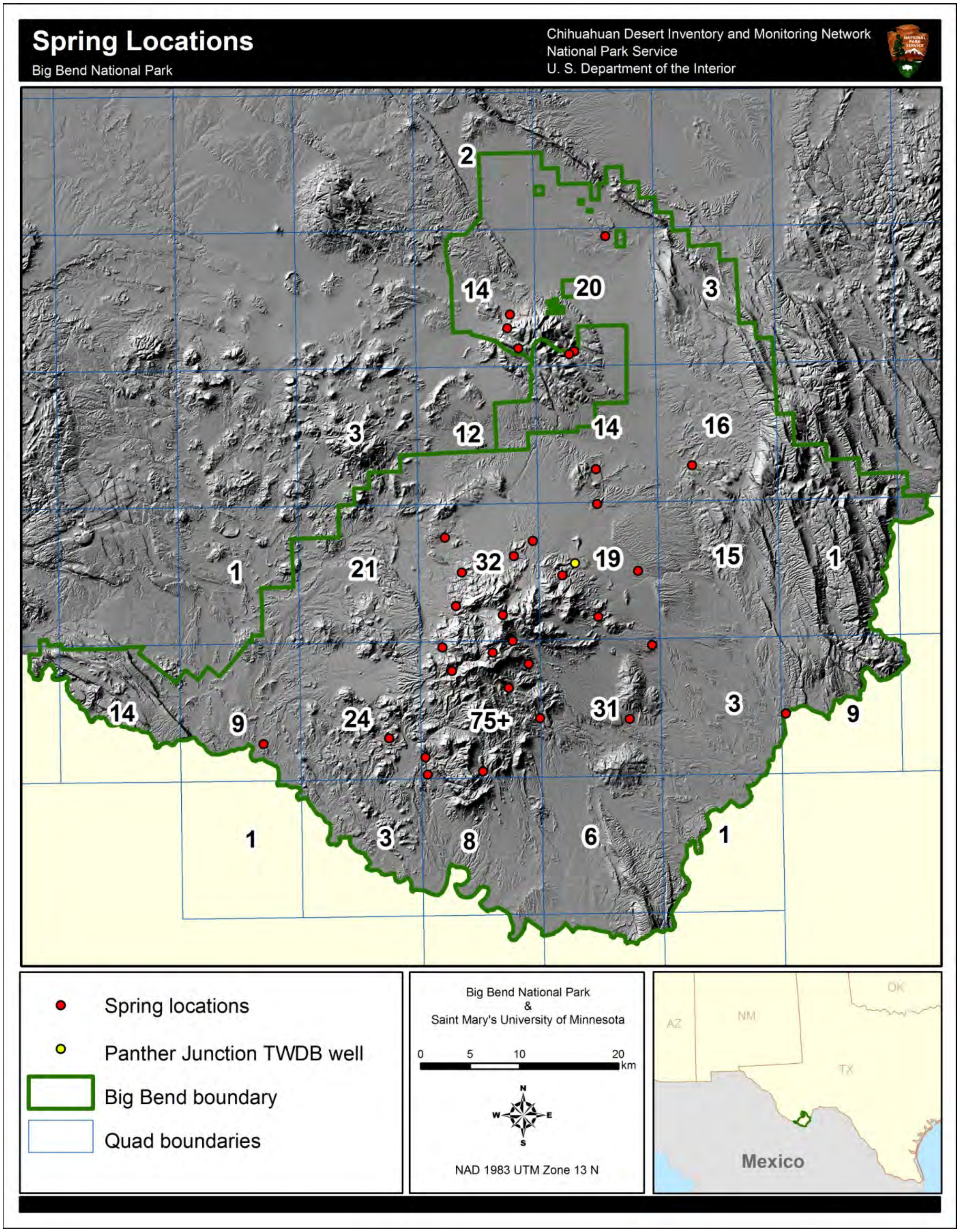

Plate 8. Locations of springs published on USGS 7.5 quad maps (additional spring locations are considered sensitive and are not released to the public). White numbers indicate the number of springs documented in each quad according to BIBE GIS data. The location of the Panther Junction observation well is also shown.

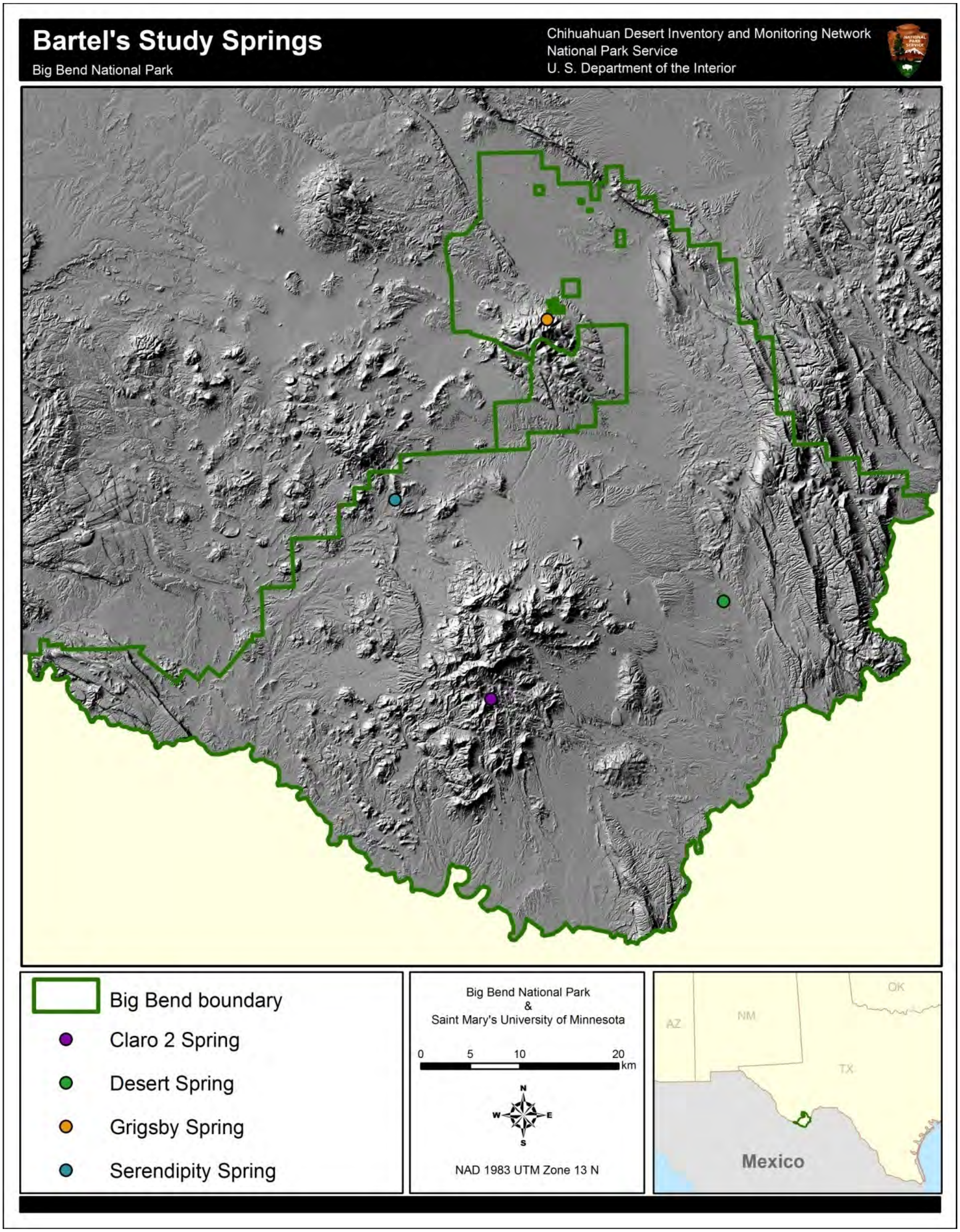

Plate 9. The locations of Bartel's (2002) four study springs within BIBE.

4.3 Montane Forest/ Sky Islands

4.3.1 Description

A montane forest is defined as a typically dense, forested area found at high elevations (above 1,372 m [4,500 ft]) isolated from the surrounding lowlands (Camp et al. 2006). The upper reaches of BIBE's montane forest are characterized by woody vegetation that is typically characteristic of more mesic or northern environments. Sky islands (Photo 3) are isolated mountainous areas that greatly differ from the surrounding lowlands. Elevations in BIBE range from 518 m (1,700 ft) in the Rio Grande valley to over 2,377 m (7,800 ft) in the Chisos Mountains, quickly transitioning from grassland and desert scrub to forest communities (Alex et al. 2006). Sky islands are sometimes physically separated by large distances from other similar mountain ranges or ecosystems. Stratified ecological zonation occurs on sky islands (i.e., colder temperatures and wetter climate correspond with increases in elevation). Montane forest/sky islands are generally surrounded by arid desert regions, creating a veritable oasis within the desert ecosystem. The term "sky island" was first used in 1967 by Weldon Heald (Heald 1993) in describing mountains as being similar to isolated islands in an ocean, both containing unique and geographically limited habitats.

Photo 3. The Chisos Mountains rise above the desert in BIBE and create mountain islands, or "sky islands" - mountainous areas of higher elevation surrounded by relatively flat and arid lowlands (Photo by Betty Alex, BIBE).

The montane forest/sky island environments in BIBE contain a diverse and unique range of flora and fauna, typical of biota found in more northern latitudes (McLaughlin 1994). The mountainous canyons are dominated by Cypress/Douglas-fir forest, unique to the elevational gradient, geographic location, and geologic diversity of montane forests in BIBE (Alex et al. 2006). Relict floral populations from the pre-desert era often occur at higher altitudes within BIBE, sometimes endemic to a specific range in elevation or geographic location. Floral and faunal species may also encounter allopatric speciation, where unique genetic lineages result in the emergence of a new biological species, because of long periods of physical isolation.

4.3.2 Measures

- Forest community structure
- Carmen white-tailed deer (*Odocoileus virginianis carminis*) population size
- Acorn woodpecker (*Melanerpes formicivorus*) abundance
- Eastern cottontail (*Sylvilagus floridanus*) abundance
- Canyon treefrog (*Hyla arenicolor*) abundance
- Guadalupe fescue (*Festuca ligulata*) abundance

4.3.3 Reference Conditions/Values

The reference condition for the montane forest/sky islands in BIBE is pre-Anglo settlement conditions within the park.

Photo 4. Guadalupe fescue in BIBE (NPS Photo).

4.3.4 Data and Methods
Krausman and Ables (1981) provided much of the baseline data for Carmen white-tailed deer populations in BIBE. The study examined distribution, habitat, food habits, and predator-prey relationships.

Plumb (1992) provided comparisons between several historically developed vegetation classification systems of the major ecological units within BIBE. Forest community structure was classified on a fine scale in order to identify specific species for each assemblage. Plumb (1992) also provided the most current classification system of the montane forest/sky island forest community.

Koenig and Haydock (1999) examined the geographical ecology of acorn woodpeckers in the southwestern United States and the Pacific Coast. Data on the diversity and abundance of oaks and their effects on acorn woodpecker populations were also discussed.

Camp et al. (2006) reported on changing fire regimes, forest structure, fire suppression, and tree species diversity within the Chihuahuan Desert borderlands. A hierarchical approach was used in assessing vegetation abundance, distribution patterns, and predictive mapping of vegetation and fuels.

Alex et al. (2006) reported on the unique and rare plant species of BIBE, and created a comprehensive list of sensitive plant species with spatial distributions, densities, and other pertinent information within the park. Alex et al. (2006) also presented information and spatial data for the Guadalupe fescue in BIBE.

4.3.5 Current Condition and Trend

<u>Forest Community Structure</u>
The montane forest biome exists primarily in the higher elevations of the Chisos Mountains, including Boot Canyon and Pine Canyon (Plumb 1992). The Arizona cypress (*Callitropsis arizonica*) and Douglas-fir (*Pseudotsuga menziesii*) community occupies Boot Canyon (Photo 5), and the Arizona pine (*Pinus arizonica* var. *stormiae*) (ecologically similar to, and under some authors, synonymous with ponderosa pine [*Pinus ponderosa*]) and Graves oak (*Quercus gravesii*) community occupies Pine Canyon (Plumb 1992). The areas surrounding the canyons also contain species characteristic of the Late Pleistocene piñon-juniper-oak woodlands, which range in elevation from roughly 1,372 m (4,500 ft) to various mountain summits (NPS 2010, NPS 2012a), with the local piñon being Mexican piñon. This community can be divided into ecological plant community subsets with similarities between groups, and is comprised of coniferous forest stand communities in the upper canyon reaches (Plumb 1992). Other tree species located in the montane forest community include the quaking aspen (*Populus tremuloides*), drooping juniper (*Juniperus flaccida*) and big tooth maple (*Acer grandidentatum*), among others (Camp et al. 2006, Alex et al. 2006, NPS 2010).

Photo 5. Boot Rock, which is located in Boot Canyon of BIBE (Photo by Joe Sirotnak, BIBE).

Vegetation classifications of BIBE have employed coarser or finer scales, depending on specific purpose, generally resulting in slightly different classification systems (Table 19). Douglas-fir and oak communities were generally considered the most dominant species between studies.

Table 19. Comparison of vegetation classification systems for the montane forest assemblage of BIBE from selected sources. Forest vegetation classification columns represent separate forest communities identified in the park by each author. Table modified from Plumb (1992).

Study	Forest vegetation classification		
Taylor et al. (1944)	Ponderosa pine - Graves oak	Arizona cypress - Douglass-fir	
Denyes (1956)	Yellowpine fir		
Warnock (1970)	Ponderosa pine - Douglas-fir		
Warnock and Kittams (1970)	Ponderosa pine - Douglas-fir		
Wauer (1971)	Cypress - Pine - Oak		
Dick-Peddie and Alberico (1977)	Ponderosa pine	Douglas-fir	Arizona cypress-Talus
Plumb (1992)	Oak - ponderosa pine - Cypress	Piñon - Talus	

Plumb (1988, 1992) developed the most complete, and perhaps useful, vegetation classification system for BIBE. Plate 10 shows the areas of montane forest within BIBE as identified by Plumb (1988, 1992); in this classification system, montane forests were strictly defined as areas containing oak-ponderosa, pine-cypress, and piñon-talus woodlands. Forest meadow, mixed oak, piñon-juniper-grassland, and piñon-oak-juniper woodlands were excluded from Plate 10. According to the Plumb (1988) classification, 1,022.86 ha (2,527.54 ac) of BIBE are classified as montane forest communities.

Carmen White-tailed Deer Population Size

The Chisos Mountain range in BIBE provides the main habitat for Carmen white-tailed deer (Photo 6) populations in the United States (Krausman and Ables 1981). Carmen white-tailed deer live primarily in the Chisos Mountain basin in pine-juniper-oak habitats above 1,372 m (4,500 ft), although they are found in isolated mountainous locations throughout BIBE and outside of the park (Krausman and Ables 1981).

Photo 6. Carmen white-tailed deer in the Chisos Mountains (Photo by Ed Bollech, NPS).

Carmen white-tailed deer populations prior to the establishment of BIBE (1912-1934) were reportedly abundant (Krausman and Ables 1981); Ross Maxwell, the first Superintendent of BIBE, suggested a "high" deer population within the park (Krausman and Ables 1981). Populations were stable on the land that now comprises BIBE from 1936 until the end of ranching and hunting in 1944. No signs of increased populations were noted from 1947 to 1952 (Murie 1954, Davis 1957, as cited in Krausman and Ables 1981). Populations increased following the end of hunting after the creation of BIBE in 1944. Stomach worms (*Haemonchus* spp.) and poisonous weeds were suspected of causing large die-offs of Carmen white-tailed deer in the early to mid-1940s (Krausman and Ables 1981). Deer populations rebounded in the late

1940s and early 1950s, but increases in mountain lion populations from 1949 to 1953 likely caused further decreases in Carmen white-tailed deer populations until the late 1950s (Figure 22).

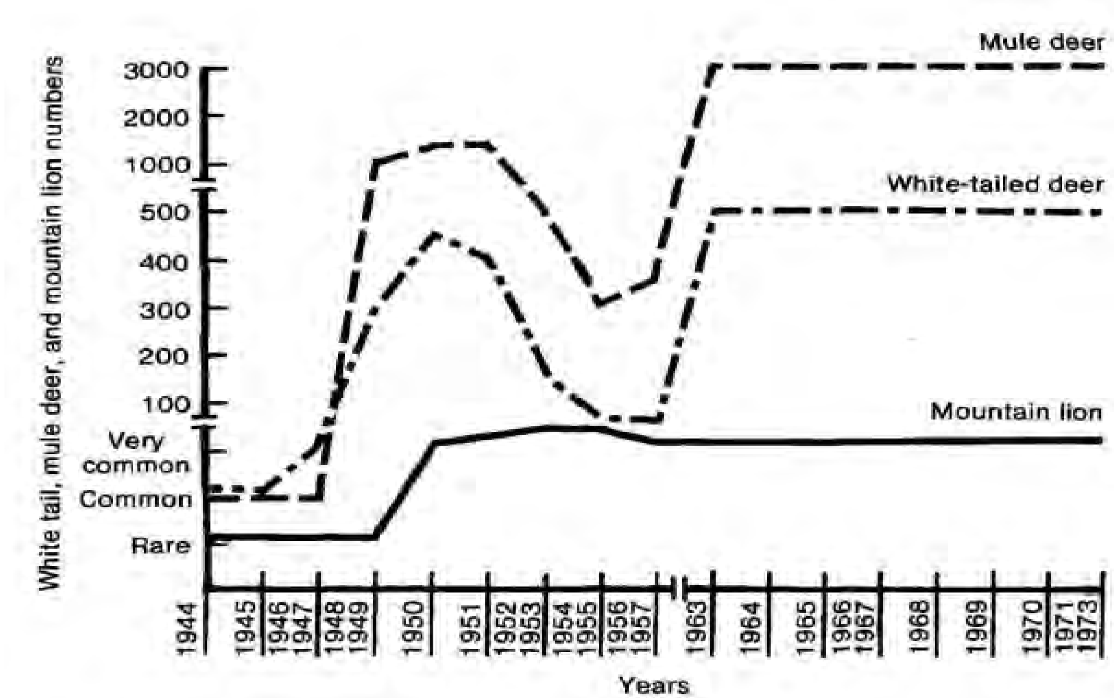

Figure 22. Population fluctuations of mule deer (*Odocoileus hemionus eremicus*), white-tailed deer, and mountain lions in BIBE from 1944-1973. Data based on NPS Annual Wildlife Reports. Figure reproduced from Krausman and Ables (1981).

Krausman and Ables (1981) reported 515-890 (90% C.I.) white-tailed deer in BIBE in 1974, which was the final year of field surveys (Figure **22**). More recently, TPWD (2012) has reported that populations of Carmen white-tailed deer in southern Brewster County and BIBE are relatively stable. TPWD (2012) also suggested that a lack of woody cover, malnutrition associated with drought, and low fawn survival rates due to predation have limited habitat expansion and kept populations in check, although NPS (2012b) states that deer densities in the Chisos Mountains are high. Because the majority of Carmen white-tailed deer live within the boundaries of BIBE, they are protected from hunting. Although current deer population numbers are unavailable, anecdotal evidence suggests that BIBE populations have varied from stable to slightly elevated since the 1960s. However, data documenting Carmen white-tailed deer abundance, densities, or distributions after 1974 are unavailable.

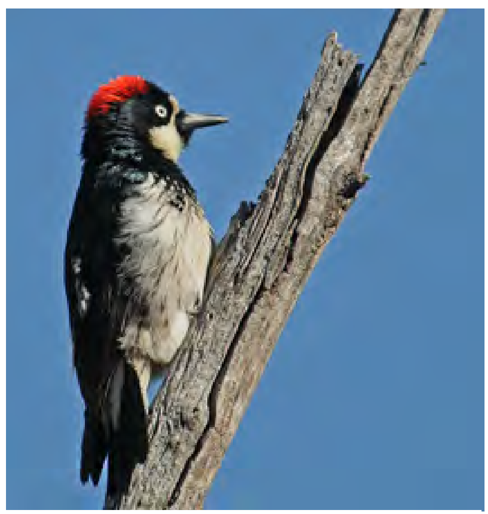

Photo 7. Acorn woodpecker (Photo by Sally King, NPS).

Acorn Woodpecker Abundance
Acorn woodpeckers (Photo 7) are frequently observed in the Chisos canyons of BIBE and are year-round residents of the Trans-Pecos Mountains. According to Bryan (2002, p. 12), the acorn woodpecker is classified as a “regular and widespread nesting species” commonly found year-round with varying numbers. However, according to NPS anecdotal reports, population numbers appear to be declining. Bock and Lepthien (1975) note that acorn woodpeckers are likely more common in western states because of predictable acorn crops. Koenig and Haydock (1999, p. 159) state that “the effective distributional limit of acorn woodpeckers is not set by the limits of oaks but rather by sites where oak diversity drops to a single species” (Figure 23).

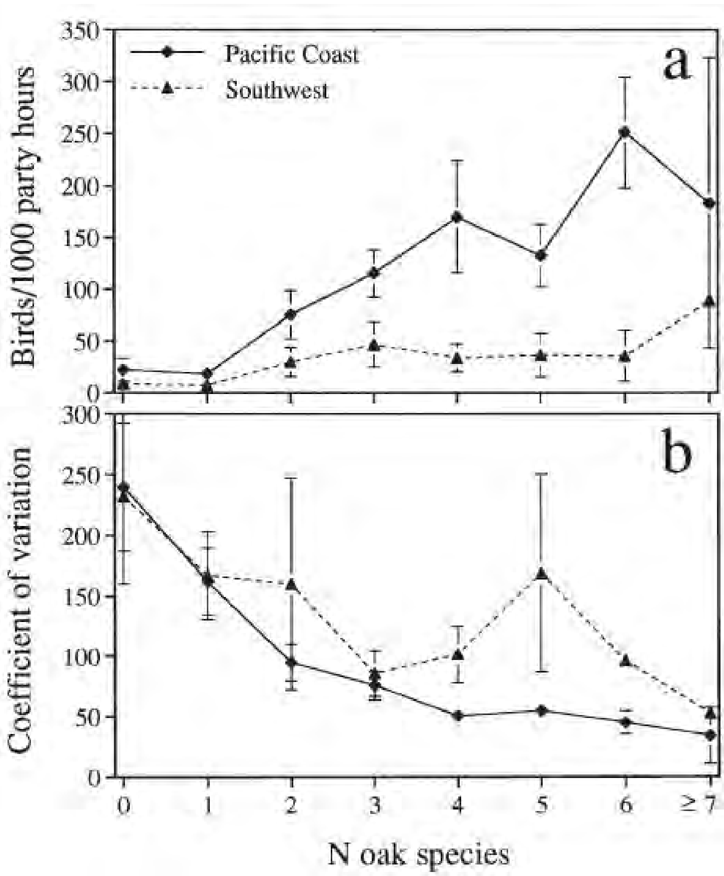

Figure 23. Mean (±SE) density (a) and CV (b) of acorn woodpecker populations along the Pacific Coast and the Southwest plotted as a function of oak species numbers present within sites. Data based on Christmas Bird Counts conducted between 1959-1960 and 1988-1989. Reproduced from Koenig and Haydock (1999).

Densities of acorn woodpeckers are notably lower in southwestern states (including west Texas); Koenig and Haydock (1999, p. 164) state that acorn woodpeckers are generally "…sparser in the Southwest than along the Pacific Coast independent of oak species or abundance." This trend is likely due to lower productivity in both quantity and quality of southwestern oak communities (Koenig and Haydock 1999). Few data exist regarding abundance and population estimates of acorn woodpeckers in BIBE and surrounding areas.

Eastern Cottontail Abundance

The eastern cottontail is one of the most common and widespread rabbit species in the United States. It is found within the montane forest community in BIBE, and thrives above elevations of approximately 1,500 m (4,921 ft) in the Chisos mountains (Schmidly and Davis 2004). Although quantifiable data on eastern cottontail abundance are lacking, Wauer and Fleming (2002) noted that the species was numerous. It is unknown from the literature whether current eastern cottontail populations reflect pre-Anglo settlement conditions within BIBE. Recent genetic testing identified the Davis Mountains/robust cottontail (*Sylvilagus robustus*) as a unique species, promoted from a subspecies of *Sylvilagus floridanus*.

Canyon Treefrog Abundance

The canyon treefrog (Photo 8) is native to the southern United States and is found in rocky canyon habitats near permanent water sources (Easterla 1973, Swann 2005, Santos-Barrera and Hammerson 2010). Within BIBE, the canyon treefrog is found only in the Chisos Mountains and surrounding foothills (Easterla 1973). The canyon treefrog is currently classified as an organism of low concern by the IUCN (indicating stable populations), and is commonly seen in the park (Santos-Barrera and Hammerson 2010). According to Swann (2005), canyon treefrogs are abundant at both high and low elevations. Wauer and Fleming (2002) noted that the canyon treefrog is commonly found at higher elevations within the Chisos Mountains in the moist rocky canyons. Despite large distributions of canyon treefrogs, the main population in BIBE is isolated, and confined primarily to the montane forest community and wet stream environments of the Chisos Mountains. Monitoring of this species may be needed in order to truly understand their abundance and survivability.

Photo 8. Canyon treefrog (NPS photo).

Threats and Stressor Factors

Sky islands are physically isolated from similar environments; isolated populations of plants and animals tend to be at greater risk of extinction and reduced colonization of new habitats (Gillespie and Clague 2009). Genetic isolation and specific available habitat can potentially limit, and consequently threaten, these isolated populations.

Uncharacteristically severe wildfires are of high concern for montane forests in BIBE, due to decades of fire suppression in the area (NPS 2012b). Extreme drought may increase intensity of fire events, especially following decades of fire suppression since the park’s establishment in 1944 (Camp et al. 2006). Camp et al. (2006) noted that regeneration pulses followed cessation of historic fire patterns, most notably following a fire in 1913 within BIBE (Figure 24). NPS (2012b) suggests that grazing from the 1880s to 1940s, drought from the 1890s to 1950s, and fire suppression since the 1940s caused forests/shrubs to dominate the landscape, leading to thicker and denser forests in the Chisos Mountains. Long-term fire suppression can create excessive amounts of dead and dried vegetation, leading to large fire events and introductions of disease or non-native species invasions. Changes in seasonal rainfall and timing of rainfall events may directly influence major fire intervals.

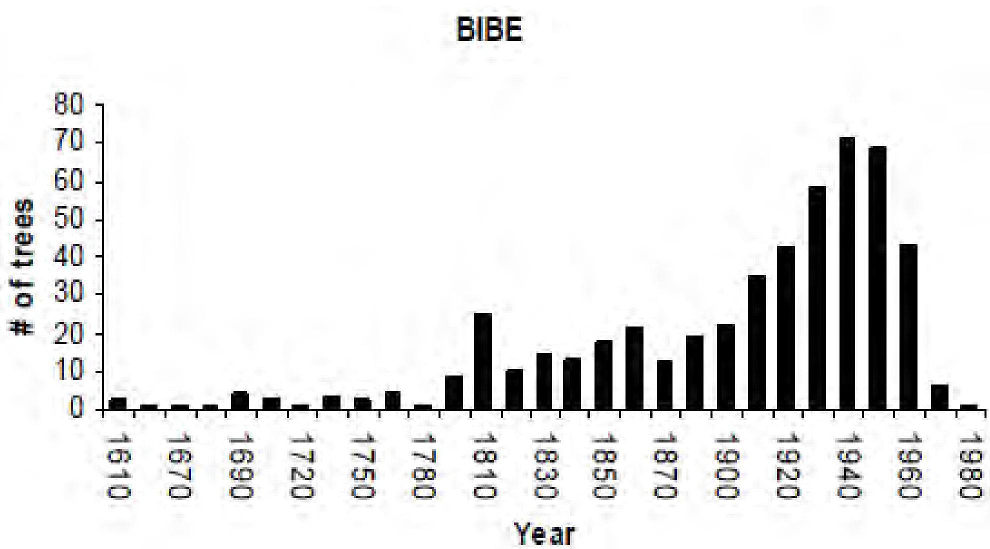

Figure 24. Innermost ring dates of mature conifer trees in BIBE (n=508). Reproduced from Camp et al. (2006).

Acorn woodpecker abundance is directly linked to the oak tree population; therefore, the health of oak trees will likely dictate the presence and abundance of acorn woodpeckers. Oak crop failures or massive die-offs could potentially threaten the survival of the acorn woodpecker in certain geographic regions, possibly leading to local extirpations. Woodpeckers that abandon areas of poor acorn crops may move between areas of higher food availability (Hannon et al 1987). Hanski and Gilpin (1991) noted that acorn woodpecker populations throughout the United States will vary independently of one another, leading to varied abundances based on differing regional processes.

Transportation and deposition of airborne contaminants may disproportionately affect amphibian species such as the canyon treefrog. Introduced parasites such as Trombiculid mites (*Hannemania* sp.) can also affect such small populations, leading to large die-offs (Sladky et al. 2000). Although the canyon treefrog has adapted well to various environments, water quality degradations, changes in aquatic insect abundance, and degradation or elimination of small specific isolated habitat (e.g., canyon streams, pools, and pine-oak-juniper woodlands) could lead to the rapid decline or extirpation of this species.

Climate change, potentially resulting in higher average yearly temperatures and drying conditions, could pose an added threat to sky island-specific species. Climate analysis by Whitson (1974) described a warming and drying trend within the park. Increased temperatures could result in shifts in species' range, which would be potentially damaging for organisms that exist in narrowly defined niche communities, such as the canyon treefrog.

The potential effects of long-term climate change became apparent in 2011, when the Big Bend region experienced the driest year on record (NOAA 2012). Effects of this dry period were seen in both desert and montane habitats, with significant overstory and understory tree mortality occurring in the Chisos Mountains (Sirotnak, email communication, 16 October 2012). Across all tree species and size classes, approximately 17% of trees living before the drought were dead in 2012, with overstory tree mortality most pronounced in Mexican piñon (Poulos, unpublished data). If such dry periods become more frequent or severe in the coming decades, the montane sky-island ecosystem is at significant risk.

Heavy visitor and NPS use of BIBE trails, and illegal collection of many flora and fauna species may directly affect overall condition of the montane forest community (NPS 2001). Non-native species introductions into high-use visitor areas, as well as loss of native plant species through competition or changing climatic regimes were listed by the NPS (2001) as threats of concern in BIBE. Overgrazing of land in the Chisos Basin prior to the establishment of the National Park increased the presence of native disturbed-site species such as broomweed and prickly pear (Whitson 1974). Overgrazing by domestic animals was one of the primary threats identified for Guadalupe fescue in Poole (1989). Additionally, recreational use of fescue habitat, exceptionally dry growing seasons, and park management/maintenance traffic may further stress the species (Poole 1989, NPS 2012c).

Anthropogenic influences such as established trails, soil upheaval, and campground usage, among others, exist as other potential stressors to the montane forest communities (Whitson 1974). De-vegetation of the Chisos Basin, particularly in regards to fire suppression activities (i.e., fuel reduction efforts), may represent another significant anthropogenic impact on the sky island community in BIBE. As recently as 1980, there were significant stands of piñon, oaks, and juniper woodlands in the basin area (B. Alex, written communication,16 October 2012). Fuel reduction efforts have largely converted these areas to grasslands, which didn't exist in these areas until recently.

Data Needs/Gaps

A planned vegetation mapping project for BIBE is currently being performed by the CHDN. This project could help to update existing classification systems or perhaps clarify existing data gaps, resulting in perhaps a better overall understanding of not only the montane forest/sky islands communities but also park-wide vegetative communities.

A lack of data regarding the vegetation of the lower Chisos (also referred to as the Sierra Quamada) is also evident, as this area is almost an entirely untouched resource area (B. Alex, email communication, 16 October 2012). This area is very remote, and is comprised of rugged terrain, but there are likely plant and vegetative communities present that are entirely different from the rest of BIBE. This unique area is part of the Chisos Mountain ecosystem, but is unique in that it does not have the typical woodland community. A better understanding and inventory of this area could provide park managers with valuable community level information.

The Sensitive Plant Project was initially funded to survey and identify unique and rare plants in the Chisos Mountains. There are thousands of acres in the Chisos Mountains that have gone unsurveyed, and this project was a spearhead to initiate these much needed surveys. However, funding for this project was temporary, and the project only lasted for half of a year. Continuation of this project would benefit park managers, especially in regards to the presence of rare species in the park and their vulnerability to fire and/or climate change. Additional Guadalupe fescue surveys in the Chisos Mountains (as well as Mexico) are needed, as additional knowledge regarding this rare species' reproductive biology, ecology, and habitat requirements would greatly aid conservation efforts in the park.

Krausman and Ables (1981) noted that little was known about pre-settlement conditions of white-tailed deer and historical data are limited. No studies documenting distribution, abundance, or habitat of Carmen white-tailed deer have been undertaken since the 1972-1974 survey by Krausman and Ables (1981). Data from unexploited whitetail deer populations would be of value since they serve as a base with which to compare exploited populations. More data are also needed in order to evaluate acorn woodpecker abundance within the park.

<u>Overall Condition</u>

Forest Community Structure
A *Significance Level* of 3 was assigned for the measure of forest community structure; this measure was assigned a *Condition Level* of 2. While a *Condition Level* of 2 indicates moderate concern, park managers have acknowledged that the winter freeze and summer drought conditions that continue to affect the park could bring about some serious structural changes parkwide, especially in the High Chisos. Furthermore, overstory trees have been rapidly succumbing to drought in the park, and climate change and stand-removing fires are significant threats that are facing this community (Sirotnak, email communication, 16 October 2012). Further monitoring of this measure is needed, and a future re-evaluation may be necessary to see if this measure warrants a higher *Condition Level*.

Carmen White-tailed Deer Population Size
A *Significance Level* of 2 was assigned for the measure of Carmen white-tailed deer population size. This measure was assigned a *Condition Level* of 0, indicating that it is of no concern to resource managers. Carmen white-tailed deer populations have been reportedly stable since the 1960s, exhibiting natural population fluctuations. TPWD (2012) suggest that populations have remained relatively stable in recent years.

Acorn Woodpecker Abundance
A *Significance Level* of 2 was assigned for the measure of acorn woodpecker abundance. This measure was not assigned a *Condition Level* due to a lack of data and information regarding acorn woodpecker population size in BIBE. Acorn woodpeckers are a frequently observed bird species within BIBE throughout most of the year. However, it is speculated that populations are decreasing.

Eastern Cottontail Abundance
A *Significance Level* of 2 was assigned for the measure of eastern cottontail abundance. Due to the limited data that are available for this measure, this measure was not assigned a *Condition Level*. While studies have looked at the BIBE eastern cottontail population and its taxonomic status (Lee and Ammerman 2010). This measure will need monitoring in the future, as the drought the area experienced in 2011 appears to have had a major impact on the eastern cottontail population, as well as other species in the Chisos (Skiles, written communication, October 2013).

Canyon Treefrog Abundance
A *Significance Level* of 2 was assigned for the measure of canyon treefrog abundance. This measure was assigned a *Condition Level* of 1 indicating that it is of low concern to resource managers. Canyon treefrog populations are uncommon in BIBE, but thrive within the Chisos

Mountains and surrounding foothills. They are listed as common (Wauer and Fleming 2002, Swann 2005, Santos-Barrera and Hammerson 2010) to uncommon (Easterla 1973) within BIBE. Dayton (2005) remains the only study to date to document the canyon treefrog in BIBE. Blaustein and Wake (1990) and Lannoo (2005) note that amphibian species across the world are in universal decline due to habitat modification, contaminants, disease, and climate change. With these threats, monitoring of this species in the park may be necessary to observe any changes or trends in the population.

Guadalupe Fescue Abundance
A *Significance Level* of 1 was assigned for the measure of Guadalupe fescue abundance. This measure was assigned a *Condition Level* of 3 indicating that it is of high concern to resource managers. The Guadalupe fescue is a tufted perennial grass found in the Chisos Mountains of BIBE (USFWS 2008). The Chisos Mountains population represents the lone extant population of this species known in the United States (Alex et al. 2006, USFWS 2008).

Guadalupe fescue occurs in one small portion of Boot Canyon at an elevation of 2,073 m (6,800 ft), and the total known population in the park is approximately 300 individuals (Sirotnak, email communication, 16 October 2012). In six permanent monitoring plots within the core of the habitat, population sizes since 1993 have ranged from a low of 27 individuals to a high of 127. On these plots, totaling 0.05 ha (0.12 ac), annual recruitment varied between zero and 82 individuals, and mortality ranges from 4 to 113 individuals. High mortality rates occur following especially dry growing seasons (NPS 2012c).

The Guadalupe fescue is currently listed as a Candidate Species by the USFWS, and it is reportedly reliant on fire in order to thrive in its natural montane forest environment (Alex et al. 2006). The presence of fire is likely a double-edged sword for this species, as understory fire might assist with seedbed preparation and grass seedling recruitment, but overstory-removing fire would probably harm this small population, which occurs in shady understory sites (Sirotnak, email communication, 16 October 2012). Fire management activities, trail erosion, fungal infection, and visitor and animal trampling along high-traffic areas are all potential threats to the survival of the Guadalupe fescue (USFWS 2008). It is also listed by Alex et al. (2006) as a “park priority 1” species, meaning that there are few recorded locations, a low number of individuals, or not enough information upon which to base management decisions. Distribution of this species is very limited; as of 2010, there were at least 115 individuals known from monitoring plots, with several dozen others outside of monitoring plots (Plate 11). However, this population has not been re-visited since the dry period that began in late 2010, which may have caused significant mortality. Alex et al. (2006) reported that Allison Freeman (Leavitt), BIBE Biological Science Technician, discovered 42 plants in addition to the small known population.

According to USFWS (2008), the population dynamics and role of disturbance in fescue habitat maintenance are not clearly understood. Alex et al. (2006) notes that BIBE staff monitors the Guadalupe fescue population located within the Chisos Mountains to ensure its continued survival, and active management may eventually be required to sustain the population (USFWS 2008). Continued survival of the Guadalupe fescue may ultimately rely on active management of both the grass itself and the habitat that supports it (USFWS 2008).

Weighted Condition Score

The overall *Weighted Condition Score* for the BIBE montane forest/sky islands component is 0.458, indicating that this resource is of moderate concern. A declining trend was indicated, as recent droughts and hard freezes have threatened the sky islands of BIBE; the effects of these threats need further investigation.

Montane Forest/Sky Islands

Measures	SL	CL
Forest Community Structure	3	2
Carmen white-tailed Deer Population Size	2	0
Acorn Woodpecker Abundance	2	n/a
Eastern Cottontail Abundance	2	n/a
Canyon Treefrog Abundance	2	1
Guadalupe Fescue Abundance	1	3

WCS = 0.458

4.3.6 Sources of Expertise

Betty Alex, BIBE GIS Specialist

Joe Sirotnak, BIBE Botanist/Ecologist

Raymond Skiles, BIBE Wildlife Biologist

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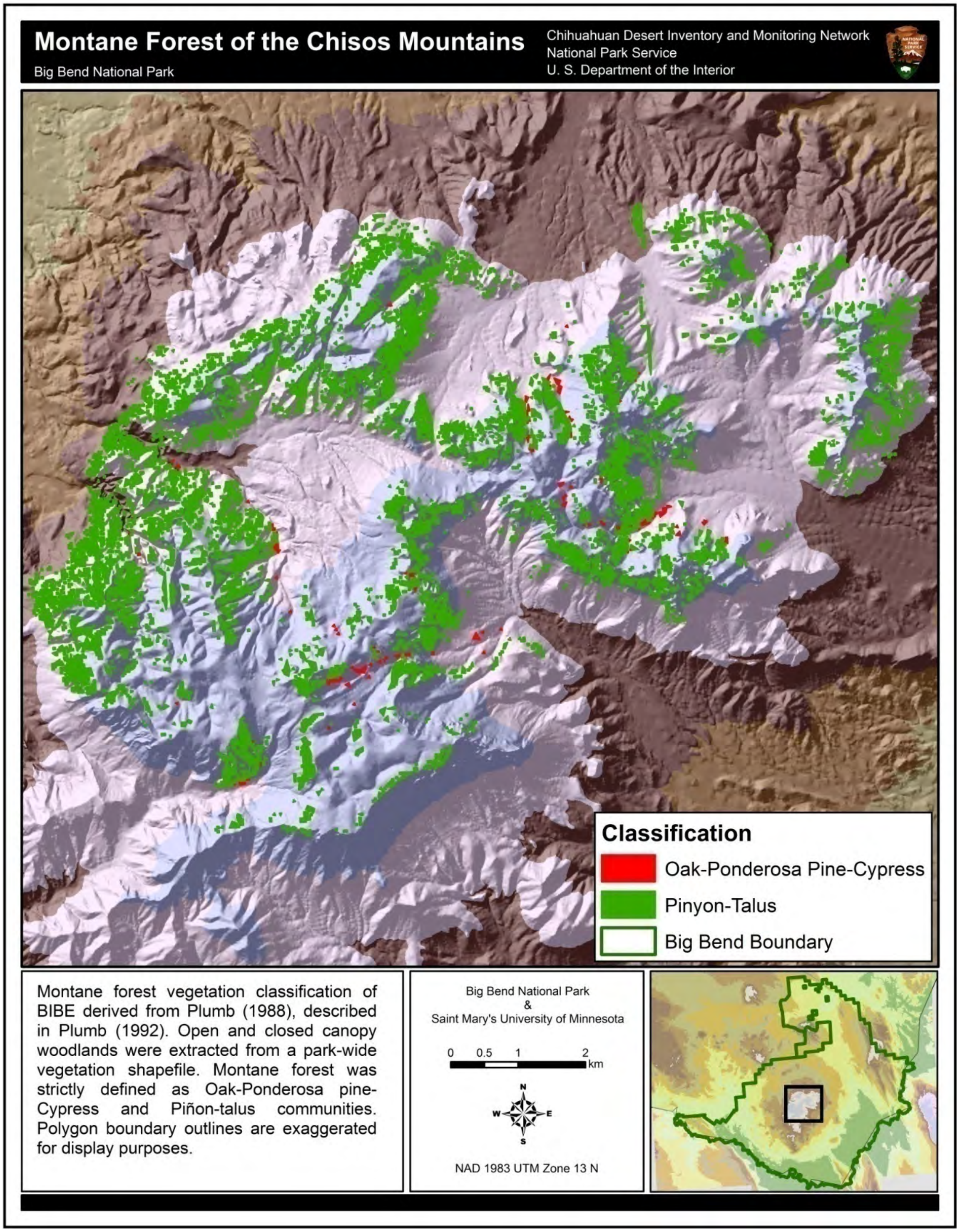


Plate 10. Montane forest of the Chisos Mountains, BIBE (Plumb 1988, 1992).

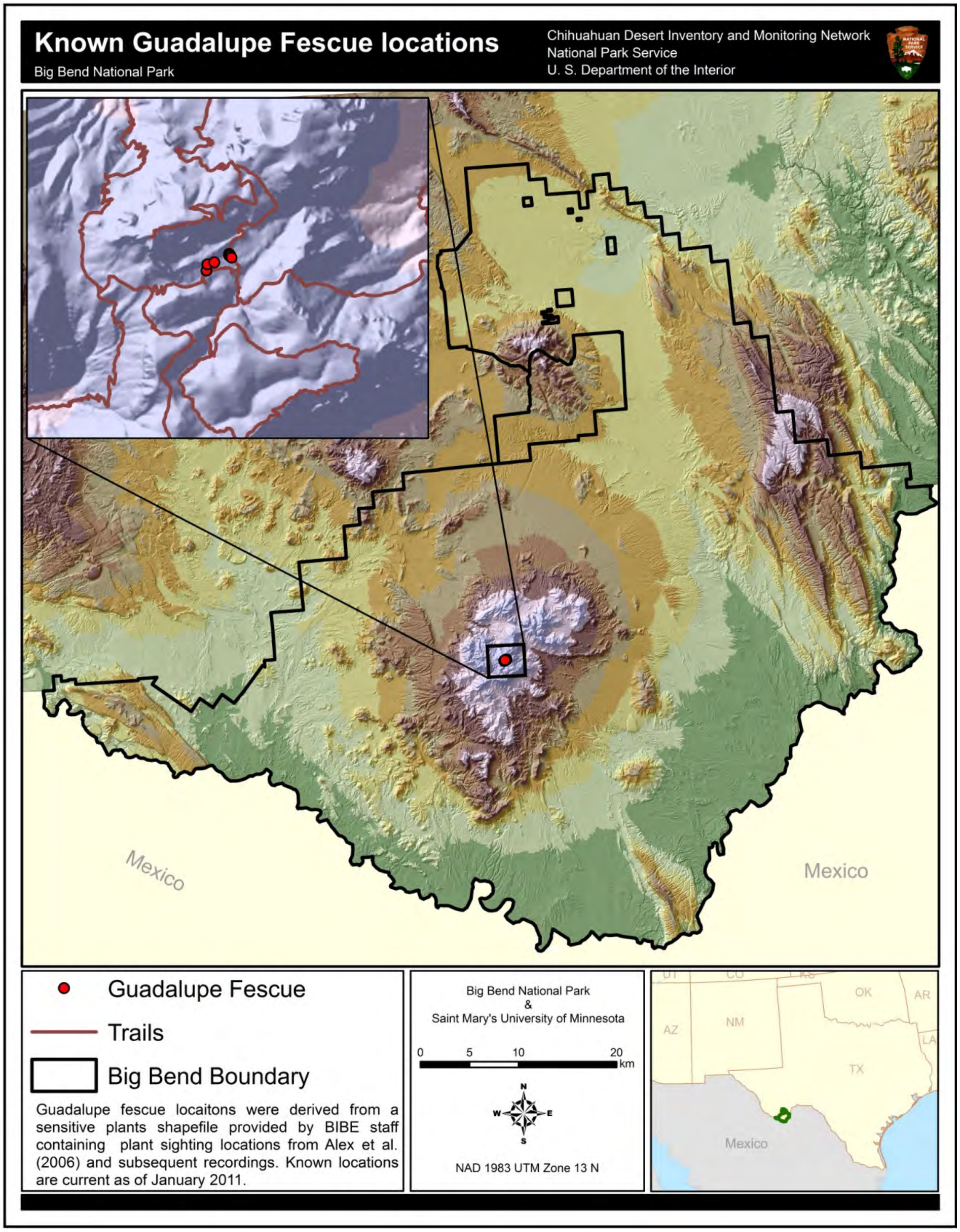


Plate 11. Known Guadalupe fescue locations in BIBE as of January 2011 (Alex et al. 2006).

4.4 Desert Grasslands

4.4.1 Description

Desert grasslands are a diverse biological community found in the Chihuahuan Desert, generally at elevations between 915 and 1,525 m (3,000 and 5,000 ft) (Von Loh and Cogan 2010). When compared to the other major vegetation categories in BIBE (floodplain/upland riparian, scrub desert, shrub woodland, grassy woodland, and forest), desert grasslands boast the highest plant diversity (Von Loh and Cogan 2010). These grasslands provide important wintering habitat for many migratory birds, including several declining species such as the ferruginous hawk (*Buteo regalis*) and Baird's sparrow (*Ammodramus bairdii*) (NPS 2010). However, BIBE is comprised of several former cattle and goat ranches (Maxwell 1985, as cited in Leavitt et al. 2010), and subsequently, grazing has impacted the desert grasslands. Changes since the late 1800s include decreased grass cover; large increases in woody species such as creosotebush, mesquite (*Prosopis* spp.), and juniper; extensive sheet and wind erosion; and formation of arroyos (Griffiths 1904, Leopold 1924, Hastings 1959, Buffington and Herbel 1965, Hastings and Turner 1965, York and Dick-Peddle 1969, as cited in Wondzell 1984). Wondzell and Ludwig (1995) attribute the changes in desert grasslands to domestic livestock grazing and climate change. Grazing in the park ended in 1947 after 40,000 head of cattle, horses, sheep, and goats were removed from BIBE (Maxwell 1947, as cited in Wondzell and Ludwig 1995). Researchers have not been able to identify if grazing or climate change is the primary driver of these changes, but Wondzell and Ludwig (1995) suggest that it is important to determine the cause to better understand the likelihood of reestablishing desert grasslands.

Photo 9. Desert grassland in BIBE (Photo by Barry Drazkowski, SMUMN GSS).

Based on the Plumb (1987) vegetation map, 45.1% of BIBE vegetation cover is high desert grassland; the primary species within this category include succulents such as foothill beargrass (*Nolina erumpens*), sotol (*Dasylirion leiophyllum*), many cacti (e.g., *Opuntia* spp.), and *Yucca* spp.; a diverse array of shrubs; and graminoids (e.g., *Bouteloua ramosa*), which are always present but rarely dominant (Fenstermacher et al. 2008; Sirotnak, written communication, 19

July 2012). However, as soil erosion continues in certain areas of the park, largely due to climate change and overgrazing, grasslands are becoming increasingly dominated by shrubs (creosote and mesquite), leaving little area for native grasses to flourish (Rinas 2009). These grasses play an important ecological role in BIBE, as they are vital for nutrient and water cycling, soil stabilization, and biodiversity preservation (Rinas 2009). NPS is conducting several grassland restoration projects in BIBE, including restoring natural drainage patterns, planting and seeding native species, exotic plant removal, and fuel reduction (Rinas 2009). Restoration projects have been largely successful thus far (Rinas 2009), but continued monitoring and attention is needed to aid in the recovery of grasslands in BIBE.

4.4.2 Measures

- Fragmentation
- Patch size
- Grassland bird diversity
- Total acreage

4.4.3 Reference Conditions/Values

The reference condition for desert grasslands is pre-Anglo settlement. However, little information regarding the condition of desert grasslands in BIBE during this time is available.

4.4.4 Data and Methods

A vegetation map developed for BIBE by Dr. Gregory Plumb in 1987 (Plumb 1987 shapefile) was used to assess the fragmentation, patch size, and total acreage measures. In addition to this map, analysts utilized a fragmentation Python script, the Landscape Fragmentation Tool v. 2.0 (LFT 2.0), developed by Parent and Hurd (2008) from the University of Connecticut's Center for Land Use Education and Research (CLEAR). This script is based on the Vogt et al. (2007) forest fragmentation study, and was developed to segment a land cover map into four main categories: patch, edge, perforated, and core; core habitat is then further broken down into small (<250 ac), medium (250-500 ac), and large core (>500 ac) habitat. Identifying these major habitat classes aids in developing a better understanding of the fragmentation dynamics of desert grasslands in BIBE. The only data required for this tool is a binary land cover grid (i.e., 1 = grassland, 2 = not grassland). Additional information for this assessment came from literature provided by BIBE.

4.4.5 Current Condition and Trend

<u>Fragmentation</u>

With over 60% (67,275 ha) of grassland habitat classified as core and only 10.56% (11,470 ha) classified as patch habitat, the grassland habitat in BIBE appears to be largely unfragmented (Table 20). Plate 12 displays the spatial trends of fragmentation in BIBE. Large core grassland habitat appears to be centered around the Chisos Mountains, in the center of the park. There is a particularly high amount of large core grassland habitat south of the Chisos Mountains. Fragmented patch grassland occurs throughout the entire park; there are no specific areas of BIBE with higher concentrations of patch grassland habitat. Only 10.56% of grassland habitat in BIBE is considered patch habitat, suggesting that desert grasslands are largely unfragmented.

There are, however, no baseline historical data to compare to these findings, making any conclusions regarding the trend of fragmentation difficult to determine.

Table 20. Grassland fragmentation analysis results.

Habitat Type	Total Area (km^2)	Total Acres	Total Hectares	% Composition
Patch	114.7	28,343.6	11,470.3	10.6%
Edge	194.6	48,076.4	19,455.8	17.9%
Perforated	104.4	25,799.5	10,440.7	9.6%
Core- Small	50.4	12,456.9	5,041.1	4.6%
Core- Medium	11.3	2,792.6	1,130.1	1.0%
Core- Large	611.0	150,992.4	61,104.5	56.2%
Total	1,086.4	268,461.4	108,642.5	

Patch Size

Using the LFT 2.0 from Parent and Hurd (2008), average patch sizes were calculated for each habitat type (Table 21). Core-large habitat contains the largest average patch size (103.39 ha per polygon), meaning 56.24% of BIBE grasslands are 103.39 ha on average. Patch and perforated habitats showed the smallest average size (1.44 ha per polygon), meaning 20.17% of BIBE grasslands are 1.44 ha on average.

Table 21. Average polygon size of each grassland habitat type.

	Patch	Edge	Perforated	Core-Small	Core-Medium	Core-Large	All
Average Size (ha)	1.44	2.72	1.44	3.50	24.57	103.39	4.44
Average Size (acres)	3.56	6.72	3.56	8.65	60.71	255.48	10.97
Average Size (km^2)	0.01	0.03	0.01	0.04	0.25	1.03	0.04

Grassland Bird Diversity

Bird populations are often considered good indicators of an ecosystem's health (Morrison 1986, Hutto 1998, NABCI 2009). The diversity of grassland bird species in BIBE may therefore provide insight into the condition of the park's desert grasslands. Refer to Chapter 4.6 for a detailed description of grassland birds in BIBE.

Threats and Stressor Factors

BIBE staff suggested climate change, presence of invasive species, and erosion are the primary threats and stressors to desert grasslands in BIBE. According to Davey et al. (2007, p. 10, citing NAST 2001), potential effects of climate change in the CHDN could include "increased surface temperatures; changes in the amount, seasonality, and distribution of precipitation; more frequent climatic extremes; and a greater variability in climate patterns." Munson et al. (*in press*) has shown that changes in cover of perennial grasses in upland and foothill settings were most sensitive to summer precipitation, while large changes in perennial grass cover in lowland grasslands was better explained by the timing of water run-on from upland areas and flooding events relative to the timing of plant growth. Climate change has the potential to further alter plant distribution, species richness (Munson et al. *in press*), reduce landscape connectivity, affect interactions between plant and animal species, and alter natural disturbance regimes (e.g., fires, flooding) (Davey et al. 2007).

Munson et al. (*in press*) also identified "climate pivot points" that were indicative of shifts from increasing to decreasing plant abundance along a climate gradient. Reductions in cover of many plant species and declines in species richness below 150 mm (~ 6 in) of summer precipitation could indicate a threshold of change in productivity for all but the most drought tolerant perennial grasses and shrubs in the Chihuahuan Desert. These changes in cover could accelerate land degradation and reduce ecosystem productivity. Additionally, high water input during cooler winter months can increase woody-vegetation performance in upland grasslands and may contribute to increasing shrub dominance throughout much of the Chihuahuan Desert (Munson et al. *in press*). In general over the past century, climate change has contributed to a shift from desert grasslands to desert scrub vegetation in the Chihuahuan Desert (Dick-Peddie 1993, as cited in Davey et al. 2007).

Invasive plants can displace native plant species, disrupt nutrient cycling and fire regimes, and promote additional species invasions (as reviewed by Young et al. 2007). While invasive plants have not been reported as a major concern in BIBE's grasslands, several species are a threat to both desert grassland and scrub habitats: buffelgrass, Bermudagrass, and Lehmann's lovegrass (Young et al. 2007). All three of these species are known to reduce native grass biodiversity through competition, while buffelgrass and Lehmann's lovegrass can also alter fire regimes (Young et al. 2007).

Land use practices prior to the park's establishment (e.g., grazing, cultivation, development) triggered erosion that continues to impact BIBE's desert grasslands (NPS 2001). The historical loss of topsoil and the slow soil development rate in this environment have contributed to further degradation. Current occasional livestock trespass can further exacerbate erosion in these fragile desert environments (NPS 2001).

<u>Data Needs/Gaps</u>
An updated vegetation map for BIBE would be useful in analyzing current desert grassland characteristics in BIBE. This map could reveal considerable changes in vegetation, which could alter the fragmentation analysis. In addition, an updated map would allow researchers to conduct a change analysis of desert grasslands in BIBE. The current vegetation map (Plumb 1987) also does not cover a section in the northern part of the park. An update that covers the entire northern section of BIBE is needed to get a complete inventory of vegetation in the park. Field data has been collected in the park for the development of a new, park-wide vegetation map; however, this project will not be completed until at least 2015 (Hildy Reiser, CHDN Science Advisor, written communication, 27 June 2012).

Further research into the distribution and impacts of invasive species in the park will help management better understand the threat these species pose to desert grasslands (NPS 2001). A CHDN exotic plant monitoring program began in the park in the fall of 2010 (Reiser et al. 2012) and may provide some insight regarding this threat in the future. Additional research needs include historical information on grassland extent and erosion rates in the park, fire effects in desert grasslands, mechanisms of grassland decline (e.g., state/transition models), and methods for desert grassland restoration (Sirotnak, email communication, 20 March 2012).

Overall Condition

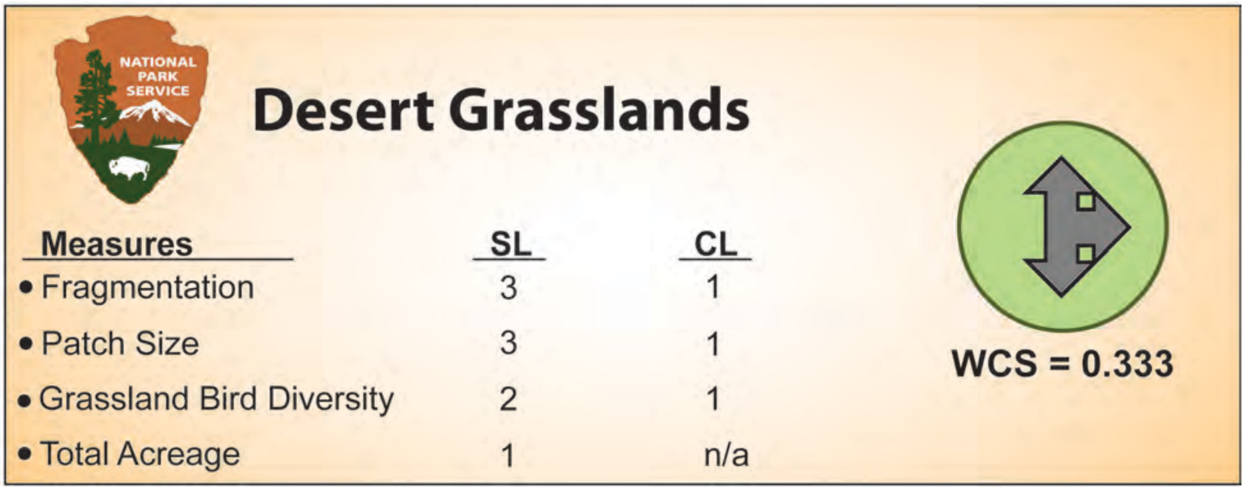
Fragmentation
The project team assigned the fragmentation measure a *Significance Level* of 3. While there are no baseline data to compare to the fragmentation findings developed from the Plumb (1987) vegetation map, the results show that over 60% (67,275 ha) of grassland habitat in BIBE is core habitat, with only 10.56% (11,470 ha) of grassland in fragmented patches. In addition, park staff are continually working to increase desert grasslands in BIBE through planting new grasses and removing exotic species. These results indicate fragmentation is of low concern and a *Condition Level* of 1was assigned.

Patch Size
The project team assigned the patch size measure a *Significance Level* of 3. While there are no baseline data to compare to the patch size findings developed from the Plumb (1987) vegetation map, the results show that 56.4% of grasslands in BIBE average a size of 103 ha (Table 20). These results indicate patch size of desert grasslands is of low concern; a *Condition Level* of 1 was assigned to this measure.

Grassland Bird Diversity
The project team assigned the grassland bird diversity measure a *Significance Level* of 2. Recent work by the Rocky Mountain Bird Observatory, combined with breeding bird surveys and Christmas bird counts, indicate that the grassland birds in the park are of low concern. However, grassland species worldwide have experienced recent declines, and because of this potential, perhaps poorly understood threat, the measure of grassland bird diversity was assigned a *Condition Level* of 1, indicating low concern.

Total Acreage
The project team assigned the total acreage measure a *Significance Level* of 1. According to the 1987 vegetation map developed by Plumb (1987), there is a total of 108,642 ha (268,460 ac) of desert grasslands in BIBE. However, without more recent data and with no baseline data to compare the available data, a *Condition Level* cannot be determined.

Weighted Condition Score
The *Weighted Condition Score* (WCS) for desert grasslands is 0.333, indicating that this component is in good condition and of low concern within the park. Given that there is little historical or recent information on BIBE’s grasslands, the trend is unknown at this time.



4.4.6 Sources of Expertise

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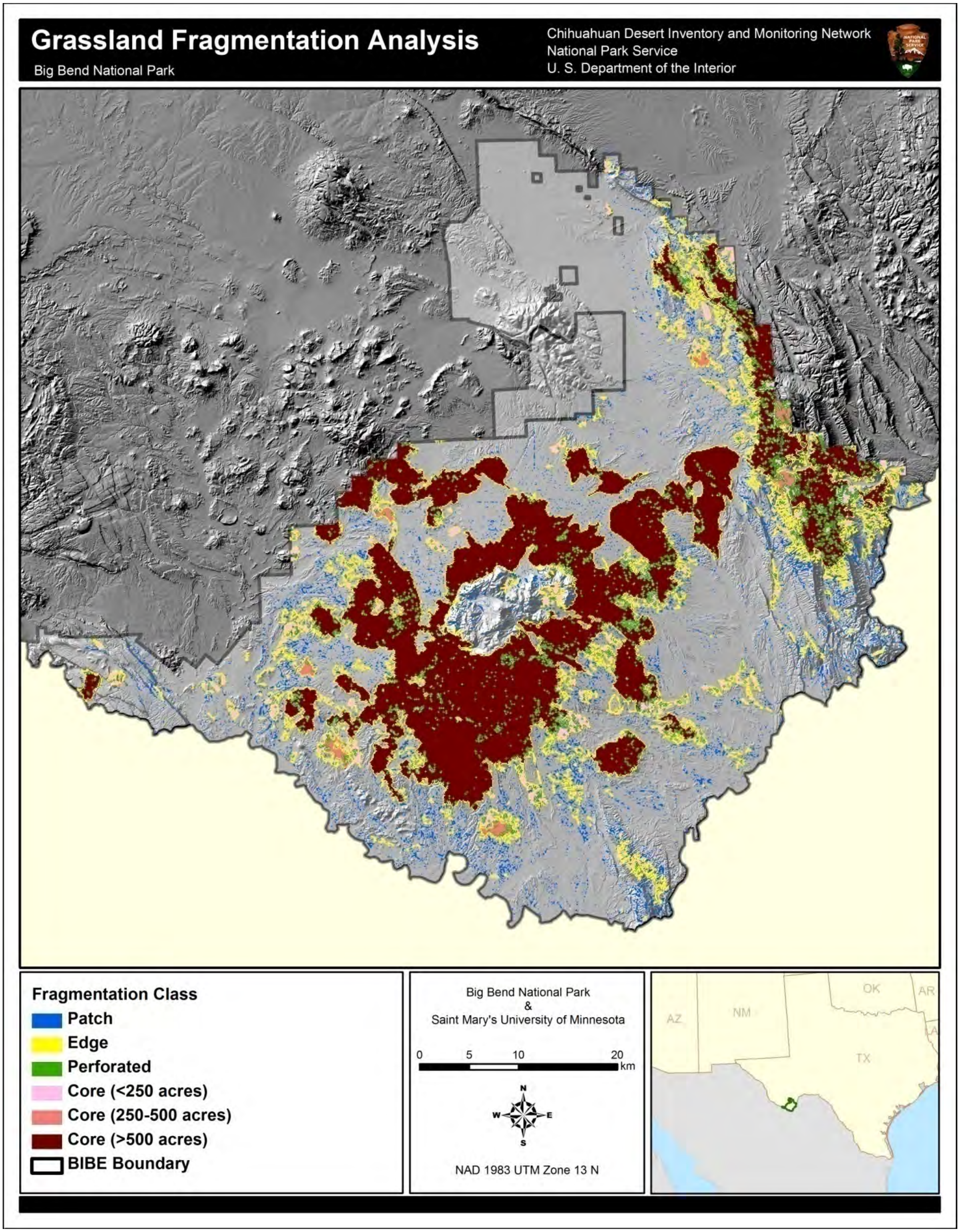


Plate 12. Grassland fragmentation analysis, BIBE (note that the vegetation layer used for this analysis does not cover the northwest corner of the park).

4.5 Rio Grande Riparian Community

4.5.1 Description

The Rio Grande flows over 3,000 km (1,900 mi) from Colorado to the Gulf of Mexico, marking the 190 km (118 mi) southern boundary of BIBE along the way (Bennett et al. 2009, NPS 2012). The river is an important source of water in the desert surrounding BIBE, and provides vital habitat for many plants and animals (NPS 1996, Bennett et al. 2009). The Rio Grande is a vital refuge for migratory birds, including waterfowl, shorebirds, and songbirds such as warblers, vireos, and flycatchers. Seventy-eight bird species regularly found along the Rio Grande in BIBE are considered "river obligates" and several are protected by Federal or State governments (Bennett et al. 2009). The canyons carved by the Rio Grande also provide "some of the most exceptional scenic attributes of the park" (NPS 1996, p. 26; Photo 10). In 1978, a 315-km (196-mi) stretch of the Rio Grande was designated by the U.S. Congress as a Wild and Scenic River, including 110 km within BIBE (NPS 1996, Figure 25). These rivers are "to be preserved in their free-flowing condition, and their associated ecosystems are to be actively protected in their natural state" (NPS 2010, p. 26).

Photo 10. The Rio Grande in Santa Elena Canyon (Photo by Andy Nadeau, SMUMN GSS).

Figure 25. Map of the Rio Grande Wild and Scenic River in relation to BIBE (NPS 1996).

The composition and extent of riparian communities in BIBE are variable; in canyon areas, these habitats may only extend a few meters from the river, while in floodplains they can spread nearly a kilometer (NPS 1996). Vegetation along the Rio Grande has changed dramatically over the last century, particularly after the construction of large dams upstream of the park. During the early 20th century, plant communities were heterogeneous with seep willow (*Baccharis* spp.) patches on sand bars, sporadic willow (*Salix* spp.) and cottonwood stands along the river's edge, backed by mesquite thickets further away from the channel (Stotz 2000; Schmidt and Dean 2011, citing Ainsworth and Brown 1933). Other native riparian species common in the park area include common reed (*Phragmites australis*), whitethorn acacia (*Acacia constricta*), desert willow (*Chilopsis linearis*), and alkali sacaton (*Sporobolus airoides*) (NPS 2007). However, non-native species invasions and the alteration of flow regime due to dams and other diversions have transformed the riparian community (Schmidt and Dean 2011). Many of the park's floodplains are now dominated by exotic species such as saltcedar (also known as saltcedar), giant cane, and Bermudagrass (Hughes et al. 1993, Schmidt and Dean 2011).

The formation and maintenance of aquatic and riparian habitat is driven by a river's flow regime (Schmidt and Dean 2011). Key characteristics of flow regime are the magnitude, duration, frequency, variability, and timing of floods and base flows (Poff et al. 1997). For the Rio Grande specifically, other important characteristics include sediment inputs from tributaries and groundwater inputs (Bennett, written communication, 12 October 2012). Flow regime influences sediment transport and deposition, which also play a key role in habitat formation and loss (Schmidt and Dean 2011). Stream flow in the BIBE region is now largely determined by the Rio Conchos, a tributary in Mexico that joins the Rio Grande approximately 80 km (50 mi) upstream of the park, and by pulsed inputs of storm water from local rainy-season events. The Rio Conchos supplies around 80-90% of the stream flow and a substantial portion of the sediment to the Rio Grande in BIBE (Schmidt and Dean 2011). However, groundwater from limestone aquifers can be important in maintaining the river's aquatic habitats during dry years (Bennett et al. 2012). For further discussion of Rio Grande hydrology, see Chapter 4.20

4.5.2 Measures

- Size and distribution of riparian species
- Aquatic invertebrates
- Width/depth ratio of river channel
- Water quality

4.5.3 Reference Conditions/Values

The reference condition for the Rio Grande riparian community is pre-river regulation, or post reset events (i.e., major floods). Prior to regulation (i.e., dams), the riparian habitat was patchy and discontinuous with a heterogeneous plant species composition (Schmidt and Dean 2011), and the Rio Grande was wide and multi-channeled (Dean and Schmidt 2010).

4.5.4 Data and Methods

Some of the earliest descriptions of the Rio Grande riparian community in the BIBE region come from Schmidly et al. (1976) and Schmidly and Ditton (1979), who studied the impact of human activity on riparian resources. In the early 1980s, while studying interactions between beaver (*Castor canadensis*) and cottonwood, Strong (1982) surveyed and mapped cottonwood and willow stands along the Rio Grande in BIBE. Information regarding the impact of non-native species (particularly saltcedar) on the riparian community was primarily found in NPS (2007) and Bennett et al. (2009). Other sources addressing the distribution and/or composition of riparian communities include Hughes et al. (1993) and park GIS data based on vegetation classifications developed by Plumb (1992) in the late 1980s. Finally, the most current information regarding the condition of the Rio Grande riparian community can be found in Schmidt and Dean (2011), who created a proposed science plan for the rehabilitation of the Rio Grande in the BIBE area. This report includes a summary of relevant past and current research, background information on Rio Grande hydrology, geomorphology, and ecology, as well as recommendations for scientific monitoring and rehabilitation of the river system.

4.5.5 Current Condition and Trend

<u>Size and Distribution of Riparian Species</u>

Very few studies have explored the size (height, diameter at breast height [dbh]) and distribution of riparian plant species within BIBE. Floodplain/arroyo vegetation was mapped by Plumb (1992) as part of a park-wide vegetation classification effort in the late 1980s. Floodplain vegetation within 1 km (0.6 mi) of the Rio Grande is shown in Plate 13 and Plate 14. From 1980-81, Strong (1982) mapped and sampled cottonwood and willow stands within the park as part of a study of beaver-cottonwood interactions. Strong (1982) identified eight cottonwood stands and 12 areas with high willow concentrations (Figure 26 and Figure 27).

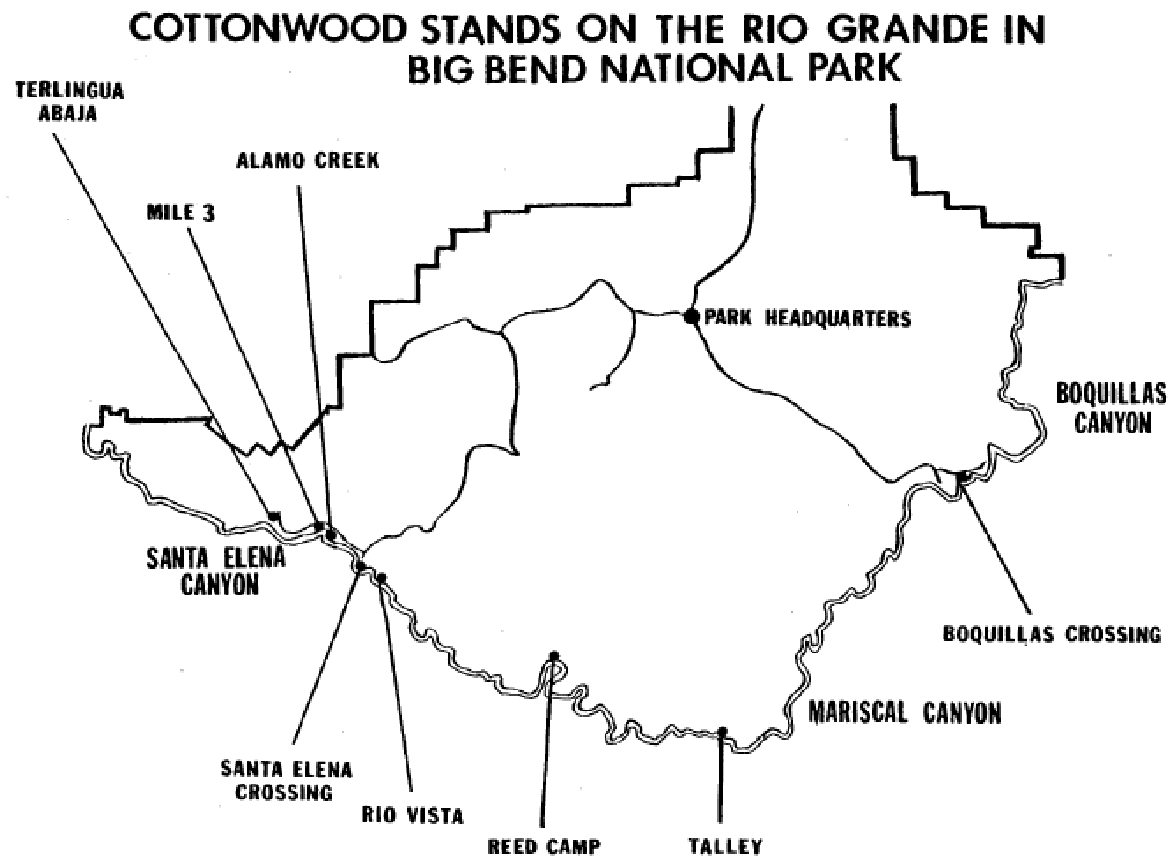


Figure 26. Location of eight cottonwood stands along the Rio Grande in BIBE during the early 1980s (Strong 1982).

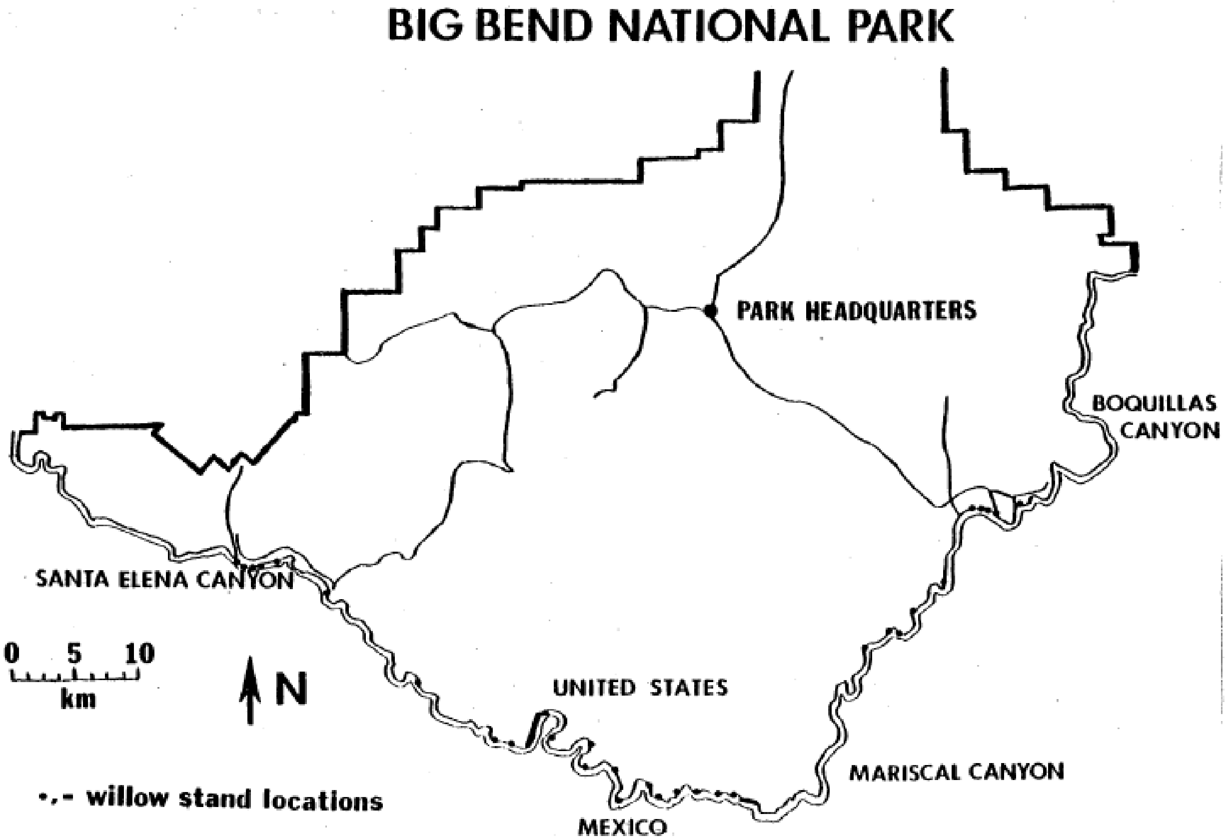


Figure 27. Location of willow stands along the Rio Grande in BIBE during the early 1980s (Strong 1982).

The number of cottonwood trees in the eight stands identified by Strong (1982) ranged from two to an estimated 100 at Santa Elena Crossing; the total number of cottonwoods identified was 232. At four of these stands, Strong (1982) recorded the height and dbh of the cottonwoods. Heights generally ranged from 5.0 to 14.9 m (16.4-48.9 ft). Means were calculated for trees damaged by beavers versus those that were undamaged (Table 22). Size distributions are also presented in Figure 28 and Figure 29.

Table 22. Size of cottonwoods in four sampled stands along the Rio Grande in BIBE. Means were calculated separately for trees damaged by beaver and those that were undamaged (Strong 1982).

Stand name	# of trees	# damaged	Mean height (m)		Mean dbh (m)	
			damaged	undamaged	damaged	undamaged
Mile 3	8	1	12.0	12.2	0.183	0.246
Alamo Creek	36	1	--	9.6	0.127	0.431
Santa Elena Crossing	100[1]	15	10.5	9.6	0.429	0.441
Rio Vista	30[1]	12	12.8	9.5	0.296	0.492

[1] - estimated totals - no exact counts were made.

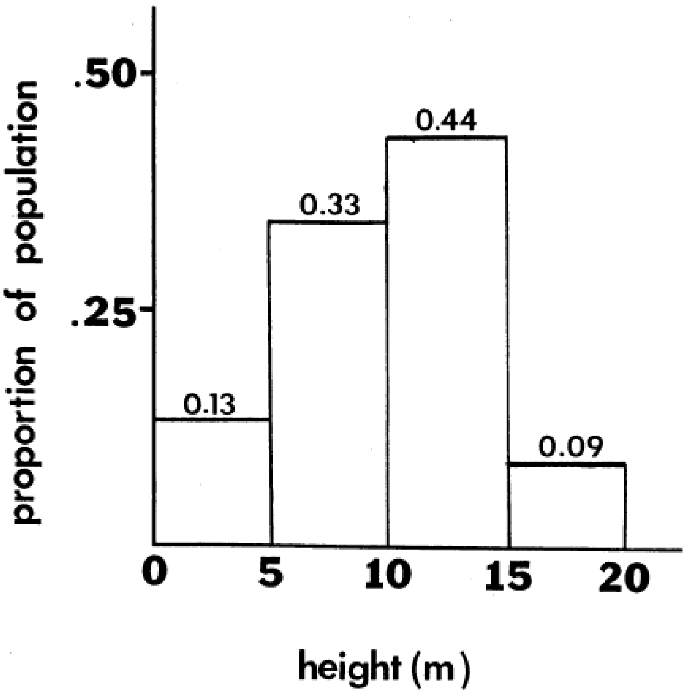


Figure 28. Height distribution of cottonwood trees in four sampled stands along the Rio Grande in BIBE (Strong 1982).

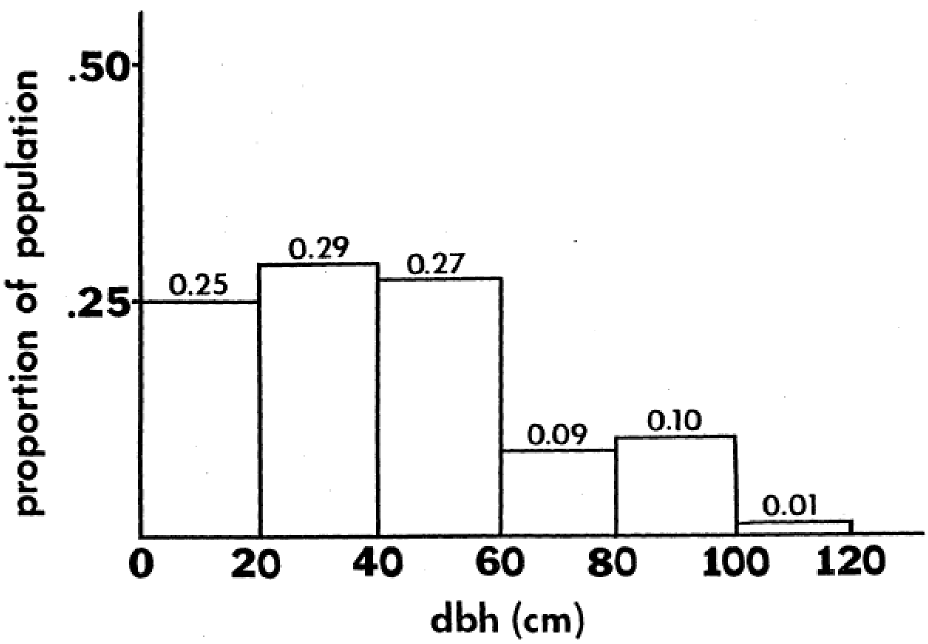


Figure 29. Distribution of cottonwood trees by diameter (dbh) in four sampled stands along the Rio Grande in BIBE (Strong 1982).

Four species of willow have been documented along the Rio Grande in BIBE: black willow (*Salix nigra*), sandbar willow (*S. exigua*), Goodding's willow (*S. gooddingii*), and yewleaf willow (*S. taxifolia*) (McDougall and Sperry 1951, as cited by Strong 1982). Strong (1982) reported that sandbar and black willow were most common in the study area. Yewleaf willow likely no longer occurs along the river (Sirotnak, written communication, October 2012). Most willows along the Rio Grande were small (1-10 cm in diameter), with a few large trees further back from the channel and often separated from the stand by saltcedar and other vegetation (Strong 1982).

The distribution and size (height, dbh) of exotic riparian species along the Rio Grande have not been systematically or comprehensively surveyed and mapped. Along much of the Rio Grande in the BIBE region, saltcedar, giant cane, and Bermudagrass are three of the most dominant species (Moring 2002). However, many researchers and NPS staff have observed these exotics increasing along the river and replacing native vegetation (Schmidly et al. 1976, Strong 1982, Hughes et al. 1993; Sirotnak, pers. communication, October 2012). Saltcedar and giant cane removal efforts have occurred near Castolon, upstream from Rio Grande Village, and in Boquillas Canyon (Bennett et al. 2009, Schmidt and Dean 2011).

Aquatic Invertebrates

Aquatic invertebrates are often used as biological indicators of overall aquatic ecosystem health (EPA 1999, Baumgardner and Bowles 2005). Invertebrates are important to the riparian community because they break down plant material which adds nutrients to the ecosystem, and are a significant food source for animals further up the food chain (NPS 2010). As a result, abundance and diversity of macroinvertebrates in aquatic systems was chosen as a Vital Sign by the CHDN (NPS 2010). Aquatic macroinvertebrates are addressed in depth in Chapter 4.11 of this report.

Width/Depth Ratio of River Channel

The width and depth of a river can impact the type and diversity of available aquatic and riparian habitat. For example, channel narrowing due to increased sedimentation often causes the loss or degradation of shallow, low velocity backwaters and side channels (Schmidt and Dean 2011). These low velocity areas provide important habitat "because they often contain warm water, resulting in higher primary production rates, and they offer refugia from larger predators" (Schmidt and Dean 2011, p. 34). These conditions are ideal for larval fish development; however, channel narrowing may have contributed to the disappearance of native fish species from the Rio Grande (Schmidt and Dean 2011).

Prior to dam construction, the Rio Grande was "a wide, laterally unstable, multi-thread river" (Dean and Schmidt 2010, p. 1). Due to changes in flow regime during the 20th century, the river is now a single, stable channel (Schmidt and Dean 2011). One of the goals identified at a bi-national workshop on the Big Bend reach of the Rio Grande in 2008 was to maintain "a river cross-section form that is relatively wide and shallow" that provides "aquatic habitat that will sustain and enhance the distribution and extent of native river biota" (BIBE et al. 2008, p. 2). According to Schmidt and Dean (2011, p. 22), the maintenance of a wide and shallow channel depends upon "the relative ratio of stream flow (magnitude and duration) and the amount and size of supplied sediment." The width/depth ratio of the Rio Grande is discussed in further detail in Chapter 4.20 of this report.

Water Quality

Water quality can significantly impact the species, both plants and wildlife, in a riparian community. Some aquatic macroinvertebrates, fish, and amphibians are particularly sensitive to water pollution. Water quality in the Rio Grande within BIBE will be discussed in detail in Chapter 4.16 of this report.

Threats and Stressor Factors

In 2007, the World Wildlife Fund (WWF) recognized the Rio Grande as one of the world's 10 most at-risk rivers (Wong et al. 2007). Primary threats to the riparian community, as identified by BIBE staff, include upstream water diversion, channel narrowing, excess sediment, groundwater pumping (e.g., for human developments or oil and gas exploration), degraded water quality, and exotic species. All of these threats are related to an altered flow regime, either as a cause or an effect. Historically, the Rio Grande received much of its flow from spring snowmelt in the Rocky Mountains and from tropical storms or monsoon rains in the Sierra Madre Occidental of Mexico. Today, all spring snowmelt from the upper Rio Grande is captured by dams and diverted for agricultural use upstream of BIBE (Schmidt and Dean 2011). Dams and diversions in Mexico also impact the Rio Conchos, which now provides the majority of flow for the Rio Grande in the BIBE region. Several large dams collect floodwaters from rains in the Sierra Madre Occidental. For example, the Luis Leon Dam typically only releases water if the reservoir is full, if there are irrigation needs downstream, or if a release is required by an international treaty (as regulated by CONAGUA, Mexico's National Water Commission) (Schmidt and Dean 2011). This reduction in flow contributes to channel narrowing, alters sediment deposition and transport, and may create conditions that favor exotic plants over native species (Glenn and Nagler 2005, Schmidt and Dean 2011, Photo 11). These changes reduce the amount of aquatic and riparian habitat available for both native plants and wildlife and can negatively impact recreational activities (NPS 2010).

Photo 11. Photos of the Rio Grande at Black Dike in 1937 (above) and in 2005 (below) show dramatic channel narrowing (NPS photos).

The invasion of exotic species can, in turn, cause channel narrowing and further alter sediment balance and flow regime. Exotic plants such as saltcedar and giant cane stabilize sandbars and river banks, as well as trap additional sediment, resulting in a narrower river channel (Dean and Schmidt 2010). According to BIBE's Exotic Plant Management Plan (NPS 2000), of all of the invasive species in the park, saltcedar poses the greatest threat to park resources. As of 2007, the NPS estimated that saltcedar infestations covered approximately 6,070 ha (15,000 ac) of the park (NPS 2007). These species have deep taproots that can reach groundwater which may be inaccessible to native vegetation (NPS 2007). Saltcedar tolerates a wide variety of environmental conditions (e.g., drought, floods, fire, extreme temperatures), and also secretes salt, which elevates soil salinity to levels unsuitable for native vegetation (NPS 2007, Bennett et al. 2009). Lastly, saltcedar often increases fuel litter which can lead to more frequent fires (DeLoach 2003, as cited in NPS 2007). Saltcedar and other exotic species also displace native plants and degrade wildlife habitat, resulting in an overall decrease in biodiversity (DeLoach 2003, as cited in NPS 2007). Saltcedar leaf beetles (*Diorhabda* spp.), a biological control agent, have been established along the Rio Grande in BIBE and are beginning to reduce the dominance of saltcedar (Sirotnak, written communication, October 2012). Efforts to remove saltcedar and giant cane from the park's riparian areas have seen some success, but unfortunately the openings left behind are often filled by other exotics such as Bermudagrass (NPS 2007). Long-term riparian monitoring plots have been established in the park to assess the ecological and geomorphic effects of saltcedar and giant cane control (Sirotnak, written communication, October 2012).

<u>Data Needs/Gaps</u>

In order to better understand the Rio Grande riparian community and potentially rehabilitate aquatic and riparian habitats, more information is needed on the river's stream flow (e.g., sources, timing and duration of low and high flows, rate of downstream flow attenuation) (Schmidt and Dean 2011). Of particular importance is determining how much water the Luis Leon Dam must release to meet downstream environmental flow requirements. Further study of the Rio Grande's sedimentation processes is also needed. This includes identifying major sources of fine sediment and the volume of sediment they contribute, as well as understanding the interactions between stream flow and sediment transport (Schmidt and Dean 2011). Work to address this need began with the development of a suspended-sediment monitoring program by Utah State University, the NPS, and the USGS Grand Canyon Monitoring and Research Center in November 2010. A similar data gap exists for gravel entering the Rio Grande from tributaries during flash floods and gravel transportation by the river itself (Schmidt and Dean 2011). To address these data needs, Schmidt and Dean (2011, p. 34-35) recommend the development of

> …a comprehensive channel and floodplain measurement and monitoring program… in order to 1) detect the rate and style of channel narrowing and habitat degradation, 2) detect the magnitude of channel 'reset' caused by rare large floods, and 3) to detect the differences in channel change throughout the study area.

Additionally, no comprehensive vegetation map exists for the BIBE reach of the Rio Grande. Schmidt and Dean (2011, p. 38) suggest that this could be accomplished with multi-spectral remote sensing imagery, and that vegetation monitoring should be integrated with geomorphic monitoring, as geomorphology and riparian vegetation are "inextricably linked." The CHDN, through an agreement with the University of Texas-Austin's Lady Bird Johnson Wildflower Center, has completed plant data collection along both sides of the Rio Grande Wild and Scenic River to be used in the development of a vegetation classification map (Reiser, written communication, October 2012). A Light Detection and Ranging (LiDAR) analysis scheduled for completion during 2013 should also provide estimates of exotic plant coverage along the Rio Grande in BIBE (Sirotnak, written communication, October 2012). Lastly, little is known about the influence of exotic plant species (specifically saltcedar and giant cane) on stream flow, groundwater, and water quality in the Rio Grande watershed (NPS 2007).

Overall Condition

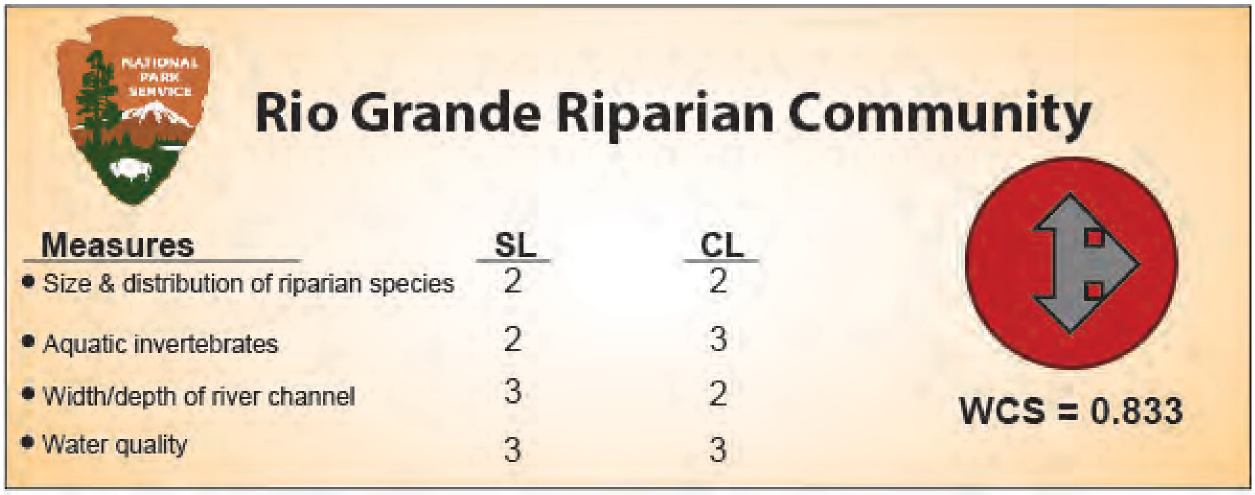
Size and Distribution of Riparian Species
The project team defined the *Significance Level* for this measure as a 2. Very little quantitative data are available regarding the size and distribution of riparian plant species within BIBE, and existing data (Strong 1982) are out-of-date. However, observations from researchers and NPS staff indicate that exotic species such as saltcedar and giant cane have largely replaced native riparian vegetation. Because of these observations, this measure is considered of moderate concern (*Condition Level* = 2).

Aquatic Invertebrates
This measure was assigned a *Significance Level* of 2. Chapter 4.11 of this report assesses the current condition of the park's aquatic macroinvertebrates and assigns this resource a *Condition Level* of 2.

Width/Depth Ratio of River Channel
A *Significance Level* of 3 was assigned to the measure of width/depth ratio of river channel. While some information is available regarding the width of the Rio Grande over time, little to no quantitative data exist on the width/depth ratio of the river channel. Channel narrowing due to flow regime alteration and exotic species invasion is a serious concern along the Rio Grande. This phenomenon can be observed in paired aerial photos taken in the park (see Photo 11, Dean and Schmidt 2010). As a result of these observations, the *Condition Level* for this measure is considered of moderate concern (*Condition Level* = 2). Additional discussion of width/depth ratios in the Rio Grande are discussed in Chapter 4.20.

Water Quality
This measure was assigned a *Significance Level* of 3. As discussed in Chapter 4.16 of this report, water quality is of moderate concern in BIBE (*Condition Level* = 2).

Weighted Condition Score
The *Weighted Condition Score* for the Rio Grande riparian community is 0.833, which falls within the significant concern range. The hydrology and geomorphology of the Rio Grande, along with its riparian vegetation, have changed drastically over the past century, likely causing dramatic changes in aquatic and riparian communities as a whole. Due to a lack of recent information, the trend for this component is unknown.



4.5.6 Sources of Expertise

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Hildy Reiser, CHDN Science Advisor

Joe Sirotnak, BIBE Botanist/Ecologist

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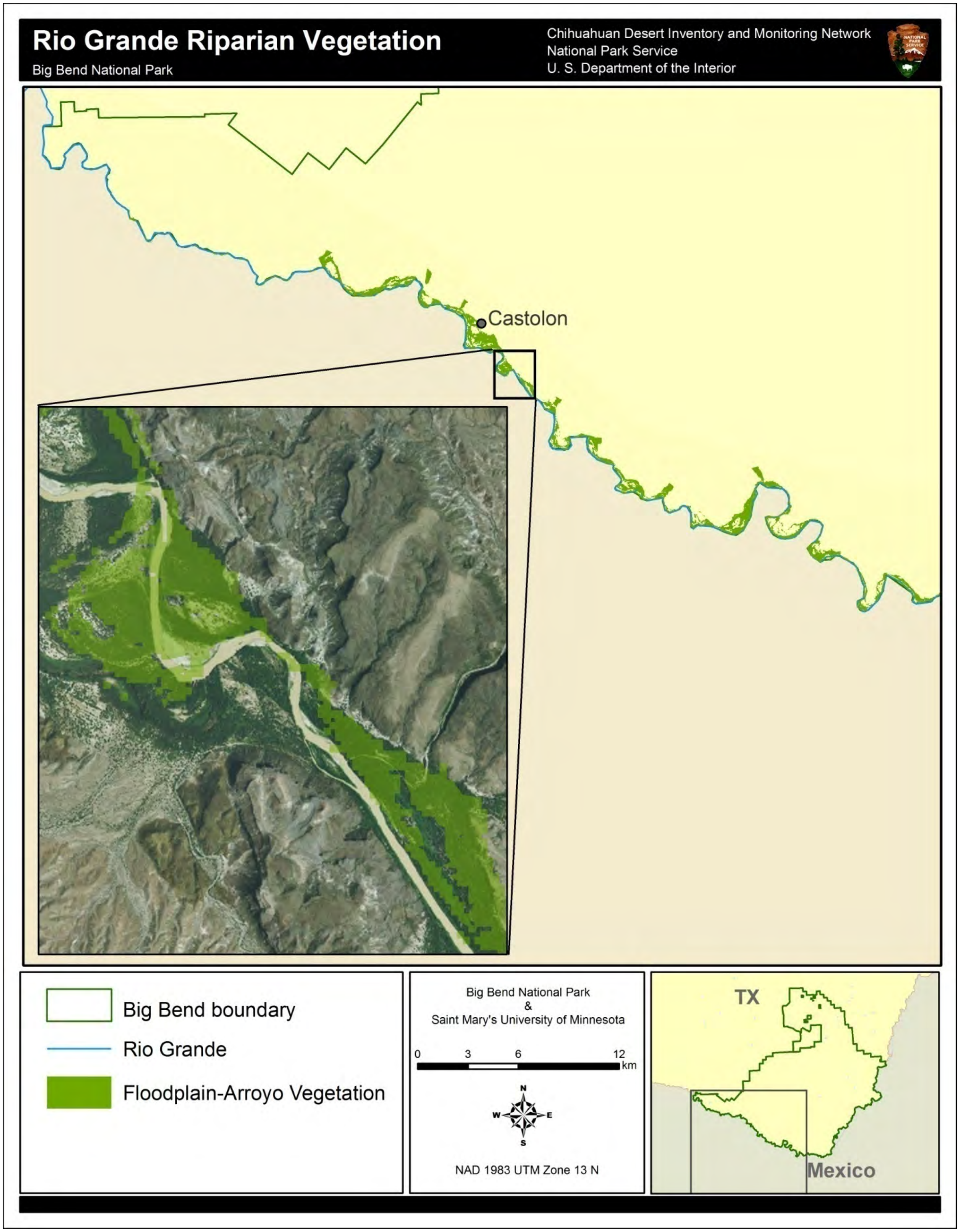


Plate 13. Distribution of floodplain vegetation along the Rio Grande (within 1 km) in the southwest portion of BIBE (based on classification by Plumb 1992).

Plate 14. Distribution of floodplain vegetation along the Rio Grande (within 1 km) in the southeast portion of BIBE (based on classification by Plumb 1992).

4.6 Birds

4.6.1 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, and bird communities often reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010). The unique ecosystems and physical formations in BIBE provide bird species with a wealth of habitat types and food sources. BIBE's tremendous bird species diversity attracts birders from across the U.S., as BIBE has more confirmed bird species within the park than any other national park (Chipley et al. 2003).

Photo 12. Mexican jay (NPS photo).

BIBE has confirmed the presence of more than 400 species of birds, and about 40% of these birds are migratory species on their way to breeding grounds in the north (LCAS 2010). Not all of the migratory species found in BIBE are travelling to their breeding grounds, however, as several species arrive in the park in the fall months and overwinter in the park. Examples of these species include the American robin (*Turdus migratorius*), white-crowned sparrow (*Zonotrichia leucophrys*), mountain bluebird (*Sialia currucoides*), and lark bunting (*Calamospiza melanocorys*) (Flippo 2004).

Many of the species present in BIBE are common to other areas of the U.S. and Mexico (e.g., red-tailed hawk [*Buteo jamaicensis*], northern mockingbird [*Mimus polyglottos*]). However, BIBE is also home to several unique species whose home ranges only extend into the U.S. near the U.S./Mexico border (Wauer 1973, 1996; Lockwood and Freeman 2004; Wauer and Flippo 2008). Examples of these species include the Mexican jay (*Aphelocoma wollweberi*) (Photo 12), the Lucifer hummingbird (*Calothorax lucifer*), and the Colima warbler. The Colima warbler's breeding range in the United States is restricted to the Chisos Mountains found within BIBE (Chipley et al. 2003, NABCI 2011).

BIBE is also home to several species of conservation concern; perhaps most notable of these species is the black-capped vireo, which is federally listed as endangered (USFWS 2007). Several other species, such as the peregrine falcon (*Falco peregrinus*), common black-hawk (*Buteogallus anthracinus*), and zone-tailed hawk (*Buteo albonotatus*) are listed as threatened or endangered by the state of Texas (LCAS 2010).

4.6.2 Measures

- Grassland species diversity
- Breeding bird diversity
- Migratory species diversity
- Peregrine falcon population size
- Black-capped vireo breeding pairs

4.6.3 Reference Conditions/Values

The reference condition for birds in BIBE is the pre-agricultural condition in the U.S. and Mexico. However, this condition is poorly represented in the literature, and is largely unknown.

4.6.4 Data and Methods

The NPS Certified Bird Species List (NPS 2011a) for BIBE was used for this assessment; this list represents all of the confirmed bird species present in the park (Appendix H). Bird names (common and scientific) and taxonomic order follow the most current Check-list of North American Birds (AOU 1998) and the Fifty-third Supplement to the American Ornithologists' Union Check-List of North American Birds (AOU 2012).

Breeding bird survey routes in the park are part of the large-scale North American Breeding Bird Survey (BBS), which began in 1966 and is coordinated by the United States Geological Survey (USGS) and the Canadian Wildlife Service (Robbins et al. 1986). The standard BBS route is approximately 40 km (25 mi) long with survey points at every 0.8 km (0.5 mi). The survey begins ½ hour before sunrise, and at each survey point the number of birds seen and heard within a 0.4-km (0.25-mi) radius during a three-minute interval is recorded. The park has three BBS routes: Hot Springs (route 83082), Chisos Basin (route 83900), and Castolon (route 83319) (Plate 15). Data are available for the Hot Springs route from 1967-2010, the Chisos Basin route from 1995-2010, and the Castolon route from 1994-2010 (USGS 2011). Despite not yet having data available, the survey has been completed in the 2011 and 2012 breeding seasons.

The BIBE Christmas Bird Count (CBC) is part of the International CBC, which started in 1900, and is coordinated internationally by the Audubon Society. The park's CBC has been conducted annually since 1964. Multiple volunteers survey a 24-km (15-mi) diameter on one day, typically between 14 December and 5 January. The center point of the 24-km diameter is near Rio Grande Village (29° 10' 59.88" N, -103° 0' W) (Plate 16). Unlike the BBS, the CBC surveys overwintering and resident birds that are not territorial and singing; this often results in different survey results than the BBS and should not be directly compared to the BBS. The total number of species and individuals are recorded each year; data for the BIBE CBC are current through the 2009-2010 winter (Appendix I, Appendix J, Appendix K); the survey was completed for the 2011 winter, but the data are not yet available online. The organization of the BIBE CBC data (which was obtained from http://audubon2.org/cbchist/count_table.html) required SMUMN GSS to make some adjustments:

- Species that were included on the CBC species list without being observed during the CBC effort (wild turkey [*Meleagris gallopavo*], cattle egret [*Bubulcus ibis*], violet-green swallow [*Tachycineta thalassina*]) were not considered in this assessment;

- Observations that were not specific to a bird species (e.g., vireo sp., wren sp.) were omitted from analyses;

- Observations of canyon towhee and brown towhee were merged as these are both accepted common names for *Pipilo fuscus*;

- Observations of American green-winged teal and green-winged teal were merged as these are both accepted common names for *Anas crecca*;

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

- The black-crested titmouse was incorrectly identified as *Baeolophus bicolor* for several years. These observations were combined with the correct observations for *Baeolophus atricristatus*;

- Observations of black-tailed gnatcatcher and black-tailed gnatcatcher (melanura) were treated as the same species (*Polioptila melanura*);

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

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

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

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

As part of a network-wide landbird monitoring project, the Rocky Mountain Bird Observatory (RMBO), in partnership with the CHDN, began monitoring birds in BIBE in the spring of 2010. The overall goal of the project was to detect potential changes in population parameters over time (White 2011), the specific objectives were to determine 1) occupancy – the measure of presence or absence of a species; 2) bird species richness and composition – the number and kinds of species; and 3) density – the number of individuals of the most common species in a sampled area

The RMBO land bird monitoring in BIBE closely parallels the RMBO's "Integrated Monitoring in Bird Conservation Regions (IMBCR)" program, which utilizes 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 utilize 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-km^2 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 30, Plate 17)

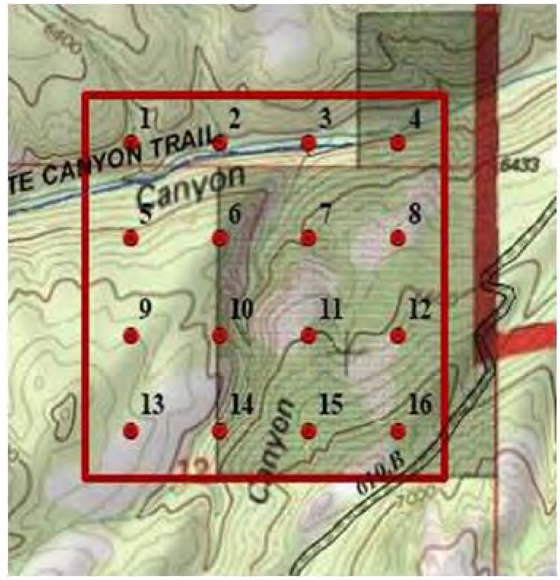


Figure 30. Example of a grid cell created by the Rocky Mountain Bird Observatory using the IMBCR design. Reproduced from White et al. (2011).

Using this procedure, 28 linear/grid transects (20 in grassland habitat, and eight in riparian habitats) (Plate 17) were sampled one time during the 2010 breeding season (from 5 May to 11 June) (White 2011).

4.6.5 Current Condition and Trend

Grassland Species 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.

Many of the declines in grassland species appear to be the result of loss and degradation of grassland habitats (Noss et al. 1995, Vickery and Herkert 2001). Six winter residents of the Chihuahuan grasslands (mountain plover [*Charadrius montanus*], Sprague's pipit [*Anthus spragueii*], lark bunting, Baird's sparrow, chestnut-collared longspur [*Calcarius ornatus*], and McCown's longspur [*Rhynchophanes mccownii*]) have shown sharp declines (68-91%) over the past 50 years (NABCI 2009). These species occur in the park only during the fall and winter months, and are not observed when the grassland monitoring in the park takes place (late spring/early summer). Commonly observed grassland species in the summer surveys, such as the black-throated sparrow (*Amphispiza bilineata*) and the cactus wren (*Campylorhynchus brunneicapillus*), do not have any discernible or reported trends in abundance at this time. Monitoring the grassland bird species diversity in BIBE (during both the winter and summer seasons) will not only help to gauge the health of the bird community, but it will also help managers estimate the condition of the grassland communities within the park.

2010 Rocky Mountain Bird Observatory Landbird Monitoring

Beginning in the spring of 2010, the RMBO (in cooperation with the CHDN) began a park-wide land bird monitoring program in BIBE. Monitoring efforts focused on both the riparian and grassland habitats in the park. In the grassland habitat, 20 linear or grid transects were established throughout the habitat type (Plate 17) (White 2011). Each site was visited one time during the breeding season, with visits occurring from 5 May 2010 to 11 June 2010 (White 2011). White (2011) recorded 1759 individual birds of 56 species on the grassland transects in 2010 (Table 23).

Table 23. Number of birds (listed alphabetically by common name) detected in the grassland habitat class by White (2011).

Common Name	Grassland Observations	Common Name	Grassland Observations
ash-throated flycatcher	47	ladder-backed woodpecker	2
barn swallow	3	lesser nighthawk	68
Bell's vireo	51	loggerhead shrike	8
Bewick's wren	1	mourning dove	51
black-chinned hummingbird	1	northern cardinal	1
black-tailed gnatcatcher	59	northern harrier	1
black-throated sparrow	368	northern mockingbird	191
blue grosbeak	39	orchard oriole	7
blue-gray gnatcatcher	6	painted bunting	23
Brewer's sparrow	4	pyrrhuloxia	199
broad-tailed hummingbird	1	red-tailed hawk	1
brown-crested flycatcher	1	rock wren	1
brown-headed cowbird	25	rufous-crowned sparrow	50
cactus wren	231	Say's phoebe	4
canyon towhee	8	scaled quail	54
canyon wren	1	scissor-tailed flycatcher	1
Cassin's sparrow	19	Scott's oriole	38
Chihuahuan raven	15	Swainson's hawk	5
chipping sparrow	4	turkey vulture	38
cliff swallow	3	varied bunting	2
common nighthawk	1	verdin	43
crissal thrasher	4	western kingbird	4
curve-billed thrasher	3	western wood-pewee	1
gray vireo	4	white-winged dove	1
great horned owl	1	yellow-billed cuckoo	2
greater roadrunner	6	yellow-breasted chat	26
green-tailed towhee	5	yellow-rumped warbler	2
hooded oriole	2	**Total Species**	**56**
house finch	22	**Total Individuals**	**1759**

Breeding Bird Diversity

NPS Certified Species List

The NPS Certified Bird Species List (accessible from: https://irma.nps.gov/App/Species/Search) confirms the presence of 413 bird species within BIBE. Of the 413 species identified, 119 species are identified as breeding in the park (Appendix H).

Breeding Bird Surveys

An index count is a method that tallies the number of bird detections during surveys of points, transects, or other defined regions (Kendeigh 1944, Verner 1985, Bibby et al. 1992, Ralph et al.

1995, Rosenstock et al. 2002). Index counts are frequently used to quantify bird species' distribution, occurrence, habitat relationships, and population trends (Rosenstock et al. 2002). In BIBE, the annual BBS efforts represent examples of long-term index counts. Results from these surveys help park managers to better understand population trends. It is important to note that counts such as the BBS are neither censuses nor density estimates, and results should only be viewed as indices of population size (Link and Sauer 1998). Possible bias of roadside count locations limit the usefulness of BBS data and it is not advisable to estimate population sizes from these data alone (Link and Sauer 1998).

Of the three active BBS routes, the Hot Springs route (BBS route 83082) has been surveyed for the longest period of time (40 years). The Hot Springs route surveys the east/east-central portion of BIBE, and terminates near Rio Grande Village (Plate 15).The number of species observed on this route has ranged from 19 (1975) to 38 (2006) (Figure 31); the average number of species observed on this route was 29.7. The number of individuals observed ranged from 160 (1985) to 867 (1969) (Figure 32). The Hot Springs route had the highest average number of individuals observed (466.8) when compared to the other two routes in the park. The black-throated sparrow, pyrrhuloxia (*Cardinalis sinuatus*), cactus wren, northern mockingbird, and scaled quail (*Callipepla squamata*) were the species recorded in the highest numbers on all three BIBE BBS routes.

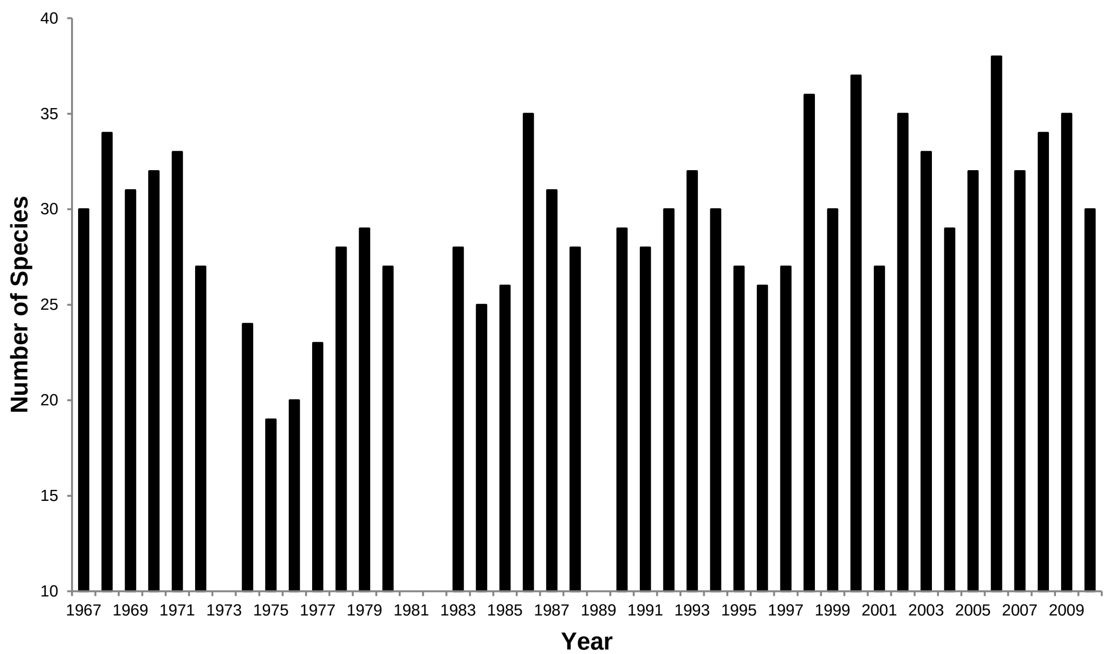


Figure 31. Number of bird species detected from 1967-2010 along the Hot Springs BBS route. Gaps in the figure represent years when data were not collected. Data retrieved from (https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm).

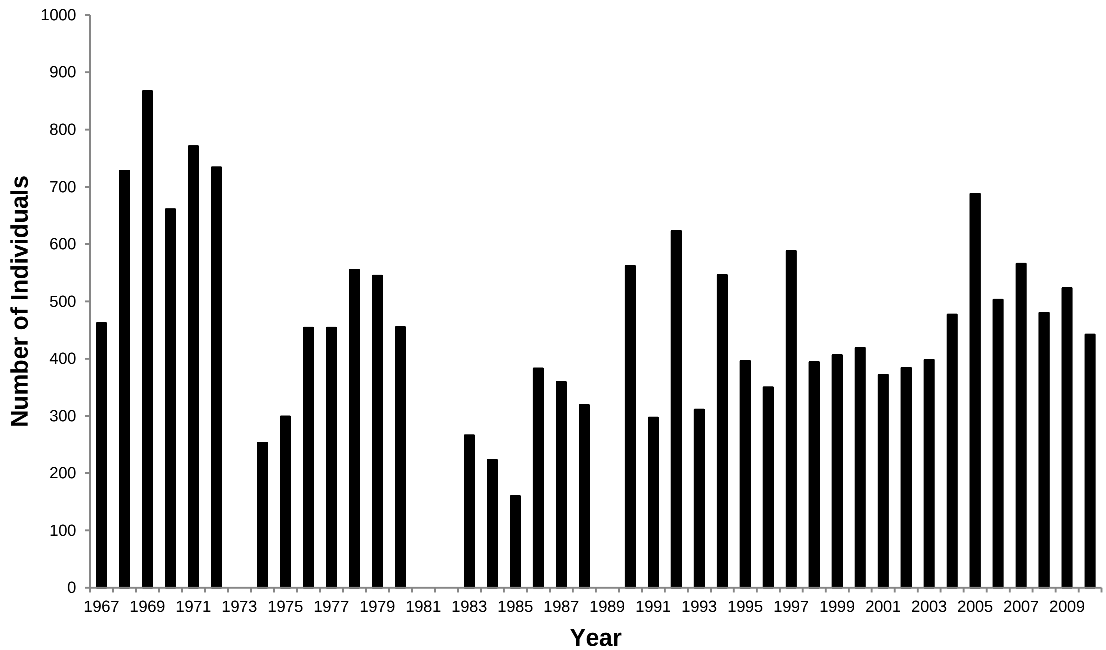


Figure 32. Number of individual birds observed from 1967-2010 along the Hot Springs BBS route. Gaps in the figure represent years when data were not collected. Data retrieved from (https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm).

The Chisos Basin route (BBS route 83900) is the most recently created BBS route in the park, and has been surveyed annually since 1995. This route surveys the north/north-central portion of BIBE, and terminates near Chisos Basin (Plate 15). The number of species observed on this route have ranged from 35 (2003) to 47 (1999) (Figure 33). The Chisos Basin route had the highest average number of species detected (41.5) when compared to the other two routes in the park. The number of individual birds observed on the Chisos Basin route ranged from 328 (2001) to 618 (2005) (Figure 34); the average number of individuals observed on the route was 459.4.

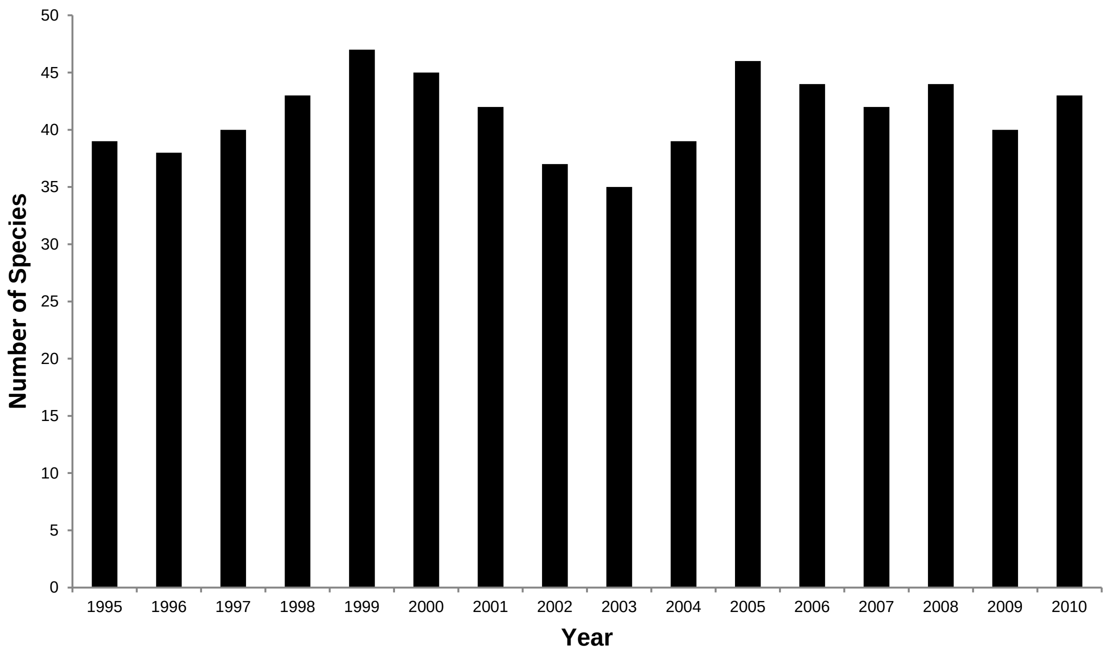


Figure 33. Number of bird species detected from 1995-2010 along the Chisos Basin BBS route. Data retrieved from (https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm).

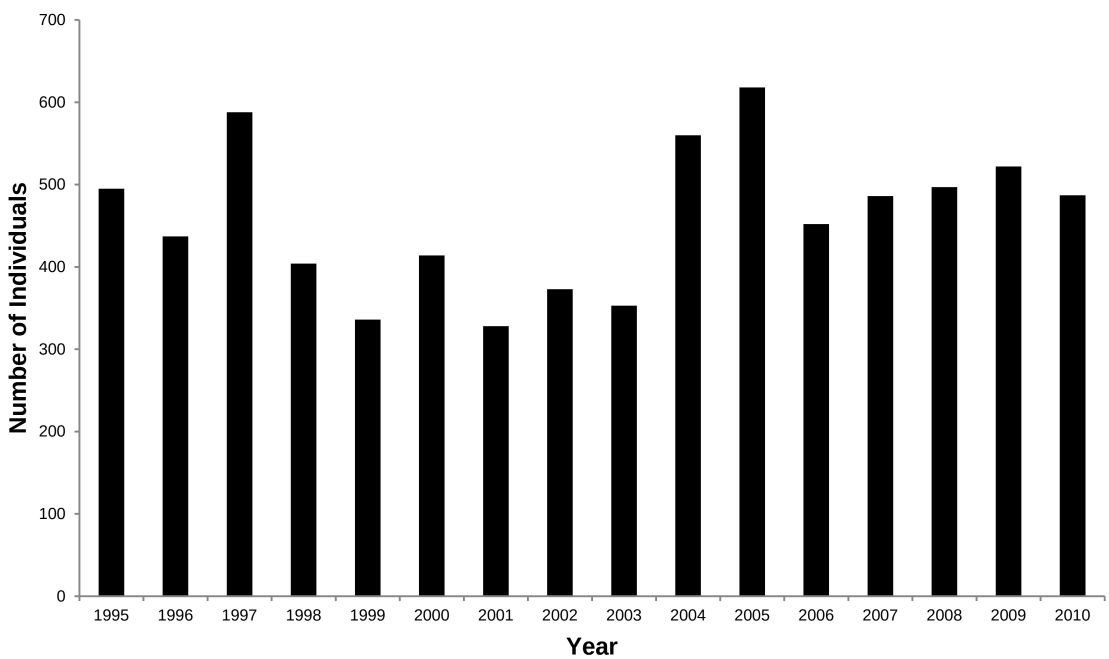


Figure 34. Number of individual birds observed from 1995-2010 along the Chisos Basis BBS route. Data retrieved from (https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm).

The Castolon route (BBS route 83319) surveys the western portion of BIBE (Plate 15), and has been surveyed annually since 1994. The number of species detected on surveys along this route have ranged from 30 (1995) to 43 (1998) (Figure 35); the average number of species detected on this route was 36.1. The number of individual birds observed on the Castolon route ranged from 293 (2003) to 555 (1994) (Figure 36); the average number of individuals observed on the route was 426.7.

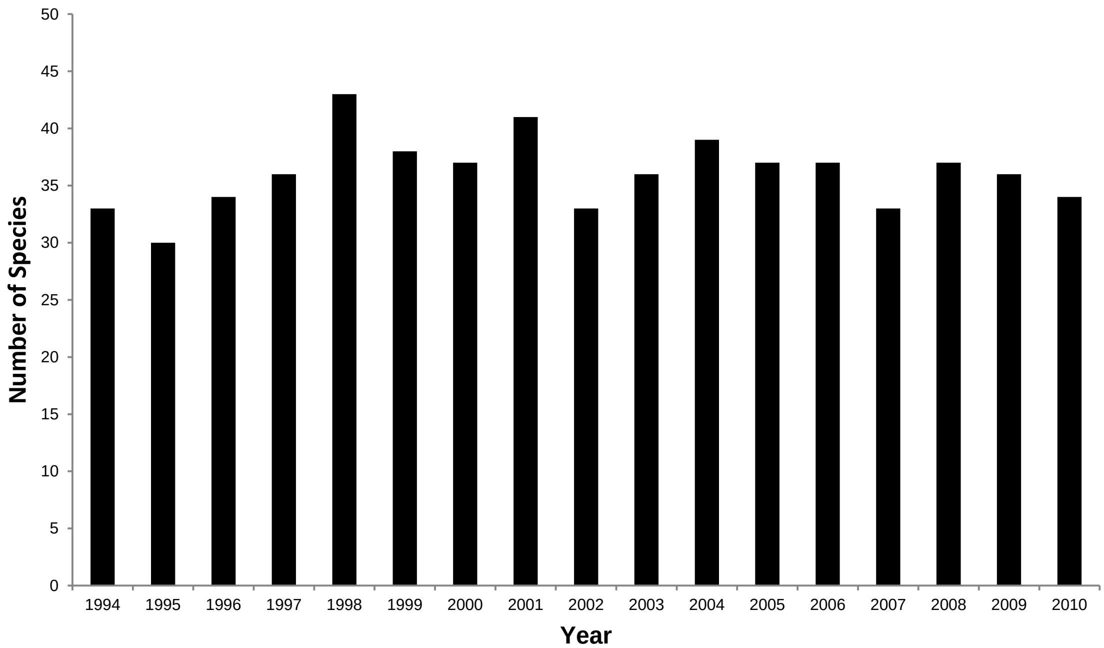


Figure 35. Number of bird species detected from 1994-2010 along the Castolon BBS route. Data retrieved from (https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm).

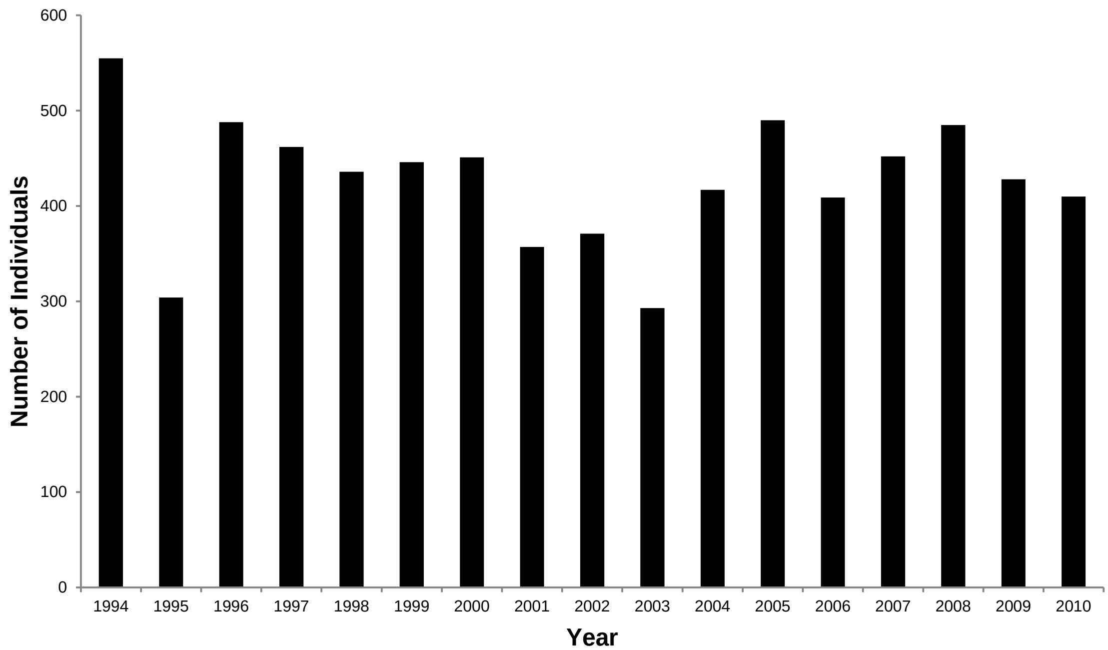


Figure 36. Number of individual birds observed from 1994-2010 along the Castolon BBS route. Data retrieved from (https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm).

Wong (1998) Breeding Bird Thesis

Wong (1998) investigated the relationship between the features of desert oases in BIBE and bird habitat. The specific variables investigated included: the presence of water, human disturbance, riparian vegetation type within an oasis, area of the oasis, quantity of adjacent desert vegetation, distance to a large riparian habitat, and distance to the Rio Grande (Wong 1998). Forty-two oases in BIBE were each visited seven to eight times a year from February to June in both 1996 and 1997 (for detailed survey methodology, see Wong 1998).

During the 1996 and 1997 surveys, Wong (1998) identified 117 different bird species, and found that transient species accounted for a very small amount of the observations at oases (5.6% of all individuals). For the variables analyzed, Wong (1998) found that:

- The presence of bird species at an oasis was not dependent on the presence of water. Birds most likely acquired their water from sources other than springs at oases (e.g., insects or seeds);

- No direct instances of human disturbance affecting bird species were observed. However, two species (brown-headed cowbird [*Molothrus ater*] and canyon towhee) were positively correlated with high levels of disturbance when the program DISTURB (a statistical analysis program that measured signs of human presence) was used;

- Species of birds that were positively associated with vegetation type most likely responded to the composition of oasis vegetation, the density of the vegetation and shrub layers, or both (depending on the bird species' habitat requirements);

- The relationship between oasis area and bird abundance was inconsistent;

- Bird species were more abundant in oases that were surrounded by a large area of desert mountains and foothills vegetation type;

- Large riparian habitats may have been too far away from the studied oases (average distance from sites was 2.6 km) and did not appear to influence bird selection of oases;

- Some species were associated with the distance to the Rio Grande, but few species responded to the Rio Grande itself (a potential exception being the white-winged dove [*Zenaida asiatica*]).

Gutzwiller and Barrow (2001)
Gutzwiller and Barrow (2001) studied the landscape relationship of 26 focal breeding bird species in BIBE from 1995-97. The study used a systematic sampling technique with a random start time, and created 70 sampling sites within the park. At each of the 70 sites, surveyors conducted 20-minute unlimited distance counts using protocol from Ralph et al. (1995). Distance counts were conducted once a week from February-May, 1995-97 (Gutzwiller and Barrow 2001).

At the conclusion of the study, Gutzwiller and Barrow (2001) had detected 157 bird species across all 70 sites. Names and occurrences of 26 focal breeding bird species are identified in Table 24. Overall mean richness (number of species per site), ranges of mean richness (number of species per count), and ranges for overall mean abundance (number of individuals per count per site) were also calculated (Table 25).

Table 24. The 26 focal breeding bird species from Gutzwiller and Barrow (2001), and the percentage of the 70 sites at which species were detected. Reproduced from Gutzwiller and Barrow (2001).

	Percentage of sites, by year		
Common Name	**1995**	**1996**	**1997**
turkey vulture	96	99	100
scaled quail	40	37	69
white-winged dove	40	39	39
mourning dove	51	53	100
greater roadrunner	61	41	66
lesser nighthawk	21	31	24
ladder-backed woodpecker	33	46	43
Say's phoebe	41	59	57
ash-throated flycatcher	89	91	90
loggerhead shrike	44	70	71
Bell's vireo	24	26	21
common raven	86	77	86
verdin	67	71	49
cactus wren	90	84	90
rock wren	71	81	90
Bewick's wren	34	29	36
black-tailed gnatcatcher	97	91	89
northern mockingbird	87	96	97
canyon towhee	23	27	39
rufous-crowned sparrow	44	57	46
black-throated sparrow	99	97	99
pyrrhuloxia	83	86	97
blue grosbeak	21	40	36
brown-headed cowbird	26	39	33
Scott's oriole	80	86	89
house finch	93	96	96

Table 25. Mean richness and mean abundance values from Gutzwiller and Barrow (2001).

Year	Overall Mean Richness [a]	Ranges of Mean Richness [b]	Ranges for overall mean abundance [c]
1995	6	2-12	0.03-1.23
1996	6	2-15	0.06-1.10
1997	8	3-17	0.06-2.32

[a] Number of species per count per site

[b] Number of species per count

[c] Number of individuals per count per site

Wauer and Flippo (2008)

Wauer and Flippo (2008) reported population changes in the breeding bird population of BIBE from 1901-2006. Changes in population numbers and status were estimated by synthesizing and analyzing historic records, observations, and studies within the park from 1901-2006. Of the 30 breeding species reported in Wauer and Flippo (2008), nine species exhibited an increase in population size, seven species exhibited a population decline (or were extirpated from the region), five species' populations appeared relatively stable, eight species were recent arrivals and did not exhibit an observable population trend, and one species had an uncertain status (Table 26).

Table 26. Estimated population changes in 30 breeding bird species in BIBE from 1901-2006 (Wauer and Flippo 2008).

Species	Population change from 1901-2006	Species	Population change from 1901-2006
mallard	I	golden-fronted woodpecker	RA
Gambel's quail	D	dusky-capped flycatcher	RA
Montezuma quail	D, LR	tropical kingbird	RA
green heron	I	loggerhead shrike	S
black-crowned night-heron	RA	Bell's vireo	S
common black-hawk	I	black-capped vireo	S
Harris's hawk	D or E	cave swallow	RA
gray hawk	I	Carolina wren	RA
golden eagle	D or E	Colima warbler	S
aplomado falcon	U	Lucy's warbler	RA
peregrine falcon	S	yellow warbler	D or E
prairie falcon	D or E	painted redstart	I
Eurasian collared-dove	RA	great-tailed grackle	I
Lucifer hummingbird	I	bronzed cowbird	I
green kingfisher	I	hooded oriole	D

I = Increasing

D = Declining

LR = Possible Limited Recovery

RA = Recent Arrival

U = Uncertain

S = Apparently Stable

E = Extirpated

Rocky Mountain Bird Observatory Landbird Monitoring

In 2010, White (2011) selected survey points in BIBE that were located either along a transect for linear features (e.g., riparian habitats), or on a grid for areal features (e.g., grassland habitats).These sample points were located in two habitat types (grassland and riparian), and were sampled during the breeding season (April-June). This period was selected for surveying because during the breeding season landbirds exhibit increased territorial behavior and become easier to observe and sample (White 2011).

White (2011) found that the park had the highest number of bird species observed (69) in CHDN parks during the 2010 landbird monitoring (Appendix L). Two habitat types were sampled (grasslands and riparian), and 2,515 individual birds were counted (Appendix L). Along the grassland transects, 1,825 individual birds of 55 species were counted. The most abundant breeding grassland species were black-throated sparrow, cactus wren, northern mockingbird and pyrrhuloxia (White 2011). Along the riparian transect, 690 individual birds of 44 species were counted. Common species observed along the riparian transects included the ash-throated flycatcher (*Myiarchus cinerascens*), Bell's vireo (*Vireo bellii*), blue grosbeak (*Passerina caerulea*) and painted bunting (*Passerina ciris*) (White 2011).

The 2011-12 data for BIBE were not yet summarized at the time of writing, however, a brief summary of the monitoring efforts is included below. From 2011-2012, an average of 2,645 birds (2,607-2,682) and 85 species (81-88) were documented in the park (White and Valentine-Darby 2012, 2013). Sixty-nine species were observed at riparian transects during this survey period, which is the second highest bird diversity of any riparian habitat site in the CHDN (White and Valentine-Darby 2012, 2013).Over 400 bird species have been documented in the park through the duration of the surveys, although many of these species have been accidental species that have been only observed once (White and Valentine-Darby 2012, 2013).

The most commonly observed species from 2011-2012 were the black-throated sparrow (11% of all observations), cactus wren (8%), turkey vulture (6%), Bell's vireo (6%), white-winged dove (6%), and ash-throated flycatcher (5%) (White and Valentine-Darby 2012, 2013). Two species, Nashville warbler and yellow-throated vireo, were observed in the riparian habitat of BIBE, incidental to the point count surveys. These species are worth noting as they have not been observed at any other park in the CHDN (White and Valentine-Darby 2012, 2013). No other new species were observed in the park during the 2011-2012 surveys.

Migratory Species Diversity

Christmas Bird Count

The total number of bird species identified annually during the park's CBC from 1964-2010 is represented in Figure 37 (Appendix I, Appendix J, Appendix K). The average number of species observed throughout the surveys was 72.51. The total number of individual birds observed from 1964-2010 is represented in Figure 38. For the duration of the survey, the average number of individuals observed was 1,230.88.

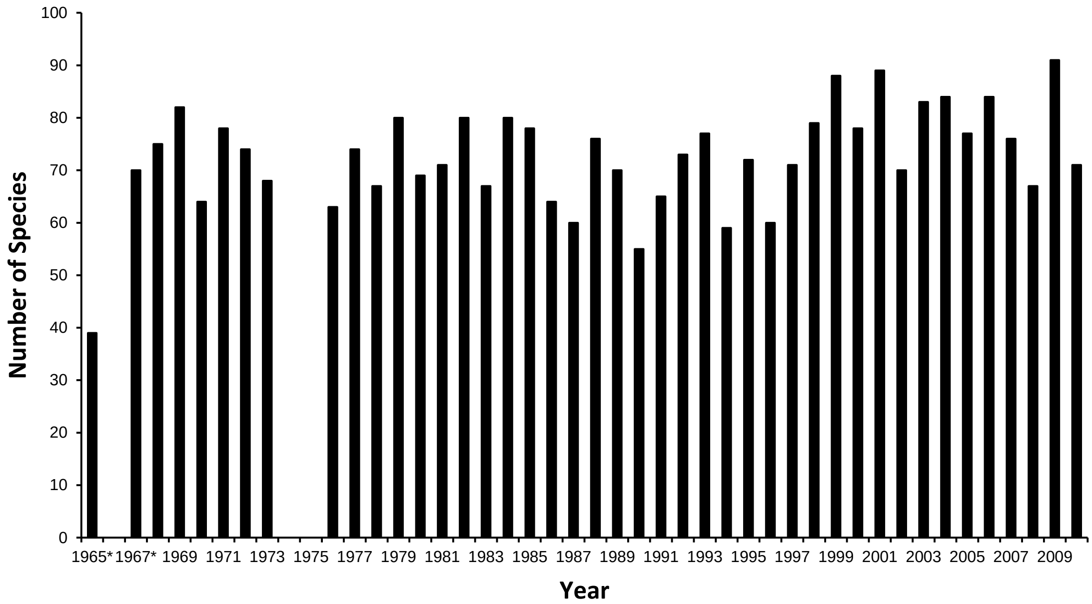


Figure 37. Number of bird species detected from 1965-2010 during the Big Bend National Park CBC. Data retrieved from (http://audubon2.org/cbchist/count_table.html). * indicates a CBC survey year that had a different center point.

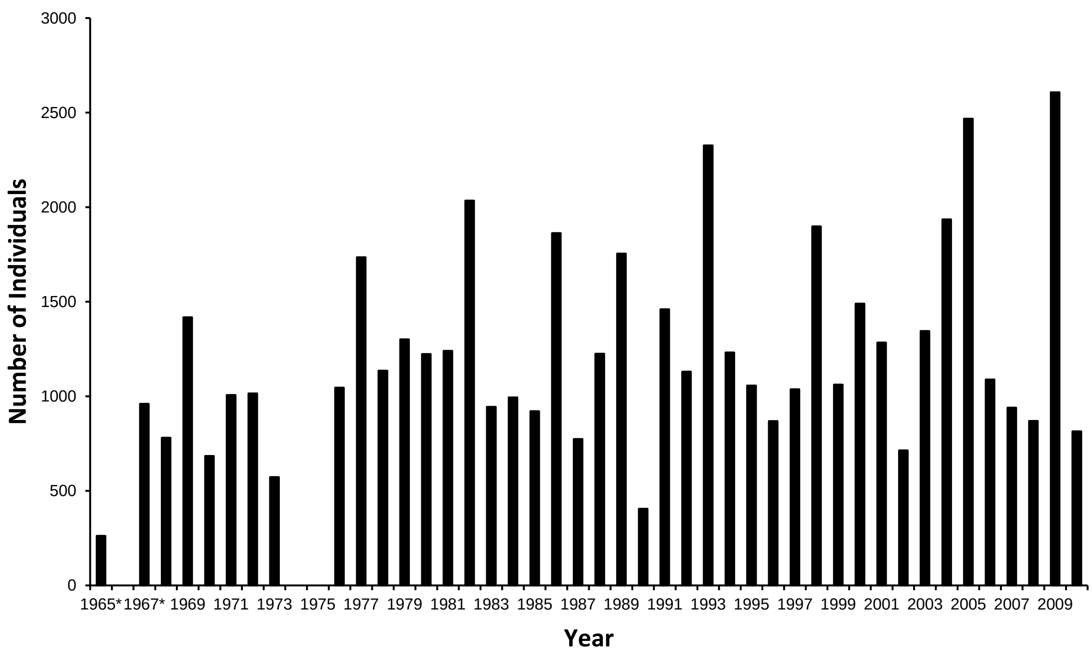


Figure 38. Number of individual birds detected from 1965-2010 during the Big Bend National Park CBC. Data retrieved from (http://audubon2.org/cbchist/count_table.html). * indicates a CBC survey year that had a different center point.

Care must be taken when interpreting count data as the data are largely dependent upon the effort of the observers, and may not always provide an accurate depiction of the species richness. The ability of the observer to identify bird species by appearance and auditory calls is essential for accurate count data. A count that includes observers who may not possess the necessary skills could lead to a lower count when compared to years where highly skilled observers are used. In addition, the number of individuals involved in the count may influence the number of species and individuals detected during a year. The lowest number of observed species and individual birds in the park occurred in 1965 when only two observers participated in the count.

Bishop (1997) Migratory Bird Thesis

Bishop (1997) investigated the effects that highlands in BIBE had on fallout patterns of Nearctic migratory bird species. A Nearctic bird is one that is a common breeding species in North America, and migrates south of the Rio Grande (Bishop 1997). In order to fully understand these patterns, Bishop (1997) looked at the relationships between the features of the highlands and bird species richness, abundance, and the probability of site use. One hundred five survey sites were established in the park, and 20-minute unlimited-distance point counts were conducted approximately once a week from late-February to late-May in 1995 (Bishop 1997).

For the duration of the Bishop (1997) survey, 46 bird species were detected. Of these 46 species, 26 were Nearctic species and 20 were en-route migratory species. Only the Scott's oriole's (*Icterus parisorum*) migratory fallout was significantly affected by highland features (Bishop 1997). This finding suggests that migratory species traveling through the park travel along broad fronts, which makes migratory habitat more difficult to identify and protect.

<u>Black-capped Vireo Breeding Pairs</u>

The black-capped vireo is a small, migratory songbird that is a summer resident of Texas, southern Oklahoma, and northern Mexico (USFWS 2007). The species' wintering range extends along the western coast of Mexico (Figure 39). Typically, black-capped vireos will nest in shrub vegetation that is patchy in distribution, and nest sites are usually1.8 m (6 ft) above the ground (USFWS 2007).

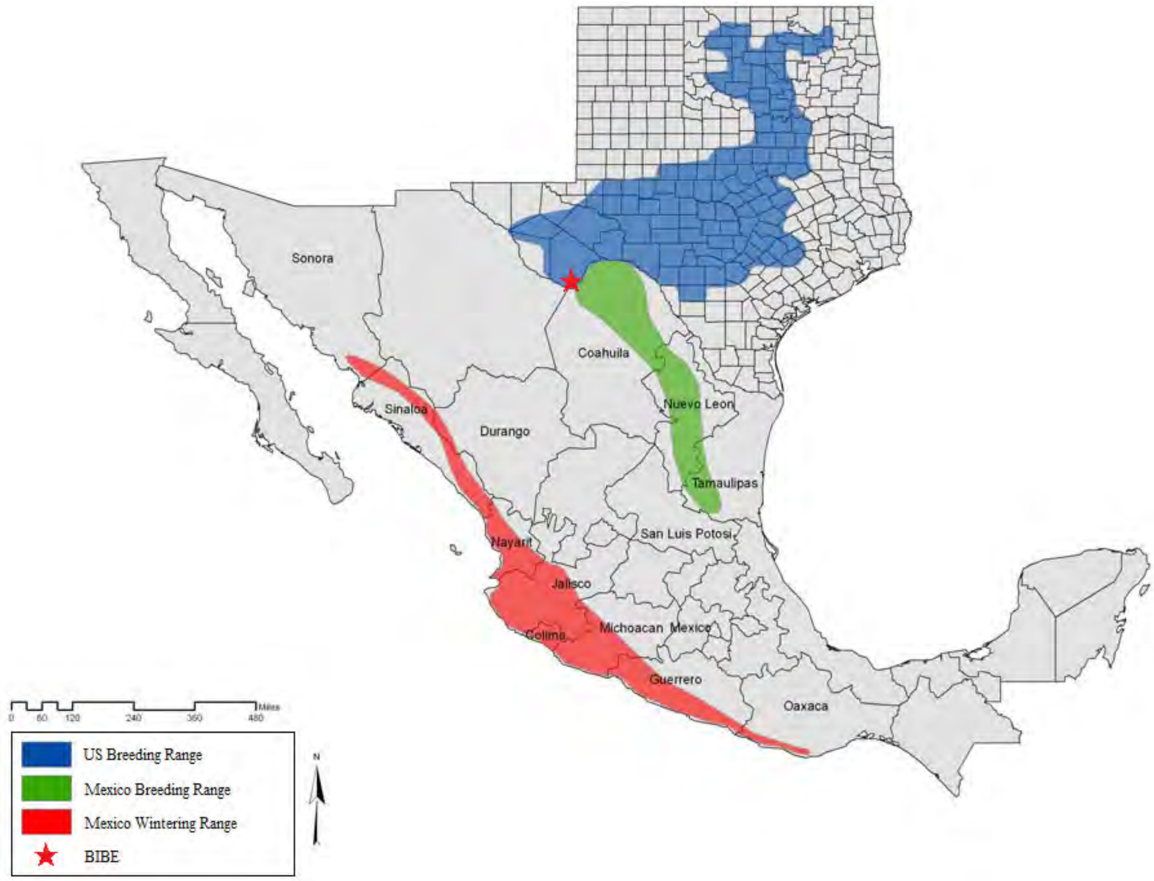


Figure 39. North American breeding and wintering ranges of the black-capped vireo. Ranges have been generalized for known locations since 1985. Image reproduced from USFWS (2007).

The black-capped vireo was listed as an endangered species under the Endangered Species Act (ESA) in 1987 (USFWS 2007); the black-capped vireo and the northern aplomado falcon (*Falco femoralis*) are the only federally listed bird species known to occur in BIBE (although the aplomado falcon has been observed less than five times within BIBE boundaries) (LCAS 2010). At the time of listing, little was known about the black-capped vireo population status outside of a few survey efforts. In 1987, the global population of black-capped vireos was estimated to be between 256 and 525 pairs (approximately 20 pairs in Oklahoma, 188 to 374 pairs in Texas, and 48 to 131 pairs in Mexico) (Marshal et al. 1985). By 2006, the global population was estimated at 6,269 males (USFWS 2007); no estimate of current female population size is available.

The black-capped vireo population was poorly studied prior to ESA listing, but the population decline may be attributed to several stressors and threats as identified by Wilkins et al. (2006) and USFWS (2007):

- Habitat loss through land use conversion;
- Grazing and browsing by domestic and wild herbivores;
- Brood parasitism by brown-headed cowbirds.

Annual monitoring of the park's black-capped vireo population began in 1985 (Griffin and Barlow 1989), and has continued through 2013 (Pomara 2011, Skiles, written communication, 1 November 2013). While no consistent monitoring protocol has been established for year-to-year surveys, surveys have typically focused on regions of the park where black-capped vireo nesting has been historically observed (e.g., Juniper Canyon, Blue Creek Canyon, and the Basin). Later surveys in 2009, 2010, and 2011 have expanded in an effort to locate breeding locations not previously identified (Pomara 2009, 2010, 2011) (Plate 18). The 2012 and 2013 black-capped vireo study were completed during the writing of this document, and were not available for analysis prior to publication.

Each of the annual black-capped vireo surveys in the park has documented the number of individuals observed during a survey year, and the results of the 1985-2011 surveys are depicted in Figure 40. For the duration of the surveys, the average number of black-capped vireos observed annually was 20.30 individuals. The lowest number of vireos observed during a survey year occurred in 1991 (five individuals), while the highest number of vireos observed occurred in 2009 (41) (Figure 40). The elevated number of individuals in 2009 may be a result of an increase in survey intensity for that season. In 2009, two surveys concurrently sampled the black-capped vireo population in BIBE; one survey was conducted by Pomara (2009), and the other survey was conducted by Texas A&M University as part of a state-wide survey of black-capped vireos. The results from Texas A&M's survey in the park were provided to Pomara (2009) and are reflected in the number of individuals observed for that season.

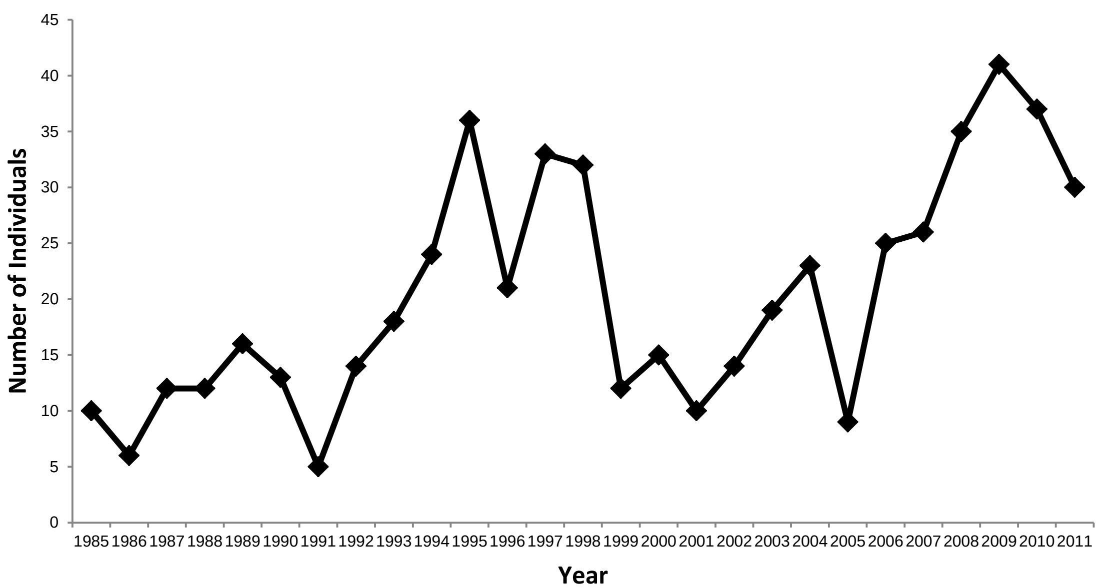


Figure 40. Number of black-capped vireos observed during Big Bend National Park's annual survey from 1985-2011 (NPS 2011b).

Griffin and Barlow (1989) suggest that an imbalanced sex ratio in a population that has already been reduced may limit reproductive success. Furthermore, Donald (2007) found that sex ratio distortion was more severe in globally threatened species when compared to non-threatened species. This phenomenon may be exaggerated in the park due to the limited connectivity between breeding locations in the park (Griffin and Barlow 1989). Annual surveys in BIBE have documented the number of male and female black-capped vireos in the park since 1985 (Figure 41). The average number of females detected during annual surveys in the park was 6.22, while the average number of males detected in the park was 14.60 (Figure 41).

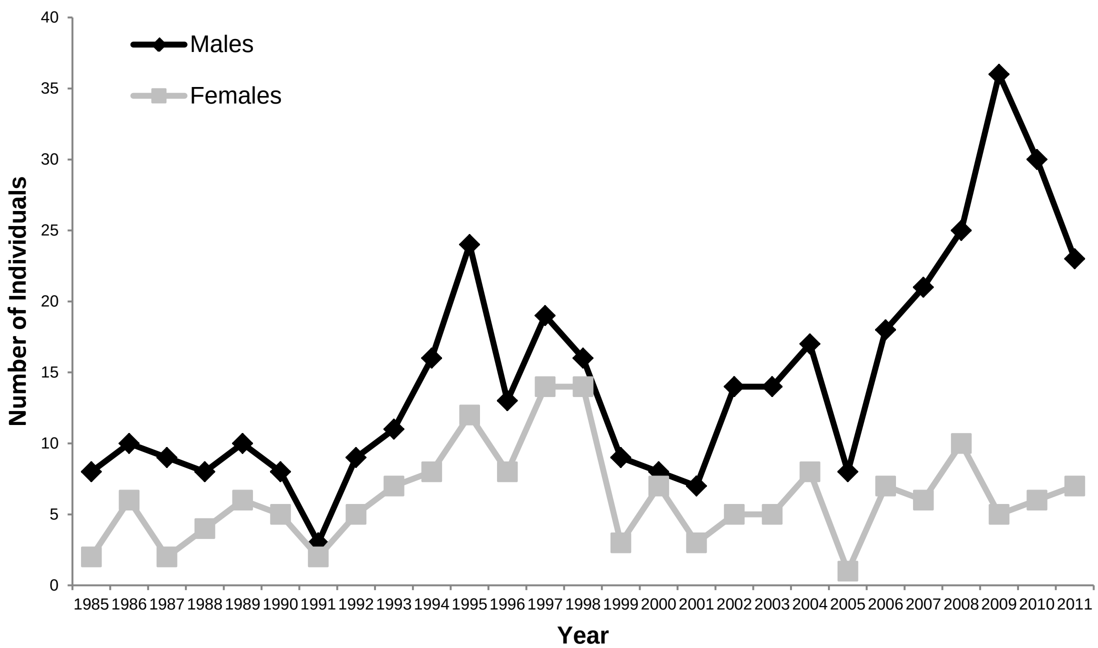


Figure 41. Number of male and female black-capped vireos observed during Big Bend National Park's annual surveys from 1985-2011 (NPS 2011b).

<u>Threats and Stressor Factors</u>

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 have been converted to agricultural lands in the last five years (NABCI 2009). Drought conditions, desertification, and overgrazing of ranch lands all contribute to the degradation of grasslands in the Chihuahuan Desert. The Chihuahuan Desert grasslands are expected to become drier due to higher temperatures and lower precipitation levels associated with climate change (NABCI 2010, Munson et al. *in press*); the loss of a continuous grassland habitat across the park and the Chihuahuan Desert could greatly influence the breeding success and population size of the park's grassland bird species.

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

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

Selenium and mercury contamination has been identified as a threat to avian species in Texas in recent years (Irwin 1989, Mora et al. 2002, 2007). In BIBE, contaminant analysis began when peregrine falcon populations in the park experienced limited reproductive success in the late 1980s-mid-1990s. Mora et al. (2002) found elevated mercury (Hg) and selenium (Se) levels in several avian species. All of the avian species collected in 1997 had concentrations of Se greater than 3 µg/g dw (Se concentrations above this level can have detrimental effects on wildlife [Lemly 1996]). Mora et al. (2007) sampled avian populations in the park again in 2001. The results of this study also found levels of Se and Hg elevated enough to infer that these toxins were likely associated with the current reproductive failure of peregrine falcons in the park. Continued monitoring of Hg and Se levels in the park's avian species is necessary to track any potential trends.

Data Needs/Gaps

Gutzwiller and Barrow (2001) represents the most comprehensive and statistically supported baseline multi-species survey conducted in the park. There is a strong need to repeat the high-validity, multi-habitat survey completed by Gutzwiller and Barrow (2001). Repetition of this survey would allow for a comparison of data that may provide valuable information on presence/absence, density, abundance, and trends.

Monitoring of the black-capped vireo population in the park has occurred annually since 1985; however, there has been no standardized methodology for the survey. Survey objectives have varied on a yearly basis; Griffin and Barlow (1989) focused on estimating the current population size, while Pomara (2009, 2010, 2011) broadened the scope of the survey and began to search for new territories. These differences in survey type and effort may introduce potential sources of bias into the data and may not accurately identify the current status of the population. The development of a standardized survey method would help to remove sources of error or bias in the survey results and may help to produce a reliable, comparable estimate of black-capped vireo population size on a year-to-year basis.

Continuation of the grassland bird monitoring efforts spearheaded by the RMBO is essential for monitoring not only the health of specialist bird species, but also for monitoring the health of the grassland communities of the park. By utilizing a spatially balanced sample design with skilled observers, the survey efforts should yield an excellent baseline for future comparisons. However, BIBE is in need of additional grassland bird surveys in the winter. NABCI (2009, 2010) identifies several grassland species that occur in BIBE in the winter as at risk; there is no current trend information for these species in the park, as surveys have not been conducted at a time when these species would be present in the park. While a park-wide winter grassland survey would be ideal, a smaller scale survey that focuses only on winter grassland species that are in decline nationally would also benefit managers.

Despite being removed from the ESA in 1999, the park's four designated post-delisting monitoring eyrie sites, monitored every three years, suggest peregrine falcon population may have had very low productivity for the past ten years. The reestablishment of an intensive park-wide survey effort would help park managers to better gauge the current status of the population. Intensive survey efforts in the park occurred in the 1980s and 1990s. Since 1999, few surveys have been conducted in the park; these studies only looked at four designated USFWS post-delisting monitoring sites and did not survey the entire park. With research suggesting that Hg and Se are above established thresholds (Mora et al. 2002, 2007), continued monitoring of these contaminants may be vital in understanding the productivity of the peregrine falcons.

Overall Condition

Grassland Species Diversity
The BIBE project team assigned the grassland species diversity measure a *Significance Level* of 3. Grassland bird species have been identified as an at risk group of birds, primarily due to their susceptibility to climate change. In the park, current indications are that the summer resident grassland bird species have not experienced any significant declines, although further research is needed to determine the condition of the winter resident grassland bird populations. A *Condition Level* of 1 was assigned to this measure, although park managers should pay particular attention to the CHDN's land bird monitoring results from the park's grassland habitat. These results will likely provide managers with necessary data to analyze changes in diversity and abundance for summer populations.

Breeding Bird Diversity
Breeding bird diversity was assigned a *Significance Level* of 3 during project scoping. BIBE is home to a tremendous variety of bird species, and is one of the premier birding locations in the NPS. This measure is well-studied in the park, with three separate BBS routes and many independent studies in the area. Analyses of the breeding bird diversity, through both independent studies and BBS results, have shown high diversity in the park for a long period. Because of this, this measure was assigned a *Condition Level* of 0.

Migratory Species Diversity
A *Significance Level* of 3 was assigned to the migratory species diversity measure. While there are no indications that migratory species diversity in the park is of concern, there is no data available to accurately assess the current condition. Long term trend data, such as what is available for the breeding bird diversity measure, are needed to analyze potential trends in diversity. The CBC data must be interpreted with caution, as count data are largely dependent upon the effort of the observers and may not always provide an accurate depiction of the species richness in the park. Bishop (1997) investigated only the effect that highlands had on migratory fallout, and occurred over a decade ago. Because of these limitations, no *Condition Level* was assigned to this measure.

Peregrine Falcon Population Size
The BIBE project team assigned the measure of peregrine falcon population size a *Significance Level* of 1. Intensive surveys of the peregrine falcon population in the park were conducted annually from 1976-2003. When the peregrine falcon was delisted from the endangered species list in 1999, intensive survey efforts were no longer required. However, as required by the USFWS post ESA-delisting protocol, annual monitoring reports were completed in the park in 2006, 2009, and 2012. These reports did not focus on the entire peregrine falcon population in the park, but only four designated by USFWS as post-delisting monitoring eyrie sites. The results of the peregrine falcon monitoring program in the park are displayed in Figure 42.

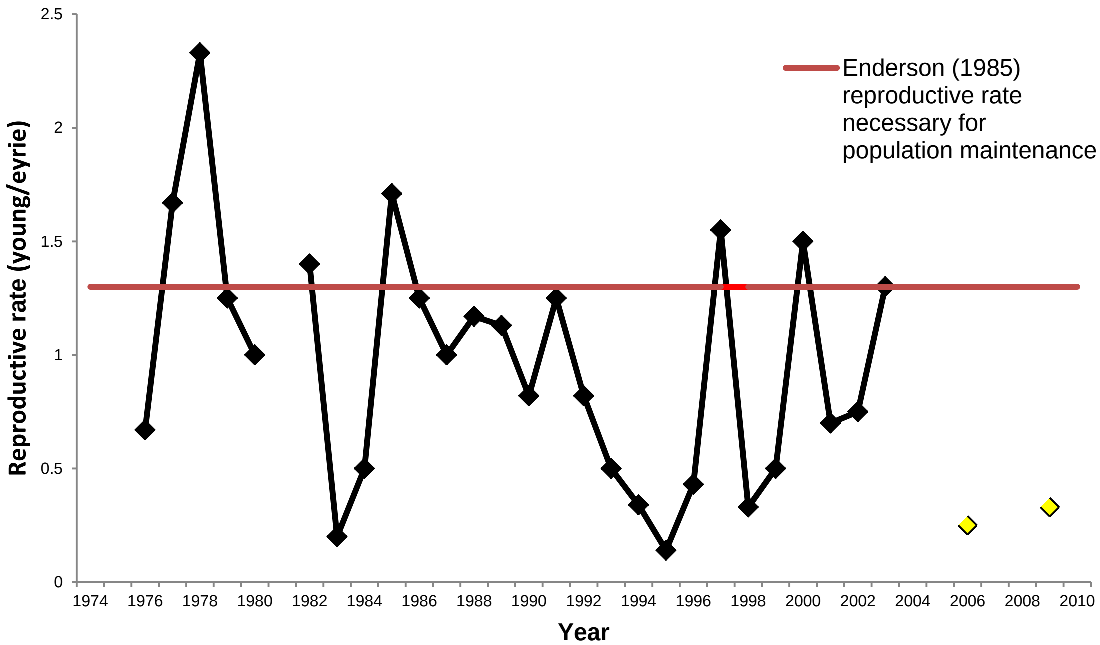


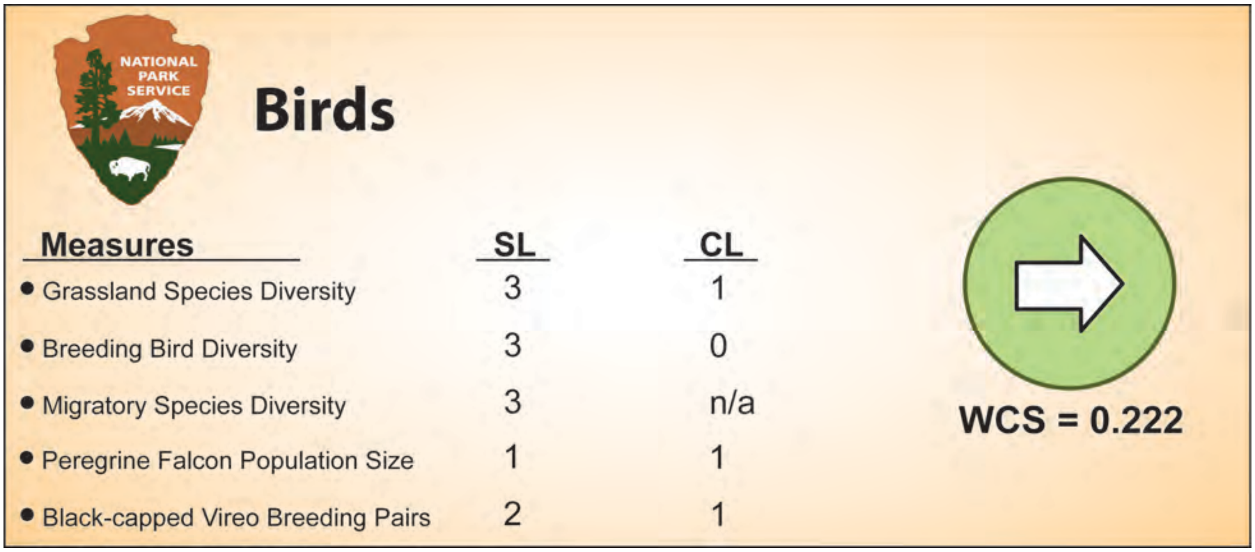
Figure 42. Reproductive success of peregrine falcons nesting in Big Bend National Park, 1976-2009. Yellow diamonds represent non-intensive survey years when only four territories were checked for occupancy/productivity (2012 data was not available at time of writing).

The suggested reproductive rate necessary for peregrine falcon population maintenance is 1.3 young/eyrie (Enderson 1985). For the majority of the survey period (20 years, excluding 2006 and 2009) the BIBE peregrine population has had a reproductive rate below this threshold. However, recent surveys have not focused on the entire park population, and it is possible that new nests have been established in the park since the end of the intensive surveys in 2003. A *Condition Level* of 1 was assigned to this measure.

Black-capped Vireo Breeding Pairs
The measure of black-capped vireo breeding pairs was assigned a *Significance Level* of 2. Annual monitoring of black-capped vireos in the park has occurred since 1985. As an endangered species, knowledge of the breeding success is vital information to both park and USFWS managers. While the exact number of breeding pairs each year is unknown, annual surveys have indicated that the BIBE population of black-capped vireos is stable, if not increasing. Research efforts have also intensified (starting in 2009), and continued intensive

surveys will provide managers with an accurate depiction of the current state of the population. The *Condition Level* of black-capped vireo breeding pairs was assigned as 1.

Weighted Condition Score (WCS)
The *Weighted Condition Score* for birds in BIBE was 0.222, indicating a current condition of low concern.



4.6.6 Sources of Expertise
David Larson, BIBE Chief of Science and Resource Management

Hildy Reiser, CHDN Science Advisor

Raymond Skiles, BIBE Wildlife Biologist

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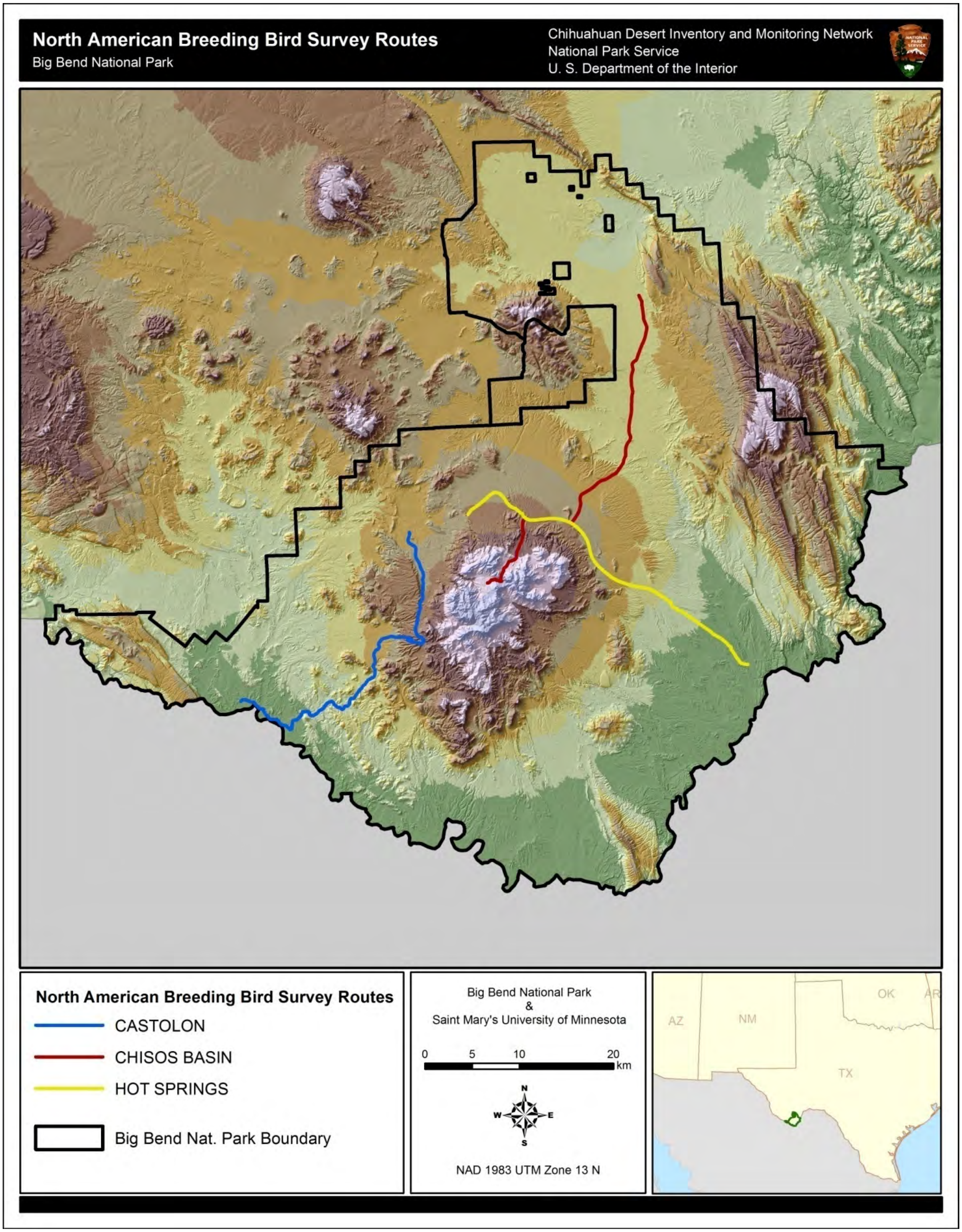

Plate 15. Breeding Bird Survey routes located within Big Bend National Park.

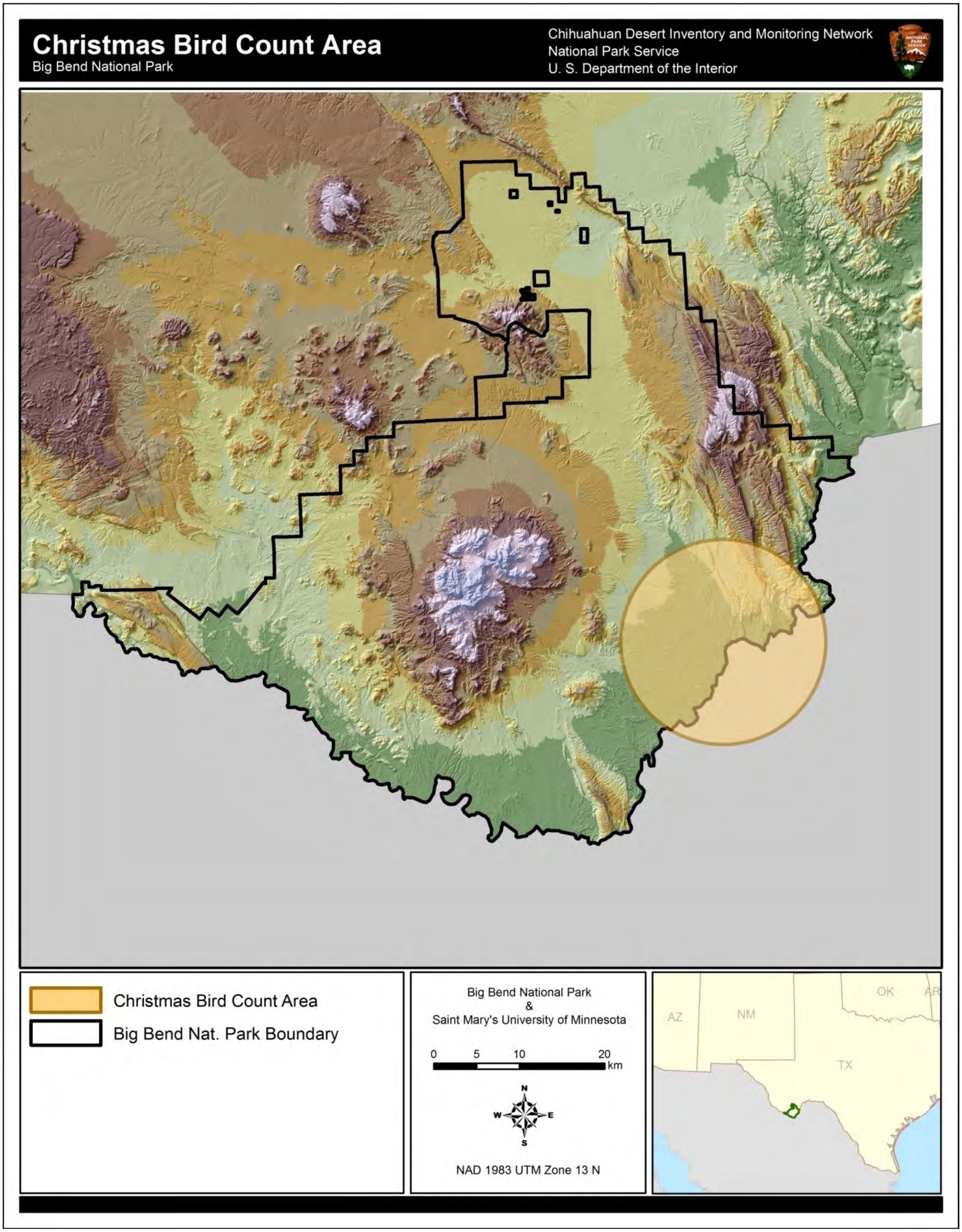

Plate 16. Christmas Bird Count survey area in BIBE. Note that only results from the region within BIBE are reported in this document.

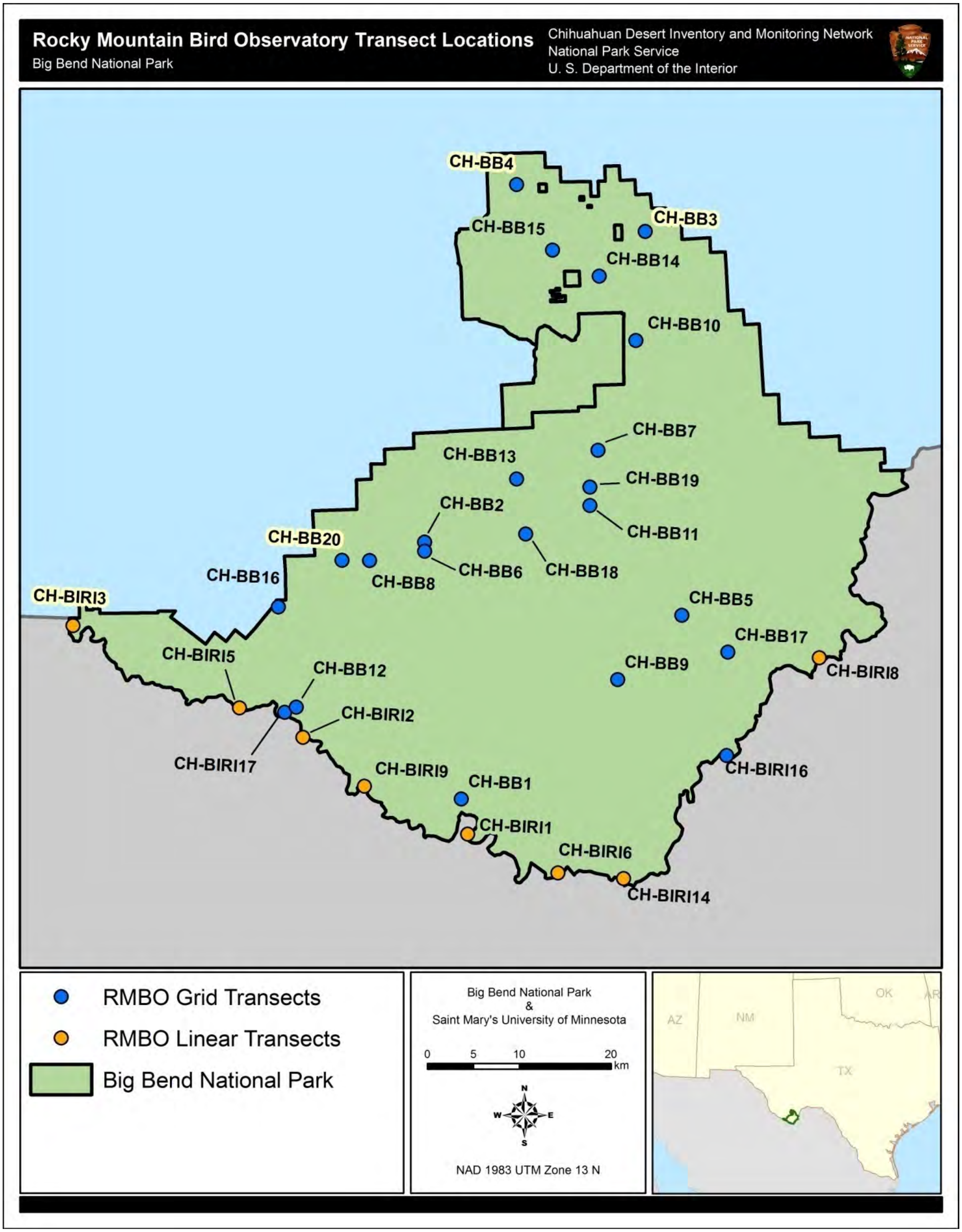

Plate 17. Locations of the Rocky Mountain Bird Observatory transects and grids within Big Bend National Park (current through 2010 survey period). Note that these markers only identify the approximate location of either a series of grids or transects, and do not represent an individual survey point.

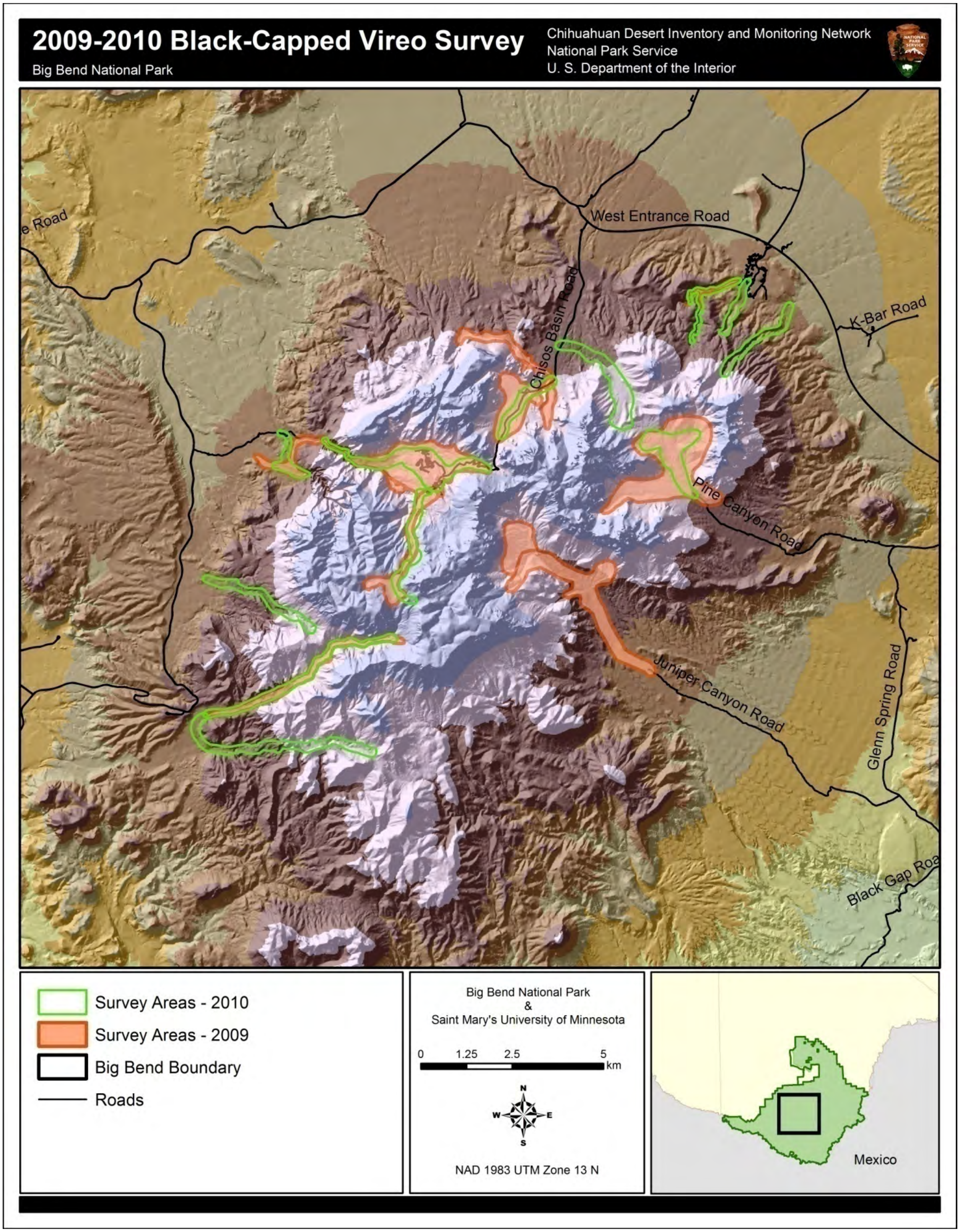

Plate 18. Black-capped vireo survey areas in Big Bend National Park from 2009-2010.

4.7 Black Bears

4.7.1 Description

The Mexican subspecies of the American black bear (*Ursus americanus emericus*)(Photo 13) is the smallest and most common bear species native to North America (Pelton 2003). They are often associated with habitat types such as coniferous forests, alpine meadows, coastal rainforests, wetlands, boreal forests, and lower-elevation tundra areas. During the summer months, bears are found frequently at higher mountainous elevations. They are typically solitary year-round, except during mating season (Ward and Kynaston 1999). Black bears grow to between 1 to 2 m (3.3 – 6.6 ft) in length; adult females average between 40 and 70 kg (88 to 154 lbs) and adult males between 60 and 140 kg (132 to 309 lbs) (Pelton 2003).

Photo 13. Black bear in BIBE at Lost Mine Trail (Photo by Mindy Brooke Barker).

Black bears were once common in western Texas and the Chisos Mountains, but by the late 1940s, sightings became limited and their presence in the area became questionable (Borell and Bryant 1942, McIntyre 1999). Borell and Bryant (1942) speculated that domestic livestock grazing reduced cover and food sources that bears relied on in the Big Bend area. In the 1970s, reports of bear sightings in the area surfaced again, but many were between the Chisos Mountains and the Sierra del Carmen Range (Skiles 1995, McIntyre 1999). However, these sightings were likely of bears that traveled to the park from mountain ranges in Mexico (McIntyre 1999). In 1988, a park visitor photographed a sow and three cubs in the Chisos Mountains, and sightings became more frequent in the park throughout the 1980s (Skiles 1995).

The natural recolonization of black bears, which occurred in BIBE, is a rare event; Onorato et al. (2004, p. 140) states, “With ever-increasing anthropogenic fragmentation of wild habitats, unpredictable political policy making, and negative attitudes frequently associated with predators, it is imperative that researchers gain knowledge from recolonization events that did not require direct anthropogenic catalysts.” Recent research on the population in the park has focused on status, distribution, and food productivity (Hellgren 1991, Doan-Crider 1995, Vose 2001, Doan-Crider 2001, Hellgren et al. 2004), as well as genetics (Onorato et al. 2004, Onorato et al. 2007) and habitat suitability assessment (Rice et al. 2008).

4.7.2 Measures

- Population size
- Quality of mast production
- Regional population size
- Genetic conservation

4.7.3 Reference Conditions/Values

The reference condition for the black bear population in the park is the intact regional population that existed in the late-19th and early-20th centuries. Bailey (1905) described black bears as common in the upper canyons of the Chisos Mountains in 1901, with many fresh tracks from all ages and of older evidence indicating bears used the area. Bailey (1905) also found abundant bear sign in the Davis Mountains along the east slope of Mount Livermore in both 1901 and 1902. No numerical description of the population at the turn of the 19th century is available.

Raymond Skiles, BIBE Wildlife Biologist, provided additional interpretation of the reference condition for bears in the park (phone and email communications, 2011). Skiles indicated that in order to achieve the reference condition, all the components of the larger metapopulation would need to be reestablished. Currently, Mexico's Maderas del Carmen range is the primary source population for bears in the park. During the reference period, it is likely that several other mountain ranges in the region (outside the park) supported source populations for BIBE, including but not limited to the Davis Mountains to the north, and Mexico's Sierra Rica and Sierra del Pino, along with populations known to have existed in the lower Pecos river basin and the Texas Hill Country.

4.7.4 Data and Methods

NPS staff provided a majority of the data and literature used in this assessment, including the bear observation database managed by park staff (NPS 2012). Multiple literature sources provided information for all measures; descriptions of these sources and how each applies to current condition are found in the current condition sections below. The bear observation database was queried and relevant data are presented in the population size section.

4.7.5 Current Condition and Trend

Population Size

Hellgren et al. (2004) examined all bear sighting records in BIBE to understand the relationship between the park's population and the larger metapopulation. In total, 576 sightings occurred from 1901 to 2002. Multiple bear sighting within the same year occurred only four times prior to 1988. After 1988, records of bear family groups exist for every year. The records examined by Hellgren et al. (2004) indicate that the lowest number of females present in the park from 1988 to 2002 was six individuals.

In addition to examining sighting records, Hellgren et al. (2004) also trapped bears using barrel traps from October 1998 to August 2000. They defined two primary zones of interest: low-country (1,000-1,800 m [3,280-5,900 ft] elevation) and high-country (>1,800 m [5,900 ft] elevation). Efforts yielded 42 captures over 1,763 trapnights, a success rate of 2.4%. The bear population was highest in 2000, with at least 29 individuals present in the park (Hellgren et al. 2004). The overall population density in 2000 (23 individuals per 100 km^2 [38.6 mi^2]) was extremely low for a black bear population (Hellgren et al. 2004).

Survey data characterizing recent trends in bear population size are not available for BIBE. However, park visitors and staff continue to report bear sightings. Wildlife program staff compile that information into a database (Skiles, pers. communication, 2011). Following analysis of the park's bear observation database through 2004 (Hellgren et al. 2004), bear sightings per year have increased in the park (Table 27). In 2008 and 2009, the number of observed cubs and total observations were the highest since 2004, respectively. Skiles (pers. communication, 2011) indicated that the increase in bear observations, especially family groups and cubs, provides support for the hypothesis that bear populations are increasing in the BIBE area. However, other factors could be contributing to visitor observations, such as variable park visitation and variation in foraging behavior due to annual variety in timing and/or distribution of mast production.

Table 27. Yearly bear observations in BIBE for all ages and cubs (NPS 2012).

	All ages				Cubs			
Year	**Individuals**	**Pairs**	**Groups**	**Total**	**Individuals**	**Pairs**	**Groups**	**Total**
2005	117	7	0	131	4	2	0	8
2006	177	39	179	878	38	103	77	478
2007	171	23	31	322	28	22	9	99
2008	315	29	133	899	28	74	107	558
2009	406	65	135	1046	48	46	40	273
2010	136	26	36	326	27	7	27	124

Quality of Mast Production

Mast is the fruit from trees that provides a food source for animals. In BIBE, there are several mast-producing species of importance: Texas madrone (*Arbutus xalapensis*), weeping juniper (*Juniperus flaccida*), alligator juniper (*J. deppeana*), and nine oak species (Powell 1998, as cited by Onorato et al. 2003). Onorato et al. (2003) hypothesize that maintenance of low-elevation black bear populations in Texas depends on the production of the aforementioned mast sources in the fall. In the early 2000s, a possible mast failure was the likely cause of female bears dispersing from BIBE to Mexico in the fall (Onorato et al. 2004). To date, numerical data regarding mast production in the Chisos Mountains are unavailable. Because of the important role mast plays in determining habitat suitability in BIBE, a long-term study of mast production could inform the understanding of bear movements to and from the park (Mitchell et al. 2005).

Regional Population Size

The black bear metapopulation that encompasses BIBE and the surrounding area is difficult to understand because of the fragmented population and unusually large spatial extent (Hellgren et al. 2004). Hellgren et al. (2004) explains that this metapopulation conforms to the "mainland-island metapopulation model" described by Hanski and Simberloff (1997). Simply, this model recognizes a large area of habitat that supports a sustaining population and provides a source for smaller areas of suitable habitat. The use of smaller habitats depends on the effective distance individuals can disperse from the source population (Hanski and Simberloff 1997). In the

Chihuahuan Desert, suitable bear habitat includes elevations greater than 1,500 m (4,900 ft) and forested woodlands. A possible source population for the Chisos Mountains is located in the Serranías del Burro range (larger than the Sierra del Carmen), which provides greater than 1,000 km^2 (380 mi^2) of suitable bear habitat (Doan-Crider and Hellgren 1996). Many different genetic analyses indicate that the population in BIBE is linked to populations in Mexico (Onorato et al. 2007).

Large distances separate suitable habitats for black bear in the Mexico-Texas metapopulation, which restricts gene flow into the Chisos Mountains' population and other small, isolated subpopulations. Doan-Crider and Hellgren (1996) examined the population of black bears in Serranías del Burro to gain insight into the hypothesis that the Sierra del Carmen range of Northern Mexico provided a source population for black bear populations in Texas. They acquired weighted density estimates in the Serranías del Burro, through methods established by Garshelis (1992), of 17 females per 100 km^2 (38.6 mi^2) and 18 males per 100 km^2 (38.6 mi^2) - an overall density of 35 bears per 100 km^2 (38.6 mi^2). Doan-Crider and Hellgren (1996) recognized that their estimates were in the upper end of the range of black bear estimates for North America, and likely greater than populations studied in similar habitats in Arizona, where studies used closed population estimation. In conclusion, Doan-Crider and Hellgren (1996, p. 406) state, "The high productivity, low mortality, and high density of the black bear population in the Serranías del Burro suggested that it may function as a reservoir from which black bears disperse into surrounding areas such as the Sierra del Carmen and the Big Bend Ecosystem."

The Texas Parks and Wildlife Department (TPWD) summarizes yearly observation reports of black bears in Texas, which provides an index for bear populations in the U.S. portion of the metapopulation that includes BIBE. TPWD receives reports of black bear observations from various sources, including from BIBE, over the course of a year and classifies the observations into three categories (TPWD 2011, p. 4):

> Class I: Bear in possession, seen, or tangible evidence documented by the investigator or bear observed by more than two reliable individuals.
>
> Class II: Detailed description of the event provided and observer seems reliable or is experienced in the outdoors and is accustomed to looking for details (i.e., biologist, trapper, birder, naturalist, hunter, etc.).
>
> Class III: Details of the observation are vague or inconsistent, or the observation has questionable accounts of details, or the description is not that of a bear.

TPWD (2011) summarizes black bear observation reports for the state of Texas from 1997 through 2011 (Table 28). TPWD (2011) reports bear observations yearly for four different regions (Plate 19). BIBE is located within administrative region 1 and accounts for a majority of the bear sightings in Texas each year. For bear observation reporting segments from 1997 to 2006 and 2009 to 2011 (the years when TPWD received data for BIBE), the average number of sightings was 225. During reporting segments 2009-2010 and 2010-2011, 386 and 424 bear sightings (not including bear sign) occurred specifically in BIBE, respectively.

Table 28. Summary of black bear sightings in Texas by the Texas Parks and Wildlife Department, Wildlife Division administrative region; 1 September to 31 August from 1997 to 2010 (TPWD 2011).

	Administrative Region							
	1							
Reporting Segment[a]	**BBNP[b]**	**GMNP[c]**	**BGWMA[d]**	**Other[e]**	**2**	**3**	**4**	**Total**
1997-1998	185	1	24	3	2	2	1	218
1998-1999	383	62	7	16	7	6	6	487
1999-2000	437	68	8	22	2	0	1	538
2000-2001	118	26	3	44	7	0	0	198
2001-2002	109	48	2	7	2	2	0	170
2002-2003	73[f]	4	4	14	7	1	7	110
2003-2004	79[f]	2	2	6	2	6	0	97
2004-2005	139[f]	2	2	5	1	3	2	154
2005-2006	149[f]	0	0	6	1	7	2	166
2006-2007	--[g]	3	0	8	4	6	3	22
2007-2008	--[g]	1	0	3	2	3	1	9
2008-2009	--[g]	0	[g]	3	5	5	1	14
2009-2010	386[f]	0	0	1	1	12	2	402
2010-2011	424	[g]	[g]	15	6	14	0	459
Totals	2482	217	52	153	49	67	26	3044

[a]Reporting segment = 1 September - 31 August

[b]BBNP = Big Bend National Park

[c]GMNP = Guadalupe Mountains National Park

[d]BGWMA = Black Gap Wildlife Management Area

[e]Other = portions of Region I outside BBNP, GMNP and BGWMA

[f]Represents bear sightings only, bear sign not reported

[g]Sighting data not received

Threats and Stressor Factors

Small, isolated populations of large carnivores in protected areas, such as black bears in BIBE, are inherently susceptible to multiple threats and stressors (Woodroffe and Ginsberg 1998). Woodroffe and Ginsberg (1998, p. 2,128) suggest, "… priority should be given to measures that seek to maximize reserve size or to mitigate carnivore persecution on reserve borders and in buffer zones." In the case of the BIBE black bear population, this could be difficult because the primary known source population is located in Mexico, making the U.S.-Mexico border a primary buffer zone. Therefore, consensual management goals for BIBE, Mexico, and other U.S. mountain ranges with potential for black bear restoration are an important aspect of managing the metapopulation as a whole. Development near the park, increased visitation, and proximity to urban landscapes are additional factors that park management described as potential stressors to the park's black bear population.

A concern regarding the long-term viability of the BIBE black bear population is climate change. In xeric environments in Florida, precipitation is a predominant determinant of acorn production, accounting for up to 74% of the variation in crop size (Abrahamson and Layne 2003). Brown et al. (1997) indicate that increases in winter precipitation from the 1970s through the 1990s produced a strong shift in animal species composition in the Chihuahuan Desert. On small study plots (50 x 50 m [98 x 98 ft]), Brown et al. (1997) determined that many once abundant animal species became locally extinct and that several other once rare species became more prolific. Shifts in species composition could alter food sources for black bear in BIBE and, therefore, alter population dynamics in the park. Due to the potential impacts of climate change, the CHDN is developing protocols for monitoring climate change that will take into account multiple biological Vital Signs (NPS 2010).

Data Needs/Gaps

There is currently not a scientifically valid black bear population monitoring strategy in place, other than the current visitor sightings reporting and analysis program. Thus, an economical, non-invasive monitoring strategy such as a hair trap and/or camera station monitoring program would be valuable. As mentioned previously, monitoring of mast production and the relationship to movements of black bears to and from the park would be beneficial to park management. In addition, a thorough examination of the park's bear observation database could yield valuable information regarding trends in the park's bear population. Skiles (pers. communication, 2011) noted that examining trends in observations during high visitor usage and determining estimates of family groups in the park are just a few of the potential projects that could expand knowledge of bears in BIBE.

Overall Condition

Population Size

The BIBE project team assigned the measure of population size a *Significance Level* of 3. Following the population study and survey by Hellgren et al. (2004), the prevalence of black bear sightings in the park increased compared to previous years. However, the cause for the increase in sightings is uncertain. Skiles (pers. communication, 2011) indicated that while an increasing population is likely, visitation changes and changes in mast distribution could contribute to sighting variability. Overall, uncertainty regarding the relationship of sightings to actual population size makes the *Condition Level* for this measure unknown.

Quality of Mast Production

The *Significance Level* of this measure is 3. The literature identifies mast production as a critical component of black bear population dynamics in BIBE. Mast production is a primary determinant of black bear distribution in the park, with shifts in production resulting in elevational movements of black bears. While numerical data do not exist for this measure, the recent long-term drought at BIBE is a cause for concern; the *Condition Level* of this measure is 3, indicating significant concern.

Regional Population Size

The *Significance Level* of this measure is 2. Hellgren et al. (2004) found that the BIBE black bear population depends on outside-park source populations to remain sustainable. While large source populations and suitable habitat have been documented in the Serranías del Burro and Sierra del Carmen of Mexico, annual data regarding the size of those populations are inconsistent. The reference condition for this component also recognizes that source populations once existed in other areas, such as the Sierra Rica, Sierra del Pino, Davis Mountains, and Pecos

River Valley. Population data for these areas are also minimal; TPWD (2011) indicates that 14 black bear sightings occurred in the Trans-Pecos area in 2011, compared to 1 in 2010. Due to the lack of data regarding the regional population, the *Condition Level* of this measure is unknown.

Genetic Conservation
The *Significance Level* of this measure is 1. Black bears in BIBE exhibit expected heterozygosity levels higher than levels exhibited in isolated populations (Onorato et al. 2007). This reinforces the hypothesis that periodic gene flow exists between the BIBE bear population and other regional populations (Onorato et al. 2007). Overall, the expected heterozygosity of the black bear population in BIBE is comparable to that of Canadian black bears and greater than isolated populations in the southeastern United States (Onorato et al. 2007). Given that a recent study (Onorato et al. 2007) did not explicitly identify abnormal genetic characteristics within the BIBE black bear population, the *Condition Level* for this measure is 0, of least concern.

Weighted Condition Score
The *Weighted Condition Score* for this component is unknown. Currently, enough data exist to define condition for two of the measures: quality of mast production and genetic conservation. The *Condition Level* of the two population measures is unknown. Even though some data exist for both population measures, long-term data that relate directly to the reference condition are not available. Future population surveys and in-depth analysis of trend count data could make condition more apparent in the future.

Black Bears

Measures	SL	CL
• Population size	3	n/a
• Quality of mast production	3	3
• Regional population size	2	n/a
• Genetic conservation	1	0

WCS = N/A

4.7.6 Sources of Expertise
Raymond Skiles, BIBE Wildlife Biologist

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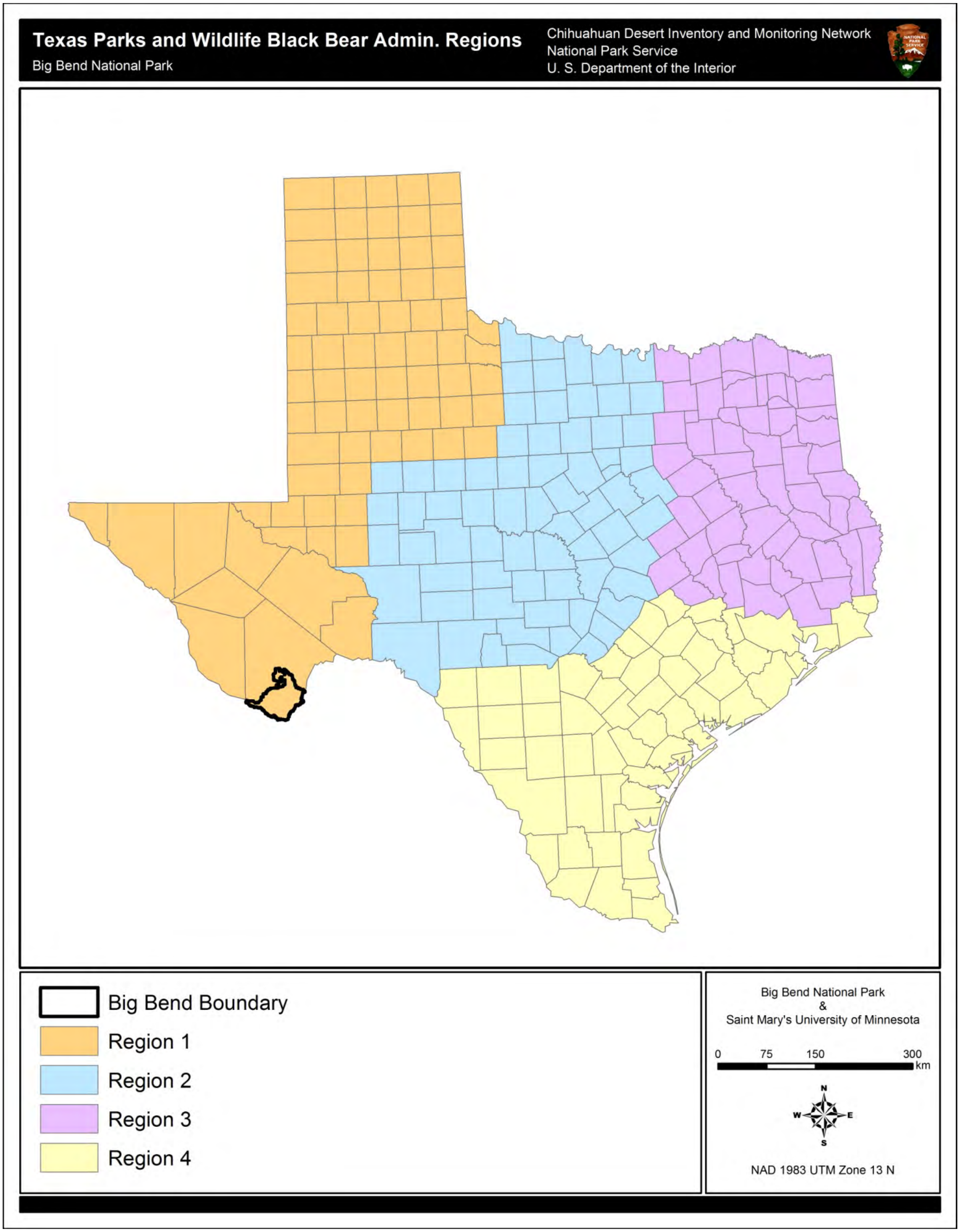

Plate 19. Texas Parks and Wildlife Department black bear administrative regions (Jonah Evans, TPWD Wildlide Diversity Biologist, pers. communication, 2011).

4.8 Mountain Lion

4.8.1 Description

Mountain lions (Photo 14) are native to the Chihuahuan Desert and have been documented in the area since at least 1929 (Borrell and Bryant 1942). The animal ranges through all five of the BIBE ecological communities (River Flood Plain, Shrub Desert, Sotol-Grassland, Woodland, and Montane Forest), and their highest population densities occur in the Chisos Mountains (Pence et al. 1986, McBride and Ruth 1988, NPS 2009). Mountain lions were once abundant in the area due to high historic ranching and livestock prey availability, which supported an abnormally high lion population (Skiles, pers. communication, 2012). Borrell and Bryant (1942) describe one rancher who claimed to have killed 55 “panthers” (a common local name for the mountain lion) between 1929 and 1937. In the early 20^{th} century, ranchers frequently hunted mountain lions because the species killed livestock (Borell and Bryant 1942, McBride and Ruth 1988). In 1984, the park population consisted of about 30 individuals, while in 1985 the population was estimated between 20 and 25 individuals (Pence et al. 1986, Ruth 1991).

Photo 14. Mountain lion in Big Bend National Park (Photo by Reine Wonite, NPS).

Pence et al. (1986) and Pittman et al. (1999) determined that lions in the BIBE area feed predominantly on deer and javelina (also referred to as collared peccary). However, mountain lions are opportunistic and also feed on species such as skunks (Mustelidae), rabbits (Leporidae), and porcupines (Erethizontidae) (Pence et al. 1986). Mountain lion populations generally exhibit low densities with relatively large home ranges. Although they are independent, and solitary creatures, NPS (2009) noted that sightings are relatively common throughout the Chisos mountains; over 2,700 sightings have been reported within the park since the 1950s (nearly 150 per year by visitors).

Mountain lions, and large carnivorous predators in general, are considered essential to ecosystem health, are aesthetically valuable, and are a staple of the BIBE landscape (Allen 1979, Ruth

1991). They are an important component of the park's biological diversity, as they function in balancing vegetation and herbivores, particularly keeping deer and collared peccary populations in check (NPS 2009). Upon creation of BIBE in 1944, the NPS guidelines stated that "no predator, such as the panther, should be destroyed on account of its normal use of any other park animal unless that animal, such as the deer, is in danger of extinction" (Welsh 2002, p. 51).

4.8.2 Measures

- Population size
- Genetic conservation

4.8.3 Reference Conditions/Values

The ideal reference condition for BIBE mountain lions is pre-agricultural U.S./Mexico conditions, prior to establishment of an Anglo-presence in the area. As current available literature does not allow for direct comparison to this reference condition, common trends in data and literature determined overall condition.

4.8.4 Data and Methods

A few sources of information exist regarding mountain lion population size in BIBE from the past few decades. However, according to McBride and Ruth (1988, p. 1), "data on mountain lion numbers [are] scarce or subjective at best." Several mountain lion studies, including Pence et al. (1986), McBride and Ruth (1988), Waid (1990), and Ruth (1991), examined a variety of topics including population size, dynamics, impacts of development, and gene flow.

Borell and Bryant (1942) provided the first list of Big Bend area mammals, including documentation and first-hand accounts of mountain lion populations. A study by McBride (1976) documented populations of mountain lions both in and outside BIBE. In recent years, a complete mammal checklist has been maintained by the Big Bend Natural History Association in cooperation with the NPS (Big Bend Natural History Association 2000). The NPS Mammal Species List (NPS 2011) for BIBE is also available online.

Periodic studies of mountain lion populations were undertaken beginning in 1984 to the early 1990s. Monitoring techniques included relocating individuals, recording mate pairings, radio-collaring individuals, and plotting home ranges (NPS 1989). These monitoring surveys relied on land tracking, as well as bi-monthly overflights that located remaining collared mountain lions. In addition, park staff infrequently examined roads and washes to obtain information about the location of uncollared mountain lions (NPS 1989). The NPS also monitored deer and other prey species to observe changes in prey population dynamics and to estimate approximate prey population sizes. BIBE staff track mountain lion sightings and trends throughout the park using a "sightings" database, with sighting information dating back as early as 1945. The database is compiled using research and observation cards from visitors and park staff (Skiles pers. communication, 2012). Sighting locations are recorded along with date/time, number of lions, and incident status. Plate 20 displays recorded sighting from January 2011 through January 2012.

From 1984 to 1985, Pence et al. (1986) used track signs and radio telemetry to track and record a small number of mountain lion individuals in the park. Estimates of lion populations were based on collared individuals, tracks found in washes, and scat findings. Pence et al. (1986) also reported on lion movements, food habits, and overall population status. A 1988 study by McBride and Ruth (1988) documented mountain lion behavior in response to visitor use changes within BIBE. In this study, seven radio-collared mountain lions were observed and monitored around high-use areas, campgrounds, and several trail systems.

Ruth (1991) examined land use of 22 mountain lions in areas of high recreational development within BIBE. Monitoring of all mountain lions using the dense Chisos trail network took place in order to determine lion densities, movement patterns, and behavioral patterns. A study by Pittman et al. (1999) in nearby Big Bend Ranch State Park (BBRSP), located adjacent to BIBE to the northwest, captured 21 mountain lions and radio-collared 16 of them in order to determine population size, home ranges, and genetic composition. Although the two parks are managed very differently, management implications are relevant due to proximity and viable populations.

4.8.5 Current Condition and Trend

Population Size

Borell and Bryant (1942) noted that mountain lions were "abundant" in the area from the 1920s to the 1930s. More recent population estimates vary from year to year based on evidence such as sightings by park staff and visitors, or presence of tracks. Pence et al. (1986) conservatively estimated that the park contained 21 adult lions during 1984. From the same study the following year, the BIBE population of mountain lions was estimated at 15 (Pence et al. 1986). Pence et al. (1986) stated that the minimum number of adult mountain lions in BIBE from 1984-1986 was 15 to 30 individuals. In addition, Pence et al. (1986) stated that the population is apparently stable and does not need direct management action since the mountain lions are located in an ideal area, and are protected from hunting. It was recommended, however, that monitoring efforts continue in order to detect changes in overall population stability (Pence et al. 1986).

Because mountain lions exhibit such a large home range, many lions are often difficult to locate, may move about in secluded locations (NPS 1989), or travel in and out of the park (Pence et al. 1986, Ruth 1991). Lion sightings by visitors generally occur along roadways and higher-use trail areas; therefore, it is difficult to estimate population size from this information alone. According to the sightings database, 166 mountain lion sightings were reported from January 2011 through January 2012, with sightings relatively consistent in number and monthly and seasonal distribution (Plate 20). Ruth (1991) used data from 22 collared lions and noted that signs alluding to the presence of other lions were seldom found, suggesting fluctuating population sizes between 20 and 30 individuals. According to Russ (1992, as cited in Pittman et al. 1999, p. 2), mountain lion populations and sightings in western, central, and southern Texas seem to be increasing, although "this information alone does not produce accurate estimates of population densities and must be supported by research." Aside from the sightings documentation system and database, there is not currently a mountain lion monitoring program in place within the park. There have been no new population estimates within BIBE since the early 1990s.

Threats and Stressor Factors

Anthropogenic habitat alterations are the main threats and stressors affecting the mountain lion population in BIBE. Current drought cycle, along with the longer-term effects of climate change, increasing development in and around BIBE, urbanization and landscape modification, rising visitation rates, and agricultural predator-control practices in Texas all represent potential threats to the persistence of mountain lion populations, according to park staff.

Vrijenhoek (1989) and Ruth (1991) noted that BIBE may not be large enough to support a viable population of mountain lions if agricultural development results in physical barriers blocking access in and out of the park (i.e., decreased gene flow between separated, semi-isolated populations). The persistence of mountain lion populations outside of BIBE is essential in sustaining gene flow.

Climate change may have a longer-term effect on mountain lion populations, shifting their territories into more urban, high-density, human-occupied areas. Climate change could slowly change habitat (e.g., plants, prey species), making it less suitable and contributing additional stress to mountain lion populations. Ruth (1991) reports that female lions spent more time in human-use recreational areas during dry winter and spring seasons. Prey species that use the water and plants in the Chisos Basin area could also be affected by climate change, leading to decreased prey populations, in turn affecting mountain lion populations.

Increased park visitation rates may become an added stressor to the BIBE mountain lion population. Use of the high-density Chisos trail network has historically led to confrontations between park visitors and mountain lions (Ruth 1991). Ruth (1991) contends that many areas of high recreational development within BIBE overlap with essential mountain lion habitat, potentially resulting in attacks on visitors or pets. Mountain lion sightings enhance the recreational experience of park visitors, but can also result in conflicts when these sightings occur at close distances (Herrero 1985, as cited in Ruth 1991). McBride and Ruth (1988) also found that mountain lions often travel the dense Chisos trail network, although there was no correlation between the distance of mountain lions to trails and visitor trail usage. However, human activity periods often overlapped with lion hunting periods. McBride and Ruth (1988, p. 1) state that while joint management of wildlife and human use is an important facet of the NPS, "at times it seems that these two objectives are in direct conflict as it is difficult to protect the resource and maximize visitor use without having some degree of impact upon that resource."

While mountain lions within the BIBE boundaries are protected, populations outside of the park can be hunted, trapped, and otherwise killed without a permit (TPWD 2013). There are no hunting seasons, limits, or restrictions in Texas and also no requirement to report captured or killed lions (Skiles, pers. communication, 2012). Mountain lions are considered a nuisance species in the state and hunting or trapping permits allow citizens to kill mountain lions regardless of season, number killed, sex or age. These predator control practices are evident in BBRSP where 19 mountain lions were killed throughout or shortly following the Pittman et al. (1999) study. This practice has ultimately limited mountain lion populations in the areas surrounding BIBE due to high mortality rates.

<u>Data Needs/Gaps</u>

At the time of publication, there were no radio-collared lions within BIBE and the most recent population estimates are from the early 1990s. A park-wide count of mountain lions, as well as death records and immigration/emigration data, would be useful for future analyses; however, this may not be feasible or cost effective. An ongoing monitoring study and creation of a genetic database would help determine lineages and population health of BIBE mountain lions (Ruth

1991). In addition, radio-collar monitoring data could help predict denning periods, track dispersal ranges, and identify areas of consistent use, especially in relation to areas of high human recreational use. A monitoring program could provide baseline and long-term data that would show broader trends in populations more effectively than a short-term research study, which provides individual animal information during a given period of time (Ruth 1991). In any case, further studies may be needed in order to better evaluate mountain lion populations in BIBE and the surrounding areas.

Ruth (1991) suggests a species protection plan in order to maintain genetic variability, as the need for genetic research is evident. A study of reproduction rates, dispersal, immigration, home range usage, mating patterns, and genetic variability would assist in creating a better understanding of population genetics and range dynamics in BIBE; information from such a study would inform management decisions and resource condition assessments in the future.

Overall Condition

Population Size
The BIBE mountain lion population size measure was assigned a *Significance Level* of 3; however, this measure was not assigned a *Condition Level*. Based on the literature, BIBE seems to contain a sustainable population of mountain lions, although many population studies are now over 20 years old (Waid et al. 1985, Pence et al. 1986, Ruth 1991). Predator control practices on lands surrounding BIBE remain a concern. However, according to Pittman et al. (1999), the population in the Trans-Pecos region seems relatively stable and not in danger of depletion. Pence et al. (1986) also state that, as of 1985, the BIBE population is apparently stable and does not need direct management action. Raymond Skiles (pers. communication, 2012) noted that there are no recent population estimates, other than inferences that are supported by the sightings database. The current population within the park is likely very similar to pre-ranching populations and, though not as abundant, are stable and in balance with the natural prey base (Skiles, pers. communication, 2012).

Genetic Conservation
The BIBE genetic conservation measure was assigned a *Significance Level* of 1 by BIBE staff. However, a lack of data prevented the assignment of a *Condition Level* for this measure. Genetic conservation is important in maintaining biodiversity and overall health of mountain lion populations. Due to increased inbreeding levels, a subsequent decrease in genetic variability and gene flow could theoretically lead to reduced fitness and adaptability (Fergus 1991, Ruth 1991). Little information is available on the genetics of mountain lions in BIBE. Packard (1991) stated that the BIBE population of mountain lions may be vulnerable due to genetic isolation. According to Ruth (1991) there is immigration into BIBE, but it appears to be low. Little gene flow has been seen between populations both in and outside of BIBE. While perhaps not an immediate issue of concern, complete genetic isolation coupled with a reduction in vegetation or prey numbers could reduce population viability (Ruth 1991).

Weighted Condition Score
An overall *Weighted Condition Score* could not be calculated for the BIBE mountain lions component, as neither measure was assigned a *Condition Level*. The current status of this resource is therefore considered unknown.

Mountain Lion

Measures	SL	CL
• Population Size	3	n/a
• Genetic Conservation	1	n/a

WCS = N/A

4.8.6 Sources of Expertise

Raymond Skiles, BIBE Wildlife Biologist

4.8.7 Literature Cited

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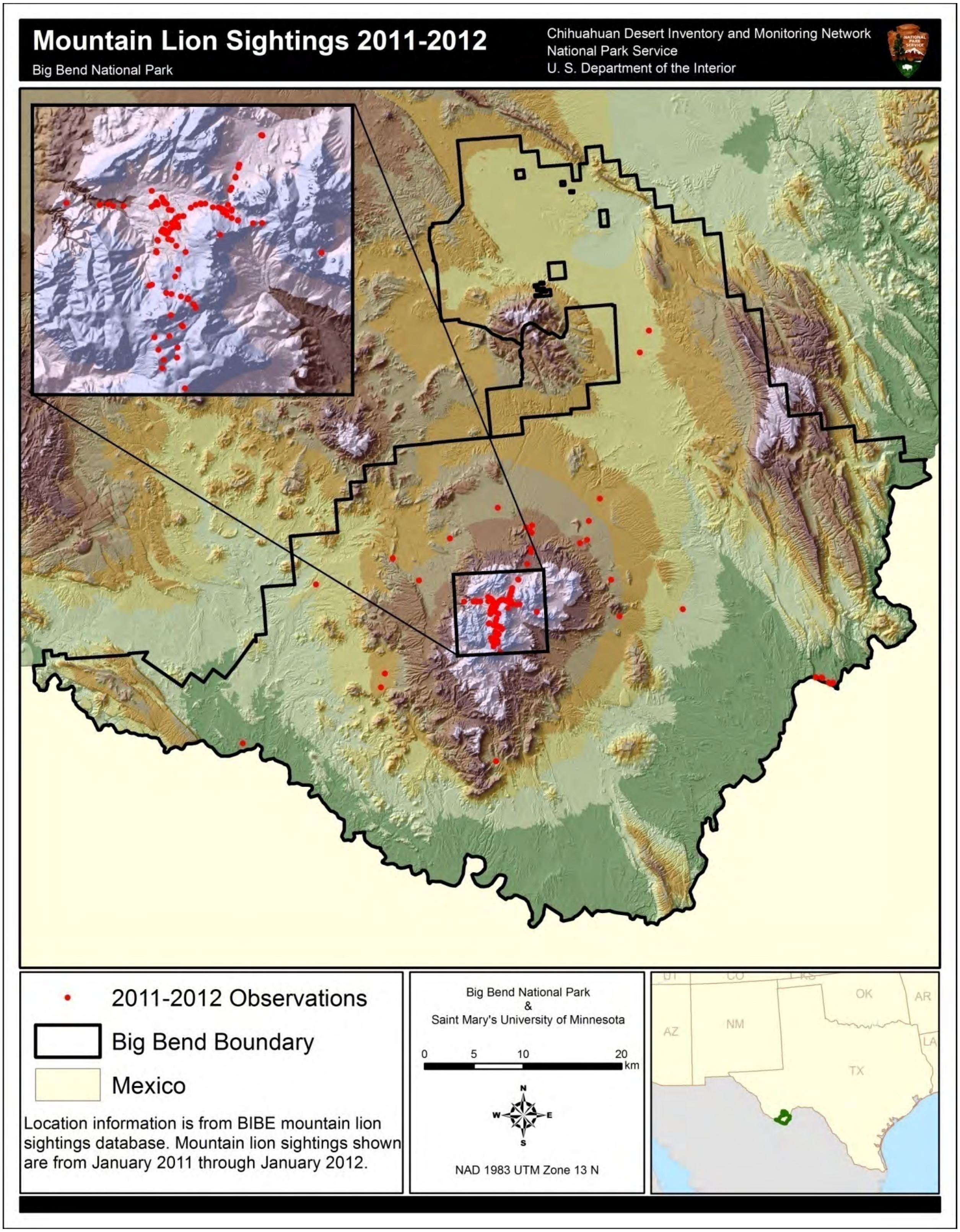

Plate 20. Mountain lion observations in BIBE, January 2011 - January 2012.

4.9 Desert Bighorn Sheep

4.9.1 Description

The desert bighorn sheep (Photo 15) is one of the smaller subspecies of the bighorn sheep (*Ovis canadensis*). Adult male desert bighorns average 68 kg (150 lbs) and adult females average 58 kg (128 lbs). Preferred habitat of the desert bighorn includes areas with adequate food sources, water availability, escape terrain, and open space away from human activity (Krausman et al. 1999, Krausman and Bowyer 2003, Young et al. 2006). Preferred browse includes shrubs and brush species such as cliffrose (*Cowania* spp.), black brush (*Coleogyne ramosissima*), and sagebrush (*Artemisia* spp.). Additional preferred foods include grasses such as wild rye (*Lolium* spp.), Indian ricegrass (*Oryzopsis hymenoides*), blue grass (*Poa* spp.), and fescue (Krausman and Bowyer 2003). Foraging activity and movements of the desert bighorn are nocturnal compared to other mountain sheep species, and this characteristic helps the sheep to avoid daytime desert heat and retain body water reserves (Krausman and Bowyer 2003).

Photo 15. Desert bighorn sheep (NPS Photo).

Desert bighorn sheep were historically present in the southwestern United States across New Mexico, Nevada, Arizona, west Texas, southern California, and northwestern Mexico (Krausman and Bowyer 2003). The desert bighorn has adapted to inhabit the arid, sparsely vegetated landscapes of these regions (Krausman et al. 1999). Desert bighorns still inhabit these regions where the habitat includes steep slopes, rocky outcrops, and cliffs, although in smaller, more isolated populations (Krausman and Bowyer 2003). Desert bighorns were extirpated from the Trans-Pecos region of Texas by overhunting and diseases transmitted by domestic livestock prior to the establishment of the park in 1944 (NPS 2006). Populations have established adjacent to BIBE, most notably the EMWMA and the BGWMA (Hernandez, pers. communication, 2011). Bighorn restored to BGWMA have ranged into the northern Deadhorse Mountains of BIBE since 1995. TPWD also began restoring bighorn to Big Bend Ranch State Park in 2010. South of BIBE, the CEMEX corporation has for a number of years conducted a program to restore bighorn to the Sierra del Carmen of Mexico's Maderas del Carmen protected area.

4.9.2 Measures

- Population size
- Barbary sheep distribution

4.9.3 Reference Conditions/Values

The reference condition for desert bighorn sheep are populations outside the park where the TPWD has restored bighorn sheep to near stable populations. These sites include the BGWMA, EMWMA, and BBRSP (Plate 21).

4.9.4 Data and Methods

Personal communications with Froylan Hernandez and Raymond Skiles provided a majority of the information on the current status of the desert bighorn sheep in the park. Froylan Hernandez also provided population survey numbers for the desert big horn sheep in the areas surrounding BIBE. Multiple literature sources provided information for all measures; descriptions of these sources and how each applies to current condition are found in the current condition sections below.

4.9.5 Current Condition and Trend

<u>Population Size</u>

The desert bighorn sheep is considered rare in BIBE; a single aerial survey in 2011 indicated the population was very small, numbering only five individuals (four rams and one ewe) (Hernandez, pers. communication, 2011; Skiles, pers. communication, 2011).

TPWD (2012) reported that over 1,115 free-ranging desert bighorn sheep inhabited Trans-Pecos Texas in 2010. Self-sustaining desert bighorn sheep populations currently inhabit the BGWMA and EMWMA (Table 29) (Hernandez, pers. communication, 2011). EMWMA sheep populations have shown a steady increase from 2002-2010 with a peak population of 167 individuals in 2010. BGWMA sheep populations also increased steadily from 2002-2008 with a peak population in 2008 of 151 individuals. Desert bighorn populations for both areas declined during the most recent 2011 survey. The EMWMA population decreased slightly to 144 sheep in 2011, but the BGWMA sheep population had a dramatic decrease to 43 individuals. A recent effort to restore desert bighorns to the BBRSP began in 2010 with the release of 30 sheep. The release marked the first time desert bighorns have inhabited the BBRSP area since the 1960s (Hernandez, pers. communication, 2011).

Table 29. Desert bighorn sheep populations in areas surrounding BIBE (Hernandez, pers. communication, 2011).

Year	Black Gap Wildlife Management Area	Elephant Mountain Wildlife Management Area	Big Bend Ranch State Park
2002	30	48*	N/A
2003	71	76*	N/A
2004	76	47*	N/A
2005	66	36*	N/A
2006	104	119	N/A
2007	138	131	N/A
2008	151	146	N/A
2009	95	159	N/A
2010	117	167	N/A
2011	43	144	30**

*count does not represent actual numbers; numbers are probably closer to 100+

**bighorns restored to BBRSP in Dec 2010; no bighorns inhabited these mountain ranges prior to 2010 since their extirpation in the early 1960s.

Barbary Sheep Distribution

Barbary sheep (also known as aoudad) are native to north Africa and were introduced to the United States in 1900. The TPWD introduced Barbary sheep to the Palo Duro Canyon (in the Texas Panhandle near the city of Amarillo) in 1956 and 1957 (Schmidly and Davis 2004). By 1984, the Barbary sheep population had reached approximately 5,000 individuals, and occurred across the trans-Pecos regions of Texas (Schmidly and Davis 2004). Young et al. (2006) reports that Barbary sheep are also located in the Chisos Mountains and throughout BIBE. Roemer and Schwenke (2003) add that these sheep have been present in BIBE for over 30 years. Barbary sheep herd sizes in BIBE are generally small and comprise less than five members. However, herds containing 20 individuals occur and cause over browsing and trampling of sensitive herbaceous vegetation (NPS 2006). The 2011 Barbary sheep population in the BIBE northern Deadhorse Mountains alone included 44 individuals (Hernandez, pers. communication, 2011). Aerial surveys have indicated a similar number occur in the southern Deadhorse mountains near Boquillas Canyon (Wick 2012). Data are limited regarding the population density and home range of Barbary sheep in other parts of BIBE, but home ranges in similar New Mexico landscapes average 4.5 to 6.5 km^2 (1.7 to 2.5 mi^2) (NPS 2006).

Threats and Stressor Factors

Disease from Domestic Sheep

Desert bighorn sheep are more susceptible to disease than other native large game species (TPWD 2010). Domestic sheep carry infectious diseases that can spread to desert bighorn sheep populations (Foreyt 1989, Callan et al. 1991). Pneumonia is the most common disease that domestic sheep pass to wild sheep; Monello et al. (2001) examined 174 bighorn sheep herds, 24 of which experienced population declines from pneumonia. Of the 24 populations examined by Monello et al. (2001), 21 (88%) suffered population declines within 3 years of a maximum population estimate, suggesting that density-dependent factors are at least partially responsible for increased vulnerability to pneumonia. In addition, proximity to domestic sheep populations also plays a factor in susceptibility to pneumonia contraction by desert bighorn sheep (Monello et al. 2001). Reducing the frequency and severity of disease outbreaks is a priority when restoring bighorn sheep populations. Monello et al. (2001) suggest that minimizing interactions between wild bighorn sheep and domestic sheep is important for limiting disease transfer and protecting wild bighorn sheep populations.

Habitat Alteration/Variability

Fire suppression, human recreation, mining, and synthetic barriers are all factors that alter or change habitat use by desert bighorn sheep (TPWD 2010). Fire suppression has been implemented in the Trans-Pecos, including what is now BIBE for the past 100 years (TPWD 2010). Fire suppression has resulted in shrubs, pinyon-juniper stands, and other woody plants colonizing open habitat previously dominated by herbaceous plants that bighorn sheep utilized as food sources (TPWD 2010).

Mining near desert bighorn sheep habitat may cause the abandonment of the area, which can be particularly devastating if mining is conducted near lambing grounds or water sources (McQuivey 1978, as cited in TPWD 2010). Other barriers such as fences and highways restrict desert bighorn sheep movements or cause death from vehicle collisions (TPWD 2010).

Unpredictable precipitation across the desert bighorn's range causes fluctuations in the availability of vegetation from year to year. These fluctuations can cause nutritional stress, migrations, and the onset of disease (Krausman and Bowyer 2003).

Small Population Size

The small population size of desert bighorn sheep has led to an increase in inbreeding, a loss of genetic variability and fitness, and has led to local extinctions (Gilpin and Soule 1986, as cited by Fitzsimmons et al. 1995). Loss of fitness may stem from a presence of recessive alleles or loss of heterozygote advantage from inbreeding. Large horns, a trait of breeding superiority in desert bighorn sheep, have shown decreasing trends in size due to loss of genetic variability (Fitzsimmons et al. 1995).

Barbary Sheep (food/territory competition, diseases, social dominance)

Barbary sheep may limit the success of efforts to restore desert bighorn sheep populations. Barbary sheep are more versatile when selecting habitat than desert bighorn sheep, but their preferred habitats are almost identical (Young et al. 2006). Barbary sheep are primary competitors for forage and water resources with desert bighorn sheep and have been observed to be socially dominant at water sources (Simpson and Gray 1983, Mungall and Sheffield 1994, Cassinello 1998). Desert bighorn sheep can contract diseases from contact with Barbary sheep (Roemer and Schwenke 2003); Barbary sheep transmit pathogens directly through enzootics within their population, or indirectly as an intermediary to domestic herds (Callan et al. 1991, Richomme et al. 2005). Recurring disease outbreaks in desert bighorn sheep populations from exposure to Barbary sheep have even been reported in regions with high quality habitat (Andersen 2006). Andersen (2006) recommends translocations and evenly distributed desert bighorn sheep populations across the landscape to avoid the spread of disease.

Data Needs/Gaps

Studies of desert bighorn sheep densities and home range sizes in the park are lacking (NPS 2006). Data on the distribution of Barbary sheep in BIBE are limited, and there is a need for future population surveys (Roemer and Schwenke 2003). Social dominance and the spread of disease from Barbary sheep are suspected, but evidence is needed for validation (NPS 2006).

Overall Condition

Population Size

The BIBE project team assigned the measure of population size a *Significance Level* of 3. The most recent population survey in 2011 of desert bighorn sheep in BIBE found four rams and one ewe (Hernandez, pers. communication, 2011). Given the stressors and threats previously outlined for the desert bighorn sheep population in BIBE, the continuation of this small population is doubtful. Bighorn sheep have returned to near stable populations in BGWMA and EMWMA. However, the bighorn sheep population in BIBE is not stable or self-sustaining; the *Condition Level* for this measure is 3, of high concern.

Barbary Sheep Distribution

The *Significance Level* of this measure is 3. The literature defines the presence of Barbary sheep as a major threat to desert bighorn sheep populations where the two species intermix. The latest survey found 44 Barbary sheep in the northern portion of BIBE's Deadhorse Mountains alone. Barbary sheep are not as susceptible to diseases as desert bighorn sheep; however, they will readily transfer disease into desert bighorn sheep populations. Given the small population of desert bighorn sheep present in BIBE and the negative effect that interactions between the species have on desert bighorn sheep, the *Condition Level* for this measure is 3, of high concern.

Weighted Condition Score

The *Weighted Condition Score* for these measures is 1.0, indicating the condition of this component is of highest concern.

Desert Bighorn Sheep

Measures	SL	CL
• Population size	3	3
• Barbary sheep distribution	3	3

WCS = 1.00

4.9.6 Sources of Expertise

Froylan Hernandez, TPWD Desert Bighorn Sheep Program Leader

Raymond Skiles, BIBE Wildlife Biologist

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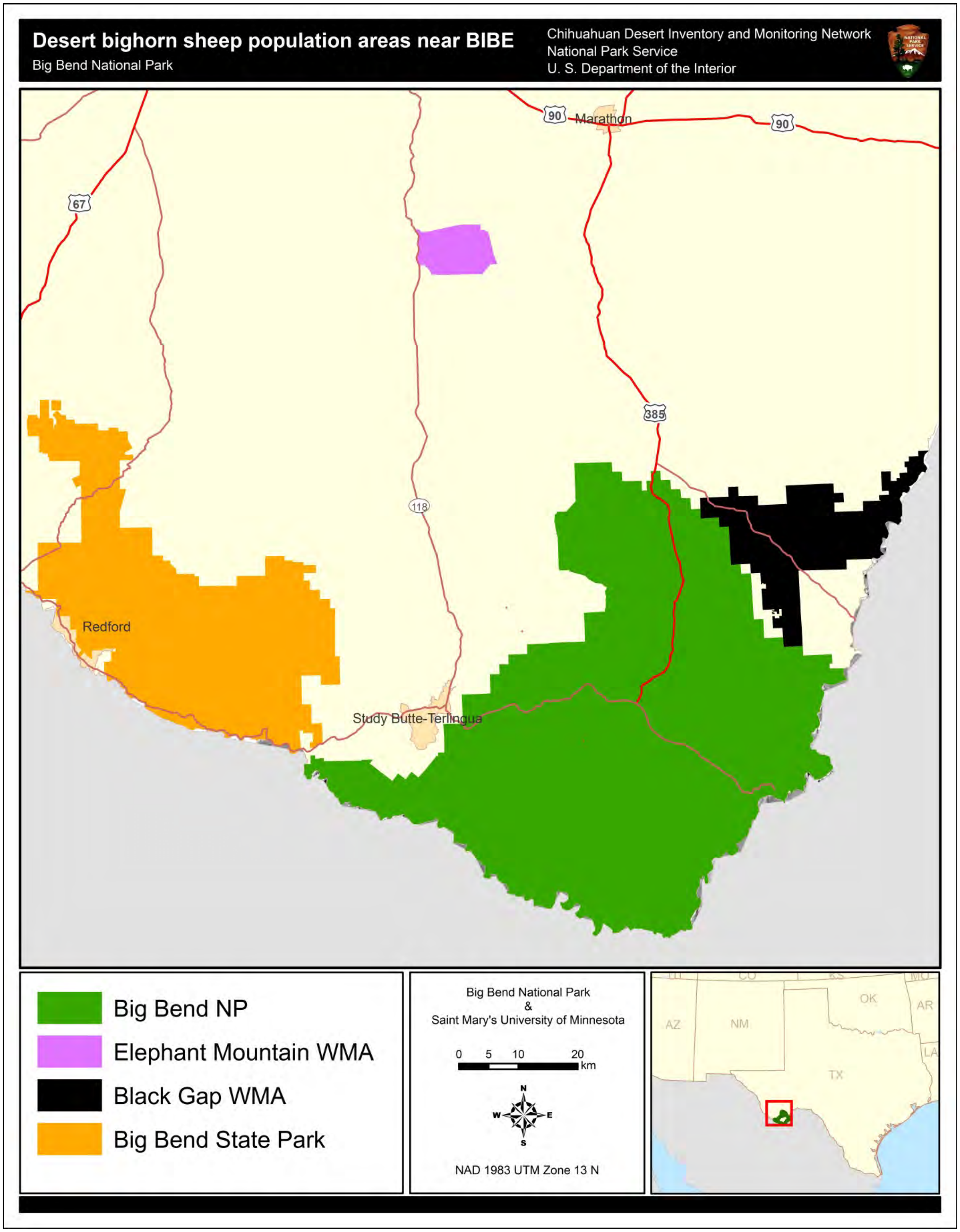


Plate 21. Desert bighorn sheep populations areas near BIBE.

4.10 Bats

4.10.1 Description

Over half of all bat species in the United States occur in the BIBE area (Bryan 1989). Bat populations are critically important indicators of an ecosystem's overall health; they contribute to an ecosystem's biodiversity, possess ecological and economic value as ecosystem components, and are exceptionally vulnerable to rapid population declines (O'Shea et al. 2003). Bats to are vulnerable to population decline for several reasons, including:

- Bats typically exhibit low reproductive rates (females typically have just one young per year) (Mattson 1994);

- Many species aggregate in large colonies, increasing their vulnerability to natural or anthropogenic disturbances while in their roost colonies (O'Shea et al. 2003).

The IUCN, the state of Texas, and the USFWS have designated the Mexican long-nosed bat, hereafter long-nosed bat, as an endangered species (USFWS 1994). This species requires several roost sites across the range of their seasonal movements, along with large areas hosting agave and night-blooming plants for foraging (USFWS 1994). In Mexico, many caves that once hosted large numbers of long-nosed bats now only host small colonies or are devoid of bats (Wilson 1985). In BIBE, long-nosed bats utilize Emory Cave as a roosting site during agave flowering. Since 1960, various parties have surveyed and researched long-nosed bats in Emory Cave.

4.10.2 Measures

- Species diversity

- Mexican long-nosed bat roosting colony size

- Paniculate *Agave* abundance

- Metapopulation size of Mexican long-nosed bat

4.10.3 Reference Conditions/Values

The reference condition for this component is pre-agricultural U.S./Mexico conditions. Data and literature available do not allow for comparison to this reference condition. Because of this, recent trends and interpretations available in data and literature determined the condition level for each measure.

4.10.4 Data and Methods

Published and unpublished literature provided by BIBE staff, and literature discovered through supplementary literature searches were primary sources of information for two measures: species diversity and long-nosed bat roosting colony size. BIBE staff provided *Agave* survey data from 1989-2011 in Microsoft Excel format, which were reorganized for display purposes. Park staff did not provide data or literature regarding metapopulation size of the long-nosed bat; an extensive literature search confirmed that no information exists.

4.10.5 Current Condition and Trend

Species Diversity

Bryan (1989) created a preliminary checklist of bat species present in BIBE (Table 30). Bryan (1989) designated the status of four species on his checklist as "hypothetical", indicating records of their occurrence in adjacent areas but not within park boundaries. In 1998, Higginbotham et al. (1999) confirmed one of the hypothetical species from Bryan's preliminary research (western yellow bat [*Lasiurus xanthinus*]) as present in the park through mist-netting and subsequent genetic testing. Today, the NPSpecies Certified Mammal List for BIBE recognizes 21 species as present in the park (NPS 2011, Table 31).

Table 30. Preliminary checklist of bat species in BIBE (Bryan 1989).

Common/Scientific Name	Status	Common/Scientific Name	Status
ghost-faced bat	Uncommon	hoary bat	Rare
Mormoops megalophylla		*Lasiurus cinereus*	
hog-nosed bat	Hypothetical	western yellow bat	Hypothetical
Choeronycteris mexicana		*Lasiurus ega*	
Mexican long-nosed bat	Endangered	canyon bat	Abundant
Leptonycteris nivalis		*Pipistrellus hesperus*	
Yuma myotis	Common	big brown bat	Uncommon
Myotis yumanensis		*Eptesicus fuscus*	
cave myotis	Common	spotted bat	Rare
Myotis velifer		*Euderma maculatum*	
Mexican long-eared myotis	Hypothetical	Townsend's big-eared bat	Common
Myotis auriculus		*Plecotus townsendii*	
fringed myotis	Common	pallid bat	Abundant
Myotis thysanodes		*Antrozous pallidus*	
long-legged myotis	Very Rare	Brazilian free-tailed bat	Abundant
Myotis volans		*Tadarida brasiliensis*	
California myotis	Rare	pocketed free-tailed bat	Uncommon
Myotis californicus		*Tadarida femorosacca*	
small-footed myotis	Very Rare	big free-tailed bat	Common
Myotis leibii		*Tadarida macrotis*	
silver-haired bat	Hypothetical	western mastiff bat	Uncommon
Lasionycteris noctivagans		*Eumops perotis*	
red bat	Very Rare		
Lasiurus borealis			

Table 31. Bat species recognized on the NPSpecies Certified Mammal List for BIBE as present.

Common Name	Scientific Name
big brown bat	*Eptesicus fuscus*
big free-tailed bat	*Nyctinomops macrotis*
Brazilian free-tailed bat	*Tadarida brasiliensis*
California myotis	*Myotis californicus*
cave myotis	*Myotis velifer*
eastern pipistrelle	*Pipistrellus subflavus*
fringed myotis	*Myotis thysanodes*
ghost-faced bat	*Mormoops megalophylla*
hoary bat	*Lasiurus cinereus*
long-legged myotis	*Myotis volans*
Mexican long-nosed bat	*Leptonycteris nivalis*
pallid bat	*Antrozous pallidus*
pocketed free-tailed bat	*Nyctinomops femorosaccus*
silver-haired bat	*Lasionycteris noctivagans*
spotted bat	*Euderma maculatum*
Townsend's big-eared bat	*Corynorhinus townsendii*
western bonneted bat	*Eumops perotis*
western pipistrelle	*Pipistrellus hesperus*
western small-footed myotis	*Myotis ciliolabrum*
western yellow bat	*Lasiurus xanthinus*
Yuma myotis	*Myotis yumanensis*

Higginbotham (1999) examined bat community structure within BIBE, sampling 17 sites within the park. Geographic location drives diversity in the park; BIBE lies within the northernmost ranges of many Neotropical bat species and within southernmost bounds of many desert bat species in the southwestern United States. BIBE also provides many types of vegetation associations and water sources, which contributes to the diversity of bats in the park. Higginbotham (1999, p. 77) concluded that "specific structural characteristics inherent to each study site undoubtedly play a large role in what bats are captured where, yet factors such as suitable roosting sites, water, climate, topology, vegetation, and prey preferences are probably also influencing the distribution of bat species in BBNP [BIBE]."

Mexican Long-Nosed Bat Roosting Colony Size

In 1937, Karl Schmidt provided the first account of long-nosed bats in Texas, from a cave on the west side of Mount Emory in BIBE (Borell and Bryant 1942). Prior to 2005, various researchers surveyed long-nosed bat populations in BIBE using various techniques, including mist-netting and visual counts. Easterla (1972) estimated that there were 10,650 bats in a single layer on the ceiling of Emory Cave in July 1967; this is the largest estimate to date. Howell (1988) estimated the population in Emory Cave to range between 5,240 and 6,630 individuals on 13-14 August 1988. Hollander (1991) estimated the population on 14-15 August 1990 to be less than 200 individuals in the main room of Emory Cave, but the author indicated that weather effects may have resulted in bats utilizing other areas of the cave during the survey.

After studying a site in Emory Cave in 2005, Ammerman et al. (2009) concluded that infrared thermal imaging provides more accurate detection of long-nosed bats and provides many advantages compared to conventional surveying methods. Ammerman et al. (2009) used a thermal imagery camera to record bats exiting Emory Cave and then analyzed the recording manually. Long-nosed bats are distinguishable using infrared imagery because of the “massive musculature along the left and right humerus resulting in a glowing ‘T’ shaped thermal image” (Ammerman 2010, p. 3). The use of thermal imaging is also a less invasive method of surveying bats, compared to typical in-cave count methods. Following the initial use of thermal imagery to census Emory Cave bats in 2005, long-nosed bat surveys in 2008, 2009, and 2010 also incorporated infrared thermal imagery (Ammerman and Tabor 2008, Ammerman et al. 2009, Ammerman 2010). Mexican long-nosed bat colonies were also surveyed in 2011, 2012, and 2013; unfortunately, the data for these surveys were not available at the time of writing.

In 2005, Ammerman et al. (2009) recorded thermal imagery of bats entering and exiting Emory Cave following sunset for six nights (4, 5 June; 4, 5 July; 4, 5 August). Bats were most active during the 4, 5 July visit, when the net emergence for all species (*Corynorhinus* and *Leptonycteris*) was 3,517 and 3,385 individuals, respectively. The net emergence for the other four survey periods was less than 520 individuals for each recording period. The authors concluded that for June, the long-nosed bat population consisted of 326-380 individuals; for July, 2,742-2,874 individuals; and for August, at least 210 individuals.

In 2008, Ammerman and Tabor (2008) surveyed emerging bats at Emory Cave on 3, 4, and 5 July. The maximum emergence rate for all species combined was 48 bats per minute, which occurred on 4 July at 48 minutes after sunset. The peak emergence rate for long-nosed bats was 36 bats per minute on 3 July at 49 minutes after sunset. Both the peak values were a result of “bats circling at the cave entrance and re-entry was much higher on 3 July” (Ammerman and Tabor 2008, p. 4). The average number of bats emerging from the cave each night over the duration of the survey was 825, with a minimum of 259 long-nosed bats. The difference in number of bats between 2005 and 2008 is likely related to the abundance of *Agave*. In 2005, the BIBE *Agave* survey yielded 347 plants, whereas in 2008 only 92 plants were present.

In 2009, Ammerman (2009) documented abnormal nighttime emergence patterns compared to previous surveys. Ammerman (2009) performed emergence surveys for three nights: 3-5 July 2009. During these surveys, bats did not completely empty the cave; in past years, the emergence usually lasted 1.5 hours until the cave was near empty. Emergences in 2009 lasted more than 2.5 hours (longer than survey equipment allows for recording). The author attributed the anomaly to

> …the presence of a bright moon (waxing gibbous phase, full moon on 7 July 2009). It is well known that bats can exhibit lunar phobia and perhaps they were minimizing time away from the cave to avoid predation by nocturnal predators (such as owls) (Ammerman 2009, p. 3).

The longest documented period of emergence occurred on 5 July 2009, recording from 9:08 pm until 11:20 pm. Based on the total number of bats leaving the cave during the peak observed emergence on 5 July, Ammerman (2009) estimated that a minimum of 3,230 individuals were present in the cave.

During 2010 surveys, Ammerman (2010) concluded that rainfall from Hurricane Alex likely affected the results. On 30 June 2010, the hurricane hit land and rainfall affected the subsequent surveys that occurred from 3-5 July. On 3 July 2010, survey data were unattainable because the cave exit was "flanked by waterfalls" (Ammerman 2010, p. 3). On 4 July 2010, the waterfalls subsided some, but still flowed. On 5 July, the weather was warmer, partly cloudy, and very windy; the survey data from 5 July provided the estimate for 2010. Based on the survey data, Ammerman (2010) estimated that the long-nosed bat population was at least 1,780 individuals.

Paniculate *Agave* Abundance

Kuban (1989) found that in the northern half of the long-nosed bat's range, it relies on the nectar and pollen of *Agave*, and acts as a key pollinator of the species. Moreno-Valdez et al. (2004, p. 456) found that long-nosed bat density in El Infierno cave in Nuevo Leon, Mexico had a positive correlation with the "number of blooming *Agave* and ambient temperature." BIBE staff performs a yearly survey to determine the abundance of flowering *Agave* at three sites within the park: Green Gulch, Chisos Basin, and Oak Spring. The mean number of *Agave* per year at the Green Gulch and Chisos Basin sites are relatively similar: 151 and 156 plants, respectively (Table 32). The mean number of *Agave* per year at the Oak Spring site is 23 plants. A study of the relationship between number of bats in Emory Cave and the number of flowering *Agave* does not exist. However, Ammerman and Tabor (2008) suggest that the reduction in bat numbers in 2008, compared to 2005, is probably due to the lower number of *Agave* plants in 2008. Yearly, the total number of flowering *Agave* for all sites combined is quite variable (mean=331, st. dev.=210; Figure 43), but does not appear to be declining in recent history.

Table 32. Summary of *Agave* surveys in BIBE and number of bats present in Emory Cave, 1986-2011.

Year	Green Gulch	Chisos Basin	Oak Spring	Total	Emory Cave Bats
1986	145	193	67	405	Unknown
1987	191	177	38	406	Unknown
1988					5240-6630
1989	208	259	33	500	Unknown
1990	54	63	17	134	<200
1991	102	109	31	242	4289-5127
1992	29	57	13	99	5000
1993	124	153	10	287	3000
1994	108	201	24	333	0
1995	25	71	5	101	1000
1996	231	492	7	730	500
1997	21	81	12	114	Unknown
1998	50	71	2	123	Unknown
1999	203	291	19	513	2500
2000	2	49	4	55	371
2001	197	173	35	405	Unknown
2002	140	145	11	296	Unknown
2003	230	223	14	467	Unknown
2004	156	115	28	299	Unknown
2005	228	96	23	347	2800
2006	96	59	14	169	Unknown
2007	615	303	43	961	Unknown
2008	38	49	5	92	821
2009	265	61	39	365	3230
2010	232	249	52	533	1780
2011	97	155	39	291	Unknown
Mean	**151**	**156**	**23**	**331**	
Standard Deviation	**123**	**104**	**16**	**210**	

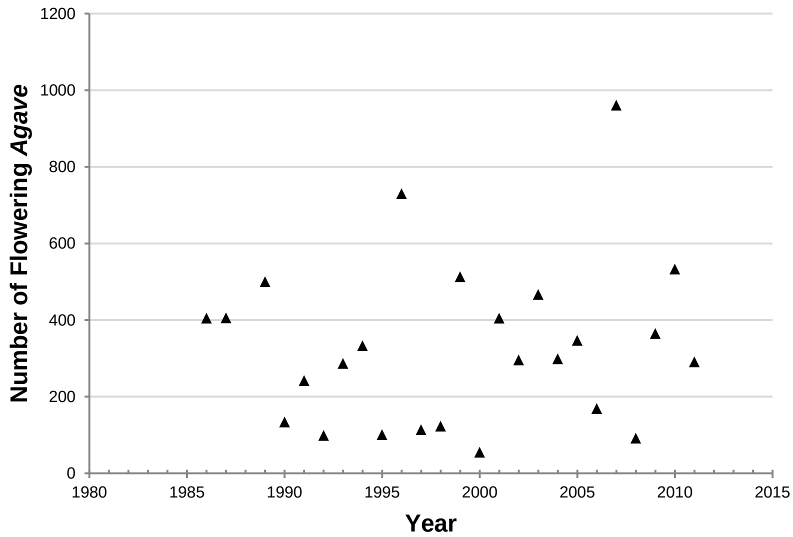


Figure 43. Total number of flowering *Agave* at Green Gulch, Chisos Basin, and Oak Spring survey sites in BIBE, 1986-2011.

Metapopulation Size of Mexican Long-nosed Bat Population

The metapopulation size for the long-nosed bat is currently unknown. An extensive literature search yielded no results for this topic. However, this species is listed as endangered because of the range-wide decline in population size (USFWS 1994), and in Mexico many caves that once held high numbers of long-nosed bats now have little or no bat utilization (Wilson 1985).

Threats and Stressor Factors

Because many bat species spend greater than half their lives roosting, exposure to different stimuli while roosting plays an important role in the ecology of bats (Kunz 1982). Due to the diversity in roosting habits, it is difficult to generalize roosting ecology for multiple species. Cave roost disturbance poses threats to colonially roosting species, such as the long-nosed bat, with roost destruction being the most harmful disturbance (Wilson 1985).

For long-nosed bats, extermination of the species in Mexico is a major concern. Citizens will destroy entire roosting populations, due to misidentification of this species as a vampire bat (Wilson 1985, USFWS 1994). This is a persistent problem and the general public often uses destructive control to exterminate the bats.

Data Needs/Gaps

Ammerman et al. (2009) suggests that continued monitoring of Emory Cave is important for developing a further understanding of the long-nosed bat:

> Future studies that incorporate surveys of flowering phenology of good plants, reliable cave censuses, assessments of sex and age structure, as well as the genetic composition of [Emory Cave and El Infierno Cave] are necessary to provide a

> greater understanding of the migratory habits and the role of Emory Cave in the life history of [long-nosed bats].

In addition, following the author's fourth bat survey in Emory Cave, Ammerman (2010) indicated that data from surveys conducted on 4 or 5 July 2007-2010 could be used as baseline data for trend examination in the future (note: exact dates that might be used in future surveys would be adjusted to meet changing environmental conditions or other factors). The author also suggests that as data continue to accumulate, researchers can begin to examine factors that are likely causing variation in observed long-nosed bats during surveys, such as weather or the prevalence of blooming *Agave* plants in BIBE and other locations long-nosed bats frequent.

<u>Overall Condition</u>

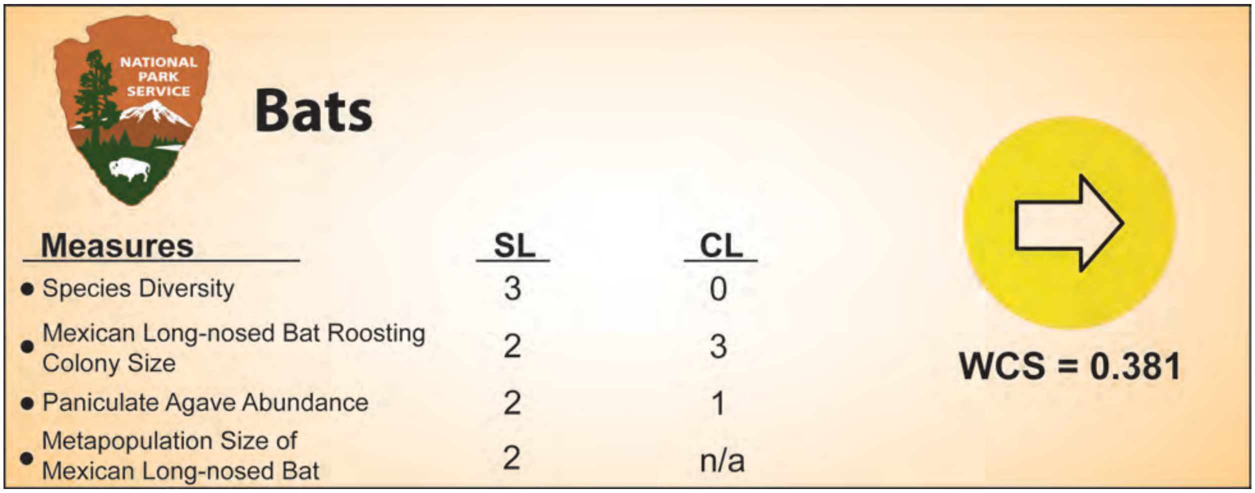
Species Diversity
The project team assigned the measure of species diversity a *Significance Level* of 3. There is no evidence that species diversity in the park is declining. Bryan (1989) compiled a list of known and probable species occurring in the park. Since that survey, additional bat species have been identified in BIBE. Higginbotham (1999) examined species diversity in the park and found that the diverse habitat and water sources, along with the location of the park make it suitable for many different species. Because of BIBE's large size and the protective characteristics associated with being designated a National Park, the *Condition Level* for this measure is 0 (low concern).

Mexican Long-Nosed Bat Roosting Colony Size
The *Significance Level* of this measure is 2. The first account of long-nosed bats in the BIBE area was in 1937 (Borell and Bryant 1942). Following the initial finding, various researchers have conducted multiple surveys through the present-day. Many of the surveys use different methodologies, which makes comparisons between them difficult, if not impossible. One account suggests that there were as many as 10,000 bats utilizing Emory Cave at one time (Easterla 1972). The four most recent surveys of the park (Ammerman and Tabor 2008, Ammerman 2009, Ammerman et al. 2009, and Ammerman 2010) utilized a standard methodology and, if continued, could provide valuable insight into the ecology of this endangered species. Currently, reasons for fluctuation in roosting colony size during early July are unknown, but the abundance of flowering *Agave* plants and weather are likely contributing factors (Ammerman 2010). Given the designation of this species as endangered by multiple agencies, and due to its range-wide decline in Mexico, the measure warrants a *Condition Level* of 3 (significant concern).

Paniculate Agave Abundance
This measure's *Significance Level* is 2. For the years data are available (1986-2011), there is no distinct trend in the number of *Agave* plants observed during surveys. It is unclear how many *Agave* plants used to be present prior to agriculture in the area. Even though there is not an obvious decline in numbers, this plant's importance as a food source for the endangered long-nosed bat warrants some concern. Therefore, a *Condition Level* of 1 (low concern) is assigned.

Metapopulation Size of Mexican Long-nosed Bat Population
Due to the limited data available for this measure (*Significance Level* of 2), *Condition Level* is unknown.

Weighted Condition Score
The *Weighted Condition Score* for bats is 0.381, indicating the condition is of moderate concern.



4.10.6 Sources of Expertise
Joe Sirotnak, BIBE Botanist/Ecologist

Raymond Skiles, BIBE Wildlife Biologist

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4.11 Aquatic Macroinvertebrates

4.11.1 Description

Aquatic macroinvertebrates are often used as biological indicators in assessing overall aquatic ecosystem health (EPA 1999, Baumgardner and Bowles 2005). Their presence or absence can reflect upon ecosystem health or disturbance and can be used to monitor effects of stressors (Moring 2002). Abundance and diversity of aquatic macroinvertebrates in aquatic systems is one of the CHDN Vital Signs chosen to represent the overall health and condition of the park's natural resources (Huff et al. 2006, Porter et al. 2009). Macroinvertebrate indicator species range from sensitive species, such as caddisflies (Trichoptera) (Photo 16) and Unionids (freshwater mussels of the family Unionidae, also known as naiads) (Photo 17) to the much more tolerant midge (Diptera) and aquatic worm (Oligochaeta) species.

Photo 16. Larval caddisfly (*Smicridea fasciatella*) (Department of the Interior Bureau of Reclamation photo).

Photo 17. Tampico pearlymussel (*Cyrtonaias tampicoensis*) (Texas Parks & Wildlife photo).

Macroinvertebrate distribution and abundance vary according to geographic and climatic constraints (Thorp and Covich 2001, Lencioni 2004), including water chemistry (toxic chemicals, pH), non-native species, anthropogenic disturbances, stream order (the Rio Grande is not a mountain or black water stream), and dissolved oxygen (DO), along with several others. Benthic macroinvertebrates are particularly sensitive to changes in their environment and will generally disappear if aquatic conditions deteriorate, leaving other, more tolerant organisms to replace them (EPA 2011). The EPA (2011) notes that macroinvertebrates are good indicators of overall system health because they:

- live in the water for all or most of their life;
- stay in areas suitable for their survival;
- are easy to collect;
- differ in their tolerance to amount and types of pollution;

- are easy to identify in a laboratory;
- often live for more than one year;
- have limited mobility;
- are integrators of environmental condition.

Macroinvertebrates often exist at greater densities and with greater diversity in clean, unpolluted waters. For example, caddisflies usually occur in areas of clean water, whereas aquatic worms are typically associated with poor water quality, although presence of a tolerant species does not necessarily mean that a water body has been degraded (EPA 2011). Evaluation usually takes place by measuring the numbers and species diversity of resident biota and integrating the chemical, physical, and biological stressor impacts on those organisms (EPA 2011).

According to Porter et al. (2009), taxa richness, defined as the number of unique taxa in a sample, represents an estimate of species diversity and relative abundance in a given sampled benthic community. E+T (Ephemeroptera [mayfly] and Trichoptera [caddisfly]) taxa richness estimates the number of "sensitive" organisms in a sample. This metric differs slightly from the common EPT (Ephemeroptera, Plecoptera [stonefly], Trichoptera) measure due to the absence of Plecoptera in BIBE streams. The only species of Plecoptera present in west Texas (*Isoperla jewetti*) is a relict population near El Paso, and is probably no longer present in that area (Baumgardner and Bowles 2005).

Generally, increases in taxa and E+T richness occur with water quality or habitat improvements (Porter et al. 2009). Benthic macroinvertebrates are simply a gauge of general aquatic system health and are not an absolute measure. More complex methods of analysis and decision-making to determine health of certain systems exist but tend to be more involved and expensive (EPA 2011).

Unionids have also been used as indicators of aquatic system health, despite having received very little attention from the scientific community and being severely undescribed or unreported in studies of the Rio Grande and its tributaries (Havlik and Marking 1987, as cited in Howells et al. 1996, Baumgardner and Bowles 2005). Richness, abundance, and distribution of these freshwater mussels can be an important water quality measurement and an evaluator of overall system health. For example, Unionids have been effective in monitoring levels of pesticides that would otherwise go unnoticed due to low concentrations (Howells et al. 1996). Baumgardner and Bowles (2005) explain that only cursory attempts have been made to document the aquatic invertebrates of the area and the need is clear for baseline reference material (Howells et al. 1996).

4.11.2 Measures

- Species richness
- Species abundance
- Species distribution

4.11.3 Reference Conditions/Values

The ideal reference condition for BIBE macroinvertebrates is pre-dam conditions on the upper Rio Grande. Dams and diversions have existed on the Rio Grande in some form for nearly 400 years, affecting macroinvertebrate densities and distributions. However, the Rio Grande Project which was an extensive network of dams and diversion canals (two large storage dams, 6 small diversion dams, two flood-control dams, 596 miles (959 km) of canals and their branches and 465 miles (748 km) of drainage channels and pipes.) in the upper Rio Grande Basin were largely built between 1905 and the early 1950's. No macroinvertebrate data exist from this time, and it is seemingly impossible to make direct comparisons to this time period as it may be impossible to accurately describe what conditions were like in the Rio Grande in the past 500 years.

Future analyses of the BIBE macroinvertebrate community could use the results obtained from Porter et al. (2009) as a baseline. Taxa richness and E+T richness are two quantifiable indices used to determine general macroinvertebrate species richness. Although these measures are variable in which different scales exist for differing geographic locations and taxonomic groups, the values give a range associated with overall system health (taxa richness in the Rio Grande ranging from 2 to 59 and E+T richness ranging from 0 to 18, based on the conclusions by Porter et al. [2009]). Future analyses of abundance and distribution could also use the results summarized here as reference conditions (see Moring 2002 and Porter et al. 2009).

4.11.4 Data and Methods

Macroinvertebrate data collections have been undertaken in the Rio Grande since the late 1970s, although with differing sampling methods, hydrologic conditions, study design, effort, etc. (Porter et al. 2009). In the Porter et al. (2009) study, samples were identified at differing taxonomic levels ranging from order to family, and/or genus. E+T richness, defined as the number of mayfly (Ephemeroptera) and caddisfly (Trichoptera) taxa were identified to family and/or genus. Porter et al. (2009, p. 5) also notes that, "differences in study design, location, collection methods, levels of taxonomic resolution (e.g., order/family compared with genus/species) confound analyses of stream condition, much less changes over time."

Historical macroinvertebrate data appeared in Davis (1980, as cited in Porter et al. 2009) from five sites along the Rio Grande both upstream and downstream from BIBE. These sites were sampled from 1976 to 1977:

1. Rio Grande near Presidio, Texas (upstream from Rio Conchos) – River kilometer 1551;
2. Rio Grande below Rio Conchos – River kilometer 1529;
3. Rio Grande at mouth of Santa Elena Canyon – River kilometer 1425;
4. Rio Grande at Foster Ranch, Texas – River kilometer 1058;
5. Rio Grande above Del Rio, Texas (below Amistad Reservoir) – River kilometer 920.

Irwin (1989) made collections of aquatic insect larvae in the BIBE extent of the Rio Grande with kick nets and seines in order to determine toxicity levels. Since the 1990s, sampling along the Rio Grande has been undertaken by the Texas Commission on Environmental Quality (TCEQ) (IWBC 2004), the USGS (Moring 2002), and graduate researchers (Ordonez 2005, Fordham

2008). Beginning in 1999, five study sites were established on the Rio Grande by the USGS to compile information on the status of benthic invertebrates (Moring 2002):

1. Colorado Canyon/Rio Grande at Colorado Canyon below Panther Creek, Big Bend Ranch State Park – River kilometer 1,468;
2. Santa Elena/Rio Grande below Santa Elena Canyon, BIBE – River kilometer 1,414;
3. Johnson Ranch/Rio Grande at Johnson Ranch, BIBE – River kilometer 1,377;
4. Boquillas/Rio Grande above Boquillas Canyon, BIBE – River kilometer 1,260;
5. Black Gap/Rio Grande below Maravillas Creek, Black Gap Wildlife Refuge – River kilometer 1,219.

Three of the five sampling sites were located within BIBE (Figure 44). In the Moring (2002) study, richest targeted habitat (RTH), qualitative multihabitat (QMH) and kick-seine sample types were collected at each of the five locations. A complete macroinvertebrate species list was compiled for the study area of the Rio Grande in and near BIBE (Appendix P).

Figure 44. Biological assessment sites in and near Big Bend National Park (Moring 2002).

Baumgardner and Bowles (2005) performed a survey of mayfly and caddisfly species in Big Bend Ranch State Park and BIBE, along with compiling data from past surveys to generate a complete list of Ephemeroptera and Trichoptera species in the park (Appendix Q).

Renfrow (2005) surveyed the Rio Grande between Lajitas and the Black Gap Wildlife Management Area's Taylor Farm site in order to identify native mussels, document their locations, and retrieve dead shells for preservation. Another study by Renfrow (unpub. data) was undertaken in 2008, downstream from BIBE at the Rio Grande Wild and Scenic River (WSR) segment of the Rio Grande, again documenting the presence and number of native freshwater mussels.

The Porter et al. (2009) study provided macroinvertebrate community information in the CHDN's major water resources. A significant analysis was done for BIBE based on the macroinvertebrate data available, compiling information from previous studies. The monitoring locations from Porter et al. (2009) can be found in Figure 45. Three of the sampling locations in BIBE were the same as those used in the Moring (2002) study.

Site	Site Name	River Km	TCEQ ID	USGS gage
A	Rio Grande near Presidio, TX (upstream from Rio Conchos)	1551	13230	08371500
B	Rio Grande below Rio Conchos	1529	13229	08374200
C	Rio Grande above Lajitas, TX	1464	18441	-------------
D	Rio Grande at mouth of Santa Elena Canyon[1]	1425	13228	-------------
E	Rio Grande at Johnson Ranch, TX[1]	1388	13227	08375000
F	Rio Grande above Boquillas Canyon	1260	--------	-------------
G	Rio Grande near LaLinda, MX[2]	1219	13225-6	-------------
H	Rio Grande at Foster Ranch, TX	1058	13223	08377200
I	Rio Grande above Del Rio, TX (below Amistad Reservoir)	920	13209	08450900

[1] Water-quality record for site D compiled from TCEQ 13227 (1968-76) + TCEQ 13228 (1974-2007)
[2] Water-quality record for site G compiled from TCEQ 13226 (1977-81) + TCEQ 13225 (1986-2007)

Figure 45. Location of surface water quality monitoring sites for which macroinvertebrate data was available along the Rio Grande in the Porter et al. (2009) study area. Reproduced from Porter et al. (2009).

Maher (2009) provides information on the occurrence and distribution of macroinvertebrates in springs found in western Texas, including seven springs in BIBE. Springs were sampled for macroinvertebrates from 2004 to 2007. Several water quality measurements were also taken at each location.

The park's mussel museum collection contains over 1,000 bivalve voucher shells from numerous locations of the Rio Grande in BIBE and Rio Grande WSR between Lajitas and the Dryden takeout. Collection dates range from mid-1998 to early-2005 and represent native mussel species Salina mucket (*Potamilus salinasensis*), Texas hornshell (*Popenaias popei*), and Tampico pearlymussel (*Cyrtonaias tampicoensis*). Most were collected systematically as part of extensive riverbank shell surveys conducted under NPS contract by Jeff Renfrow (documented in the online Interior Collection Management System).

4.11.5 Current Condition and Trend

Species Richness

Using the Benthic Macroinvertebrate Rapid Bioassessment Index of Biotic Integrity (BRBIBI), Rio Grande site scores in the Porter et al. (2009) study area were generally found to be in the "intermediate" aquatic life-use category. Aquatic life-use in the BIBE segment of the Rio Grande (2306) was designated by the TCEQ as "high", indicating that the designated use is not being met (IBWC 2004, Porter et al. 2009). The 2009 study also concluded that, based on data collected from the 1970s to the 1990s, "there is no compelling evidence to suggest that the condition of macroinvertebrate communities in the Rio Grande has changed appreciably" (Porter et al. 2009, p. 5).

Macroinvertebrate richness was studied in Tornillo Creek in the eastern portion of the park by Bane and Lind (1978). Taxa richness varied from 14 in the summer months to 39 in the fall months; during this time mean biomass varied significantly from 1.1 mg/m^2 to over 1,000 mg/m^2. The Terlingua Creek site, upstream from Rio Grande site TCEQ 13107 on the west side of the park, showed stressed conditions in which five taxa, including only one mayfly taxa, were reported in 1993 (Porter et al. 2009). According to Porter et al. (2009), most streams become stressed when there is no streamflow for substantial portions of the year, essentially "resetting" taxa richness since the previous zero-flow disturbances.

A study conducted by the TCEQ in 1998 found that taxa richness ranged from 10 (site A) to 14 (sites B and D) and E+T richness from 6 (A and C to I) to 7 (site B) (IBWC 2004, Porter et al. 2009; refer to Figure 45 for site locations). TCEQ data from other Rio Grande tributaries in the BIBE region showed taxa richness to be between 15 and 29, and E+T richness from 3-10 taxa (Porter et al. 2009).

Ninety-two benthic invertebrate species were identified within the Moring (2002) study area (see Figure 44). Eighteen of the taxa were non-insect, including worms (Oligochaeta), clams (Bivalvia), snails (Gastropoda), ostracods (Ostracoda), leeches (Hirudinea), mites (Acari), and flat worms (Turbellaria), with the remainder being aquatic insect species. Blackflies (*Simulium* and *Cnephia* spp.) constituted the dominant aquatic insect species along with various midge (Chironomidae) species. Resh and Rosenberg (1984, as cited in Moring 2002, p. 23) state that "midges often are the dominant aquatic-insect taxon in number of species, number of individuals, and in biomass in large rivers such as the Rio Grande."

The Baumgardner and Bowles (2005) study found sixteen species of mayflies (four families and twelve genera) and thirty-five species of caddisflies (seventeen genera and nine families) in the study area (Appendix Q). This study found a broad diversity of aquatic insects within the park and suggested a rich variety of aquatic invertebrate species. The highest species diversity was found in the Rio Grande, accounting for nine of the 16 species collected. A relatively low number of mayfly species were present in the Baumgardner and Bowles (2005) study, possibly due to the lack of suitable habitat. Baumgardner and Bowles (2005) also note that many spring-fed creeks provide necessary habitat to a variety of invertebrate species, although little research has been done to monitor or inventory these species. Caddisfly populations in BIBE were relatively diverse. Undersampling may have contributed to a slight underestimate of species numbers, as numerous smaller springs usually support smaller isolated populations of mayflies and caddisflies (Baumgardner and Bowles 2005).

Within the CHDN, macroinvertebrate numbers were dependent on the permanency of continuous stream flow, especially in smaller streams. Porter et al. (2009) reported that taxa richness in many intermittent BIBE streams was generally low, despite good water quality. Taxa richness in the Rio Grande at sites sampled by Porter et al. (2009) varied from 2 to 59. In the same study, E+T richness was found to range from 0 to 18. Median richness at sites A, D, and G were lowest of all nine sites (Figure 45). Both taxa and E+T richness improved downstream from study site A, perhaps because of the influence of the Rio Conchos (Porter et al. 2009). Porter et al. (2009) also reported a decrease in taxa and E+T richness at site D when compared with the 1976 and 1999 sampling efforts. Downstream from site D, taxa richness increased while E+T richness varied from constant to declining. Porter et al. (2009) speculate that increases in tolerant organisms are likely responsible for these trends rather than increased water quality, and that macroinvertebrate condition has not changed significantly since the 1976 study period. Figure 46 shows the results of the Porter et al. (2009) study compared to the studies of Davis (1980) and Moring (2002).

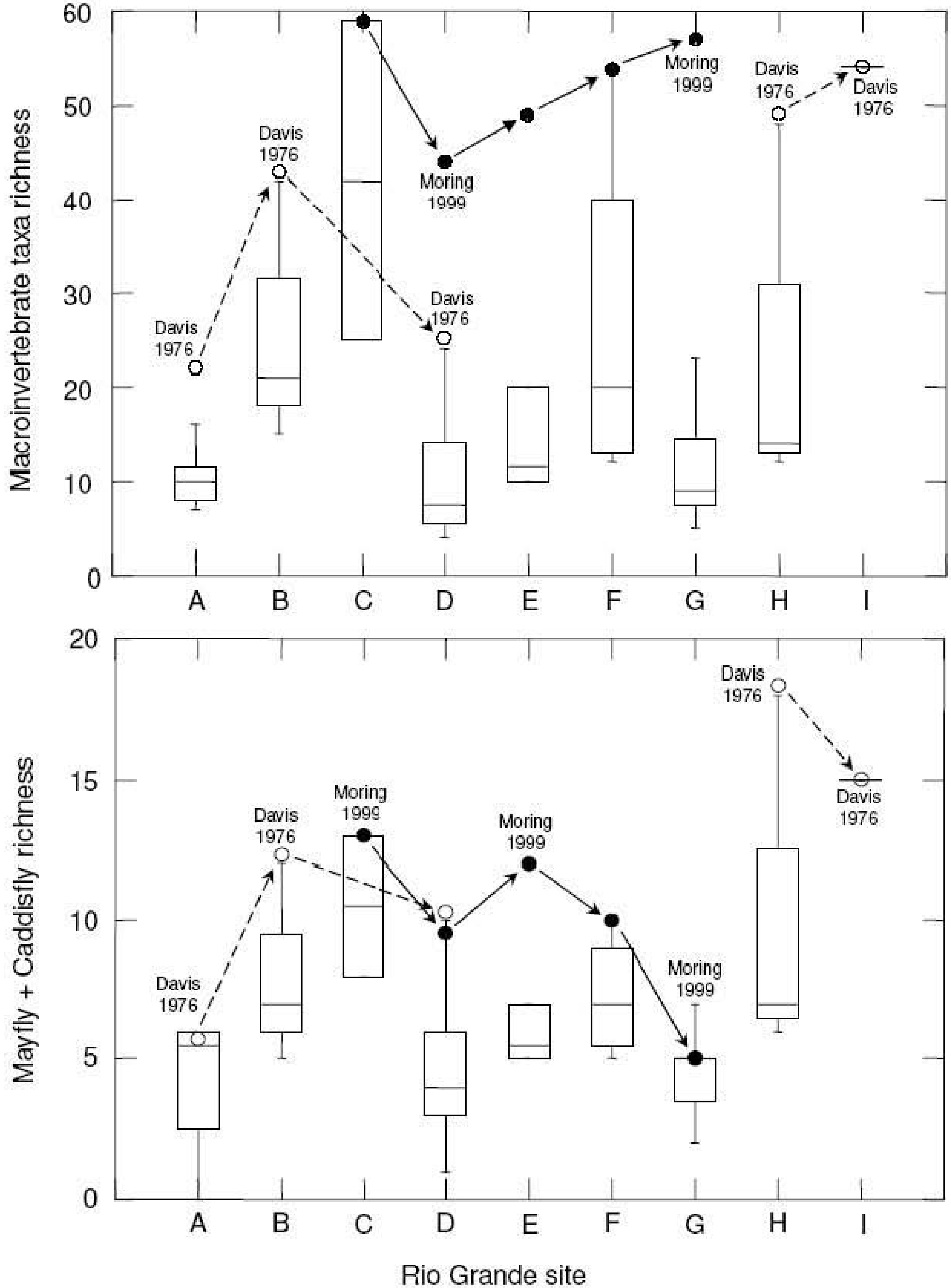

Figure 46. Macroinvertebrate taxa richness and E+T richness in the Rio Grande at nine sampling sites in and around Big Bend National Park. Also shown are results from prior 1976 (Davis 1980) and 1999 (Moring 2002) studies. Reproduced from Porter et al. (2009).

Some macroinvertebrate data are available for Alamito Creek near USGS gage 0837400 (below Rio Conchos but upstream of BIBE) with three samples from 1988-89 and one from 1993 (Porter et al. 2009). At this location, taxa richness varied from 4 to 5 and E+T richness ranged from 0 to 2 (Porter et al. 2009). Porter et al. (2009, p. 64) state that "macroinvertebrate richness metrics at these Rio Grande tributary sites suggest poor water quality and (or) habitat conditions (including lack of streamflow)."

Moring (2002) reveals that aquatic insects comprised over eighty percent of the total collected macroinvertebrate samples in or near the park and that blackflies were the most frequently collected taxon. Caddisflies were also common at most of the sample collection sites. The total number of taxa for each sampled location as found by Moring (2002) is shown in Figure 47.

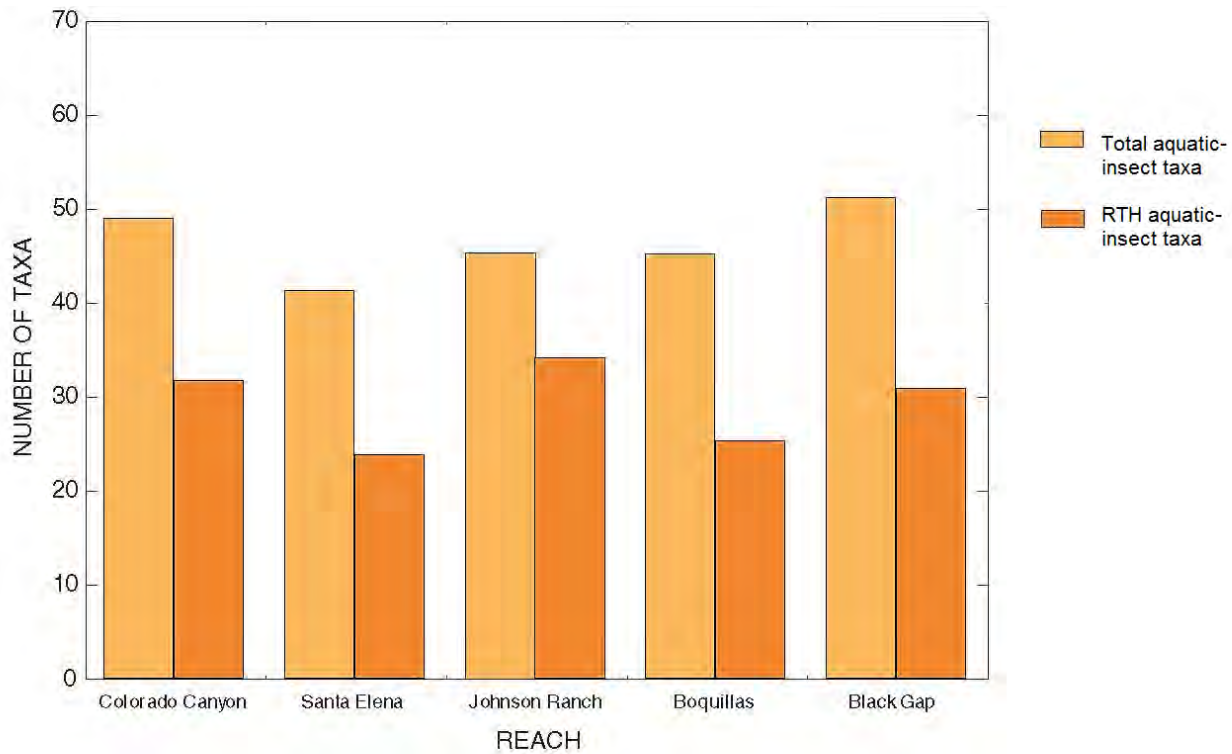

Figure 47. Comparison of total aquatic-insect taxa and richest targeted habitat (RTH) aquatic-insect taxa for five sample locations in and around Big Bend National Park (Moring 2002).

While species richness is the most basic measure of species biodiversity, there are several caveats associated with this measure. Since species richness is simply a count of the number of different species in a given area, the measure is dependent on sampling size as well as effort, possibly leading to sampling bias (Moring 2002). Moring (2002) uses a species index called Menhinick's diversity index which takes into account the total number of individuals in the sample (N) and the number of species recorded (S). The equation for Menhinick's diversity index is:

$$\text{Menhinick's diversity index } (D_{Mn}) = \frac{S}{\sqrt{N}}$$

Taxa richness using Menhinick's diversity index for the five sampling locations in and around BIBE from the Moring (2002) study is found in Figure 48. Figure 49 shows the number of aquatic-insect taxa versus number of individuals collected for the same five locations in the Moring (2002) study.

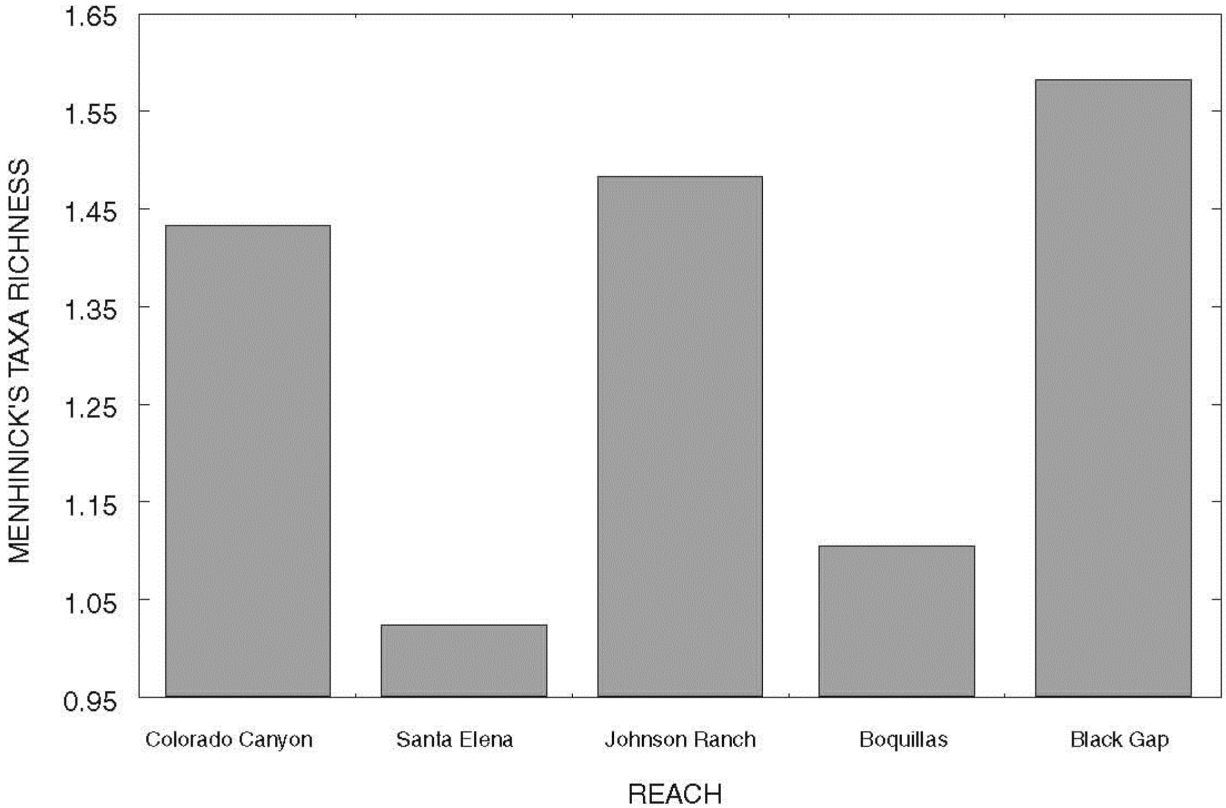

Figure 48. Menhinick's taxa richness for aquatic insects for five sample locations in and around Big Bend National Park. Reproduced from Moring (2002).

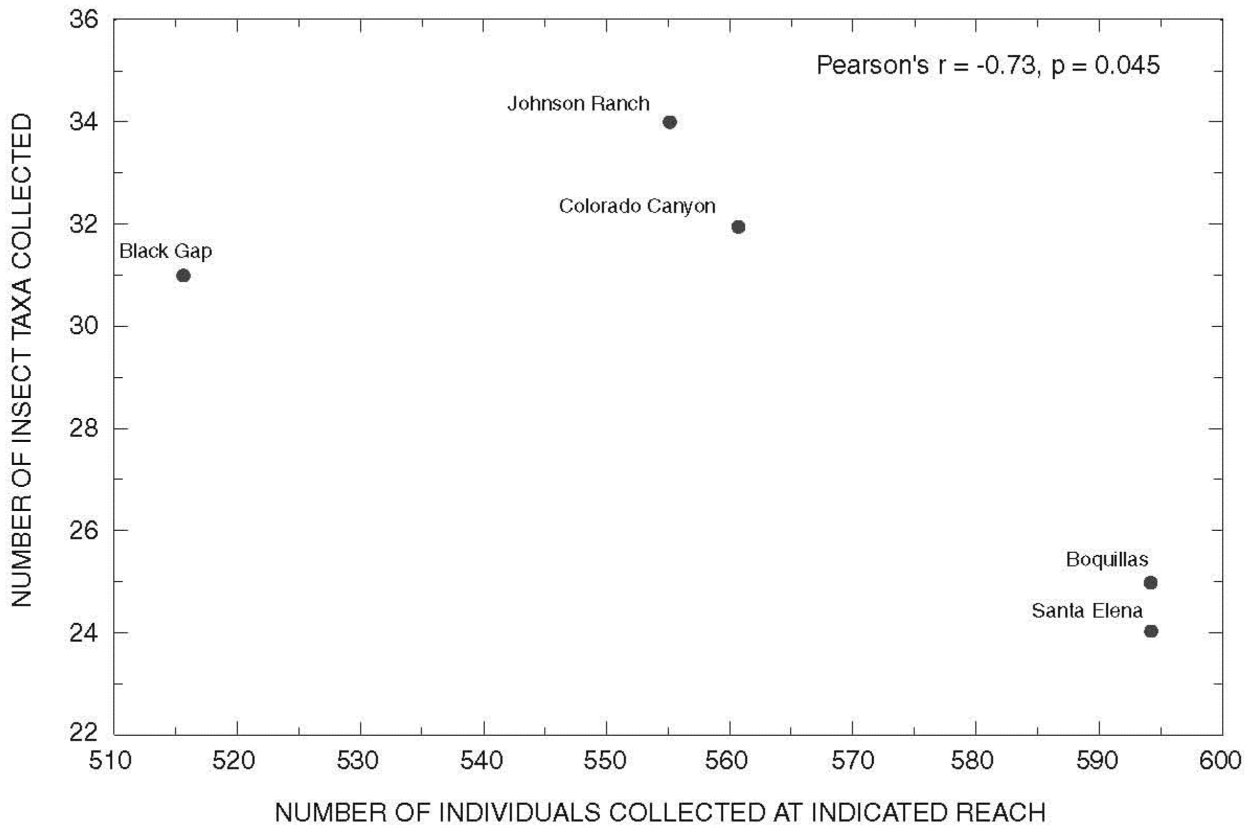

Figure 49. Number of aquatic-insect taxa versus number of individuals collected for richest targeted habitat (RTH) samples for five sample locations in and around Big Bend National Park. An “r” value of “1” in the Pearson’s correlation coefficient suggests that the X and Y correlation is perfect, whereas “-1” implies a decrease in Y as X increases. Reproduced from Moring (2002).

Information on macroinvertebrates in the park’s springs is limited. Maher (2009) sampled macroinvertebrates in 41 west Texas springs from 2004-2007, including seven springs in BIBE. The most common and diverse organisms across all sample sites were midges (Chironomidae) and mayflies (Baetidae), found at 88% and 83% of springs respectively (Maher 2009). Taxa richness for all the west Texas springs sampled averaged 22.6 (± 10.8). Richness values for each of the BIBE springs sampled are presented in Table 33, along with notable collections at several springs.

Table 33. Macroinvertebrate data for seven springs in Big Bend National Park sampled by Maher (2009).

Spring	# of samples	Taxa richness	Total macroinvertebrates	Notable collections
Oak	5	33	425	*Stygobromus (near limbus)* – significant range extension for taxon
Buttrill	7	32	840	Previously undescribed Trichopteran species of the *Marilia* genus
Burro	2	25	355	
Mule Ear	3	23	454	
Glenn	1	20	205	*Thiara granifera* – range extension for the species
Peña	3	19	393	Previously undescribed Trichopteran species of the *Marilia* genus
McKinney	1	12	120	

Species Abundance

Aquatic macroinvertebrate species abundance varies with seasonal changes, closely mirroring seasonal periods of low flow and corresponding water variables such as temperature, DO, and pH (Porter et al. 2009). Moring (2002) notes that very little data exist on macroinvertebrate abundance for the majority of the Rio Grande in BIBE. A cluster analysis based on macroinvertebrate absolute abundance data showed a similarity between communities in the Santa Elena and Black Gap regions (Figure 50). Moring (2002, p. 24) states that “Colorado Canyon, Santa Elena, Black Gap, and Johnson Ranch were more similar in aquatic-insect community structure than any one of these reaches was to Boquillas.” Midge abundance was found to be significantly lower at Boquillas Canyon.

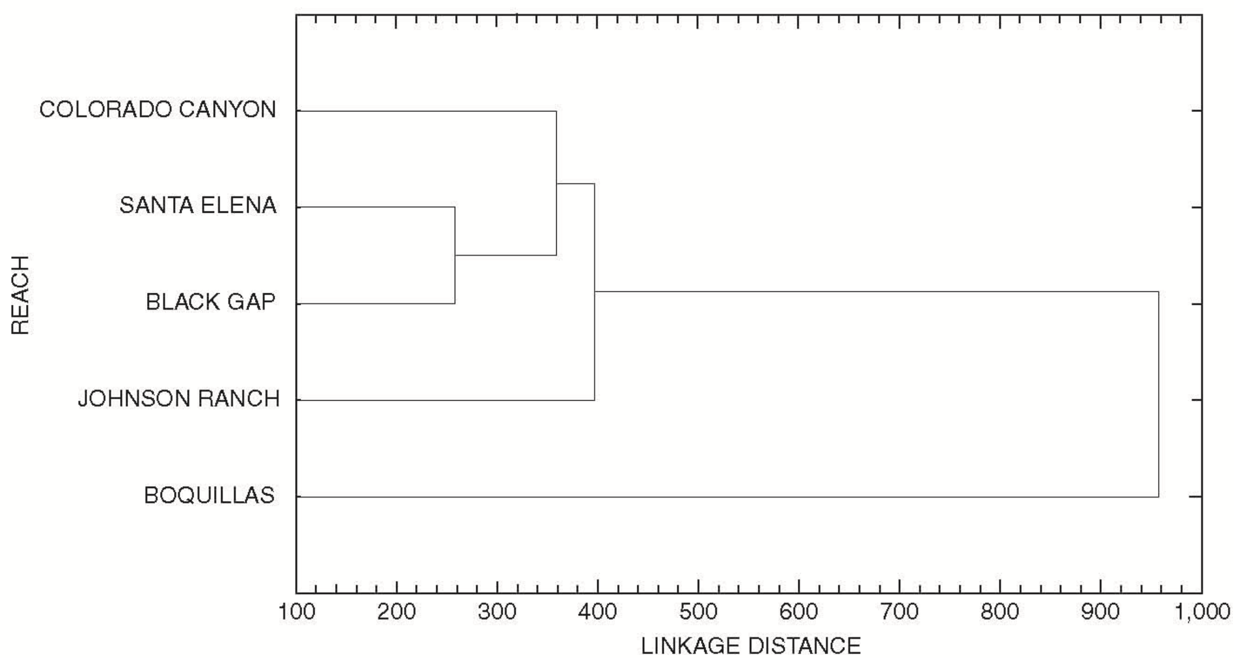

Figure 50. Similarity of benthic aquatic communities using cluster analysis for five sample locations in and around Big Bend National Park. Figure reproduced from Moring (2002).

Several Ephemeroptera species, such as *Callibaetis pictus* and *Thraulodes gonzalesi* were relatively common in the Baumgardner and Bowles (2005) study whereas Trichoptera species such as *Phylloicus aeneus* and *Nectopsyche gracilis* were poorly represented. The relative abundance of E+T are shown in Figure 51 and the relative abundance of major aquatic insect trophic groups found in BIBE are shown in Figure 52.

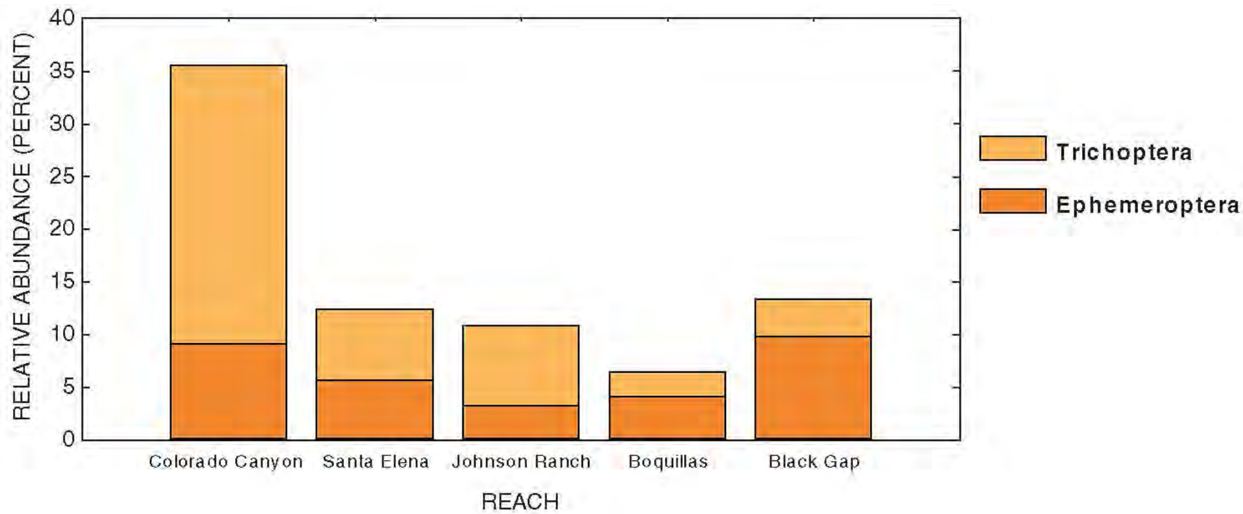

Figure 51. Relative abundance of Ephemeroptera and Trichoptera taxa for richest targeted habitat (RTH) samples for five sample locations in and around Big Bend National Park. Figure reproduced from Moring (2002).

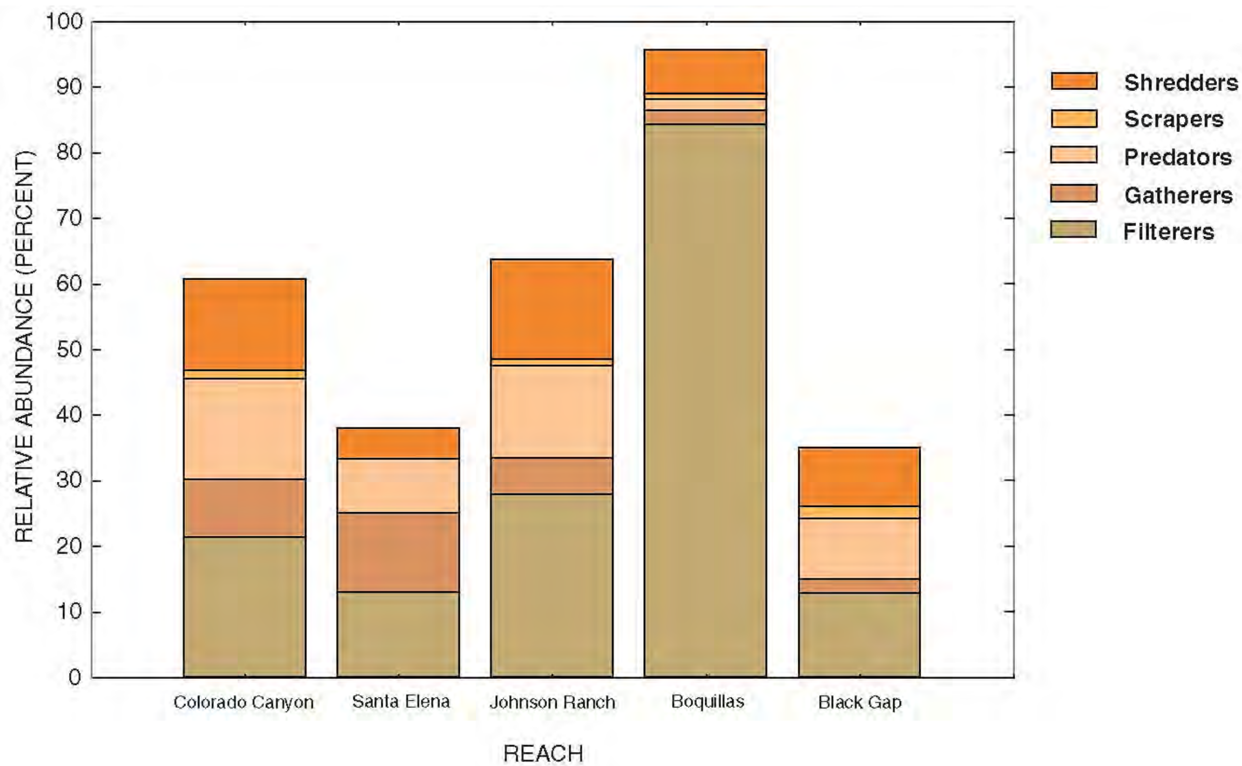

Figure 52. Relative abundance of major aquatic insect trophic groups for richest targeted habitat (RTH) samples for five sample locations in and around Big Bend National Park. Figure reproduced from Moring (2002).

According to the Renfrow (2005, p. 1) mussel survey, "diversity and abundance of mussel species increased from upstream to downstream." There was some variability in abundance numbers between locations; for example Lajitas and Cottonwood Campground sections reported no specimens collected and others, such as the Rio Grande Village, La Linda, and Taylor Farm sections, reported significantly higher numbers. Data on aquatic fauna in the BIBE region are sparse, but several studies have reported a loss of freshwater mussel species in perennial streams and rivers (Howells and Garrett 1995, Garrett and Edwards 2001 as cited by Maher 2009). The Renfrow (2005) study collected 46 salina muckets, 20 Tampico pearlymussels, two Texas hornshells and four unidentified shell fragments between 16 January 2004 and 27 May 2005. A May 2008 collection was also undertaken in the Rio Grande WSR in which over 500 mussels were collected and identified, including salina mucket, Tampico pearlymussel, and Texas hornshell. During the collection processes, non-native Asiatic clams (*Corbicula* sp.) were observed but not collected.

Howells et al. (1996) explain that the abundance of mussels in Texas has not been well-studied. They mention that abundance studies, for mussels especially, are all but non-existent. Furthermore, abundance estimates prior to commercial harvest are also unavailable (Howells et al. 1996). However, Howells et al. (1996) states that the future of this unique group of mollusks will remain in question, noting that as of 1996, nearly 50% of native mussels are presumed extinct, listed as threatened or endangered, or awaiting inclusion on that list.

Species Distribution

Distribution of macroinvertebrate species is varied throughout BIBE. According to Maher (2009), dispersal and distribution of invertebrates is greatly affected by topographic barriers. Therefore, distribution of macroinvertebrates in springs is dependent on several factors such as temperature and geographic isolation. Data on distribution of freshwater mussels in BIBE streams and the Rio Grande within the park are underreported or severely lacking (Howells et al. 1996). Howells et al. (1996) does not include much distributional data for western Texas or the BIBE portion of the Rio Grande, focusing mainly on eastern Texas and the lower Rio Grande.

According to several sources, macroinvertebrate populations and distributions are not clearly understood (Ordonez 2005, Baumgardner and Bowles 2005, Fordham 2008 as cited in Maher 2009). Most species distribution lists, including Howells et al. (1996), show presence of salina mucket, Tampico pearlymussel, yellow sandshell (*Lampsilis teres*), and Texas hornshell in the vicinity of BIBE. These mussels are generally scattered and sporadic and not randomly distributed (Howells et al. 1996).

Maher (2009) reported that an analysis of western Texas springs identified distinct groups of sites, varying in levels of conductance, alkalinity, elevation, and proximity to permanent water sources, which affect the distributions of aquatic macroinvertebrates. However, according to Baumgardner and Bowles (2005), the lack of macroinvertebrate distribution data for BIBE severely impedes further ecological investigations.

Threats and Stressor Factors

Several threats and stressor factors can potentially affect the richness, distribution, and abundance of macroinvertebrates. These include changes in water chemistry, toxins, non-native competitive species, stream channel characteristics, altered flow regimes, episodic oxygen deficiency, parasites, and diseases. Pollution, habitat alterations (e.g., dam building, urban development, waterway modifications), overharvesting, and exotic species introductions have all severely hurt native freshwater mussel populations (Howells and Garrett 1995).

Baumgardner and Bowles (2005, p. 2) state that "introductions of [non-native] species, water quality monitoring of pollution events, and other anthropogenic disturbances can be severely confounded by a paucity of aquatic invertebrate data." Asiatic clams are an invasive species that could greatly threaten the biodiversity and overall health of an aquatic ecosystem. The Asiatic clam is a filter feeder that is able to rapidly reproduce (sometimes by self-fertilization at different ploidy levels), and has a high tolerance of water temperatures (2-30°C [35.6-86°F]) (Qiu et al. 2001, USGS 2012). This species of clam was first observed in the United States in 1938 in Washington, and is currently distributed throughout 38 states (Counts 1986, USGS 2012). This non-native species may have the ability to disrupt natural processes and slowly force out or eliminate native mussels from the system, although there are no studies that explain the decline of native mussels in the Rio Grande. It is also hypothesized that an increase in Asiatic clams could potentially make native freshwater mussel species even more susceptible to parasites and diseases, although this is only speculation at this time.

Macroinvertebrates tend to be sensitive to water quality conditions such as DO, pH, water temperature, and sediment. These communities may become altered over time in response to land-use practices or climate change (Maher 2009). Channel narrowing and continually altered flow regimes in the Rio Grande and BIBE may eliminate much of the habitat necessary for these macroinvertebrates to survive. As suggested by Maher (2009), taxonomic composition of macroinvertebrate communities in springs is influenced by several factors such as ecoregion, differences in aquifer properties, differences in elevation, and distance of springs from permanent water sources. Modifications to these communities could lead to decreased aquatic insect and native freshwater mussel populations.

According to Porter et al. (2009), long periods of low flow throughout the year are the primary stressor to most BIBE streams, and, as previously mentioned, a complete lack of streamflow essentially eliminates taxa richness until flow is restored. Also, surface water pollution impairments, as found in Texas stream segment 2306, suggest chronic toxicity and high bacterial concentrations that are detrimental to aquatic organisms (Huff et al. 2006). The TCEQ states that local macroinvertebrate species richness is often influenced by ecological factors (McGinley 2010). The 2306 segment of the Rio Grande is on the 2010 TCEQ list of impaired water bodies for total dissolved solids (TDS) (first listed as impaired in 2010), chloride (first listed in 2010), sulfate (first listed in 2010), and bacteria (first listed as impaired in 1999) (TCEQ 2010).

Algae are the main food source for macroinvertebrates, especially mayflies and snails. Excessive algal growth or decomposition can adversely affect the balance of DO in the aquatic system (Porter et al. 2009). Porter et al. (2009, p. 47) note that "although algal-community data have not been reported for the Rio Grande, samples for phytoplankton chlorophyll *a* (CHLa), a photosynthetic pigment present in all algae and an indicator of eutrophication, have been collected since the 1970s and found to be representative of mesotrophic conditions at the majority of sampled sites." Huff et al. (2006) list excessive algal growth and high levels of chloride, sulfate, and dissolved solids as areas of concern in Texas stream segment 2306, which will continue to be worthy of future monitoring and analysis.

Irwin (1989) found that 67 harmful chemical compounds were present in 53 fish, turtle, aquatic insect, and sediment samples in the Rio Grande. Dichlorodiphenyldichloroethylene (DDE), a breakdown product of dichlorodiphenyltrichloroethane (DDT), was found in a sample of aquatic insects. Irwin (1989) postulates that aquatic insects may be one way DDE is biomagnified into the food chains of several predator species.

It has been suggested that DDT found in the Rio Grande originates primarily from Mexican sources. Irwin (1989, p. 22) indicates that "continued sale of DDT in Mexico, its use in farming upstream in Mexico, and the presence of a pesticide facility upstream on the Rio Conchos (near Delicas, Mexico) have all been suggested as potential sources of DDT and its breakdown product, DDE, in the Rio Grande." Furthermore, other complex mixtures of contaminants (e.g., raw or poorly treated sewage, industrial wastes) can be transported to the BIBE region during periods of high flow on the Rio Grande reach between El Paso, Texas and the park (Aim and Tomaso 1989a, 1989b, Irwin 1989).

Freshwater mussels typically undergo five life stages: 1) fertile and developing eggs retained in gill pouches, 2) glochidia (larval stage), 3) parasitic stage on fishes, 4) juveniles, and 5) adults (Howells et al. 1996). These mussels must have an available larval fish host during the development period of parasitism; therefore, reduction or extirpation of viable fish hosts is an important threat to mussel reproductive success.

Data Needs/Gaps

No macroinvertebrate data exist for either the Rio Grande or Rio Conchos prior to the first dam construction. Macroinvertebrate datasets were first collected in the late 1970s. These data were not available for all sample locations and are rather limited, incomplete, or unavailable in several CHDN parks. Furthermore, the TCEQ database also contains limited results concerning macroinvertebrates (Porter et al. 2009). While conclusions may still be drawn using available datasets and anecdotal observations, larger or more complete data would help in creating a clearer and more complete picture of BIBE macroinvertebrates.

For many available BIBE datasets, complex data were reduced to two metrics: number of taxa in a sample and the number of mayfly + caddisfly taxa in samples. As previously mentioned, differing sampling methods, hydrologic conditions, study design, taxonomic resolution, and effort caused discrepancies between datasets. Even water quality assessments based solely on these two metrics are not absolute and must be interpreted with caution (Porter et al. 2009). In their report, Porter et al. (2009, p. 61) recommend that the CHDN "consider a process for developing a high-quality macroinvertebrate database to document baseline aquatic-life conditions at sites associated with BIBE and the Rio Grande WSR segment of the Rio Grande. Study consistency and established inter-study "rules" would greatly help in the understanding of macroinvertebrate and aquatic habitat condition.

Baseline data on aquatic spring-inhabiting fauna are sparse, but several studies indicate losses of freshwater mussel species in regional rivers and streams (Bestgen and Platania 1988, Howells and Garrett 1995). Very little data exist for many of the BIBE Rio Grande tributaries and springs. Moring (2002) states that, as of 2002, there has not been a comprehensive characterization of the invertebrate communities in BIBE, and that no monitoring program is in place to observe changes in the invertebrate community. Baumgardner and Bowles (2005, p. 2) note that the lack of data on abundance and distribution of invertebrate groups "seriously impedes ecological investigations that could be used to support management decisions."

Overall Condition

Species Richness

A *Significance Level* of 3 and a *Condition Level* of 2 were assigned to the measure of macroinvertebrate species richness. This measure is currently of moderate concern to resource managers, showing pronounced signs of degradation. Relatively high numbers of macroinvertebrates were found in the Moring (2002) and Baumgardner and Bowles (2005) studies. However, BRBIBI scores were reported to be in the "intermediate" aquatic life-use range in the Porter et al. (2009) study, whereas TCEQ designated the area as "high", indicating that designated use standards for the Rio Grande segment 2306 are not being met (IBWC 2004).

Species Abundance

A *Significance Level* of 2 and a *Condition Level* of 1 were assigned to the measure of BIBE macroinvertebrate species abundance. This measure is currently of low concern to resource managers, showing slight signs of impairment and degradation. Howells et al. (1996) reports a decreased number of native freshwater mussels due to stressors such as dam creation and the introduction of invasive species like the zebra mussel (*Dreissena polymorpha*), and Renfrow (2005) did not collect any mussel specimens from Lajitas to the Cottonwood Campground during sampling in 2004-2005. Abundance numbers have significantly declined in recent decades and will likely continue to remain an important issue for resource managers in the future (Howells et al. 1996).

Species Distribution
A *Significance Level* of 3 was assigned to the species distribution measure; however, a *Condition Level* was not assigned to this measure. This measure cannot currently be evaluated due to a lack of information and available studies. While few studies have focused on taxa richness and abundance, even fewer have been undertaken concerning distribution of aquatic macroinvertebrates in BIBE or the Rio Grande. While some information exists, most is anecdotal and unquantifiable. Howells et al. (1996) noted that mussels are usually scattered and sporadic in certain areas rather than randomly distributed. Distributions in non-isolated communities will generally vary throughout the year depending on flow conditions and water chemistry.

Weighted Condition Score (WCS)
The overall *Weighted Condition Score* (WCS) for BIBE aquatic macroinvertebrates is 0.667, indicating that this resource is currently of high concern. A declining trend across the measures was assigned to this component.

Aquatic Macroinvertebrates

Measures	SL	CL
• Species Richness	3	2
• Species Abundance	2	2
• Species Distribution	3	N/A

WCS = 0.667

4.11.6 Sources of Expertise
Jeffery Bennett, BIBE Physical Scientist

4.11.7 Literature Cited

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4.12 Fish

4.12.1 Description

The fish community of BIBE is found primarily within the nearly 190 km (118 mi) of the Rio Grande, and in its two primary tributaries, Tornillo and Terlingua Creeks along the southern park border (NPS 2010a). Over 40 species of fish are found in BIBE, and the fish community is notably dominated by several minnow (Family Cyprinidae) species (Moring 2002). While most fish species are minnow-sized, larger fish such as the freshwater drum (*Aplodinotus grunniens*) and longnose gar (*Lepisosteus osseus*) occur in the Rio Grande, and several species of catfish (Order Siluriformes) attract fishermen to the area each year. The endemic Big Bend gambusia (Photo 18) is listed as a Federal and State endangered species (USFWS listing: March 11, 1967, TPWD 2012). Big Bend gambusia are found in only a few warm springs and spring-fed ponds in the park (Hubbs et al. 2008, NPS 2010a). It is a livebearing fish, approximately 30 mm long, that has been the focus of recovery efforts because of rapid population declines (Rio Grande Fishes Recovery Team 1984). Several fish species have been extirpated from the park; others, native to the park and region, have seen their natural ranges reduced due to factors such as reduced water quality, channelization of the Rio Grande, impoundments, and introductions of non-native species. Hubbs (1978, p. 363) notes that since water is such a limiting factor in the Chihuahuan Desert, "the well being of fish fauna may provide insight as to the fate of the entire biota." Edwards et al. (2002) further suggested that fish species in the mid-Rio Grande region could serve as biological indicators of environmental quality, and even provide baseline data for future scientific studies.

4.12.2 Measures

- Species diversity
- Big Bend gambusia population size

Photo 18. Big Bend gambusia (*Gambusia gaigei*) (USFWS photo).

4.12.3 Reference Conditions/Values

The reference condition for fish in BIBE is pre-dam conditions on the Rio Conchos and the upper-Rio Grande. This reference condition describes habitat status prior to the channelization of the Rio Grande and major hydrologic modifications, reduced streamflow due to irrigation, anthropogenic structures and diversions, extirpation of native fish species, and introductions of non-native species. Little information exists for the reference period, and direct comparisons may not be possible.

4.12.4 Data and Methods

Several studies and management plans by Hubbs (Hubbs 1963, Hubbs et al. 1977, Hubbs 1990) provided information on the history, status, conservation, and restoration efforts of the Big Bend gambusia since the mid-1950s. Hubbs et al. (2008) also provided voluminous fish voucher and sampling results for the Rio Grande.

Garrett (2002) sampled the fish population of the Rio Grande in BIBE between 1999 and 2000 at 43 sample locations. Garrett (2002) compared observed species to historical population studies to identify in ichthyofauna of the BIBE extent of the Rio Grande.

Moring (2002) sampled five sites on the Rio Grande in and near BIBE in 1999, documenting baseline stream habitat and fish community data. Moring (2005) again evaluated the status of the Rio Grande's fish community in BIBE between 2003 and 2004, following periods of low flow. Three river reaches sampled in 1999 were re-evaluated to detect measurable changes: Santa Elena, Boquillas Ranch, and Johnson Ranch (Moring 2005).

Bonner et al. (2005) examined and compared fish survey data from Independence Creek, Terrell County, Texas between three separate collection periods in order to determine change in fish diversity and assemblages over a large temporal scale.

The USFWS recovery plan for Big Bend gambusia provided information on gambusia and goals regarding the recovery of the species (Rio Grande Fishes Recovery Team 1984). Lastly, the NPS maintains a certified species list for all fish in the national parks including BIBE (NPS 2010b).

Hubbs et al. (2008) provides the most current checklist for freshwater fish in Texas. This document provides an updated list of families and species for the state, and is modified from previous work completed by Hubbs (1982) and Hubbs et al. (1991). The fish identified in the BIBE reach of the Rio Grande River are presented in Appendix R.

4.12.5 Current Condition and Trend

<u>Species Diversity</u>

There are a total of 41 documented fish species in BIBE (NPS 2010b). Table 34 displays all fish species that have been certified in BIBE (NPS 2010b).

Table 34. Certified species list for fish in BIBE (NPS 2010b).

Scientific Name	Common Name	Scientific Name	Common Name
Ameiurus natalis	yellow bullhead	*Lepisosteus osseus*	longnose gar
Aplodinotus grunniens	freshwater drum	*Lepomis cyanellus*	green sunfish
Astyanax mexicanus	Mexican tetra	*Lepomis gulosus*	warmouth
Campostoma ornatum	Mexican stoneroller	*Lepomis macrochirus*	bluegill
Carpiodes carpio	river carpsucker	*Lepomis megalotis*	longear sunfish
Cycleptus elongatus	blue sucker	*Lepomis microlophus*	redear sunfish
Cyprinella lutrensis	red shiner	*Macrhybopsis aestivalis*	speckled chub
Cyprinella venusta	blacktail shiner	*Menidia beryllina*	inland silverside
Cyprinus carpio	common carp	*Micropterus salmoides*	largemouth bass
Dorosoma cepedianum	gizzard shad	*Morone chrysops*	white bass
Dorosoma petenense	threadfin shad	*Moxostoma austrinum*	Mexican redhorse
Fundulus grandis	Gulf killifish	*Notropis braytoni*	Tamaulipas shiner
Fundulus zebrinus	plains killifish	*Notropis chihuahua*	Chihuahua shiner
Gambusia affinis	western mosquitofish	*Notropis jemezanus*	Rio Grande shiner
Gambusia gaigei	Big Bend gambusia	*Notropis stramineus*	sand shiner
Hybognathus amarus	Rio Grande silvery minnow	*Oreochromis aureus*	blue tilapia
Ictalurus furcatus	blue catfish	*Pimephales promelas*	fathead minnow
Ictalurus punctatus	channel catfish	*Pimephales vigilax*	bullhead minnow
Ictiobus bubalus	smallmouth buffalo	*Pylodictis olivaris*	flathead catfish
Ictiobus niger	black buffalo	*Rhinichthys cataractae*	longnose dace
Lepisosteus oculatus	spotted gar		

Moring (2002) found 18 fish species, a total of 474 individuals, within five sampled sites in 1999 (Figure 53); 348 of the 474 fish were minnow species. Diversity ranged between the five sites; 15 species (highest) were collected at the Santa Elena reach and nine (lowest) were collected at the Colorado Canyon and Johnson Ranch reaches (Moring 2002). Moring (2002) concluded that the Colorado Canyon fish community showed the greatest difference from the other four reaches.

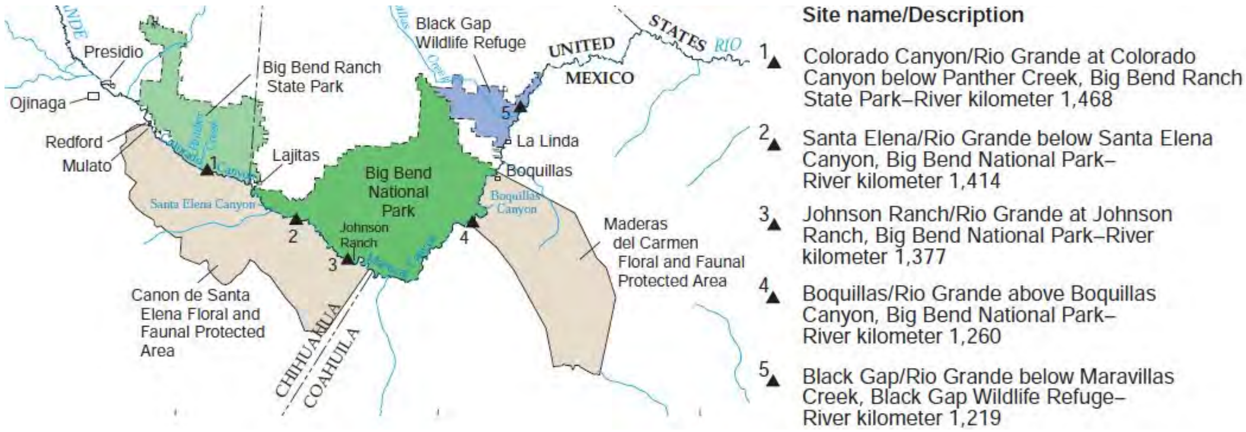

Figure 53. Biological assessment sites in and near BIBE. Reproduced from Moring (2002).

Between 1999 and 2004, Moring (2005) found that fish communities shifted from minnow-dominated to gar (*Lepisosteidae*) and catfish (*Ictaluridae*) at the Boquillas and Johnson Ranch sites. At the Santa Elena site, fish communities were very similar between 1999 and 2004. A period of low flow in 2003 may be a reason for the fish community shift at two of the three sample sites. Additional factors that may explain the shifts include salinity, algal toxins, bioavailable contaminants, and exotic species (Moring 2005). The study found a total of 19 fish species between the three river reaches. The most commonly collected species was the red shiner (*Cyprinella lutrensis*), and the least common species were smallmouth buffalo (*Ictiobus bubalus*) and the western mosquitofish (*Gambusia affinis*), both in number of individuals collected and the number of sites where each were found (Moring 2005). Overall, the number of individual fish collected was greater in the 1999 study than in the 2004 study.

Bonner et al. (2005) noted that between three collection periods (1952 to 1968, 1976 to 1994, and 2001 to 2002) at Independence Creek, Terrell County, Texas, the number of collected species between studies declined from 28 to 26 (plus one hybrid) to 23 (plus one hybrid) respectively. Five native species of fish were lost from the earliest surveys, along with four non-native species (Bonner et al. 2005). However, little change in species diversity was observed within the 50 years between surveys, especially compared to total native species loss throughout the entire Rio Grande watershed (Bonner et al. 2005).

NPS (2010a) observed a decline in fish populations and fish diversity along the Rio Grande. As early as 1990, Hubbs (1990) noted that nearly half of the native fish species in the Chihuahuan Desert are threatened, endangered, or extinct. Known extinctions include species such as the Maravillas red shiner (*Cyprinella lutrensis blair*), the phantom shiner (*Notropis orca*), and Amistad gambusia (*Gambusia amistadensis*), among others (Miller et al. 1989, as cited in Edwards et al. 2002). Extirpations of fish and other aquatic species were noted throughout the BIBE Rio Grande area (Howells and Garrett 1995). Studies by Hubbs (1990) and Edwards and Contreras-Balderas (1991) suggested a general decline or disappearance of many native, and once plentiful, fish species throughout the past 100 years. NPS (2001) noted that BIBE fish were a high priority for further inventory work in the CHDN. Several restoration efforts were undertaken in BIBE, including the reintroduction of the Rio Grande silvery minnow (*Hybognathus amarus*), another federally endangered species, to the Rio Grande in 2008 (Rio Grande Fishes Recovery Team 1984, USFWS 2008).

Big Bend Gambusia Population Size

Big Bend gambusia habitat has been historically limited, and the species has been close to extinction on several occasions (Hubbs 1963, Rio Grande Fishes Recovery Team 1984, Minckley 1995). The current gambusia population descended from three individuals stocked in BIBE ponds in 1960 (Hubbs 1963). Hubbs et al. (2008) noted that the Big Bend gambusia's range was limited to a series of springs in the Boquillas Crossing and Rio Grande Village of BIBE. Two historical populations are known to have existed at Boquillas Springs and east of the Rio Grande Village campground, with the Boquillas Spring population now considered extinct (Rio Grande Fishes Recovery Team 1984, Hubbs et al. 2008). "Spring 4," located east of the Rio Grande Village campground and also thought to have been extirpated, now contains the only known wild population of Big Bend gambusia (Rio Grande Fishes Recovery Team 1984, Hubbs et al. 2008, NPS 2010a). Two ponds, Spring 1 Pond and Hubbs Pond (Near Spring 4), constructed within the Rio Grande Village warm-spring habitat, in the 1960's and 2007 respectively, for the sole purpose of providing protected habitat to the species, contain the majority of the current population (Raymond Skiles, pers. communication, 2013). Big Bend gambusia have been considered imperiled since initial studies in the 1950s (Rio Grande Fishes Recovery Team 1984). Population decline was attributed to habitat alteration, competition with the western mosquitofish and predation by the non-native green sunfish (*Lepomis cyanellus*) (Hubbs et al. 1977, Minckley 1995, CBD 2012). There have been repeated efforts to restore gambusia populations on the brink of extinction (Hubbs et al. 1986, Minckley 1995). Now protected by the USFWS as an endangered species, the population size of the Big Bend gambusia was reportedly in excess of 50,000 fish, as of 2005 (C. Hubbs, pers. communication, 2005, as cited in CBD 2012).

Big Bend Gambusia Genetic Conservation

There is little information available regarding genetic conservation of Big Bend gambusia in BIBE. The current gambusia population is descended from three individuals, likely leading to reduced genetic variability. Hubbs et al. (1986, as cited in Minckley 1995, p. 305), state that Big Bend gambusia are "homozygous for 60 allozymes, in full accord with inbreeding, bottlenecking, or a founder effect." Minckley (1995) notes that this effect is to be expected with such a history; furthermore, small populations of Big Bend gambusia could have been subject to historical bottlenecks (Echelle 1991, as cited in Minckley 1995). No signs of maladaptation have been observed, and when adequate habitat conditions returned to the BIBE region, Big Bend gambusia began to thrive. Continued genetic monitoring of Big Bend gambusia is likely needed in order to ensure the continued survival and genetic diversity of this species.

Threats and Stressor Factors

BIBE staff identified a number of potential threats and stressors to the fish population in the park. It is likely that introduced non-native species, reduced water quality, and intermittent instream flows caused significant declines in species diversity, population size, and genetic diversity (Poff et al. 1997). Furthermore, threats such as channel narrowing, stream depletions, and altered flow regime will likely directly affect the BIBE fish population in the future.

Stream depletions caused by upstream diversions, alter the flow regime and sediment dynamics of the Big Bend reach of the Rio Grande (and reaches of the Rio Grande outside of the park) and result in channel narrowing (Schmidt and Wilcock 2008). According to Dean and Schmidt (2010), the width of the Rio Grande channel below the confluence of the Rio Conchos has decreased 36-52% since 1991. Dean and Schmidt (2010) found a feedback mechanism between the establishment of non-native riparian vegetation (e.g., *Tamarix*) and channel narrowing. Decreases in mean annual flow and flood flows have been seen throughout the Rio Grande. Dean and Schmidt (2010) note that between 1901 and 1944, mean annual flow below the confluence of the Rio Conchos was 64.0 m^3/s, compared to 28.8 m^3/s between 1945 and 2008. Similarly, over a 50% reduction in channel width occurred throughout Hot Springs Canyon between 1901 and 2004 (Dean and Schmidt 2010). Dean and Schmidt (2010) also note that the duration of high flows has decreased markedly; flood pulses of long duration are missing from the BIBE region, The absence of large flood pulses (in terms of size and duration) is important as Heard et al. (2012) found that large flood pulses and maintenance of habitat heterogeneity are necessary for the persistence of the native fish community in the Rio Grande.

Impoundments create reservoirs along the Rio Grande, establishing pools and increasing surface water area. However, fish in rivers are often adapted to specific riverine conditions, and alterations to the river's flow regime may reduce their ability to survive in areas of reduced streamflow or with barred spawning routes. Hubbs (1978) states that depletion and diversion of surface water flows compromise healthy fish populations, especially in reservoir conditions. Anthropogenic disturbances such as the damming of the Rio Grande, both upstream and downstream of BIBE, have been linked to the decline and eventual disappearance of species such as the American eel (*Anguilla rostrata*) and Atlantic sturgeon (*Acipenser oxyrhynchus*) (NPS 2010a). While a reintroduction of the Rio Grande silvery minnow was completed recently, populations may still be susceptible to extirpation due to channel narrowing, reductions in streamflow, non-native species introductions, and channel drying (Moring 2002, USFWS 2008).

Edwards et al. (2002, p. 130) state that drought and decreased flow have become even more destructive to fish communities because “extreme conditions put stress on fish community equilibrium with more tolerant species gaining a competitive and numerical advantage.” Furthermore, impoundments and fragmentation of the river will affect several of the native pelagic spawners, who require long, free-flowing reaches of river for successful reproduction (Bennett, email communication, 12 Oct 2012).

Edwards and Contreras-Balderas (1991) suggested that the aforementioned decreased streamflows, presence of non-native species, and increases in pollution contributed to the ichthyofaunal changes in the Rio Grande within the past century. According to Jeffery Bennett, (email communication, 12 October 2012), very low DO concentrations in the Rio Grande can be associated with flood pulses and can result in fish kills. The exact cause of these low dissolved oxygen events is poorly understood, and it is unknown if the events are linked to eutrophication brought on by urban and agricultural runoff, or nutrient concentration brought on by decreased flows. Urban and industrial waste has been historically discharged into the Rio Grande further upstream of BIBE (Moring 2002). Toxins such as mercury, arsenic, cadmium, chromium, copper, lead, nickel, and zinc were found in the study by Porter et al. (2009). However, levels were typically low and reflected regional background levels (IBWC 2004). There is no indication that these chemicals play a role in the reported fish kills. All that can be stated with certainty is that there are frequent reports of fish kills associated with rises in river level (Bennett, email communication, 12 October 2012). While concentrations of metals in the Rio Grande were low, biomagnification through the food web may be a concern in the future, especially in areas of heavy historic mining.

The Rio Grande silvery minnow, one of the most historically widespread and abundant species in the BIBE region, has seen its range and population reduced due to competition and hybridization with the plains minnow (*Hybognathus placitus*) (Bestgen and Platania 1991). According to Bestgen and Platania (1991), the construction of the downstream Amistad reservoir and increased non-native fish competition led to many local extirpations of the silvery minnow along the Rio Grande.

Degraded channel condition and altered flow regimes can lead to subsistence flow conditions in the upper reach of Rio Grande throughout the winter and spring. Subsistence flow plays an important role in structuring fish communities, as persistent subsistence flow conditions can have detrimental impacts on fish populations (Bennett, email communication, 12 October 2012). As reported in Poff et al. (2010), a naturally variable flow regime, rather than persistent minimum flows, is required to sustain firewater ecosystems. Furthermore, all of the aforementioned stressors (e.g., eutrophication, altered flow regimes, channel narrowing) could increase incidences of parasites and disease, further altering aquatic species diversity and population size.

Introduced species and unusually cold weather events have forced the Big Bend gambusia to the brink of extinction and, while they have endured several translocations and reintroduction efforts since the mid-1950s, Big Bend gambusia still face a myriad of threats such as spring habitat loss, reduction of streamflow, water contamination, sedimentation, extreme weather events, decreases in genetic variability, and continued competition and hybridization between introduced species (Hubbs et al. 1977, Minckley 1995, CBD 2012, TPWD 2012).

Data Needs/Gaps

Garrett (2002) noted the lack of replicated sampling along the Rio Grande in BIBE. This makes it difficult to compare fish species composition and abundance over time. Until recently, there had been no regular assessment of habitat use, and there had not been any collections of flow-dependent biological data. Recent projects coordinated by the NPS have been established to investigate some of these data gaps. Additionally, Heard et al. (2012) was published after the completion of this document, and it’s omission from this component is a noticeable data gap

Only one record on the presence of Big Bend gambusia exists prior to 1954, and population, distribution, or abundance information is nonexistent prior to that date (Hubbs et al. 1977).

Overall Condition

Species Diversity

A *Significance Level* of 3 was assigned to the BIBE fish species diversity measure by park staff. This measure was assigned a *Condition Level* of 2, indicating that it is of moderate concern to resource managers. As of 1990, approximately 50% of native Chihuahuan Desert fish species were threatened, endangered, or extinct. Sources note declining species diversity and decreased population size within the Rio Grande (Hubbs 1990, Edwards and Contreras-Balderas 1991, Moring 2005, NPS 2010a).

Big Bend Gambusia Population Size

A *Significance Level* of 2 was assigned for the measure of Big Bend gambusia population size. This measure was assigned a *Condition Level* of 2, indicating that Big Bend gambusia population size is of moderate concern to resource managers. Efforts have been undertaken since the mid-1950s to restore adequate numbers of Big Bend gambusia to BIBE. Populations are reportedly increasing since 1978 with a population size of approximately 50,000 individuals in 2005. However, Big Bend gambusia are still faced with threats such as decreased water quality, sedimentation, introductions of non-native species, and limited range.

There is little information available regarding genetic conservation of gambusia in BIBE; the current population is descended from three individuals, which likely led to reduced genetic variability in the population. Hubbs et al. (1986) also indicated that the Big Bend gambusia displays the typical characteristics of a population that was created through a founder event or a recent population bottleneck (i.e., high levels of observed homozygosity and inbreeding).

Weighted Condition Score
The overall *Weighted Condition Score* for the BIBE fish component is 0.667, indicating that this resource is on the border of moderate and high concern. After reviewing the literature and data sources, SMUMN analysts decided to favor the significant concern level. Managers should pay particular attention to this resource to prevent further degradation of condition in the future. A declining trend was seen across available literature in comparison to pre-dam reference conditions on the Rio Conchos and the Rio Grande.

Fish

Measures	SL	CL
• Species Diversity	3	2
• Big Bend Gambusia Pop. Size	2	2

WCS = 0.667

4.12.6 Sources of Expertise
Jeffery Bennett, BIBE Physical Scientist

Joe Sirotnak, BIBE Botanist/Ecologist

Raymond Skiles, BIBE Wildlife Biologist

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4.13 Amphibians

4.13.1 Description

All 12 species of amphibians in BIBE are anurans (frogs or toads) (NPS 2010). Two of the amphibian species in the park are exotic: the American bullfrog and green treefrog (*Hyla cinerea*). The diversity of the amphibian population in BIBE is unique, particularly the desert species found there; only 3% of anuran species worldwide exist in desert ecosystems (Dayton et al. 2004). Amphibians require access to water at all life stages, and wet seasons are essential for the survival of many species in BIBE (Schmidly et al. 1996). Adequate water sources are necessary for successful reproduction; amphibians in a harsh desert ecosystem likely go for years without a successful breeding event (Dayton 2005b). Amphibians act as key indicator species as they are especially susceptible to ecological changes due to their permeable skin (Smith and Keinath 2007). Toxins absorbed through an amphibian's skin can quickly spread throughout the ecosystem, as amphibians are important prey for many species (Smith and Keinath 2007).

Photo 19. Red-spotted toad (*Bufo punctatus*) (Photo by Dave Prival, University of Arizona).

4.13.2 Measures

- Species diversity
- Species distribution

4.13.3 Reference Conditions/Values

The reference condition for amphibians in BIBE is the condition of the park's amphibian habitats prior to European settlement and habitat alteration. Unfortunately, species diversity and distribution information from this period are largely unknown.

4.13.4 Data and Methods

Schmidly et al. (1996) conducted a biodiversity survey of the North Rosillos area of BIBE (northwest portion of the park), including amphibians, between 1990 and 1993. Drift fences and pit traps were employed to collect specimens during the survey.

Jung et al. (2000) conducted an amphibian survey of BIBE springs and the Rio Grande, and established monitoring strategies for both. The study utilized a variety of techniques to locate anurans in the park, including canoe surveys, spotlighting to conduct visual surveys, call surveys, frogloggers (automated recording devices), night driving, and tadpole dye capture-recapture techniques. Jung et al. (2002) specifically discussed the canoe survey portion of the Jung et al. (2000) study.

Dayton et al. (2004) used night driving surveys to study habitat associations of four anuran species in BIBE, and established monitoring strategies for them. The survey examined soil types and vegetation communities associated with the Couch's spadefoot (*Scaphiopus couchii*), red-spotted toad (*Bufo punctatus*), Texas toad (*Bufo speciosus*), and western green toad (*Bufo debilis*). The survey was conducted on four different paved road transects throughout the park. Prival and Goode (2005) also surveyed reptiles and amphibians in BIBE, focusing on three mountain ranges (the Sierra Quemada, Sierra del Caballo Muerto, and Mesa de Anguila; see Plate 22), from 2003-2004.

Dayton and Fitzgerald (2006) created habitat suitability models using GIS for four amphibian species in BIBE based on seven years of breeding site data and several environmental factors, including soil water holding capacity, soil texture, slope, elevation, and proximity to drainage channels. Rotenberry et al. (2008) used ecological niche modeling to assess habitat suitability for reptiles and amphibians in CHDN parks. Habitat suitability maps were produced for four amphibian species at BIBE.

4.13.5 Current Condition and Trend

Species Diversity

There are a total of 19 anuran species in the Chihuahuan Desert (Dayton et al. 2004). Table 35 displays the 12 species present in BIBE.

Table 35. Amphibians present in BIBE (USGS 2006, NPS 2011).

Scientific Name	Common Name
Bufo debilis insidior	western green toad
Bufo punctatus	red-spotted toad
Bufo speciosus	Texas toad
Bufo woodhouseii	southwestern Woodhouse's toad
Eleutherodactylus guttilatus	spotted chirping frog
Gastrophryne olivacea	Great Plains narrow-mouthed toad
Hyla arenicolor	canyon treefrog
Hyla cinerea	green treefrog
Rana berlandieri	Rio Grande leopard frog
Rana catesbeiana	American bullfrog
Scaphiopus couchii	Couch's spadefoot
Spea multiplicata	Mexican spadefoot

Schmidly et al. (1996) documented seven anuran species in the North Rosillos area of BIBE: Couch's spadefoot, Mexican spadefoot (*Spea multiplicata*), red-spotted toad, western green toad, Texas toad, Great Plains narrow-mouthed toad (*Gastrophryne olivacea*), and the Rio Grande leopard frog (*Rana berlandieri*). The Couch's spadefoot was the most abundant species encountered during this survey, and the red-spotted toad was a common species encountered at every drift fence in the study (Schmidly et al. 1996).

Jung et al. (2002) summarized data gathered from anuran canoe surveys on the Rio Grande in BIBE from 1998-1999. Seven species were documented during the survey, although 96% of visual observations were Rio Grande leopard frogs (Jung et al. 2002). Bullfrogs, red-spotted toads, Texas toads, Couch's spadefoots, spotted chirping frogs, and a single Great Plains narrow-mouthed toad were encountered during the survey.

Dayton et al. (2004) compiled species counts of the four species studied during the 1998-1999 habitat association study (Table 36). The Texas toad was the most common of the four species, while the western green toad was the rarest species in the survey (Table 36). The total counts for transect routes over the two-year period illustrate the spatial and temporal variability of anuran distribution in BIBE. Routes 2 and 3 have substantially different total count values between 1998 and 1999, and abundance varies significantly among the different routes.

Table 36. Anuran counts from the 1998-1999 habitat association survey (Dayton et al. 2004).

	Route 1		Route 2		Route 3		Route 4		
Species	**1998**	**1999**	**1998**	**1999**	**1998**	**1999**	**1998**	**1999**	**Total**
western green toad	0	8	2	0	7	23	0	0	40
red-spotted toad	33	68	8	48	16	92	11	10	286
Texas toad	130	274	1	6	2	259	17	7	696
Couch's spadefoot	25	142	11	47	24	177	13	8	447
Total	188	492	22	101	49	551	41	25	1469

The green treefrog and American bullfrog are two non-native species identified in BIBE (Dayton 2005c). A single green treefrog was heard calling in 1999, and the species was observed in the park again in 2006 (Dayton 2005c, Leavitt and Fitzgerald 2009).

One species included in the BIBE amphibian list (Table 35), Woodhouse's toad, has not been seen in the park for several decades. Documentation of the Woodhouse's toad is minimal in BIBE, and the species has not been observed in the Rio Grande floodplain since the early 1970s (Goode 2006; Skiles, pers. communication, 2011). Habitat loss may have extirpated the species, as it is dependent on backwater pools, many of which were lost following alterations to the Rio Grande River (Skiles, pers. communication, 2011).

<u>Species Distribution</u>
The majority of anuran species in the Chihuahuan Desert ecosystem depend on ephemeral pools created by large rain events for breeding (Dayton et al. 2004). As a result, the distribution of amphibians is characterized by areas of great abundance interspersed with areas of scarce abundance.

Schmidly et al. (1996) conducted an ecological survey in the North Rosillos area of BIBE and recorded locations and habitat types for seven amphibian species. The Couch's spadefoot was most prevalent in the Alkali Grassland below 1,068 m (3,500 ft) in areas with a soft substrate for burrowing. The Mexican spadefoot was found in one location bordering Nine Point Draw (see Plate 22), and is likely confined to the Alkali Grassland as well. The red-spotted toad was found in all vegetation communities below 1,068 m (3,500 ft) and was most commonly encountered along the County Road and in the Arroyo Scrub community. Green toads were restricted to an area along the Chalk Hills, and were located in the Alkali Grassland. The Texas toad was commonly found along County Highway 385 between a chalk hill and Nine Point Draw. The species was also found in the Mariola Scrub Community by the lodge headquarters and in the

Arroyo Scrub community. The Great Plains narrowmouth toad was captured at one drift fence location and was found along the county road. The Rio Grande leopard frog was found at every permanent water body in the study area, and in temporary pools along Nine Point Draw. The leopard frog was particularly common at Buttrill and Alamo Springs (Schmidly et al. 1996).

The Couch's spadefoot and the western green toad are most abundant in the northern regions of the park and near the Rio Grande; the western green toad is also present near the western boundary of BIBE (Dayton and Fitzgerald 2006). Both species have similar habitat requirements, preferring clay loam soils with a high water holding capacity, and primarily breed in temporary pools on alluvial floodplain (Dayton and Fitzgerald 2006). The red-spotted toad is widely distributed throughout BIBE, and is associated with permanent and temporary water bodies in a variety of habitats (Dayton and Fitzgerald 2006). The Great Plains narrow-mouthed toad is also widely distributed in BIBE, primarily found in low to mid-elevation ranges in a variety of habitats from well-drained rocky areas to clay-loam flats with high water holding capacity (Dayton 2005b).

Jung et al. (2002) noted that the Rio Grande leopard frog was generally associated with mud banks (93.8% of the time) and near seep willow and open area habitats during canoe surveys of the Rio Grande River. Bullfrog occurrences declined significantly as the survey moved from west to east along the river. Bullfrogs were found on mud banks 95% of the time (Jung et al. 2002).

Dayton et al. (2004) examined the soil types and vegetation communities associated with Couch's spadefoots, red-spotted toads, Texas toads, and western green toads. These species were all strongly associated with high clay content soils that are frequently inundated. The western green toad and red-spotted toad were associated with creosote and mixed scrub vegetation, whereas the Texas toad and Couch's spadefoot were associated with mesquite scrub vegetation (Dayton et al. 2004). At the regional level, the distribution of all four species overlapped. Anuran species richness and abundance were highest in areas with Tornillo and Glendale-Harkey soils; almost 50% of anurans were found on these soils, which comprise only 12% of the area covered by transects in the survey (Dayton et al. 2004).

Amphibians were collected in the park during 2002-2003 as part of a larger herpetofauna survey conducted between 2001 and 2004 (Dayton 2005a). Plate 23 displays amphibian locations in BIBE. The red-spotted toad and Couch's spadefoot were the two most abundant species collected in this survey.

Bullfrogs are found in Beaver Pond (near Rio Grande Village) and along the Rio Grande River in BIBE, but have not become established in the interior of the park (Dayton 2005c). Green treefrogs were discovered in 2006 in a spring-fed pond near a campground in the park, suggesting that the species arrived as a stowaway or was intentionally released (Leavitt and Fitzgerald 2009). The local population of green treefrogs has grown rapidly since its discovery in the park, and the species is currently known to exist in two ponds in the Rio Grande Village region of BIBE (Plate 22): Beaver Pond and Spring 4 Pond (Leavitt and Fitzgerald 2009). Raymond Skiles (pers. communication, 2012) has also observed green treefrogs in an irrigation settling pond near Daniels Ranch and in other camping and picnic areas subject to irrigation.

Prival and Goode (2005) surveyed reptiles and amphibians in BIBE between 2003 and 2004, focusing on three mountain ranges (the Sierra Quemada, Sierra del Caballo Muerto, and Mesa de Anguila) that had received little previous attention from herpetologists. This study focused more heavily on locating reptiles, but amphibians were generally recorded when they were encountered. Plate 24 displays the distribution of amphibian species encountered during the survey.

Dayton and Fitzgerald (2006) created habitat suitability models for four amphibian species in BIBE: Couch's spadefoot, western green toad, red-spotted toad, and the Great Plains narrow-mouthed toad. The models predicted a greater area of suitable habitat for the red-spotted toad and Great Plains narrow-mouthed toad than the other two species (Dayton and Fitzgerald 2006). The models were better at predicting where Couch's spadefoot and the western green toad were likely to occur in BIBE than for the other two species (Dayton and Fitzgerald 2006).

Rotenberry et al. (2008) mapped the habitat suitability (i.e., potential distribution) within BIBE for four amphibian species. According to their niche modeling, two of the four amphibian species showed limited suitable habitat within the park: Texas toad and Rio Grande leopard frog. The four amphibian species studied and general descriptions of suitable habitat locations are presented in Table 37.

Table 37. General locations of suitable amphibian habitat within BIBE, according to Rotenberry et al. (2008).

Common Name	Habitat locations
red-spotted toad	throughout park
Texas toad	southwest park
Rio Grande leopard frog	central and east park
Couch's spadefoot	throughout park, except in mountains

Threats and Stressor Factors

The Rio Grande's channel and flow characteristics have been modified by dams, reservoirs, and channelization. Additionally, at least 80% of the river's surface water is diverted for agriculture (Jung et al. 2002). These alterations have changed the natural flooding regime and the quantity and quality of wetlands and floodplains along the Rio Grande (Jung et al. 2002). As a result of these changes, amphibian species may have less suitable habitat and fewer breeding opportunities (Jung et al. 2002).

Airborne transport and deposition of contaminants may have negative health consequences for amphibian species in BIBE. There are a large number of factories in the border region of the Chihuahuan Desert (approximately 326 on the Mexican side of the border and 26 on the U.S. side) which have greatly increased air pollution in the region (Ford and Finch 1999). These factories produce a wide range of products including electronic equipment, petroleum products, and textiles (EPA 1992). Because amphibians have thin, permeable skin, they are particularly susceptible to anthropogenic pollution in all life stages (Ford and Finch 1999).

Bullfrogs pose a potential threat to native amphibians in BIBE; the species is believed to be playing a role in the decline of native amphibians in the southwestern United States (Dayton 2005c). If bullfrogs were to colonize springs and tanks within the interior of the park, they would be very difficult to eradicate. Bullfrogs can out-compete, prey upon, and spread diseases to native amphibians and reptiles (NPS 2006). Culling bullfrogs where they currently exist would reduce the likelihood of further colonization in the park (Dayton 2005c).

Non-native green treefrogs have recently experienced rapid population growth in BIBE (Leavitt and Fitzgerald 2009). NPS (2006) stated that habitat in BIBE was unlikely to support a population of the species, but the green treefrog has displayed the ability to exploit novel resources outside its native range (Leavitt and Fitzgerald 2009). Beaver Pond was the only site identified in the Exotic Animal Management Plan as potentially suitable habitat for the species in BIBE, where predation on native invertebrates would be the primary threat (NPS 2006). The species is now present in Beaver Pond as well as Spring 4 Pond (Leavitt and Fitzgerald 2009). The distribution of the green treefrog population includes the only remaining habitat for the federally endangered Big Bend gambusia (Leavitt and Fitzgerald 2009). The potential implications for the Big Bend gambusia are unknown.

Jung et al. (2001, 2002) documented high levels of chiggers (*Hannemania* spp.) on Rio Grande leopard frogs during the 1998-1999 survey (88% of individuals). Chiggers were also found on spotted chirping frogs, red-spotted toads, and canyon treefrogs in BIBE (Jung et al. 2001). Chiggers are parasites of vertebrates, and may pose potential health risks for the frogs (Jung et al. 2001). In BIBE, chiggers formed reddish-orange bumps on anuran species (Jung et al. 2001).

The parasitic chytrid fungus (*Batrachochytrium dendrobatidis*) causes the zoosporic fungal infection chytridiomycosis in frogs and toads (Bradley et al. 2002). Chytridiomycosis has been identified as a cause of massive frog declines and localized extinctions in Australia and Central America (Berger et al. 1998). To date, chytridiomycosis has not been documented in any amphibians in BIBE (Skiles, pers. communication, 2011). The chytrid fungus does not appear to be a problem at BIBE currently, but it does pose a significant potential threat to amphibians in the park.

Data Needs/Gaps

Certain anuran species are better studied in BIBE than others, perhaps due to their abundance. The Dayton et al. (2004) habitat association survey provided good insight into habitat associations of four species in the park; it would be beneficial to conduct a similar survey for the remaining species. Goode (2006) commented that most amphibian surveys in BIBE have been incomplete (limited area of the park) and provide limited information on species distribution. NPS (2006) notes that conducting research on the interactions between bullfrogs and native amphibians in BIBE could identify species that are particularly vulnerable to this invasive species. Leavitt and Fitzgerald (2009) discuss the importance of studying the potential ecological implications of the non-native green treefrog on the endangered Big Bend gambusia in BIBE.

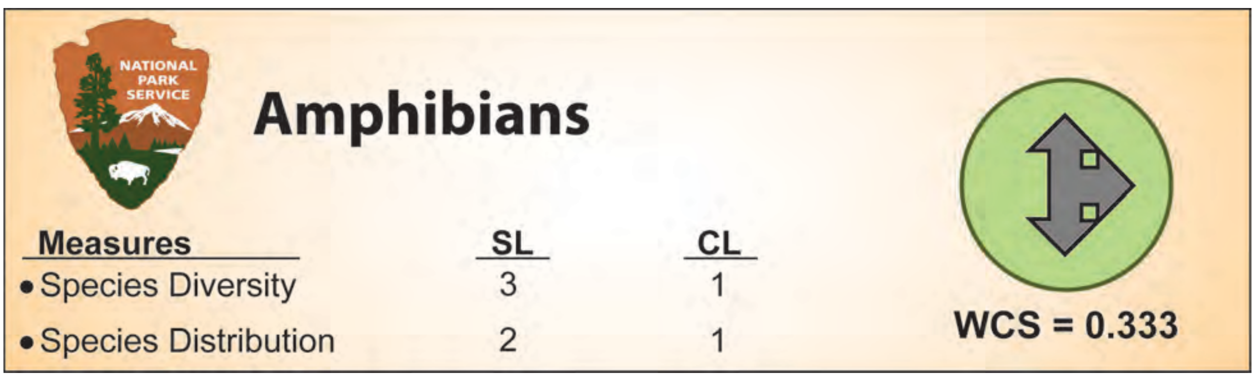
Overall Condition

Species Diversity

The project team defined the *Significance Level* for species diversity as a 3. Ten native species and two non-native species have been documented in BIBE. The level of amphibian diversity in BIBE is high for a desert ecosystem. The presence of two non-native anurans is undesirable, and these species pose a potential threat to native species in the park. However, there has not been any documentation of these species negatively impacting native anurans in BIBE to date. The *Condition Level* of species diversity is a 1, indicating a low level of concern.

Species Distribution
A *Significance Level* of 2 was assigned for the measure of species distribution. Amphibians are naturally restricted to areas with close access to water, and are found primarily in water-associated areas within BIBE. The non-native green treefrog has been documented in two pools, and the bullfrog is present along the Rio Grande and in Beaver Pond. The bullfrog has not invaded the interior portions of BIBE, however. The *Condition Level* of species distribution is 1 due to the moderate distribution of non-native amphibians.

Weighted Condition Score
The *Weighted Condition Score* (WCS) for amphibians in BIBE is 0.333, indicating a low level of concern for the component. However, this condition score falls just below the threshold for moderate concern. Had additional factors like the chytrid fungus and other stressors been considered in the score, it would likely increase. The overall trend of amphibians in BIBE is unknown.



4.13.6 Sources of Expertise
Raymond Skiles, BIBE Wildlife Biologist

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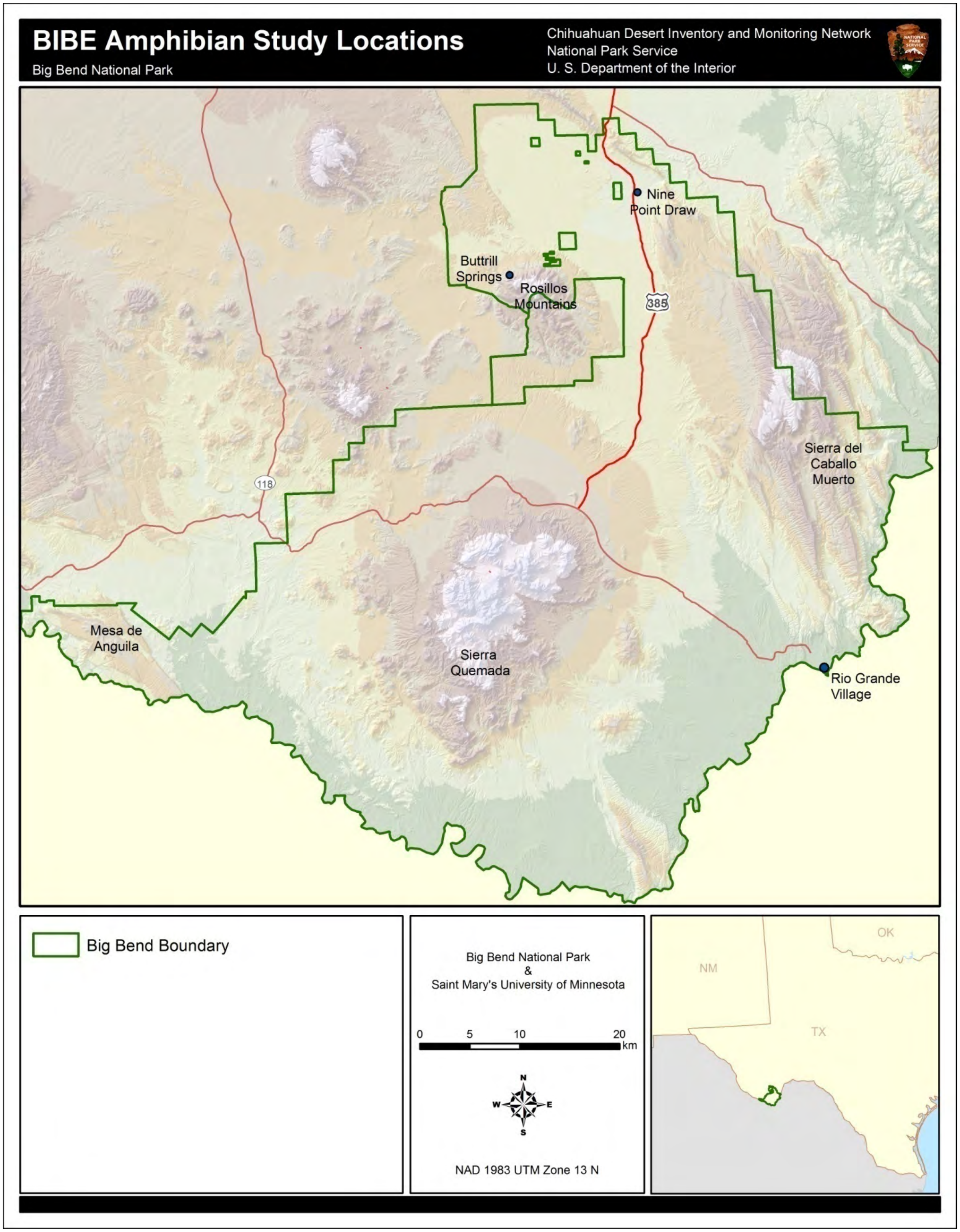

Plate 22. Locations identified in amphibian surveys of the park discussed in this assessment.

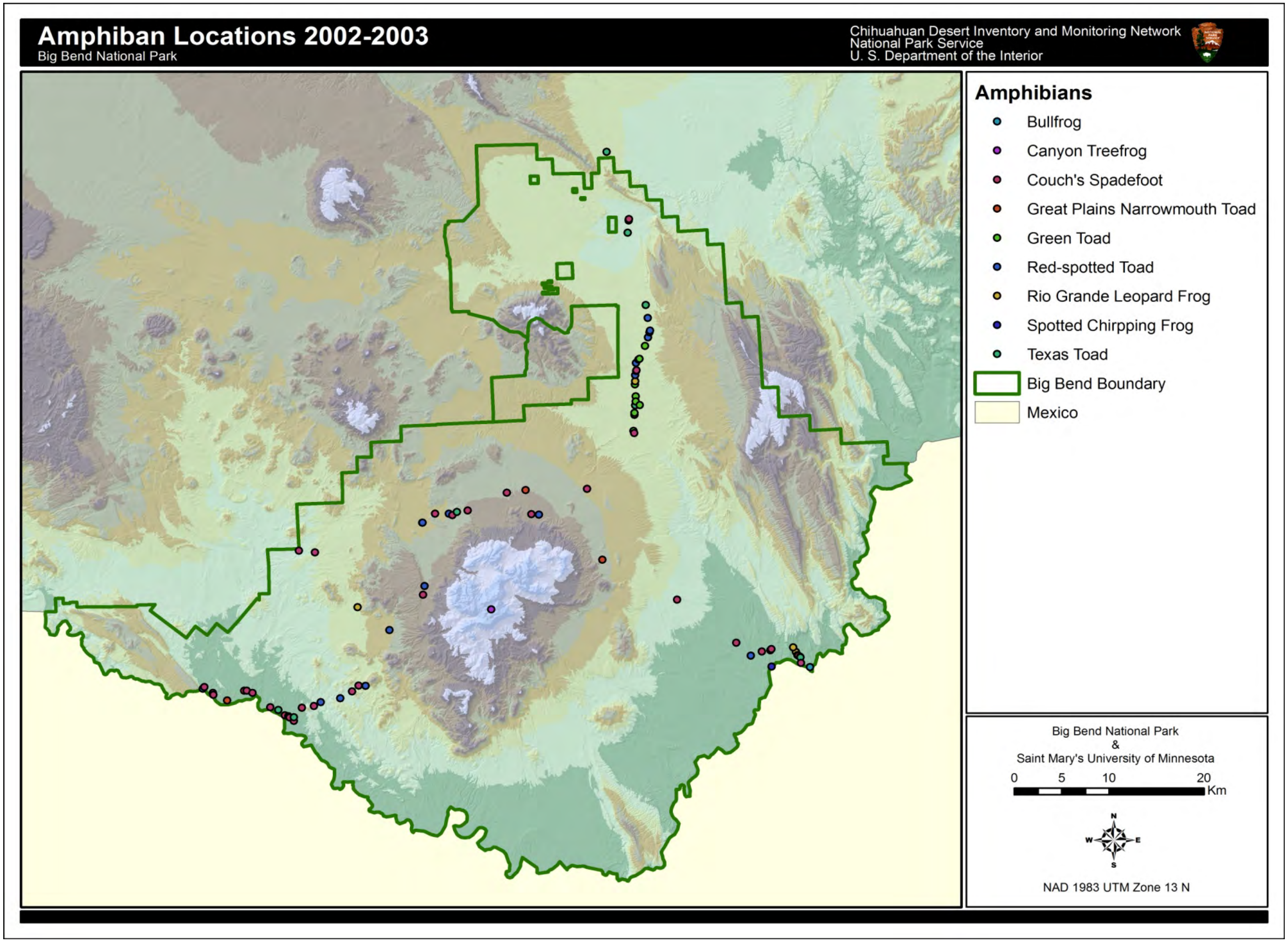

Plate 23. Amphibians captured in BIBE herpetofauna survey, 2002-2003 (Dayton 2005c).

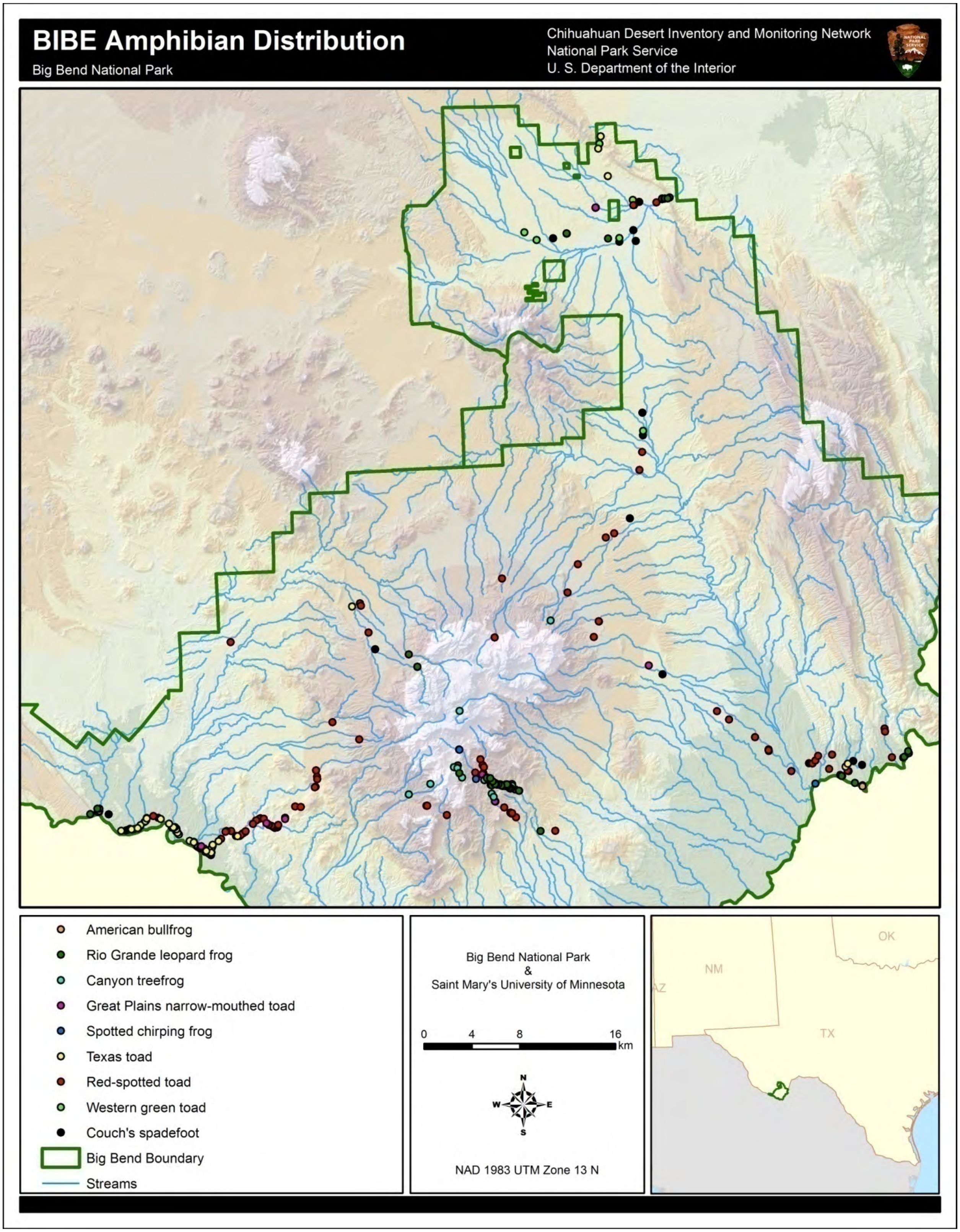

Plate 24. Amphibian locations during 2003-2004 survey (Prival and Goode 2005).

4.14 Reptiles

4.14.1 Description

BIBE provides habitat for a number of reptiles, including snakes, lizards, turtles, and tortoises. Snakes are the most diverse reptile group in BIBE, with 30 species documented in the park (NPS 2011; Appendix S). There are 22 lizard species documented in BIBE. Lizards are a major prey item for other animals in the park, such as the greater roadrunner (*Geococcyx californianus*), and are a major predator of insects and other species (NPS 2010a). Six turtle species have been found in BIBE, including one non-native species, the red-eared (elegant) slider, as well as one species of tortoise, Berlandier's tortoise. The Berlandier's tortoise has not been observed in the park in several years, and it's documentation in the park was likely the result of an introduction near a development site. It is unlikely that this species currently exists in the park (Skiles, written communication, 1 November 2013). Although reptiles are less dependent on water for survival than amphibians, their populations have responded positively to wet seasons in BIBE as their food base increases (Schmidly et al. 1996).

Photo 20. Reticulate banded gecko (*Coleonyx reticulatus*) (Photo by Ian Murray, University of Arizona).

4.14.2 Measures

- Species diversity
- Species distribution

4.14.3 Reference Conditions/Values

The reference condition for reptiles in BIBE is pre-exotic grassland invasion of the desert ecosystem.

4.14.4 Data and Methods

Schmidly et al. (1996) conducted a biodiversity survey of the North Rosillos area of BIBE (northwest portion of the park) between 1990 and 1993, employing drift fences and pit traps to collect reptiles. Dayton (2005b) conducted a herpetofauna survey of BIBE between 2001 and 2004. Prival and Goode (2005) surveyed reptiles in BIBE from 2003-2004, focusing on three mountain ranges (Sierra Quemada, Sierra del Caballo Muerto, and Mesa de Anguila). Prior to this study, these areas received little attention from herpetologists.

Leavitt (2007) conducted a lizard census in BIBE using six study quadrats developed in 1955. The lizard per acre index used in this study was the same measurement used in the original surveys of the quadrats, which were last sampled in 1969. Jackson et al. (2007) trapped turtles in

BIBE between 2005 and 2006 in order to study the non-native red-eared (elegant) slider and its hybridization with the native Big Bend slider (*Trachemys gaigeae*). Native turtles were marked and released, while non-natives and hybrids were removed from the park and genetic information was collected from specimens.

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

4.14.5 Current Condition and Trend

<u>Species Diversity</u>
There are 59 species of snakes, lizards, turtles and tortoise documented in BIBE. Appendix S displays the NPS Certified Species List for reptiles in the park (NPS 2011). Four species of reptiles in BIBE are listed as threatened in Texas: the reticulate banded gecko, Berlandier's tortoise, Texas horned lizard (*Phrynosoma cornutum*), and the Trans-Pecos black-headed snake (*Tantilla cucullata*) (TPWD 2010). All four species are considered rare within BIBE (NPS 2011).

Schmidly et al. (1996) collected 34 species of reptiles in the North Rosillos ecological survey: 17 snake species, 16 lizards, and one turtle species (Appendix S). The two most common lizards encountered in this survey were the Chihuahuan greater earless lizard (*Cophosaurus texanus*) and the marbled whiptail (*Aspidoscelis marmorata*). The least frequently observed lizard in the study was the long-nosed leopard lizard (*Gambelia wislizenii*). The survey found one protected species, the Texas horned lizard. Snakes were not encountered as often as lizards during the survey; the most common snake species was the western diamond-backed rattlesnake (*Crotalus atrox*) (Schmidly et al. 1996). The only turtle species encountered in the North Rosillos study was the yellow mud turtle (*Kinosternon flavescens*); a number of individuals were trapped in Turtle Pond 1 (Schmidly et al. 1996). Minton (1959) found two additional snake species and one lizard in this region not encountered during the Schmidly et al. (1996) survey: the desert patch-nosed snake (*Salvadora deserticola*), western black-necked garter snake (*Thamnophis cyrtopsis*), and the short-lined skink (*Eumeces tetragrammus brevilineatus*).

Prival and Goode (2005) surveyed the reptiles of three mountain ranges in BIBE: the Sierra Quemada, Sierra del Caballo Muerto, and the Mesa de Anguila ranges. A total of 21 lizard species, 26 snakes, and three turtles were documented (Appendix S). The Big Bend canyon lizard was by far the most common species encountered during this survey, and the western diamond-backed rattlesnake was the most common snake species (Prival and Goode 2005). Three state threatened species were encountered: Texas horned lizard, reticulate banded gecko, and the Trans-Pecos black-headed snake (Prival and Goode 2005).

Leavitt (2007) surveyed the BIBE lizard populations in 2005 using six original study quadrats developed in 1955 by Dr. William G. Degenhardt. In addition, the percentage of vegetation cover was measured during the study, and was found to have increased since the previous quadrat survey. Overall, the lizard per acre index was lower in 2005 than in 1969 (Leavitt 2007). The changes in lizard composition and density appear to be partially dependent on vegetative cover (Leavitt 2007). The marbled whiptail was found in much greater numbers in 1969 compared to

2005 at three low elevation quadrats. During the same time period, the Big Bend spotted whiptail (*Aspidoscelis septemvittata*) increased in higher elevation quadrats (Leavitt 2007). Table 38 displays the lizard per acre index mean values for five quadrats between 1956 and 2005.

Table 38. Ground lizard per acre index values in five quadrats from 1956 to 2005. Sampling was conducted twice in 1968 and 1969 (Leavitt 2007).

Quadrats	1956	1957	1958	1960	1968	1969	2005
Tornillo Flat (TORN)	--	1.2 ± .2	1.6 ± .2	1.7 ± .2	1.7 ± .2, 2.4 ± .3	2.0 ± .2 , 2.8 ± .3	1.3 ± .5
Grapevine (GRAP)	8.7 ± .7	8.2 ± .8	--	--	4.6 ± .7	7.0 ± 1.0, 5.7 ± .7	2.5 ± .6
Burnham Flat (BURN)	--	4.0 ±.6	7.9 ± .9	--	4.5 ± .8, 4.4 ± .7	4.9 ± .4, 2.7 ± .4	4.7 ± .6
Green Gulch1 (GG 1)	--	12.8 ± .4	9.9 ± .6	--	1 ± .5, 1.3 ± .3	0 ± .0, 0 ± .0	2.8 ± .6
Green Gulch2 (GG 2)	--	4.0 ± .6	5.5 ± 3.5	--	0.7 ± .7	0.2 ± .2	1.3 ± .5

A lizard species assemblage similarity index value was calculated for five of the quadrats to compare the proportional similarity between quadrats from different survey iterations (Table 39). The index value can range between zero and one, where zero indicates no overlap between censuses and a value of one indicating complete overlap between censuses (Leavitt 2007).

Table 39. Assemblage similarity index values from 1957, mean prior to 2005, a general index mean for all quadrats, and the 2005 mean index value (Leavitt 2007).

Quadrat	1957	Quadrat mean prior to 2005	General index mean	2005 mean
Tornillo Flat (TORN)	0.84	0.99	0.66	0.52
Grapevine (GRAP)	0.48	0.69	0.74	0.9
Burnham Flat (BURN)	0.8	0.83	0.63	0.53
Green Gulch 1 (GG 1)	0.01	0.01	0.12	0.48
Green Gulch 2 (GG 2)	0.55	0.73	0.12	0.48

The red-eared slider is a non-native turtle present in BIBE (NPS 2006). This species was introduced to Texas from human release of pet turtles (Jackson et al. 2007). The red-eared slider is a species of concern in the park because it may be altering the genetic integrity of the native Big Bend slider through interbreeding (NPS 2006). Turtles were trapped in 2005 and 2006 in BIBE and surrounding areas; Big Bend sliders were marked and released while non-native red-eared sliders and potential hybrids were removed (Jackson et al. 2007). Genetic data were collected via blood samples from captured turtles and used to evaluate the ability of researchers to correctly identify hybrid and non-native turtles in the field. Over 600 turtles representing five species were captured during the survey, including eight red-eared sliders and four potential red-eared/Big Bend hybrids (Jackson et al. 2007). Results of this survey were compared to similar data from 1997-1998; the frequency of non-native turtles was not significantly different (Jackson et al. 2007).

Several other non-native species have been documented in BIBE. Berlandier's tortoise is not native to BIBE, but is a native species in other areas of Texas where it is protected as a threatened species (Prival and Goode 2005, TPWD 2010). The green anole (*Anolis carolinensis*) is a non-native species that has been recorded sporadically in BIBE (Dayton 2005c). The Mediterranean house gecko (*Hemidactylus turcicus*) is another non-native reptile in BIBE (NPS 2006). The species is highly associated with human structures in the park, and is thought to occupy an ecological niche that was unoccupied by native species (NPS 2006).

Species Distribution

Herptile composition and abundance are affected by the composition of plant communities and substrates present (Schmidly et al.1996). In the North Rosillos ecological survey, the greatest diversity of reptiles occurred in areas where two or more plant communities (as described and delineated by Schmidly et al. 1996) overlapped. In BIBE, the Arroyo Scrub Community had the highest herptile diversity because it often overlapped with other vegetative communities. The Canyon Scrub and grama grassland communities had the lowest herptile diversity in the North Rosillos region of BIBE (Schmidly et al.1996).

Lizard species fill a variety of different ecological niches in the park. The Chihuahuan greater earless lizard and the marbled whiptail were the two most commonly encountered species in the Schmidly et al. (1996) survey, and were present in every plant community below 1,068 meters (3,500 ft) (Schmidly et al. 1996). The Big Bend tree lizard (*Urosaurus ornatus*) is generally associated with trees or large shrubs. The Big Bend canyon lizard (*Sceloporus merriami*) is found on rocky bluffs, regardless of the surrounding vegetation. The common side-blotched lizard (*Uta stansburiana*) is found in a variety of vegetative communities as long as a sandy substrate is present.

Table 40 displays reptile species captured during the North Rosillos survey (Schmidly et al. 1996) as well as the habitat, community, or specific location each was found in. It is important to note that as few as one individual of a particular species may have been captured during the study, while other species were ubiquitous. Schmidly et al. (1996) occasionally used different common names than the NPS Certified Species List.

Table 40. Locations and/or habitats of reptiles from North Rosillos survey (Schmidly et al. 1996).

Species	Habitat/Location
yellow mud turtle	Turtle Pond 1; some in Turtle pond number 2 in the alkaline grassland community
Texas banded gecko	Mariola and Lechuguilla scrub community with a limestone substrate
eastern collared lizard[1]	Mosaic of semidesert grassland - Mariola and Lechuguilla scrub, the Arroyo scrub, and mixed shrub and succulent scrub communities on rocky substrates
long-nosed leopard lizard	Bajada habitat with sandy to gravelly soil as a substrate
Texas earless lizard	Substrate with some rock rubble; bajada type habitat, chalk hills, arroyo scrub community
crevice spiny lizard	Lodge field headquarters; buttrill springs
twin-spotted spiny lizard	Mesquite scrub and arroyo scrub communities, captured at Nine Point Draw during survey
southern prairie lizard[2]	Human structures, found in every plant community except the grama grassland and oak woodland
Big Bend canyon lizard	Rocky bluffs and outcrops, common in chalk hills
Big Bend tree lizard	Basaltic outcrops of Rosillos Mountains
side-blotched lizard	Sandy to gravel-sandy soils, most abundant in alkaline grassland community
Texas horned lizard	Transitional zone between a mariola scrub and a creosote scrub community

Table 40. Locations and/or habitats of reptiles from North Rosillos survey (Schmidly et al. 1996) (continued).

Species	Habitat/Location
round-tailed horned lizard	Creosote Scrub Community and Mariola Scrub Community
Trans-Pecos striped whiptail	Arroyo Scrub, Mariola Scrub, and mosaic of Semidesert Grassland and Mariola and Lechuguilla Scrub communities
marbled whiptail	Every substrate except bluffs and rocky outcrops
plateau spotted whiptail	Rocky hillsides, valleys, and arroyos; grama grassland community; Chalk Hills in the Mixed Shrub and Succulent Scrub Community; Chisos Mountains
Great Plains skink	Chalk Hills
checkered garter snake	Usually found in or near water
western black-neck garter snake	Riparian community
regal ring-neck snake[3]	Arroyo Scrub Community in the survey, found almost anywhere except very sandy desert substrates
western coachwhip	Valley floor in the Rosillos Mountains
central Texas whipsnake	Goat Spring
Trans-Pecos rat snake	Arroyo Scrub Community, Semidesert Grassland Community
Great Plains rat snake	Arroyo Scrub Community
Kansas glossy snake	Sandy substrates , found in Creosote Scrub Community and the Mariola Scrub Community during survey
Sonoran gopher snake	All individuals in survey were found in different plant communities
Texas longnose snake	Creosote Scrub Community
variable groundsnake	Creosote Scrub Community
southwestern black-headed snake	One individual on a rocky ledge
Texas nightsnake	Transitional zone between Arroyo Scrub Community and the Semidesert Grassland Community
Trans-Pecos copperhead	Only found near permanent water; abundant at Buttrill Springs (in Creosote Scrub Community)
western diamondback rattlesnake	Every plant community below 1,211 meters (4,000 feet)
Mojave rattlesnake	East side of the Rosillos Mountains in survey; Creosote Scrub, Arroyo Scrub, or Mariola Scrub communities below 914 meters (3,000 feet)
black-tailed rattlesnake	Semidesert Grassland Community
mottled rock rattlesnake	Alamo Spring in Arroyo Scrub Community; Bone Spring in Creosote Scrub Community

[1]Formerly classified as the western collared lizard (*Crotaphytus collaris baileyi*), a subspecies that is no longer recognized as distinct
[2]Southern prairie lizard (*Sceloporus undulatus consobrinus*) not included in NPS Certified Species List
[3]Regal ring-neck snake (*Diadophis punctatus regalis*) is a subspecies of ring-necked snake; not included in NPS Certified Species List

Plate 25 and Plate 26 display reptile locations from an unpublished survey by Dayton (2005a) between 2001 and 2004. During this study, locations were documented in the park for 17 snake and 13 lizard species.

Prival and Goode (2005) focused their survey efforts on three mountain ranges within the park. The Sierra Quemada range is located just south of the Chisos Mountains, while the Sierra del

Caballo Muertos are on the eastern edge of the park and the Mesa de Anguilas lie in the park's southwest corner. The species found in each of these ranges are presented in Table 41.

Table 41. Reptile species documented in each of the three mountain ranges within BIBE surveyed by Prival and Goode (2005).

Scientific Name	Sierra Quemada	Sierra del Caballo Muerto	Mesa de Anguila
Trans-Pecos striped whiptail		x	x
marbled whiptail	x	x	x
Big Bend spotted whiptail	x	x	x
common checkered whiptail			x
Trans-Pecos rat snake		x	
Texas banded gecko	x	x	x
reticulate banded gecko		x	x
Chihuahuan greater earless lizard	x	x	x
western diamondback rattlesnake	x		x
mottled rock rattlesnake		x	
black-tailed rattlesnake		x	x
ring-necked snake		x	
Great Plains skink	x	x	
short-lined skink		x	
Chihuahuan hook-nosed snake	x	x	
Texas nightsnake	x	x	x
western coachwhip	x		
central Texas whipsnake	x		
Texas long-nosed snake		x	x
mountain patch-nosed snake	x	x	
Big Bend patch-nosed snake	x		
southwestern fence lizard	x	x	
Big Bend canyon lizard	x	x	x
crevice spiny lizard	x	x	
ground snake; variable groundsnake		x	
southwestern black-headed snake	x	x	
western black-necked garter snake	x		
Texas lyresnake		x	
Big Bend tree lizard	x		x
side-blotched lizard	x	x	

Rotenberry et al. (2008) mapped the habitat suitability (i.e., potential distribution) within BIBE for 11 lizard and 5 snake species. According to their niche modeling, only three of the studied reptile species showed limited suitable habitat within the park: the eastern collared lizard (*Crotaphytus collaris*), the southwestern fence lizard (*Sceloporus cowlesi*), and the mottled rock rattlesnake (*Crotalus lepidus*). Species with broader habitat suitability in the park, along with a general description of habitat locations, are listed in Table 42.

Table 42. General locations of suitable reptile habitat within BIBE, according to Rotenberry et al. (2008).

Common name	Habitat locations
Lizards	
Trans Pecos striped whiptail	east and central park
marbled whiptail	north and central park
Big Bend spotted whiptail	north and central park
Texas banded gecko	throughout park
greater earless lizard	scattered throughout park
canyon lizard	throughout park
crevice spiny lizard	throughout park, mostly in west
Big Bend tree lizard	scattered throughout
side-blotched lizard	north and central park
Snakes	
western diamondback rattlesnake	throughout park
northern black-tailed rattlesnake	throughout park
Texas nightsnake	throughout park
coachwhip	throughout park

Turtle species in BIBE are restricted to the few areas in the park with permanent water features (NPS 2010b). The non-native red-eared slider is present in Beaver Pond at Rio Grande Village, and one individual was captured in the Rio Grande River within 36.6 m (40 yds) of the pond (Jackson et al. 2007). The non-native Berlandier's tortoise has been found in the Chisos Basin and Rio Grande Village regions of BIBE, where they were likely released as unwanted pets (Prival and Goode 2005).

The Mediterranean house gecko is also non-native, and its distribution is restricted to human structures within BIBE (NPS 2006). Prival and Goode (2005) found the Mediterranean house gecko on the walls of the Barker House near the Rio Grande Village, in the Rio Grande Village, and at Panther Junction. The species was not found in any natural areas of BIBE during the survey. The non-native green anole is found on buildings, in shrubs, or high in trees; the only records of the species in BIBE include an individual seen climbing a tree near Beaver Pond, and another individual in a tree along the boardwalk (Dayton 2005c).

Threats and Stressor Factors

Road-kill by vehicles is the most significant anthropogenic cause of reptile fatality in BIBE (Skiles, pers. communication, 2011). Poaching is another problem affecting targeted species along roads in the park (Skiles, pers. communication, 2011). Significant poaching occurred in BIBE and the surrounding area during the mid to late 1980s before laws were put into place to curtail the practice in Texas, although poaching remains a threat to reptiles in and around the Park (B. Alex, pers. communication, 2011).

The non-native red-eared slider poses a threat to the genetic integrity of the endemic Big Bend slider in BIBE. The two species have been shown to hybridize in the park; however, the abundance of the red-eared slider is low and the species appears to have an isolated distribution focused in and around Beaver Pond (Jackson et al. 2007). A lesser threat posed by the red-eared slider is the potential for the turtle to outcompete native species for resources (Jackson et al. 2005).

Data Needs/Gaps

More long-term reptile monitoring would provide better information on changes in species abundance, diversity, and distribution over time. Reptile surveys have been conducted sporadically and generally cover only a portion of BIBE. Betty Alex (pers. communication, 2011) has noted a significant decline in snake abundance between 1981 and the present; more long-term reptile abundance and distribution studies could quantify this potential trend at BIBE.

Overall Condition

Species Diversity

The project team defined the *Significance Level* for species diversity as a 3. Reptile diversity is high in BIBE, representing many different taxa. There are several non-native reptile species present in the park as well. The *Condition Level* of species diversity is a 1, representing a low level of concern.

Species Distribution

A *Significance Level* of 2 was assigned to the measure of species distribution. Reptiles are present throughout the desert ecosystem in BIBE, but appear to be more abundant at lower elevations. The *Condition Level* of species distribution is a 0.

Weighted Condition Score

The *Weighted Condition Score* for reptiles in BIBE is 0.200, indicating a low level of concern for this component. However, anecdotal descriptions of reptile declines in BIBE not discussed in published literature indicate that more concern may be warranted for this component. There is not enough long-term data available to determine a trend for reptiles in the park.

Reptiles

Measures	SL	CL
• Species Diversity	3	1
• Species Distribution	2	0

WCS = 0.200

4.14.6 Sources of Expertise

Betty Alex, BIBE GIS Specialist

Raymond Skiles, BIBE Wildlife Biologist

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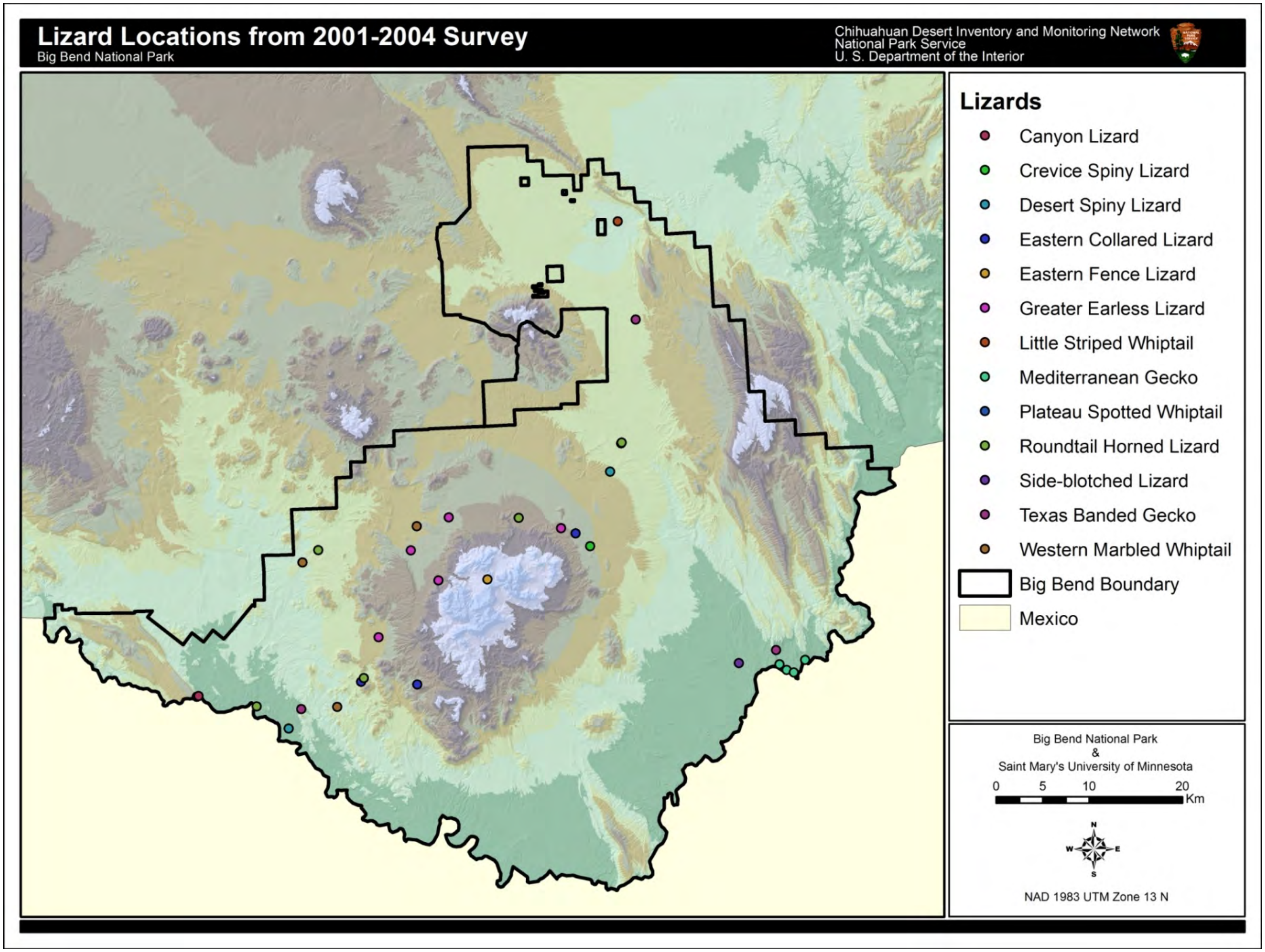

Plate 25. Lizards captured in BIBE herpetofauna survey, 2001-2004 (Dayton 2005b).

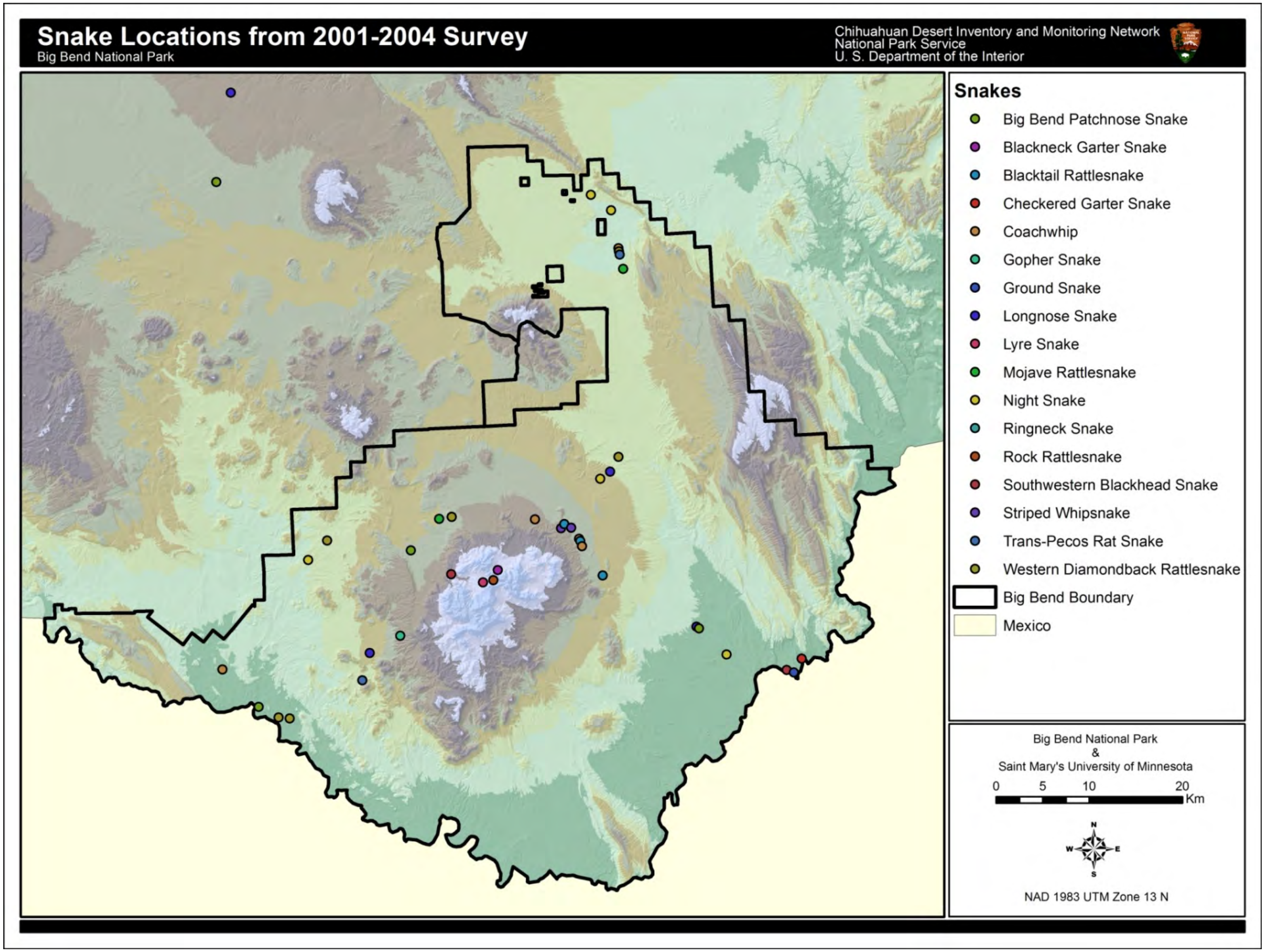

Plate 26. Snakes captured in BIBE herpetofauna survey, 2001-2004 (Dayton 2005b).

4.15 Air Quality

4.15.1 Description

Air pollution can significantly affect natural resources and their associated ecological processes, and the health of visitors and residents. Consequently, air quality in parks and wilderness areas is protected and regulated through the 1916 Organic Act and the Clean Air Act of 1977 (CAA) and the CAA's subsequent amendments. The Clean Air Act defines two distinct categories of protection for natural areas, Class I and Class II airsheds. Class I airsheds receive the highest level of air quality protection as offered through the CAA; only a small amount of additional air pollution is permitted in the air shed above baseline levels. For Class II airsheds, the increment ceilings for additional air pollution above baseline levels are slightly greater than for Class I areas and allows for moderate development (EPA 2008a). BIBE is designated as a Class I airshed.

Parks designated as Class I and II airsheds typically use the Environmental Protection Agency's (EPA) National Ambient Air Quality Standards (NAAQS) for criteria air pollutants as the ceiling standards for allowable levels of air pollution. The EPA believes these standards, if not exceeded, protect human health and the health of natural resources (EPA 2008a). The CAA also establishes that current visibility impairment in these areas must be remedied and future impairment prevented (EPA 2008a). However, the EPA acknowledges that the current NAAQS are not necessarily protective of ecosystems and is currently developing secondary NAAQS for ozone, nitrogen, and sulfur compounds to protect sensitive plants, lakes, streams, and soils (EPA 2010a, EPA 2010b). To comply with CAA and NPS Organic Act mandates, the NPS established a monitoring program that measures air quality trends in many park units for key air quality indicators, including atmospheric deposition, ozone, and visibility (NPS 2008).

Despite BIBE's remote location in rural southwest Texas, air quality conditions in the park are degraded at times and vary significantly depending on the season (Pitchford et al. 2004, NPS 2011a). A number of pollution sources, both domestic and international, influence air quality within the park, particularly pollutants that affect visibility (NPS 2010b). Emissions from coal-burning power plants and other industrial operations in eastern Texas, the Gulf Coast (Houston and Galveston, Texas), other parts of the southern and eastern U.S., and northeastern and central Mexico travel to BIBE on prevailing summer winds (Malm 1999, Pitchford et al. 2004, NPS 2011a). These significantly reduce visibility in the park and contribute to deposition of nitrogen and sulfur onto park lands (Malm 1999, Pitchford et al. 2004, NPS 2011a). BIBE air quality is also affected by particulate matter (carbon), which tends to peak in spring due to fires burning in Mexico and Central America, while windblown dust and soil from the African continent impact the park in summer months (Pitchford et al. 2004).

4.15.2 Measures

- Atmospheric deposition of nitrogen
- Atmospheric deposition of sulfur
- Deposition/concentration of mercury
- Ozone concentration
- Visibility
- Particulate matter (PM 2.5)

Atmospheric Deposition of Sulfur and Nitrogen

Sulfur and nitrogen oxides are emitted into the atmosphere primarily through the burning of fossil fuels, industrial processes, and agricultural activities (EPA 2008b). While in the atmosphere, these emissions form compounds that may be transported long distances and settle out of the atmosphere in the form of pollutants such as particulate matter (e.g., sulfates, nitrates, ammonium) or gases (e.g., nitrogen dioxide, sulfur dioxide, nitric acid, ammonia) (EPA 2008b, NPS 2008). Atmospheric deposition can be in wet (i.e., pollutants dissolved in atmospheric moisture and deposited in rain, snow, low clouds, or fog) or dry (i.e., particles or gases that settle on dry surfaces as with windblown dusts) form (EPA 2008b). Deposition of sulfur and nitrogen can have significant effects on ecosystems including acidification of water and soils, excess fertilization or increased eutrophication, changes in the chemical and physical characteristics of water and soils, and accumulation of toxins in soils, water and vegetation (NPS 2008, reviewed in Sullivan et al. 2011a and 2011b). Due to an abundance of calcium minerals in the soils and rocks, surface waters and aquatic communities in BIBE have a high buffering capacity for acidity from atmospheric deposition (Zak 2006, NPS 2011a). However, the native vegetation in the arid upland and grassland communities in BIBE are adapted to low nitrogen conditions and, thus, are sensitive to excess nitrogen deposition; non-natives that prefer nitrogen rich environments (like the invasive cheatgrass [*Bromus tectorum*] may displace native species in these sensitive communities as nitrogen deposition increases (Zak 2006, NPS 2011a, Sullivan et al. 2011a and 2011b).

Mercury

Sources of atmospheric mercury include fuel combustion and evaporation (especially coal-fired power plants), waste disposal, mining, industrial sources, and natural sources such as volcanoes and evaporation from mercury-enriched soils, wetlands, and oceans (EPA 2008b). Mercury deposited into rivers, lakes, and oceans can accumulate in various aquatic species resulting in exposure to wildlife and humans (EPA 2008b).

Ozone

Ozone occurs naturally in the earth's atmosphere where, in the upper atmosphere, it protects the earth's surface against ultraviolet radiation (EPA 2008b). However, it also occurs at the ground level (i.e., ground-level ozone) where it is created by a chemical reaction between nitrogen oxides and volatile organic compounds (VOCs) in the presence of heat and sunlight (NPS 2008). Ozone is also one of the most widespread pollutants affecting vegetation in the U.S. (NPS 2008).

Considered phytotoxic, ozone can cause significant foliar injury and growth effects for sensitive plants in natural ecosystems (EPA 2008a, NPS 2008). Specific effects include reduced photosynthesis, premature leaf loss, and reduced biomass; prolonged exposure can increase vulnerability to insects and diseases or other environmental stresses (NPS 2008). At high concentrations, ozone can aggravate respiratory and cardiovascular diseases, reduce lung function, cause acute respiratory problems, and increase susceptibility to respiratory infections (EPA 2008b, EPA 2010c); this would be a concern for visitors and staff engaging in aerobic activities in the park, such as hiking.

Particulate Matter (PM) and Visibility

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets that become suspended in the atmosphere. PM is categorized as fine particles ($PM_{2.5}$), which are 2.5 micrometers in diameter or smaller, and inhalable coarse particles (PM_{10}), which are smaller than 10 micrometers (the width of a single human hair) (EPA 2009a). Particulate matter largely consists of acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (EPA 2008a, EPA 2009a). Fine particles are a major cause of reduced visibility (haze) in many national parks and wildernesses (EPA 2010b). $PM_{2.5}$ can be directly emitted from sources such as forest fires or they can form when gases emitted from power plants, industry and/or vehicles react with air (EPA 2009a, EPA 2010d). Sources of coarse particles (PM_{10}) include grinding or crushing operations and windblown or stirred up dust from dirt surfaces (e.g., roads, agricultural fields). Particulate matter either absorbs or scatters light. As a result, the clarity, color, and distance seen by humans, decreases, especially during humid conditions when additional moisture is present in the air (EPA 2010d). BIBE has several panoramic vistas that attract a number of visitors each year; however, the average natural visual range is frequently impaired by air pollution and panoramic views often appear hazy as a result of elevated levels of fine particles in the air (NPS 2011a). PM_{10} and $PM_{2.5}$ are also a concern for human health as these particles can easily pass through the throat and nose and enter the lungs (EPA 2008b, EPA 2009a, EPA 2010d). Short-term exposure to these particles can cause shortness of breath, fatigue, and lung irritation (EPA 2008b, EPS 2009a).

4.15.3 Reference Conditions/Values

The ideal reference condition for air quality in BIBE is the condition prior to Anglo settlement of the area. Although no baseline data exist that characterize air quality conditions in BIBE prior to settlement, there are estimates of air quality natural conditions available from the literature that can be used to establish reference conditions. These estimated reference conditions can be used for comparison with current air quality conditions. Substantial monitoring efforts have been ongoing in the park since 1978 and, thus, monitoring data for the period of record may be examined for trends in air quality. The NPS Air Resources Division (ARD) developed an approach for rating air quality conditions in national parks, based on the current NAAQS, ecosystem thresholds, and visibility improvement goals (Table 43) (NPS 2010a). Assessment of current condition of nitrogen and sulfur atmospheric deposition is based on wet (rain and snow) deposition. Ozone condition is based on the NAAQS standard of 75 parts per billion (ppb) (an annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years). Visibility conditions are assessed in terms of a Haze Index, a measure of visibility, termed deciviews, that is derived from calculated light extinction and represents the minimal perceptible change in visibility to the human eye (NPS 2010a). Finally, NPS ARD recommends the following values for determining air quality condition (Table 43). The "good condition" metrics may be considered the reference condition for BIBE.

Table 43. National Park Service Air Resources Division air quality index values (NPS 2010a).

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

*a unit of visibility proportional to the logarithm of the atmospheric extinction (TCEQ 2012); one deciview represents the minimal perceptible change in visibility to the human eye.

4.15.4 Data and Methods

Monitoring in the Park

An air quality monitoring program was established in BIBE in 1978 in response to noticeable changes in air quality during the 1970s (NPS 2010b). Air quality monitoring in the park includes ozone monitoring (NPS Gaseous Pollutant Monitoring Program [GPMP]), wet deposition monitoring of atmospheric pollutants, including nitrogen and sulfur (National Atmospheric Deposition Program [NADP]), dry deposition monitoring of atmospheric pollutants (Clean Air Status and Trends Network [CASTNet]), and visibility monitoring (Interagency Monitoring of Protected Visual Environments Program [IMPROVE]) (NPS 2010c). Particulate matter concentrations are monitored via the IMPROVE monitor and the TCEQ. However, TCEQ has yearly average summaries available only for 2008 through 2011. Data provided through IMPROVE represent a much longer record (1994 through 2010) and, thus, is used as the primary data source for reporting on particulate matter concentrations in the park. Additionally, data from all on-site monitors are used to evaluate trends in air quality at the park, most recently for the period 1999-2008.

NPS Data Resources

In addition, NPS ARD provides estimates of ozone, wet deposition of nitrogen and sulfur, and visibility that are based on interpolations of data from all air quality monitoring stations operated by NPS, EPA, various states, and other entities, averaged over five years (2005-2009). These estimates are available from the Explore Air website (NPS 2011b) and are used to evaluate air quality conditions. Note that on-site or nearby data are needed for a statistically valid trends analysis, while a five-year average interpolated estimate is preferred for the condition assessment. NPS ARD (2010d) reports on air quality conditions and trends in an annual report for over 200 park units, including BIBE.

CHDN (2004) reports on the estimated risk of foliar injury from ozone on native vegetation in national parks in the CHDN. Information on ozone sensitive plant species present in the parks, levels of ozone exposure, and relationships between exposure and soil moisture are synthesized into a risk assessment of foliar injury for each park, including BIBE.

Special Air Quality Studies

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

The Visibility Information Exchange Web System (VIEWS) database provided average annual visibility monitoring data (in deciviews [dv]) and trend graphics for BIBE from 1989 through 2005 (VIEWS 2010). The IMPROVE Program provided access to annual summary data for particulate matter concentrations in the park (IMPROVE 2011), as well as a catalogue of standardized visibility photos with examples of visibility conditions that range from very poor to excellent visibility in the park (IMPROVE 2010). BIBE also maintains a permanent camera that takes photos of one scene and distance three times each day (9:00 AM, 12:00 PM, and 3:00 PM), to capture daily visibility conditions in the park. Images capturing the current condition are available on the park website daily.

The Big Bend Regional Aerosol and Visibility Observational (BRAVO) study was initiated to characterize impacts to visibility and causes of haze conditions in BIBE. Sponsored by the EPA, NPS, and the TCEQ, the study consisted of a 4-month intensive monitoring effort in 1999 (July to October) and subsequent data analysis (Pitchford et al. 2004). The goals of the study were to better distinguish pollution source regions and source types, to determine the chemical constituents of fine particles responsible for regional hazes affecting BIBE, and to determine the effects of meteorological conditions on air pollution particles and haze conditions (Pitchford et al. 2004). The study employed a perfluorocarbon tracing technology that allowed researchers to determine sources of emissions pollution contributing to particulate haze in BIBE by examining the travel of traceable particles via predominant airflow regimes leading into BIBE. Results are presented in the Current Condition and Trend section.

Following growing concerns about decreased air quality in BIBE in the late 1970s, Wetmore (1980) resurveyed locations in the park where lichen species were surveyed previously (1966, 1969, and 1970). These earlier surveys were conducted prior to the dramatic decline of air quality in the park. Researchers compared lichen flora present in 1980 to lichen flora present prior to declines in air quality in an attempt to determine if changes in the lichen communities may be coinciding with increased air pollution.

The Western Airborne Contaminants Assessment Project (WACAP) by Landers et al. (2008) was a large collaborative research effort (among EPA, NPS, USGS, U.S. Forest Service [USFS], Oregon State University, and Washington State University) to determine the risk from airborne contaminants (including persistent organic pollutants, pesticides, nitrates and sulfates) to the ecosystems of national parks in the western U.S., including BIBE. Over the course of 6 years (2002-2007), researchers assessed the concentrations and associated biological effects of numerous airborne contaminants on various ecosystem components including air, snow, water, soils, lichens, conifer needles, and fish across multiple national parks. In BIBE, samples of air, lichens, and conifer needles were examined for presence and effects of certain contaminants, such as current and historic use pesticides, combustion by-products, and industrial compounds.

4.15.5 Current Condition and Trend

Atmospheric Deposition of Nitrogen and Sulfur

Five-year interpolated averages of total nitrogen (from nitrate and ammonium) wet deposition and total sulfur (from sulfate) wet deposition are used to estimate condition for deposition; using a five-year average smoothes out annual variations in precipitation, such as heavy precipitation one year versus drought conditions in another (NPS 2011b). The current 5-year average (2005-2009) estimates total wet deposition of nitrogen in BIBE at 1.09 kg/ha/yr, while total wet deposition of sulfur is 0.83 kg/ha/yr (NPS 2011b). Relative to the NPS ratings for air quality conditions (see Table 43 for ratings values), atmospheric deposition of nitrogen falls into the *Moderate Concern category*, while deposition of sulfur is in *Good Condition*. However, several factors are considered when rating the condition of atmospheric deposition, including effects of deposition on different ecosystems (NPS 2010a). Based on the NPS process for rating air quality conditions, ratings for parks with ecosystems considered potentially sensitive to nitrogen or sulfur deposition are typically adjusted up one condition category. In general, arid and semi-arid ecosystems are considered to be sensitive to increased levels of nitrogen and sulfur, as acidification and nutrient enrichment cause shifts in native species composition and encroachment of exotic species and grasses (Zak 2006, reviewed in Sullivan et al. 2011a and 2011b). BIBE comprises extensive arid and semi-arid vegetation communities, which are at risk from increased deposition, particularly nitrogen. Thus, the condition for deposition of nitrogen in the park may be considered to be of *Significant Concern*, while sulfur deposition may be considered to be of *Moderate Concern*. Trend analysis of wet deposition data collected in BIBE from 1999-2008 indicates a possible, but not statistically significant, improvement in nitrate deposition based on trend, while sulfate deposition is stable (NPS 2010d).

The impact of nitrogen deposition varies depending on the habitat type and the condition of the habitat. For example, intact grasslands can integrate additions of nitrogen, while highly degraded grasslands may no longer have the biogeochemical capacity to take in nitrogen additions (Bennett, pers. communication, 1 November 2013). In some of the highly degraded areas of BIBE, researchers have found nitrogen levels to be near toxicity in bare patches; it has been hypothesized that these bare/highly degraded areas will not be able to be restored unless the altered carbon/nitrogen ratio is addressed and more completely understood.

Concentrations (mg/L) of nitrogen, sulfur, and ammonium compounds in wet deposition can be used to evaluate trends in deposition of total nitrogen and sulfur. Since atmospheric wet deposition can vary greatly depending on the amount of precipitation that falls in any given year, it can be useful to examine concentrations of pollutants, which factor out the variation introduced by precipitation. Annual averages from 2000-2010 indicate that nitrate and sulfate concentrations in BIBE are decreasing slightly (NADP 2011) (NPS 2011b) (Figure 54).

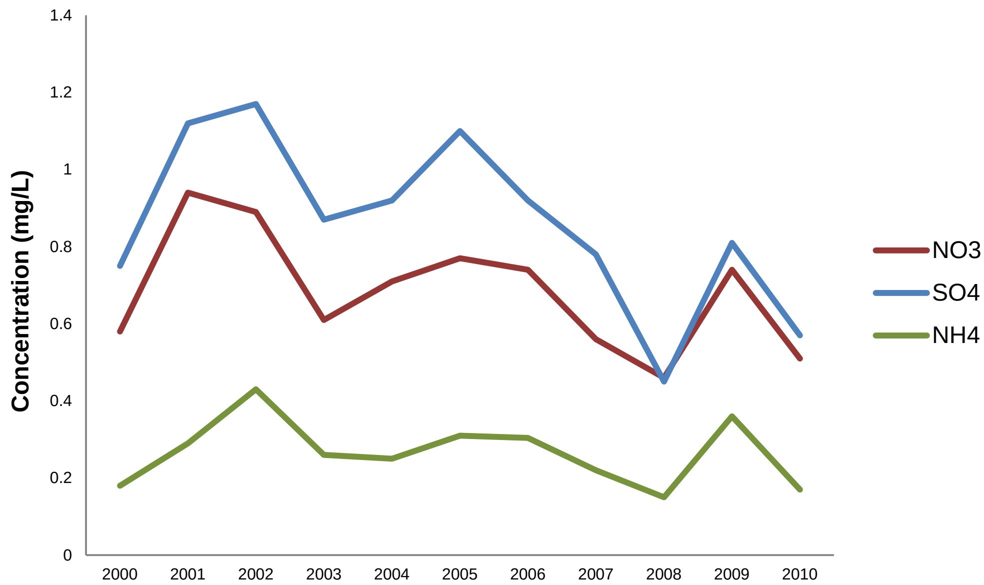

Figure 54. Annual average concentrations of sulfate (SO_4), nitrate (NO_3), and ammonium (NH_4) (mg/L) in precipitation in BIBE, 2000-2010 (NADP monitoring site TX04) (Source: NADP 2011). Note: Ammonium (NH_4) is included because it adds significantly to total nitrogen deposition.

Though nitrate, sulfate, and ammonium concentrations in wet deposition seem to be declining slightly, Landers et al. (2008) observed elevated nitrogen concentrations in lichens and an abundance of nitrophytic lichens (lichens that require or tolerate high amounts of nutrients) at various sites in the park, suggesting enhanced nitrogen or other nutrient deposition in the region. Further investigation of aerosol particulate data (via IMPROVE) indicates ammonium sulfate may contribute significantly to this finding (Landers et al. 2008).

Dry deposition (dust, particles, and aerosols) also contributes significantly to total deposition at BIBE. CASTNet data indicate that dry and wet forms contribute about equally to total deposition (EPA 2012) (Figure 55 and Figure 56). Figure 55 indicates that reduced forms of nitrogen (i.e., ammonium [NH_4]) contribute about 40% of total nitrogen deposition; this is likely an underestimate because ammonia gas is not included in the measurements.

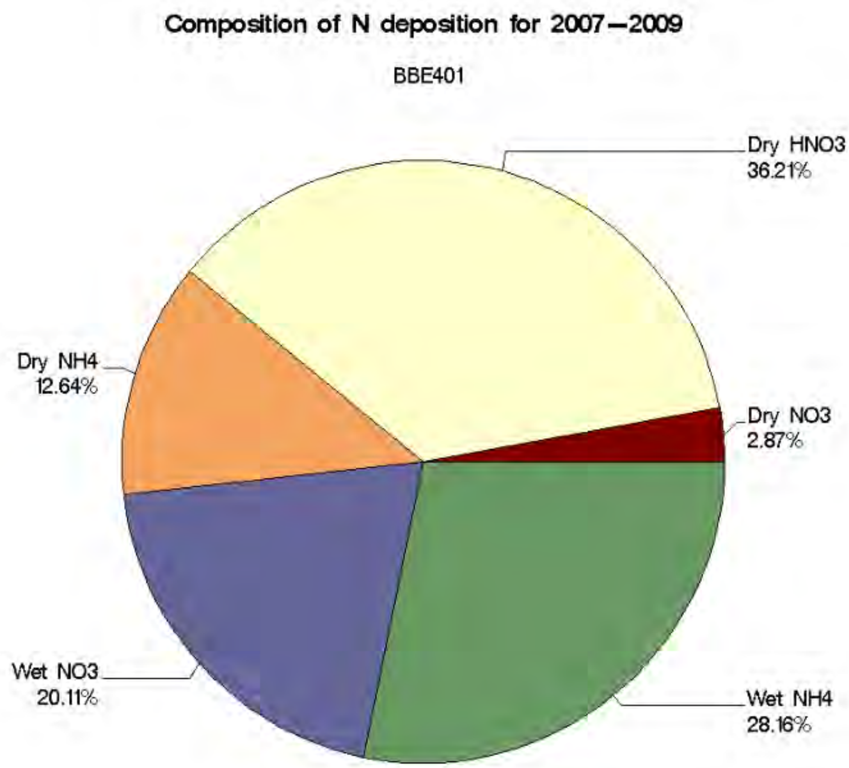

Figure 55. Composition of nitrogen deposition in BIBE, 2007-2009 (EPA 2012). Monitoring site ID number is BBE401.

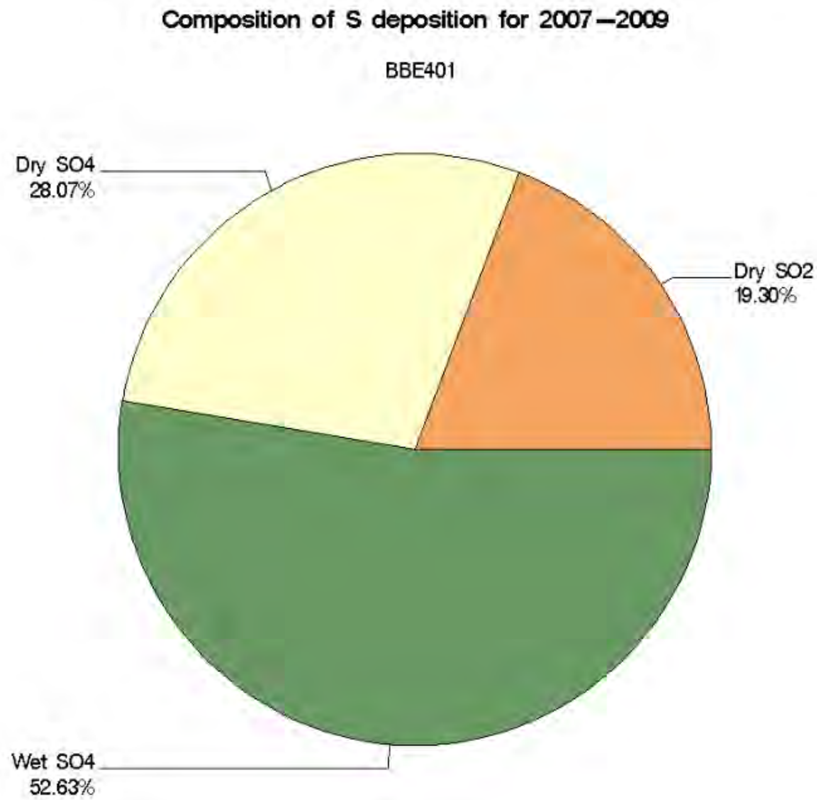

Figure 56. Composition of sulfur deposition in BIBE, 2007-2009 (EPA 2012). Monitoring site ID number BBE401).

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

Atmospheric Deposition of Mercury

To date, no monitoring data are available for mercury deposition or concentration in BIBE. The nearest monitoring station is located in south central New Mexico, approximately 676 km (420 mi) northwest of the park. It is not appropriate to interpolate from stations that far from the park.

Mercury mining was prevalent in the BIBE region beginning in 1888 and operating intermittently through approximately 1972 (Gray et al. 2008). Gray et al. (2008) evaluated mercury emissions in soil gas and air at abandoned mercury mine sites in BIBE. Although concentrations of mercury in soil gas in mine waste were elevated for the mines studied (up to 21,0000 ng/m^3), researchers found that persistent winds rapidly dispersed mercury emissions to concentrations that were similar to those found at regional baseline sites (1.2-17 ng/m^3). Baseline measurements in BIBE were similar to mercury concentrations found in ambient air measurements worldwide (1-4 ng/m^3). Gray et al. (2008) concluded that mercury concentrations found in air and soil gases at baseline sites in BIBE suggest that emissions from mine sites in the park contribute little influence on mercury concentrations in the region. Concentrations do not pose an inhalation health risk for visitors to the park.

Ozone

The NAAQS standard for ground-level ozone is the benchmark for rating current ozone conditions within park units. The condition of ozone in NPS park units is determined by calculating the 5-year average of the fourth-highest daily maximum of 8-hour average ozone concentrations measured at each monitor within an area over each year (NPS 2010a). The current 5-year average (from 2005-2009) for BIBE indicates an average ground-level ozone concentration of 66.4 ppb (NPS 2011b), which falls under the *Moderate Concern* category based on NPS guidelines. Trend analysis of annual data collected in the park from 1999-2008 indicates ozone concentrations in the park are of moderate concern but are stable overall (NPS 2010d). Figure 57 illustrates this trend using average annual ozone concentrations (in ppm) from 1992, when monitoring began in BIBE, to 2010, with respect to the national standard.

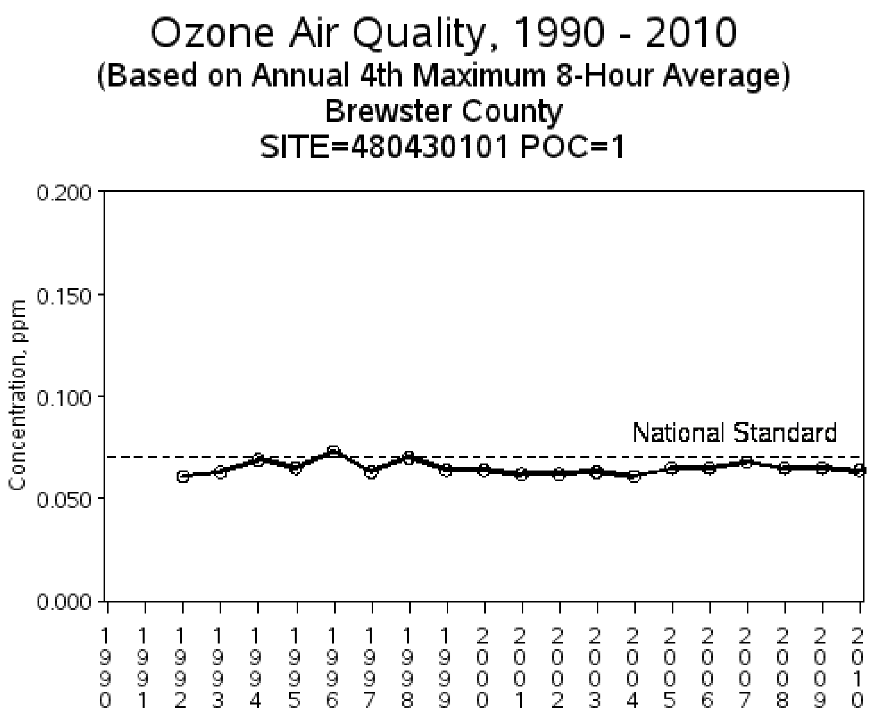

Figure 57. Average annual 4th highest 8-hour ozone (O_3) concentrations (ppm) for BIBE, 1992-2010 (Source: EPA 2009b). Note: Site 480430101 is the monitor located in the park.

CHDN (2004) assessed ozone concentrations in the CHDN and the risk of injury to plant species that are sensitive to sustained ozone exposure. Data from 1995-1999 indicate ozone concentrations in BIBE during this time frequently exceeded 60 ppb for a few hours each year and rarely exceeded 80 ppb; ozone concentrations never exceeded 100 ppb. Sensitive plant species begin to experience foliar injury when exposed to ozone concentrations of 80-120 ppb/hour for extended periods of time (8 hours or more) (CHDN 2004). Thus, the risk of foliar injury to plants is deemed to be low due to the low levels of ozone exposure and the dry soil moisture conditions in BIBE (CHDN 2004). However, if ozone concentrations should increase in the future, an on-site monitoring program that assesses foliar injury and growth progress may be necessary (CHDN 2004).

Various species of plants and trees are often monitored to track air pollution impacts. BIBE has five species known to be sensitive to excessive or extended concentrations of ozone: green ash (*Fraxinus pennsylvanica*), ponderosa pine, skunkbush (*Rhus trilobata*) (Photo 21), swamp milkweed (*Asclepias incarnata*), and white sage (*Artemisia ludoviciana*) (CHDN 2004, NPS 2006, NPS 2010c).

Photo 21. Skunkbush, which grows in BIBE, is known to be sensitive to ozone (NPS photo).

Visibility

Visibility impairment occurs when airborne particles and gases scatter and absorb light; the net effect is called "light extinction," which is a reduction in the amount of light from a view that is returned to an observer (EPA 2003). In response to the mandates of the CAA of 1977, federal and regional organizations established IMPROVE in 1985 to aid in monitoring of visibility conditions in Class I airsheds. The goals of the program are to 1) establish current visibility conditions in Class I airsheds; 2) identify pollutants and emission sources causing the existing visibility problems; and 3) document long-term trends in visibility (NPS 2009).

The most current 5-year average (2005-2009) estimates visibility in the park to be 7.0 dv (this is an estimate above the estimated natural conditions) (NPS 2011b). This falls into the *Moderate Concern* category for NPS air quality condition assessment.

The clearest and haziest 20% of days each year also are examined for parks (NPS 2009). Conditions measured near 0 dv are clear and provide excellent visibility, and as dv measurements increase, visibility conditions become hazier. Figure 58 depicts visibility data (in dv) collected in BIBE for the 20% best (clearest) and 20% worst (haziest) days, as well as the default natural conditions for both (VIEWS 2010). Trend analysis of data from 1999-2008 indicate visibility to be of moderate concern with a possible improvement in visibility conditions on both the clearest and haziest days; however, this was not indicated to be a statistically significant change (NPS 2010d). Photo 22 provides examples of visibility conditions during the least hazy and haziest days.

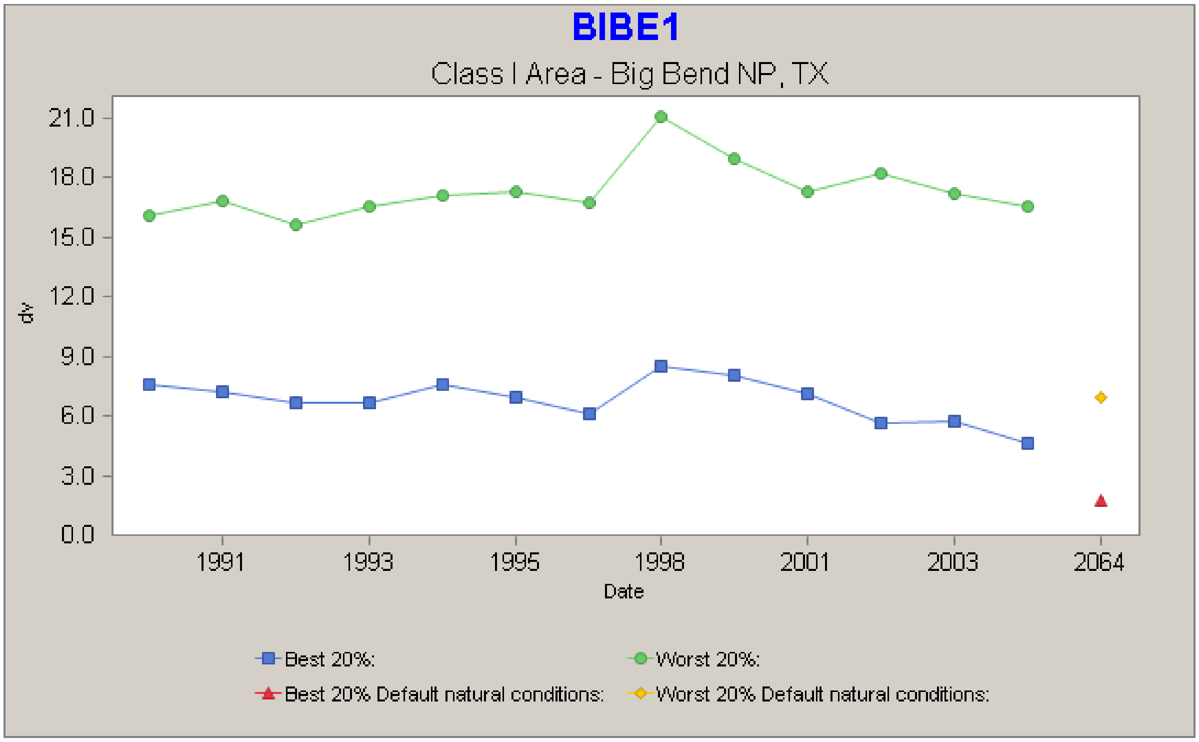

Figure 58. Annual visibility in BIBE, 1990-2004 (VIEWS 2010). Values at 2064 are the natural background visibility conditions, set by EPA Regional Haze Rule, to which all Class I areas are required to restore visibility conditions by 2064.

Photo 22 (left to right). Views of Dagger Mountain in BIBE during "excellent" and "poor" visibility (Source: IMPROVE 2010).

BRAVO Study

Results from the intensive sampling during the BRAVO study indicate that, although a variety of aerosol pollutants affect air quality and visibility in the park, particulate sulfate compounds are the primary contributor to haze in BIBE, more so than any other type of aerosol compound or component (Pitchford et al. 2004). Sulfate compounds accounted for approximately 50% of the overall haze in the park during the BRAVO study period, and organic compounds and light absorbing carbon constituted the majority of the remaining haze in the park during the study (Pitchford et al. 2004).

Perfluorocarbon tracing technology allowed researchers to examine the origin of particulate matter, and how it is carried on predominant airflows into BIBE. During the 4-month study period, Pitchford et al. (2004) determined that various regions of the U.S. contributed on average approximately 26% of the particulate haze during the study, with emissions originating from the eastern U.S. (the biggest contributor), western U.S., and Texas (particularly eastern Texas); Mexico contributed on average approximately 18% of the particulate haze in BIBE (Pitchford et al. 2004). Emissions originated from such sources as coal-burning power plants, oil refineries, metal smelters, agricultural burning, and other industrial processes in the U.S. (especially northeast Texas) and Mexico. The largest single sources of sulfate emissions was determined to be the two *Carbón* power plants located in northern Mexico approximately 48 km (30 mi) from BIBE and the Big Brown coal-fired power plant in northeast Texas; however, these plants do not seem to be primarily responsible for the haziest days in BIBE (Pitchford et al. 2004).

Figure 59 illustrates the proportion of sulfate haze versus non-sulfate haze (e.g., soil, dust, organic carbon) for the 20% haziest and 20% least hazy days experienced in BIBE during the study period, and the origin of these sulfate compounds. On the haziest days in the park, regions of the U.S. accounted for the majority of sulfate haze in the park, while on the least hazy days, approximately equal amounts of sulfate compounds originated in the U.S. and Mexico.

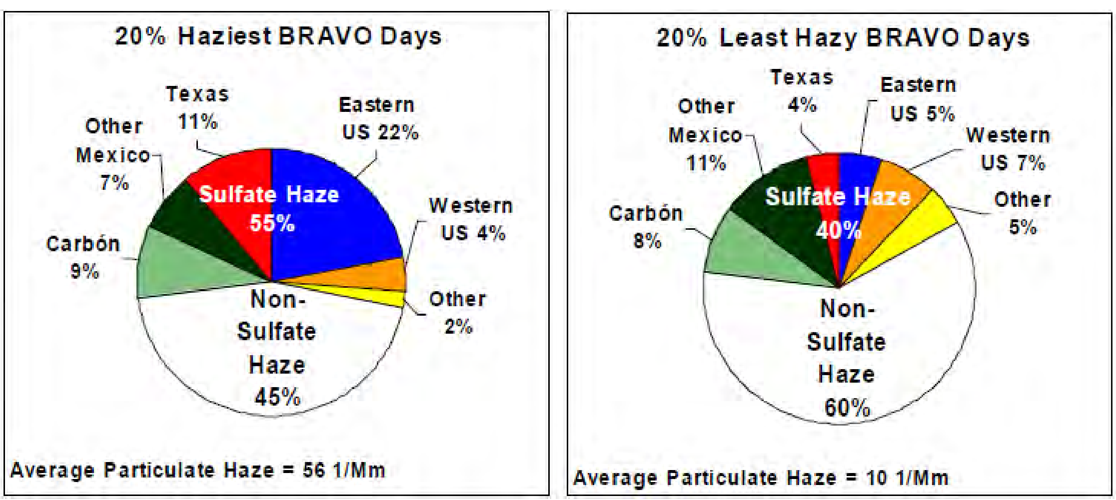

Figure 59. Estimated contributions of particulate sulfate by various source regions to BIBE haze levels on the 20% haziest days and the 20% clearest days during the BRAVO study period (Source: NPS 2004 BRAVO Study Factsheet).

Visibility in the park is affected differently depending on the time of year and the predominant wind direction during these periods (Pitchford et al. 2004). Throughout the majority of the year, air masses moving toward BIBE typically travel over northern Mexico. During winter months, when haze levels are the lowest, air masses travel to BIBE from the western U.S. (Watson et al. 2000, Pitchford et al. 2004). From May to September, southeasterly airflows that arrive in the park travel through areas of high emissions density in eastern Texas and northeastern Mexico, which contribute high concentrations of sulfate aerosols to BIBE air quality; these airflows are also frequently influenced by agricultural and forest burning in Mexico and Central America (Watson et al. 2000, Pitchford et al. 2004).

Particulate Matter ($PM_{2.5}$)

Data on average particulate matter concentrations in BIBE are available from 1994 through 2010, and are summarized as an annual average concentration and average concentrations on the 20% haziest and 20% clearest days in the park (IMPROVE 2011). Overall, average annual $PM_{2.5}$ concentrations in BIBE have been decreasing since 2001 (Figure 60). Concentrations are substantially higher during the 20% haziest days, suggesting that fine particulate matter is a significant contributor to haze in the park. The NAAQS standard for $PM_{2.5}$ is a weighted annual mean of 15.0 $\mu g/m^3$ or 35 $\mu g/m^3$ in a 24-hour period over an average of 3 years (EPA 2010d). Although $PM_{2.5}$ concentrations in BIBE are well within the EPA standards for levels that are protective of human health, concentrations on the haziest days contribute significantly to impaired visibility in the park.

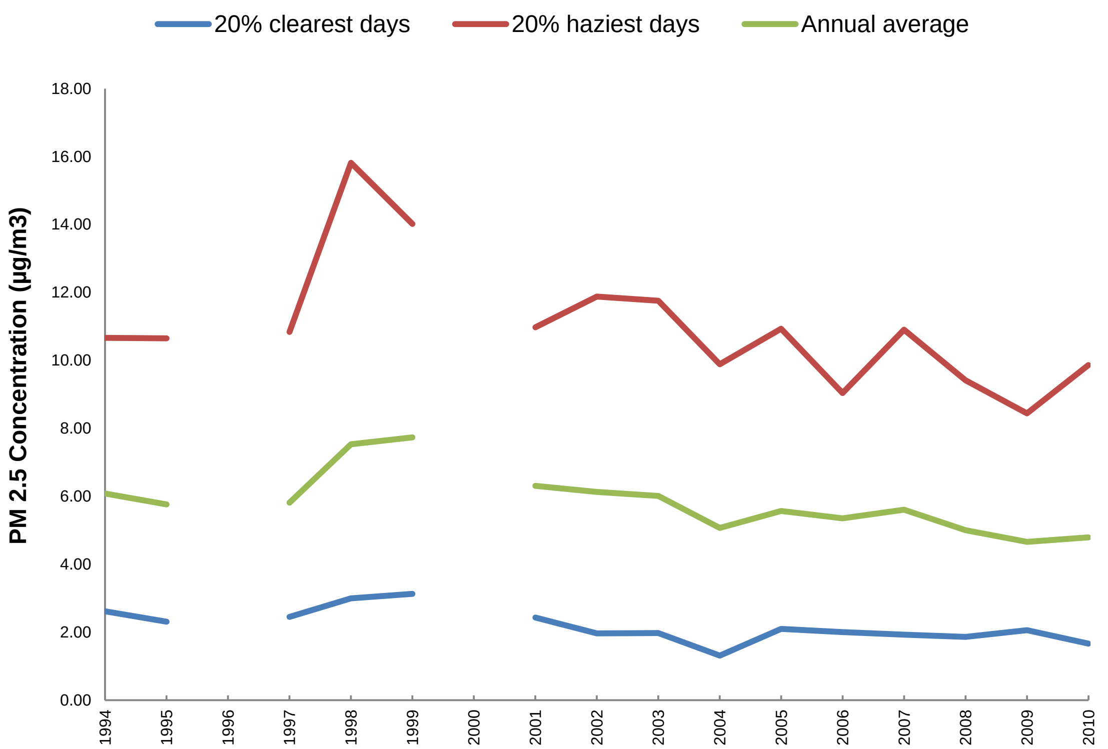

Figure 60. Particulate matter (PM2.5) concentration in BIBE, 1994-2010 (Source: IMPROVE 2011).

Pitchford et al. (2004) collected air quality samples that included coarse and fine particulate matter (PM_{10} and $PM_{2.5}$) measurements during the four months of the BRAVO study (from July to October 1999). Samples were collected daily and analyzed for concentrations of elements, ions, carbon material, and gravimetric mass (less than 2.5 and 10.0 µm). Across the study period, concentrations of fine particulate matter ($PM_{2.5}$) averaged 6.85 $\mu g/m^3$ and were comprised mostly of ammoniated sulfate; coarse particles averaged 4.69 $\mu g/m^3$ and were comprised primarily of soil and organic carbon materials with some ammoniated sulfate and coarse nitrate (Pitchford et al. 2004).

Threats and Stressor Factors

The primary threats to air quality in BIBE are emissions from power plants, energy development activities, and industrial operations in the region. Malm (1999) states that a significant proportion of haze that obscures visibility in the park is composed of airborne sulfate particles that originate from eastern Texas and Mexico. The BRAVO study identified several regional locations, both in the U.S. and Mexico, as the primary sources of sulfur aerosol that affects BIBE air quality and visibility (Pitchford et al. 2004). Sulfur emissions are believed to originate from such sources as coal-fired power plants, petroleum refining, and chemical processing operations (Watson et al. 2000, Pitchford et al. 2004).

Primary sulfur sources in Texas include power plants in east and southeast Texas, as well as oil refineries and industrial plants located along the Gulf Coast, primarily in the Houston area (Watson et al. 2000, Pitchford et al. 2004). Twenty-two coal-burning power plants are located along the extensive Lignite coal belt that stretches from northeast of Dallas-Ft. Worth to the U.S.-Mexico border south of San Antonio; the power plants use coal from this deposit as their primary fuel (Watson et al. 2000). Sources of airborne sulfate in nearby Mexico include coal-burning power plants, oil refining, oil-burning power production, steel production, and other industrial operations (Watson et al. 2000, Pitchford et al. 2004). Two large coal-burning power plants, *Carbón I* and *II*, are located approximately 230 km southeast of BIBE in Mexico. Additionally, the Tampico region on the Gulf of Mexico is the center of oil refining and oil-burning power generation in Mexico; prevailing winds in the summer carry emissions from this region to BIBE (Watson et al. 2000, Pitchford et al. 2004).

Energy development activities such as horizontal drilling, hydro-fracturing (fracking), and extraction in the Eagle Ford Shale of south Texas or the Barnett Shale of northeast Texas, may produce emissions locally and regionally (Bennett, written communication, 15 October 2012). These emissions could be picked up by air masses that move seasonally across Texas (as detailed in the BRAVO study) and carried into BIBE, where it could affect overall air quality.

Nitrogen deposition is a significant threat to ecosystems in BIBE. Nitrogen deposition results from emissions of nitrogen oxides from vehicles, power plants, and other combustion sources, and ammonia from agricultural activities and fires. In ecosystems adapted to naturally low amounts of nitrogen, increased nitrogen deposition can alter plant communities and reduce diversity. Higher nitrogen levels favor certain plant species, like fast-growing invasives, at the expense of native forbs and shrubs (Sullivan 2011b).

Data Needs/Gaps

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

To date, there is no consistent monitoring effort in BIBE that tracks the plant and animal species known to be sensitive to increases in certain pollutants. Nitrogen and sulfur deposition can affect plant communities (e.g., promoting invasive species, loss of biodiversity, or encouraging transition/succession of plant communities), while ozone can cause foliar injury and inhibit growth. Despite having a low risk of exposure to nitrogen and sulfur deposition, Sullivan et al. (2011a, 2011b) indicate that the highly sensitive arid and semi-arid vegetation communities and soils in the park are at moderate risk of acidification due to acid deposition, and at very high risk of various effects from increased nitrogen enrichment if pollutant exposure increases in the future. The sparse vegetation communities of BIBE are particularly sensitive to increases in nitrogen (Zak 2006). Monitoring of plant communities in conjunction with monitoring of nitrogen deposition and soil levels can be used to evaluate impacts from nitrogen impacts.

If ozone levels increased, several plant and tree species in the park could be used to evaluate injury from ozone, including species known to be sensitive to ozone, such as skunkbush, ponderosa pine, white sage, and green ash (NPS 2006). Such species could be used as bioindicators to track potential increases in ozone, as well as long-term impacts to the health of the ecosystem. In 1980, Wetmore (1980) re-examined locations of sensitive fruticose lichens from a 1970 survey in BIBE to look for changes in lichen flora due to increased air pollution and deposition of sulfates and nitrates. The author found lichens in all previously surveyed locations and they exhibited no damage in the past decade (Wetmore 1980); however, subsequent surveys of these lichen sites have not been conducted.

Overall Condition

Atmospheric Deposition of Nitrogen
The project team defined the *Significance Level* for atmospheric deposition of nitrogen as a 1. Sullivan et al. (2011b) and NPS (2010a) rate the arid and semi-arid ecosystems in BIBE as highly sensitive to nutrient enrichment by nitrogen deposition despite an estimate that the park is at low risk of exposure to nitrogen deposition. Nitrogen deposition has fluctuated slightly in recent years but appears relatively stable. Current measurements fall into the significant concern category based on NPS criteria for rating air quality when factoring in the sensitivity of the ecosystem. Landers et al. (2008) found evidence of enhanced nitrogen deposition in the park, while Zak (2006) suggests increased plant productivity may be a result of increased nitrogen in soils. Therefore, deposition of nitrogen is of significant concern (*Condition Level* = 3).

Atmospheric Deposition of Sulfur
The project team defined the *Significance Level* for atmospheric deposition of sulfur as a 3. Sullivan et al. (2011a) and NPS (2010a) also rate the arid and semi-arid ecosystems in the park as highly sensitive to acidification by sulfur deposition and other acids despite an estimate of very low risk of pollutant exposure. Sulfur deposition has fluctuated somewhat in recent years but remains relatively stable. Pitchford et al. (2004) has established that the majority of

particulate haze affecting BIBE is comprised of sulfur compounds. Current measurements fall into the moderate concern category based on NPS criteria for rating air quality. Therefore, deposition of sulfur is of significant concern (*Condition Level* = 2).

Deposition/concentration of Mercury
The project team defined the *Significance Level* for mercury concentration as a 2. No data are available to summarize mercury deposition/concentration rates in or near BIBE. Gray et al. (2008) determined that mercury emissions from abandoned mercury mine waste are rapidly dispersed into the atmosphere and have little to no influence on regional baseline concentrations. Because there is no record of mercury deposition/concentration for much of south and western Texas, it is not possible to determine a *Condition Level* for this measure.

Ozone Concentration
The project team defined the *Significance Level* for ozone concentration as a 2. Current average ground-level ozone concentrations fall into the moderate concern category based on NPS criteria for rating air quality; the trend in 5-year averages indicates a slight increase in concentrations (measured in ppb), while the annual average concentrations (measured in ppm) indicate a stable trend. Therefore, the *Condition Level* for ozone concentration is a 2, of moderate concern.

Particulate Matter (PM 2.5)
The project team defined the *Significance Level* for concentration of fine particulate matter (PM 2.5) as a 3. $PM_{2.5}$ concentrations in the park are well within the EPA standards for levels that are protective of human health. Trends in average concentrations show a slight decline over the last decade; however, concentrations on the haziest days contribute significantly to impaired visibility in the park. The *Condition Level* for $PM_{2.5}$ is a 2, of moderate concern.

Visibility
The project team defined the *Significance Level* for visibility as a 3. Current average visibility falls into the moderate concern category based on NPS criteria; trends in 5-year averages indicate visibility conditions are relatively stable. Average visibility conditions on the 20% clearest days are improving slightly, while visibility for the 20% haziest days remains stable; both still far exceed the specified default natural conditions for the region. The *Condition Level* for visibility is a 2, of moderate concern.

Weighted Condition Score
The *Weighted Condition Score* (WCS) for the air quality component is 0.694, indicating the condition is of high concern with a stable trend.

Air Quality

Measures	SL	CL
• Deposition of nitrogen	1	3
• Deposition of sulfur	3	2
• Mercury deposition/concentration	2	N/A
• Ozone concentration	2	2
• Particulate matter (PM 2.5)	3	2
• Visibility	3	2

WCS = 0.694

4.15.6 Sources of Expertise

Jeffery Bennett, BIBE Physical Scientist

Ellen Porter, NPS Air Resources Division Biologist

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4.16 Water Quality

4.16.1 Description

Water quality monitoring is useful in understanding the chemical and biological condition of aquatic systems, the health of which often depends on specific water quality conditions that sustain native life and processes for plants and animals in the systems. Water quality is a Vital Sign for parks in the CHDN, including BIBE (Huff et al. 2006, NPS 2010). Total dissolved solids, chloride, sulfate, dissolved oxygen, coliform bacteria, and macroinvertebrates are core water quality measures identified by the park.

Changes in surface-water dynamics, such as a reduction in flow and overall availability, can substantially influence water quality, causing impairment to increase. As such, impaired water quality can lead to the loss of species intolerant to poor water quality, a decrease in biodiversity, and shifts in animal and plant species distribution. Consequences such as these, as well as the listing of the Rio Grande as impaired for certain water quality parameters, cause resource managers in BIBE and the CHDN substantial concern about the degradation of surface water quality in the park and throughout the region (NPS 2010).

Photo 23. The Rio Grande in BIBE (Photo by Andy Nadeau, SMUMN GSS).

4.16.2 Measures

- Total dissolved solids (TDS)
- Chloride
- Sulfate
- Dissolved oxygen
- Fecal coliform (*E. coli*)
- Macroinvertebrates

<u>Total Dissolved Solids</u>

Total dissolved solids (TDS) represent the concentration of dissolved inorganic and organic matter in the water. Most TDS are inorganic salts including calcium, magnesium, carbonates, nitrates, chlorides, and sulfates (SDWF 2012). These can accumulate in greater concentrations in arid systems, due to higher rates of evaporation (USGS 1997); these then can make their way into waterways, primarily through runoff. Sources of TDS often include highly erodible landscapes (i.e., soils) that deposit materials into waterways, mineral springs, and agricultural or urban runoff. The concentration of TDS affects the water balance in the cells of aquatic organisms (EPA 2012b); if the TDS are extremely low, an organism's cells will swell, and if the TDS are too high, an organism's cells will shrink. The TDS determines the ease of an organism's ability to remain (i.e., float) in the water column (EPA 2012b).

Chloride

Chloride is an inorganic salt found naturally in water, but additional chloride also can be washed into surface waters from several general sources, including agricultural and urban runoff, road salting, and oil and gas wells (McDaniel 2012). However, road salting and oil and gas wells are not known to be important issues in BIBE to date (Bennett, written communication, 15 November 2012). In arid landscapes, higher rates of evaporation increase mineral accumulation (such as sodium chloride, borates, or gypsum) in soils, lakes, and rivers (USGS 1997). Large amounts of chloride present in surface water are toxic to aquatic life such as fish and macroinvertebrates. Chloride becomes more toxic when combined with potassium or magnesium (NHDES 2008). Toxic metals can also be released when chloride is present in water. Dissolved oxygen levels, a core water quality measurement, are reduced when these metals are released, causing added stress to the aquatic life in the area (NHDES 2008).

Sulfate

Sulfate, like chloride, is an inorganic salt found naturally in surface and ground water. In arid landscapes, sulfates can become concentrated in soils due to higher rates of evaporation (USGS 1997); these can then be carried into waterways by runoff. Elevated levels of sulfate in waterways can be toxic to aquatic life (Lenntech 2011). Some aquatic species are more sensitive to sulfate than others, such as intolerant macroinvertebrates. Possible sources of excess sulfate include sulfate ores, large deposits resulting from evaporation, and industrial wastes (Lenntech 2011), as well as deep circulating ground water aquifers.

Dissolved Oxygen

Dissolved oxygen (DO) is critical for organisms that live in water. Fish and zooplankton filter out or "breathe" dissolved oxygen from the water to survive (USGS 2010). Oxygen enters water from the air, when atmospheric oxygen mixes with water at turbulent, shallow riffles in a water way, or when released by algae and other plants as a byproduct of photosynthesis. As the amount of DO drops, it becomes more difficult for aquatic organisms to survive (USGS 2010). The concentration of DO in a water body is closely related to water temperature (cold water holds more DO than does warm water), altitude, salinity, and steam structure (turbulent, rapid waterways integrate more DO than slow-moving, stagnate waterways) (USGS 2010). Thus, DO concentrations are subject to seasonal fluctuations as low temperatures in the winter and spring allow water to hold more oxygen, and warmer temperatures in the summer and fall cause water to hold less oxygen (USGS 2010).

Fecal Coliform (*E. coli*)

Bacteria are a common natural component of surface waterways and are mostly harmless to humans. However, certain bacteria, specifically those found in the intestinal tracts and feces of warm-blooded animals, can cause illness in humans (USGS 2011). Fecal coliform bacteria are a subgroup of coliform bacteria that, when used in monitoring water quality, can indicate if fecal contamination has occurred in a specific waterway. *E. coli* (*Escherichia coli*) is a species of bacteria that belongs to the larger group of coliform bacteria and is characterized by its ability to break down urease (USGS 2011). Thus, *E. coli* is a preferred indicator for determining if potential pathogens are present in freshwater resources. It is tested by counting colonies that grow on micron filters placed in an incubator for 22-24 hours. High concentrations of *E. coli* can cause serious illness or even death in humans (USGS 2011).

<u>Macroinvertebrates</u>
Macroinvertebrates are aquatic organisms that can be seen by the naked eye. Blackflies, stoneflies, riffle beetles, crayfish, clams, snails, and worms are all examples of macroinvertebrates that inhabit freshwater waterways (EPA 2012a). They can be found in a variety of streams and rivers (e.g., slow and fast moving, clear, muddy) across a diversity of landscapes and climates; the quality of water can affect the composition of species present in a system as well as the abundance of different species (EPA 2011). Macroinvertebrates are generally considered good indicators of stream water quality because they are affected by physical, chemical and biological conditions. Some macroinvertebrates are more sensitive than others and are considered intolerant species, such as stonefly larvae. For example, stoneflies (Order Plecoptera) may be absent in a stream due to low DO levels, elevated temperatures, and agricultural and urban runoff (EPA 2012a).

4.16.3 Reference Conditions/Values
The reference condition for BIBE's water quality is the Texas Commission on Environmental Quality (TCEQ) water quality criterion considered to be protective of aquatic life and human recreation for the Rio Grande in BIBE (river section 2306 that flows throughout the park). Table 44 shows water quality parameter standards set by the TCEQ, which are current as of 2010. It is possible that Segment 2306 may undergo a reorganization and splitting of the segment in the next year (2013-2014) to better capture the variation in water quality characteristics along this stretch of river. This reorganization may change water quality parameter values and standards along the Rio Grande adjacent to BIBE.

Table 44. Current Texas Commission on Environmental Quality surface-water quality standards along Rio Grande Segment 2306 (which encompasses BIBE) (TCEQ 2010a).

Parameter	TCEQ standard
Total dissolved solids	1,550 mg/L
Chloride	300 mg/L
Sulfate	570 mg/L
Dissolved oxygen	> 5.0
Fecal coliform (*E. coli*)	≤126 CFU/100 ml
Macroinvertebrates	N/A

4.16.4 Data and Methods
In 1995, the NPS published results of an inventory of surface-water quality data retrievals for locations in or near BIBE using five of the EPA national databases: Storage and Retrieval (STORET) water quality database management system, River Reach File (RF3), Industrial Facilities Discharge (IFD), Drinking Water Supplies (DRINKS), and Flow Gages (GAGES) (NPS 1995). The retrievals resulted in 18,551 observations for various parameters at 29 monitoring stations operated by USGS, EPA, and the Texas Water Commission from 1953 to

1993. There were a number of stations (14) found within the park; however, only four stations yielded long-term records (at least six parameters measured an average of one or more times per year for at least two years) (NPS 1995). These locations include: BIBE0002 (located on the Rio Grande 2 miles upstream from Johnson Ranch N), BIBE0003 (located on the Rio Grande 2 miles upstream from Johnson Ranch), and BIBE0005 and BIBE0006 (both located on the Rio Grande at the mouth of Santa Elena Canyon) (Plate 27). This inventory used EPA standards for water quality to determine exceedances, which are noted as results from this inventory are presented.

TCEQ provides continuous data collected for several water quality parameters at two monitoring stations located within BIBE park boundaries. Station C720 is located on the Rio Grande at Castolon (near Cottonwood Campground) in the western part of the park, and Station C721 is located at the boat ramp on the Rio Grande at Rio Grande Village (near the Daniels Ranch Picnic Area) in the eastern part of the park (Plate 27). Both stations are maintained by the USGS for the TCEQ, and both stations record continuous data on water temperature, flow rate, gage height, specific conductance, dissolved oxygen, and pH. Data summaries for dissolved oxygen are used in this assessment. These stations also correspond with USGS gage stations 08374550 and 08375300 respectively. The locations of monitoring stations maintained by all agencies (IBWC, NPS and TCEQ) are shown in Plate 27.

The International Boundary and Water Commission (IBWC) is a federal government agency that oversees and applies the boundary and water treaties of the United States and Mexico. Their responsibilities include monitoring the water quality of the Rio Grande along the border of Texas and Mexico, which is divided into river segments that each comprise a set of sampling locations (IBWC 2012). In cooperation with BIBE personnel, the IBWC maintains three water quality sampling sites located along the Rio Grande within or near BIBE park boundaries: Site 18441 at the Lajitas Resort approximately 250 m (820 ft) upstream from the Black Hills Creek Confluence just west of the BIBE boundary (data collected from 2010 through 2012; site is operated by TPWD and is upstream of the BIBE boundary), Site 13228 located at the mouth of Santa Elena Canyon (data collected from 1995 through 2012), and Site 16730 at Rio Grande Village (data collected from 1999 through 2012). These data are not continuous, rather each site is sampled on multiple dates across the course of each year up to eight times per year. Some years contain only one or two observations. River conditions may also influence sampling dates (e.g., high flows make it difficult to sample from the river versus days when flow is lower) and thus, samples may not capture the true variation of water quality conditions in the park and how these may be affected by seasonal changes or weather events. A variety of water quality parameters are assessed, including chloride, sulfate, total dissolved solids, *E. coli*, and dissolved oxygen, which are presented for conditions in BIBE. Plate 27 displays the locations of these water quality monitoring locations, as well as the TCEQ and NPS sites.

4.16.5 Current Condition and Trend

<u>Total Dissolved Solids (TDS)</u>

Data collected from the three IBWC monitoring locations show several exceedances for TDS in Segment 2306 of the Rio Grande. Table 45 shows the summary characteristics of TDS concentrations at each of the IBWC monitoring locations across the history of sample collection at these sites. Of six observations recorded between 2010 and 2011at Station 18441, located at Lajitas Resort at the upper boundary of Segment 2306, four observations exceeded the TCEQ standard considered protective of freshwater aquatic life (1,550 mg/L) (IBWC 2012). At Station 13228, located at the mouth of the Santa Elena Canyon, 128 observations were made from 1995 to 2011; 87 observations (67%) exceeded the TCEQ standard (IBWC 2012). One observation at this station was recorded at 70,300 mg/L, and is an extreme outlier compared to all other values at this station. Thus, it was not included in calculations of range or mean values. A total of 81 observations were recorded between 1999 and 2011 at Station 16730, located at Rio Grande Village; 38 observations (50%) exceeded the TCEQ standard for acceptable TDS concentrations in the river (IBWC 2012).

Table 45. Total dissolved solid concentrations at IBWC water quality monitoring locations in BIBE, including range, mean, median, and exceedances (IBWC 2012).

Station	Years Sampled	Number of Observations	Range (mg/L)	Mean (mg/L)	Median (mg/L)	Exceedances (TCEQ standard)
IBWC 18441	2010-2011	6	836-2240	1490	1462	4
IBWC 13228	1995-2011	128	348-4500	2305	1895	87*
IBWC 16730	1999-2011	81	120-2300	1400	1530	38**

*In 2010 six (6) of nine (9) observations exceeded the threshold; in 2011, all observations (3) exceeded the threshold.
**In 2010, three (3) of seven (7) observations exceeded the threshold; in 2011, two (2) of five (5) observations exceeded the threshold.

Figure 61 shows the mean annual TDS concentrations for each IBWC monitoring location over the history of sample collection. These intermittent data indicate that TDS concentrations may regularly exceed TCEQ standards considered protective of freshwater aquatic life; however, continuous data are more appropriate for determining specific trends in concentrations.

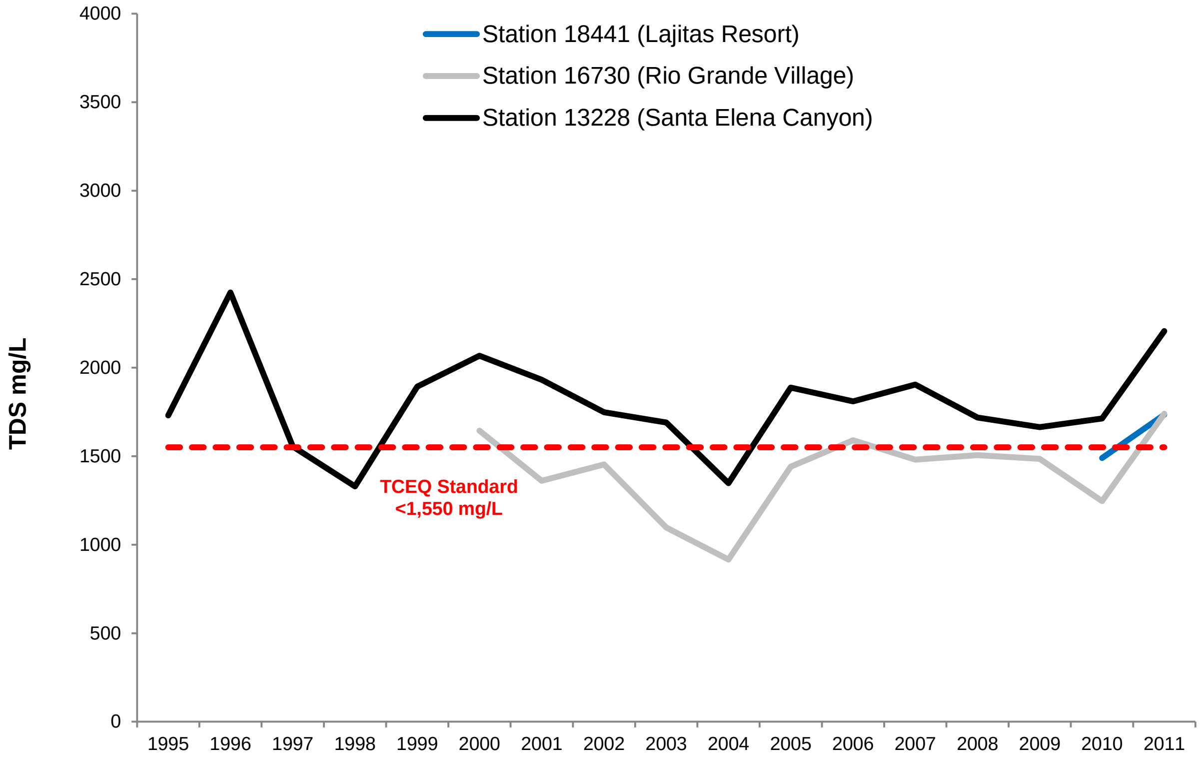

Figure 61. Mean annual total dissolved solids concentrations recorded at IBWC water quality monitoring locations on the Rio Grande in or near BIBE (Source: IBWC 2012). Note: data represented in this graph are intermittent samples rather than continuously recorded over a period of time.

In the 2010 Texas Integrated Report of Water Quality Impairments, the entire stretch of Section 2306 of the Rio Grande (subsections 2306-1 through 2306-8 from 1.8 km [1.1 mi] downstream of the confluence of Ramsey Canyon in Val Verde County to the Rio Conchos confluence in Presidio County) was identified as not meeting water quality standards for total dissolved solids. This section of the Rio Grande was 303[d] listed as impaired by excess concentrations of total dissolved solids (TCEQ 2010b). Continuous data for TDS were not available from the TCEQ database for monitoring stations C720 and C721 on the Rio Grande in BIBE.

Bennett et al. (2012) found that total dissolved solid concentrations in the BIBE reach of the Rio Grande are related to rate of water flow and discharge volumes, in that TDS is often above designated water quality standards during periods of low flow. Long term trends in flow rate show that flows are decreasing consistently over time, which is likely contributing to increased TDS concentrations in segment 2307 of the Rio Grande (directly upstream from BIBE), which then contributes to increases in the upper part of segment 2306 of the Rio Grande bordering BIBE. Historically, water inputs from the Rio Conchos helped improve TDS concentrations in the Rio Grande bordering BIBE, but this effect is no longer evident due to decreased flows. Conversely, ground water inputs into the lower part of segment 2306 (near Boquillas Canyon) seem to help improve water quality in this part of the reach, including decreasing TDS concentrations; however, trends are difficult to identify (Bennett et al. 2012). Bennett et al.

(2012) recommend that discharge and flow rate data should be collected and analyzed in conjunction with water quality samples to better understand the influence of water flow on water quality in the Rio Grande.

Chloride

NPS (1995) reported on observations of chloride concentrations in the Rio Grande from four water monitoring stations located in the park. Based on the EPA standards used in this inventory, zero chloride observations collected during these years exceeded the standard for acute freshwater aquatic life (860 mg/L); however, maximum values show that observations exceeded the TCEQ standard (300 mg/L) at least twice (500, 311 mg/L) from 1974-1992 (NPS 1995). Because data from individual sampling efforts across the years are not available in the NPS (1995) inventory, it is difficult to determine how often observations during this time exceeded the TCEQ standard for chloride. In addition, these data are not continuous and, therefore, likely do not reflect the impact of periods of high or low flows, weather events, or seasonal changes. Table 46 displays the summary characteristics of the chloride observations recorded at all water quality monitoring locations on the Rio Grande flowing adjacent to the park.

Intermittent data collected from the three IBWC monitoring locations show a wide variability in chloride concentrations and a number of exceedances in the segment of the Rio Grande flowing adjacent to the park (Table 46). Three of six observations collected at Station 18441, near Lajitas Resort, exceeded the TCEQ standard considered protective of aquatic life (IBWC 2012). Of 77 samples collected at Station 16730, at Rio Grande Village, 39 observations exceeded the TCEQ standard. Of the 135 observations collected at Station 13228, at Santa Elena Canyon, 85 observations exceeded the TCEQ standard (IBWC 2012). Across all three IBWC monitoring locations, data suggest chloride concentrations are widely variable across each year, which may be influenced by weather events, flow rates, or seasonal changes. Figure 62 shows the mean annual chloride values from each IBWC monitoring location.

Table 46. Chloride observations at water quality monitoring locations in BIBE, including range, mean, median, and exceedances from 1968-2011 (NPS 1995, IBWC 2012).

Station	Years Sampled	Number of Observations	Range (mg/L)	Mean (mg/L)	Median (mg/L)	Exceedances
BIBE0002	1968-1974	48	12-184	81.8	82.5	0+
BIBE0003	1971-1974	12	50-184	98	89	0+
BIBE0005	1974-1992	56	7-500	173	164	0+
BIBE0006	1974-1978	15	12-311	122	113	0+
IBWC 18441	2010-2011	6	83-615	387	555	3*
IBWC 16730	1999-2011	80	7-620	544	294	39*
IBWC13228	1995-2011	133	9-680	372.6	421	85*

+EPA standard (860 mg/L)
*TCEQ standard (300 mg/L)

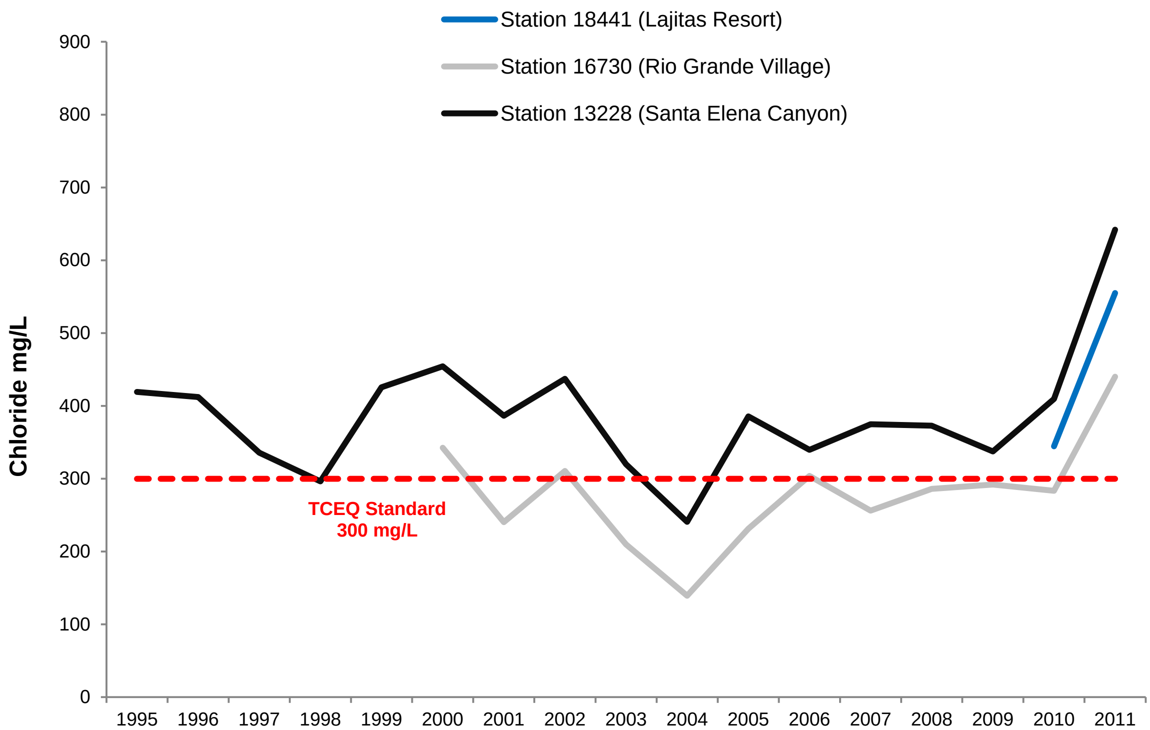

Figure 62. Mean annual chloride concentrations recorded at IBWC water quality monitoring locations on the Rio Grande in or near BIBE (IBWC 2012). Note: data represented in this graph are intermittent samples rather than continuously recorded over a period of time.

Bennett et al. (2012) have found that chloride concentrations in the BIBE reach of the Rio Grande are increasing in recent years and appear to be related to decreases in water flow rates and discharge volumes.

In the 2010 Texas Integrated Report of Water Quality Impairments, the entire stretch of Section 2306 of the Rio Grande (subsections 2306-1 through 2306-8 from 1.8 km downstream of the confluence of Ramsey Canyon in Val Verde County to the Rio Conchos confluence in Presidio County) was determined as not meeting water quality standards for concentrations of chloride. This section of the Rio Grande was 303[d] listed as impaired by excess chloride concentrations (TCEQ 2010b). Continuous data for chloride concentrations were not available from the TCEQ database for monitoring stations C720 and C721 on the Rio Grande in BIBE.

<u>Sulfate</u>

NPS (1995) reported on observations of sulfate concentrations in the Rio Grande from four water quality monitoring stations located in the park. Based on the EPA standards used in this inventory (400 mg/L for safe drinking water), a total of 44 exceedances were detected during the time samples were collected (34 detected at location BIBE0005 and 10 detected at BIBE0006) (NPS 1995). Maximum values show that observations exceeded the TCEQ standard considered protective of aquatic life (570mg/L) at least four times (580, 580, 784, 660 mg/L) from 1968-1992 (NPS 1995). However, because data from individual sampling efforts across the years are not available in the NPS (1995) inventory, it is difficult to determine how often observations during this time exceeded the TCEQ standard for sulfate. In addition, these data are not continuous and, therefore, likely do not reflect the impact of periods of high or low flows, weather events, or seasonal changes. Table 47 displays the summary characteristics of the sulfate observations recorded at all water quality monitoring locations on the Rio Grande flowing adjacent to the park.

Table 47. Sulfate observations at water quality monitoring locations in BIBE, including range, mean, median, and exceedances from 1968-2011 (NPS 1995, IBWC 2012).

Stations	Years Sampled	Number of Observations	Range (mg/L)	Mean (mg/L)	Median (mg/L)	Exceedances
BIBE0002	1968-1976	41	103-580	359	377	18+
BIBE0003	1971-1976	13	147-580	389	400	7+
BIBE0005	1974-1992	56	45-784	431	445	34+
BIBE0006	1974-1978	15	45-660	429	454	10+
IBWC 18441	2010-2011	6	392-995	672	731	3*
IBWC 16730	1999-2011	79	1-867	195	593	49*
IBWC13228	1995-2011	131	69-1100	664	655	94*

+EPA standard (400 mg/L)
*TCEQ standard (570 mg/L)

Intermittent samples collected from the three IBWC monitoring locations show a wide variability in sulfate concentrations as well as a number of exceedances in the Rio Grande in BIBE. Three of six observations collected between 2010 and 2011 at Station 18441, near Lajitas Resort, exceeded the TCEQ standard (IBWC 2012). Of 79 observations collected at Station 16730, at Rio Grande Village, 49 observations exceeded the TCEQ standards. The range of sulfate concentrations was 1 to 867 mg/L (IBWC 2012). Of 131 observations collected at Station 13228, at Santa Elena Canyon, 94 observations exceeded the TCEQ standard (IBWC 2012). Figure 63 shows the mean annual sulfate concentrations from each IBWC monitoring location. Intermittent data indicate sulfate concentrations are highly variable and regularly exceed TCEQ standards considered protective of aquatic life at the Santa Elena Canyon monitoring location.

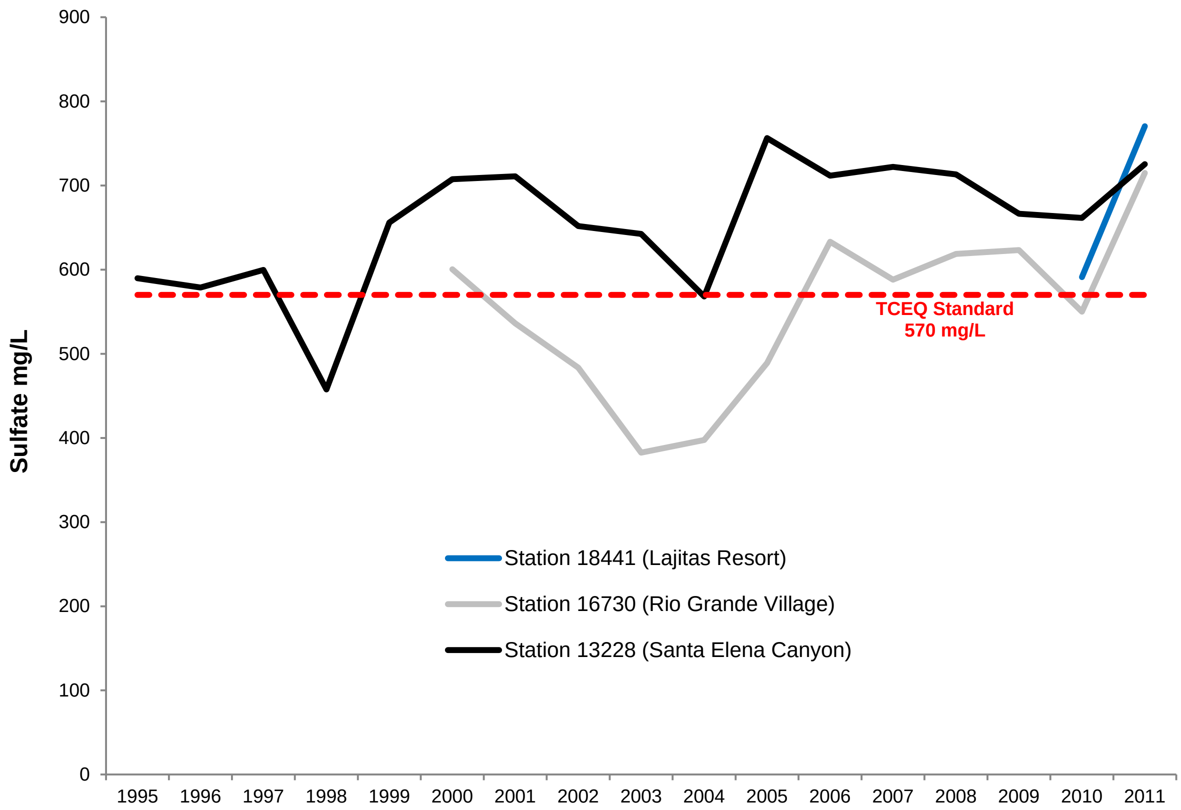

Figure 63. Mean annual sulfate concentrations recorded at IBWC water quality monitoring locations on the Rio Grande in or near BIBE (Source: IBWC 2012). Note: data represented in this graph are intermittent samples rather than continuously recorded over a period of time.

Bennett et al. (2012) have found that sulfate concentrations in the BIBE reach of the Rio Grande are increasing in recent years and appear to be related to decreases in water flow rates and discharge volumes.

In the 2010 Texas Integrated Report of Water Quality Impairments, the entire stretch of Section 2306 of the Rio Grande (subsections 2306-1 through 2306-8 from 1.8 km downstream of the confluence of Ramsey Canyon in Val Verde County to the Rio Conchos confluence in Presidio County) was determined as not meeting water quality standards for acceptable concentration of sulfate. This section of the Rio Grande was 303[d] listed as impaired by excess sulfate concentrations (TCEQ 2010b). Continuous data for sulfate concentrations were not available from the TCEQ database for monitoring stations C720 and C721 on the Rio Grande in BIBE.

<u>Dissolved Oxygen (DO)</u>

NPS (1995) reported on observations of dissolved oxygen concentration in the Rio Grande from four water quality monitoring stations located in the park. Based on the EPA standards used in this inventory (>4 mg/L), a total of three exceedances were detected during the time samples were collected (NPS 1995). Minimum values show that observations exceeded the TCEQ standard considered protective of freshwater aquatic life (≥5 mg/L) at least three times from

1968-1992 (NPS 1995). However, because data from individual sampling efforts across the years are not available in the NPS (1995) inventory, it is difficult to determine how often observations during this time exceeded the TCEQ standard for dissolved oxygen. In addition, these data are not continuous and, therefore, likely do not reflect the impact of periods of high or low flows, weather events, or seasonal changes. Table 48 displays the summary characteristics of dissolved oxygen concentrations recorded at all water quality monitoring locations on the Rio Grande flowing adjacent to the park.

Table 48. Dissolved oxygen observations at water quality monitoring locations in BIBE, including range, mean, median, and exceedances from 1968-2011 (NPS 1995, IBWC 2012).

Stations	Years Sampled	Number of Observations	Range (mg/L)	Mean (mg/L)	Median (mg/L)	Exceedances
BIBE0002	1968-1976	68	4-11	7.73	8	1+
BIBE0003	1971-1976	33	6-10	8.14	8	0+
BIBE0005	1974-1992	61	3.3-16.5	8.54	8.2	1+
BIBE0006	1974-1978	19	3.3-13	8.44	7.9	1+
IBWC 18441	2010-2011	7	5.8-12.9	8.4	7.4	0*
IBWC 16730	1999-2011	79	2.4-12.5	7.8	7.6	2*
IBWC13228	1995-2011	135	5.5-15.3	9.01	8.5	0*

+EPA standard (>4 mg/L)
*TCEQ standard (≥5 mg/L)

Intermittent samples collected at the three IBWC water quality monitoring locations indicate that average dissolved oxygen concentrations were within the TCEQ standard considered protective of freshwater aquatic life at the time the samples were taken (Table 48, Figure 64). Of seven observation collected at Station 18441 (located near the Lajitas Resort), zero exceeded the TCEQ standard. Seventy-six observations were collected at Station 16730 (at Rio Grande Village); of these, only two observations exceeded TCEQ standards (IBWC 2012). Of 135 observations collected at Station 13228 (Santa Elena Canyon), zero exceeded the TCEQ standard (≥5 mg/L) (IBWC 2012). Because these data are collected intermittently across each year, they likely do not reflect the impact of periods of high or low flows, weather events, or seasonal changes that continuous data are able to illustrate. For instance, recent periods of super-low flows in the Rio Grande and surrounding tributaries have resulted in very low DO concentrations, which are not captured easily with intermittent sampling efforts (J. Bennett, written communication. 15 November 2012). Figure 64 shows the mean annual DO concentrations (based on intermittent data) for the extent of sampling history at each IBWC sampling location.

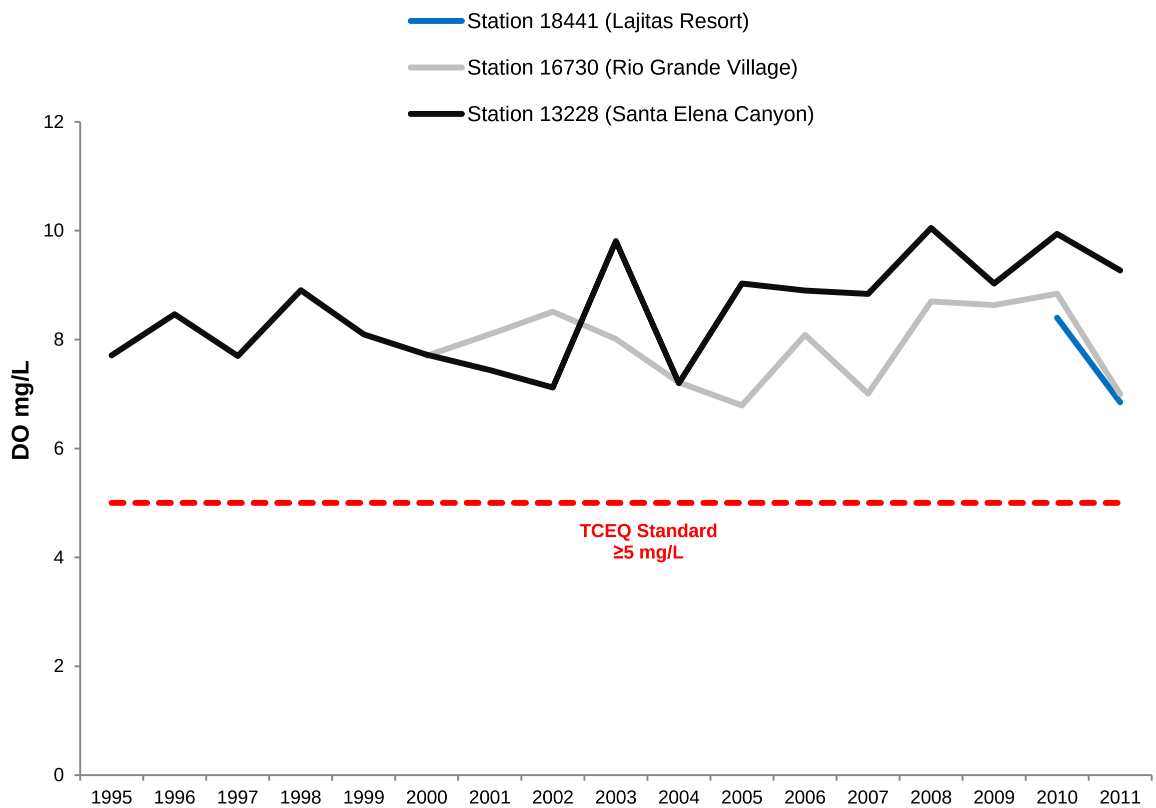

Figure 64. Mean annual dissolved oxygen concentrations recorded at IBWC water quality monitoring locations on the Rio Grande in or near BIBE (Source: IBWC 2012). Note: data represented in this graph are intermittent samples rather than continuously recorded over a period of time.

Two TCEQ water quality monitoring stations have recorded observations of dissolved oxygen concentrations on the Rio Grande in BIBE continuously since 2005 (TCEQ 2012). Figure 65 shows the mean annual DO concentrations based on continuous data collected at two TCEQ water quality monitoring stations on the Rio Grande in BIBE. The range of observations for Station C720 at Castolon was 0.0 to 24.8 mg/L across all years sampled; the range at Station C721 at Rio Grande Village was 0.1 to 17.3 across all years of record (TCEQ 2012). Data indicate high variability in dissolved oxygen concentrations from year to year, which suggests the influence of other factors such as temperature, weather events, and seasonal or chronic changes in flow rates. Mean annual DO concentrations presented in Figure 65 show a gradual decrease in DO concentrations in the Rio Grande in the park in recent years.

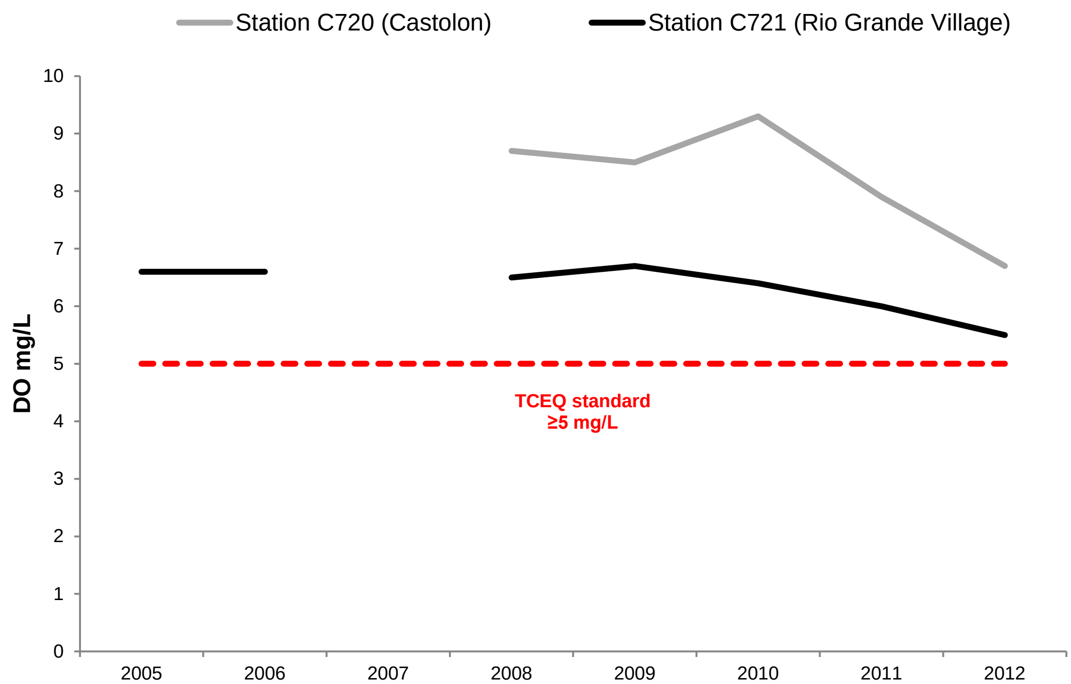

Figure 65. Mean annual dissolved oxygen concentrations based on continuous data recorded at TCEQ water quality monitoring stations on the Rio Grande in BIBE (TCEQ 2012).

Fecal coliform (*E. coli*)

NPS (1995) reported on observations of fecal coliform in the Rio Grande from two water quality monitoring stations located in the park (BIBE0005 and BIBE0006, both located near the mouth of the Santa Elena Canyon). Based on the EPA standards used in this inventory (200 CFU/100 ml), a total of 13 exceedances were detected during the time samples were collected (NPS 1995). Maximum values indicate that observations exceeded the TCEQ standard (126 CFU/100 ml) at least two times (5530 CFU/100 ml) from 1974-1992 (NPS 1995). However, because data from individual sampling efforts across the years are not available in the NPS (1995) inventory, it is difficult to determine how often observations during this time exceeded the TCEQ standard for fecal coliform concentration. Table 49 displays the summary characteristics of the fecal coliform (*E. coli*) observations recorded at monitoring locations in BIBE.

Intermittent samples collected at the three IBWC water quality monitoring locations indicate that some exceedances of *E. coli* bacteria have occurred in recent years. All monitoring locations had at least one exceedance in the last year; Station 13228 at Santa Elena Canyon had 15 exceedances recorded during the history of observations at this location. Examination of the median versus the mean calculation for *E. coli* samples at the different stations indicate that there likely are concentrated contamination events that occur along this stretch of the Rio Grande, during which very high concentrations of fecal bacteria are recorded on one date only to return to much lower levels at the next sampling date (typically one month later). Median values are well-within the TCEQ standard for safe bathing, while mean values show the influence of isolated events with exceptionally high concentrations of bacteria.

Table 49. Fecal coliform (*E. coli*) observations at water quality monitoring locations in BIBE, including range, mean, median, and exceedances from 1974-2011 (NPS 1995, IBWC 2012).

Stations	Years Sampled	Number of Observations	Range (CFU/100ml)	Mean (CFU/100ml)	Median (CFU/100ml)	Exceedances
BIBE0005	1974-1992	36	1-5530	432	14.5	8+
BIBE0006	1974-1978	14	2-5530	1011	15	5+
IBWC 18441	2010-2011	5	1-140	49	63.8	1*
IBWC 16730	1999-2011	59	0-2910	105	21.35	4*
IBWC13228	1995-2011	81	1-2400	200	29	15*

+EPA standard (200 CFU/100 ml)
*TCEQ standard (126 CFU/100 ml)

In the most recent water quality impairments assessment, the 2306-8 subsection of the Rio Grande from Alamito Creek confluence upstream to the Rio Conchos confluence was determined as not meeting water quality standards for harmful bacteria. This subsection was 303[d] listed as impaired for *E. coli* concentrations in 2010 (TCEQ 2010b).

Macroinvertebrates

Aquatic macroinvertebrates are considered an indicator of stream and river health. For a detailed description of macroinvertebrates in BIBE, refer to the Macroinvertebrates component of this report (Chapter 4.11).

Threats and Stressor Factors

A number of stressors and threats may influence water quality in this segment of the Rio Grande and impact aquatic life in the river. These stressors and threats include drought conditions, consistently decreasing water flow rates, increased runoff from storm events (increasing dissolved and suspended solid concentrations), reduction of ground water inputs into the river, and contamination or other impairments in Rio Grande tributaries upstream from and along segment 2306 of the river. NPS (2010) indicates that possible threats may also include nutrient overload due to agricultural runoff and urban development located upstream from BIBE. To date, observations for several water quality parameters have been found to exceeded TCEQ standards regularly for either protection of freshwater aquatic life (sulfate, chloride, and total dissolved solids) or safe bathing and recreation for humans (*E. coli* concentration). Other parameters considered Vital Signs by the CHDN, but not included in this assessment (such as specific conductance, pH, temperature, etc.), may also be subject to impairment from current or anticipated threats and stresses to water quality.

A sub-section of Segment 2306 of the Rio Grande, which included the Alamito Creek confluence just upstream of the Rio Conchos confluence, was first listed as 303[d] impaired for harmful bacteria in 1999 (TCEQ 2010a). As of 2010, all sub-sections of 2306 became listed as 303[d] impaired for chloride, sulfate and total dissolved solids (TCEQ 2010a). All four parameters were classified under category 5c, which means additional information and data need to be collected before a total maximum daily load (TMDL) is scheduled (TCEQ 2010a).

Data Needs/Gaps

The greatest data gap related to water quality is a shortage of comparable historic and recent data. The data from the NPS (1995) inventory are outdated, with the most recent measurement recorded in 1992. In addition, much of the data comes from short-term, intermittent sampling rather than continuous monitoring of conditions. This study also used different water quality standards to determine exceedances, some of which are less conservative than the TCEQ standards applicable for the region. This makes it impossible to know the total number of observations that met or exceeded TCEQ standards for this inventory and what that means for water quality conditions prior to the record established through IBWC monitoring or TCEQ continuous monitoring.

The IBWC 18441 monitoring location has only two years of data recorded thus far. Additional years of monitoring data, although it is intermittent in nature, would be helpful in understanding water quality conditions at various locations along the Rio Grande in BIBE. Ideally, these monitoring locations would eventually collect continuous data, which would better capture trends in conditions that could be correlated with other influences such as weather events, fluctuations in flow rates, and drought or rainy conditions. TCEQ has two stations within park boundaries that record continuous data for several parameters including water temperature, flow rate, gage height, specific conductance, dissolved oxygen, and pH; however, these stations do not capture data on sulfate, chloride, or TDS concentrations, nor are bacteria concentrations sampled from these locations.

<u>Overall Condition</u>

Total Dissolved Solids
The project team defined the *Significance Level* for total dissolved solids as a 3. Of 215 observations collected at three IBWC monitoring locations along the Rio Grande in BIBE, 129 observations exceeded the TCEQ standard considered protective of freshwater aquatic life. All subsections of Segment 2306 of the Rio Grande (flowing adjacent to BIBE) were 303[d] listed in 2010 as impaired for total dissolved solids. Additionally, Bennett et al. (2012) found TDS concentrations are increasing consistently, and are likely influenced by consistently decreasing flow rates in the Rio Grande. For this reason, a *Condition Level* of 3 was assigned to total dissolved solids, indicating significant concern.

Chloride
The project team defined the *Significance Level* for chloride as a 3. Of 219 observations collected at three IBWC monitoring locations, 127 observations exceeded the TCEQ standard considered protective of freshwater aquatic life. At least three observations queried from the NPS (1995) inventory exceeded this standard as well. Bennett et al. (2012) found that chloride concentrations are increasing in the BIBE reach of the Rio Grande in recent years. In 2010, all subsections of Segment 2306 of the Rio Grande were 303[d] listed as impaired for chloride concentrations. Thus, a *Condition Level* of 3 was assigned for chloride, indicating significant concern.

Sulfate
The project team defined the *Significance Level* for sulfate as a 3. The NPS (1995) inventory reported on 125 observations from four long-term stations in the park; 44 observations exceeded EPA standards (400 mg/L). The TCEQ standard (570 mg/L) is more flexible for this section of the Rio Grande, so the total number of exceedances for these observations is unknown when considering the TCEQ standard. Of 216 observations from three IBWC monitoring locations, 146 observations exceeded the TCEQ standard. Bennett et al. (2012) found that sulfate

concentrations are increasing in the BIBE reach of the Rio Grande in recent years. In 2010, all subsections of Segment 2306 of the Rio Grande were 303[d] listed as impaired for sulfate concentrations. Thus, a *Condition Level* of 3 was assigned to sulfate, indicating significant concern.

Dissolved Oxygen
The project team defined the *Significance Level* for dissolved oxygen as a 3. The NPS (1995) inventory reported on 181 DO observations, of which only three in 24 years exceeded the EPA standard (>4 mg/L). Of 221 observations collected at three IBWC monitoring locations, only two exceeded the more conservative TCEQ standard (≥5 mg/L). These data sets are intermittent sampling efforts that may not capture trends in DO conditions as well as continuous data. Data collected from two TCEQ long-term continuous monitoring stations indicate high variability in DO concentrations from year to year, ranging from 0 mg/L to 24 mg/L at times; mean annual concentrations show a gradual decrease in DO concentrations in recent years. A *Condition Level* of 2 was assigned for dissolved oxygen, indicating moderate concern.

Fecal Coliform (E. coli)
The project team defined the *Significance Level* for coliform bacteria as a 2. The TCEQ standard for section 2306 of the Rio Grande is less than 126 CFU/mg/L (TCEQ 2010b). Since 1999, a reach of the Rio Grande between the Alamito Creek confluence and the Rio Conchos confluence has been 303[d] listed as impaired for harmful bacterial. Data from three IBWC monitoring locations indicates that bacteria concentrations exceed TCEQ standards occasionally, typically as events with exceptionally high concentrations of bacteria. Therefore, a *Condition Level* of 3 was assigned for fecal coliform bacteria contamination, indicating significant concern.

Macroinvertebrates
The project team defined the *Significance Level* for macroinvertebrates as a 2. According to the Macroinvertebrates section (Chapter 4.11), a *Condition Level* of 3 was assigned, indicating a significant concern.

Weighted Condition Score
The *Weighted Condition Score* (WCS) for the water quality component is 0.933, indicating the condition is of significant concern.

Water Quality

Measures	SL	CL
• TDS	3	3
• Chloride	3	3
• Sulfate	3	3
• Dissolved Oxygen	3	2
• Fecal coliform (E. coli)	2	3
• Macroinvertebrates	2	3

WCS = 0.933

4.16.6 Sources of Expertise

Jeffery Bennett, BIBE Physical Scientist

Kirsten Gallo, CHDN Program Manager

4.16.7 Literature Cited

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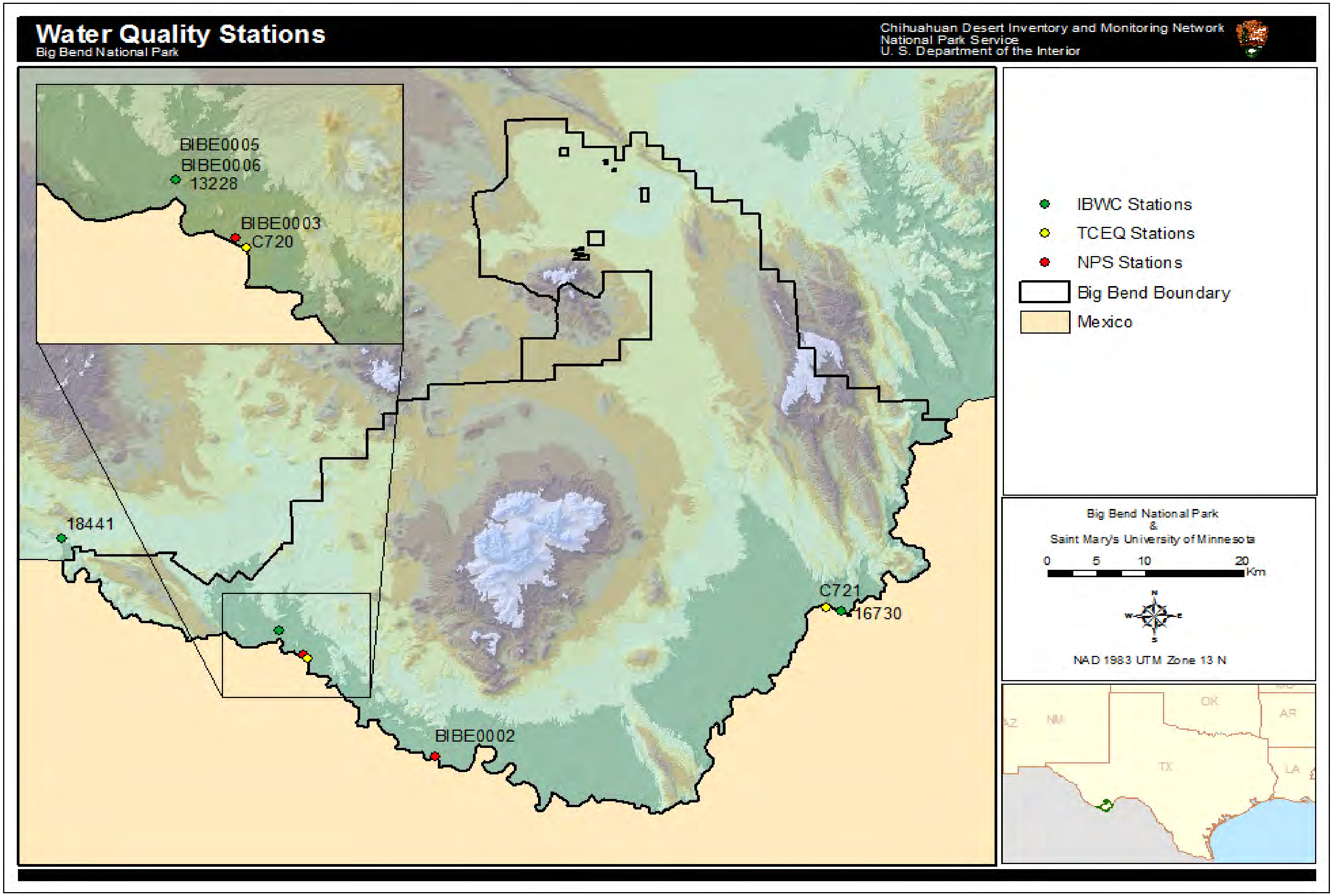


Plate 27. Location of water quality monitoring stations along the Rio Grande in BIBE. Note: IBWC station 13228, BIBE0005, and BIBE0006 are located within a few hundred meters of one another (IBWC 2012, NPS 1995, TCEQ 2012).

4.17 Soundscape

4.17.1 Description

The definition of soundscape in a national park is the total ambient sound level of the park, comprised of both natural ambient sound and human-made sounds (NPS 2000). The National Park Service's mission is to preserve natural resources, including natural soundscapes associated with the national park units. Intrusive sounds are of concern to park visitors, as they detract from their natural and cultural resource experiences (NPS 2000); intrusive sounds also impact wildlife, and may disturb natural functions such as reproduction and stopover times. According to a survey conducted by the NPS, many visitors come to national parks to enjoy, equally, the natural soundscape and natural scenery (NPS 2000).

As described in BridgeNet (2005), different frequencies (A-weighted, B-weighted, and C-weighted) are used to compute sound loudness levels. The most common measurement used is the A-weighted decibel scale (dBA), which approximates the sensitivity to the human ear. In an A-weighted decibel scale, every day sounds range from 30 dBA (very quiet) to 90 dBA (very loud). Presented in Table 50 are examples of human-perceived sound levels of comfort expressed in dBA (BridgeNet 2005).

Table 50. Examples of various A-weighted decibel sound environments (BridgeNet 2005).

dBA	Human Sensitivity	Outdoor Example
130		Military Jet Takeoff (130)
120	Uncomfortably Loud	
110		
100		Boeing 747 Takeoff (101)
90	Very Loud	Power Mower (96)
80		
70	Moderately Loud	Passenger Car @ 65 mph (77)
60		Propeller Airplane Takeoff (67)
50	Quiet	Large Transformers (50)
40		Bird Calls (44)

4.17.2 Measures

- Occurrence of human-caused sound

- Natural ambient sound level

4.17.3 Reference Conditions/Values

The reference condition for BIBE soundscape is that all vehicles meet NPS maximum decibel standards, all generators are the best available technology, and non-essential over-flights are not allowed over NPS land.

4.17.4 Data and Methods

There are no existing data related to park soundscape.

4.17.5 Current Condition and Trend

Occurrence of Human-caused Sound
BIBE is relatively free of non-natural sounds (NPS 2004). Motor vehicles, particularly motorcycles, recreational vehicle (RV) generators, park construction activities, and aircraft over-flights are some of the more common sources of human-caused sounds in BIBE (Skiles, pers. communication, 2011).

Natural Ambient Sound Level
There are no ambient sound level data currently available for BIBE. The NPS Natural Sounds Program conducted baseline natural sound monitoring in BIBE backcountry during the fall of 2010. However, the results of this survey are not available at this time. Wind gusts provide a constant background noise in the park. Sudden natural sounds stem from trees falling or rock slides in the park (NPS 2009). Wildlife produce noise as part of the natural acoustic ecology of BIBE as well (NPS 2009).

Threats and Stressor Factors
Vehicles traveling in and around BIBE can create noise that penetrates deep into the backcountry of the park. Motorcycles, utility and delivery trucks, and military and security overflights are considerable sources of noise in the park(Skiles, pers. communication, 2011). Aircraft flights over BIBE are another transportation-related threat to the park soundscape. Flights from government agencies, private individuals, and commercial airplanes are all contributing factors; the first local commercial air tour business was recently established in the area. Although these flights are rare, they have been increasing in frequency over time (Skiles, pers. communication, 2011). Laughlin Air Force Base is located near BIBE and conducts training flights over the park, although modifications have been made to avoid heavily visited portions of the park during peak visitation times (USAF and NPS 2002).

Construction activities in the park have a localized and temporary negative effect on the soundscape near developments, campgrounds, and lodging facilities (Skiles, pers. communication, 2011). Also, generators used for RVs in campgrounds contribute non-natural sounds to BIBE’s soundscape (Skiles, pers. communication, 2011).

The BIBE Exotic Animal Management Plan addresses potential effects of species control activities in the park. The park soundscape could experience moderate short-term adverse impacts if exotic animal control programs are carried out using certain methods such as ground or helicopter shooting (NPS 2006).

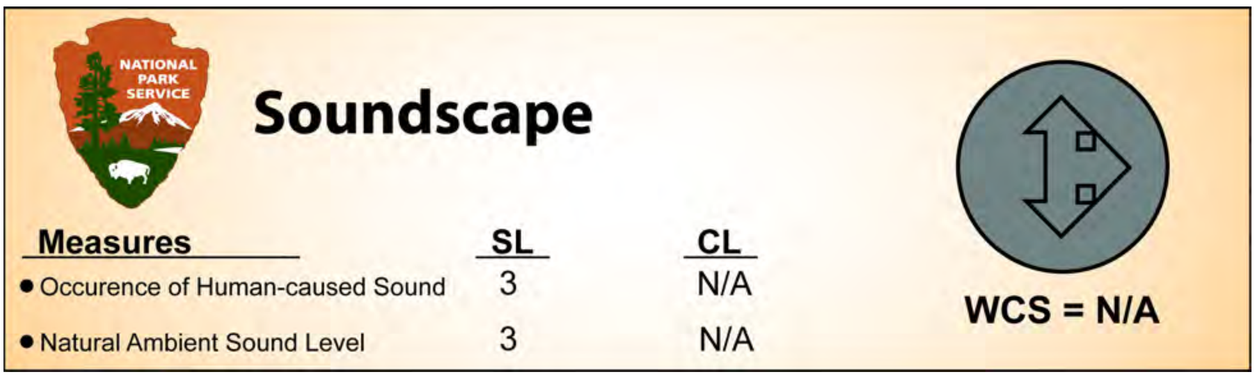
Data Needs/Gaps
Continued monitoring of the natural ambient sound level in BIBE is needed, as there are currently limited data for the natural ambient sound level in BIBE. Publication of the baseline monitoring completed in 2010 would benefit researchers and would allow for a comparison to gauge current condition.

Overall Condition

Occurrence of Human-caused Sound
The BIBE project team defined the *Significance Level* for occurrence of human-caused sound as a 3. While there are several human-caused threats to the natural soundscape in BIBE, NPS (2004) states the park is relatively free of non-natural sounds. There are no quantitative data on noise levels in the park, so a *Condition Level* cannot be assigned.

Natural Ambient Sound Level
A *Significance Level* of 3 was assigned for the measure of natural ambient sound level. BIBE is described as a very quiet national park (NPS 2009). There are currently no data available on baseline sound levels in BIBE, therefore a *Condition Level* cannot be assigned.

Weighted Condition Score
A *Weighted Condition Score* cannot be assigned for soundscape in BIBE due to a lack of quantitative data.



4.17.6 Sources of Expertise
Jeffery Bennett, BIBE Physical Scientist

Raymond Skiles, BIBE Wildlife Biologist

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4.18 Viewscape

4.18.1 Description

A viewshed is the area that is visible from a particular location or set of locations, often determined using GIS analysis tools. Two datasets are required to calculate a viewshed using GIS: a DEM, and point or polyline data defining points at which a person would be viewing a landscape. With the defined data, GIS software determines visibility to and from a particular cell or set of cells in a DEM, resulting in a viewshed layer. This viewshed layer is a raster that defines the visible area on the landscape from the point or set of points contained within an outline of a polygon. Combining viewshed layers with layers that identify areas of undesirable impacts on the landscape creates a quantitative description of visual stress on a viewshed; repeating this process for multiple viewshed layers in a pre-defined landscape, such as a national park, provides a quantitative description of stress across the viewscape in the area.

Multiple studies indicate that people prefer natural landscapes compared to developed landscapes (Sheppard and 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 park units (parks, monuments, historical site, etc.). In addition, the Clean Air Act acknowledges the need to protect national parks that have exceptional visibility. Parks are defined as having exceptional visibility if they are located within a Class I airshed (BIBE is located in a Class I airshed).

Recognizing the necessity to protect viewsheds within Class I airsheds, the NPS created the Integral Vistas program, which focuses on identifying these crucial viewing areas. Through formal identification of integral vistas, the NPS is better equipped to protect those areas from visual degradation and air pollution (NPS 1980). The NPS identified Integral Vistas within these viewsheds through a systematic process that accounted for a variety of factors in a given landscape, including legislation, cultural importance, scientific importance, and the propensity of visitation of non-local park patrons (NPS n.d.).

4.18.2 Measures

- Change since 1980 integral vista photography

4.18.3 Reference Conditions/Values

The reference condition for this component is an undeveloped and natural park setting. Deviations from this condition or changes in viewscape within the BIBE region found through GIS analyses or photo interpretations are reported in this document.

4.18.4 Data and Methods

BIBE staff identified and provided data for this analysis. NPS (1980) Integral Vista GIS and photo point data were the benchmark for this analysis. Another important data source was a 10-m DEM with an extent of 968,347 ha (2,392,834 ac) covering BIBE and the surrounding area. The Integral Vista GIS data resides in a geodatabase comprised of three feature classes: “Vista”, “View_Angles”, and “Features”. The “Vista” point feature class describes the points where Integral Vistas are located. The “View_Angles” polyline feature class identifies the angles from where the vistas are viewed. The “Features” point feature class identifies key features visible within the vistas. The photo point data collected supports the GIS data by enabling individuals to view the actual on-the-ground conditions, with labels describing the locations of features identified in the “Features” feature class (Figure 66). The NPS also provided GIS and photo point data for a second group of locations in 1997 (Figure 67). The 1997 point location GIS data reside in a geodatabase comprised of one feature class, entitled “Vista”. This feature class defines the point location where photos were taken in 1997. The photo point data collected supports the GIS data by enabling individuals to view the actual on-the-ground conditions, with labels describing the locations of prominent park features identified.

Attachment 4

Name of Vista: Dominguez Mountain

Photograph Date: 8-25-80 Time: 1459 Camera Data: f16 @ 1/125

View Direction: East View Angle: from 180 ° to 215 °

Observation Point: Mt. Emory

Can Also Be Viewed From Observation Points: None

PHOTOGRAPH INTERPRETATION

Key	Feature	Distance	
A	South Rim	1.5 miles	(inside park)
B	Dominguez Mountain	7 miles	(inside park)
C	Rio Grande	9 miles	(outside park)

Figure 66. Example of a photo point picture acquired during the development of the 1980 Integral Vistas database. The photo is of the view looking southwest from Mt. Emory in BIBE.

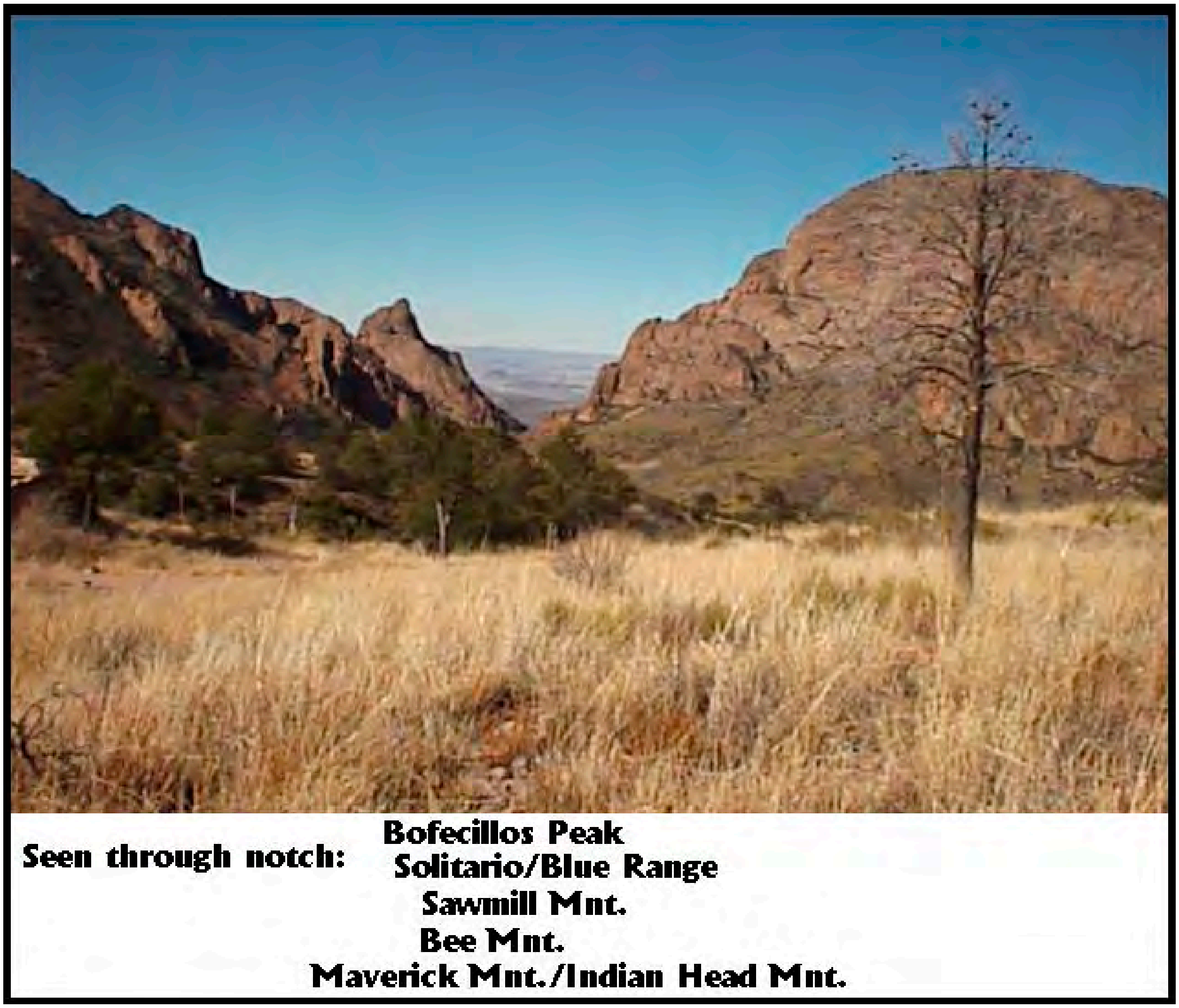


Figure 67. Example of a photo point location picture acquired during the development of the 1997 database. The photo is of the view looking west-northwest from The Window in BIBE.

Viewshed points were created around each of the 1980 Integral Vista locations and the 1997 point locations in an effort to simulate viewable landscapes a park visitor would observe from each observation point. This resulted in a cluster of points around each Integral Vista or point location; these clusters were input into the viewshed tool. Viewshed point clusters were created using the Integral Vista or location points, viewshed photo angles associated with each Integral Vista (1980 viewsheds only), a 10-m DEM, trails data, roads data, and Google Earth images of BIBE to better understand the landscape around each point. The output viewshed, viewshed angles (1980 viewsheds only), and prominent land features map was then paired with the corresponding Integral Vista or point location photographs from 1980 or 1997.

Landcover within the viewsheds of the 1980 Integral Vista points was completed by adding the nine 1980 Integral Vista viewsheds together in an effort to define the most viewable areas of the study region. This analysis was combined with a 2006 NLCD (National Landcover Dataset) landcover class raster and 10-m DEM used in the viewshed analysis to produce an output defining the most viewable landcover areas of the region in 2006. The NLCD also provided a field defining the change in landcover classes between the years 2001 and 2006; overlaying this field with the viewable landcover classes produced an output defining areas of BIBE that were both viewable and had a changed landcover classification from 2001 to 2006.

4.18.5 Current Condition and Trend

Change Since Integral Vista Photography

Observed Photo Change

Only five of the original nine Integral Vista points from 1980 were examined again in 1997: Glenn Spring Intersection, Hannold Draw, Persimmon Gap, Sotol Vista, and Tornillo. Figure 68-Figure 72 display photos from 1980 and 1997 for sites where both years of photography were available (Table 51). No accurate statements regarding landscape changes can be made by comparing photos taken from Integral Vista points in 1980 and 1997.

Table 51. Park-provided point location photos included in this document (NPS 1980, NPS 1997, NPS 2013).

Location	1980 Integral Vista Photo Point Locations	1997 Park Staff Photos	2013 Park Staff Photos
Glenn Spring Intersection	X	X	
Hannold Draw	X	X	
Maverick Mountain	X		
Mount Emory	X		X
Persimmon Gap	X	X	
Santa Elena Canyon	X		
Sotol Vista	X	X	
South Rim	X		
Tornillo	X	X	
Burro Mesa Fault Vista		X	
Green Gulch Vista		X	
Dagger Mountain Vista		X	
Desert Mountain Vista		X	
Rio Grande Nature Trail Vista		X	
South Rim Trail (Mule Ears) V		X	
Sunset Hill Vista		X	
Dagger Flat Road Vista		X	
Hernandez Store Vista		X	
The Window Vista	X	X	X
Maverick Mountain West		X	
Maverick Mountain east		X	
Basin	X		X
Casa Grande	X		X
Castolon	X		X
Dominguez Mountain	X		X
East Rim	X		X
Panther Pass	X		X
Sierra del Carmen	X		
Southeast Rim	X		X
Terlingua	X		X
Ward Mountain	X		X

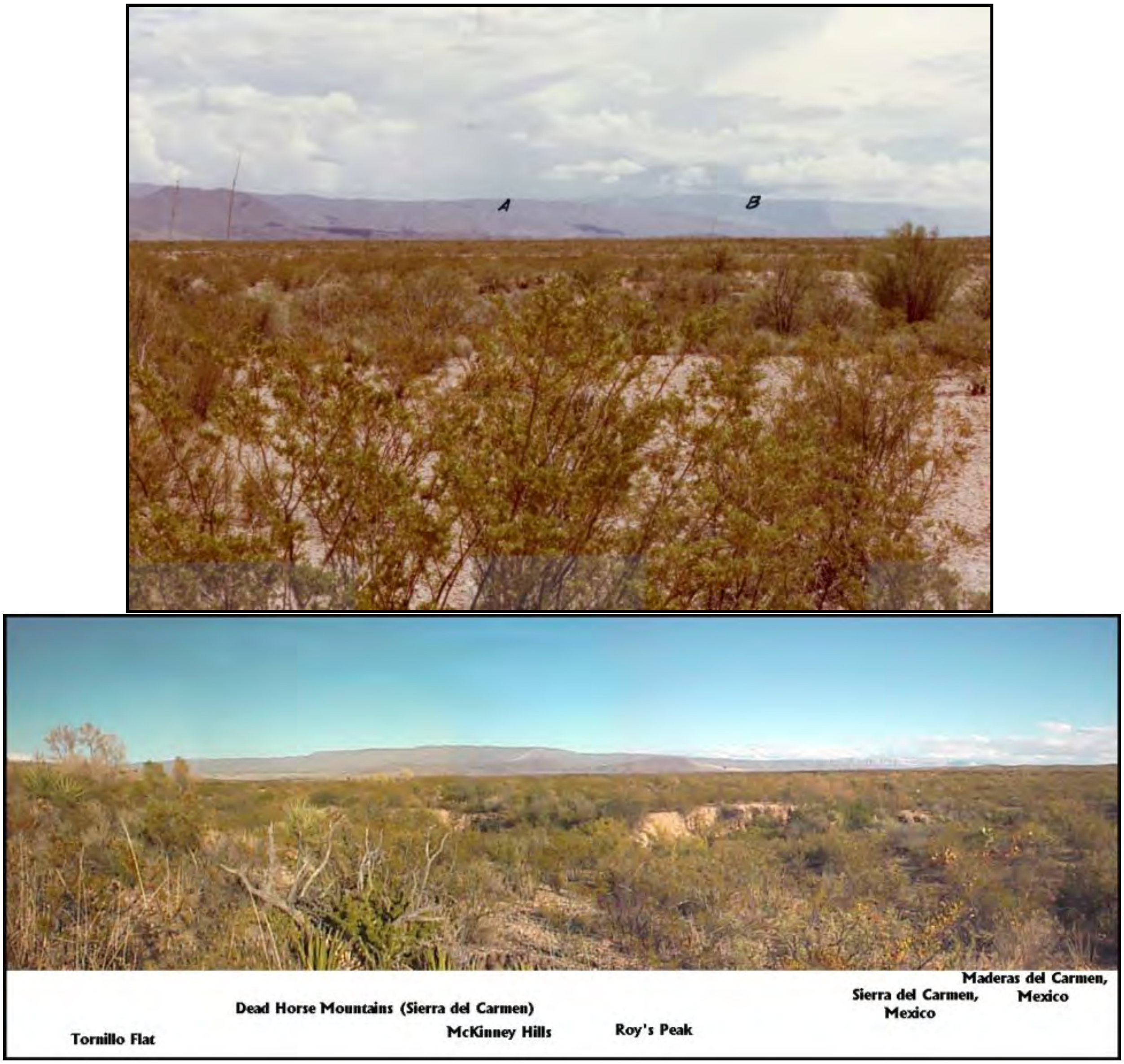


Figure 68. Hannold Draw, 1980 Integral Vista photo (top, A=Sierra del Caballo Muerto, B=Sierra del Carmen) and 1997 reshoot (bottom) (NPS 1980, NPS 1997).

Figure 69. Glenn Springs, 1980 Integral Vista photo (top, A=Sierra del Caballo Muerto, B=Tornillo Flats, C= Sierra del Carmen) and 1997 reshoot (bottom) (NPS 1980, NPS 1997).

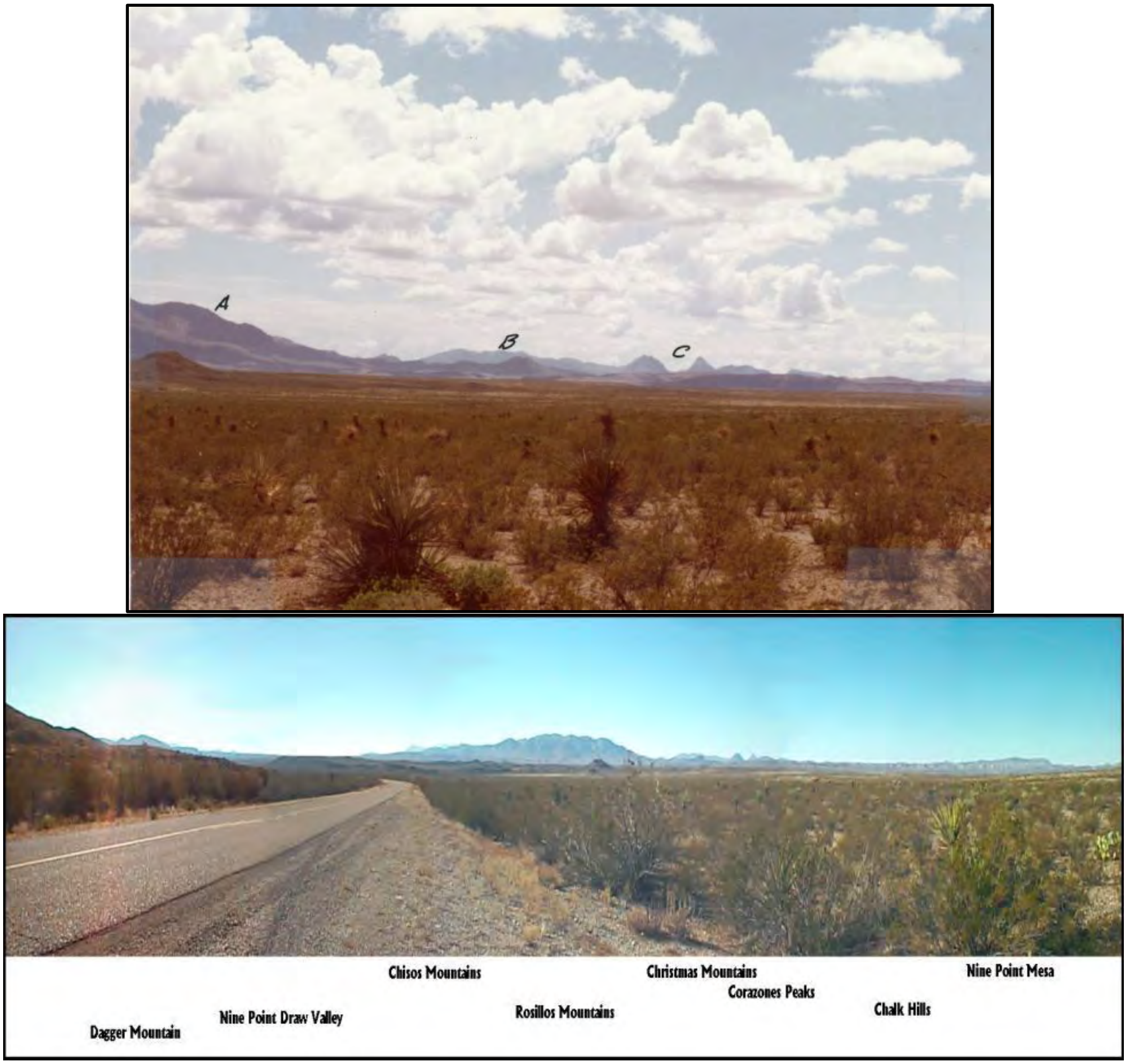


Figure 70. Persimmon Gap, 1980 Integral Vista photo (top, A=Rosillos Mountains, B=Christmas Mountains, C= Corazones Peaks) and 1997 reshoot (bottom) (NPS 1980, NPS 1997).

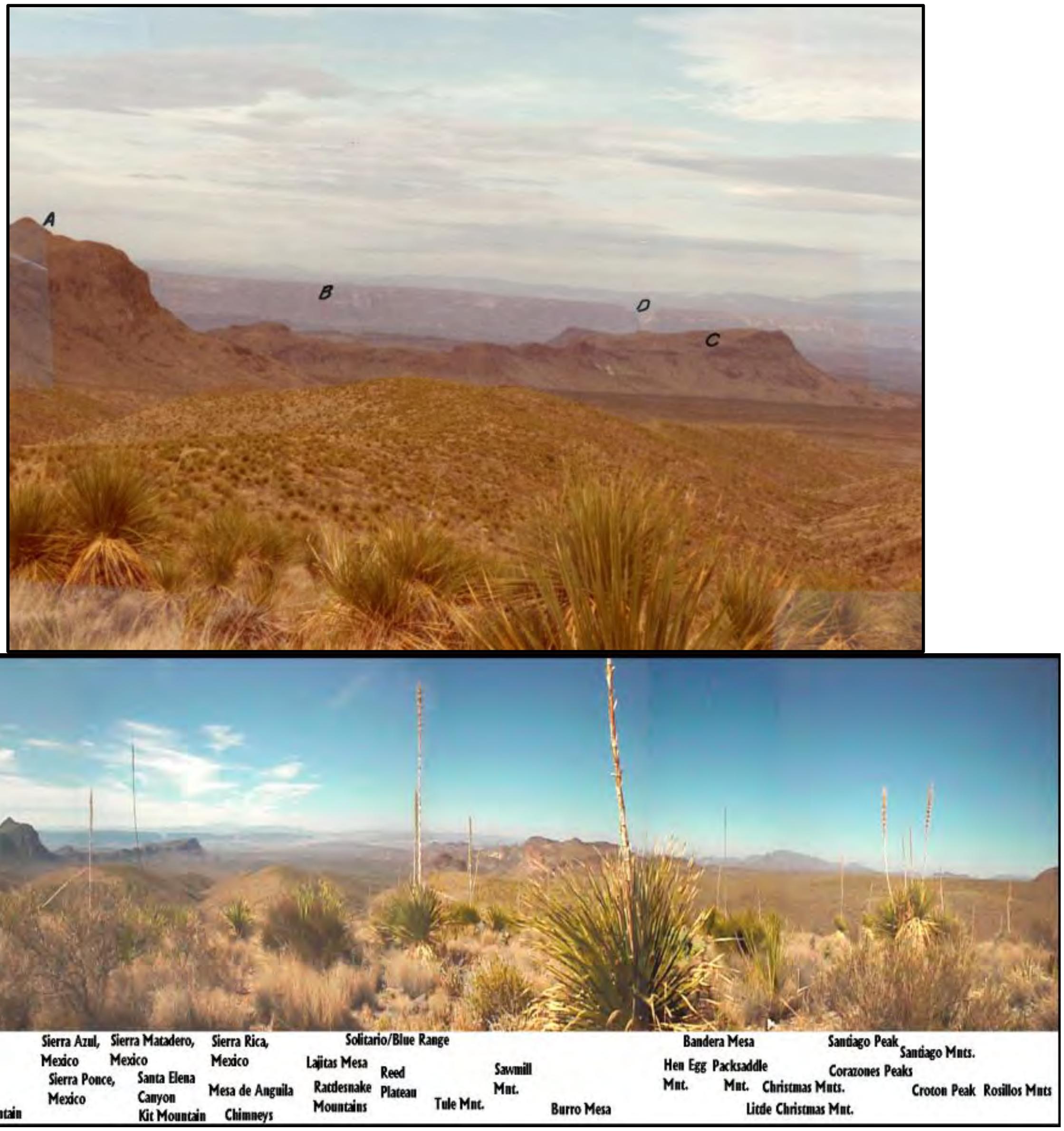


Figure 71. Sotol Vista, 1980 Integral Vista photo (top, A=Goat Mountain, B=Sierra del Santa Elena, C= Kit Mountain, D= Santa Elena Canyon) and 1997 reshoot (bottom) (NPS 1980, NPS 1997).

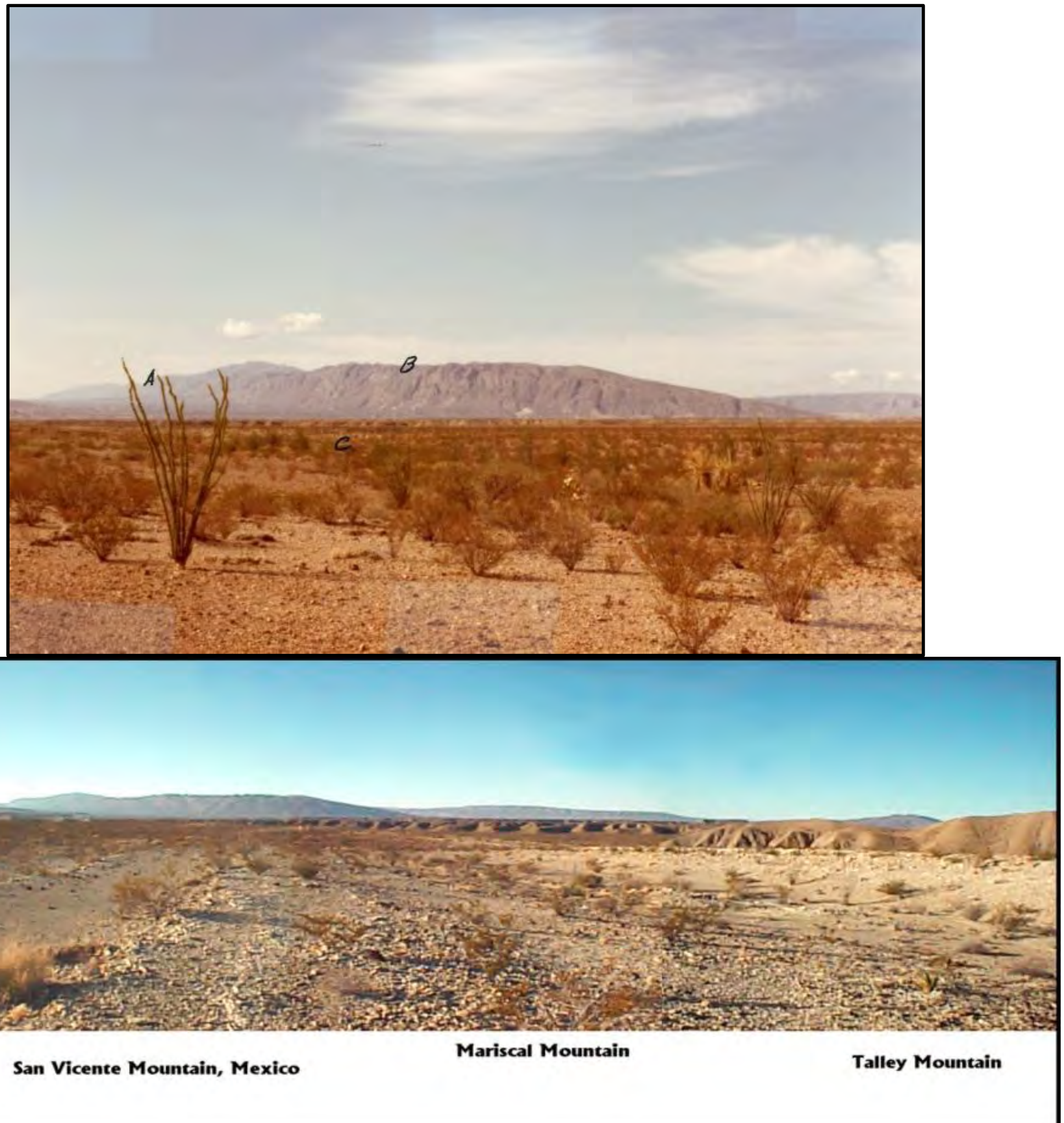


Figure 72. Tornillo, 1980 Integral Vista photo (top, A=Sierra de San Vicente, B=Mariscal Mountain, and C= Chilicotal Flat) and 1997 reshoot (bottom) (NPS 1980, NPS 1997).

1980 Integral Vista Viewshed and Photos

This analysis defines the visible areas from each Integral Vista location. Combining the Integral Vista picture, viewshed, and defined features of interest allows for a general understanding of the on-the-ground conditions from each Integral Vista (Plate 28-Plate 59). Some Integral Vista locations, including but not limited to Mount Emory and South Rim, have large view angles and viewsheds. Multiple pictures shot from varying directions are provided with the corresponding features of interest for these Vistas; pairing multiple pictures with the corresponding viewshed provides a complete analysis of the on-the-ground viewable area and features from each of these Integral Vista locations.

1980 Composite Viewshed and Landcover Change

A total of 385,822 ha (953,386 ac) can be viewed from the nine BIBE Integral Vista locations (Plate 60, Plate 61). However, the viewable area calculation is limited, as some of the viewsheds would have returned viewable areas beyond the extent of the DEM. Utilizing the NLCD, 16 landcover classes were identified within the viewable area in 2006. Among the landcover classes identified, Shrub/Scrub was the most commonly viewed landcover class, totaling 235,826 viewable ha (582,740 ac) (Table 52; Fry et al. 2011). A total of 840,081 ha (2,075,884 ac) were defined as being either not visible (704,755 ha [1,741,486 ac]) or not within NLCD coverage (135,326 viewable ha [334,398 ac] within Mexico).

Table 52. 2006 Viewable landcover classes from the 1980 BIBE Integral Vista locations.

Landcover Type	Hectares	% Landcover
Not Visible	704756	65
Shrub/Scrub	235827	22
Visible Within Mexico	135326	12
Barren Land	10282	<1
Evergreen Forest	2074	<1
Developed, Open Space	656	<1
Woody Wetlands	586	<1
Grassland/Herbaceous	330	<1
Cultivated Crops	205	<1
Developed, Low Intensity	205	<1
Deciduous Forest	135	<1
Emergent Herbaceous Wetlands	68	<1
Open Water	45	<1
Shrub/Scrub	45	<1
Cultivated Crops	17	<1
Barren Land	15	<1
Developed, Medium Intensity	4	<1
Open Water	3	<1

Landcover change occurring between 2001 and 2006 was found to be minimal and did not warrant visual representation. Only 81 ha (201 ac) were assigned a different landcover classification during that time frame, while 87% of the landcover stayed the same (Table 53; Fry et al. 2011). The unanalyzed extent within Mexico (136,874 ha [338,222 ac]) accounted for nearly all landcover areas not classified.

Table 53. 2001 to 2006 landcover change within the viewable areas from the nine 1980 BIBE Integral Vista locations (Fry et al. 2011).

Landcover Class	Hectares	% Landcover
No Change	953,544	87
Unanalyzed extent (Mexico)	136,874	12
Shrub/Scrub	45	<1
Cultivated Crops	18	<1
Barren Land	16	<1
Open Water	3	<1
Evergreen Forest	<1	<1

Viewsheds and Photos

In total, 12 point locations were provided for viewshed analysis corresponding with the 1997 photo point locations (Table 51). Viewshed angles were not provided for these point locations; however, a photo direction was provided allowing for a general understanding of the view direction and on-the-ground view from each Integral Vista (Plate 62-Plate 73).

1980 Vista Photos Paired with 2013 Vista Reshoot Photographs

Photo 24. 1980 photograph of Basin vista (NPS Photo).

Photo 25. 2013 vista reshoot photograph of Basin vista (NPS Photo).

Photo 26. 1980 photograph of Casa Grande vista (NPS Photo).

Photo 27. 2013 vista reshoot photograph of Casa Grande (NPS Photo).

Photo 28. 1980 photograph of Castolon vista (NPS Photo).

Photo 29. 2013 vista reshoot photograph of Castolon vista (NPS Photo).

Photo 30. 1980 photograph of Dominguez Mountain vista (NPS Photo).

Photo 31. 2013 vista reshoot photograph of Dominguez Mountain (NPS Photo).

Photo 32. 1980 photograph of East Rim vista (NPS Photo).

Photo 33. 2013 vista reshoot photograph of East Rim (NPS Photo).

Photo 34. 1980 photograph of Panther Pass vista (NPS Photo).

Photo 35. 2013 vista reshoot photograph of Panther Pass (NPS Photo).

Photo 36. 1980 photograph of Southeast Rim vista (NPS Photo).

Photo 37. 2013 vista reshoot photograph of Southeast Rim (NPS Photo).

Photo 38. 1980 photograph of Terlingua vista (NPS Photo).

Photo 39. 2013 vista reshoot photograph of Terlingua vista (NPS Photo).

Photo 40. 1980 photograph of Ward Mountain vista (NPS Photo).

Photo 41. 2013 vista reshoot photograph of Ward Mountain vista (NPS Photo).

Photo 42. 1980 photograph of The Window vista (NPS Photo).

Photo 43. 2013 vista reshoot photograph of The Window vista (NPS Photo).

Threats and Stressor Factors

BIBE staff identified a few potential threats and stressors to the viewshed in the park. Those threats include development within and outside of the park, light pollution, and visibility impairments.

Development Within and Outside of Park

Within BIBE, almost 526 ha (1,300 ac; less than 1% of the total park area) are categorized as being affected by development. However, power lines and structures are already obstructing scenic views along roads, trails, and key resource areas (NPS 2004). The city of Terlingua, and the surrounding area within the Terlingua census block located approximately 9 km (6 mi) northwest of BIBE, has experienced recent population expansion from 621 people in 2000 to 799 people in 2010 (Zip Code Database 2013). Scenic views from BIBE Integral Vista locations could be affected through the addition of shopping and infrastructure facilities to accommodate the needs of the growing population of Terlingua and surrounding area.

The Terlingua Ranch is an expanding tourist area located on the west northwest park boundary; this developing area is considered one of the major threats to the pristine BIBE landscape. Developments can be viewed from the park already and expansion is expected to continue on these private lands in the future. Growth is also expected from the newly-opened border town of Boquillas, Mexico which could impact vista views to the east of the park (David Larson, BIBE Chief of Science and Resource Management, pers. communication, 2013).

Light Pollution

BIBE is located in an area of west Texas that is very remote from cities and towns of any size. The night sky as seen from BIBE is nearly pristine. The area has been described as possessing "perhaps the darkest, least light polluted skies of any park in the continental United States" (Nordgren 2010, p. 24). BIBE was recently classified as a Gold Tier International Dark Sky Park by the International Dark-Sky Association (NPS 2012). These near-pristine conditions result in a situation where even small increments of anthropogenic light are easy to detect as a change from the natural condition. The Chisos Basin development, which serves guests with a hotel, restaurant, market, and campground, recently reduced its potential for impacting the dark night skies by retrofitting all external lights to reduce light pollution levels. The towns of Study Butte, Terlingua, and Boquillas, as well as other infrastructure within the park (e.g., light poles), and the expansion of the Terlingua Ranch have the greatest potential to affect the pristine BIBE night sky (Larson, pers. communication, 2013).

Visibility

The natural visual range of BIBE Integral Vistas is frequently impaired by air pollution and panoramic views often appear hazy as a result of elevated levels of fine particles in the air (NPS 2011). For a detailed discussion of visibility in the park, refer to Chapter 4.15 of this assessment.

Data Needs/Gaps

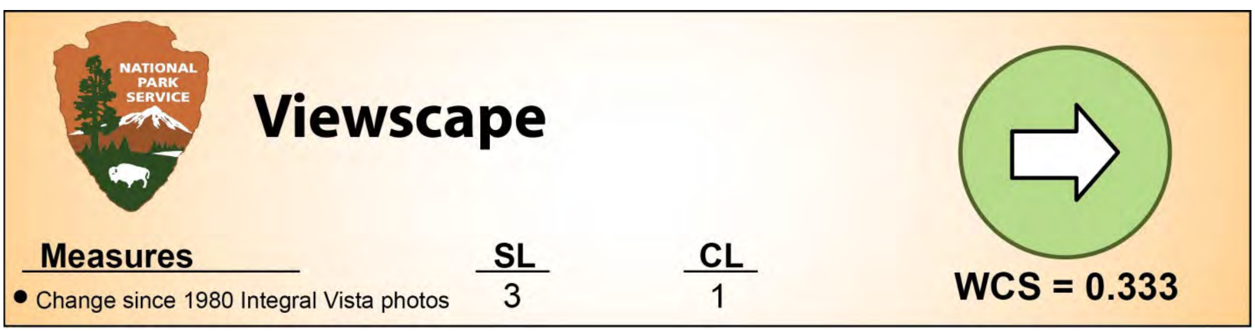
Updating photographs taken from Integral Vista locations could provide a data source stretching back to the first photographs taken in 1980. Five of the nine Integral Vistas were reshot in 1997; however, the photographs were taken from different angles, distances and directions between years, making comparisons difficult. The 12 1980 photos taken from points in the Chisos mountains were reshot in 2013, using high resolution digital photography. Observing consistency of these parameters during future Integral Vista photo reshoots could allow for viewscape differences over time to be observed. Future comparisons should be made using the original high resolution photography that the 1997 photos (currently missing) were shot in and not the composite photos presented in this document (Reiser, pers. communication, 2013). It is also important to note that the 1980 photos are of poor quality and few landscape changes or distance details can be determined (H. Reiser, pers. communication, 2013).

Two additional Vista locations on Route 13 (looking towards Terlingua Ranch), along with the viewsheds stretching towards San Vicente, Mexico, are in need of future analysis to determine the visual intrusion these two developing areas are imposing upon BIBE (Reiser, pers. communication, 2013).

<u>Overall Condition</u>

Change Since 1980 Integral Vista Photography
This measure was assigned a *Significance Level* of 3, indicating it is of high importance in determining the condition of the viewscape. Overall, the amount of landcover change that occurred within the viewscape of the Integral Vista viewsheds from 2001 to 2006 was extremely small. However, new development since 2006 northwest of the park in the Terlingua area is a concern for BIBE's viewscape. Therefore, the *Condition Level* of the measure is 1, indicating low concern.

Weighted Condition Score
The *Weighted Condition Score* for this component is 0.333, indicating the condition is currently of low concern.



4.18.6 Sources of Expertise
Betty Alex, BIBE GIS Specialist

Drew Bingham, Geographer, Air Resources Division, Natural Resource Stewardship and Science (NRSS) directorate

Raymond Skiles, BIBE Wildlife Biologist and Wilderness Coordinator

4.18.7 Literature Cited

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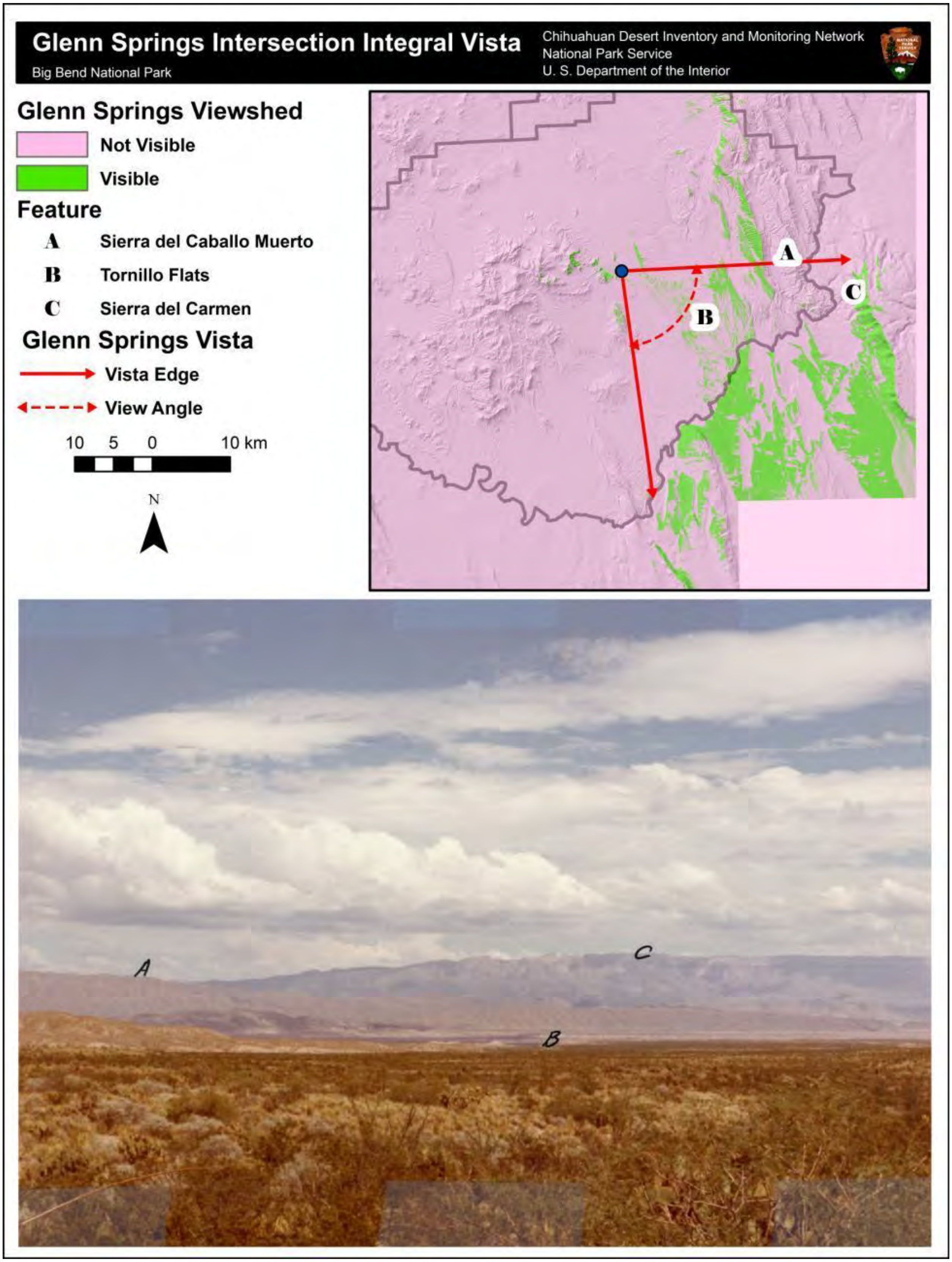


Plate 28. Glenn Spring Intersection Integral Vista, viewshed and 1980 photograph.

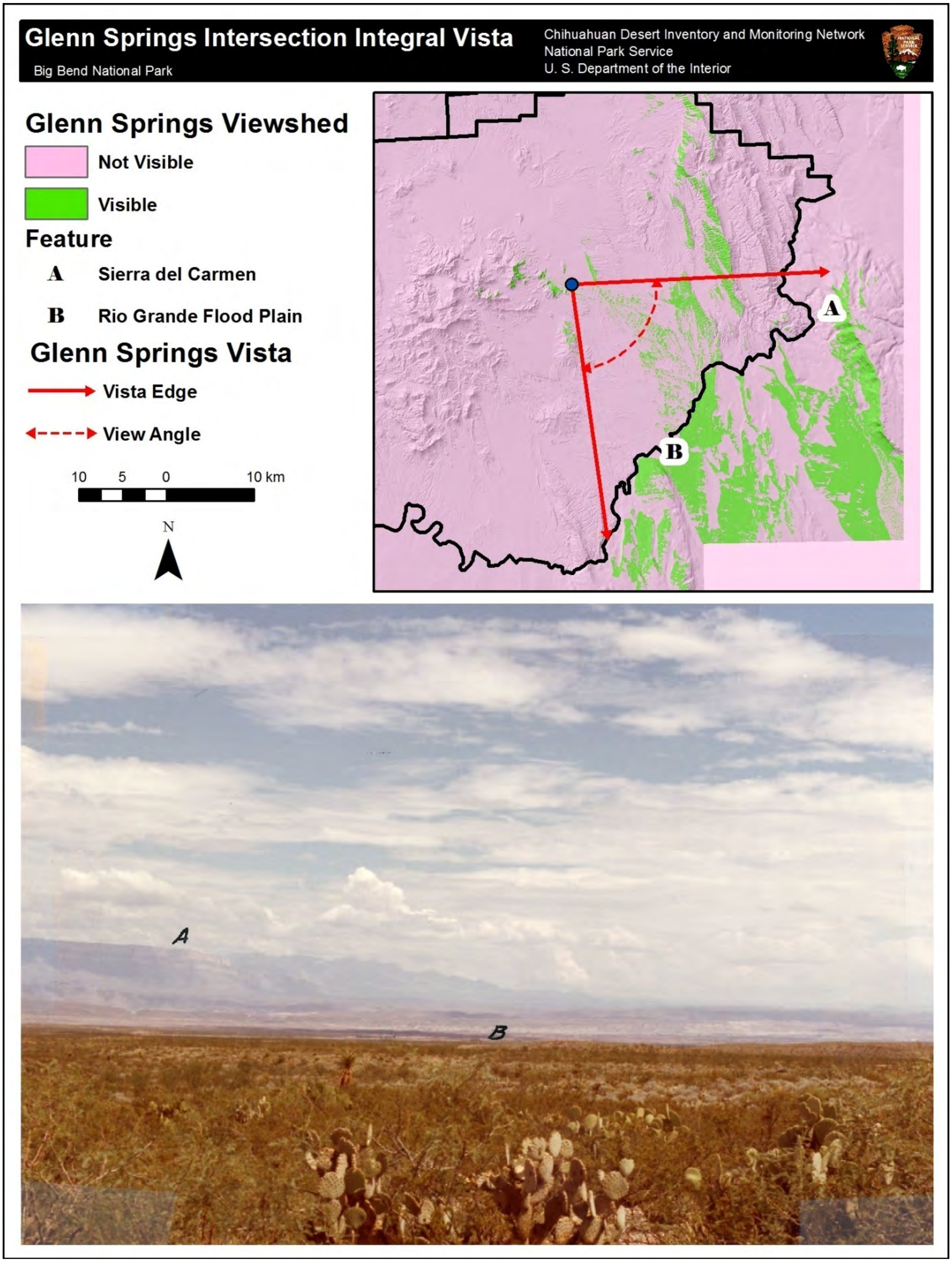


Plate 29. Glenn Spring Intersection Integral Vista, viewshed and 1980 photograph.

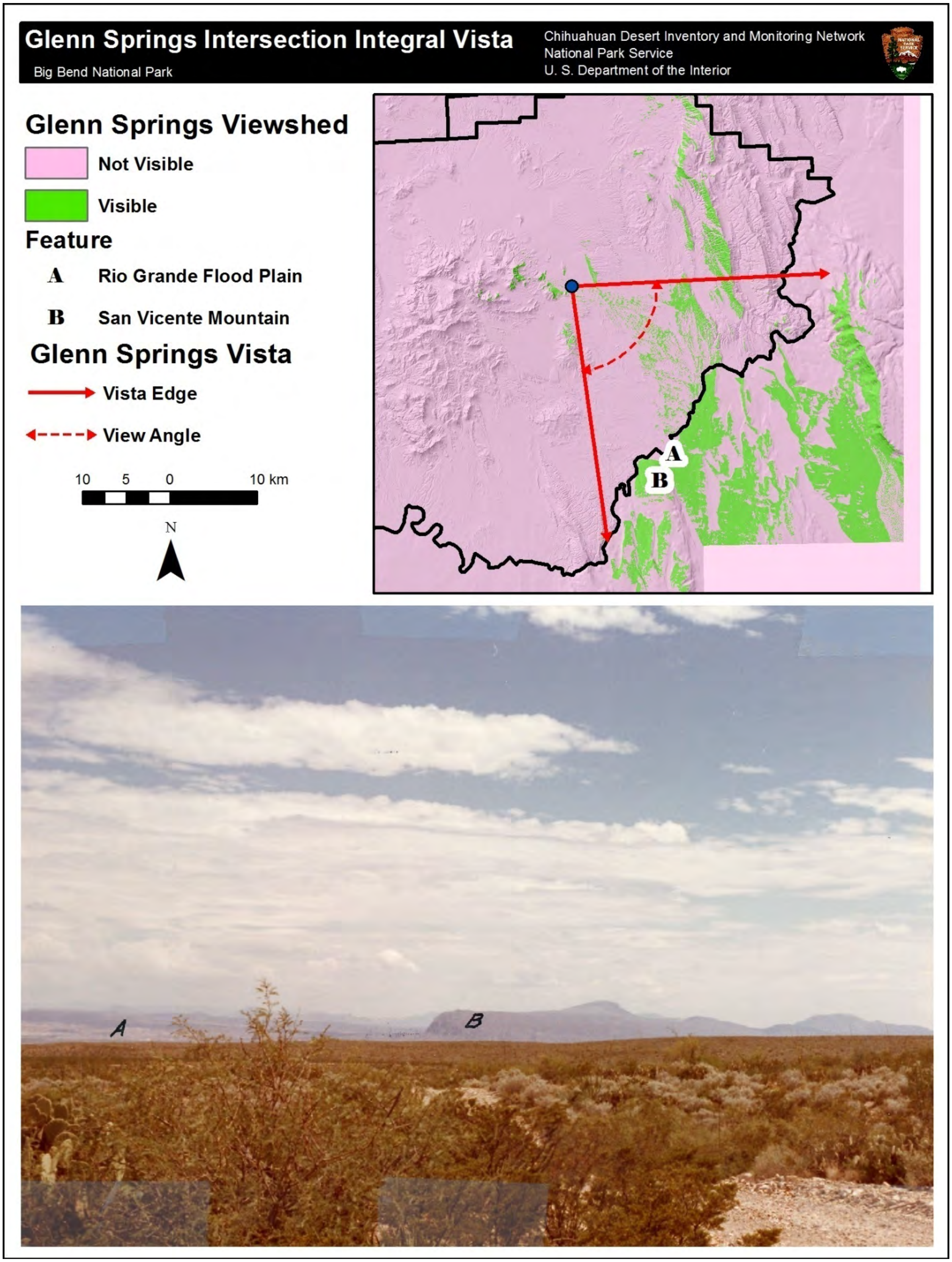


Plate 30. Glenn Spring Intersection Integral Vista, viewshed and 1980 photograph.

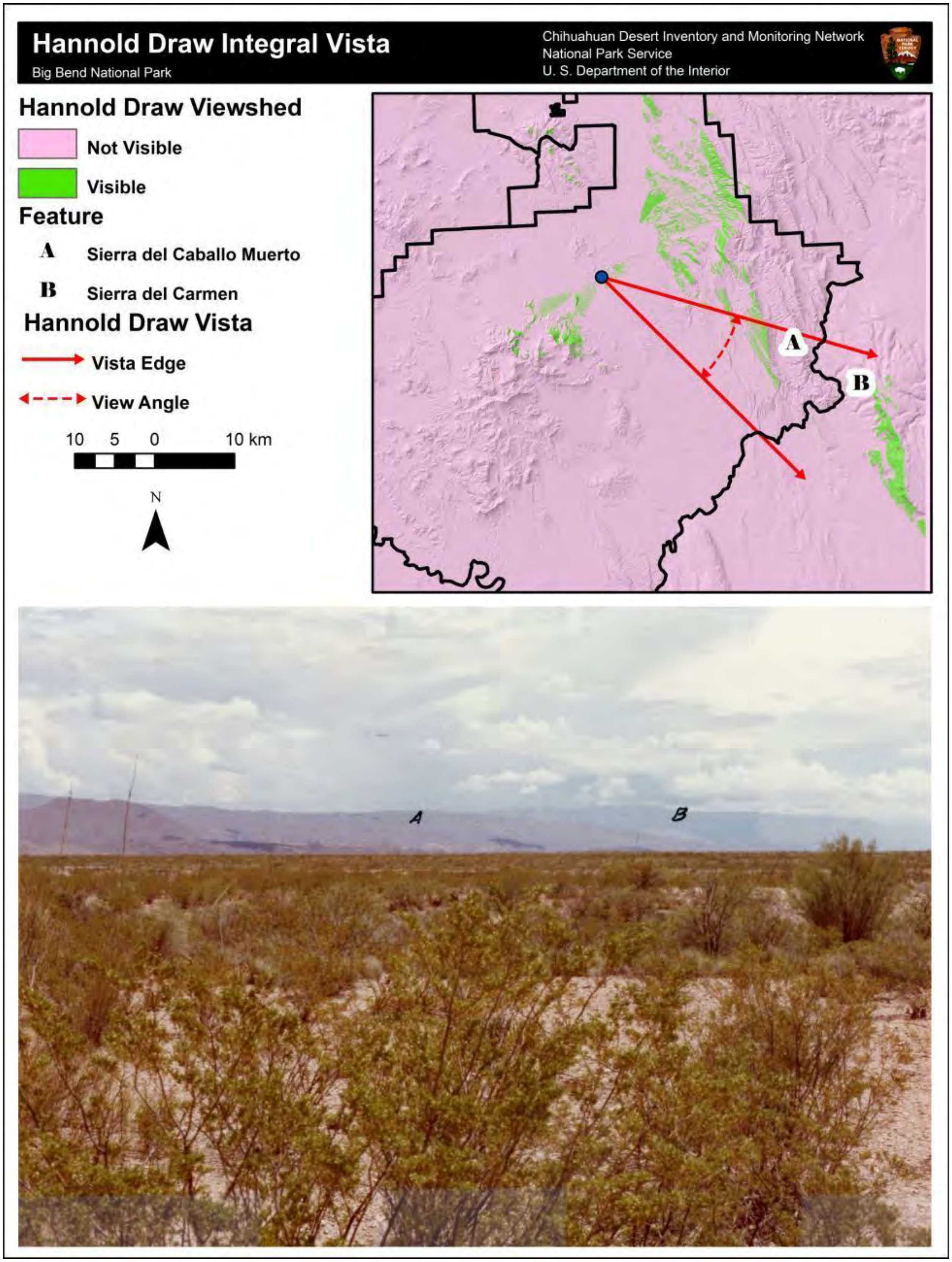


Plate 31. Hannold Draw Intersection Integral Vista, viewshed and 1980 photograph.

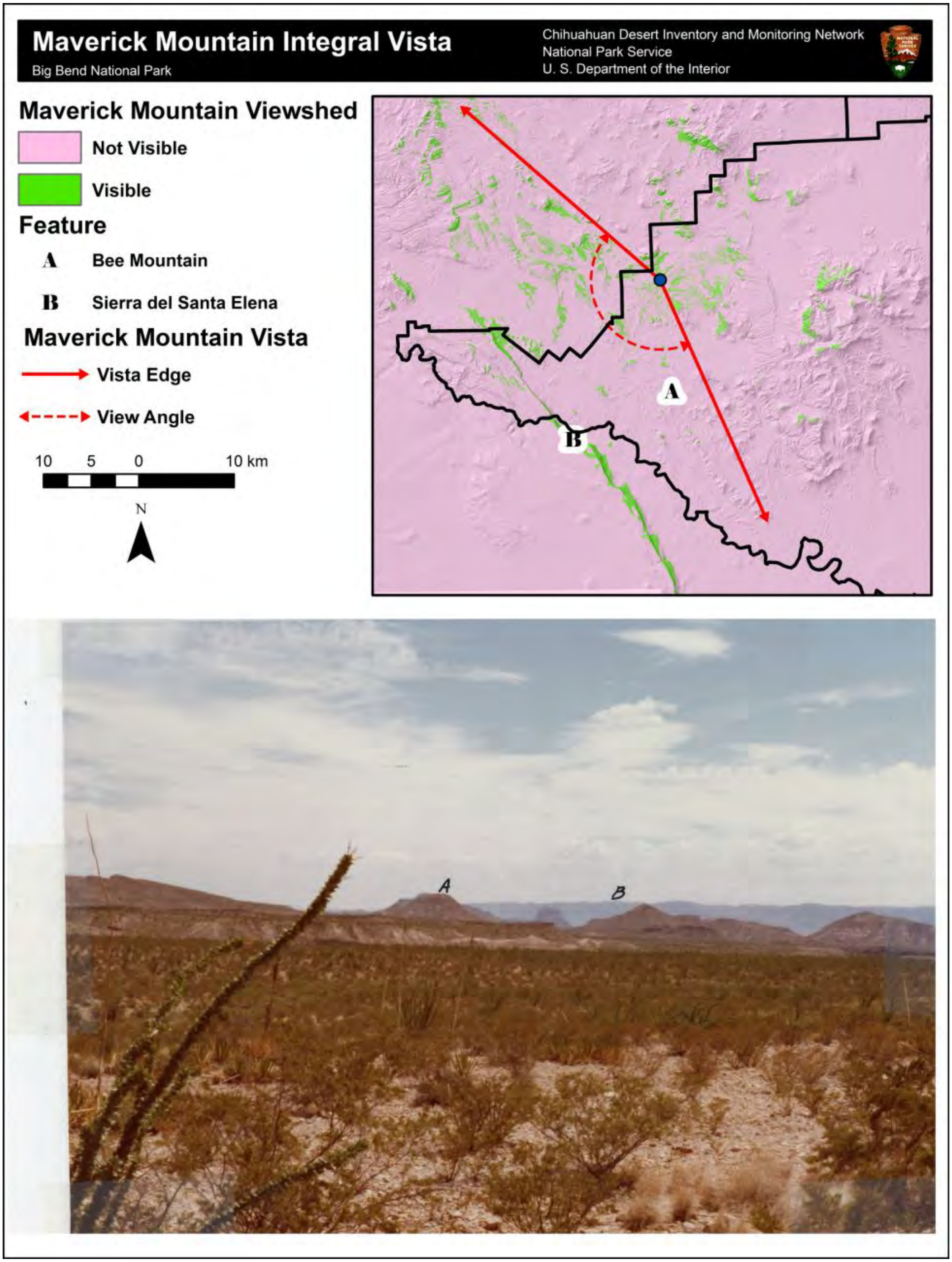


Plate 32. Maverick Mountain Integral Vista, viewshed and 1980 photograph.

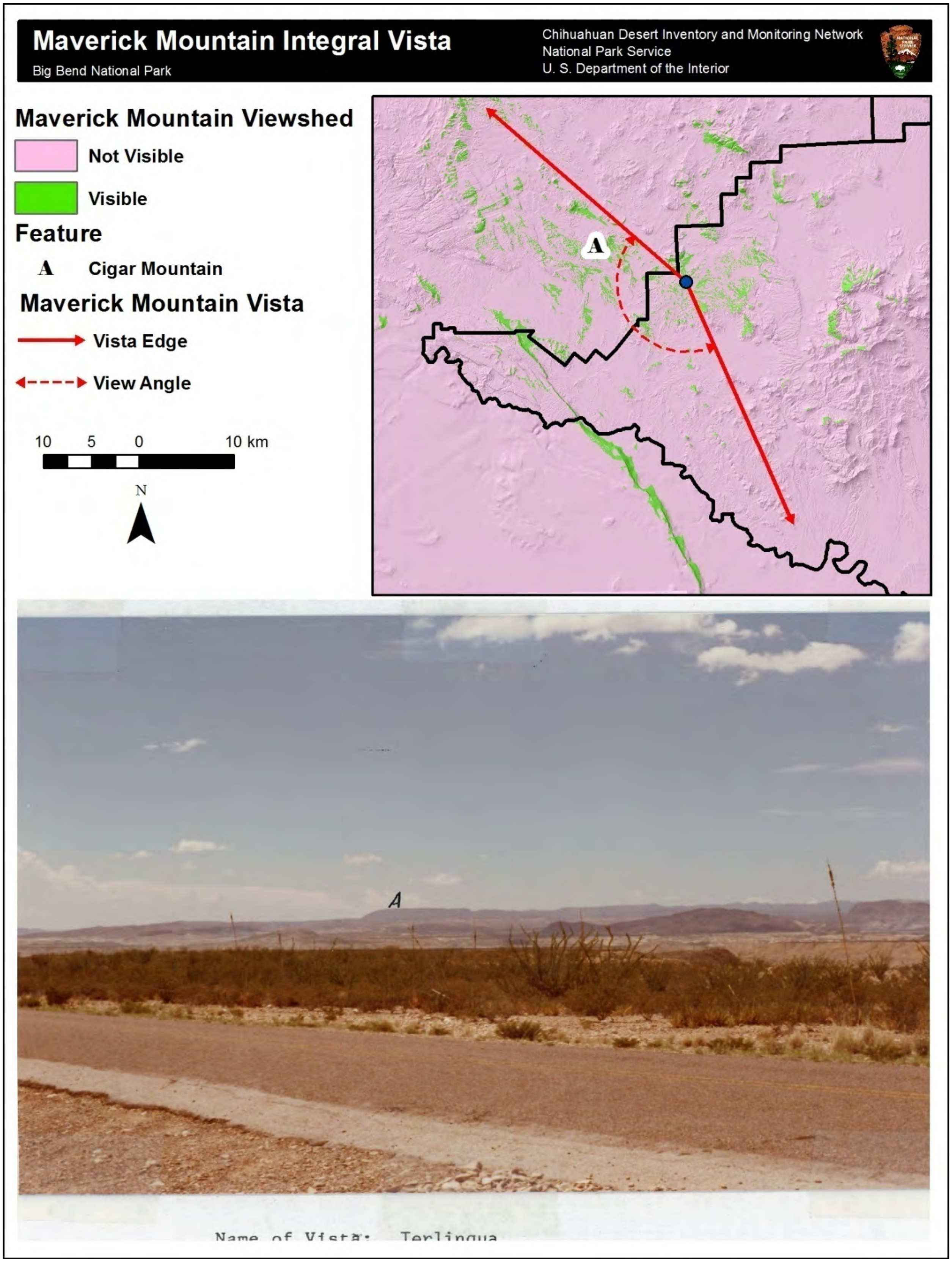


Plate 33. Maverick Mountain Integral Vista, viewshed and 1980 photograph.

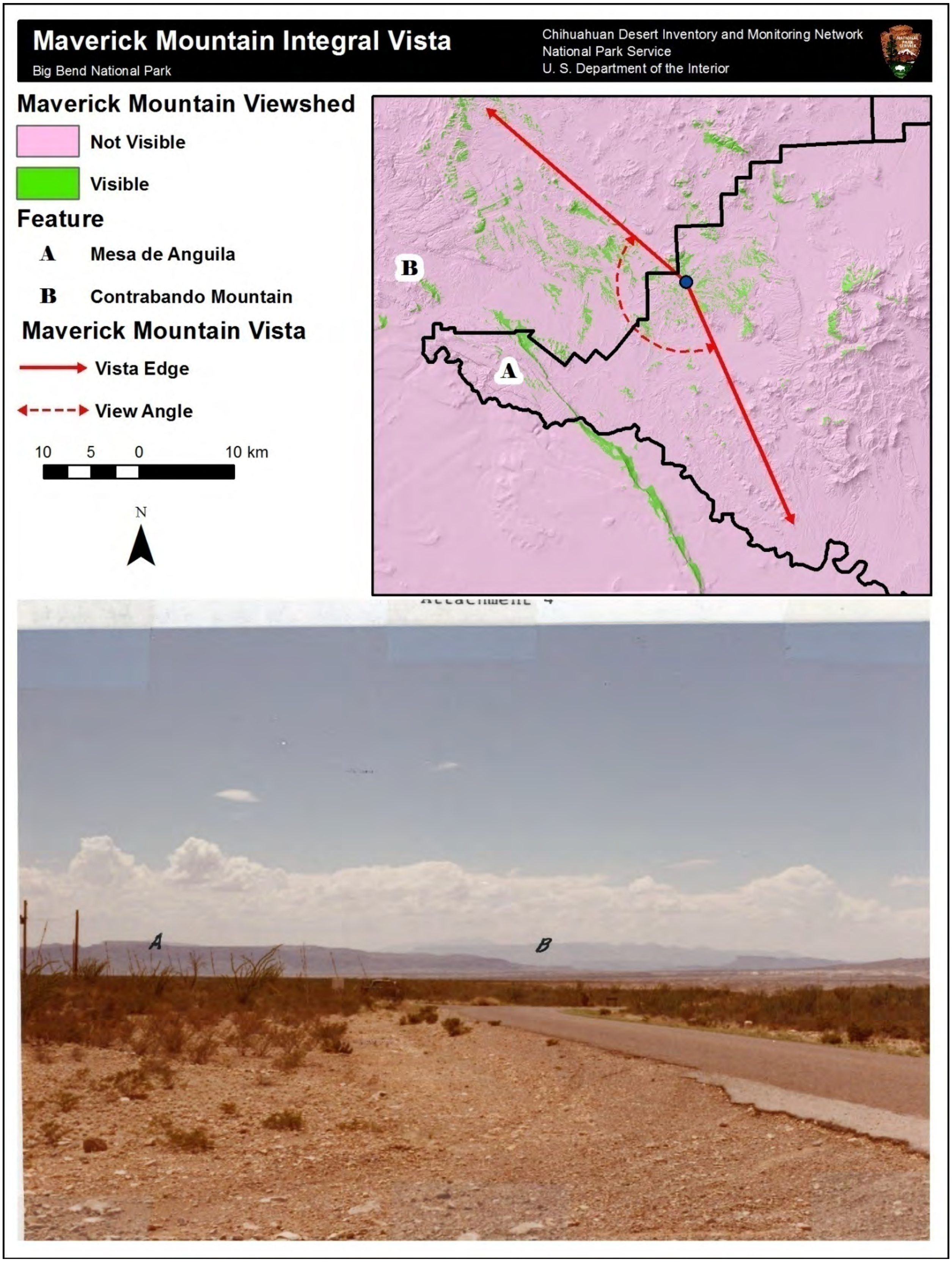


Plate 34. Maverick Mountain Integral Vista, viewshed and 1980 photograph.

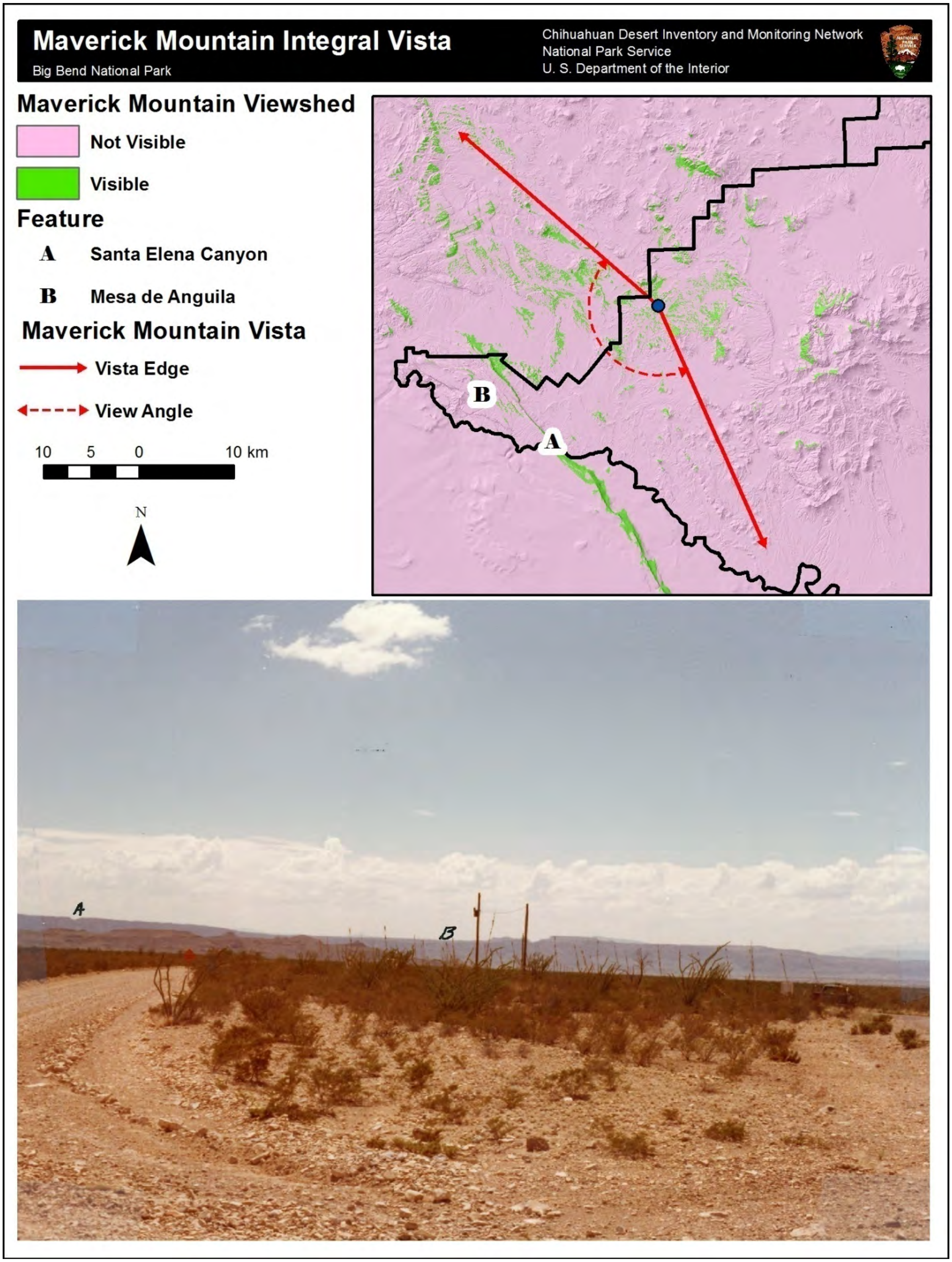


Plate 35. Maverick Mountain Integral Vista, viewshed and 1980 photograph.

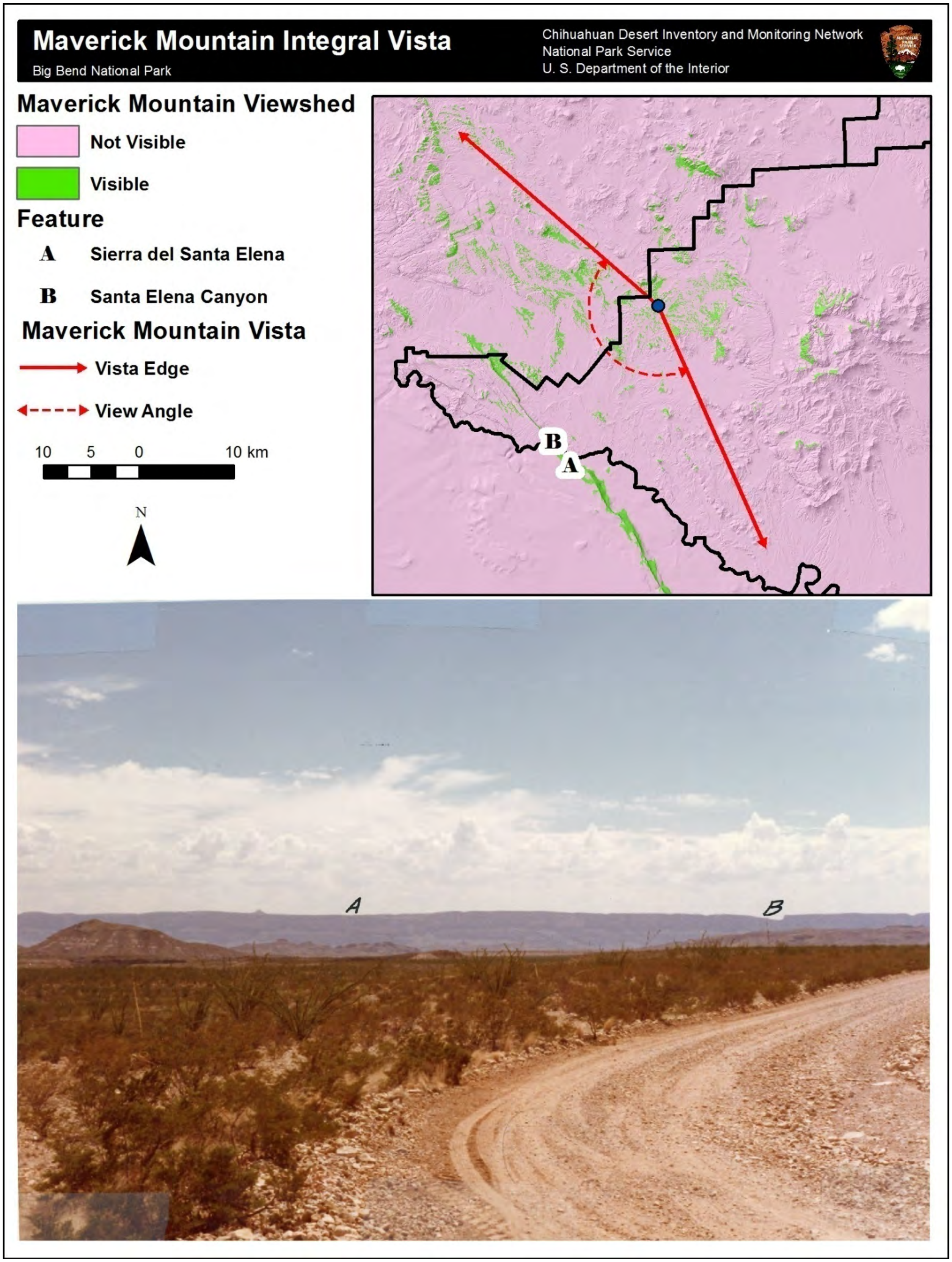


Plate 36. Maverick Mountain Integral Vista, viewshed and 1980 photograph.

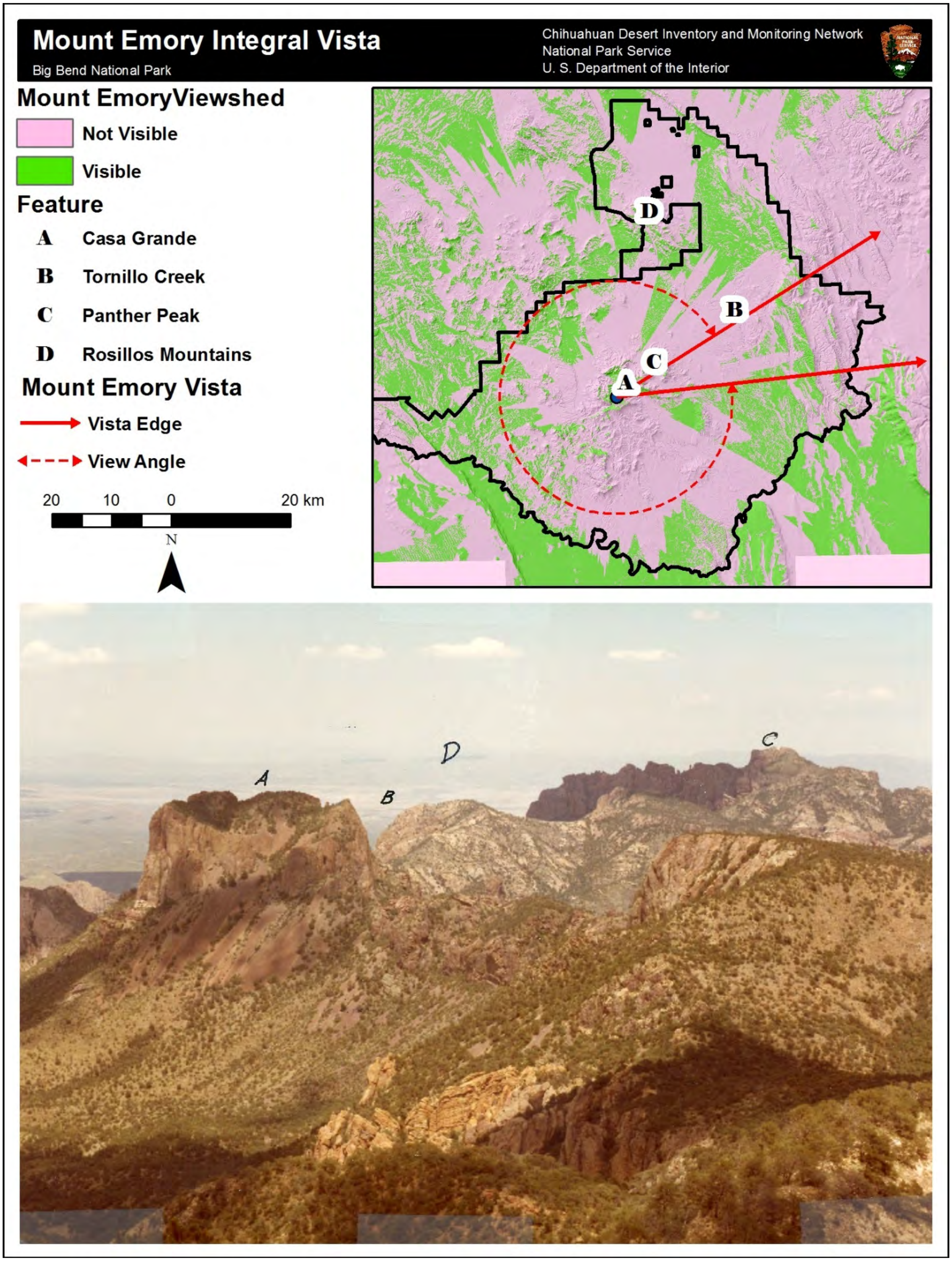


Plate 37. Mount Emory Integral Vista, viewshed and 1980 photograph.

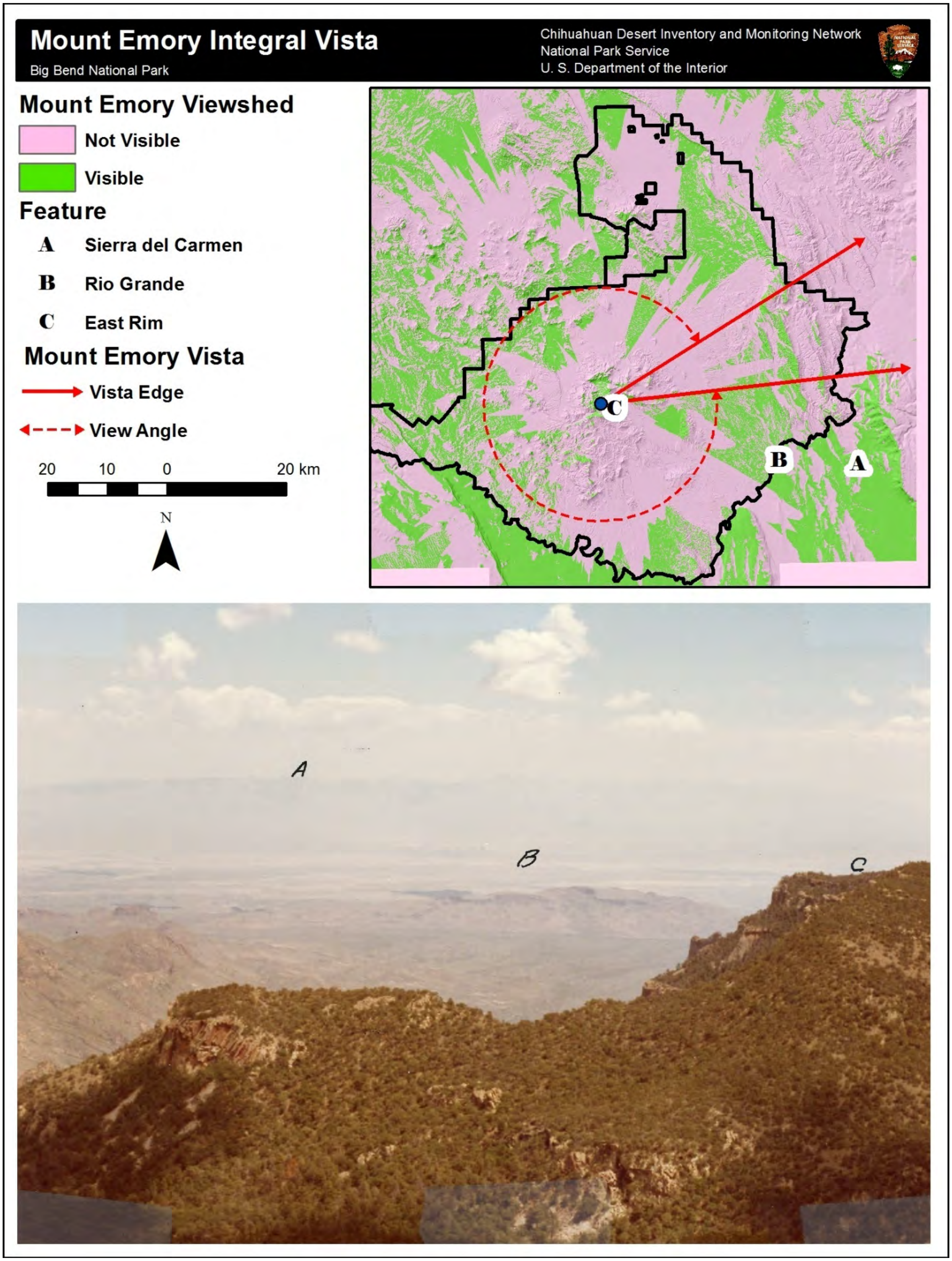


Plate 38. Mount Emory Integral Vista, viewshed and 1980 photograph.

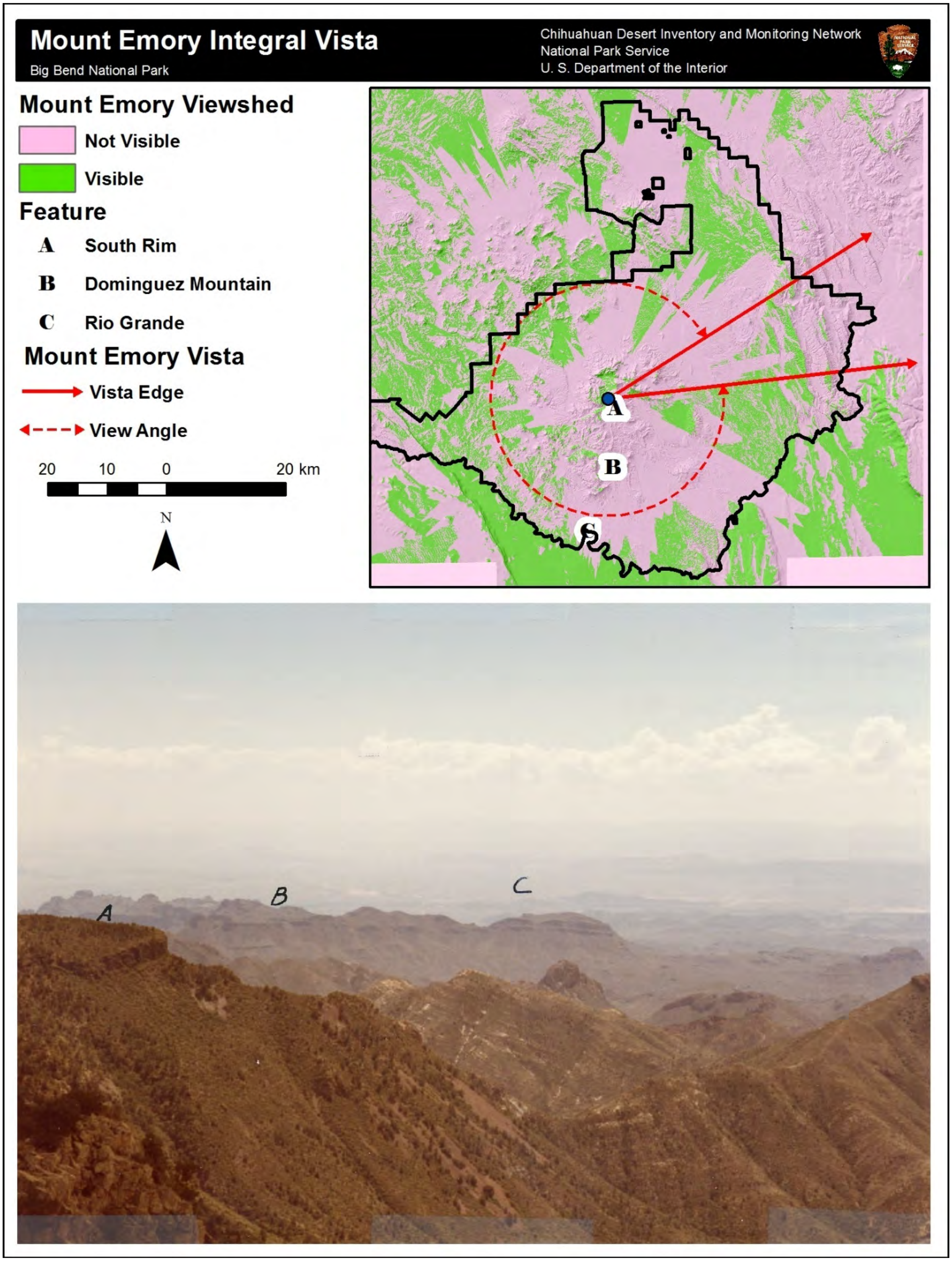


Plate 39. Mount Emory Integral Vista, viewshed and 1980 photograph.

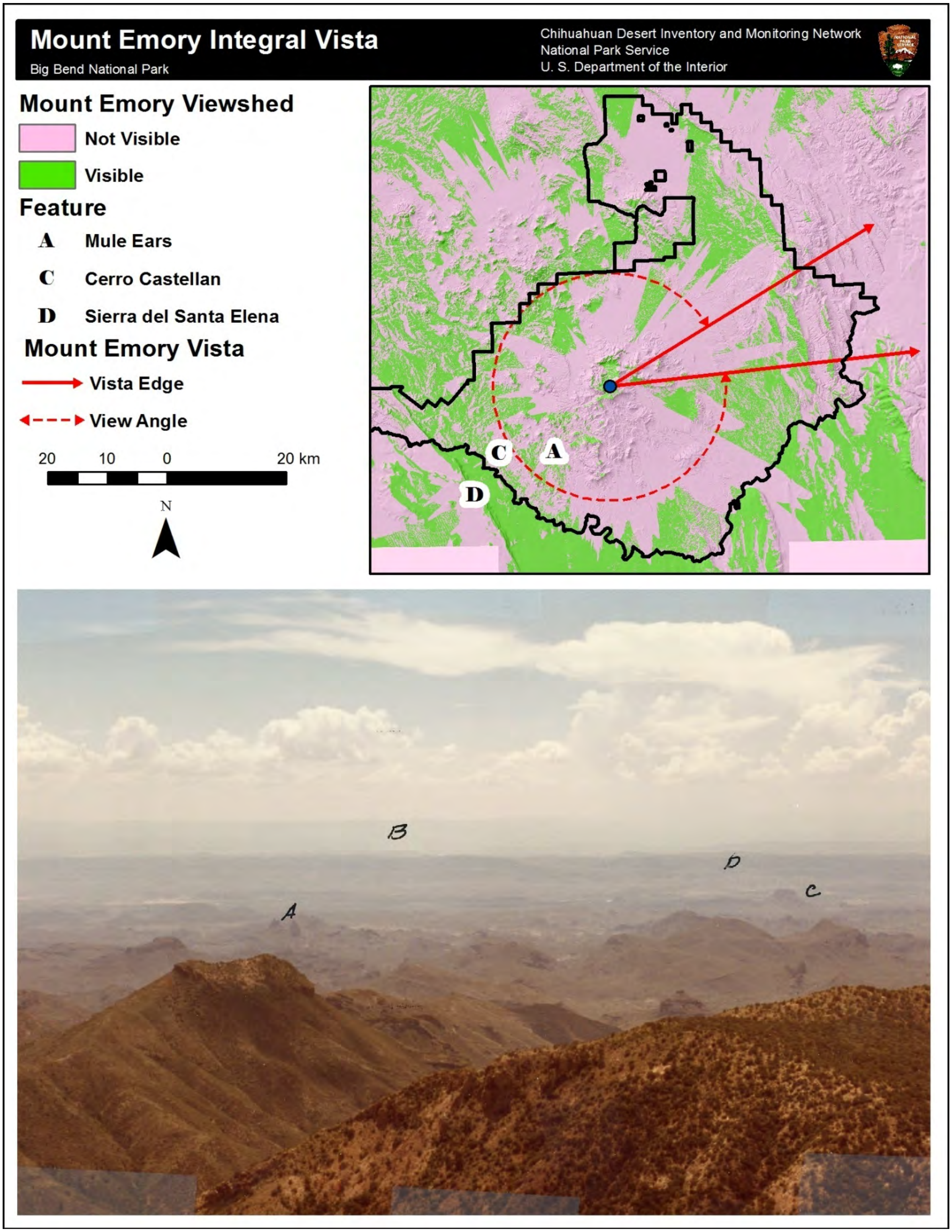


Plate 40 Mount Emory Integral Vista, viewshed and 1980 photograph. The location for feature B (Sierra de Heceiros) was not provided in the 1980 Integral Vista dataset.

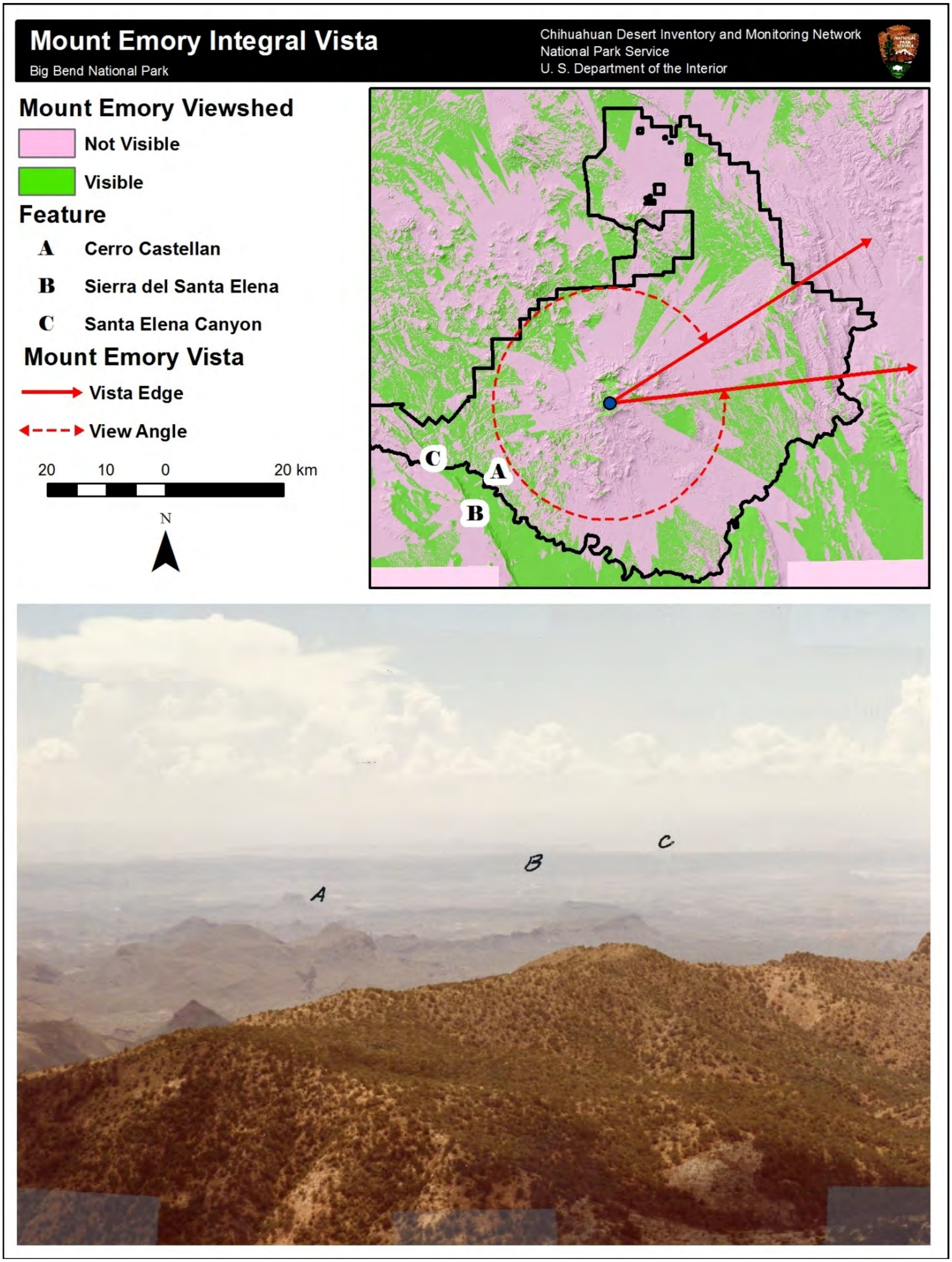


Plate 41. Mount Emory Integral Vista, viewshed and 1980 photograph.

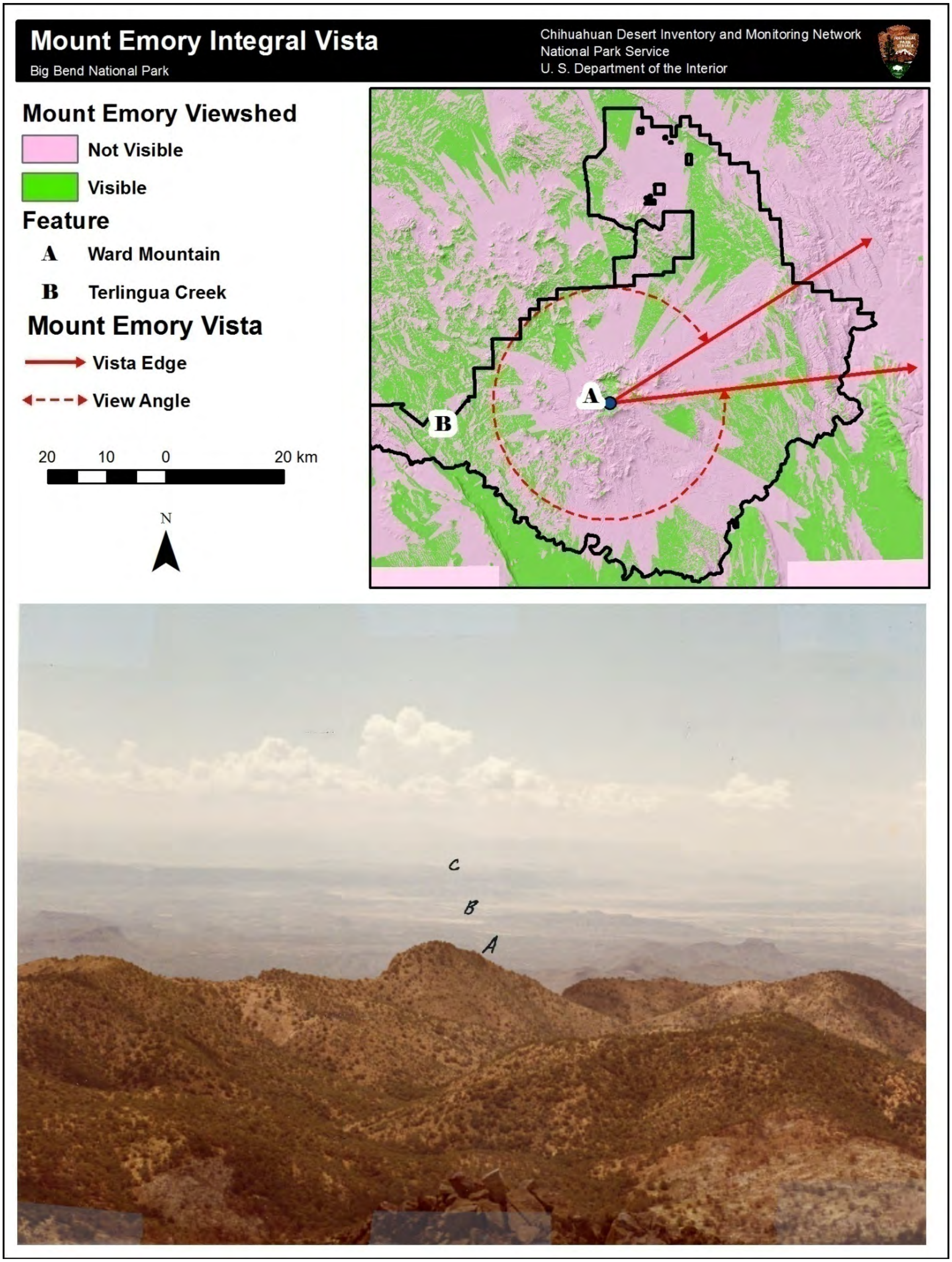


Plate 42. Mount Emory Integral Vista, viewshed and 1980 photograph.

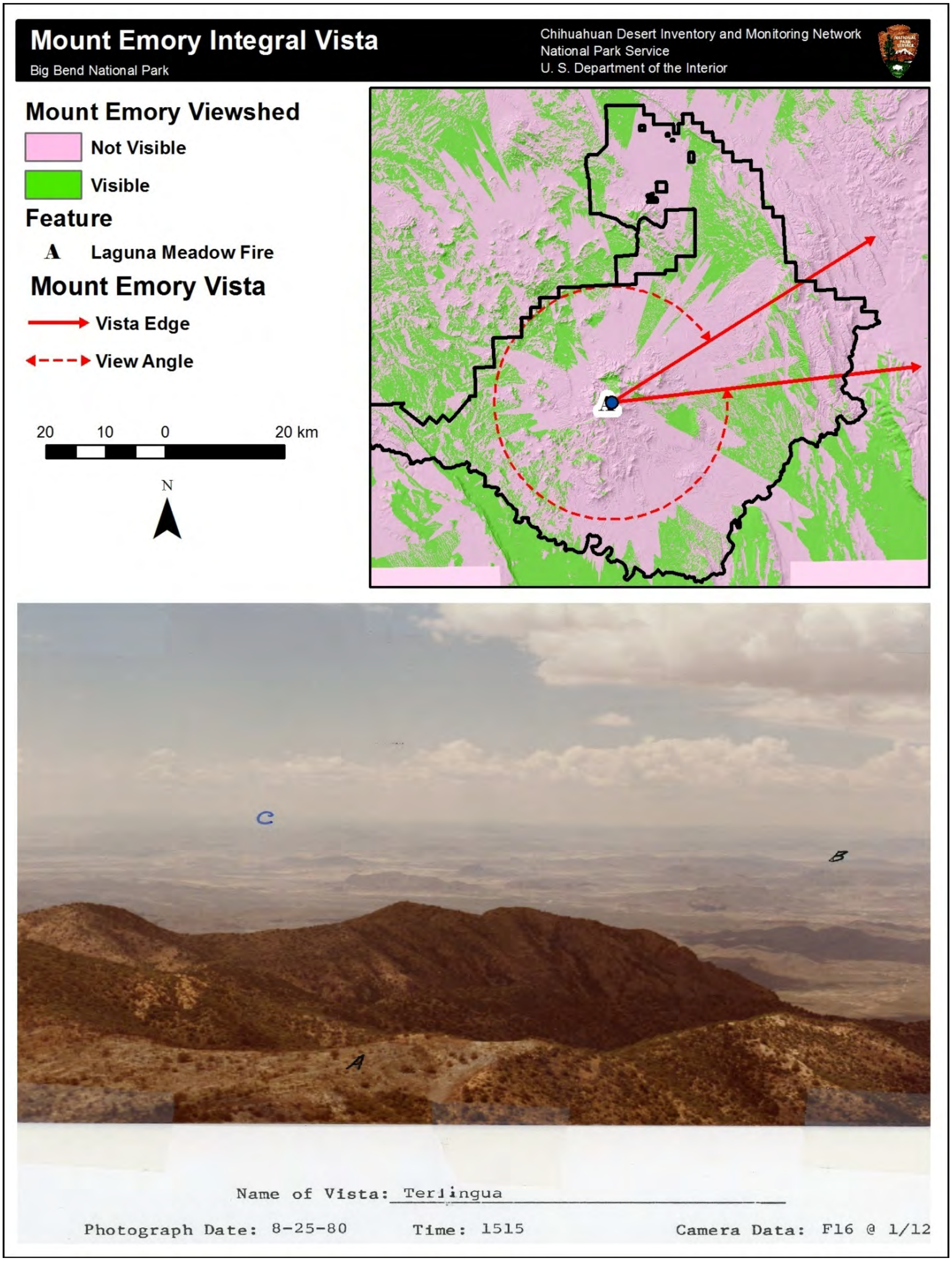


Plate 43. Mount Emory Integral Vista, viewshed and 1980 photograph.

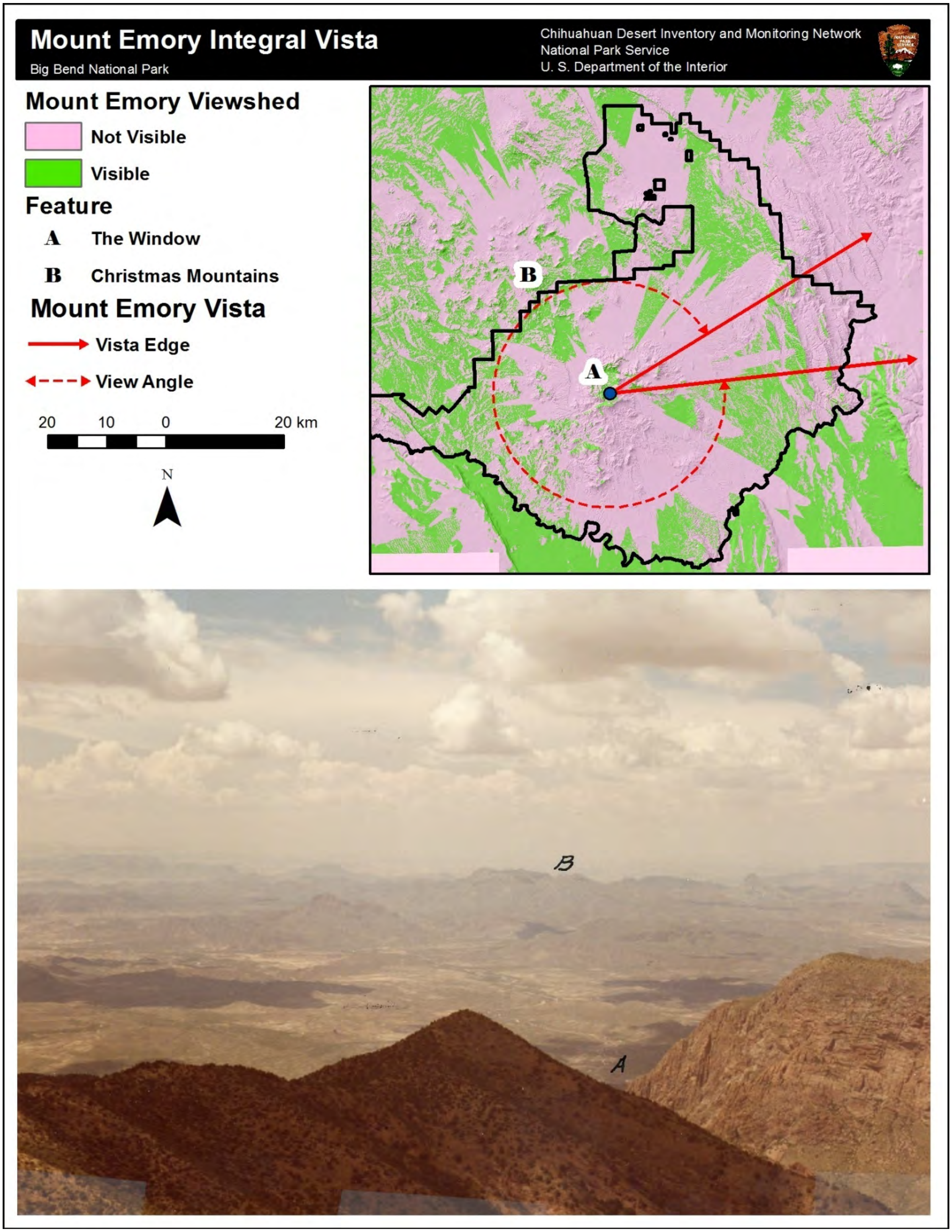


Plate 44. Mount Emory Integral Vista, viewshed and 1980 photograph.

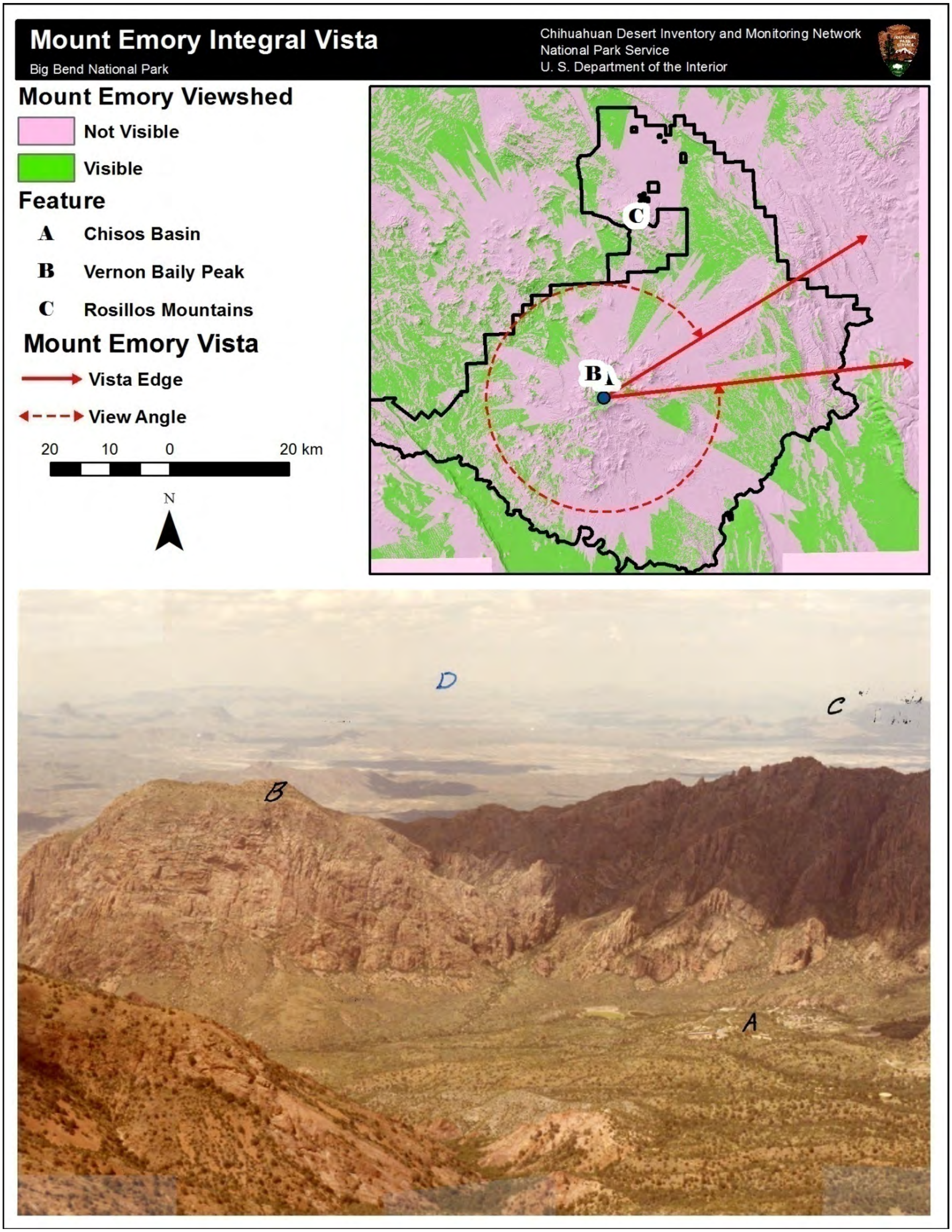


Plate 45. Mount Emory Integral Vista, viewshed and 1980 photograph. Feature A is obscured by feature B in order to maintain extent consistensies of the viewshed.

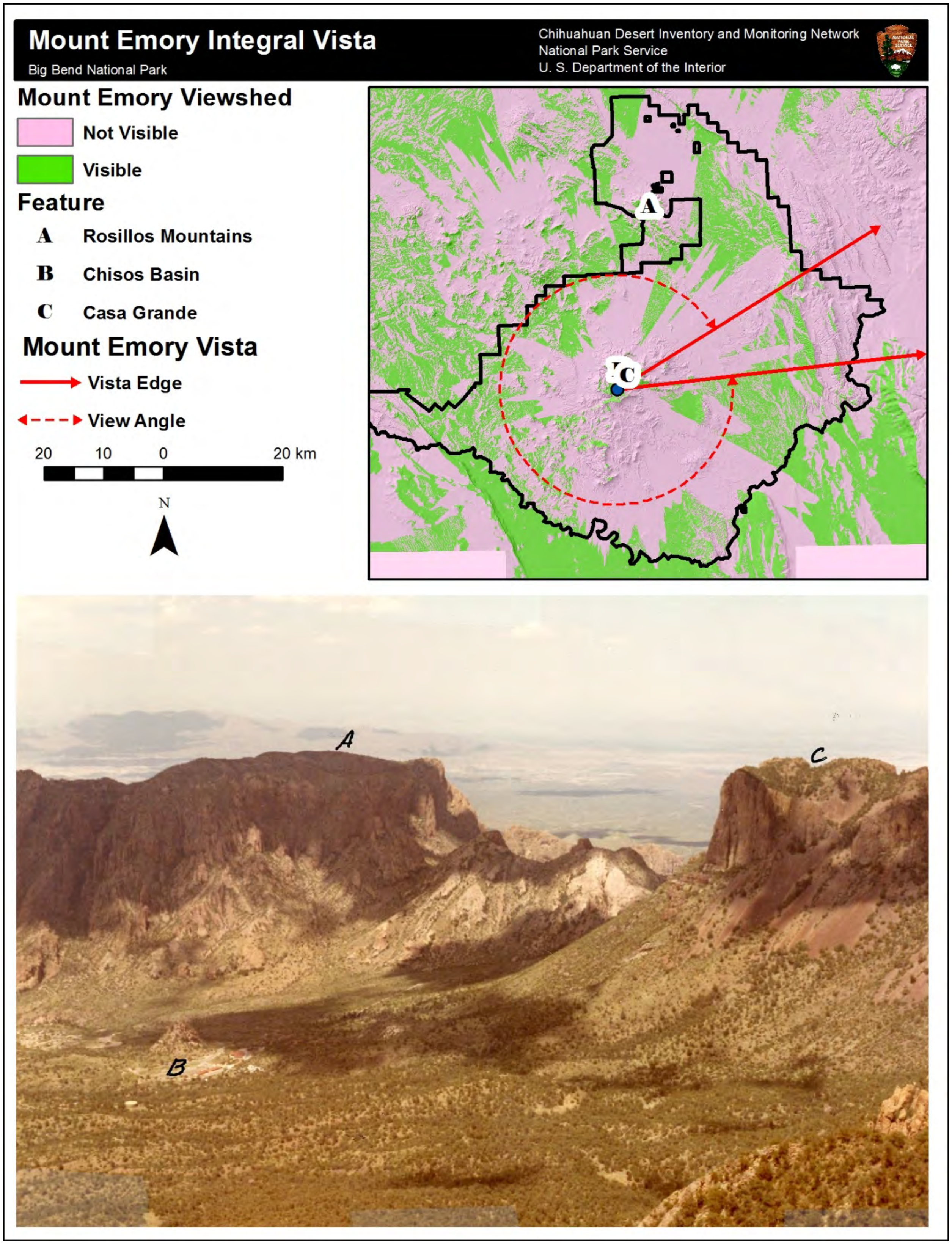


Plate 46. Mount Emory Integral Vista, viewshed and 1980 photograph. Feature B is obscured by feature C in order to maintain extent consistensies of the viewshed.

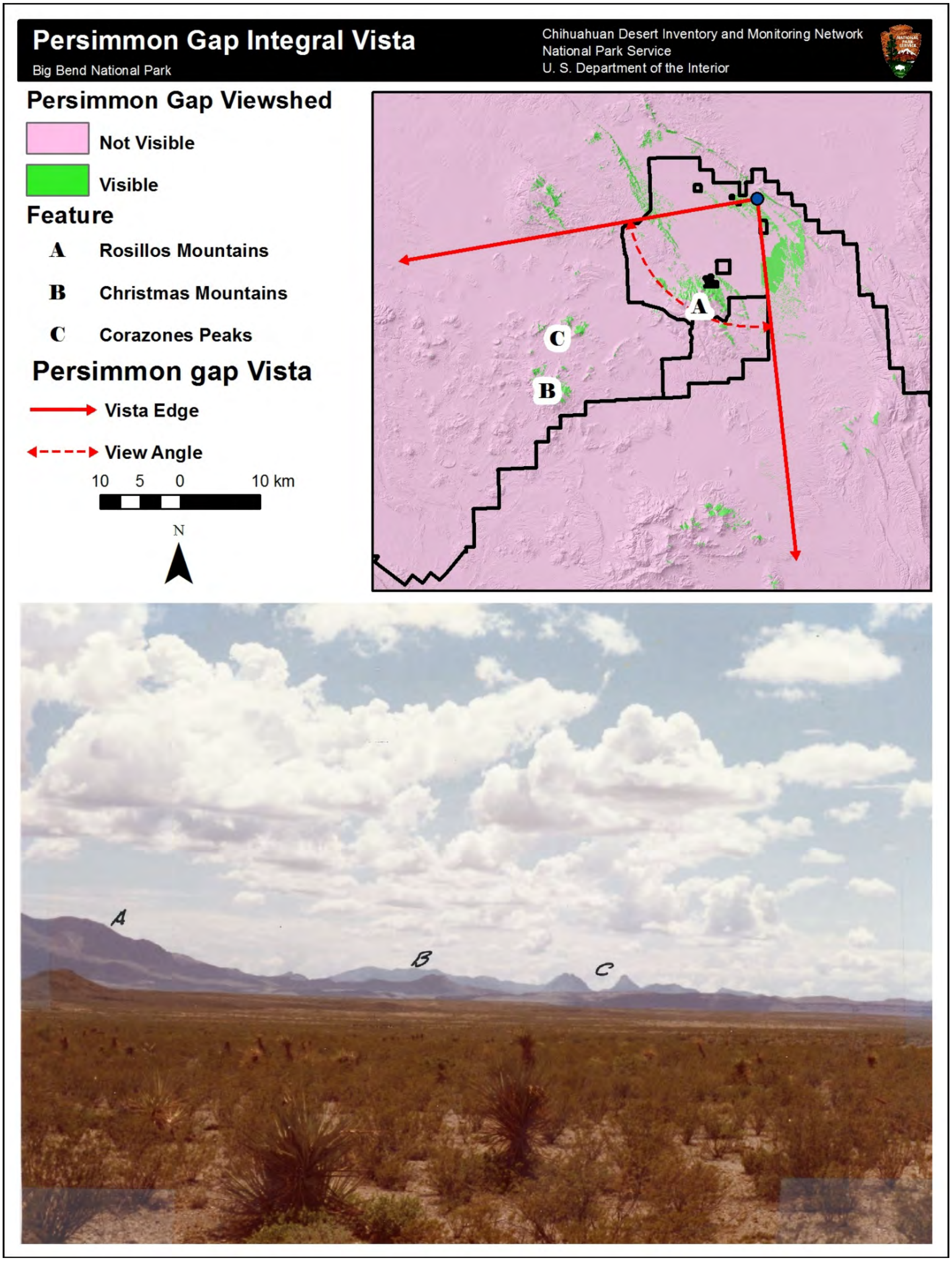


Plate 47. Persimmon Gap Integral Vista, viewshed and 1980 photograph.

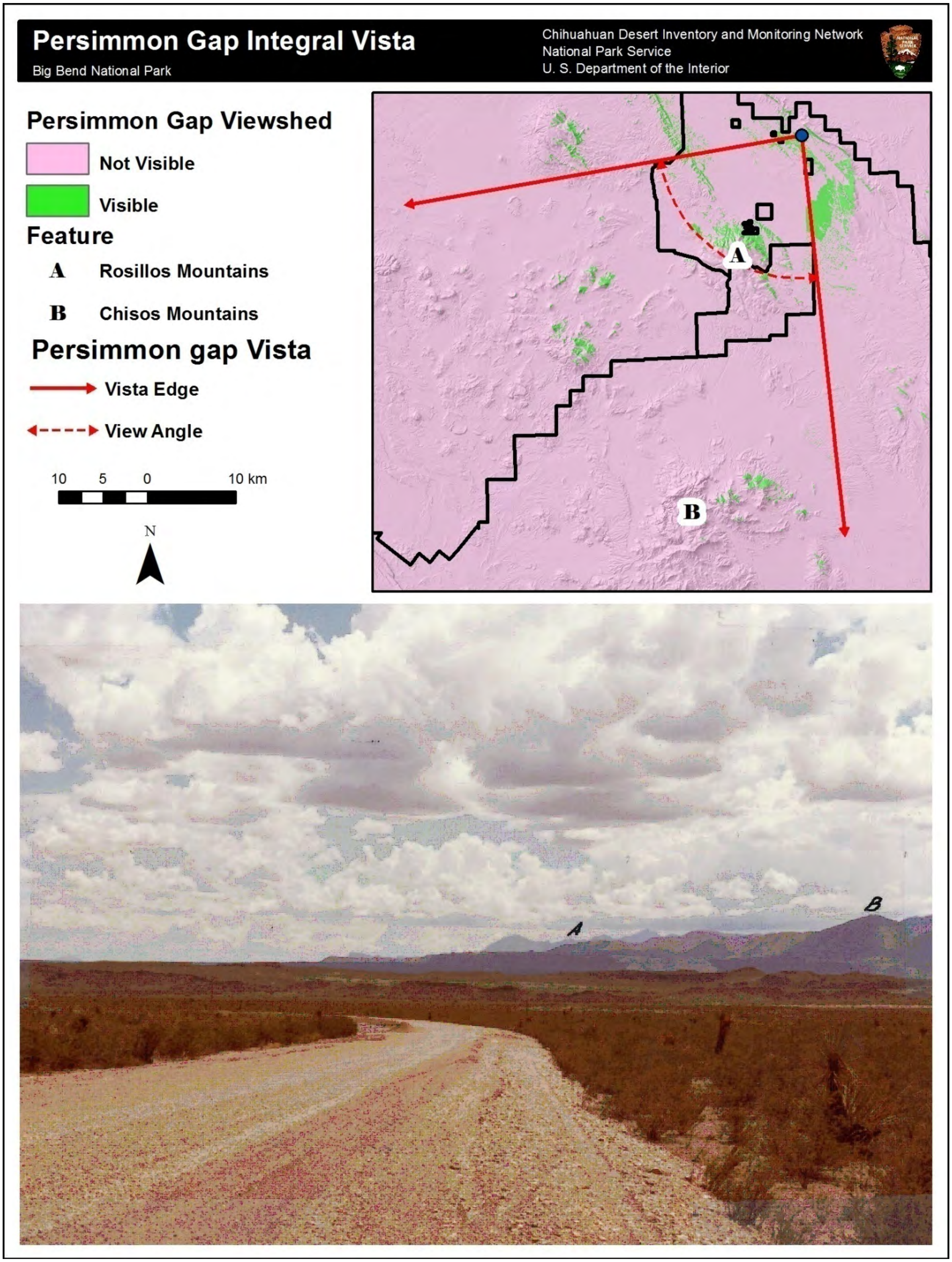


Plate 48. Persimmon Gap Integral Vista, viewshed and 1980 photograph.

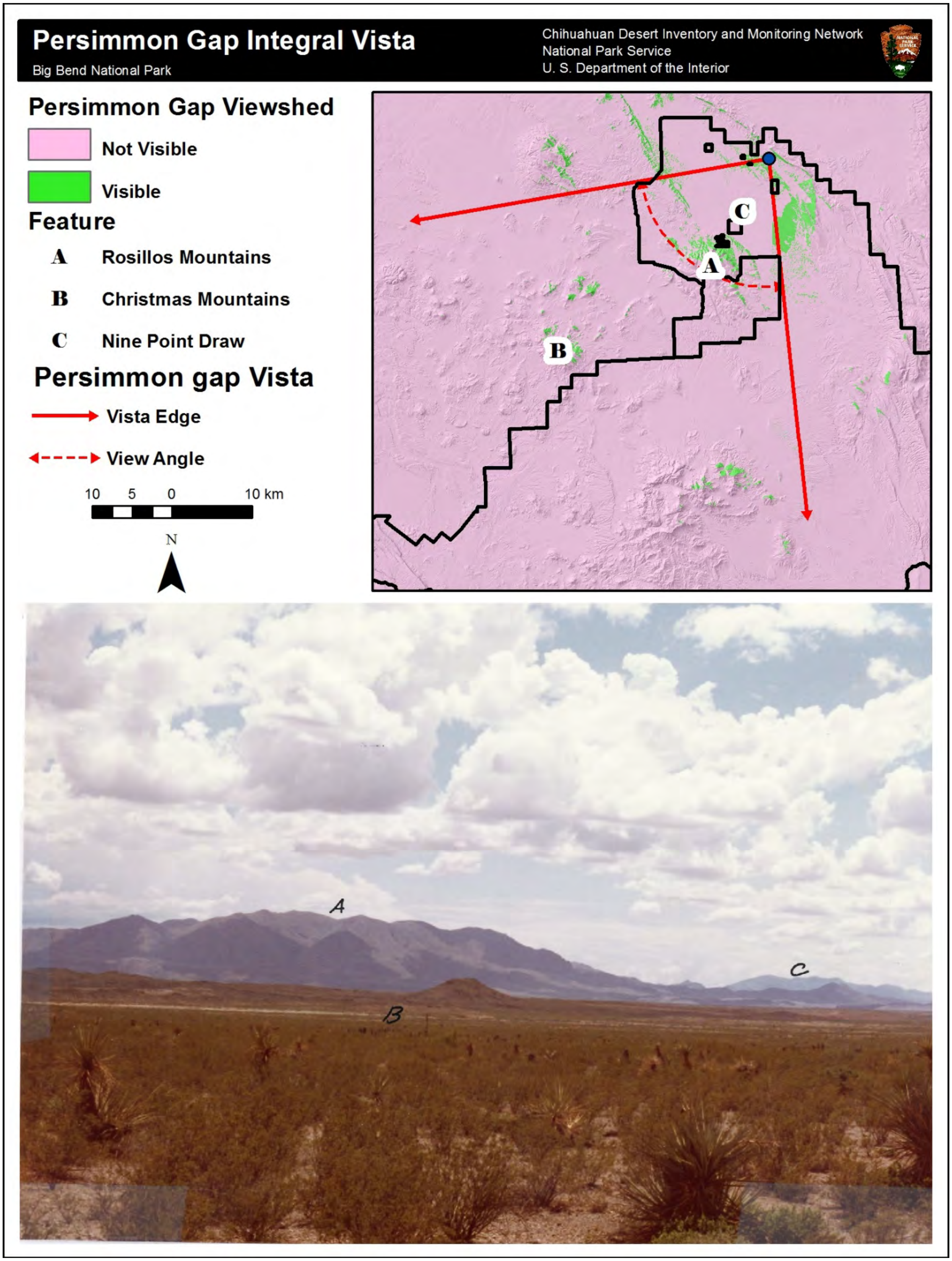


Plate 49. Persimmon Gap Integral Vista, viewshed and 1980 photograph.

Plate 50. Santa Elena Canyon Integral Vista, viewshed and 1980 photograph.

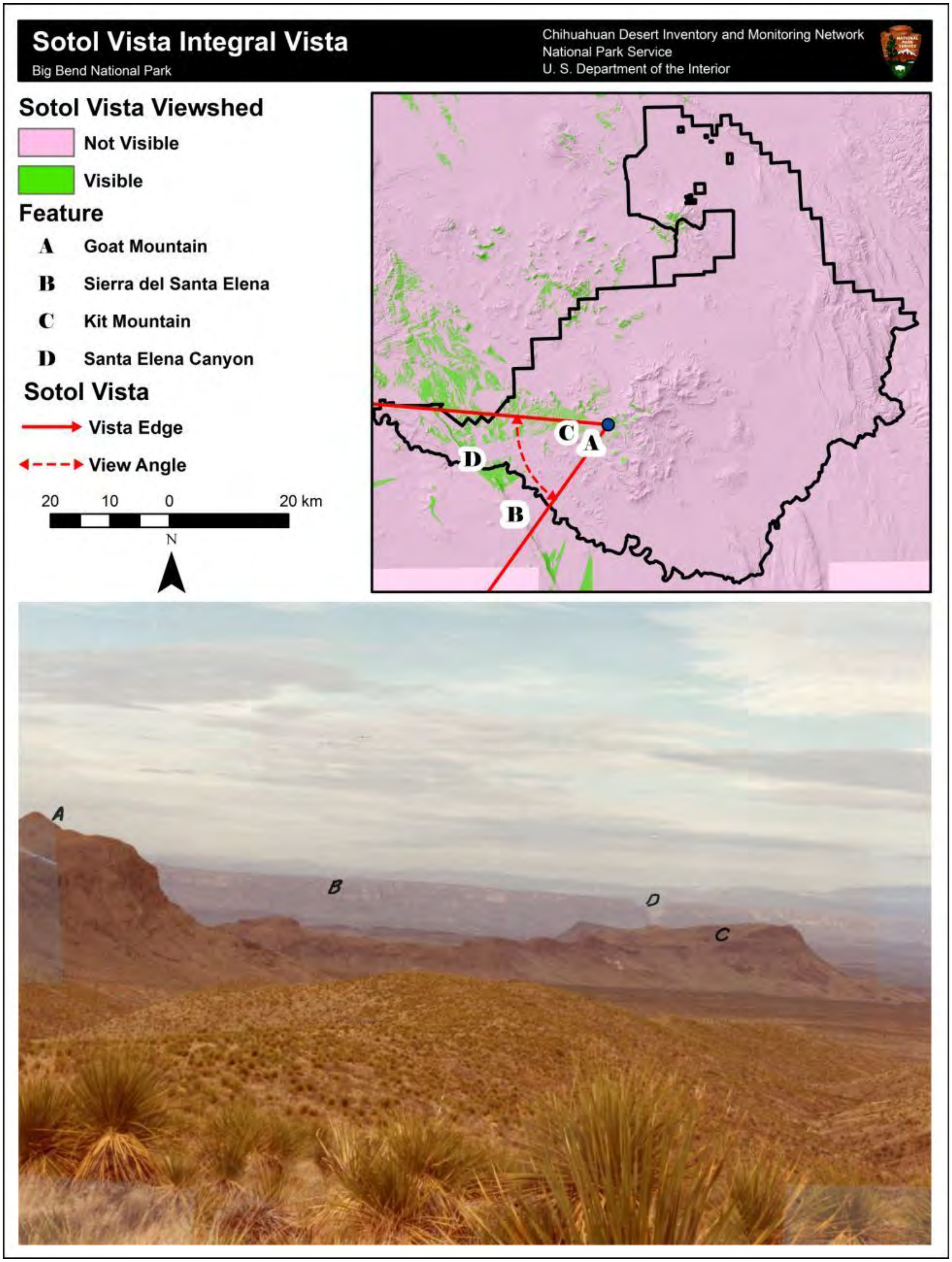


Plate 51. Sotol Vista Integral Vista, viewshed and 1980 photograph.

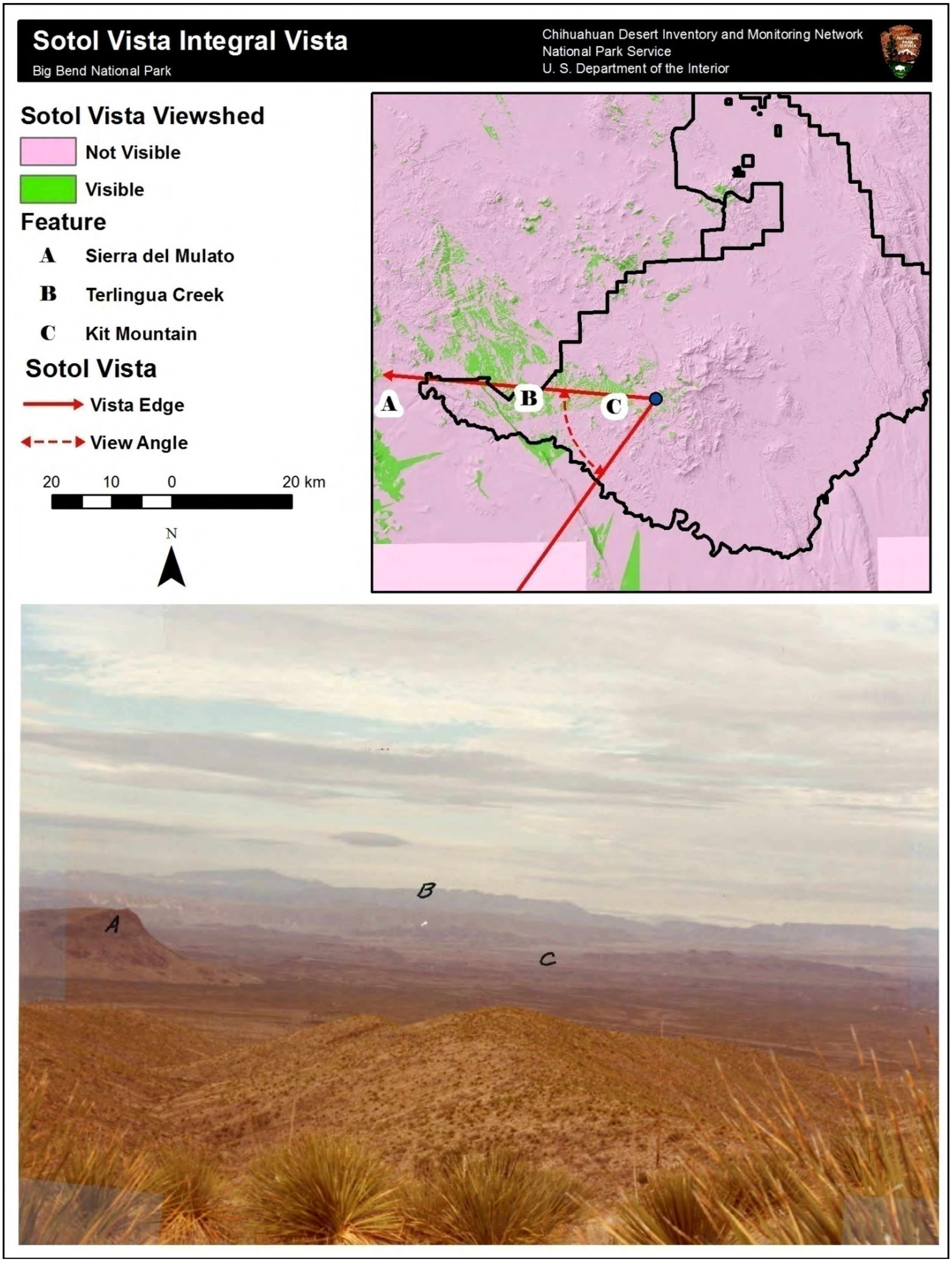


Plate 52. Sotol Vista Integral Vista, viewshed and 1980 photograph.

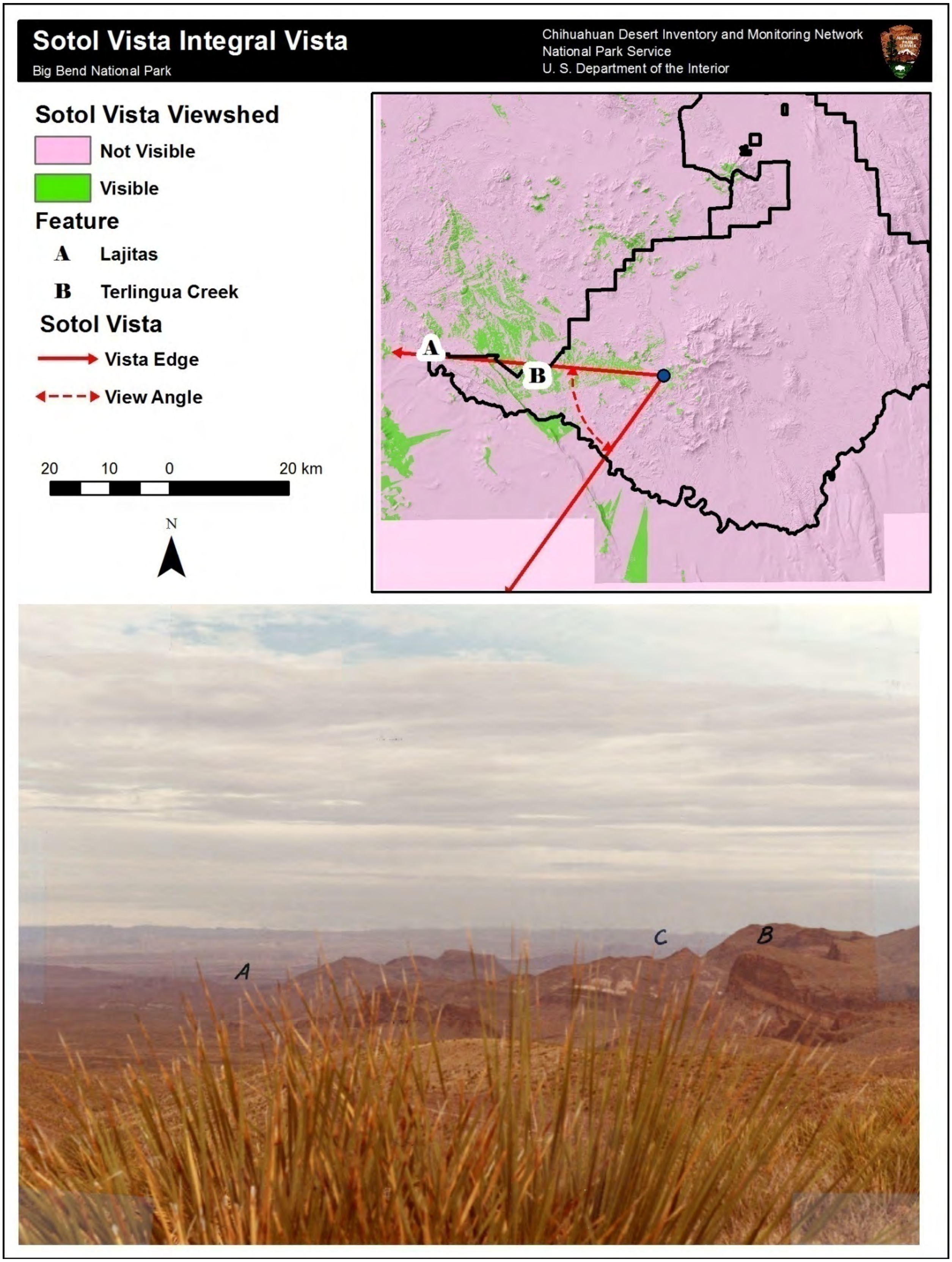


Plate 53. Sotol Vista Integral Vista, viewshed and 1980 photograph.

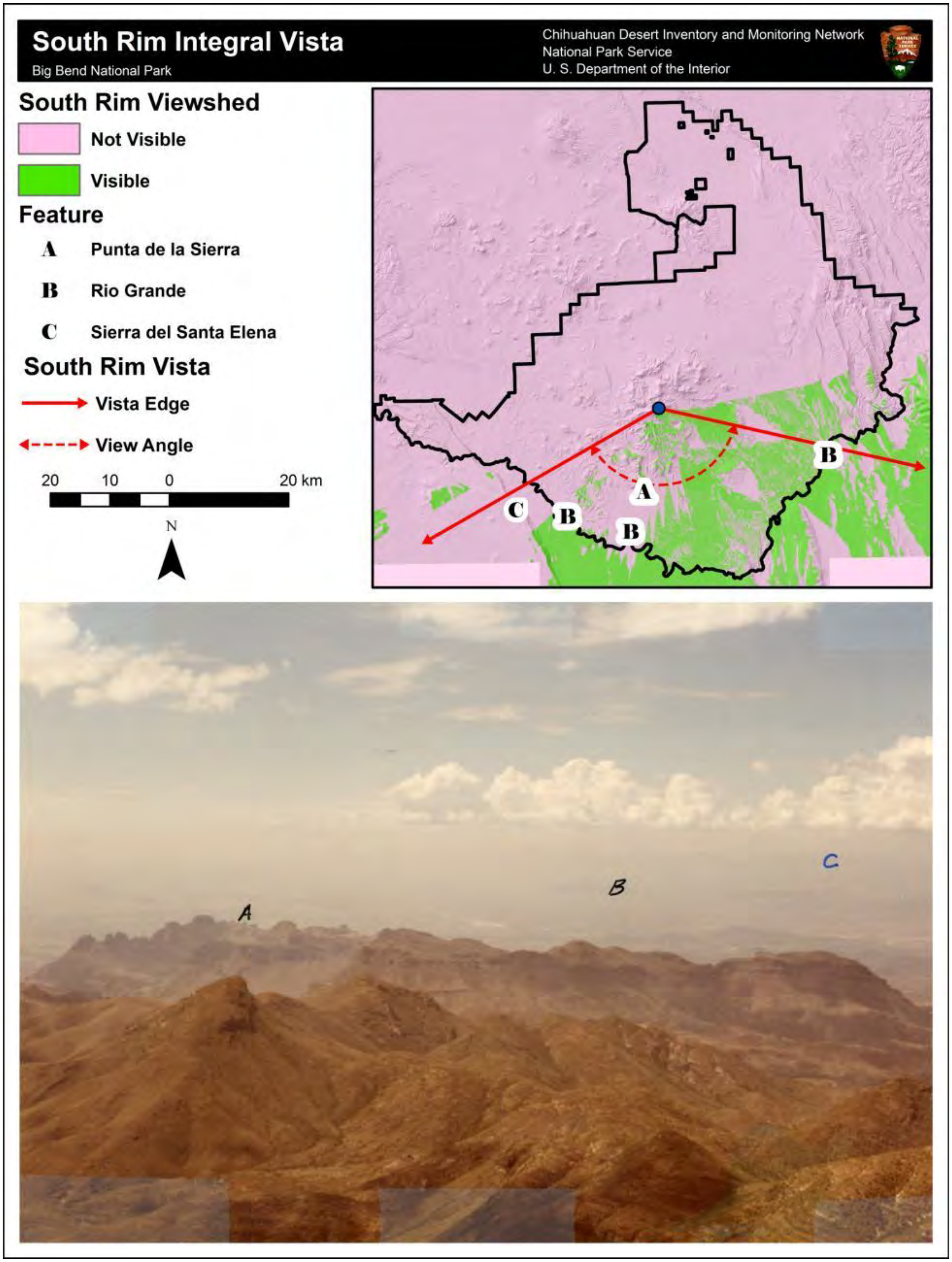


Plate 54. South Rim Integral Vista, viewshed and 1980 photograph.

Plate 55. South Rim Integral Vista, viewshed and 1980 photograph.

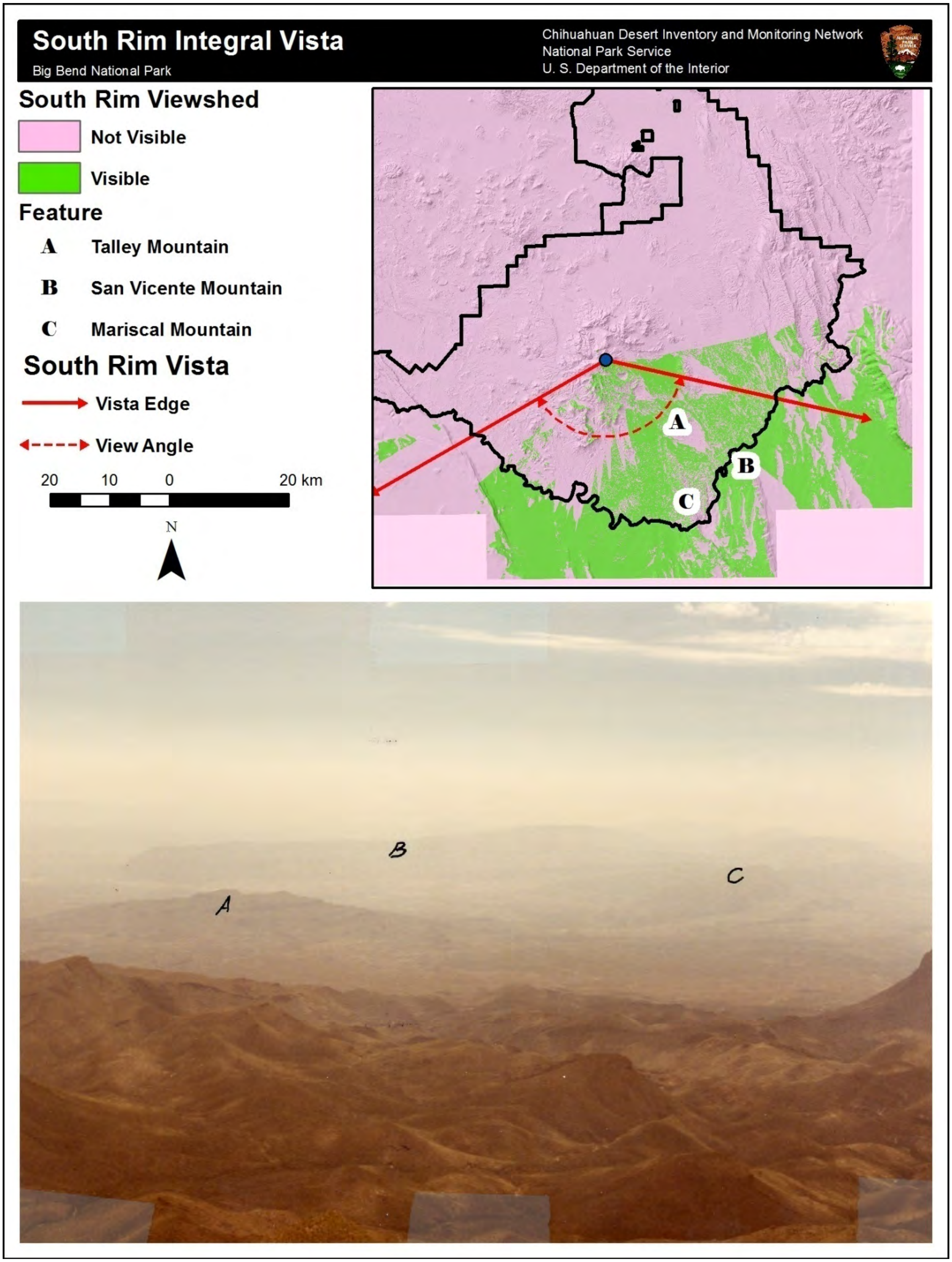


Plate 56. South Rim Integral Vista, viewshed and 1980 photograph.

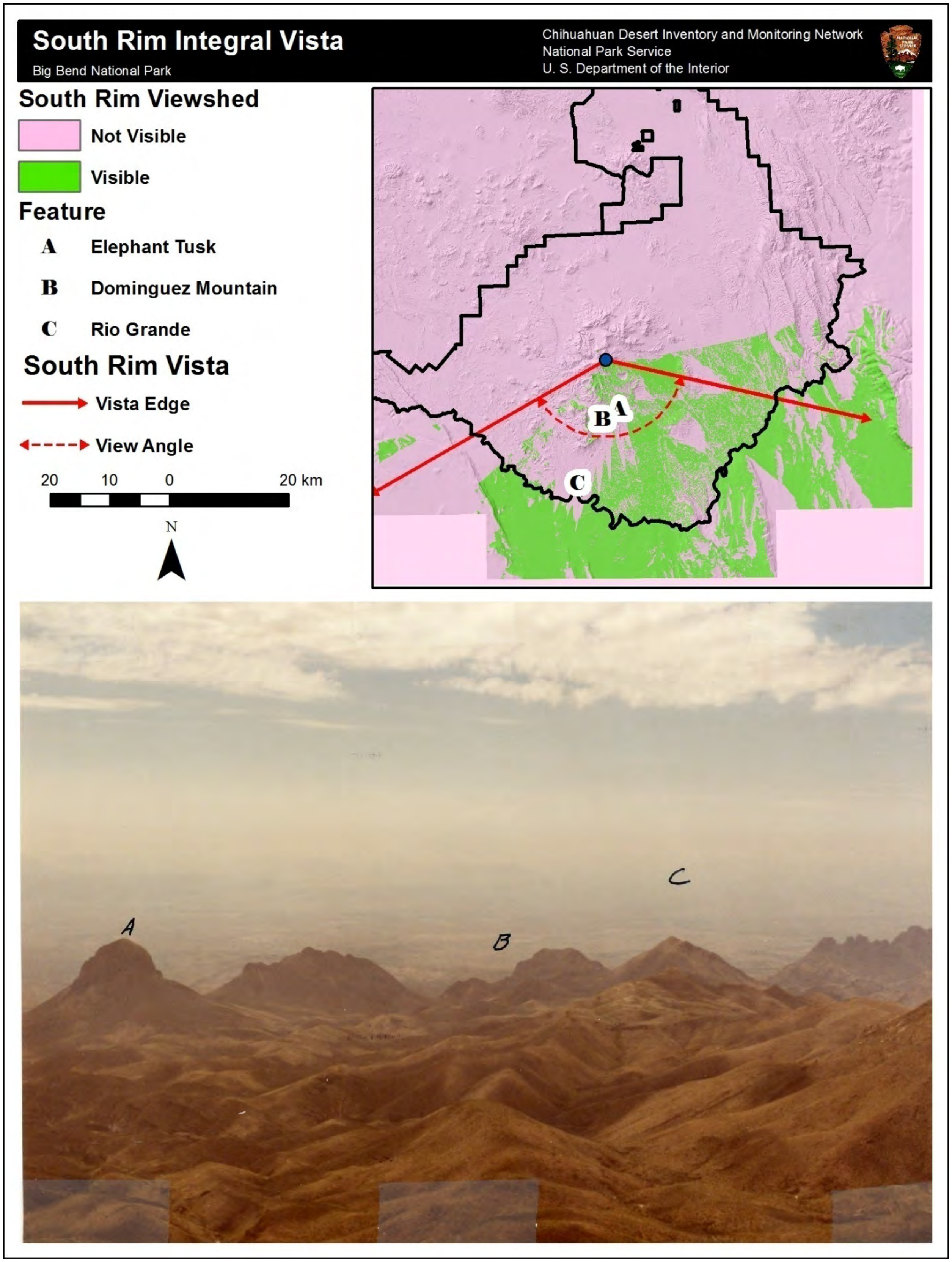


Plate 57. South Rim Integral Vista, viewshed and 1980 photograph.

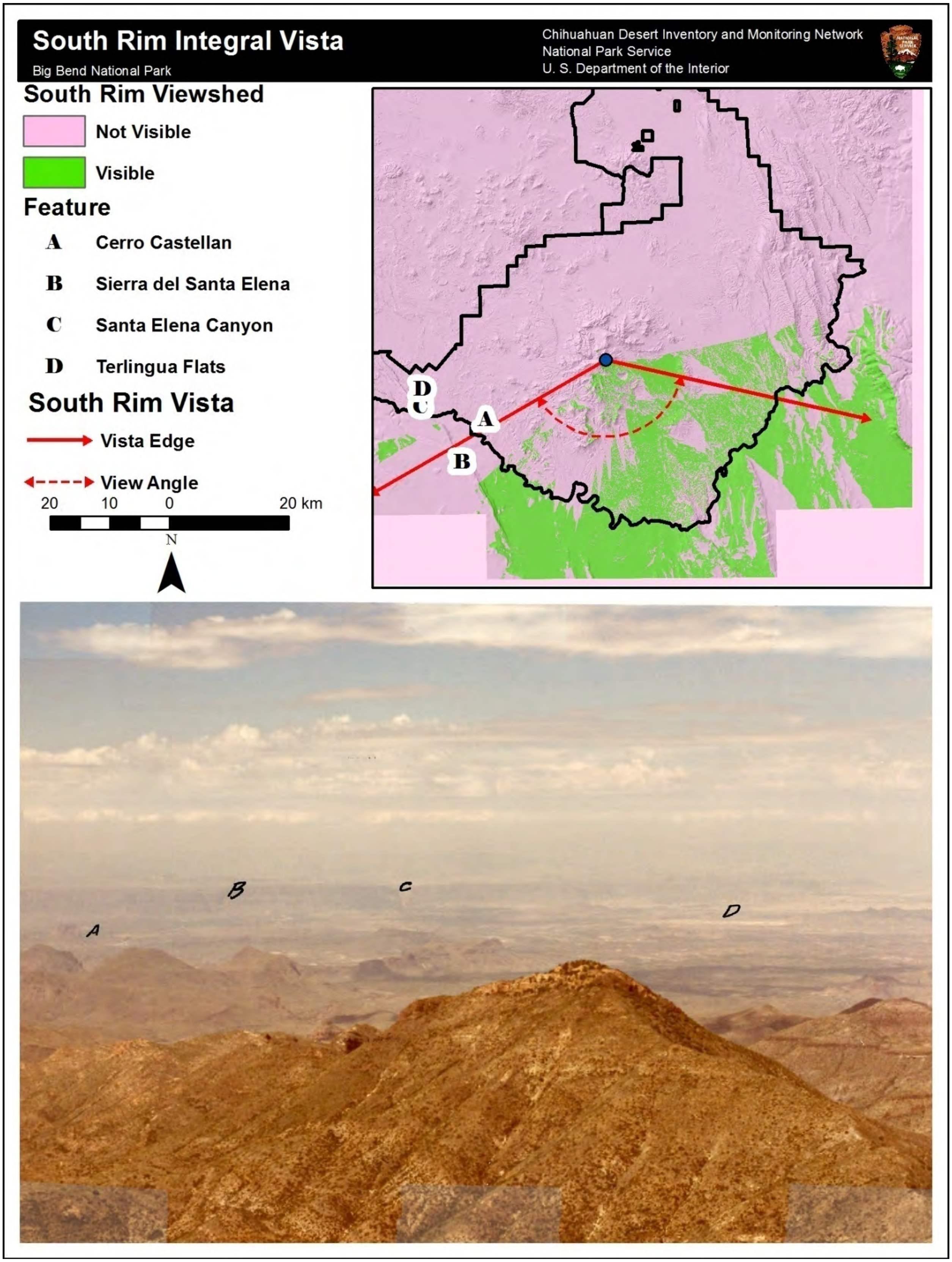


Plate 58. South Rim Integral Vista, viewshed and 1980 photograph.

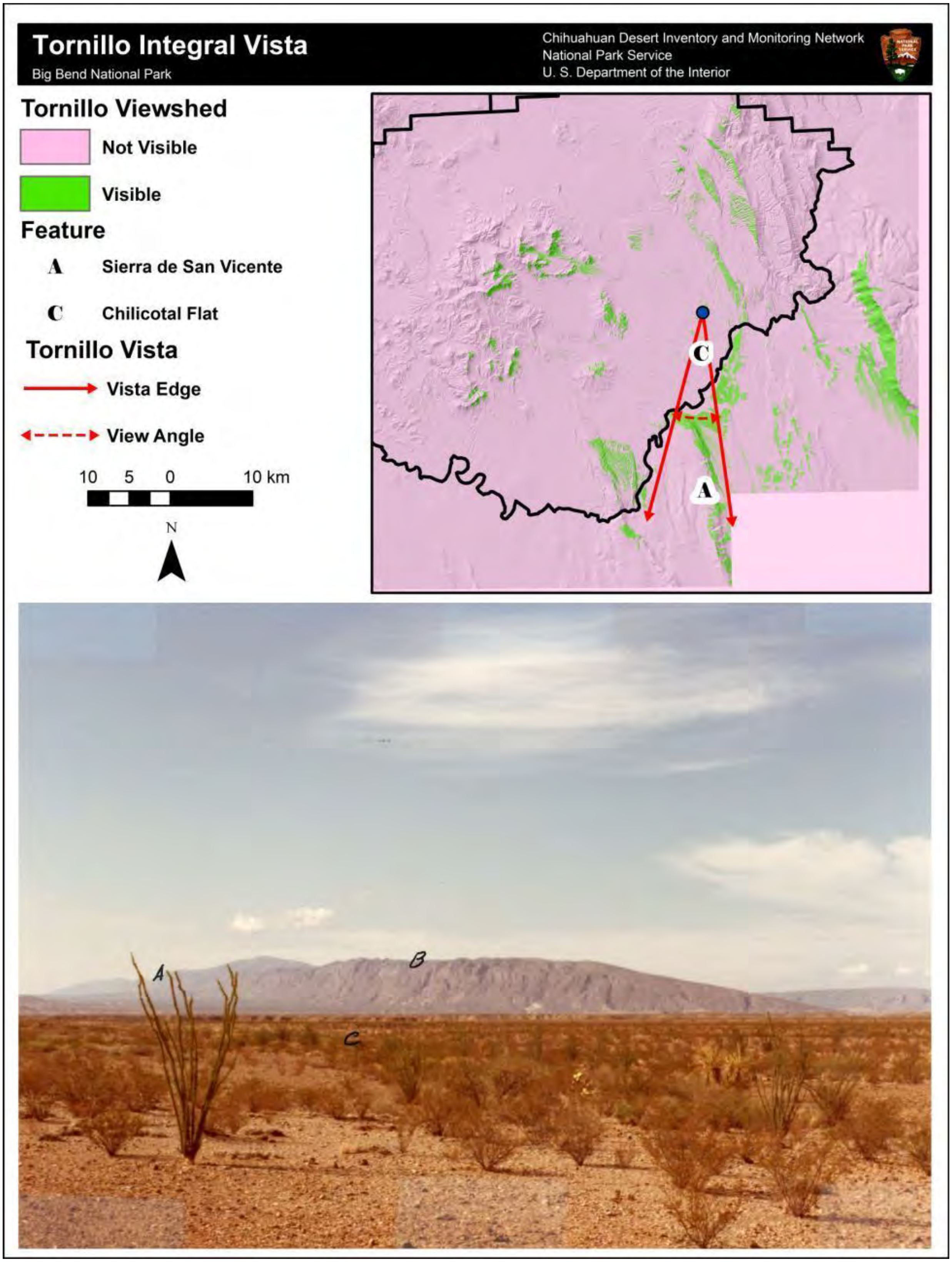


Plate 59. Tornillo Integral Vista, viewshed and 1980 photograph. The location for feature B (Sierra de Vicente) was not provided in the 1980 Integral Vista dataset.

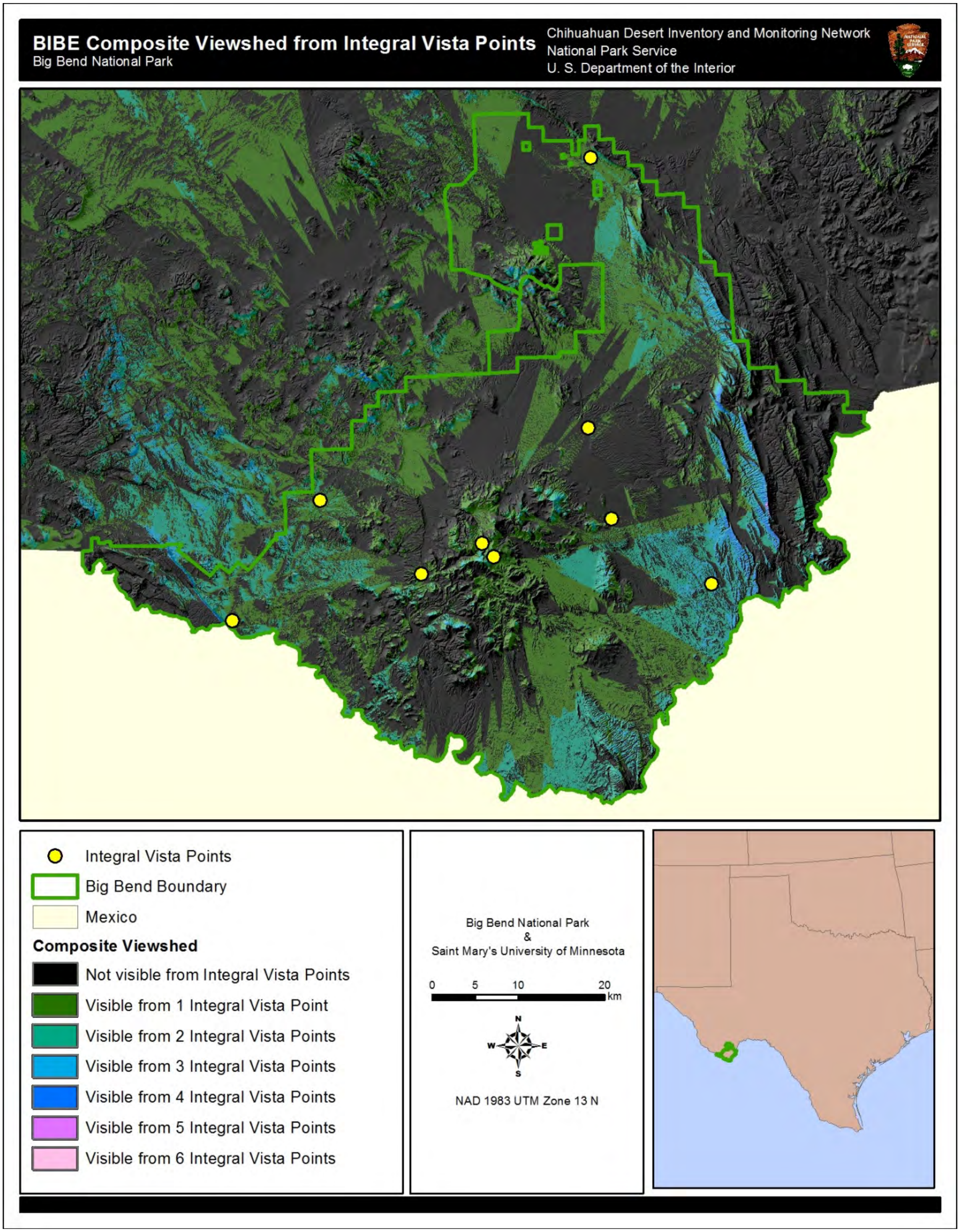


Plate 60. Combined viewshed from all 1980 Integral Vistas. Defines the most viewable areas within BIBE from the nine 1980 Integral Vista locations.

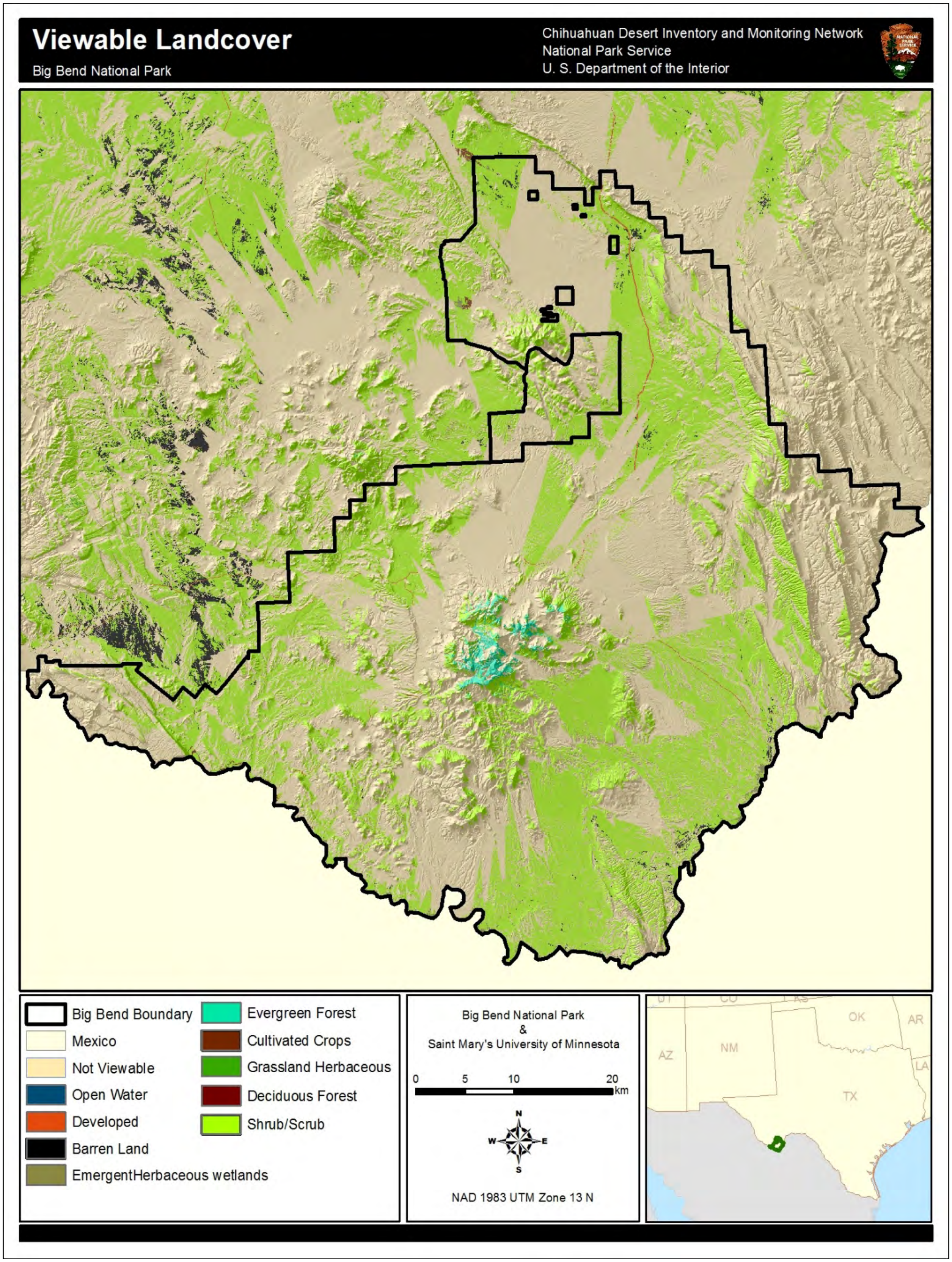


Plate 61. Viewable landcover classes from 1980 BIBE Integral Vista locations.

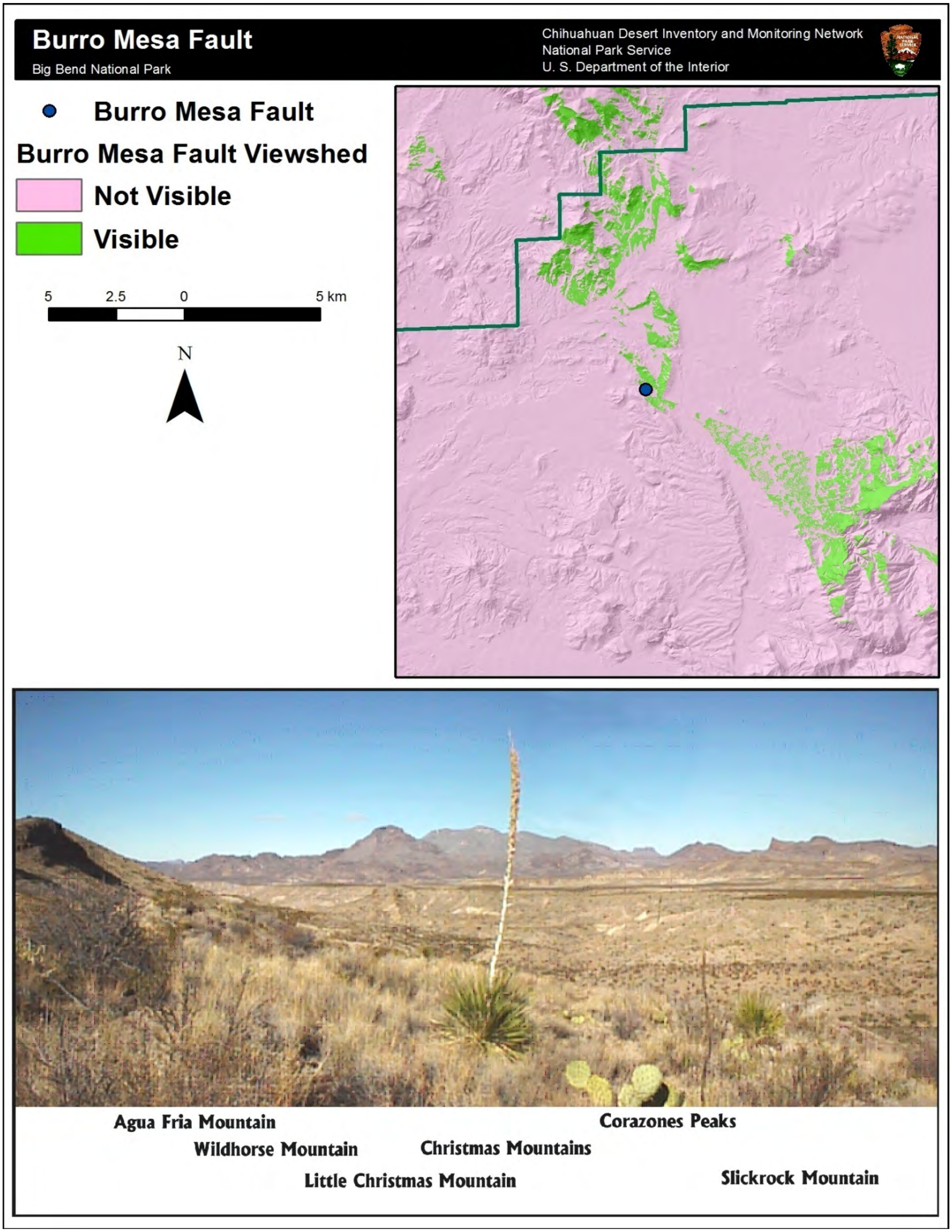


Plate 62. Burro Mesa Fault Integral Vista, viewshed and 1997 photograph with a view angle of 315-40 degrees from true North. The view angle indicates that the center of the above photograph is North.

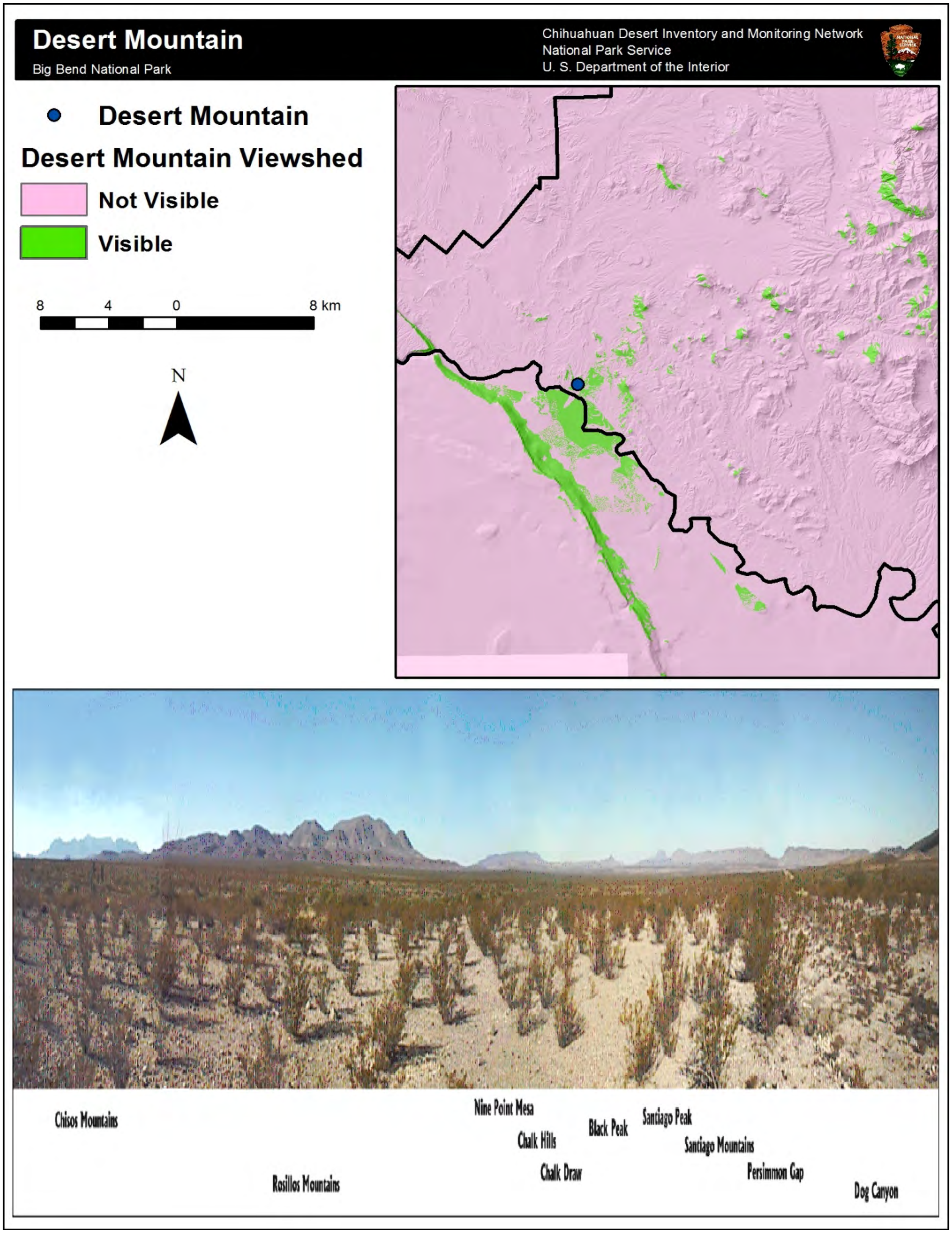


Plate 63. Desert Mountain Vista, viewshed and 1997 photograph with a view angle of 125-190 degrees from true North. The view angle indicates that the center of the above photograph is south-southeast.

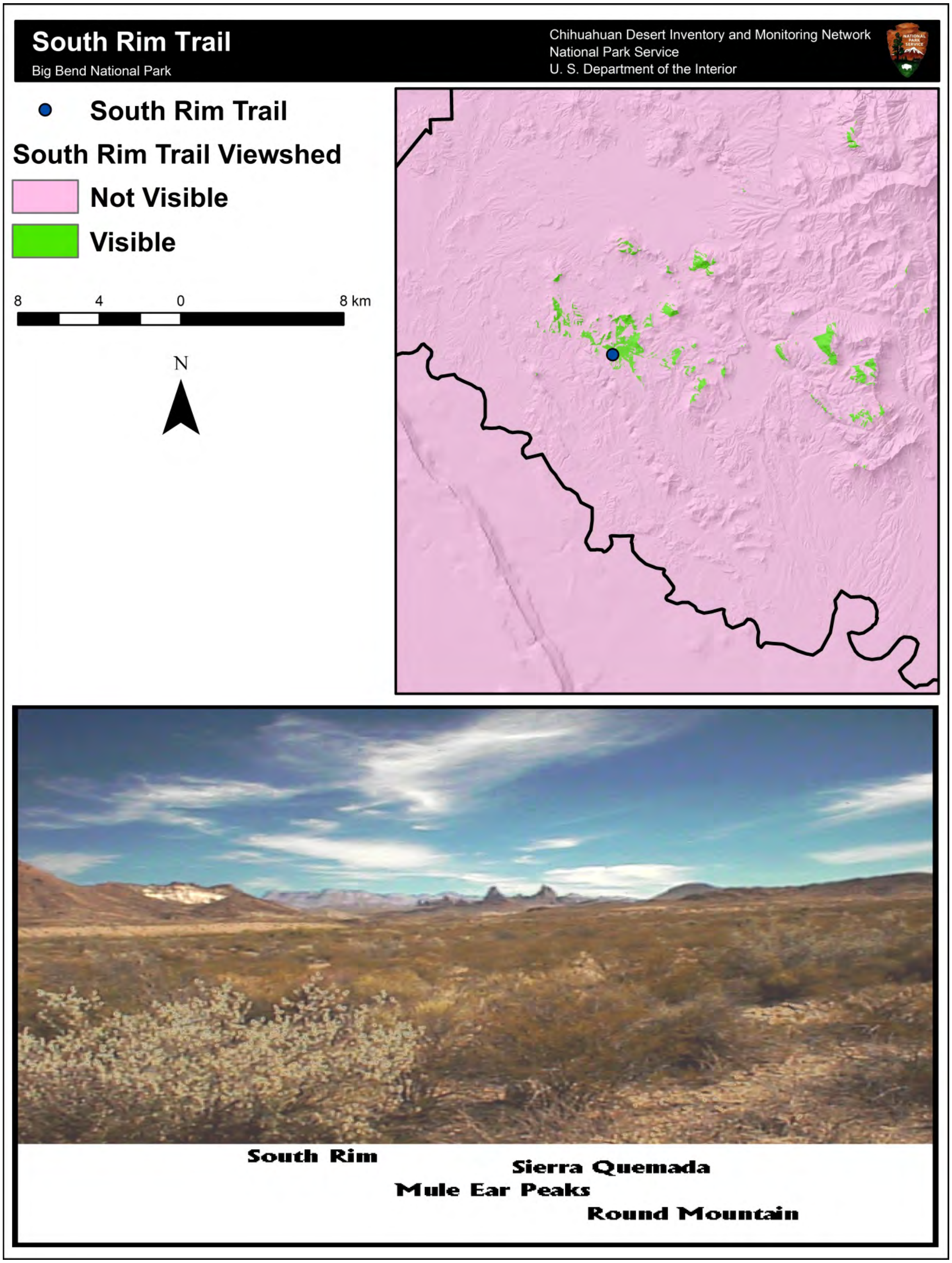


Plate 64. South Rim Trail (Mule Ears) Vista, viewshed and 1997 photograph with a view angle of 68-98 degrees from true North. The view angle indicates that the center of the above photograph is east-northeast.

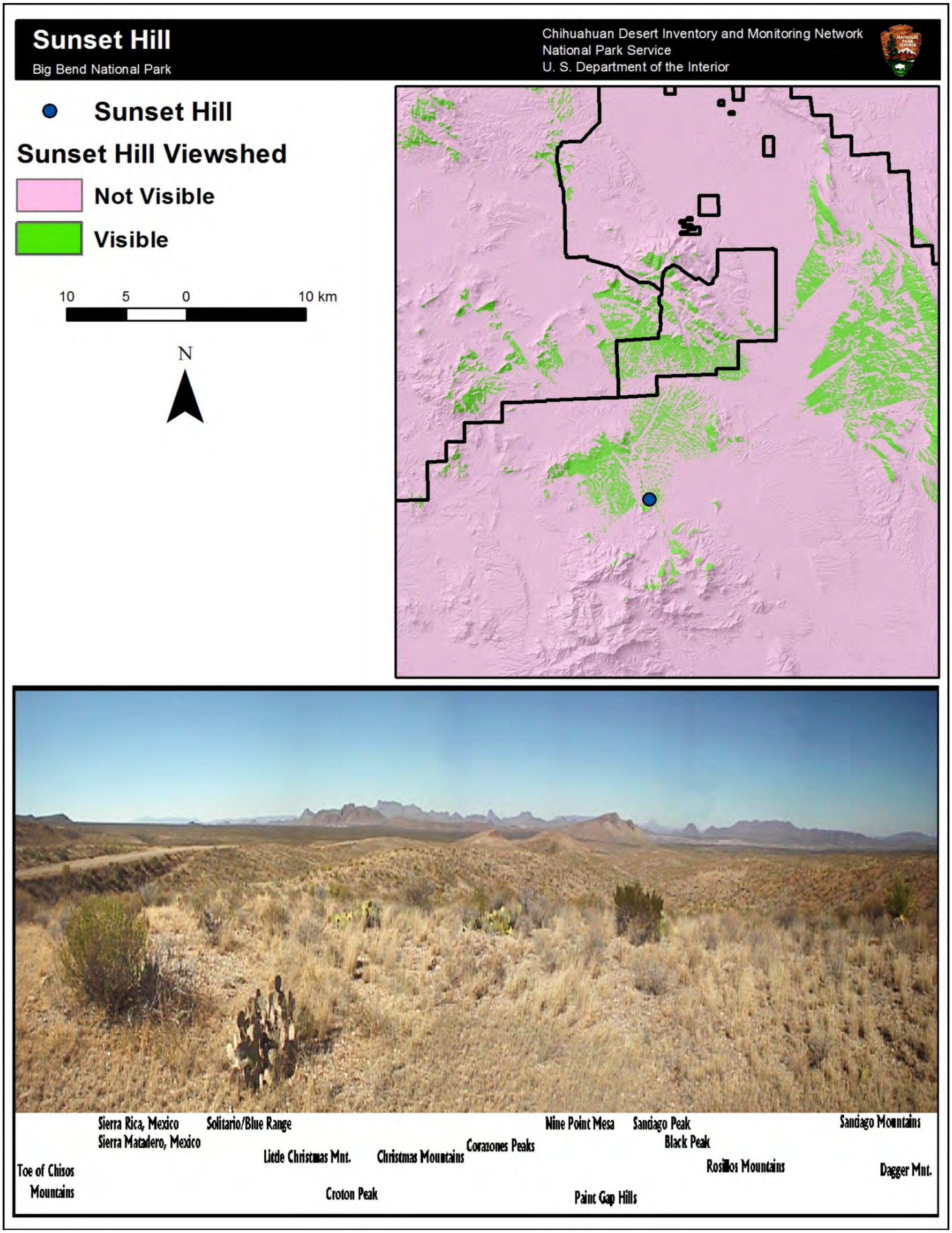


Plate 65. Sunset Hill Integral Vista, viewshed and 1997 photograph with a view angle of 245-35 degrees from true North. The view angle indicates that the center of the above photograph is northwest.

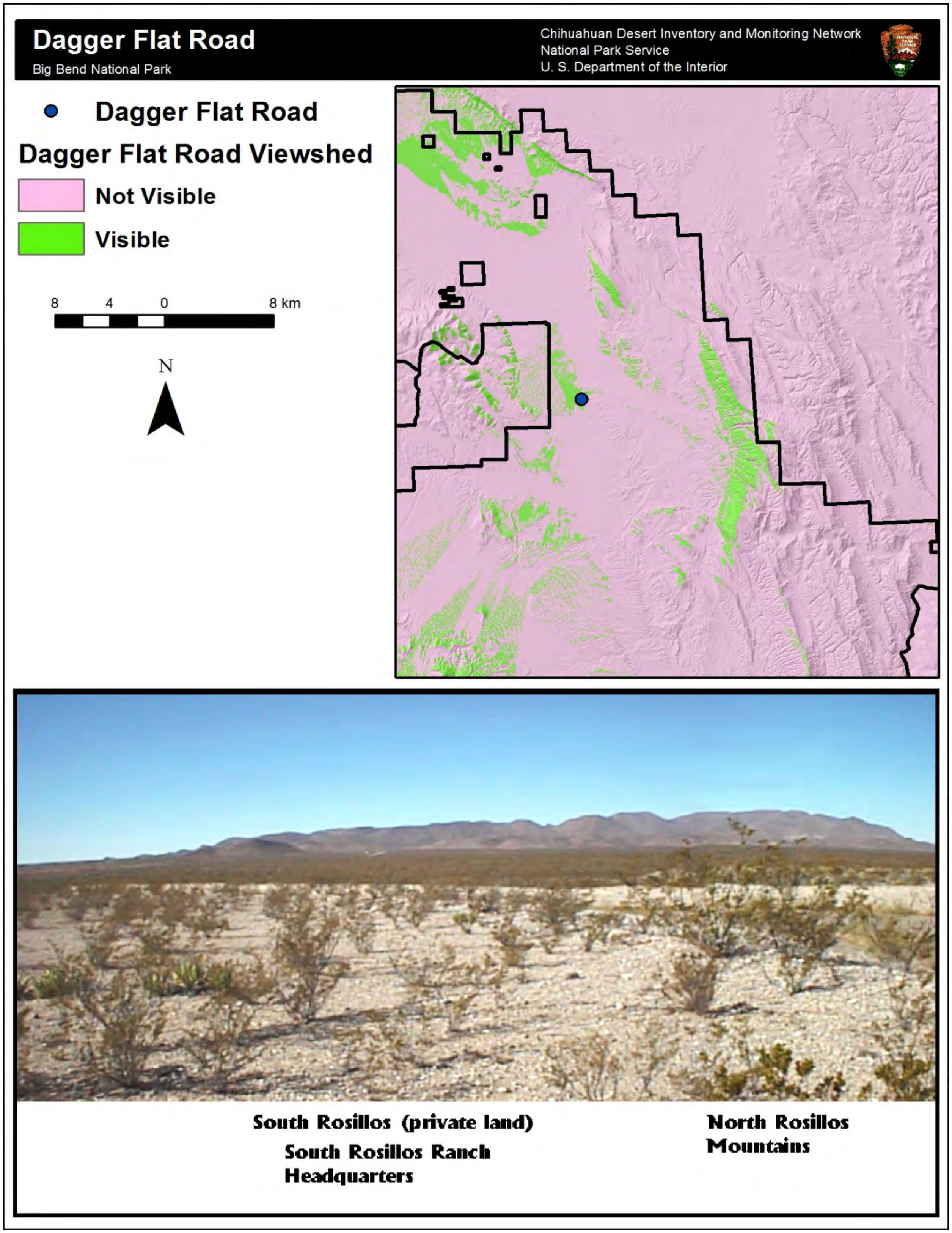


Plate 66. Dagger Flat Road Integral Vista, viewshed and 1997 photograph with a view angle of 240-310 degrees from true North. The view angle indicates that the center of the above photograph is west.

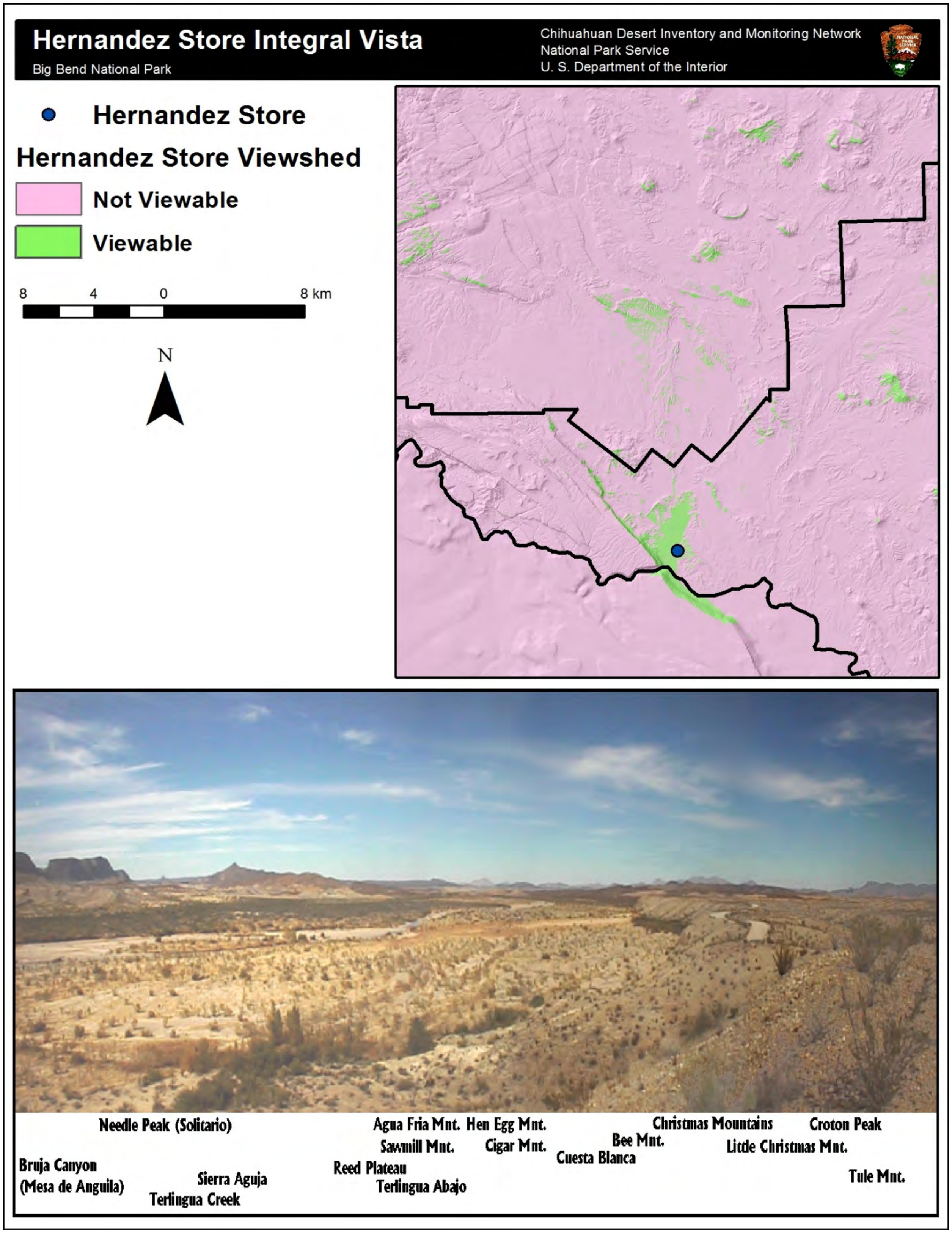


Plate 67. Hernandez Store Integral Vista, viewshed and 1997 photograph with a view angle of 310-50 degrees from true North. The view angle indicates that the center of the above photograph is north.

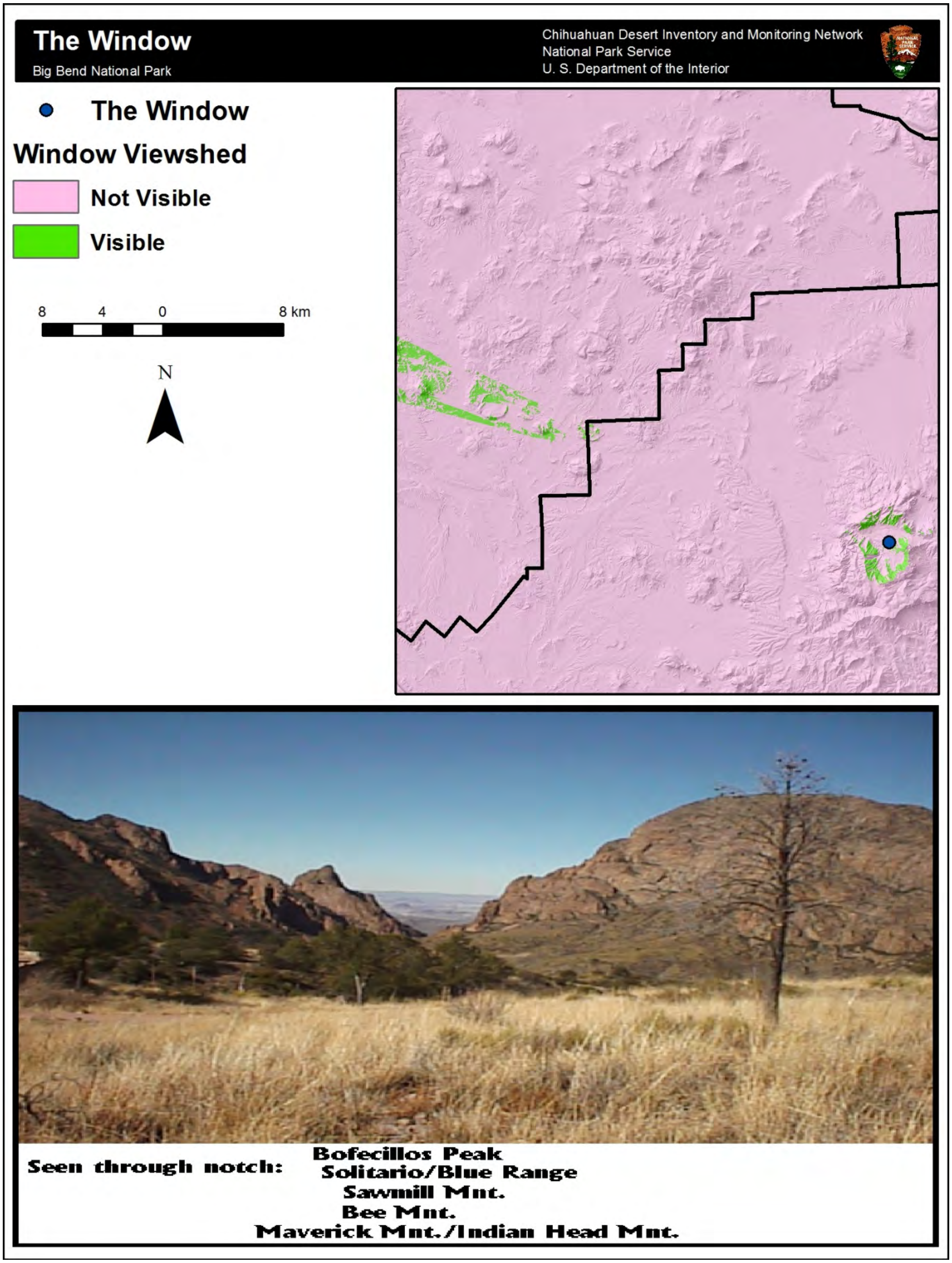


Plate 68. The Window Integral Vista, viewshed and 1997 photograph with a view angle of 285-295 degrees from true North. The view angle indicates that the center of the above photograph is west-northwest.

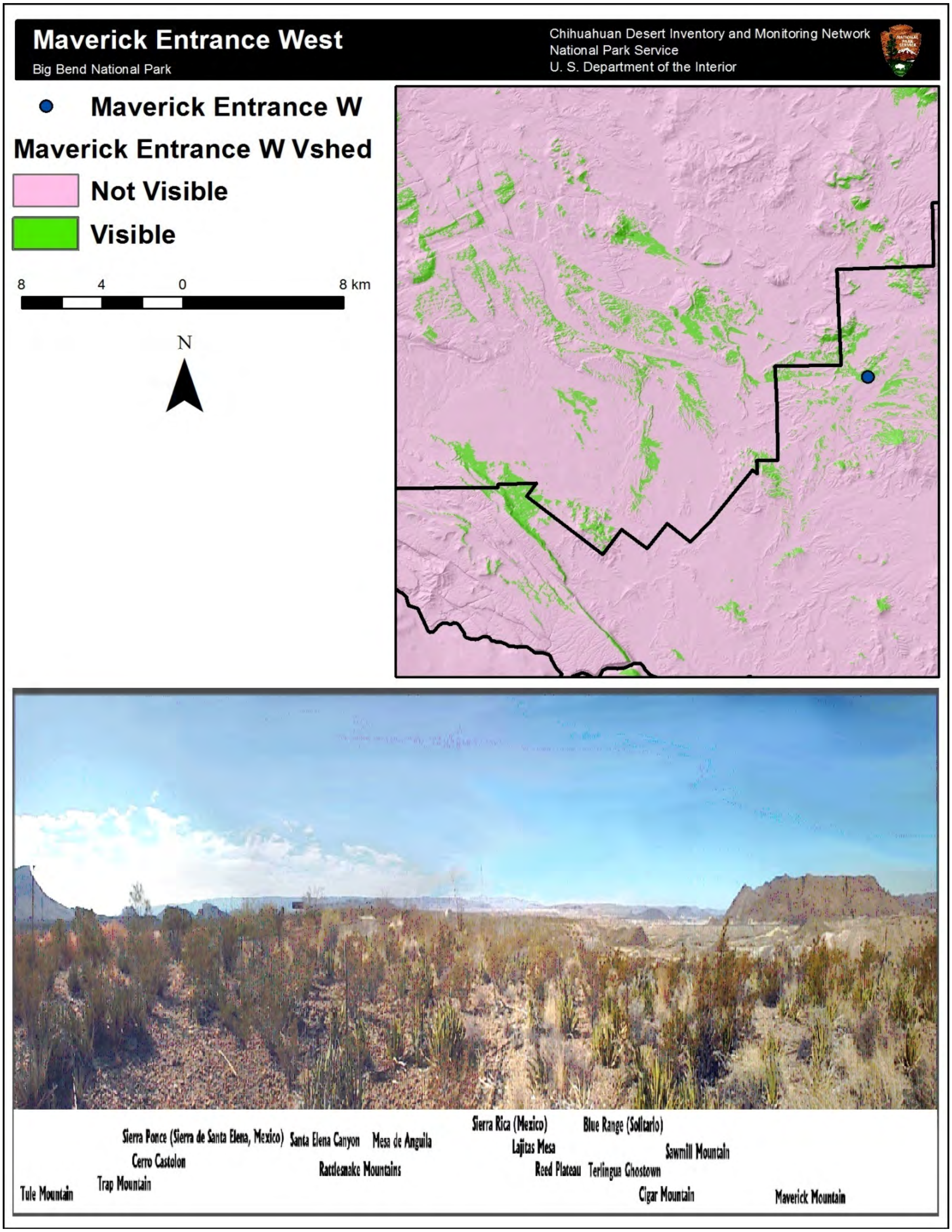


Plate 69. Maverick Entrance West Integral Vista, viewshed and 1997 photograph with a view angle of 180-360 degrees from true North. The view angle indicates that the center of the above photograph is west.

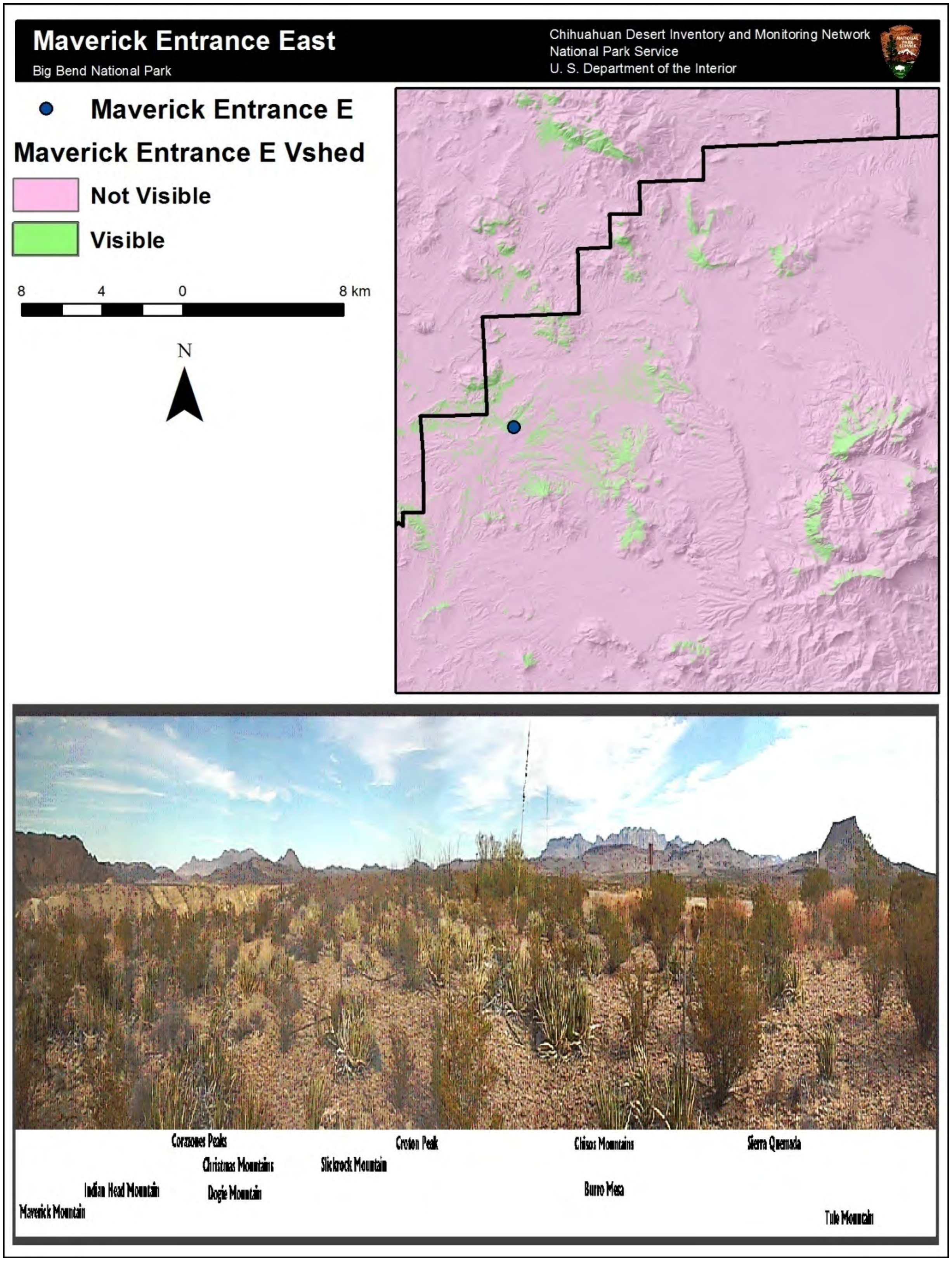


Plate 70. Maverick Entrance East Integral Vista, viewshed and 1997 photograph with a view angle of 0-180 degrees from true North. The view angle indicates that the center of the above photograph is east.

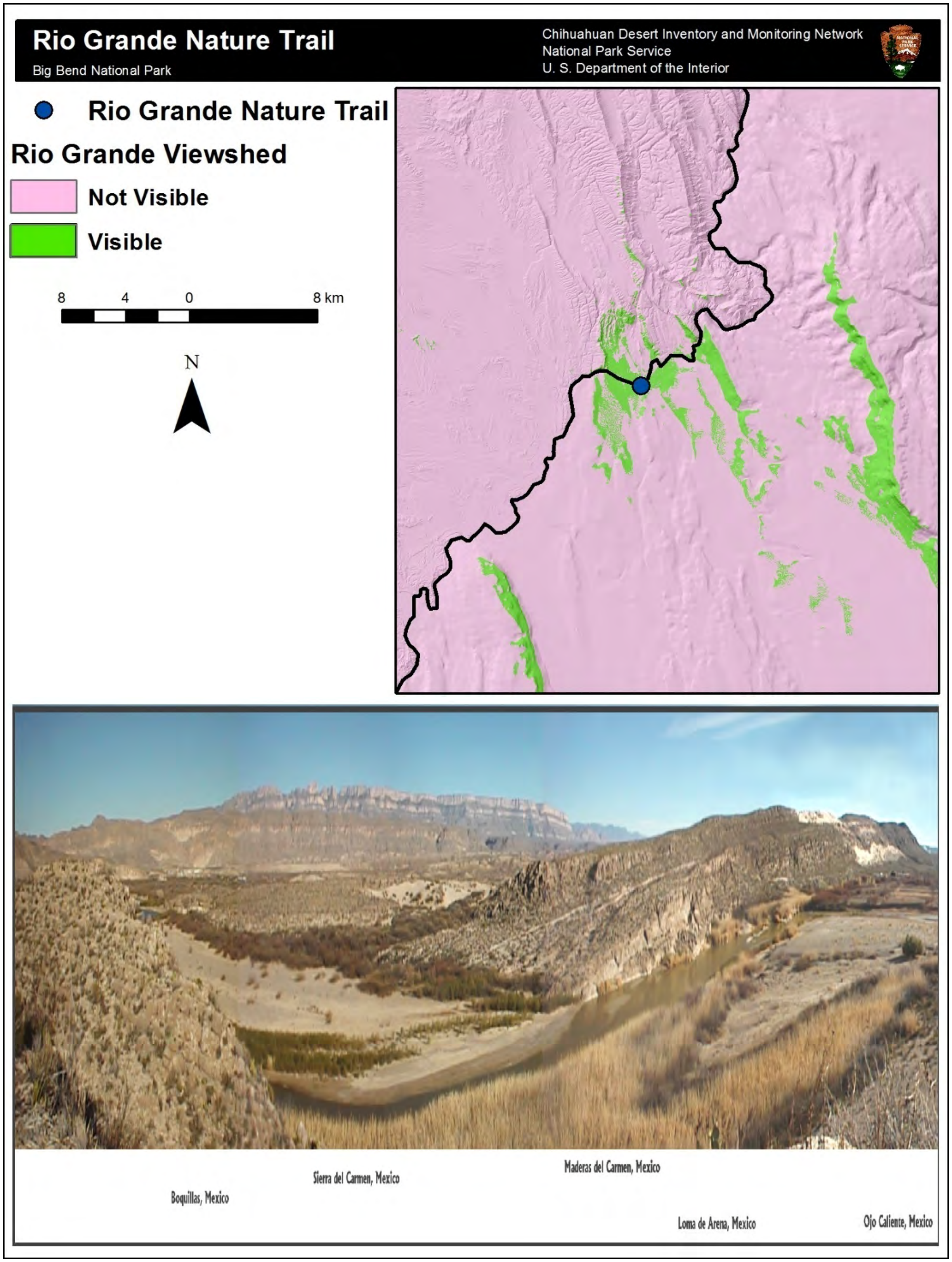
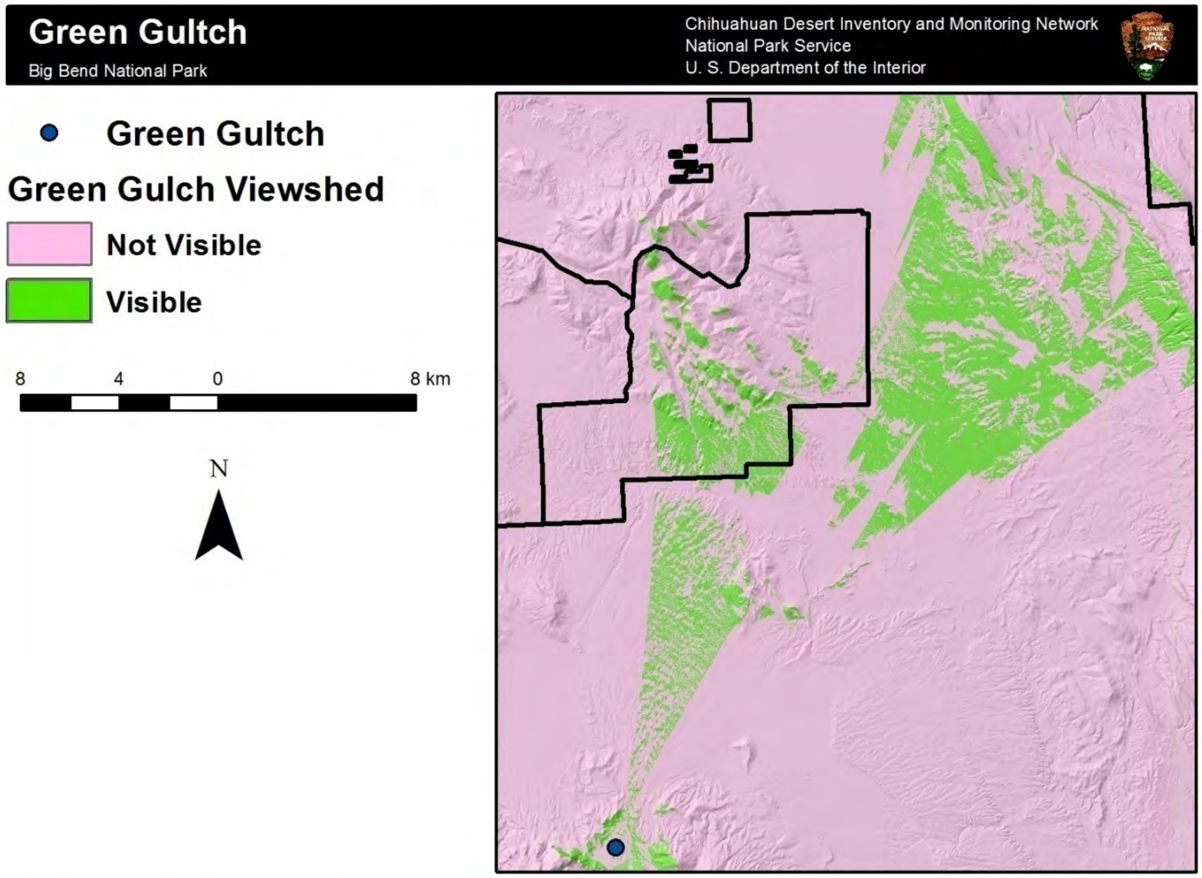


Plate 71. Rio Grande Nature Trail Integral Vista, viewshed and 1997 photograph with a view angle 40-305 degrees from true North. The view angle indicates that the center of the above photograph is south.



Key Features: Rough Mountain; Rosillos Mountains; Tornillo Badlands; Santiago Mountains; Pine Mountain; Grapevine Hills; Dead Horse Mountains; Tornillo Flat

Plate 72. Green Gulch Integral Vista, viewshed and 1997 photograph with a view angle 10-45 degrees from true North. The view angle indicates that the center of the above photograph is north-northeast.

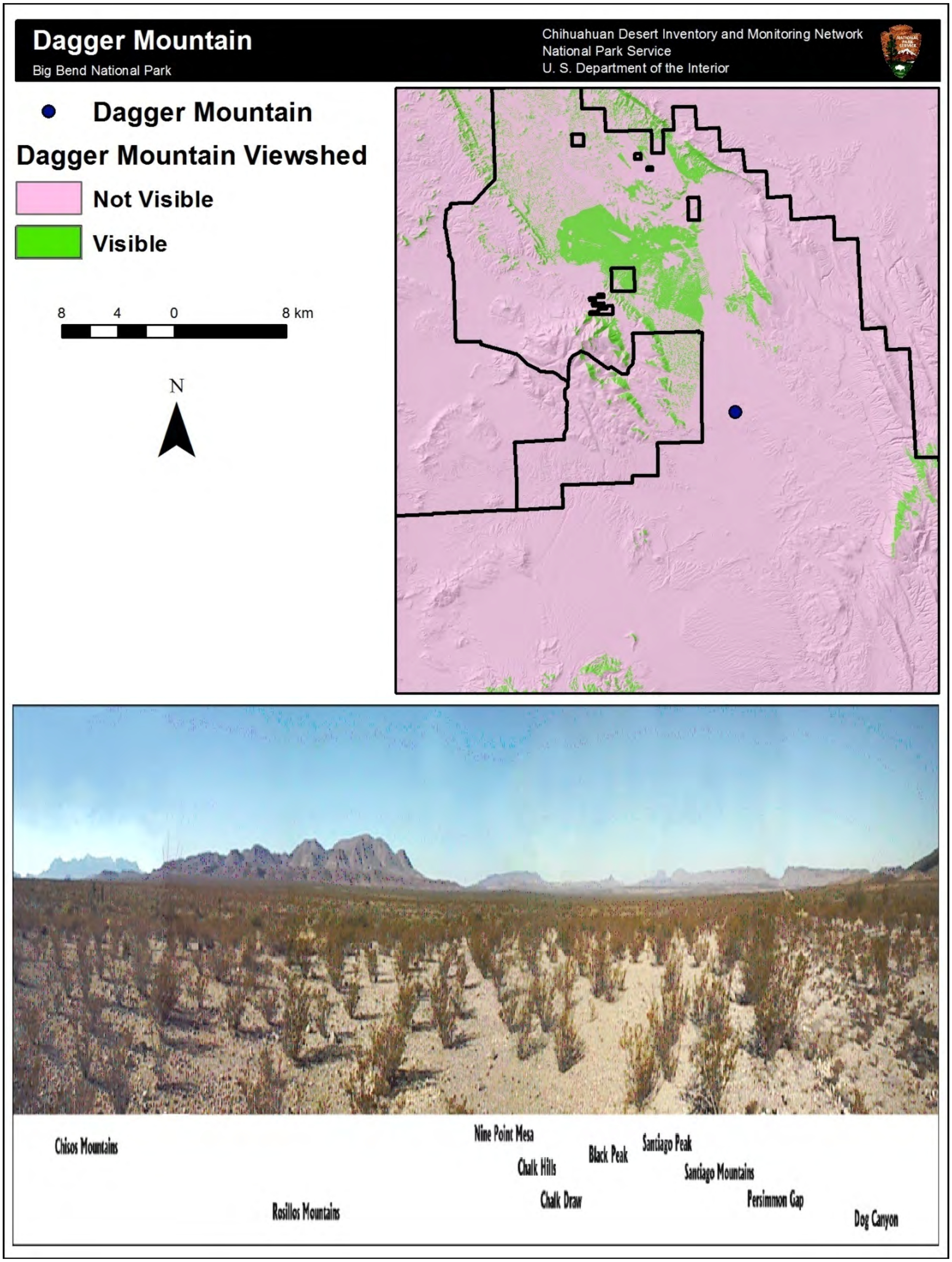


Plate 73. Dagger Mountain Integral Vista, viewshed and 1997 photograph with a view angle 190-10 degrees from true North. The view angle indicates that the center of the above photograph is west.

4.19 Dark Night Skies

4.19.1 Description

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

Big Bend National Park is located in an area of west Texas that is very remote from cities and towns of any size. In fact, this area is one of the least influenced by anthropogenic light in the contiguous United States (Figure 73); the NPS identifies BIBE as having the least amount of light pollution out of any of the national park units in the contiguous U.S. Therefore, the night sky as experienced within this park is of very high quality, and few external or internal threats result in impairment of its quality. This near-pristine condition results in a situation where even small increments of anthropogenic light will be easy to detect as a change from the natural condition. In addition, it is particularly important that within-park sources of light be contained, eliminating light trespass and minimizing anthropogenic sky glow.

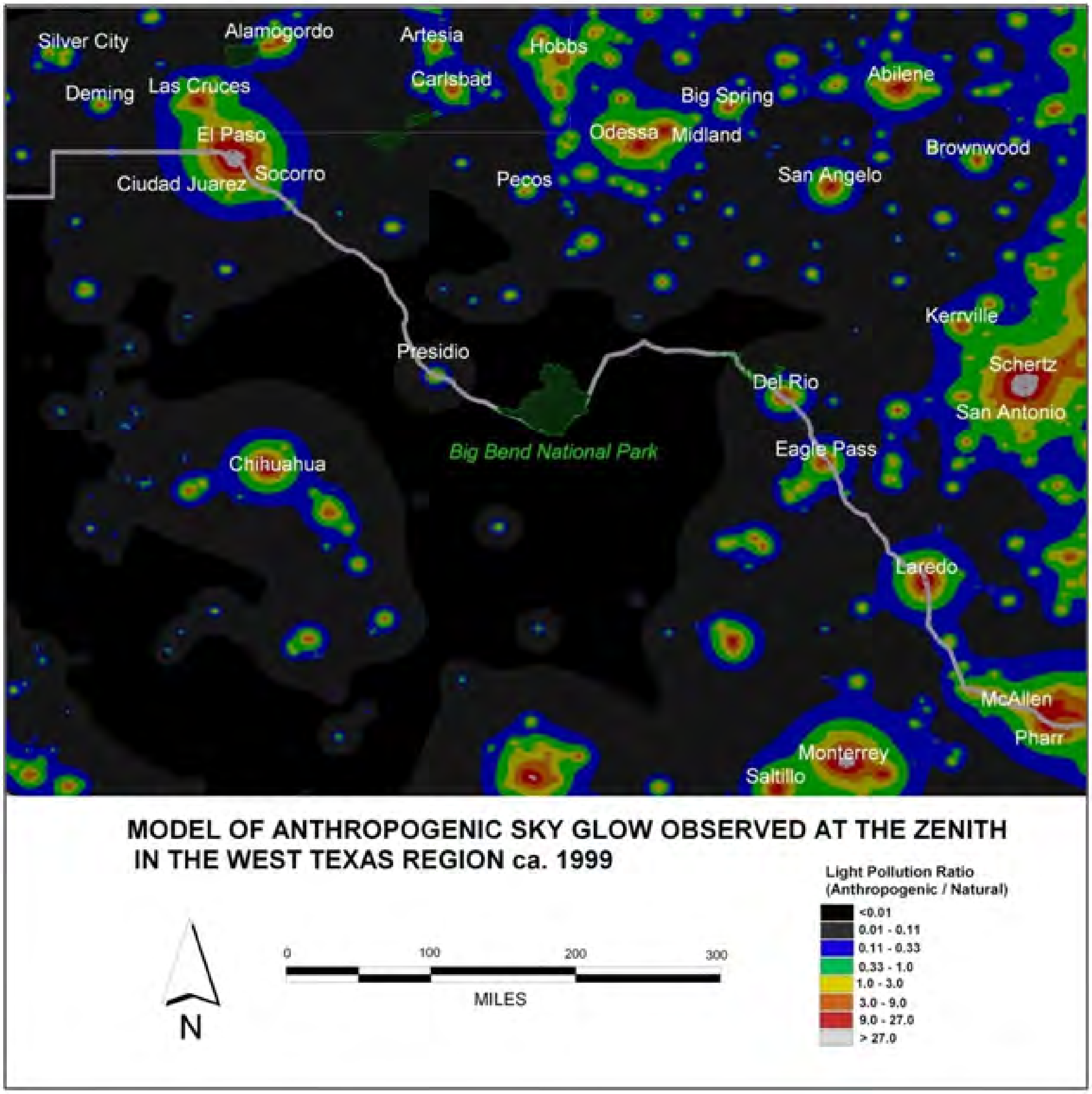


Figure 73. Model of sky glow from late 1990s satellite imagery at night and sky glow model by Cinzano et al. (2001).

4.19.2 Measures

- Sky luminance over the hemisphere in high resolution (thousands of measures comprise a data set), reported in photometric luminance units (V magnitudes per square arc second or milli-candela per square meter) or relative to natural conditions, often shown as a sky brightness contour map of the entire sky. V magnitude is a broadband photometric term in astronomy, meaning the total flux from a source striking a detector after passing through a "Johnson-Cousins V" filter. It is similar to the "CIE photopic" broadband function for wavelengths of light to which the human eye is sensitive (Bessell 1990)

- Integration of measures of anthropogenic sky glow from selected areas of sky that may be attributed to individual cities or towns (known as city light domes), reported in milli-Lux of hemispheric illuminance or vertical illuminance

- Integration of the entire sky illuminance measures, reported either in milli-Lux of total hemispheric (or horizontal) illuminance, milli-Lux of anthropogenic hemispheric (or horizontal) illuminance, V-magnitudes of the integrated hemisphere, or ratio of anthropogenic illuminance to natural illuminance

- Vertical illuminance from individual (or groups of) outdoor lighting fixtures at a given observing location (such as the Wilderness boundary), in milli-Lux

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

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

4.19.3 Reference Conditions/Values

The reference condition for this resource is defined in terms of sky luminance and illuminance at the observer's location from anthropogenic sources as follows:

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

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

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

Implementing this directive in BIBE requires that facilities within the park that utilize outdoor lighting, local communities, and, to a lesser degree, distant cities meet outdoor lighting standards that provide for the maximum amount of environmental protection while meeting human needs for safety, security, and convenience. This means that outdoor lights within the park produce zero light trespass beyond the boundary of their intended use, be of an intensity that meets the minimum requirement for the task but does not excessively exceed that requirement, be of a color that is toward the yellow or orange end of the spectrum to minimize sky glow, and be controlled intelligently, preventing unnecessary dusk to dawn bright illumination of areas.

4.19.4 Data and Methods

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

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

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

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

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

Light domes from many cities as they appear from a location within Joshua Tree National Park are shown in Figure 74 and Figure 75, as a grayscale and in false color. This graphic demonstrates that the core of the light dome may be tens or hundreds of times brighter than the extremities. A logarithmic scale for sky luminance and false color are commonly used to display monochromatic images or data with a very large dynamic range, and are used extensively in reports of sky brightness by the National Park Service Night Sky Team (NST).

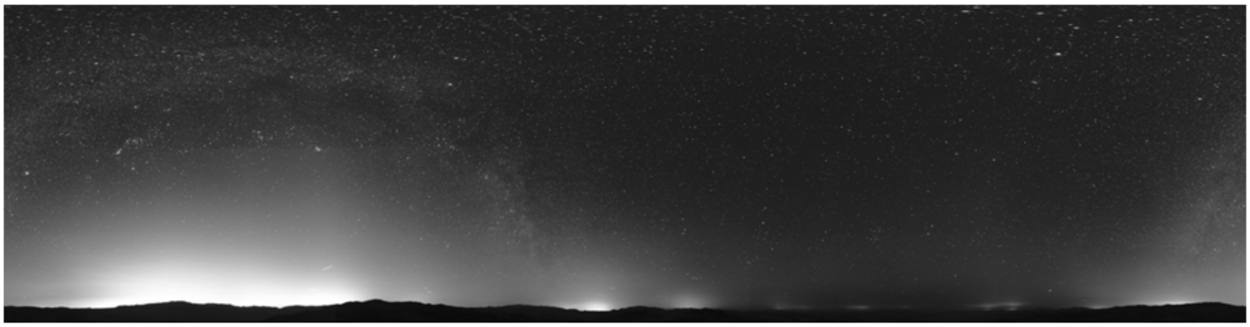


Figure 74. Grayscale representation of sky luminance from a location in Joshua Tree National Park.

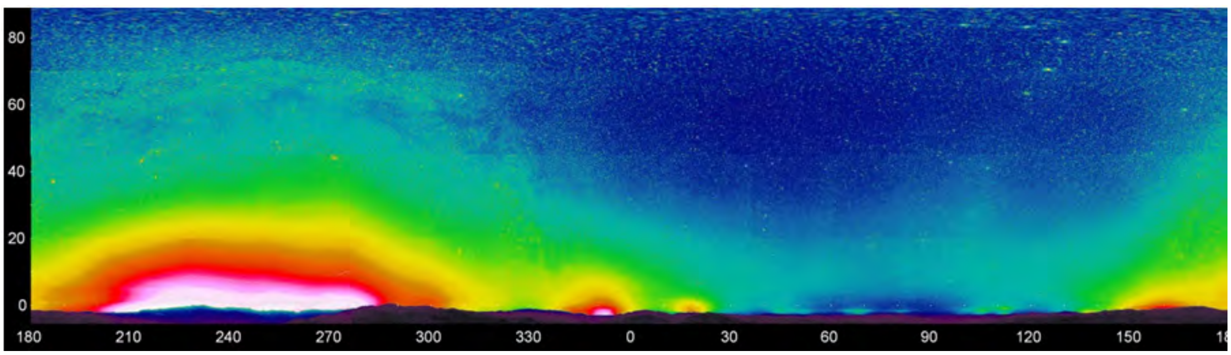


Figure 75. False color representation of Figure 74 after a logarithmic stretch of pixel values.

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

Figure 74 and Figure 75 contain information on natural sources of light in the night sky as well as anthropogenic sources. The appearance of the natural night sky may be modeled and predicted in terms of sky luminance and illuminance over the hemisphere, given the location, date and time, and the relative brightness of the natural airglow, the so-called “permanent aurora” which varies in intensity over time periods as short as minutes, but usually on the scale of hours (Roach and Gordon 1973). The NST has constructed such a model and uses it in analysis of data sets to remove the natural components, resulting in a more accurate measure of anthropogenic sky glow (Figure 76). Figure 75 represents "total sky brightness" while Figure 76 displays "anthropogenic sky glow" or "net light pollution." This is an important distinction, especially in areas where anthropogenic sky glow is of relatively low intensity.

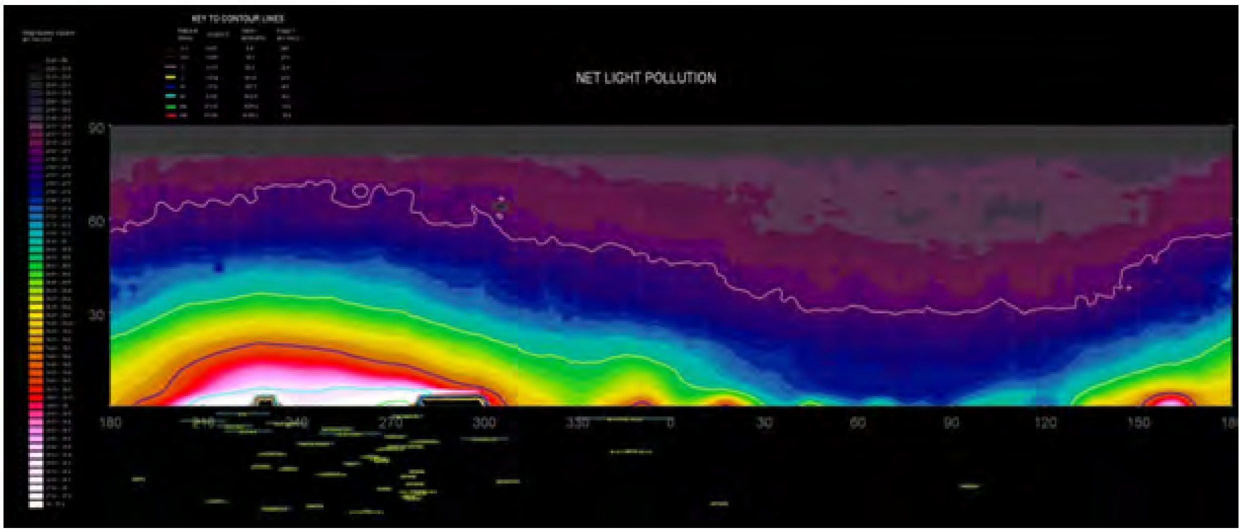


Figure 76. Contour map of anthropogenic sky glow at a location in Joshua Tree National Park, analogous to Figure 75 with natural sources of light subtracted.

The accurate measurement of both anthropogenic light in the night sky and the accurate prediction of the brightness and distribution of natural sources of light allows for the use of a very intuitive metric of the resource condition - a ratio of anthropogenic to natural light. Both luminance and illuminance for the entire sky or a given area of the sky may be described in this manner (Hollan 2008). This so-called "light pollution ratio" is unitless and is always referenced to the brightness of a natural moonless sky under average atmospheric conditions, or, in the case of the NST data, the atmospheric conditions determined from each individual data set.

The reference conditions for anthropogenic sky luminance are given in a previous section as no more than 200 percent brighter than natural conditions in *any* area of the sky and no more than 10 percent brighter at the Zenith. These values correspond to light pollution ratios of 2.0 and 0.1, respectively. The NST has obtained values of 50-100 for this measure at the core of city light domes seen from several areas administered by the NPS, including Lake Mead National Recreation Area, Saguaro National Park, and Colorado National Monument (NPS Night Sky Team, unpublished data). This is because these NPS areas are very close to the cities of Las Vegas, Nevada; Tucson, Arizona; and Grand Junction, Colorado, respectively. BIBE is in the fortunate location of being very distant from large cities. As such, the park provides a refuge from bright light domes, which can significantly impair sky quality at distances of 100 mi or more from the center of the city. The sky glow model of Cinzano et al. (2001) predicts a Zenith light pollution ratio of less than 0.01 for all of BIBE based on late 1990s satellite data (see Figure 73).

The reference condition for light trespass of 0.1 milli-Lux represents a light pollution ratio of 0.1/0.4 or 0.25, since the average vertical illuminance experienced under the natural night sky on a moonless night is 0.4 milli-Lux (derived from Garstang 1989, Jensen et al. 2006, and unpublished NPS Night Sky Team data).

A method of quantifying sky brightness near the Zenith quickly and accurately is the use of a Unihedron Sky Quality Meter. The Unihedron Sky Quality Meter is single-channeled and is a hand held photometric device. A single number in magnitudes per square arc second is read from the front of the device after its photodiode and associated electronics are pointed at the Zenith and the processor completes its integration of photon detection. Because this device is relatively inexpensive and easy to use, a database of measures has grown since its introduction (see http://unihedron.com/projects/darksky/database/index.php). The NST produces this value with each data set as both a synthesized value derived from the high-resolution images and by hand held measures with a Unihedron Sky Quality Meter. The performance of the device has been tested and reviewed by Cinzano (2005). While fairly accurate and easy to use, the value it produces is biased toward the Zenith. Therefore, the robustness of data collected in this manner is limited to areas with relatively bright sky glow near the Zenith, corresponding to severely light polluted areas. While not included in the reference condition, a value of about 21.85 would be considered "pristine", providing the Milky Way is not overhead and/or the natural airglow is not unusually bright when the reading is taken.

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

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

4.19.5 Current Condition and Trend
The night sky as seen from BIBE is nearly pristine. The area has been described as possessing "perhaps the darkest, least light polluted skies of any park in the continental United States" (Nordgren 2010, p. 24). This statement is supported by quantitative data. The NPS has conducted an inventory of night sky quality at BIBE, with data collection beginning in 2003. The preferred

location for measuring sky luminance is the summit of Emory Peak, near the geographic center of the park. It is also the highest point in the park (2,384 m), allowing a commanding view of surrounding areas, and is within a Wilderness area. Data were collected in March of 2003 and April of 2007 at this location. Important statistics from these data are presented in Appendix T (2003) and Appendix U (2007). The 2007 data utilized a higher resolution camera and summary data are somewhat more complete, but both years are accurately calibrated to known standard stars. However, the higher resolution camera may make a more complete image of the distant light domes since they are of relatively small size. In addition, the light pollution ratios have only been calculated for the 2007 data because of differences in the processing procedures that are yet to be worked out.

The narratives from each of these nights reveal some interesting differences in conditions that may affect the sky brightness results. First, the natural airglow in 2003 appears to have been much brighter than in 2007. This is consistent with the sunspot cycle, where higher solar activity usually brings about brighter natural airglow. This in itself does not affect sky quality, but will lower the contrast between stars and the sky, resulting in a brighter ZLM. This trend is observed in the 2003 and 2007 Emory Peak survey narratives (ZLM 6.8 for 2003, 7.4 for 2007). Bright airglow may be more difficult to model and subtract from the total sky brightness, resulting in an increased error in the estimate of anthropogenic sky glow.

The extinction coefficient for each of these nights indicates clear air, but the 2003 night was exceptionally clear at 0.12 magnitudes/airmass, close to Rayleigh scattering conditions with aerosols virtually absent. This value compares with about 0.15 magnitudes/airmass for the 2007 night. Therefore, one would expect light domes from distant cities to be slightly brighter in the 2003 data, if cities produced constant output over the two nights. However, the opposite is true. One should interpret this result with caution, as layered haze was reported in 2007. Layered haze indicates temperature inversion, which can refract light from distant sources making them appear brighter or causing a “mirage”, or mirroring. In any case, the maximum anthropogenic sky brightness seen in either night’s data is below the reference condition (light pollution ratio of 2). In addition, the sky near the Zenith is described as near pristine, and given the measurement error of the system, the light pollution ratios shown for the Zenith in Appendix V (all less than 0.1) cannot be distinguished from zero.

Results for these nights are shown graphically as false color contour maps. The brighter natural airglow is obvious in Figure 77 (2003) compared to Figure 78 (2007) as an overall brightening of the sky background. When the natural sources are removed (Figure 79 and Figure 80), both nights reveal virtually no anthropogenic sky glow throughout the entire sky. The small size and low intensity of the light domes that do exist are apparent in Figure 81, a panoramic projection of the 2007 anthropogenic sky glow data.

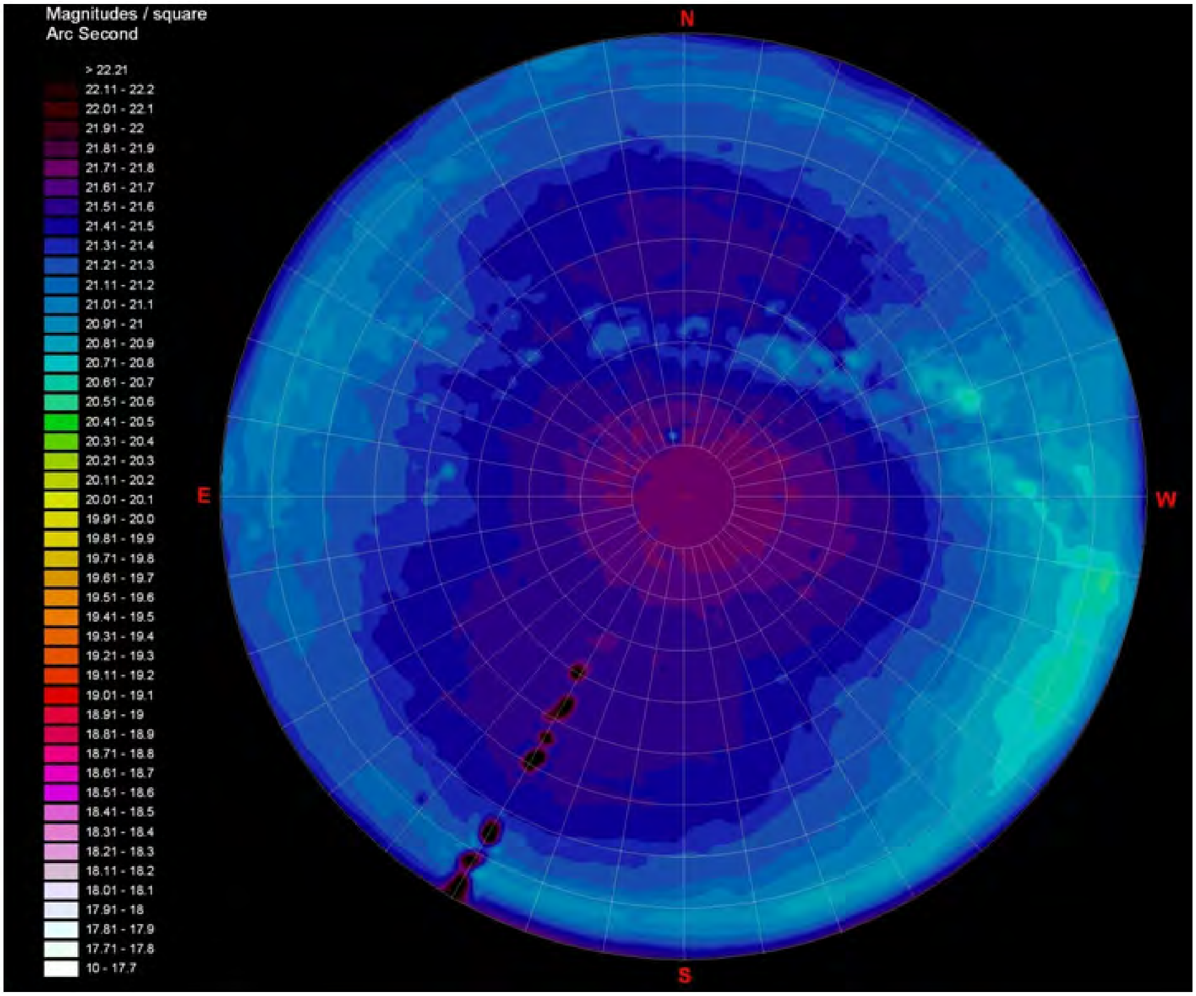


Figure 77. Contour map of night sky brightness in fisheye projection, Emory Peak, 20 November 2003. The single dark linear feature in the lower left is a radio antenna, the Milky Way is seen curving over the upper portion of the map. Light blue areas about 10 degrees above the horizon are the natural airglow, while the Zodiacal Light is seen as a bright area to the right.

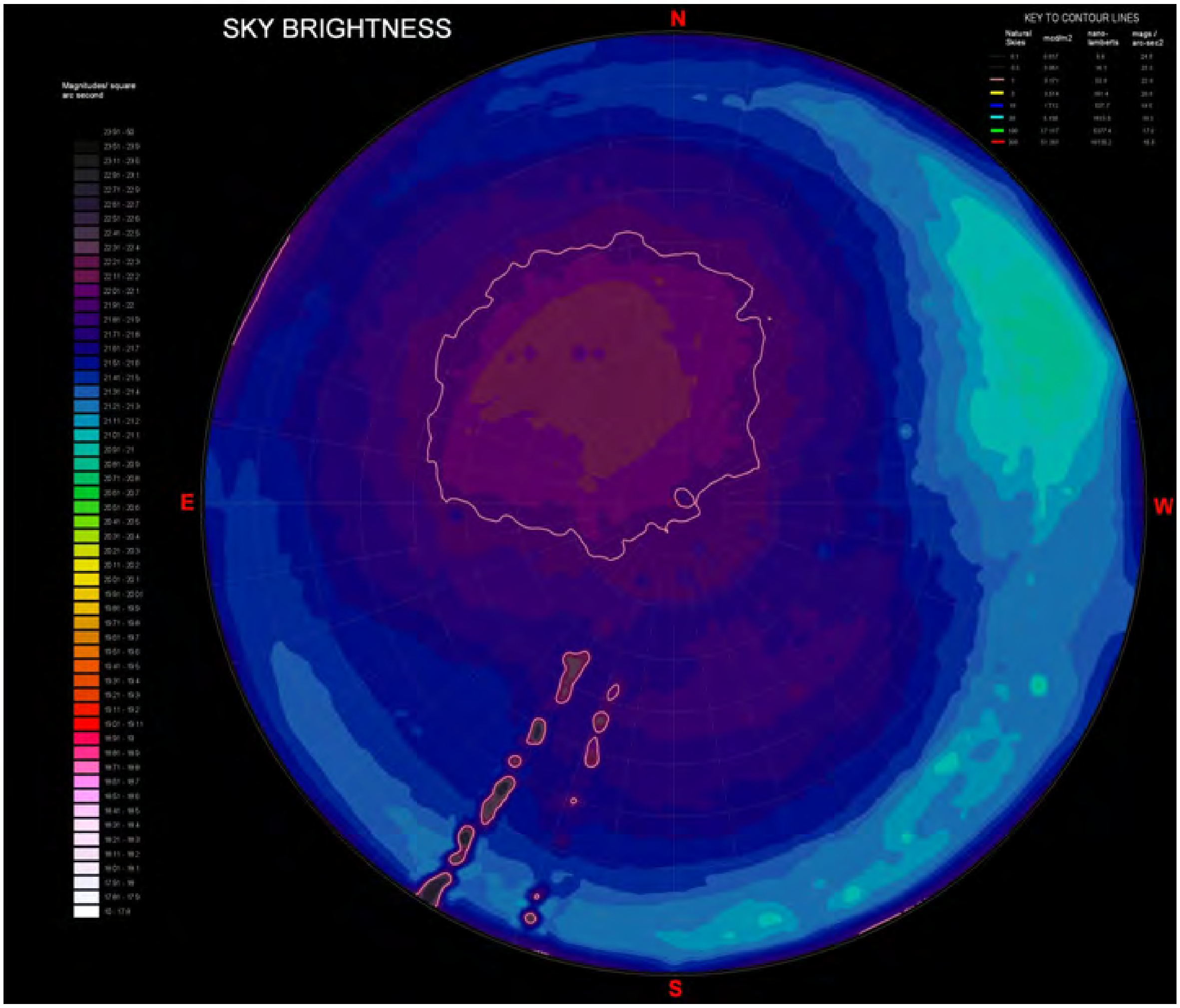


Figure 78. Contour map of night sky brightness in fisheye projection, Emory Peak, 15 April 2007. A second radio antenna has been added since 2003. The Milky Way is seen near the horizon to the south and west. The natural airglow is much less intense on this night, while the Zodiacal Light is strong, seen on the right side (slightly north of west).

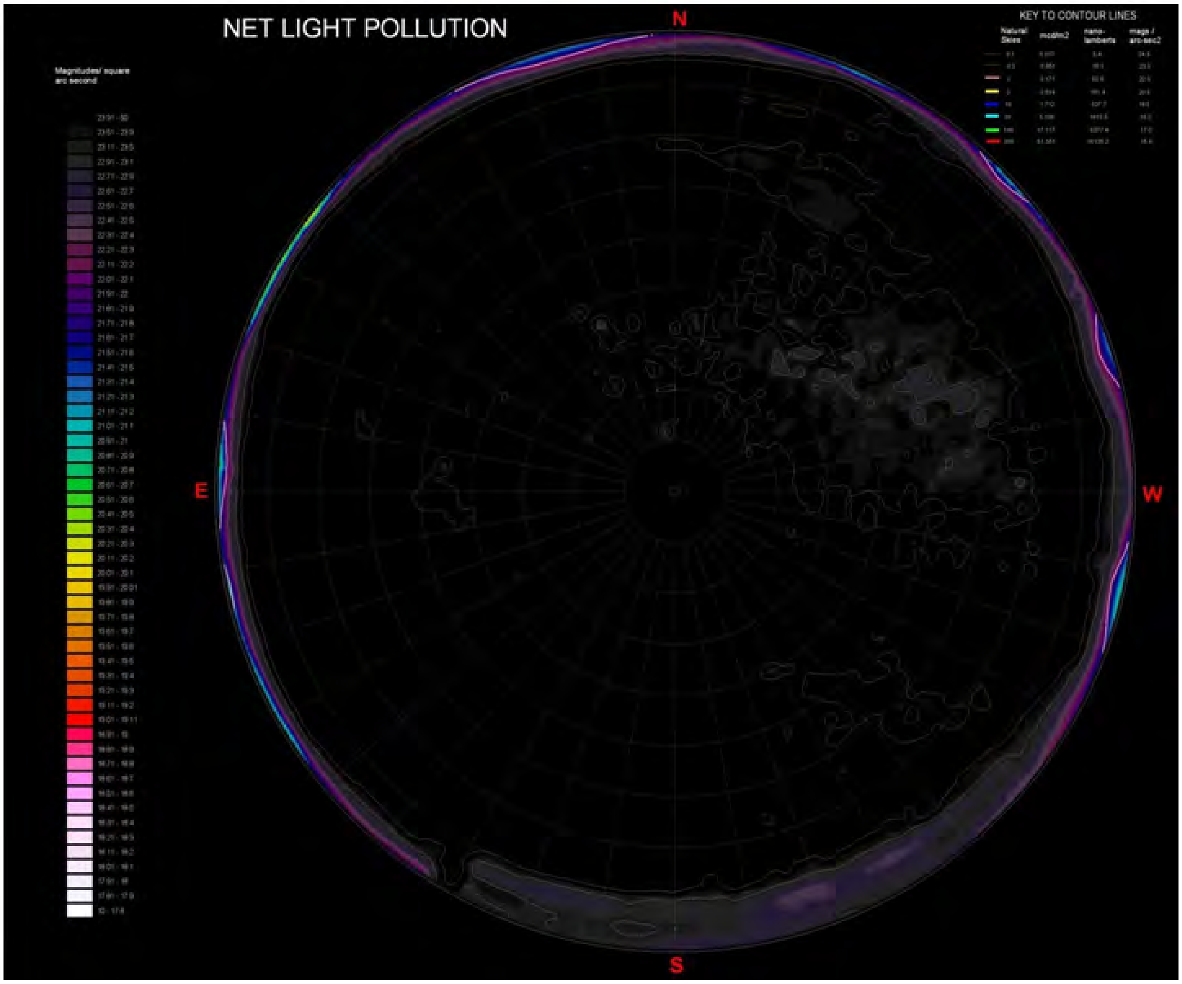


Figure 79. Contour map of anthropogenic sky glow in fisheye projection, Emory Peak, 20 November 2003. The bright, thin light in the upper left is an artifact of the spline fitting process and does not represent light pollution.

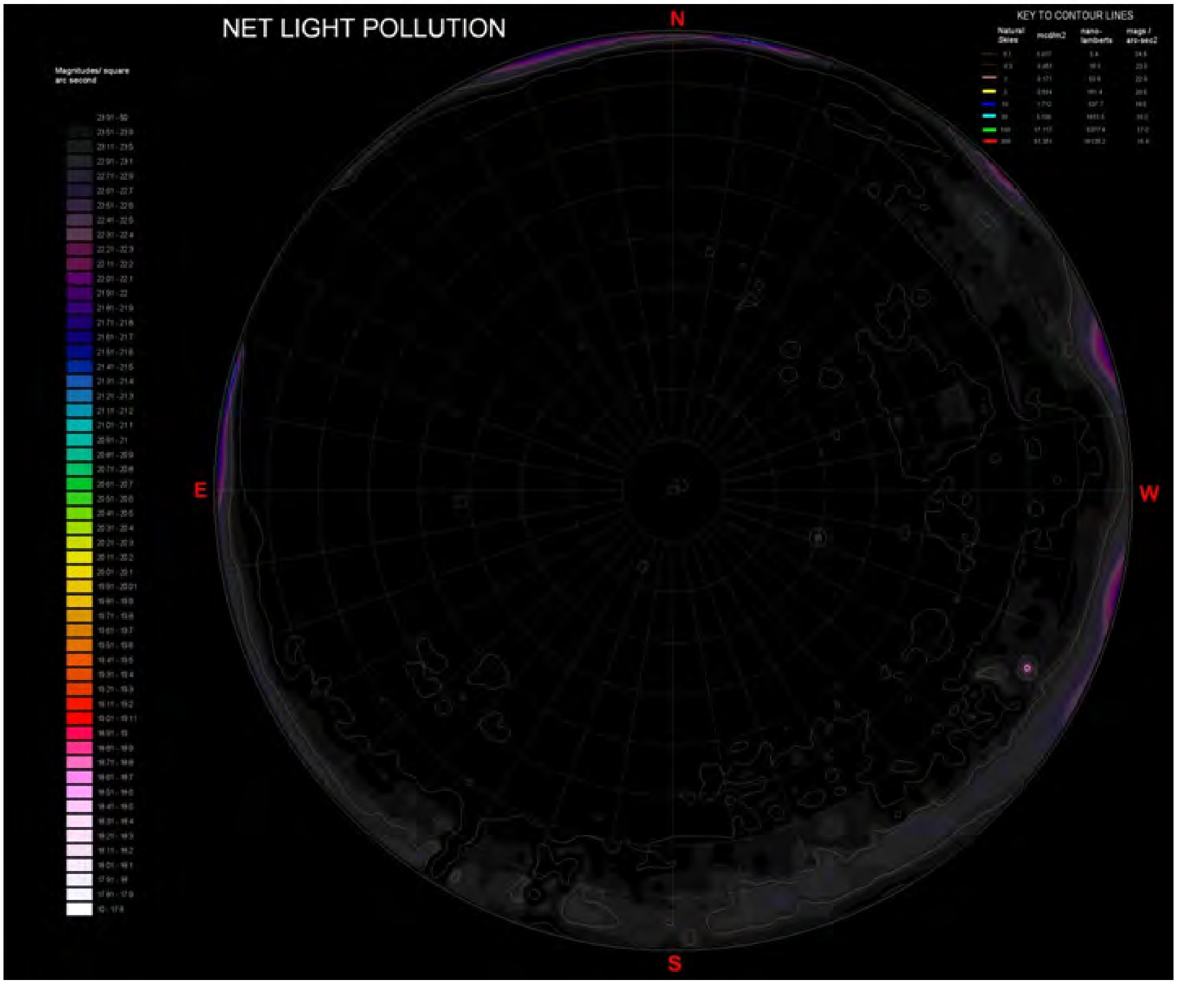


Figure 80. Contour map of anthropogenic sky glow in fisheye projection, Emory Peak, 15 April 2007. A realistic depiction of the small, faint light domes around the horizon, with the vast majority of the sky free of light pollution.

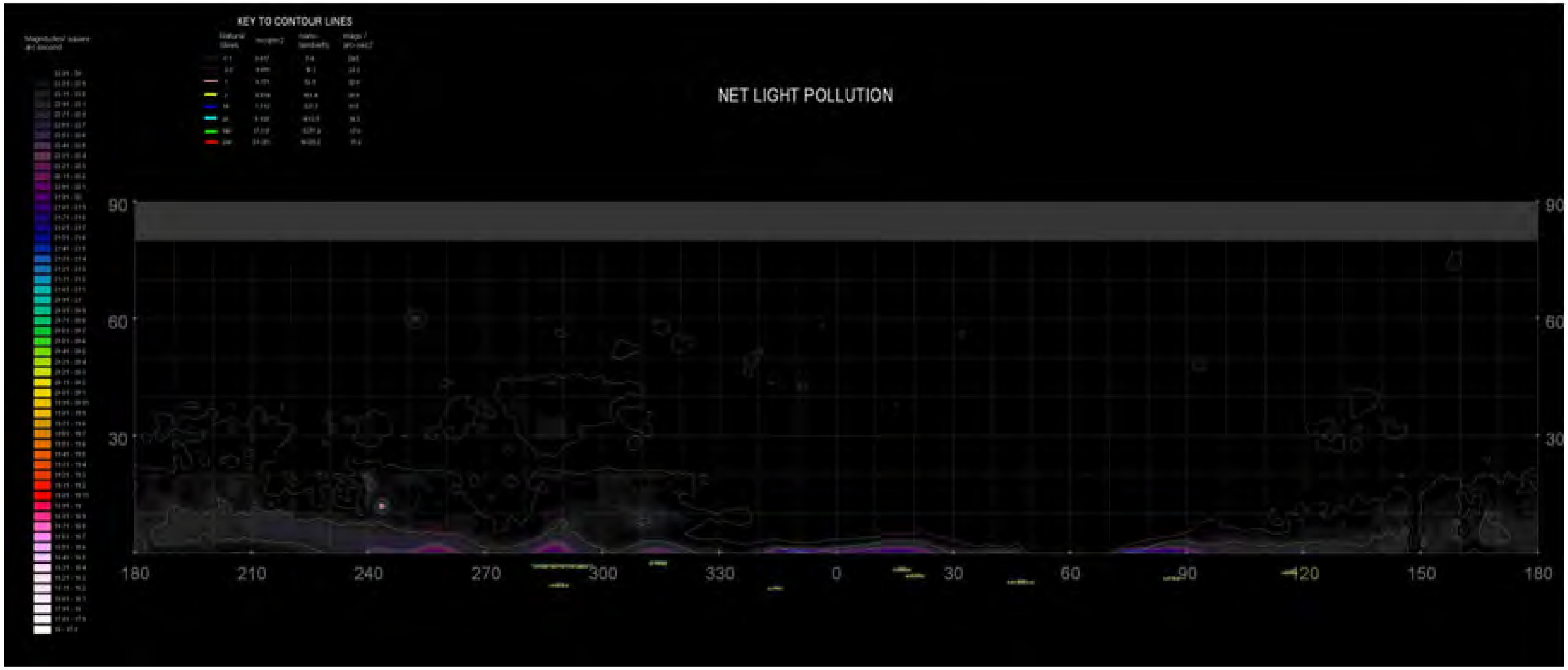


Figure 81. Anthropogenic light measured at Emory Peak, 15 April 2007, in panoramic projection.

No quantitative light trespass measures have been made within the park, but there are some visual observations incorporated in the narratives for the Emory Peak data. These will be discussed below and in the next section.

In summary, here are the quantities from the 2007 data night for the measures described in a previous section:

- **Sky luminance, ratio of anthropogenic to natural**: Maximum 1.14, Average 0.04, Minimum 0.00

- **Illuminance from city light domes**: Brightest 0.027 mLux (Presidio/Ojinaga) vertical, Total 0.2 mLux (entire sky) hemispheric

- **Illuminance of entire sky, ratio of anthropogenic to natural**: Average 0.05 (hemispheric), 0.04 (horizontal), 0.14 (vertical)

- **Vertical Illuminance from light trespass**: No data, visual observations from Emory Peak indicated three lights from Basin development “each about as bright as Sirius”, corresponding to 0.012 mLux each, or 0.36 mLux total.

- **Visual Observations**: Bortle Class 2, ZLM 7.4

- **Sky quality meter**: 21.85-21.92.

Threats and Stressor Factors

While anthropogenic light in the form of sky glow observed from BIBE is virtually non-existent at this time, the potential for a brightening of existing light domes or the creation of new ones from new developments exists. The notes from Emory Peak observation state “Del Rio seems brighter than 3 years ago”; an examination of the data from 2003 and 2007 reveals a slight brightening of the light domes from both Del Rio and Presidio (Appendix T, Appendix U, Figure 82, Figure 83). The layered haze in 2007 exaggerates the top of each light dome, but the cores (near the horizon) are significantly brighter, despite the higher extinction coefficient. While the light domes from distant cities do not currently exceed the reference condition for sky luminance, the trend of increasing brightness may eventually represent a threat.

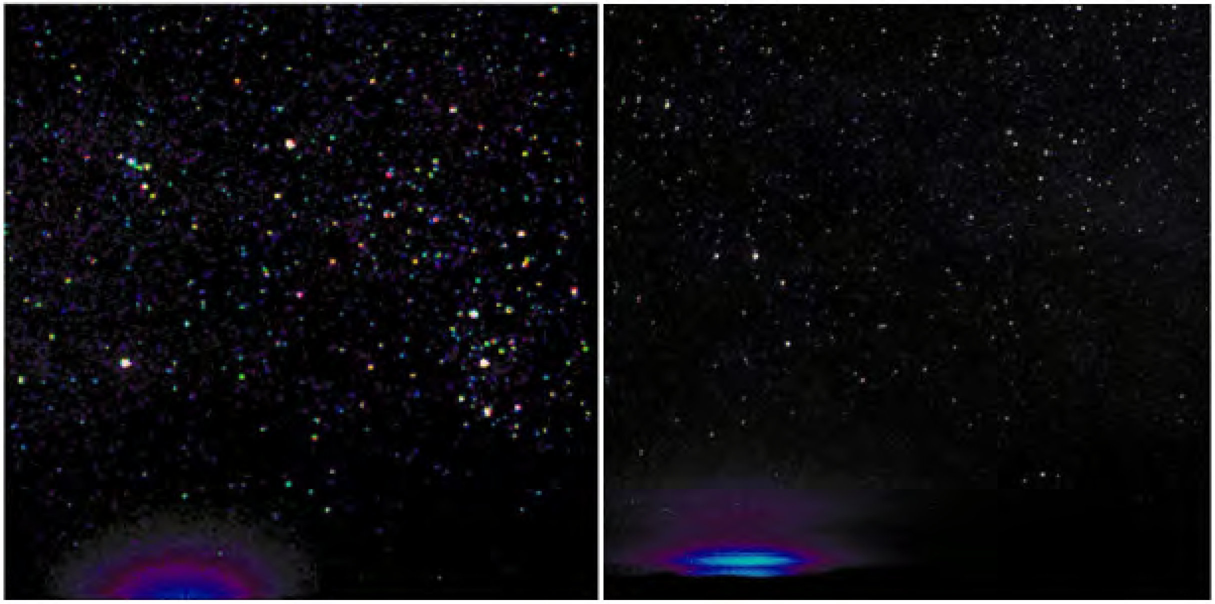


Figure 82. On left: Del Rio light dome in 2003. On right: Del Rio light dome in 2007.

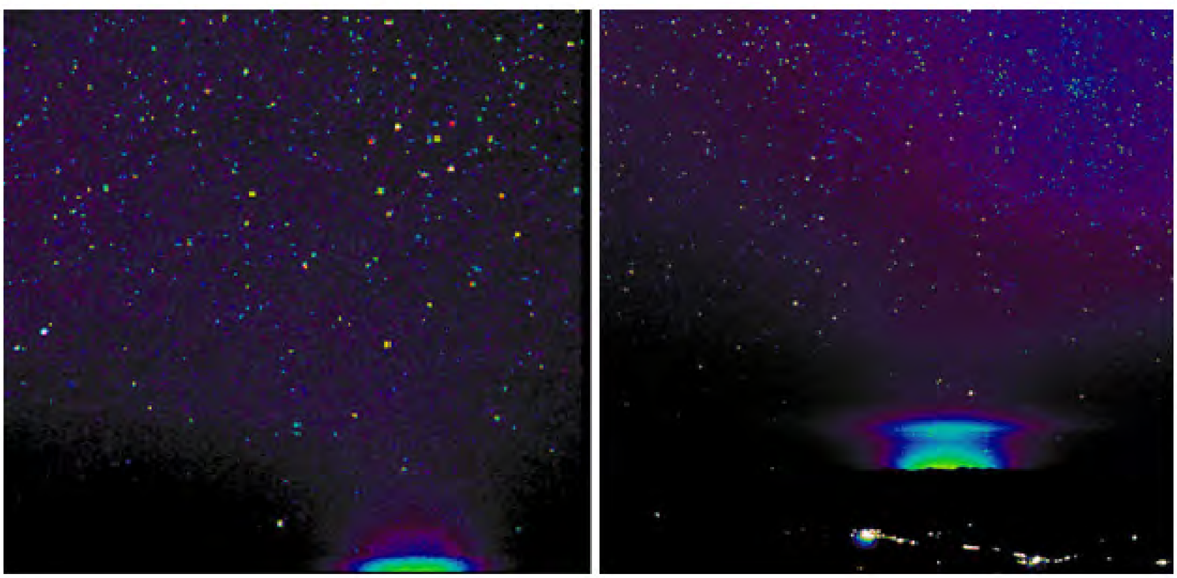


Figure 83. On left: Presidio/Ojinaga light dome in 2003. On right: Presidio/Ojinaga light dome in 2007 (light trespass from Study Butte/Terlingua below the light dome)

The much closer towns of Study Butte and Terlingua represent a more significant threat, especially with regard to light trespass. From the summit of Emory Peak in 2007, dozens of unshielded light sources were observed and appear on the images (Figure 83, right image). Outreach to these local communities may encourage the use of full cutoff outdoor lights, eliminating light trespass that would be visible from within the park.

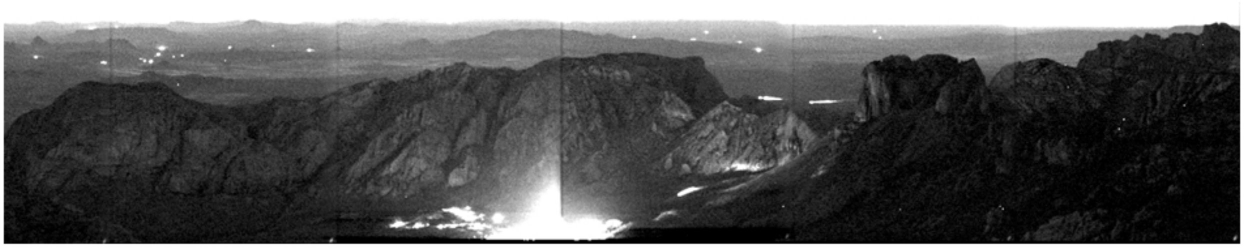


Figure 84. Below horizon panorama from Emory Peak, 20 November 2003. Light trespass from the Basin development is overexposed, but illumination of the cliffs surrounding it are evident in this image. Vertical bands are an artifact of the camera system and mosaicking processes.

Possibly the most significant threat to the dark sky resource is from outdoor lights within the park. The Chisos Basin development has the greatest potential for impact, serving guests with a hotel, restaurant, market, and campground. In 2003, a mosaic of monochrome images was made with the CCD camera from the summit of Emory Peak (Figure 84). While of low resolution, this panorama shows significant light trespass from the Basin Development at this time. By 2007, notes from the observers at Emory Peak indicated that improvements had been made, but three unshielded lights were still visible, each as bright as Sirius. Further lighting retrofits have been performed since that time. While no actual light trespass measurements have been made since the retrofits in this area, improvements are significant (Figure 85).

Figure 85. Below horizon panorama from Emory Peak after Basin lighting retrofits had been installed.

Air transparency will affect night sky quality. Estimates of optical depth or b_ext from PM10 air monitoring stations correlate well with this effect. Haze and smoke will reduce contrast and dim light from the night sky, resulting in a loss of detail and character in the Milky Way, and a reduction in the number of stars seen by the observer, particularly near the horizon. These effects are reduced by higher altitude observations. However, pristine night sky quality may only be truly observed when pristine air quality exists above the observer.

Data Needs/Gaps

A draft plan for natural lightscape management in BIBE, which includes zoning the park area to indicate where outdoor lighting is required and where the naturally dark zone occurs, would greatly benefit park managers and researchers. Light trespass measurements should be taken at the boundary of the naturally dark zone close to park developments and close to the towns of Study Butte and Terlingua. In this manner, it may be determined if standards for environmental protection are being met. While monochromatic and color digital photographs provide qualitative information, calibrated photometry is required to make a definitive judgment of the resource condition.

Continued measurement of the entire sky brightness condition should occur on a periodic basis, about once every 5 years, with Emory Peak as the preferred observing site, in order to track external threats.

Overall Condition

The National Park Service Night Sky Team, along with BIBE staff, assigned all measures for this component a *Significance Level* of 3. All the measures reported in this document met or exceeded the standard for the reference condition for this resource and may be judged to be in excellent condition (*Condition Level* = 0).

Weighted Condition Score (WCS)

The *Weighted Condition Score* (WCS) for dark night skies in BIBE is 0.000, indicating low concern.

Dark Night Skies

Measures	SL	CL
Sky luminance over the hemisphere in high resolution, reported in photometric luminance units or relative to natural conditions, often shown as a sky brightness contour map of the entire sky	3	0
Integration of measures of anthropogenic sky glow from selected areas of sky that may be attributed to individual cities or towns (known as city light domes),	3	0
Integration of the entire sky illuminance measures, reported either in milli-Lux of total hemispheric (or horizontal) illuminance, milli-Lux of anthropogenic hemispheric (or horizontal) illuminance, V-magnitudes of the integrated hemisphere, or ratio of anthropogenic illuminance to natural illuminance	3	0
Vertical illuminance from individual (or groups of) outdoor lighting fixtures at a given observing location (such as the Wilderness boundary), in milli-Lux	3	0
Visual observations by a human observer, such as Bortle Class and Zenithal limiting magnitude	3	0
Integrated synthesized measure of the luminance of the sky within 50 degrees of the Zenith, as reported by the Unihedron Sky Quality Meter, in V magnitudes per square arc second	3	0

WCS = 0.000

4.19.6 Sources of Expertise

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

Raymond Skiles, BIBE Wildlife Biologist

Lisa Turecek, BIBE Chief Facility Management

4.19.7 Literature Cited

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4.20 Hydrology/Spring Hydrology

4.20.1 Description

The Rio Grande Basin is one of the largest drainage areas in the United States, flowing east along the Mexican border and the southernmost boundary of BIBE to the Gulf of Mexico. The Rio Grande encompasses a watershed of over 541,000 km^2 (336,000 mi^2), with approximately 393 km (244 mi) of the river monitored by the NPS (nearly one quarter of the U.S.-Mexico border), of which 190 km (118 mi) is within BIBE (NPS 2010b). Water plays a crucial role within the arid desert environment through its influence on surficial geology, biological community distribution, and human settlement patterns (NPS 1992). The CHDN has identified three hydrological Vital Signs in its ecological monitoring framework: groundwater quantity, surface water dynamics, and persistence of springs (NPS 2009).

Photo 44. The Rio Grande at Mariscal Canyon when flow ceased in some areas during 2003 (photo by Jeffery Bennett, NPS).

The Rio Grande Basin extends from southwestern Colorado, through central New Mexico, and incorporates much of western Texas and northern Mexico. Dams, water diversions, agricultural extraction, and domestic use of water resources in urban areas have reduced much of the Rio Grande's historic streamflow (particularly from its source waters of melting snow and glaciers in the southern Rocky Mountain range), resulting in periods of seasonally intermittent flow (Saunders 1987, Porter et al. 2009). During these periods of low-flow, the flow regime is controlled primarily by the influence of the Rio Conchos in Mexico, which enters the Rio Grande near Presidio, Texas (Figure 86; Porter and Longley 2011). Continuous streamflow records from 1961–2007 indicate that over 80% of the Rio Grande's flow in the park originates from the Rio Conchos basin, occasionally reaching nearly 100% during low-flow events (Saunders 1987, Porter et al. 2009). The growing demand for surface and groundwater upstream of BIBE has steadily diminished the flow of the Rio Grande, increasing the concern of downstream users regarding water availability (Porter et al. 2009).

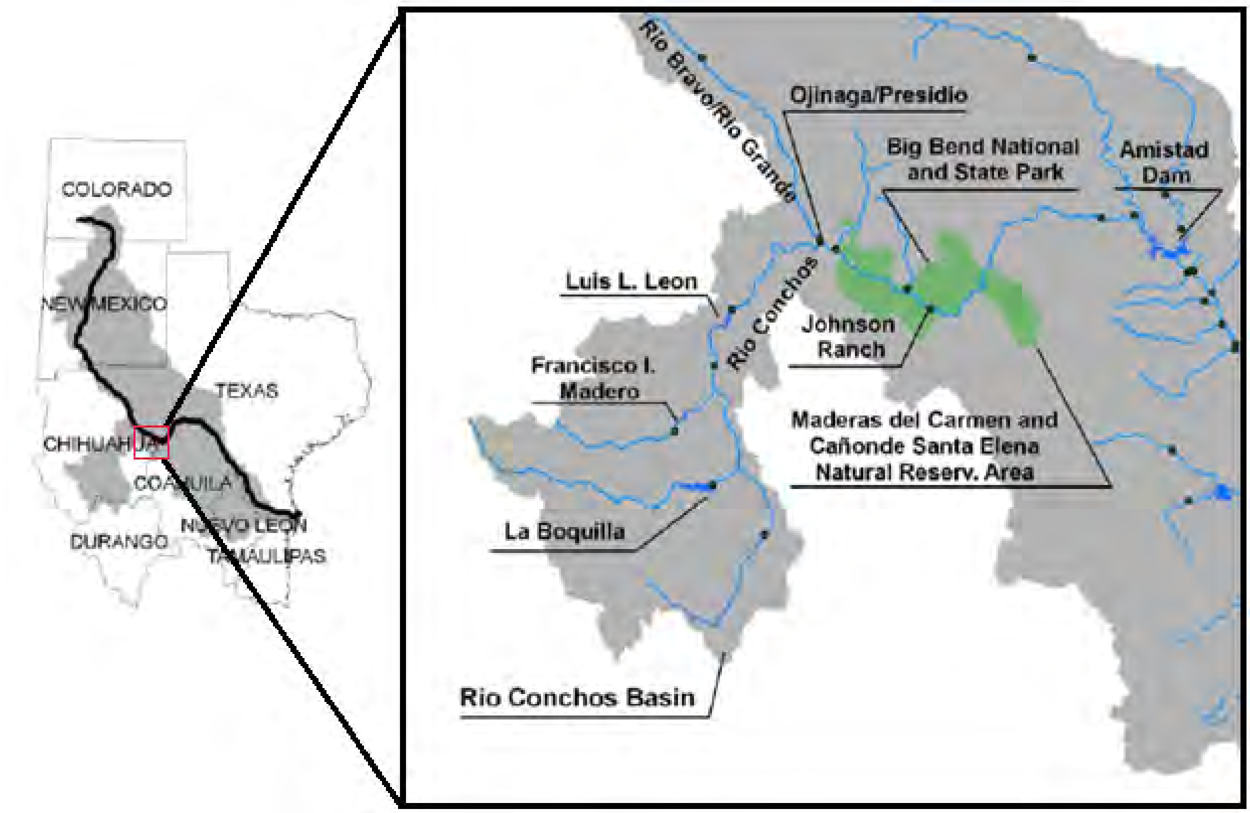

Figure 86. Map of the entire Rio Grande Basin (left) and the basin in the BIBE region (right), including the locations of three dams on the Rio Conchos in Mexico (Sandoval-Solis et al. 2010).

According to Fordham (2008), the integrity of the Rio Grande has been threatened by anthropogenic sources for much of the past century, which have modified flow regimes, reduced sediment transport, and increased water pollution. Dams and reservoirs have altered many of the river's hydrologic properties, allowing the formation of a narrow single-thread channel with steep banks and resulting in fewer large flood events (Dahm et al. 2005, Sandoval 2010). Two major upstream river impoundments established in the 1910s (Elephant Butte Reservoir in New Mexico and La Boquilla Reservoir in Mexico) have decreased annual mean flow, narrowed much of the channel, decreased sediment transport (i.e., gain and discharge of sediments), and altered width-to-depth ratios (Porter et al. 2009). These modifications have also contributed to an increase in invasive plant species in the area, most notably saltcedar (*Tamarix* spp.) (Porter et al. 2009).

While the Rio Grande is the most visible water body in the park, many intermittent tributaries and ephemeral springs play a major role in the region's hydrology (Saunders 1987). BIBE contains many springs that discharge directly into the Rio Grande, such as the Langford Hot Springs Complex located near the confluence of Tornillo Creek and the Rio Grande (Plate 74). This spring complex and the Lower Canyons Thermal Spring Complex are both designated by the park as important areas for protection (Huff et al. 2006). More than 300 water sources have been documented within BIBE (Alex 2008), many of which provide an important contribution to the base flow of the Rio Grande (Reid and Reiser 2005). Spring discharge is directly related to groundwater levels, which are, in turn, influenced by precipitation and groundwater well withdrawals (Porter et al. 2009). The quality of discharge from these springs has a strong influence on the water quality of the Rio Grande within BIBE (Huff et al. 2006). According to Saunders (1987), most of the Rio Grande's streamflow is attributed to rainfall and surface runoff; however, springs and groundwater discharges are extremely important to the desert environment of BIBE.

4.20.2 Measures

- Quality of discharge
- Quantity of discharge

4.20.3 Reference Conditions/Values

The ideal reference condition for hydrology/spring hydrology is the condition prior to Anglo settlement of the BIBE area. While no baseline data exist for hydrology characterization under pre-settlement conditions, there are several historical streamflow datasets for Rio Grande gaging stations (Plate 74) dating back to the early 1900s. Streamflow monitoring has taken place since the early 1930s at two IBWC gaging stations in the park: the gage at Terlingua Creek near Terlingua, Texas (station ID 8374500 - beginning in 1932), and the gage at Johnson Ranch near Castolon, Texas (station ID 8375000 - beginning in 1936). These locations provide large, long-term datasets for analysis (IBWC 2012).

4.20.4 Data and Methods

A Rio Grande water quantity, quality, and streamflow monitoring program was initiated in BIBE in the early 1930s. These data are published annually by the IBWC on their website and are generally available from the early 1900s through 2010, with data variability at different gage locations (Porter et al. 2009, IBWC 2012). Saunders (1987) conducted the first comprehensive study of water quality and quantity in BIBE, in which all available streamflow data for seven Rio Grande gaging stations were analyzed. Schmidt and Everett (2000) and Sandoval-Solis et al. (2010) analyzed Rio Grande stream flow before and after major regulation (e.g., dams and diversions) occurred in the basin.

NPS (1995) provided surface-water-quality data retrievals for BIBE using five EPA databases, as described previously in Chapter 4.16. This information provides descriptive water quality information for the park, as well as historical water data.

Porter et al. (2009) provide analysis of surface water quality and quantity using streamflow trends and historic records of annual mean discharge at selected USGS/IBWC gaging stations. Four gaging stations within the Porter et al. (2009) study area yielded long-term records for analyzing and comparing historic and current flow trends in the Rio Grande near BIBE.

The IBWC monitors several gaging sites along the Rio Grande, including one located inside the park at Johnson Ranch (station ID 8375000) (Plate 74, Table 54). An additional IBWC gage is located on Terlingua Creek in the western portion of the park. The TCEQ, in cooperation with the USGS, has developed a continuous monitoring program with two stations located on the Rio Grande within the park's boundaries near Castolon and Rio Grande Village (NPS 1995; Bennett, pers. communication, 2011). Data from several gages upstream of the park, on both the Rio

Grande and the Rio Conchos, could also be useful in assessing hydrology within the park (Table 54).

Table 54. Gaging units for the Rio Grande and tributaries from Presidio, Texas downstream to BIBE (Huff et al. 2006, Plate 74).

Station Number	Station Operator	Latitude	Longitude	Description of Station	Years of Continuous Operation
In BIBE					
8374500	IBWC	29° 12' 10"	103° 37' 10"	Terlingua Creek near Terlingua, Texas	1932-current
8374550	TCEQ/ USGS	29° 08' 14"	103° 31' 28"	Rio Grande near Castolon, Texas	2005-current
8375000	IBWC	29° 02' 05"	103° 23' 25"	Rio Grande at Johnson Ranch near Castolon, Texas	1936-current
8375300	TCEQ/ USGS	29° 11' 08"	102° 58' 23"	Rio Grande at BIBE (Rio Grande Village), Texas	2005-current
Upstream of BIBE					
8371500	IBWC	29° 36' 15"	104° 27' 05"	Rio Grande above Rio Conchos near Presidio, Texas	1889-current
8373000	IBWC	29° 34' 57"	104° 25' 52"	Rio Conchos near Ojinaga, Chihuahua	1896-1913; 1924-current
8374200	IBWC	29° 31' 10"	104° 17' 10"	Rio Grande below Rio Conchos near Presidio, Texas	1955-current[1]

[1] 1999-current (USGS)

Daily mean discharge data for the Johnson Ranch (08375000) and Terlingua Creek (8374500) gages were obtained from the IBWC online database (IBWC 2012). These records extend from 1 January 1937 (the first complete year of readings) to the most recently published records for 31 December 2010. Monthly mean discharge data for the two TCEQ/USGS stations (Castolon and Rio Grande Village) from fall of 2007 through the end of 2011 were obtained from the USGS National Water Information System website (USGS 2013).

4.20.5 Current Condition and Trend

Quality of Discharge

As noted by Porter et al. (2009), water quality degradation has occurred throughout much of the Rio Grande south of Presidio and into BIBE; however, this interpretation was developed from limited point data. Over the past 30-35 years, very little change has been noted in water quality indicators such as dissolved oxygen (DO), water temperature, and pH values in Rio Grande discharge (Porter et al. 2009). Naturally, water temperature readings were higher at hot-spring discharges than at other Rio Grande gage locations (Porter et al. 2009). DO concentrations vary with flood pulses, sometimes resulting in early-season fish kills when DO reaches low concentrations. BIBE has reported several low DO readings below the minimum 4 ppm (4 mg/L) adequate to support fish health (Saunders 1987, Porter et al. 2009).

According to Porter et al. (2009), levels of heavy metals such as mercury, arsenic, chromium, and nickel were generally low at all sampled locations along the Rio Grande. Fecal coliform and *E. coli* levels within the park were positively correlated with streamflow and were often elevated during summer months when flow is reduced (Porter et al. 2009).

Huff et al. (2006) indicates that water quality impairments are present in Texas Stream Segment 2306, which includes all of the Rio Grande within BIBE, as well as the entire portion of the river designated as the Rio Grande Wild & Scenic River (RIGR). According to the TCEQ (2010), this segment was first listed as impaired in 1999 due to elevated bacterial concentrations. As of 2010, only the reach from the Rio Conchos confluence to Alamito Creek (upstream of the park) was cited for high bacteria levels. However, several reaches of segment 2306, including some reaches in BIBE, were listed as 303(d) impaired for chloride, sulfate, and total dissolved solids in 2010 (TCEQ 2010). For an in-depth discussion of these and other water quality parameters, see Chapter 4.16 of this report.

NPS (1995) found that surface waters within BIBE were moderately high in dissolved solids (sodium, sulfate, and chloride), indicating that discharge from mineral rich springs or agricultural runoff may play a significant role in discharge water quality. Christiansen (1981) previously noted that water in BIBE spring discharge tends to be hard (high dissolved mineral content), but of good quality. During USGS surveys in the 1960s, researchers collected water samples from selected BIBE springs and compared them to 1962 federal drinking water quality standards (NPS 1996). These standards are shown in Table 55, along with the 2010 TCEQ surface-water quality standards for comparison (note that TCEQ standards are less strict, as they are not intended for drinking water). The water quality of the selected springs during the 1960s is presented in Table **56**, along with more recent water quality data collected by the CHDN from 2010-2012 (NPS 2013a). Parameters measured by the CHDN included total dissolved solids (TDS), dissolved oxygen (DO), and sulfate. While all the springs sampled between 2010 and 2012 met 2010 TCEQ standards for TDS and sulfate, just over half fell short of the DO standard.

Table 55. 1962 federal drinking water quality standards (PHS 1962), in comparison to current Texas Commission on Environmental Quality surface-water quality standards (TCEQ 2010a).

Parameter	1962 drinking water standards	2010 TCEQ standards
Total dissolved solids	500 mg/L	1,550 mg/L
Chloride	250 mg/L	300 mg/L
Sulfate	250 mg/L	570 mg/L
Dissolved Oxygen	--	≥ 5 mg/L
Fecal coliform (E. coli)	4 colonies/100 ml	≤126 CFU/100 ml

Table 56. Water quality information from selected BIBE springs during the late 1960s (relative to 1962 federal drinking water standards; Garza 1966, Leggat et al. 1968, as cited in NPS 1996) and from 2010-2012 (NPS 2013a)

Spring name	Quality (according to 1962 standards)	2010-2012 Measurements (mg/L)		
		TDS	DO	Sulfate
Oak	good		-- dry --	
Cattail Falls	good	377	6.1	130
Croton	high sulfate; very hard	1,144	1.16	190
Rock	--	369.2	--	37
Yule	good		-- not sampled --	
Burro	good	305.5	4.17	49
Word	good			
Chilicotal	good	217.1	5.61	>0.01
Mule Ear*	good	350.4	3.6	31
Glenn	good	429	5.65	13
Moore	extremely high sulfate; very hard		-- not sampled --	
Indian Head	moderate	819	7.36	76
McKinney	--	448.5	1.19	--
Rio Grande Village Hot Springs	moderate	838.5	2.65	--
Rosillos Ranch	moderate; very hard		-- dry --	

*2010-2012 measurements for Mule Ear Spring are an average of three samples taken during the study period.

Quantity of Discharge

Analyses from Porter et al. (2009) show that discharge at four gaging stations upstream of and within BIBE have decreased over the past century. While most stations experienced an increase in discharge during the 1960s and 1970s, recent measurements are below those taken when record-keeping began (Figure 87-Figure 90). Mean and peak discharges in the Rio Grande have also declined since the development of Elephant Butte Reservoir in 1915-1916 (Porter et al. 2009). After this development, mean discharge decreased from 22.4 cubic meters per second (cms) to 5.8 cms at the Rio Grande above Rio Conchos station (8371500), and from 72.2 cms to 32.8 cms at the Rio Grande below Rio Conchos station (8374200) (Porter et al. 2009).

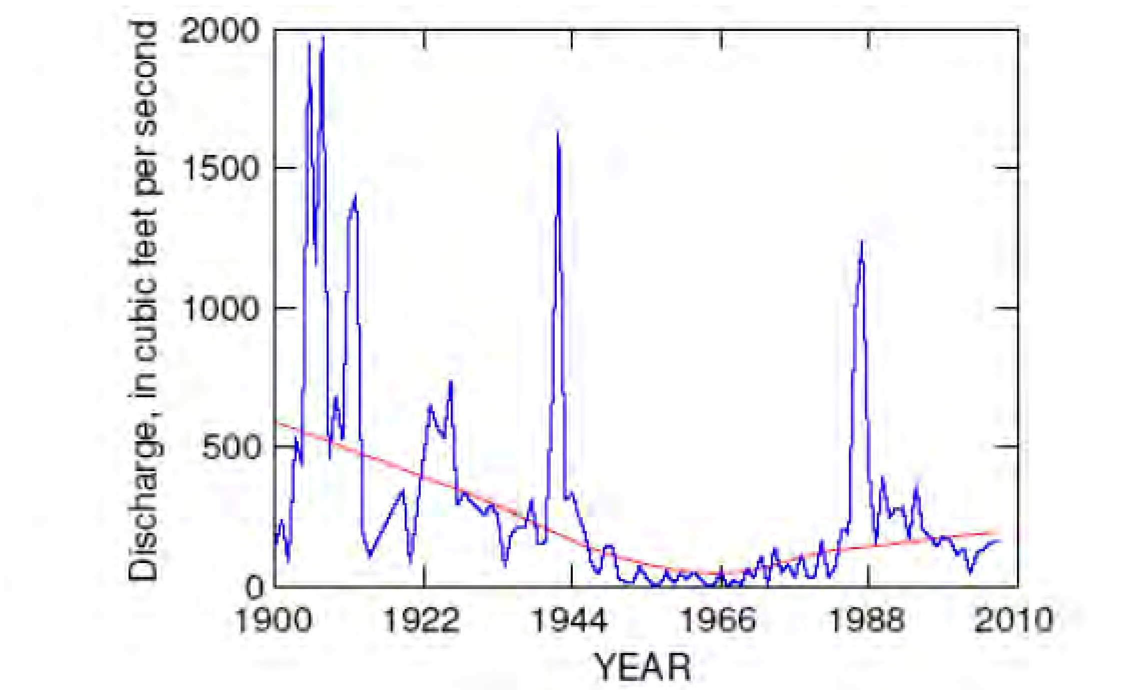

Figure 87. Annual mean discharge (blue) and trend (red) for the Rio Grande above the Rio Conchos (Station 8371500) (Porter et al. 2009). Note that 1,000 cfs = 28.3 cms.

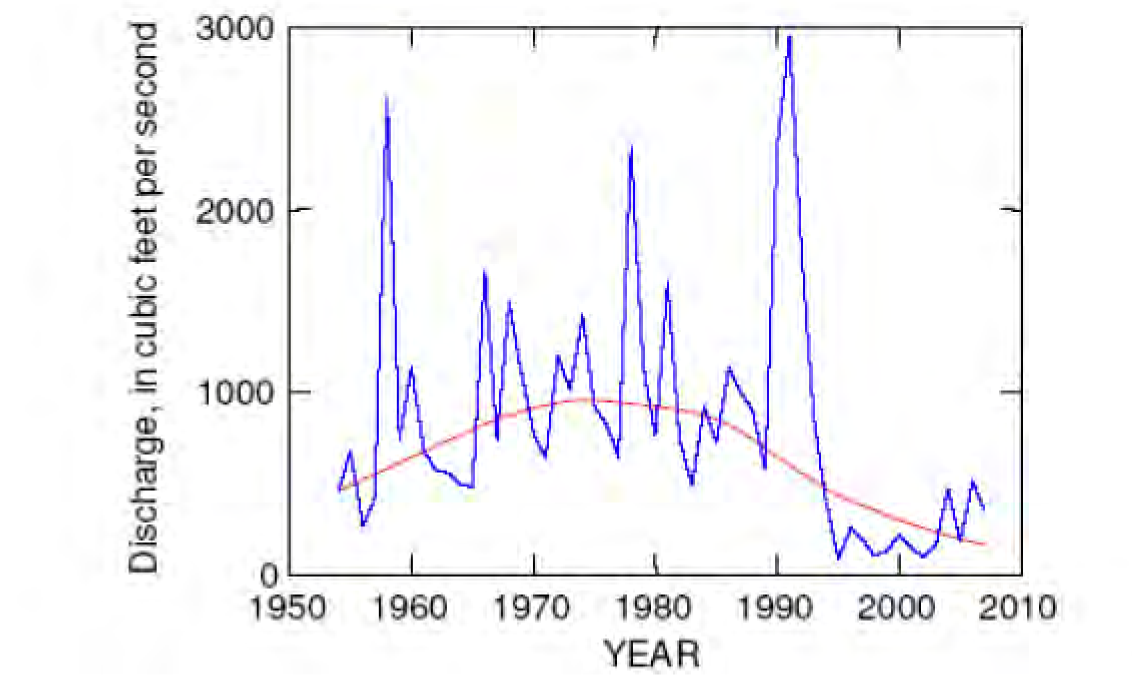

Figure 88. Annual mean discharge (blue) and trend (red) for the Rio Conchos (Station 8373000) (Porter et al. 2009).

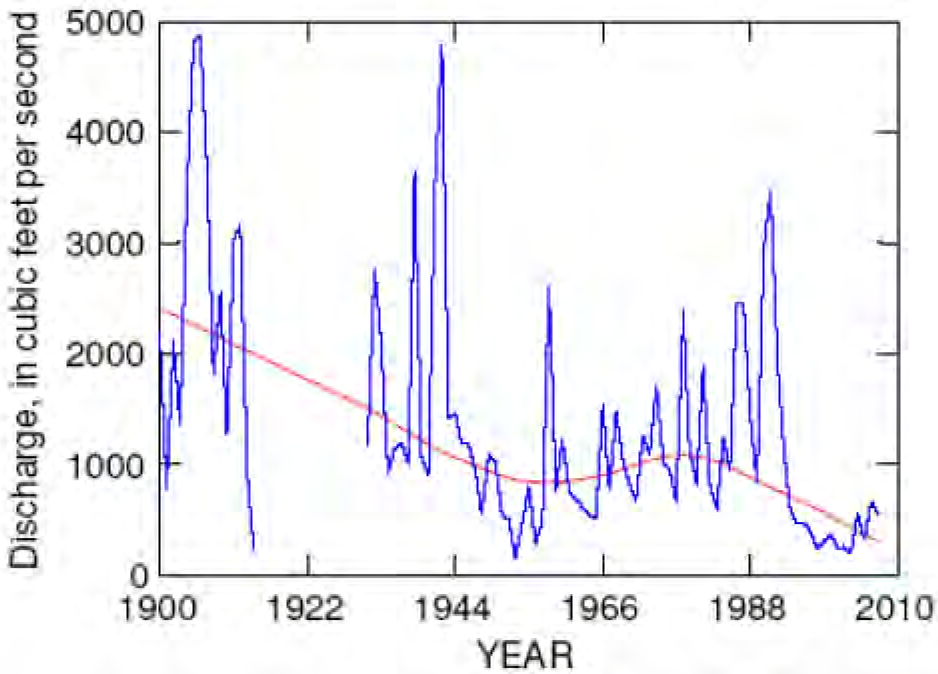

Figure 89. Annual mean discharge (blue) and trend (red) for the Rio Grande below the Rio Conchos (Station 8374200) - no data were reported between 1914 and 1930 (Porter et al. 2009).

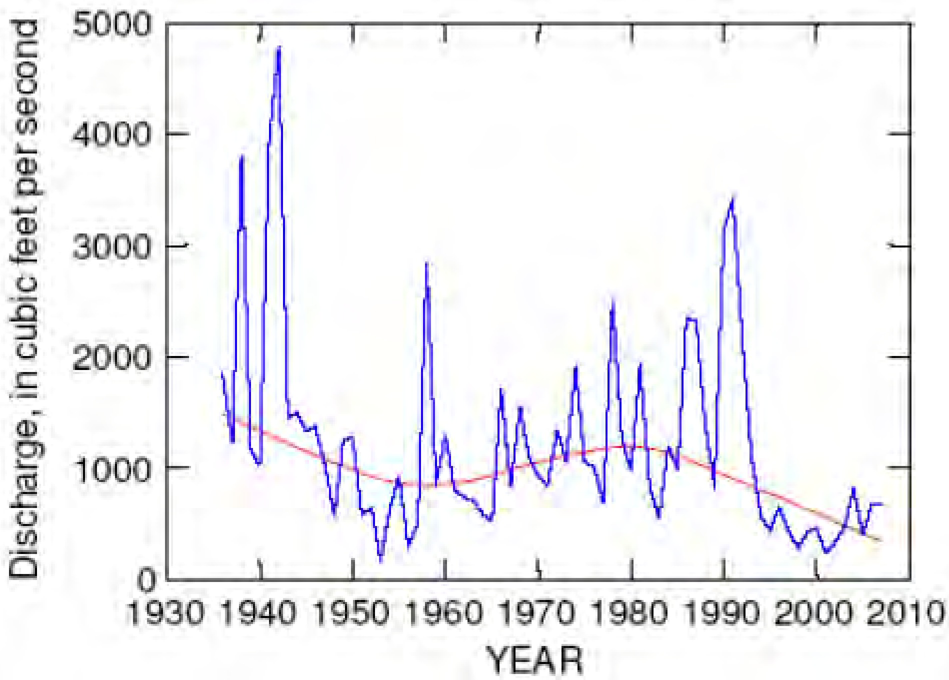

Figure 90. Annual mean discharge (blue) and trend (red) for the Rio Grande at Johnson Ranch in BIBE (Station 8375000) (Porter et al. 2009). Note that 1,000 cfs = 28.3 cms.

Records of daily mean discharge from 1937-2010 were obtained for two IBWC Rio Grande gaging stations in BIBE. These are located on Terlingua Creek (a tributary of the Rio Grande) near Terlingua, Texas (8374500), and at Johnson Ranch near Castolon, Texas (8375000).

Discharge measurements at the Terlingua Creek station have not changed noticeably over time. Readings, both historically and recently, are consistently <1 cms, with occasional peaks following precipitation events (Figure 91). Discharge dropped to zero several times (during the 1950s, 1980s, and 1990s) and has twice exceeded 400 cms, reaching 487 cms in June 1937 and 458 cms in September 2004. Figure 92 shows daily discharge readings at the Terlingua Creek gaging station during 2010.

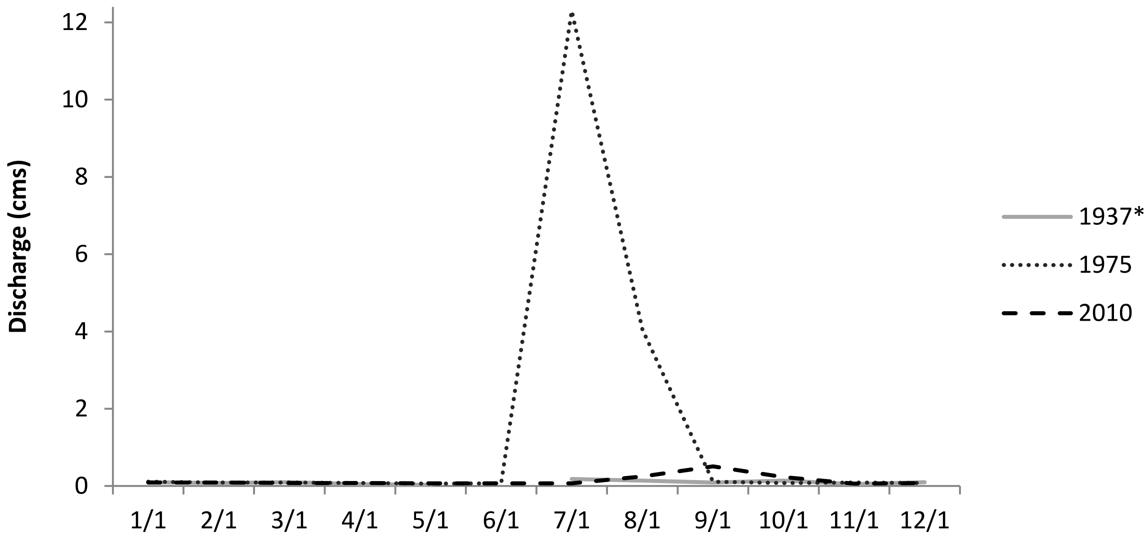

Figure 91. Daily discharge at the Terlingua Creek gaging station on the first of each month during 1937 (first year available), 2010 (most recent available), and 1975 (approximately halfway between) (IBWC 2012). * It is important to note that the measurement for 1 June of 1937 is not shown due to scale, as discharge was measured at 487 cms, likely due to precipitation.

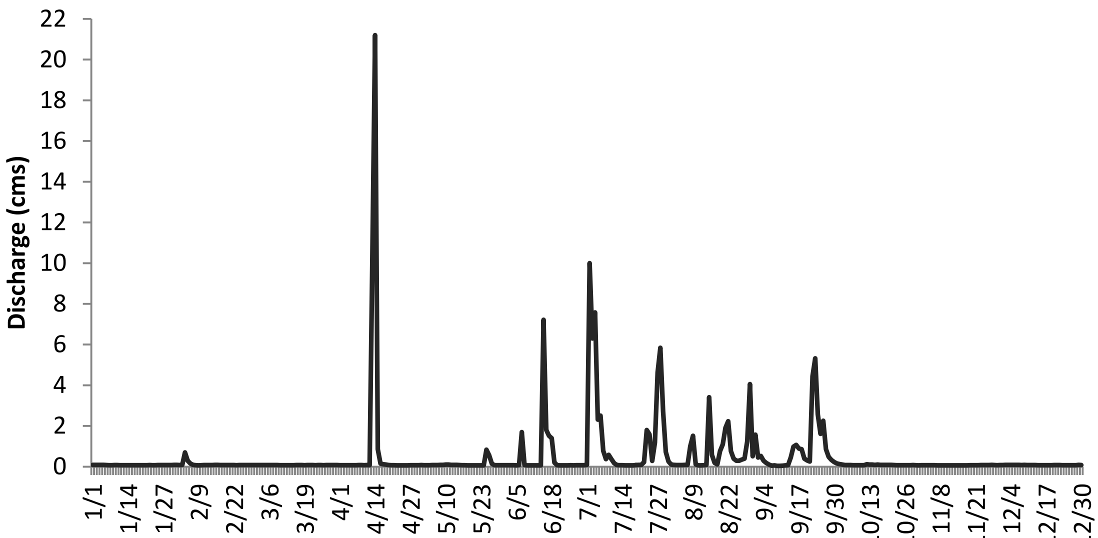

Figure 92. Daily discharge at the Terlingua Creek gaging station in 2010 (IBWC 2012).

Daily discharge measurements for the Rio Grande at Johnson Ranch in 2010 are presented in Figure 93. A comparison of selected years of data from this gage suggests that daily discharge may have changed over the past century. As shown in Figure 94, daily discharges were more variable over the year and peak discharges were higher during 1937 and 1975 than in 2010. During the 1940s, daily discharge ranged from 1.2 to 1,610 cms with a mean of 51.7 cms (IBWC 2012). During the 2000s, in contrast, daily discharge ranged from 0.07 to 1,490 cms with a mean of 22.8 cms. Forty-two discharge measurements above 500 cms were recorded during the 1940s, while only 30 measurements above 500 cms occurred during the 2000s (IBWC 2012). Patterns in discharge and change over time at the Rio Grande gaging station near Presidio (upstream of the park) are very similar to those at Johnson Ranch, as shown in Figure 95.

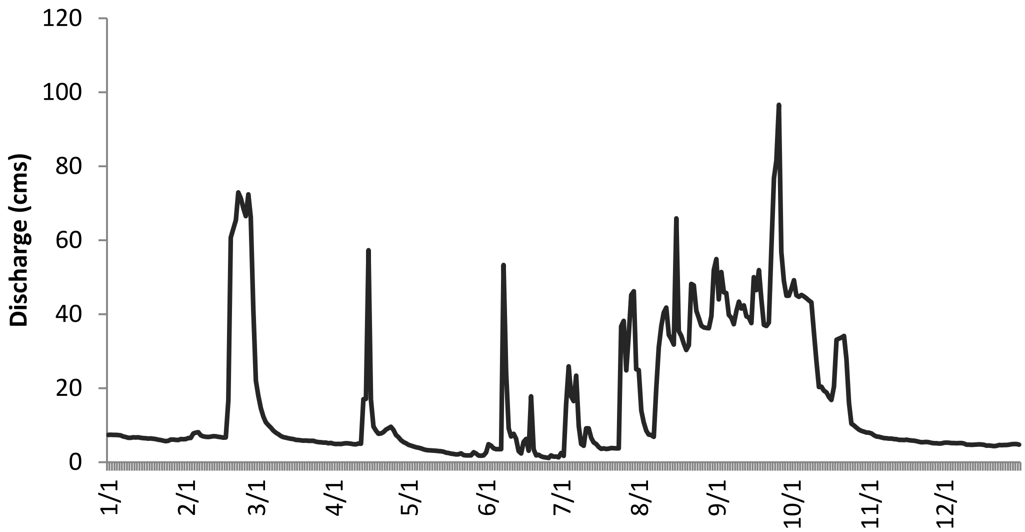

Figure 93. Daily discharge at the Rio Grande gaging station at Johnson Ranch in 2010 (IBWC 2012).

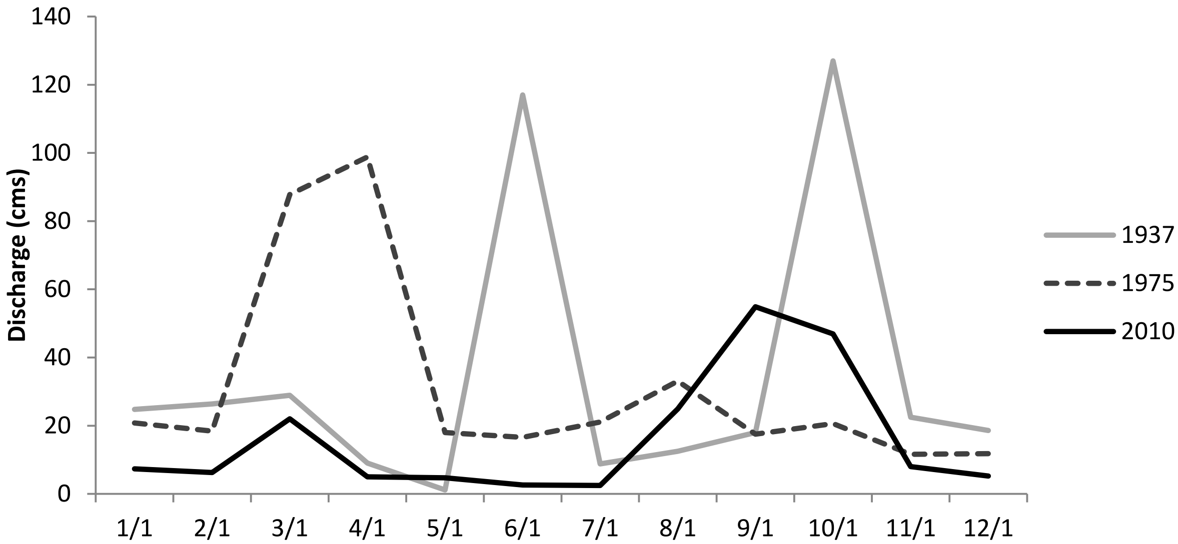

Figure 94. Daily discharge at the Rio Grande gaging station at Johnson Ranch on the first of each month during 1937 (first year available), 2010 (most recent available), and 1975 (approximately halfway between) (IBWC 2012).

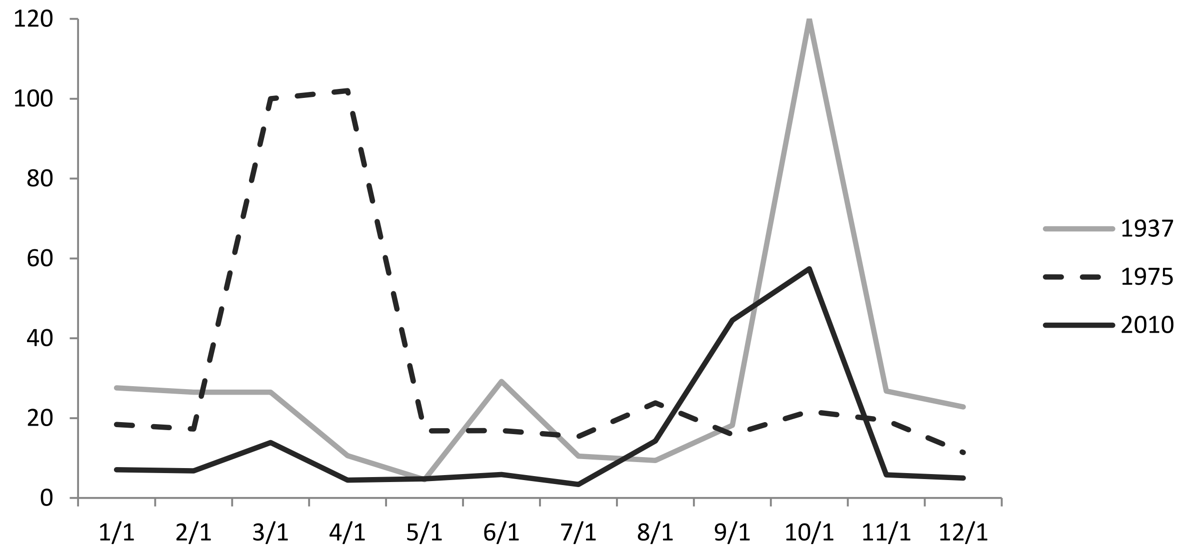

Figure 95. Daily discharge at the Rio Grande gaging station near Presidio (upstream of BIBE) on the first of each month during 1937, 1975, and 2010 (IBWC 2012).

An analysis of discharge data from Johnson Ranch by Sandoval-Solis et al. (2010) showed changes, particularly in peak discharges and floods, pre- and post-river regulation (i.e., dams). Prior to regulation (pre-1946), median monthly discharge ranged from 11 to 98 cms. A median of two small floods with peak flows around 400 cms occurred annually, one in September and the other in July, August, or October (Sandoval-Solis et al. 2010). After river regulation (post-1946), median monthly discharge ranged from 8 to 24 cms. The median number of small floods declined to 0.5, meaning that floods occur only every other year, typically in September and with peak flows around 340 cms (Sandoval-Solis et al. 2010).

Monthly mean discharge measurements for the two TCEQ/USGS Rio Grande gages in the park (Castolon and Rio Grande Village) from August 2007 through the end of 2011 are presented below in Figure 96 and Figure 97. While mean discharge generally fluctuated between 5 and 50 cms, two drastically higher measurements occurred at both stations in September and October of 2008. Discharge at the Castolon station also dropped below 1 cms several times during the spring and winter of 2011 (Figure 96).

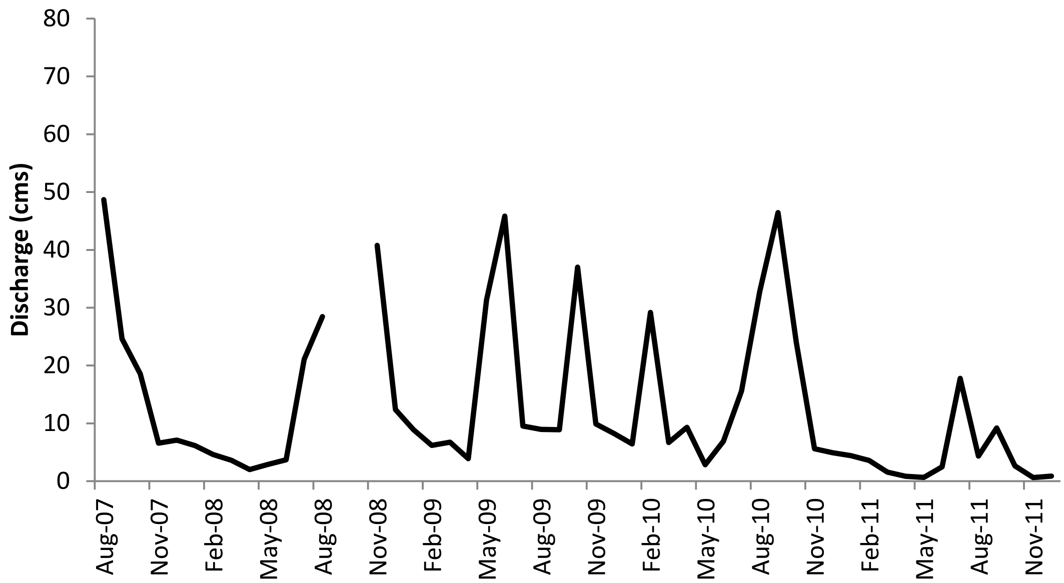

Figure 96. Mean monthly discharge at the Castolon gaging station from 2007-2011 (USGS 2013). For reasons of scale, the readings from September and October of 2008 were removed from the graph, as they measured 821.3 and 355.7 cms respectively.

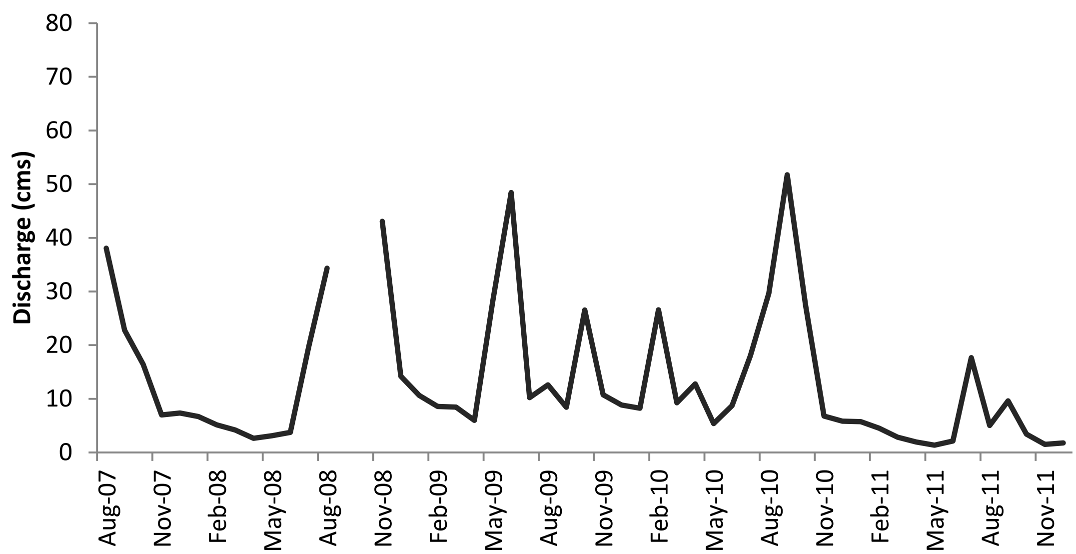

Figure 97. Mean monthly discharge at the Rio Grande Village gaging station from 2007-2011 (USGS 2013). For reasons of scale, the readings from September and October of 2008 were again removed, as they measured 588.9 and 248.7 cms respectively.

Monthly discharge, averaged over the period of record (late 2007-2011) for the two TCEQ/USGS gaging stations is also presented below (Figure 98). During this period, discharge at both stations peaked in early fall (September-October), similar to readings at the Johnson Ranch station in 2010 (see Figure 94).

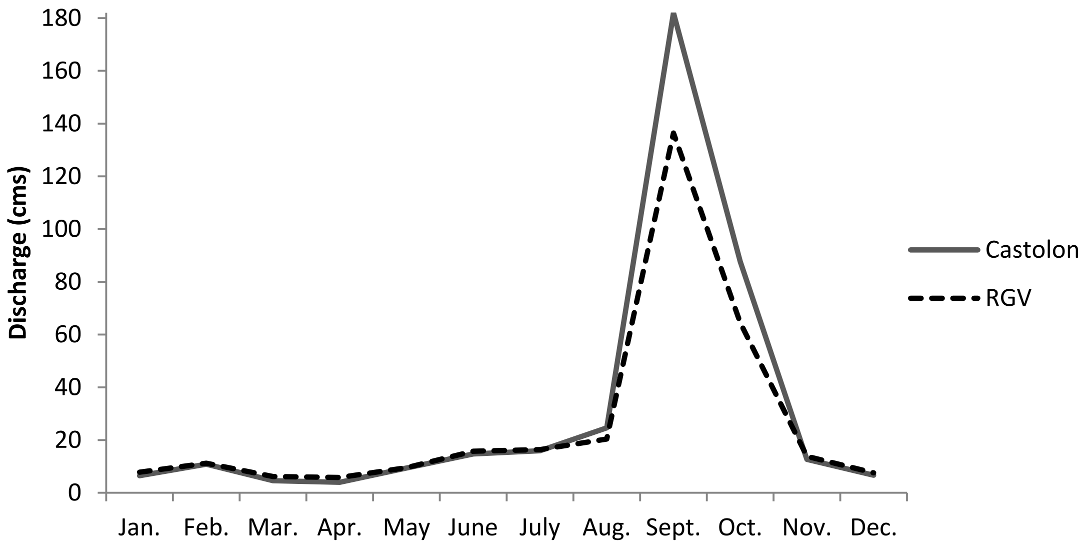

Figure 98. Average mean monthly discharge at the Castolon and Rio Grande Village (RGV) gaging stations from 2007-2011 (USGS 2013).

Discharge (i.e., flow) from the park's springs is highly variable. Many of the park's springs are ephemeral and do not flow year-round. Historic records (prior to 2008) for the 82 perennial water sources (springs, tinajas, etc.) in BIBE indicate that 38 have average flows above 4 liters per minute (lpm) (Alex 2008). Fourteen flowed at a rate between 2 and 4 lpm, while 18 had discharges below 2 lpm and six sources were seeps with immeasurable flow. Additionally, 11 water sources not categorized as perennial generally had a flow above 4 lpm (4 lpm = 0.004 cms) (Alex 2008).

During the mid to late 1960s, the USGS collected discharge measurements from selected springs in BIBE (NPS 1996). From 1985-1986 and in 1990, the NPS surveyed BIBE springs and again collected discharge data (NPS 1996). More recently, 371 park springs were surveyed by the CHDN between 2010 and 2012. Discharge data was collected for any springs where flow was detected, as well as water quality data (Kirsten Gallo, CHDN Program Manager, pers. communication, 25 April 2013). Discharge data for selected individual springs during the late 1960s and from 2010-2012 are provided in Table 57 below. It is important to note that differences in discharge between the two studies could be partially due to differences in sampling methodology (e.g., exact sample location, measurement methods) as opposed to actual change over time. The NPS (1996) did not provide individual spring discharge data from their 1985-86 and 1990 studies, but a summary (range and mean for sampled springs) is shown in Table 58. Summary information is also shown for the 2010-2012 survey in this table.

Table 57. Discharge (lpm) at BIBE springs sampled by the USGS during the mid to late 1960s (Garza 1966, Leggat et al. 1968, as cited in NPS 1996) and from 2010-2012 (NPS 2013b).

Spring name	1960s Discharge	2010-2012 Discharge
Oak	37.8	0
Cattail Falls ^	189.3	--
Croton	0.4	0.01
Rock	0	NM*
Yule	0-3.8	--
Burro ^	7.6	--
Ward	5.7	12.0
Chilicotal	0.8	10.0
Mule Ear	0-3.8	3.0
Glenn	0-3.8	32.8
Moore	15.1	--
Indian Head	1.9	NM*
McKinney	0	6.0
Rio Grande Village Hot Springs	189.3-757	30.0
Rosillos Ranch	56.8	0
Adler	--	6.0
Bell	--	14.0
Buttrill A	--	4.1
Canyon	--	3.0
Hop	--	10.0
Lower Tornillo	--	20.0
Trap	--	5.0
Lower Bee	--	5.0
Dodson (Lower)	--	4.0

^ While Cattail Falls and Burro Spring were flowing during CHDN surveys, no suitable location could be found to take an accurate measurement.

*NM = Discharge was so low it could not be measured.

Table 58. Summary of spring discharge data for springs sampled by the NPS in BIBE during 1985-86, in 1990 (NPS 1996), and from 2010-2012 (Julie Christian, CHDN Ecologist, written communication, 20 June 2013). For the 1985-86 and 1990 NPS data, springs were grouped by USGS quads and only quads totaling at least 10 gpm (37.9 lpm) in either of the two periods were included (NPS 1996).

		Discharge (lpm)		
	# of springs sampled	**Minimum**	**Maximum**	**Mean**
1985-86	199	0	246	9.7
1990	264	0	341	43.8
2010-2012	371 (188/98)*	0	32.8	1.6 (3.0)*

* While 371 springs and other water features (tinajas, seeps, etc.) were visited by the CHDN from 2010-2012, only 188 had flow and, of these, only 98 had discharge ≥ 0.01 lpm. In the final column, 1.6 lpm represents the mean discharge for all 188 springs that were not dry, while 3.0 is the mean for those 98 springs with discharges ≥ 0.01 lpm.

During the 2010-2012 survey, 28 of the 82 perennial springs (34%) were dry, possibly reflecting the extreme drought occurring at the time (Gallo, written communication, 19 June 2013). These dry springs appear to be equally distributed throughout the park and are not concentrated in any particular area. Discharge was above 4 lpm at 13 of the perennial springs. Four springs had flow rates between 2 and 4 lpm, and 15 had flows less than 2 lpm. Discharge at nine springs was too low to measure. Eleven springs not classified as perennial had flows greater than or equal to 4 lpm (CHDN unpublished data). In comparison to historic spring discharge data presented previously (Alex 2008), fewer springs were flowing above 4 lpm during this more recent study period, and more water sources had immeasurable flow (Figure 99). According to the summary data in Table 58, it appears that spring discharge may have decreased over the past 20 years. However, it is difficult to know if this is due to actual change or simply differences in sampling methodology and statistical calculation.

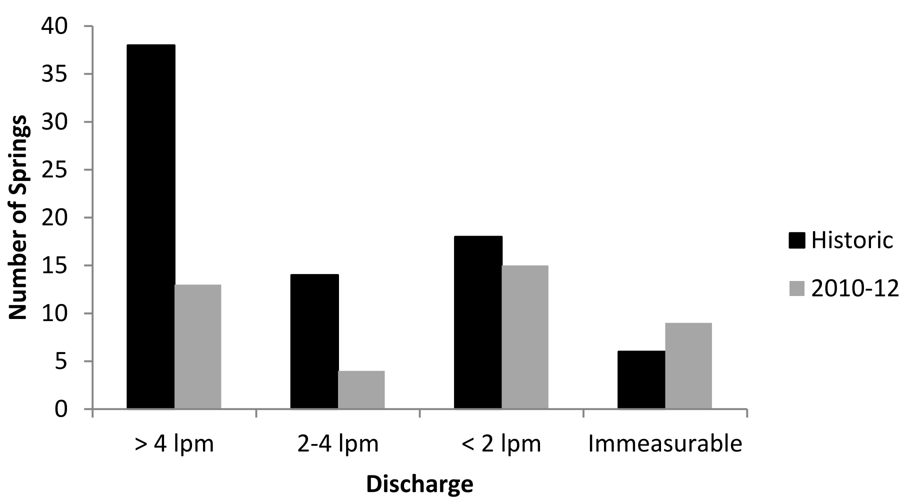

Figure 99. Number of BIBE perennial water sources (springs, seeps, etc.) with various levels of discharge, historically (pre-2008; Alex 2008) and from 2010-2012 (Gallo, written communication, 19 June 2013).

Many springs in the park contribute to the base flow of the Rio Grande, including the Boquillas Warm Springs in the Langford Hot Springs Complex (Saunders 1987). Discharge from these springs into the river was measured by the Texas Water Development Board (TWDB) several times between the 1930s and 1970s. Measurements ranged from 0.01 to 0.05 cms, as shown in Table 59 (Saunders 1987).

Table 59. Discharge (cms) from Boquillas Warm Springs (TWDB 1975, as cited in Saunders 1987). Note that 0.01 cms = 600 lpm.

	1936	1953	1964	1965	1966	1971
Discharge (cms)	0.02	0.05	0.02	0.02	0.02	0.01

Threats and Stressor Factors

The primary stressor of hydrology in BIBE is anthropogenic alterations within the Rio Grande Basin, particularly dam construction and increased water usage in urban areas and for agricultural use (Blackstun et al. 1998). Additional threats include changes in precipitation patterns, which influence watershed recharge, and atmospheric deposition of pollutants. Anthropogenic alterations upstream of BIBE have greatly reduced the amount of water in the Rio Grande by the time it reaches the park. According to Blackstun et al. (1998, p. 4), "the availability of streamflows sufficient in variability, magnitude, and duration to protect natural resources that are dependent on these flows is the most serious water-quantity issue in the Rio Grande sub-area" (extending from the Rio Conchos confluence to the Amistad Reservoir). Adequate stream flow is required to maintain and support a variety of habitats, both aquatic and terrestrial, as well as to meet recreational needs in the park. For example, high, scouring flows adequate to remove accumulating fine sediments, expose gravel and cobble bars, create back-water pools, and create sandy stream-bottom conditions are required for many native fishes and Unionids (mussels). Dams and diversions have also greatly reduced the flooding that historically shaped the Rio Grande ecosystem (Sandoval-Solis et al. 2010).

Climate is a major driver of hydrology, and the Rio Grande is strongly influenced by regional climate variations (Costigan et al. 1999). Precipitation patterns (timing and amount) impact the quantity of water moving through a particular system through runoff and discharge. Therefore, the Rio Grande is likely highly vulnerable to climate changes predicted for the region over the next century. Temperatures are expected to increase in Texas (Herbert 2006), which will accelerate evapotranspiration, potentially causing even drier conditions in the BIBE region.

Threats to the quality of discharge in BIBE include contamination from anthropogenic sources such as urban runoff, agriculture, mining, or various industrial activities (NPS 1995, Huff et al. 2006). According to Porter et al. (2009), agricultural runoff has caused increases in salinity and nutrient concentrations in the Rio Grande. Atmospheric deposition of pollutants from industrial and urban sources far from the park is also a concern (Blackstun et al. 1998). Toxic substances such as heavy metals, pesticides, and PCBs can be transported long distances in the air, and then settle on land or water miles away. Low flows can impact water quality as well, as they often result in higher water temperatures and increases in salinity and total dissolved solids.

Data Needs/Gaps

According to Schmidt and Dean (2011), further research is needed regarding the Rio Grande's stream flow (e.g., sources, timing and duration of low and high flows, rate of downstream flow attenuation, etc.). This would include studying how much water upstream dams would have to release to meet downstream environmental flow requirements. More readings/data from high flows are especially needed (Schmidt and Dean 2011). Research into how spring discharge varies with season, precipitation, and other environmental factors would also be useful (Alex 2008). Further investigation into the threat of hazardous coliform bacteria levels and their potential impacts on park resources and/or visitors would be helpful for park managers (MacNish et al. 1996). The discharge measurements that were taken by the TWDB at Boquillas Warm Springs in the Langford Hot Springs Complex from 1930-1970 have been re-measured in recent years. Due to an oversight, the data and trip reports from these visits were not included in this component but are available for future condition assessments.

Overall Condition

Quality of discharge
BIBE's quality of discharge measure was assigned a *Significance Level* of 3. The *Condition Level* is also a 3, indicating high concern. See the water quality component of this report (Chapter 4.16) for further details.

Quantity of discharge
This measure was also assigned a *Significance Level* of 3. Declines in discharge and low flows on the Rio Grande within BIBE are a significant concern for the park. Discharge in Terlingua Creek, a Rio Grande tributary in the park, appears to have changed little over time. Spring discharge in BIBE is highly variable, both by location and season (often depending on precipitation patterns); recent data suggests that spring discharge may be decreasing (see Table 58). The overall *Condition Level* for this measure is therefore a 3 (high concern).

Weighted Condition Score
The *Weighted Condition Score* for BIBE hydrology/spring hydrology is 1.00, indicating significant concern. Given the many stressors on the Rio Grande (e.g., dams and diversions, urban and agricultural pollutants), and the observed declines in discharge, a declining trend was assigned to this component.

Hydrology/Spring Hydrology

Measures	SL	CL
• Quality of discharge	3	3
• Quantity of discharge	3	3

WCS = 1.00

4.20.6 Sources of Expertise
Jeffery Bennett, BIBE Physical Scientist

Julie Christian, CHDN Ecologist and Field Coordinator

Kirsten Gallo, CHDN Program Manager

4.20.7 Literature Cited

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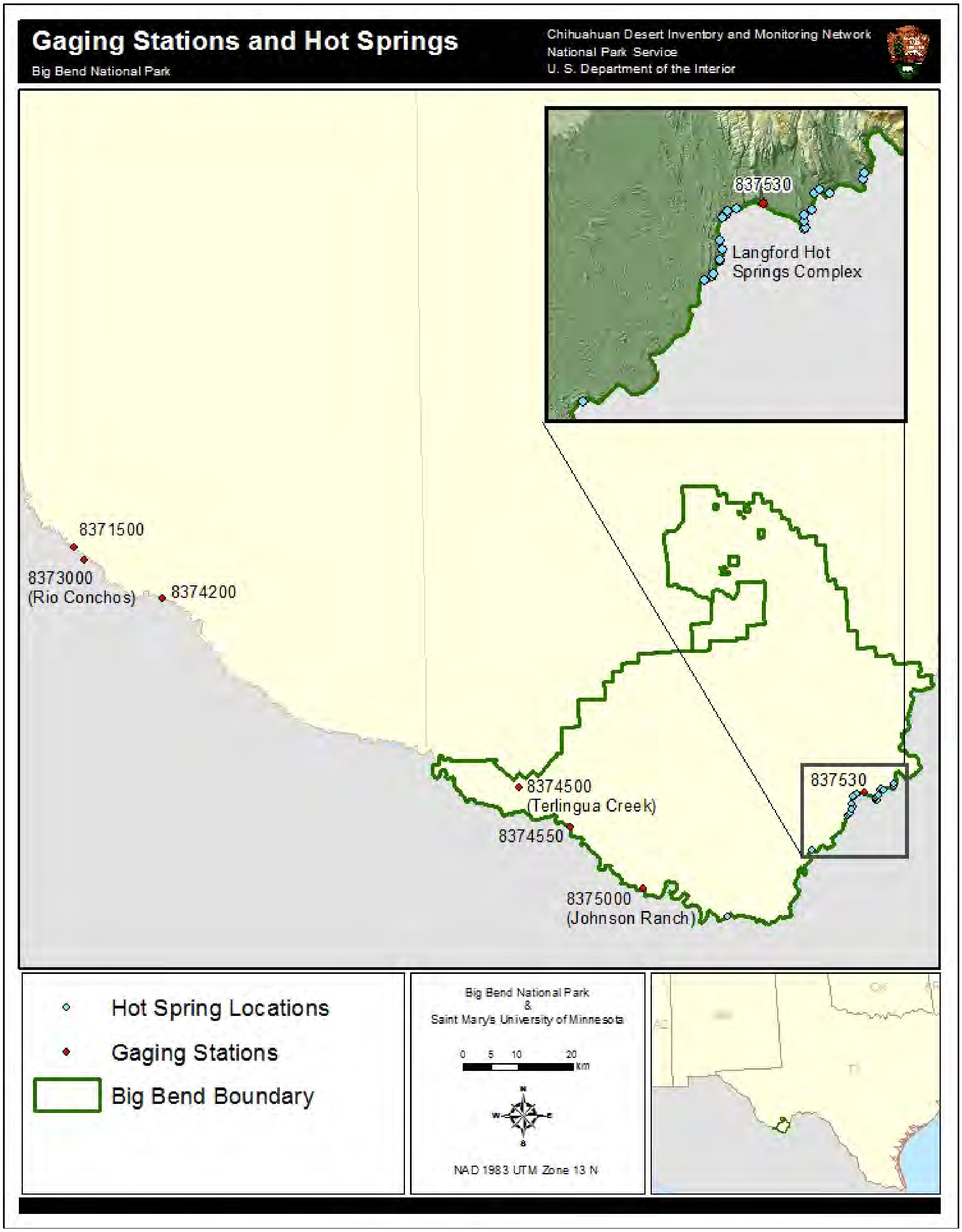

Plate 74. Gaging station locations within and upstream of BIBE. The locations of hot springs along the Rio Grande in the park are also shown.

4.21 Soils

4.21.1 Description

NPS (2012) describes soil as “the unconsolidated portion of the earth’s crust modified through physical, chemical, and biotic processes into a medium capable of supporting plant growth.” Information about the chemical, physical, and biological properties of park soils can help managers predict how soils will respond to a variety of uses or stressors (NPS 2012). Soil is a dynamic medium that is shaped by five interacting factors: 1) the type and composition of the *parent material* (i.e., rock) 2) the various *climates* these parent materials have been exposed to, 3) the amount of *time* natural forces have been acting on the soil, 4) the *living organisms* in and on the soil, and 5) the *relief* or topography of the landscape (NRCS 2011). Examples of living organisms that influence soils include plant roots, burrowing animals, and cryptobiotic soil crusts (e.g., algae, lichens) (NRCS 2011).

Soils strongly influence the type of ecosystem or plant community that an area can support. As part of the NRCS (2011) soil survey of BIBE, researchers created ecological site descriptions and correlated them with soil map units. These are shown in Plate 75 and Table 60. Three different soil types that occur in BIBE are depicted in Photo 45.

Photo 45. Examples of soils in BIBE (left to right): Ninepoint clay loam, Leyva very gravelly loam, and Geefour silty clay (NRCS photos).

Table 60. Soil mapping units of BIBE with the associated soil series and ecological site designations (NRCS 2011). PZ = precipitation zone.

Mapping unit	Primary soil series	Ecological site
AAC	Altar - 83%	Gravelly, desert grassland
ADE	Altuda - 75%	Limestone hill and mountain, mixed prairie
ADG	Altuda - 60%	Limestone hill and mountain, mixed prairie
BIE	Bissett - 50%	Limestone hill and mountain, desert grassland
BIG	Bissett - 55%	Limestone hill and mountain, desert grassland
BLD	Blackgap - 85%	Limestone hill and mountain, 8-14” PZ
BLE	Blackgap - 50%	Limestone hill and mountain, 8-14” PZ
BLG	Blackgap - 50%	Limestone hill and mountain, 8-14” PZ
CIC	Chilicotal - 70%	Gravelly, desert grassland
CLE	Chilicotal - 60%; Paisano - 25%	Gravelly, desert grassland
CNB	Chillon - 81%	Arroyo, hot desert shrub
COC	Corazones - 85%	Gravelly, hot desert shrub
COE	Corazones - 70%	Gravelly, hot desert shrub
EUB	Equipaje - 45%; Agust 40%	Gravelly, hot desert shrub
GEE	Geefour - 60%	Salty clay hill, hot desert shrub
GEF	Geefour - 70%	Salty clay hill, hot desert shrub
HRE	Hurds - 70%	Foothill slope, mixed prairie
LEE	Leyva - 75%	Igneous hill and mountain, desert grassland
LGG	Lingua - 41%	Igneous hill and mountain, desert grassland
LMF	Liv - 30%; Mainstay - 30%	Igneous hill and mountain, mountain savannah
MCC	Mariscal - 70%	Flagstone hill, 8-14” PZ
MDE	Mariscal - 45%	Flagstone hill, 8-14” PZ
MNE	Mariscal - 45%; Terlingua - 40%	Flagstone hill, 8-14” PZ (Mariscal); Basalt hill, hot desert shrub (Terlingua)
MSE	Musgrave - 92%	Clay hill, hot desert shrub
NNB	Ninepoint - 85%	Loamy, hot desert shrub
NPB	Ninepoint - 85%	Loamy, hot desert shrub
PUF	Puerta - 50%; Madrone - 35%; Lazarus - 3%	Igneous hill and mountain, mountain savannah (Puerta & Madrone); Loamy (Lazarus)
RIA	Pantera - 30%	Arroyo, hot desert shrub
RKG	Brewster - 30%	Igneous hill and mountain, mixed prairie
RTE	Terlingua - 40%	Basalt hill, hot desert shrub
RTG	Terlingua - 25%	Igneous hill and mountain, hot desert shrub
SKE	Solis - 45%	Sandstone hill and mountain, hot desert shrub
SKG	Solis - 50%	Sandstone hill and mountain, hot desert shrub
STC	Strawhouse - 60%; Stillwell - 25%	Gravelly, 8-14” PZ
STE	Strawhouse - 45%; Stillwell - 40%	Gravelly, 8-14” PZ
SUE	Studybutte - 60%	Igneous hill and mountain, hot desert shrub
SUG	Studybutte - 55%	Igneous hill and mountain, hot desert shrub
TOA	Tornillo - 80%	Loamy, hot desert shrub
VCA	Vicente - 40%; Lomapelona - 30%; Castolon - 25%	Loamy bottomland, hot desert shrub

4.21.2 Measures

- Soil texture
- Soil structure
- Organic matter content
- Infiltration
- Soil aggregate stability
- Inorganic nitrogen accumulation
- Percent cover of soil crusts

4.21.3 Reference Conditions/Values

The ideal reference condition for the BIBE soils component is pre-Anglo settlement. However, no information or data on soils are available from this time.

4.21.4 Data and Methods

The primary source of information for this assessment was the Big Bend soil survey (NRCS 2011), released by the NRCS in 2011. The report and associated GIS data provide background information on the park's soils as well as data regarding soil structure, texture, organic matter content, and infiltration. Dunne (1989) provided background information regarding cryptobiotic soil crusts. Patrick et al. (2009) included some soil inorganic nitrogen measurements from the park, gathered during a study of desert plant response to precipitation variability in BIBE's Pine Canyon watershed from 2004-2006.

An earlier soil survey of BIBE was published in 1985 (SCS 1985); however, this survey did not include a portion of the park added in 1990 and soil classifications (soil mapping units) are not directly comparable to the 2011 survey. The earlier survey (SCS 1985) may provide some insight into changes in certain soil characteristics (e.g., organic matter content) over time.

4.21.5 Current Condition and Trend

<u>Soil Structure</u>

Soil structure influences many other soil properties, including permeability, erodibility, and texture, as well as the vegetation that an area can support (NRCS 2011). Soil structure is defined as "the grouping or arrangement of primary particles (sand, silt, clay and organic matter) into larger, secondary particles called aggregates or peds" (CSS 2012). Descriptions of soil structure include three characteristics of these aggregates: grade (distinctness), shape, and size. Soil structure is not necessarily uniform across a soil mapping unit or even

Photo 46. Examples of different soil aggregate shapes (NPS photo).

within a soil series; structure often varies between horizons (depths) of the same soil series. The structures of soil series within BIBE are described in Table 61.

Table 61. Soil structure by soil series, and associated soil map units, in BIBE (NRCS 2011). Structure often varies between horizons within a soil series; in this case, various structures are listed in depth order, with surface horizon structure given first. Structure descriptions are explained in Table 62 - Table 64.

Soil series	Soil map units	Soil structure
Agust	EUB	weak medium granular; weak medium subangular blocky
Altar	AAC	weak fine subangular blocky to weak very fine granular
Altuda	ADE, ADG	moderate medium granular
Bissett	BIE, BIG	weak medium granular
Blackgap	BLD, BLE, BLG	weak fine subangular blocky; weak fine granular
Brewster	RKG	weak medium granular
Castolon	VCA	weak medium platy; weak medium granular
Chilicotal	CIC, CLE	weak fine granular; weak fine subangular blocky; moderate very fine granular; weak very fine granular
Chillon	CNB	weak medium subangular blocky to weak very fine subangular blocky; weak fine subangular blocky to weak fine granular
Corazones	COC, COE	weak medium granular; weak fine granular
Equipaje	EUB	weak medium platy; weak medium and coarse subangular blocky to weak fine and medium subangular blocky
Geefour	GEE, GEF	moderate medium subangular blocky; massive
Hurds	HRE	moderate medium granular; moderate fine granular; moderate medium subangular blocky
Lazarus	PUF	moderate medium subangular blocky to moderate fine granular; strong fine and medium subangular blocky to moderate fine granular and strong very fine and fine subangular blocky
Leyva	LEE	moderate fine and medium subangular blocky to moderate very fine granular; moderate medium subangular blocky to moderate fine subangular blocky
Lingua	LGG	weak fine subangular blocky
Liv	LMF	weak medium granular; moderate fine subangular blocky
Lomapelona	VCA	weak fine granular; single-grain
Madrone	PUF	weak medium granular; weak very fine subangular blocky; moderate medium subangular blocky
Mainstay	LMF	moderate medium subangular blocky; strong medium angular blocky to strong fine angular blocky
Mariscal	MCC, MDE, MNE	moderate fine and medium granular
Musgrave	MSE	moderate fine and medium subangular blocky; massive
Ninepoint	NNB, NPB	moderate medium subangular blocky; strong coarse subangular blocky to strong fine subangular blocky; moderate fine prismatic to moderate fine and medium subangular blocky; weak medium prismatic to weak fine and medium subangular blocky
Paisano	CLE	weak medium granular; moderate medium granular; moderate medium subangular blocky; massive
Pantera	RIA	single-grain
Puerta	PUF	moderate fine granular ;moderate very fine subangular blocky; moderate medium angular blocky
Solis	SKE, SKG	weak medium granular; single-grain
Stillwell	STC, STE	weak fine granular; single-grain; weak fine granular
Strawhouse	STC, STE	weak medium subangular blocky; massive
Studybutte	SUE, SUG	weak medium granular
Terlingua	MNE, RTE, RTG	moderate very fine granular; weak very fine granular
Tornillo	TOA	weak medium granular; moderate medium subangular blocky; weak fine subangular blocky; weak medium subangular blocky
Vicente	VCA	weak medium platy; weak medium granular; single grain; massive

Table 62. Grade or "distinctness" categories of soil aggregates/particles (Cooperative Soil Survey [CSS] 2012).

Grade	Description
Weak	Aggregates are barely observable, fall apart with even slight disturbance
Moderate	Aggregates are well-formed and easily distinguished
Strong	Aggregates are clearly seen and shape is easily identifiable; particles retain their shape when disturbed.

Table 63. Categories for shape/form of soil aggregates/particles (CSS 2012).

Shape	Description
Granular	Generally spherical in shape; aggregates may be easily separable as outside surfaces do not fit well together
Platy	Thin, horizontally oriented particles that look like stacked plates
Angular blocky	Cube-shaped particles with sharp, well-defined edges and distinct faces
Subangular blocky	Cube-shaped particles with somewhat rounded edges
Prismatic	Particles are longer than they are wide, with horizontally flat and angular tops
Single-grain	Particles show little or no tendency to adhere to other particles (e.g., sand in a dune)
Massive	Large cohesive masses, unlikely to break apart under light pressure

Table 64. Soil particle/aggregate size categories by shape (CSS 2012).

Size	Diameter of particles (mm)			
	Angular and subangular blocky	Granular	Platy	Prismatic
Very fine	<5	<1	<1 (very thin)	<10
Fine	5-10	1-2	1-2 (thin)	10-20
Medium	10-20	2-5	2-5	20-50
Coarse	20-50	5-10	5-10 (thick)	50-100
Very coarse	>50	>10	>10 (very thick)	>100

Plate 76 shows that the majority of surface soil horizons in BIBE have a weak structural grade, meaning aggregates are indistinct and fall apart with just slight disturbance (NRCS 2011, CSS 2012). Most surface soils in the park are granular in shape, or granular mixed with another shape (Plate 77) (NRCS 2011). Surface soil aggregates are nearly all fine or medium in size, or a mixture of the two size classes (NRCS 2011). However, the actual size of particles varies by shape (e.g., granular, angular blocky, etc.), as shown in Table 64.

It is difficult to compare soil structure between the two soil surveys of BIBE (1985 and 2011), as different soil series were identified in the two surveys. Of the soil series identified in both surveys, most have identical structures, although two series (Hurds and Liv) classified as granular in 2011 were identified as subangular blocky in the 1985 survey (SCS 1985, NRCS 2011).

Organic Matter Content

Organic matter in the soil consists of decomposing plant and animal material; its content is typically measured as the percent (by weight) of soil material less than 2 mm in diameter (NRCS 2011). Organic matter provides nutrients (e.g., nitrogen) for plants and soil microorganisms, and positively impacts water infiltration, available water capacity, and soil organism activity. The accumulation of organic matter is, in turn, tied to the amount and type of vegetation growing in an ecosystem (NRCS 2011).

NRCS organic matter content data consist of a percentage range rather than a single value. BIBE soils range from low to medium in organic matter content (NRCS 2011). Plate 77 shows that the majority of BIBE soils have an organic matter content of less than 2% (NRCS 2011). Soil units with the highest organic matter content are found along the Rio Grande and in the eastern portion of the park (Plate 78). Organic matter measurements from this most recent soil survey are similar to those from the previous survey (SCS 1985), although no soils with organic matter content above 5% were documented at that time.

Infiltration

Soil infiltration rates can help managers estimate the runoff potential in an area. Soils are classified based on the rate of infiltration when the soil is not protected by vegetation, is thoroughly wet, and experiences long-duration precipitation (NRCS 2011). The classification system consists of four hydrologic soil groups (A-D), described as follows (NRCS 2012):

- Group A - high infiltration rate (low runoff potential),
- Group B - moderate infiltration rate,
- Group C - slow infiltration rate,
- Group D - very slow infiltration rate (high runoff potential).

Less than one-third of BIBE’s soils were classified as showing high or moderate infiltration rates (Groups A and B; Figure 100). In BIBE, several soil units were not classified, perhaps due to the prevalence of impermeable rock outcrops. Over 45% of BIBE soils have slow or very slow infiltration rates, suggesting that a large portion of the park has high runoff potential (Figure 100, Plate 78). During the 1985 soil survey, less than 1% of park soils were classified in Group A, while over 50% were in Group D (SCS 1985).

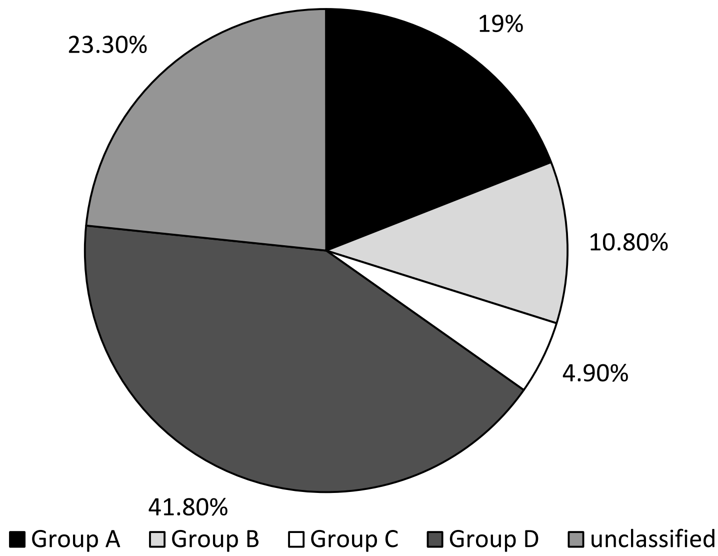

Figure 100. Percent of BIBE soils (by area) by hydrologic group (NRCS 2012). Note that 23% of soil mapping units were not classified.

Soil Aggregate Stability

Soil aggregate stability has been identified as a key indicator of soil health, as it is related to parameters such as soil organic matter, soil biotic activity, infiltration capacity, and erosion resistance (reviewed in Herrick et al. 2001). Despite this, aggregate stability has not been widely used in soil assessments due to cost and sampling limitations (Herrick et al. 2001). Aggregate stability is evaluated by placing soil samples in water for 5 minutes and observing how much or how fast they disintegrate. Ratings range from one to six, as shown below in Table 65. Soil aggregate stability measurements have only been taken in the North Rosillos area of BIBE, where erosion due to past ranching and other land manipulation activities is a particular concern (B. Alex, email communication, 12 September 2012). These data have not yet been published, but will likely be available for future assessments.

Table 65. Criteria used in assigning soil stability classes (adapted from Herrick et al. 2001).

Stability class	Criteria
0	Soil too unstable to sample (falls through a sieve)
1	50% of structural integrity lost within 5 seconds of immersion in water
2	50% of structural integrity lost 5-30 seconds after immersion
3	50% of structural integrity lost 30-300 seconds after immersion, OR <10% of soil remains after 5-minute period
4	10-25% of soil remains after 5-minute period
5	25-75% of soil remains after 5-minute period
6	75-100% of soil remains after 5-minute period

Inorganic Nitrogen Accumulation

Inorganic nitrogen in soils is often the limiting nutrient for plant growth in an ecosystem (Rosswall 1976). The most common forms of inorganic nitrogen in soils are ammonium (NH_4) and nitrate (NO_3). Inorganic nitrogen typically enters the soil through the decomposition of organic matter or nitrogen fixation by soil microorganisms (Rosswall 1976), but may also come from atmospheric deposition. Nitrogen may build up to levels toxic for plants in semiarid grasslands, and could be correlated with bare ground patches or bands in these grasslands (Zak 2006; Bennett, phone communication, 12 September 2012).

Inorganic nitrogen data have only been gathered in small areas of BIBE. Patrick et al. (2009) measured soil nitrate and ammonium levels in the Pine Canyon watershed, where soils are sandy-loamy with little to no litter layer (Aide et al. 2003, as cited in Robertson et al. 2009). Precipitation levels varied during the three sampling years; 2005 was an average year, while 2004 and 2006 were wetter and drier than average, respectively (Patrick et al. 2009). Mean values by year and by season (averaged over all years) are presented in Table 66. Patrick et al. (2009) noted that soil nitrate levels were higher in late summer than in late winter, while soil ammonium levels were much higher during a dry year (2006).

Table 66. Mean soil nitrate (NO_3) and ammonium (NH_4) levels in the Pine Canyon watershed of BIBE by year (along with precipitation levels) and season (Patrick et al. 2009).

	Mean NO_3 (mg/kg of soil)	**Mean NH_4 (mg/kg of soil)**
2004 (wet)	4.06	6.46
2005 (average)	3.79	4.72
2006 (dry)	3.65	18.2
Season		
Winter/Spring	2.50	10.2
Summer/Fall	5.17	9.39

Percent Cover of Soil Crusts

Biological (or cryptobiotic) soil crusts consist of a protective layer of organisms such as lichens and cyanobacteria that grow on the soil surface (Rinas 2009). These crusts are common in arid scrub and grasslands, including the desert grasslands of BIBE. The organisms in the soil crust have the capacity to capture and store water, and can convert atmospheric nitrogen to a form that is usable by plants (Dunne 1989, Rosentretter et al. 2007). They also stabilize soils and can contribute other nutrients such as phosphorus and organic carbon (Dunne 1989). The formation and persistence of biological soil crusts is influenced by soil characteristics (e.g., texture and soil chemistry), climate, competition from plants, and disturbance (animal and human) (Dunne 1989).

Biological soil crusts are extremely fragile and are easily damaged by human activities such as hiking and off-road vehicle use, as well as by livestock grazing (Dunne 1989, Belnap and Eldridge 2001). The soil crusts in BIBE appear to be more durable than most soil crusts (Bennett, pers. communication, 1 November 2013), and may not be as fragile as soil crusts found elsewhere in North America. Nonetheless, the disturbances mentioned above can increase erosion, which causes further damage; when surrounding cryptobiotic soils are covered by wind- or water-borne sediment they are unable to photosynthesize and may die (Belnap and Eldridge 2001). Despite their importance in desert ecosystems, soil crusts have only been studied in a small area of BIBE (North Rosillos) where erosion is a concern (B. Alex, email communication, 12 September 2012). These findings have not been published, but will likely be available through the NRCS for future assessments.

Threats and Stressor Factors

Photo 47. A man-made water diversion at Harte Ranch in BIBE (NPS photo).

Threats to BIBE's soils include erosion (particularly in grasslands), alterations to hydrologic patterns (e.g., roads, water diversions for historic ranching), legacy management activities (e.g., grassland restoration efforts in the 1950s and 60s), atmospheric deposition of nutrients/pollutants, and climate change. Water retaining structures built for ranching prior to park establishment have altered natural hydrological flow patterns in the park (Photo 47; Rinas 2009). These structures can channel water in some areas, increasing the potential for erosion, and prevent water from reaching other areas, reducing the plant cover there. With this loss of cover, rainfall can actually compact the soils, creating a crust which then reduces water infiltration. This further inhibits plant growth and can increase runoff (Rinas 2009).

Atmospheric deposition, especially of nitrogen, can change the levels of nutrients available for plants and microorganisms in the soil. Arid and semi-arid ecosystems, such as those in BIBE, are generally considered to be sensitive to increased levels of nitrogen and sulfur, as acidification and nutrient enrichment can cause shifts in native species composition and encroachment of exotic plant species (Zak 2006, reviewed in Sullivan et al. 2011a and 2011b). Soil crust organisms, particularly lichens, may also be sensitive to atmospheric deposition (Sullivan et al. 2011b). Changes in climatic factors such as temperature, precipitation, evaporation rate, wind, and growing season length can all impact soils. Temperature shifts, for example, can affect the rates of organic matter decomposition, microbial activity, and other vital chemical reactions (NRCS 2011).

Data Needs/Gaps

Inorganic nitrogen accumulation studies within BIBE are limited. Further research is needed to understand the impacts of too much or too little nitrogen on BIBE's soils and plant communities. Data on soil aggregate stability and soil crusts have only been gathered in a small portion of the park (North Rosillos) where erosion is a concern, and have not been published (B. Alex, email communication, 12 September 2012). These data may be available from the NRCS for future assessments. Research into how various activities (e.g., recreation, development) affect BIBE soils and how the different measures discussed here interact specifically within the park could be helpful for park managers.

Overall Condition

Soil Texture

The project team assigned the soil texture measure a *Significance Level* of 1. Data on soil textures within BIBE and their prevalence are presented in Table 67.

Table 67. Percentage of soils in BIBE by soil texture (NRCS 2012).

Texture	% of survey area	Texture	% of survey area
Very gravelly loam	28.4%	Loam	1.0%
Very gravelly sandy loam	17.2%	Silty clay loam	1.0%
Fine sandy loam	10.4%	Very cobbly silt loam	0.5%
Very gravelly sandy clay loam	9.3%	Gravelly sandy loam	0.3%
Very gravelly fine sandy loam	9.1%	Very cobbly loam	0.3%
Silty clay	7.2%	Very gravelly silt loam	0.3%
Extremely channery loam	5.5%	Very gravelly clay loam	0.2%
Clay loam	4.0%	Undefined	1.3%
Bedrock	3.7%		

Soil texture is primarily a concern in areas of the park with fine-grained soils which are susceptible to erosion (Bennett, phone communication, 12 September 2012). In these areas, texture is a high concern, while in the rest of the park it is of low concern. Therefore, across the park as a whole, soil texture is of moderate concern (*Condition Level* = 2).

Soil Structure

Soil structure was assigned a *Significance Level* of 3. Soil structure is important, particularly given its influence on other properties such as texture and permeability. As with soil texture, soil structure is a high concern in areas with weak, fine soils with little stability, typically found in the park's lowlands (Bennett, phone communication, 12 September 2012). Since soil structure is a low concern in other portions of the park, the *Condition Level* for the park overall is a 2.

Organic Matter Content

The organic matter content measure was assigned a *Significance Level* of 2. Organic matter content is low (<2%) in most of the park. This can limit nutrient availability for plants and soil microbial activity and impact water infiltration and storage capacity. The *Condition Level* for this measure in BIBE is a 2, indicating moderate concern.

Infiltration

The project team assigned this measure a *Significance Level* of 2. Water infiltration of soils is important for providing plants with moisture and preventing runoff and erosion. A high percentage of BIBE's soils show slow or very slow infiltration rates, indicating high potentials for runoff. Therefore, infiltration is a moderate concern for the park (*Condition Level* = 2).

Soil Aggregate Stability

Soil aggregate stability was assigned a *Significance Level* of 3. Some data has been gathered for this measure in an area of the park where erosion is a particular concern, but this data has not been published. Therefore, a *Condition Level* could not be assigned for the park as a whole.

Inorganic Nitrogen Accumulation

This measure was assigned a *Significance Level* of 2. Soil nitrogen data for the park are very limited. Researchers are still studying soil nitrogen dynamics in the ecosystem and how these impact plant communities. Because of this, a *Condition Level* was not assigned for this measure.

Percent Cover of Soil Crusts
The project team assigned this measure a *Significance Level* of 3. While soil crusts are an important element of arid ecosystems, they have only been studied in a small area of BIBE. Therefore, a *Condition Level* for the park as a whole could not be assigned.

Weighted Condition Score
A *Weighted Condition Score* was not calculated for BIBE soils, as *Condition Levels* could not be assigned for three measures (two of which had high *Significance Levels*). Considering the measures with known *Condition Levels*, the overall condition is likely on the cusp between moderate and high concern. Furthermore, soils as a whole difficult to assign a single condition to, as the surface soils and the deep, fine-grained soils likely differ in condition. Jeffery Bennett indicates that the most of the soils in BIBE are likely in good condition, but the deep soils in the park are likely in poor condition (some more than others), and that none of the soils have recovered completely from the historic grazing practices in the park (pers. communication, 1 November 2013). However, due to data gaps, the current condition and trend for soils across BIBE is considered unknown.

Soils

Measures	SL	CL
• Soil texture	1	2
• Soil structure	3	2
• Organic matter content	2	2
• Infiltration	2	2
• Soil aggregate stability	3	n/a
• Inorganic N accumulation	2	n/a
• % cover of soil crusts	3	n/a

WCS = N/A

4.21.6 Sources of Expertise
Betty Alex, BIBE GIS Specialist

Jeffery Bennett, BIBE Physical Scientist

Joe Sirotnak, BIBE Botanist/Ecologist

4.21.7 Literature Cited

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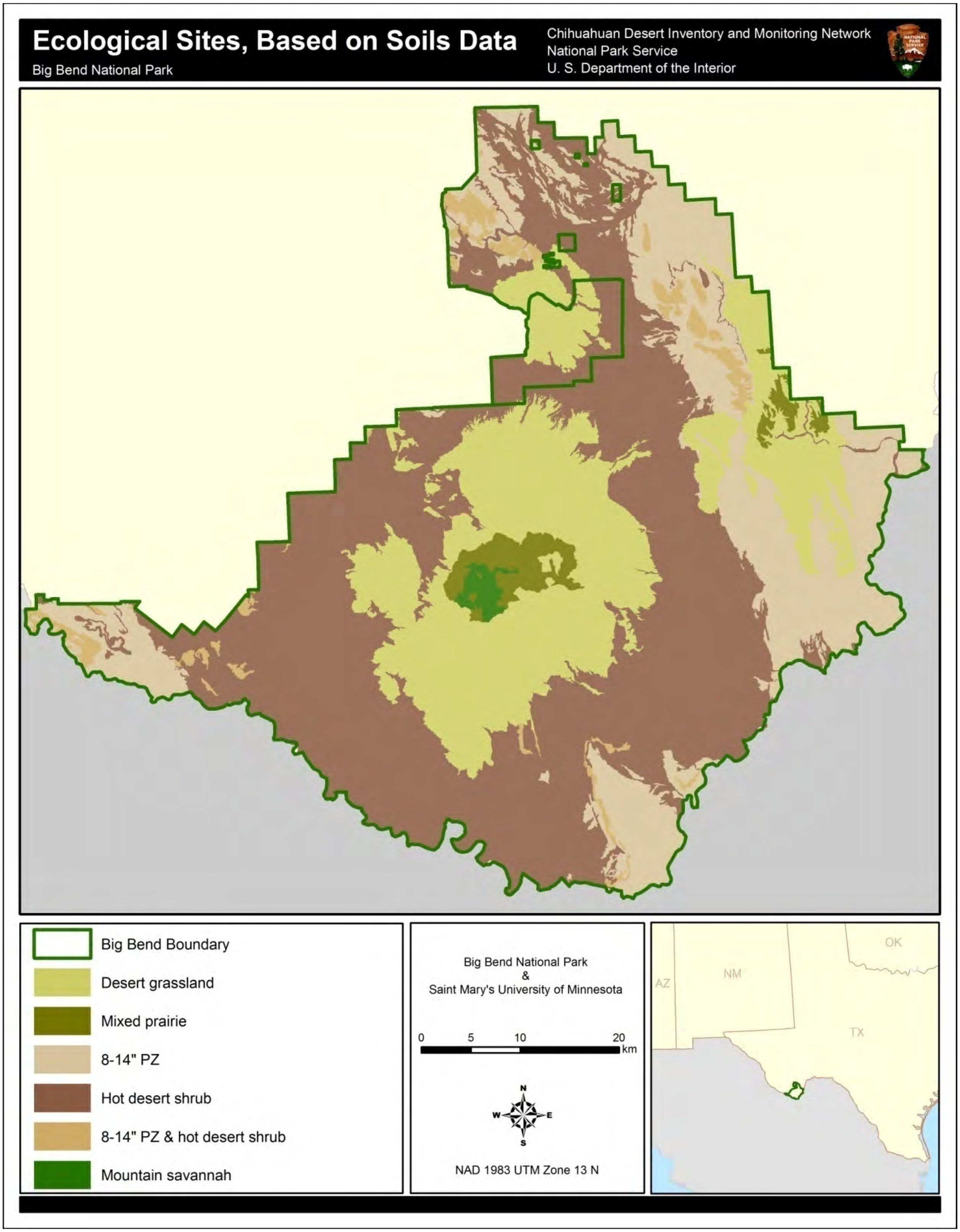


Plate 75. Ecological sites, as determined by NRCS soil map unit correlations (NRCS 2011). PZ = precipitation zone.

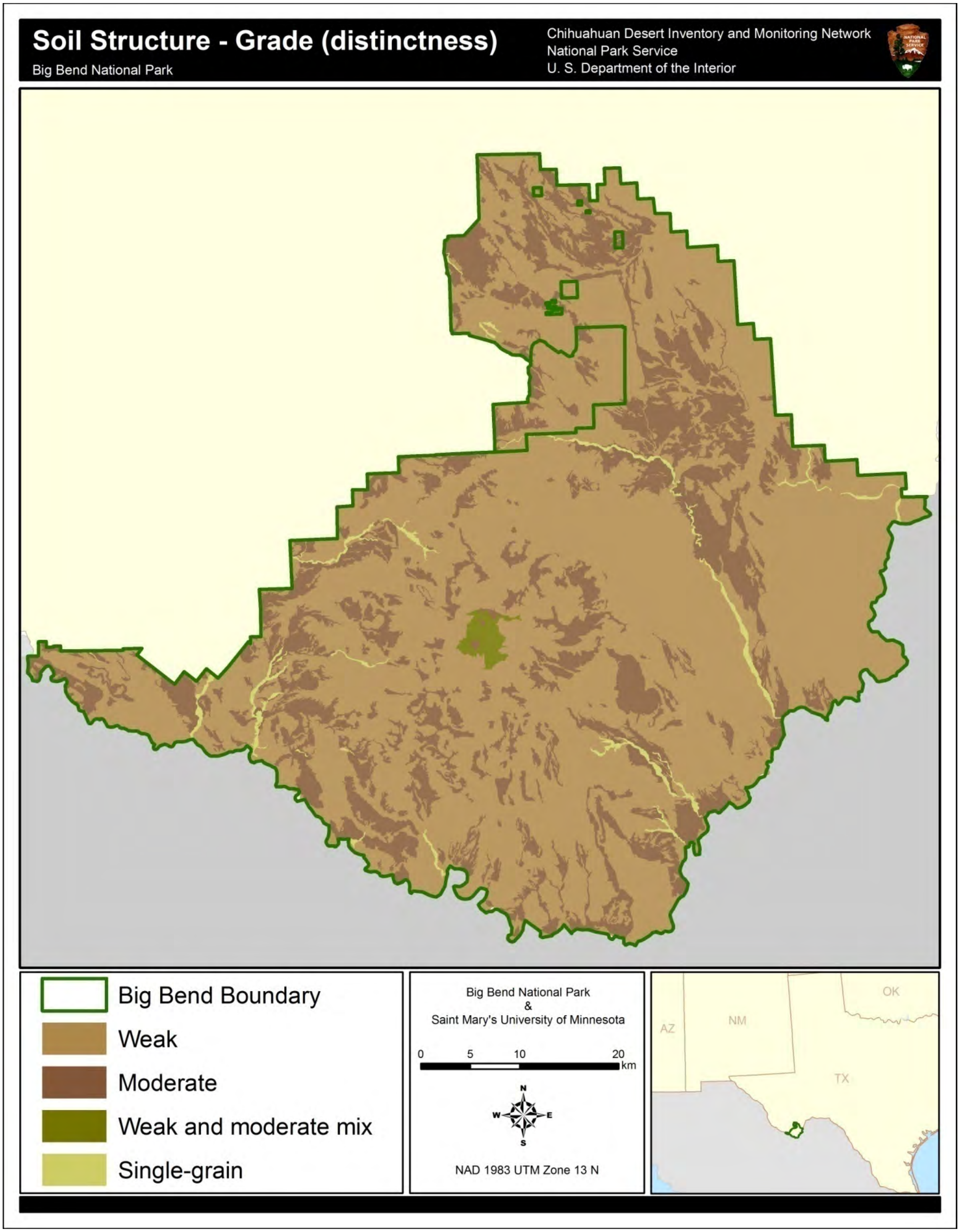


Plate 76. Grade of surface soils (A horizon) in Big Bend National Park (NRCS 2011).

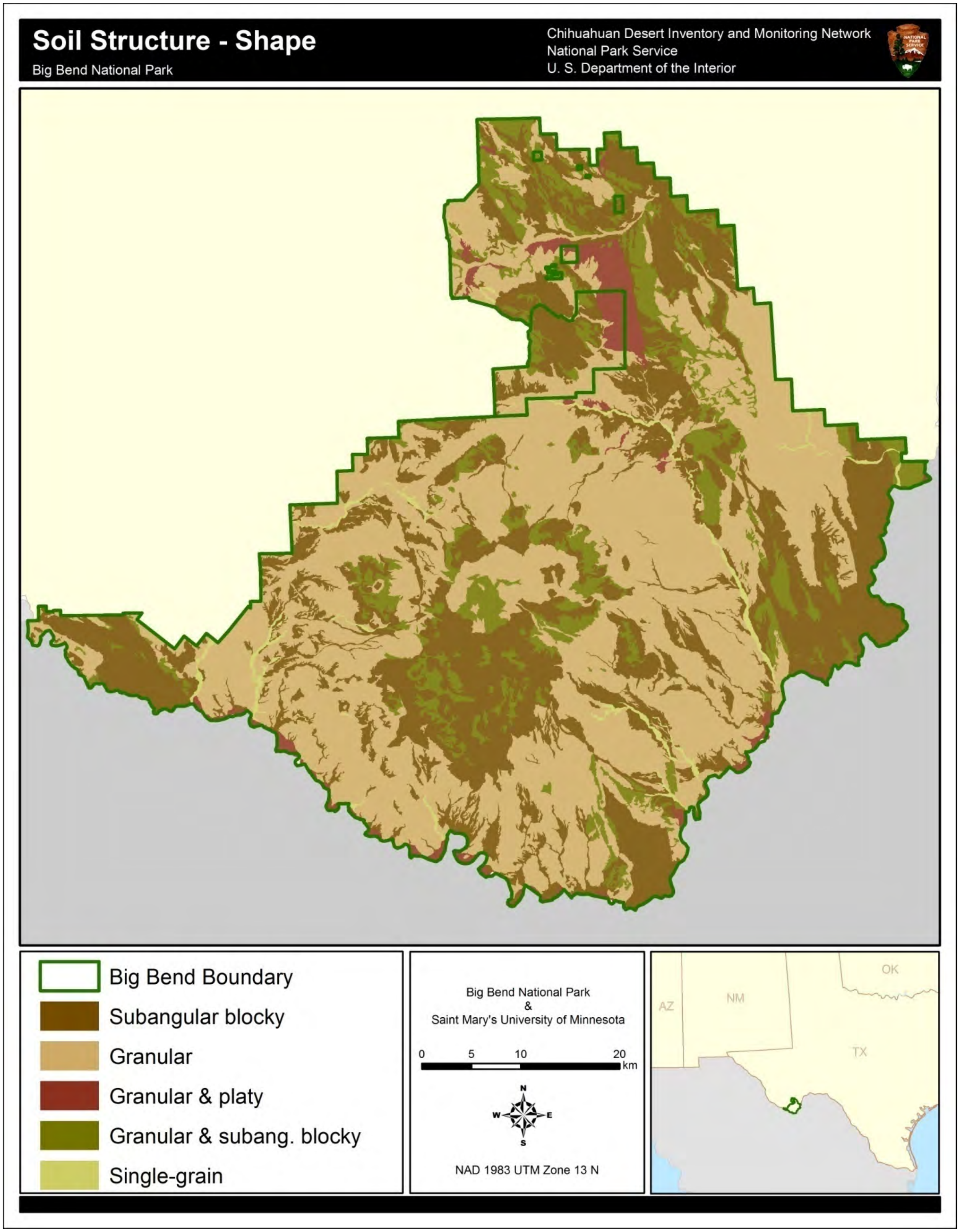


Plate 77. Shape of aggregates in surface soils (A horizon) in Big Bend National Park (NRCS 2011).

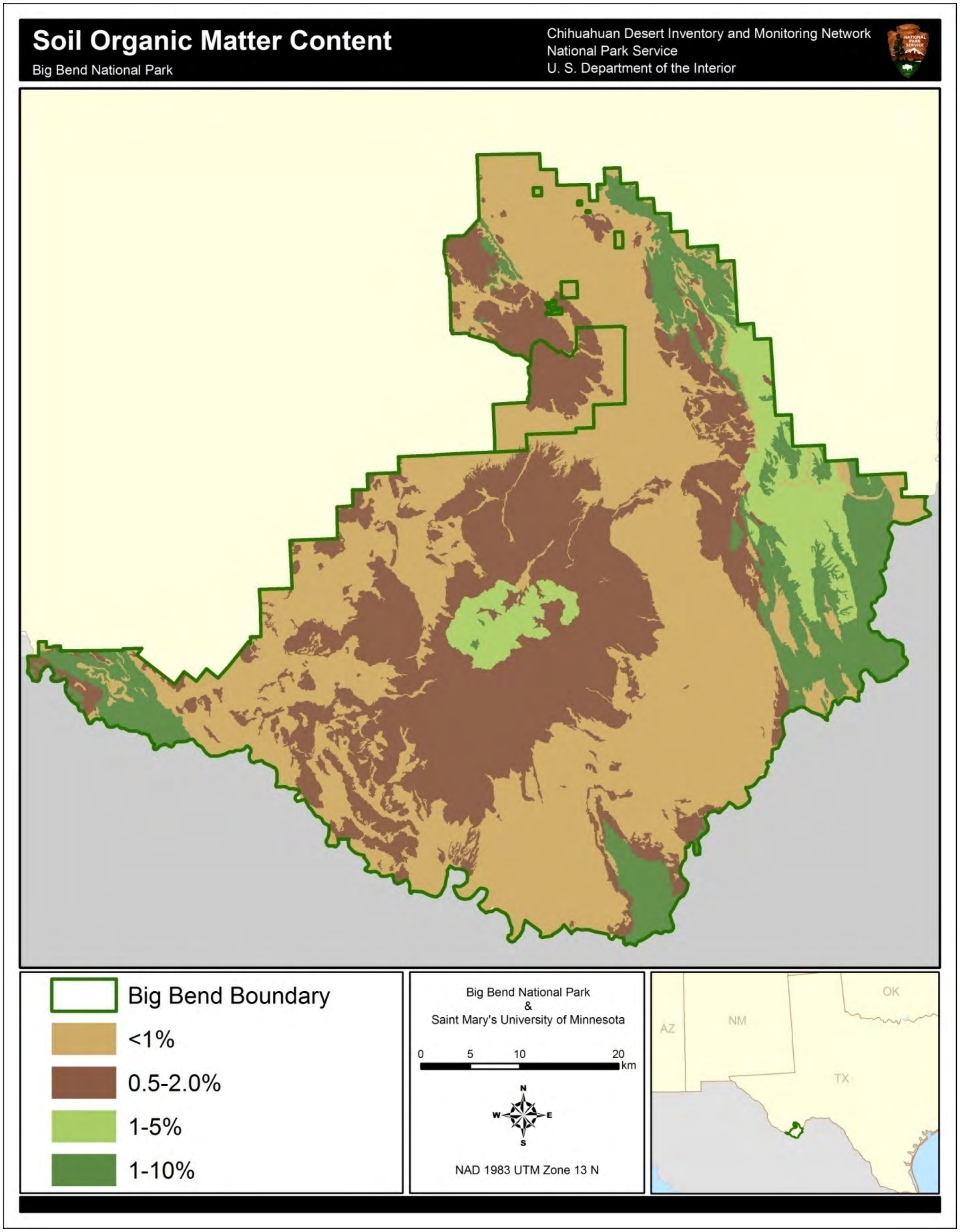


Plate 78. Organic matter content of Big Bend National Park soils (NRCS 2011). NRCS organic matter content data consists of a percentage range rather than a single value. These ranges were further grouped into the four categories above by SMUMN GSS analysts.

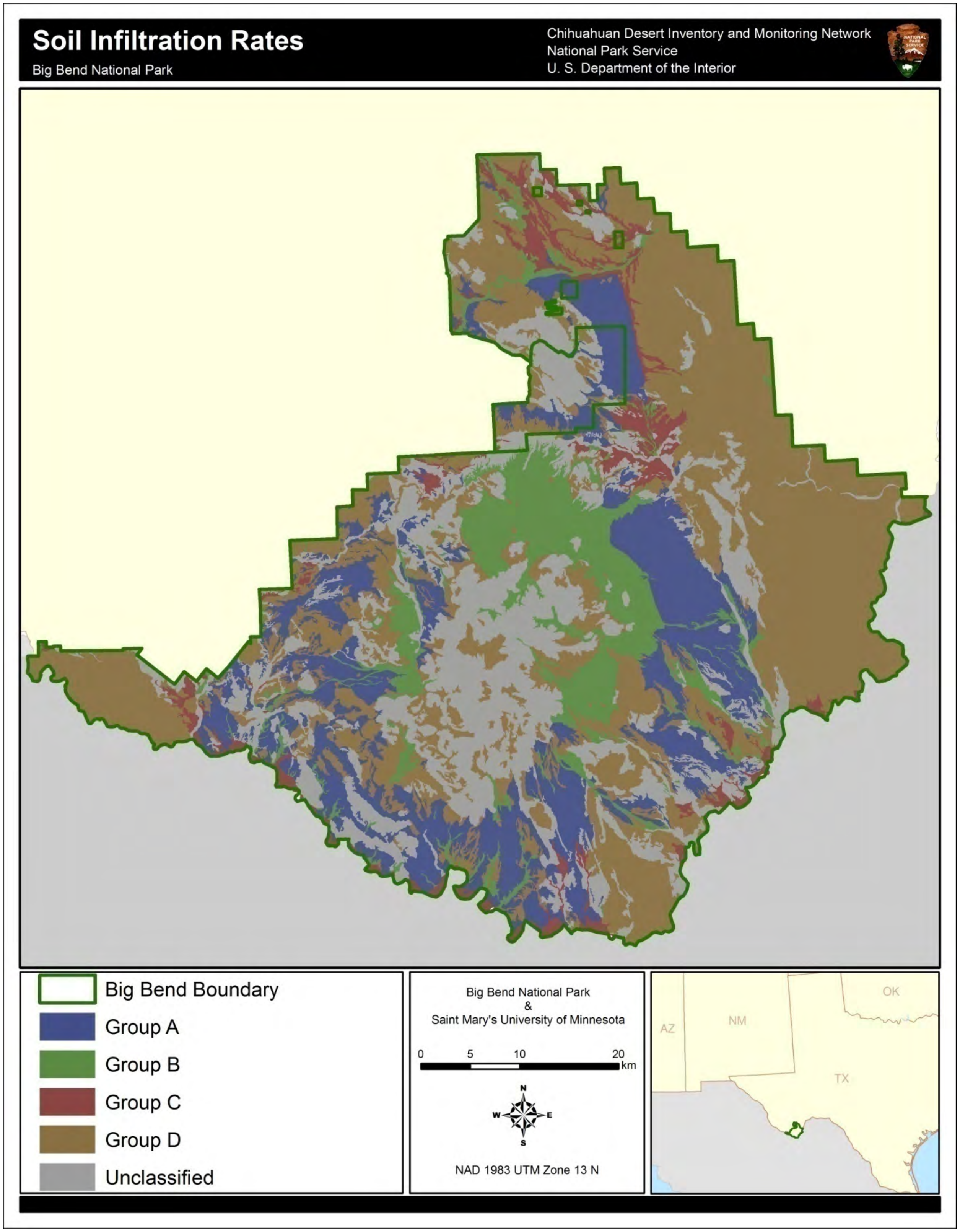


Plate 79. Soil hydrologic groups (a measure of infiltration) in Big Bend National Park (NRCS 2012). Group A = high infiltration rate, B = moderate, C = slow, and D = very slow.

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 68 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 68. Identified data gaps or needs for the featured components in BIBE.

Component	Data Gaps/Needs
Fire Regime	➢ Completion of the vegetation mapping project that is currently underway, and continued monitoring of fire effects in the Chihuahuan Desert Borderlands ➢ Additional reports, such as the Muldavin et al. (2010) effort, are needed to report the results of ongoing monitoring efforts ➢ Updated fire occurrence GIS datasets are needed, as well as an estimate of spatial accuracy of fire occurrence points ➢Additional research is needed to understand how the timing of burns may affect vegetation structure and composition in BIBE, particularly in regards to the seasonality of prescribed fires and non-fire fuel treatments
Spring Habitats	➢ Little research has been done on small, isolated, often ephemeral springs in general. A better understanding of the processes, patterns, and ecological interactions at these sites would help managers in maintaining these areas and assessing their condition ➢ Little information exists that relates spring data to season, precipitation, or any other environmental factors or variables that may influence the amount of water that may be available. ➢ Additional aquatic invertebrate data, consistent and comparable vegetation surveys, and continued groundwater level monitoring are needed
Montane Forests/Sky Islands	➢ Completion of the planned vegetation mapping project, currently scheduled by the NPS I & M Program is needed ➢ A better understanding and inventory of the remote lower Chisos region (Sierra Quamada) is needed ➢ Continuation of the dormant Sensitive Plant Project would help to survey the thousands of un surveyed acres in the Chisos Mountains ➢ No studies have documented the distribution, abundance, or habitat availability of the Carmen white-tailed deer since 1974 (Krausman and Ables [1981] survey) ➢ More data are needed to evaluate acorn woodpecker abundance within the park
Desert Grasslands	➢ An updated vegetation map for BIBE is needed to analyze current desert grasslands characteristics in the park. The current vegetation map does not cover the northern portion of the park. Data has been collected for an updated vegetation map, but the project will not be completed until at least 2015 ➢ Further research is needed regarding the distribution and impacts of invasive species in the park
Rio Grande Riparian Community	➢ More information is needed regarding the Rio Grande's stream flow (e.g., sources, timing and duration of high/low flows, rate of downstream attenuation). Specifically, attention should be given to how much water the Luis Leon Dam must release to meet downstream environmental flow requirements ➢ No comprehensive vegetation map exists for the BIBE reach of the Rio Grande; completion of the LiDAR analysis (estimated in 2014) should help provide estimates of exotic plant coverage along the Rio Grande ➢Little is known about the influence of exotic plant species (e.g., saltcedar, giant cane) on stream flow, groundwater, and water quality in the Rio Grande Watershed ➢ Further study of the Rio Grande's sedimentation processes are needed

Table 68. Identified data gaps or needs for the featured components in BIBE (continued).

Component	Data Gaps/Needs
Birds	➢ Repetition of the Gutzwiller and Barrow (2001) survey is needed to allow for more accurate comparisons in presence/absence, density, abundance, and species-wide trends ➢ Creation of a standardized black-capped vireo survey protocol would allow for more accurate year-to-year comparisons of the population in the park ➢ Grassland bird monitoring should continue, and additional winter grassland bird surveys would help managers to understand the health of overwintering grassland species ➢ Expanded monitoring of the peregrine falcon population, especially in regards to contaminants analyses, may be vital for managers to better understand the productivity of the park's population
Black Bears	➢ The establishment of a population monitoring protocol is needed; currently the population is only monitored via visitor sightings reporting and analysis program, and, several automated wildlife cameras in the Chisos Basin ➢ Examining trends in observations during high visitor usage and determining estimates of family groups in the park are a few of the potential projects that could expand knowledge of bears in BIBE
Mountain Lions	➢ While a park-wide count of mountain lions as well as death records and immigration/emigration data would be useful, the feasibility and cost-effectiveness of these tasks make them unlikely ➢ No lions are currently radio-collared in the park. Collar monitoring data could help predict denning periods, track dispersal ranges, and identify areas of high visitor use. ➢ As is suggested in Ruth (1991), a species protection plan would help to maintain genetic variability, as the need for genetic research is evident
Desert Bighorn Sheep	➢ Studies of desert bighorn sheep in the park are lacking, and little is known regarding home range sizes and sheep density. Future population surveys are needed to detect potential fluctuations due to social dominance or the spread of disease from Barbary sheep
Bats	➢ Continued monitoring at Emory Cave is needed to develop a further understanding of the Mexican long-nosed bat ➢ Future studies that incorporate surveys of flowering phenology of food plants, cave censuses, assessments of sex and age structure, and genetic composition are necessary to better understand the migratory habits of the Mexican long-nosed bat and the role that Emory Cave plays for this species
Aquatic Macroinvertebrates	➢ No microinvertebrate data exist for either the Rio Grande or the Rio Conchos prior to the first dam construction. Furthermore, very few baseline data exist for macroinvertebrates in the tributaries and springs of the Rio Grande ➢ Many datasets for this component were reduced to two metrics; study consistency and established inter-study "rules" could greatly help in the understanding of macroinvertebrates and the condition of their aquatic habitats
Fish	➢ There is a lack of replicated fish sampling along the BIBE reach of the Rio Grande, which makes comparisons of species composition and abundance difficult over time
Amphibians	➢ A complete amphibian survey is needed in BIBE; Dayton et al. (2004) only investigated the habitat association of four species in the park. Furthermore, several areas of the park have not been surveyed and the amphibian abundance/diversity in those areas are unknown
Reptiles	➢ No annual monitoring of reptiles occurs in BIBE. Long-term reptile monitoring would provide park managers with better information regarding species abundance, diversity, and distribution over time

Table 68. Identified data gaps or needs for the featured components in BIBE (continued).

Component	Data Gaps/Needs
Air Quality	➢ Since plant communities in BIBE are likely sensitive to increases in nitrogen, park managers may be able to develop and implement a critical load approach for monitoring and assessing damage from air pollutants, and to set goals for resource protection within the park ➢ No consistent monitoring that tracks the plant and animal species known to be sensitive to increases in certain pollutants exists in BIBE.
Water Quality	➢ The greatest data gap for water quality is the shortage of comparable historic and recent data in the park. Many data are now outdated, and are the result of short-term, intermittent sampling efforts ➢ Additional years of monitoring data from the IBWC 18441 station are needed (currently ongoing)
Soundscape	➢ Limited soundscape data has been collected in the park. Soundscape monitoring in the park is needed to identify baseline levels of natural and human-caused sounds.
Viewscape	➢ Updated photos from all of the Integral Vista photo locations (using the same view angles, distances, and directions) would provide a data source that stretches back to 1980. ➢ Additional Integral Vista locations on Route 13 looking towards Terlingua Ranch, as well as the viewsheds stretching towards San Vicente, Mexico are needed.
Dark Night Skies	➢ A draft plan for natural lightscape management in the park, including discussion of zoning the park area to indicate where outdoor lighting is required and where the naturally dark zones occur, would greatly benefit park managers/researchers ➢ Continued monitoring of the entire sky brightness by the NPS NST should occur every 5 years at Emory Peak
Hydrology/Spring Hydrology	➢ Further research is needed regarding the Rio Grande's stream flow, specifically in regards to high flow events ➢ Research into how much water upstream dams would have to release to meet downstream environmental flow requirements is needed ➢ Data concerning spring discharge variation, in regards to season, precipitation, and other environmental factors are needed ➢ An investigation into the threat of hazardous coliform bacteria levels and their potential impacts on park resources and visitors would be helpful for park managers
Soils	➢ Further research is needed to understand the impacts of too much or too little nitrogen on BIBE's soil and plant communities ➢ Research into how various activities (e.g., recreation, development) affect BIBE's soils is needed

Many of the park's data needs involve the establishment of an annual monitoring program, as some of the park's components have either outdated data or no data at all. Several of the components analyzed in this report had outdated data, and did not have data that facilitated long-term trend analyses.

Fire was the only disturbance regime analyzed in this assessment. The completion of the ongoing vegetation mapping project currently underway is needed for managers to have a better understanding of the current vegetative classes and their locations in the park. Furthermore, the fire GIS data sets are in need of an update, especially regarding the accuracy of fire occurrence points. As controlled burn practices continue in the park, additional research is needed to understand how the timing of the burns affects the vegetative structure in the park.

The ecological communities discussed in this assessment included spring habitats, montane forests/sky islands, desert grasslands, and the Rio Grande riparian community. All of these communities would benefit from an updated vegetation map for the park; the current vegetation map does not cover the northern portion of the park, and little is known regarding the extent of the grasslands in this area. There are instances of complete data gaps in each of these communities, and the establishment of annual or baseline monitoring of these gaps would greatly improve the knowledge of these diverse ecosystems.

Nearly all of the wildlife components discussed in this document are in need of established, annual surveys that document various population parameters. The charismatic large mammal species (black bear, mountain lion, and desert bighorn sheep) are understudied, and much of the data that exists comes from visitor sightings reports or anecdotal information. The other wildlife components discussed in this document face similar data gaps, as very few have annual monitoring programs in place; the notable exception is birds, which are monitored annually during CHDN monitoring and during the park's annual CBC and BBS. While monitoring does exist for birds in the park, expansion of the monitoring to the winter months for grasslands, and standardization of the black-capped vireo surveys are needed.

The data gaps for the environmental quality-related components varied across the resources. Air quality and dark night skies had excellent data sources, and were in need of additional monitoring in the future to track potential trends. The development of a critical load approach for the air quality monitoring in the park would improve the quality and robustness of that component's data. After being recognized by the IDA as a Gold Tier Dark Sky Park, it will be important for park managers to stay current in dark night sky data collection. Viewscape also had a good amount of data available, although updated photos from all of the Integral Vista locations (using the same orientation) are needed. The water quality component is in need of comparable historic and recent data in the park, and additional monitoring at the IBWC 18441 station. The soundscape component is lacking data, and soundscape monitoring protocols are needed in the future.

The geologic and hydrologic components for BIBE (hydrology/spring hydrology, soils) had several data gaps. Further research is needed regarding the Rio Grande's stream flow, specifically in regards to high flow events. Data are also needed that relate to spring discharge variation, water releases from upstream dams, and coliform bacteria in the water sources in the park. For the park's soils, further research is needed to understand the impacts of nitrogen on the community, and how various activities affect the soil structure and composition.

5.2 Component Condition Designations

The conditions assigned to each resource component presented in Chapter 4 are presented in Table 69 (definitions of condition graphics are located in Figure 101 following Table 69). It is important to remember that the graphics represent simple symbols for the overall condition and trend assigned to each component. Because the condition of a component (as represented by the symbols in Table 69) is based on a number of factors and an analysis of multiple literature and data sources, it is strongly recommended that the reader refer back to each specific component assessment in Chapter 4 for a detailed explanation and justification of the assigned condition. Condition designations for some components are supported by existing datasets and monitoring information and/or the expertise of NPS staff, while other components lack historic data, a clear understanding of reference conditions (i.e., what is considered desirable or natural), or even current information.

Table 69. Summary of current condition and condition trend for featured NRCA components. Higher Weighted Condition Scores indicate higher concern. See Figure 101 for symbol and color legends.

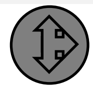
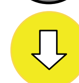
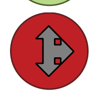
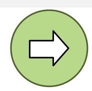
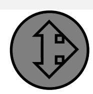
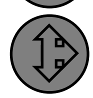
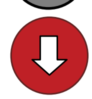
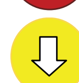
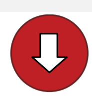
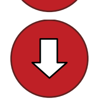
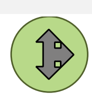
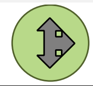
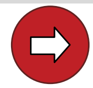
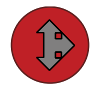
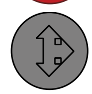
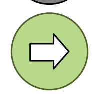
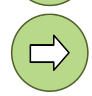
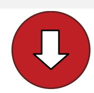
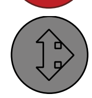
Component	WCS	Condition
Ecosystem Extent and Function		
Disturbance Regimes		
Fire	0.667	
Biological Composition		
Ecological communities		
Spring Habitats	N/A	
Montane Forests/Sky Islands	0.458	
Desert Grasslands	0.333	
Rio Grande Riparian Community	0.833	
Birds		
Birds	0.222	
Mammals		
Black Bear	N/A	
Mountain Lion	N/A	
Desert Bighorn Sheep	1.000	
Bats	0.380	
Aquatics		
Macroinvertebrates	0.667	
Fish	0.667	
Herptiles		
Amphibians	0.333	

Table 69. Summary of current condition and condition trend for featured NRCA components. Higher Weighted Condition Scores indicate higher concern (continued).

Component	WCS	Condition
Herptiles		
Reptiles	0.200	
Environmental Quality		
Air quality	0.694	
Water quality	0.933	
Soundscape	N/A	
Viewscape	0.333	
Dark night skies	0.000	
Ecosystem Extent and Function		
Geologic & Hydrologic and		
Hydrology/Spring Hydrology	1.000	
Soils	N/A	

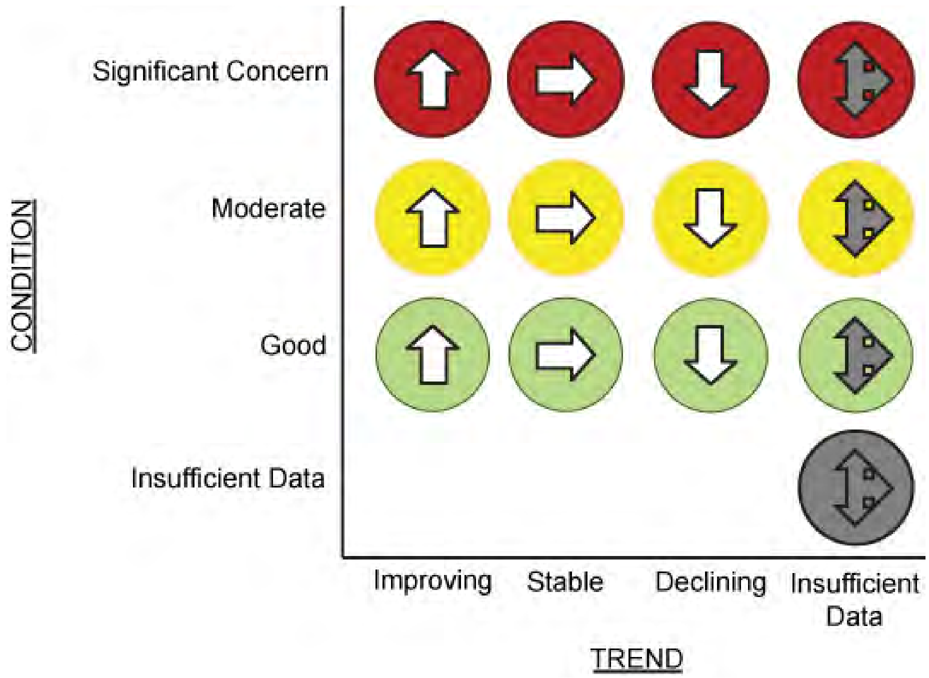


Figure 101. Symbols used for individual component assessments with condition or concern designations along the vertical axis and trend designations along the horizontal.

For featured components with available data and fewer data gaps, assigned conditions varied. Six components were considered to be of low concern: desert grasslands, birds, amphibians, reptiles, viewscape, and dark night skies. Only two components (montane forests/sky islands and bats) were of moderate concern. Eight components were deemed to be of high concern: fire, Rio Grande riparian community, desert bighorn sheep, macroinvertebrates, fish, air quality, water quality, and soils. Of those components of high concern, fire, Rio Grande riparian community, and water quality did not have enough detailed information to assess a current trend. Air quality was the only component of significant concern to exhibit a stable trend, while desert bighorn sheep, macroinvertebrates, and fish exhibited declining trends.

5.3 Park-wide Condition Observations

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

5.3.1 Disturbance Regimes

The park's fire regime has the potential to affect nearly every component in this document. A trend could not be assigned to this component during analysis, but the current condition of the fire regime was deemed to be of high concern. Much of FMU #3 has not burned in over 50 years, which is well over the fire return intervals reported historically for the park. Furthermore, the dry climate and high fuel loads put several areas at risk as temperatures warm under climate change scenarios. With the potential to dramatically affect many of the vegetative and ecological communities in the FMU, fire is a component of this NRCA that is likely to influence many of the resources discussed in this document.

5.3.2 Ecological Communities

The ecological communities of BIBE are vital resources for the park, providing habitat for wildlife and performing critical ecological functions, while attracting many visitors to the area. These ecosystems and communities showcase the tremendous diversity that is found in the park, as each of these communities occupies a unique niche and location in the park, and are home to several species endemic to that ecotype. The ecological communities vary greatly between different elevations and different soil types of the park. As different as these ecosystems are, they share several similar threats, most notably invasive species and climate change.

The current condition of the native vegetative and ecological communities varied as greatly as the flora and fauna found in these ecosystems; all four communities were assigned a different condition. The montane forests/sky islands component was determined to be of moderate concern. This component's vast diversity is seen in the selected measures, as amphibian, mammal, bird, and plant species' abundance all factored in to the overall condition assessment. This was the only vegetative community component of the four that had enough data to assess a current trend (declining). This declining trend is primarily attributed to recent hard freezes in the winter and droughts in the summer (threats that are affecting all of the native vegetation communities in the park). The declining trend also represents the increasing concern managers have regarding the health of this community, as this area of the park has high vulnerability to stand-replacing fires. Further complicating the health of this community are the current mortality events of the Mexican pinyon and other tree species (Larson, written communication, 1 November 2013).

Despite threats from climate change and invasive species, the desert grasslands in the park are currently of low concern, although baseline data to assess a current trend are not available and the tobosa grasslands are in danger of being lost (Bennett, written communication, 1 November 2013). The Rio Grande riparian community has a very unique and variable composition and range as the Rio Grande travels through the park; this variability exposes the ecosystem to several threats and stressors that have taken their toll on this unique community. Identified as one of the world's 10 most at-risk rivers (Wong et al. 2007), the Rio Grande community is impacted by invasive species, altered flow regimes, channel narrowing, and many other external threats. Currently, the condition of this component is deemed to be of high concern.

5.3.3 Other Biotics

Several animal species were featured as components in this NRCA, including: birds, black bears, mountain lions, desert bighorn sheep, bats, macroinvertebrates, fish, amphibians, and reptiles. As a whole, birds had the widest distribution of the animal species discussed in this report, and occupied almost all habitat zones of the park. Birds act as excellent indicator species, and the condition designation of low concern is encouraging to managers. However, habitat alterations (both local and along migratory routes) continue to affect the park's population.

The large, charismatic mammalian species discussed in this report (black bears, mountain lions, and desert bighorn sheep), all have limited, but very specific, ranges in the park. Unlike the black bears and desert bighorn sheep, mountain lions face hunting pressure when they range outside of the park (there is no closed season for mountain lions in Texas). This has resulted in an isolated lion population with limited migration into BIBE. Due to a lack of data necessary for condition assessment, the condition and trend could not be determined for black bears and mountain lions.

Although no condition was assessed, the populations of these two species are very limited in the park and are likely sustainable; managers do not believe there to be any immediate threat of extirpation in the park. Desert bighorn sheep were determined to be of high concern, with a declining recent trend. The bighorns present in the park are the result of a reintroduction effort in the areas surrounding BIBE, and the current population in the park is likely very small (five individuals were counted in 2011). Unlike the other mammalian species discussed, the primary threat to this species is not habitat-related, but rather related to the presence of non-native species; Barbary sheep often outcompete desert bighorn sheep, and domestic sheep transfer infectious diseases to desert bighorns.

The only other mammalian species that were discussed were the park's bats. Over half of all bat species in the United States exist in the BIBE area, and the bat population in BIBE represents a critically important ecosystem indicator. Emory Cave serves as the primary roosting location for bats in the park, and recent fluctuations in roosting colony sizes in early July are potentially cause for concern, leading to this component being assigned a condition of moderate concern.

The aquatic components of this NRCA (macroinvertebrates and fish) are both of considerable concern to managers, and have been exhibiting declining trends as of late. Both components were assigned the same WCS (which was borderline moderate to significant concern), and park managers felt that these components should be designated as significant concern. As is obvious by the WCS designation, these two components are closely interrelated; the health of both groups is tied to the health of the water resources in the park, and the macroinvertebrate community acts as an important food source for the park's fish population.

Herptiles in the park were found to be of similar condition, as both components were assigned a condition of low concern with unknown trends. BIBE is home to a unique assemblage of amphibians, as only 3% of anuran species worldwide exist in desert ecosystems (Dayton et al. 2004). Both of these groups are very sensitive to changes in habitat type and quality, particularly in regards to water availability; the permeability of amphibian skin also makes them excellent indicators of ecosystem changes. Amphibians require water at all life stages, and reptiles in the park respond positively to wet seasons as their food base increases. Like many of the components in BIBE, climate change and human activity are major threats for these groups in the future.

5.3.4 Environmental Quality

Environmental quality is important in maintaining healthy functioning ecosystems. The health of terrestrial and aquatic organisms in parks can be substantially affected by the condition of air and water quality. The park's air quality is currently of significant concern with a stable trend. Nitrogen deposition represents one of the major issues facing the park's air quality, although the deposition of mercury and sulfur are also of concern. The water quality in the park is of high concern, although a trend could not be assigned at this time. While water quality may vary in the park depending on the sampling location (especially as you move downstream on the Rio Grande), almost all of the measures reported for this component were of significant concern. Water quality directly affects many of the resources in the park, particularly the macroinvertebrate community.

Very limited soundscape monitoring has taken place in BIBE and a condition was not assigned to this component. Park managers indicate that BIBE is relatively free of non-natural sounds, apart from the occasional vehicle, generator, or aircraft noise. The park's viewscape is currently of low concern, with little land use change (e.g., conversion for developments) occurring within the park or in areas outside of park boundaries that are visible from within the park.

BIBE's dark night skies are nearly pristine, and the park has been classified as a Gold Tier International Dark Sky Park by the IDA; only three national park units have been classified as Gold Tier parks, and BIBE has the darkest recorded night skies of those three parks. Accordingly, this component was assigned a condition of low concern with a stable trend.

Like many of the components discussed in this document, the primary threats for the environmental quality-related components come from human-related sources. Pollution is having a significant impact on the park's air quality, despite the park's remote west Texas location, and water quality is impacted by communities in both the United States and Mexico. Runoff, impoundments, diversion, and industrial activity along the banks of the Rio Grande are likely to continue to degrade the quality of the river's water. Soundscape can only be marred by the presence of non-natural sounds (i.e., human-caused), and with continued visitation and development the soundscape of the park is likely to be threatened. The dark night skies of the park are threatened most by non-natural lighting, often exterior lighting on buildings and residences. While BIBE has retro-fitted most of the exterior lighting in the Chisos Basin, there is still light trespass from the nearby communities of Study Butte and Terlingua, as well as from within BIBE.

5.3.5 Overall Conclusions

BIBE is an extremely diverse park, supporting a range of unique features, from the low land desert grasslands, to the isolated sky islands high in the Chisos Mountains. The park is also home to a great variety of wildlife, some of which are endemic to BIBE (e.g., Big Bend gambusia). As unique and diverse as the park is, nearly all of the components discussed in this document are linked, either through food web connectivity or through a common threat or stressor.

This assessment serves as a review and summary of available data and literature for featured natural resources in the park. The information presented here may serve as a baseline against which any changes in condition of components in the future may be compared. Current condition could not be determined for many components due to data gaps; several of these needs are being addressed by recently implemented CHDN monitoring programs, which will provide valuable information for condition assessment in the near future. For resources where condition could be assessed, there was a divide between significant concern and low concern (only three components were of moderate concern). Understanding the condition of these resources can help managers prioritize management objectives and better focus conservation strategies to maintain the health and integrity of these ecosystems.

5.4 Literature Cited

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Appendices

Appendix A. Assigned fuel models and canopy characteristics as determined by NPS staff (John Morlock, Richard Gatewood, Joe Sirotnak, and Betty Alex) in 2004 for BIBE.

Vegetation Type(s)	FPBS Fuel Model	Canopy Cover (percent)	Tree Height (feet)	Estimated conditions for torching and Assigned CBH (in feet)
Closed Canopy Woodland	2	70%	19	Eyelevel winds > 8mphFine Dead Fuel Moisture <5% Live fuel moisture < 100% Slope > 25% CBH calculated using NEXUS = 14.4
High Desert Grassland	2	NA	NA	NA
Lechuguillia Scrub	2	NA	NA	NA
Riverine Riparian	3	NA	NA	NA
Scrub Woodland	6	5	15	Eyelevel winds > 8mph Fine Dead Fuel Moisture <5% Live fuel moisture < 100% Slope > 25% CBH calculated using NEXUS = 18.5
Upland Riparian	8	50	7	Eyelevel winds > 10mph Fine Dead Fuel Moisture <4% CBH calculated using NEXUS = 1.5
Creosote Scrub	99	NA	NA	NA

Appendix B. Explanatory variables used for mapping fuel characteristics in Big Bend National Park and the Maderas del Carmen Protected Area. Reproduced from Table 1 in Poulos (2009).

Variable code	Definition
Landscape metric	
Elevation	Elevation (m), from 30 m digital elevation model (DEM)
North aspect	Cosine transformation of aspect (degrees) (Beers et al. 1966) 1.0 north to –1.0 south
East aspect	Sine transformation of aspect (degrees) (Beers et al. 1966) 1.0 west to –1.0 east
Slope	Slope (degrees) from the 30 m DEM
PRR	Cumulative potential relative radiation based on hourly solar position, topography, and topographic shading (Pierce et al. 2005)
Topopos 150	Topographic position, calculated as the difference between a cell's elevation (m) and the mean elevation of cells within a 150 m radius
Topopos 450	Topographic position, calculated as the difference between a cell's elevation (m) and the mean elevation of cells within a 450 m radius
Topo configuration	Topographic configuration ranging from concave to convex calculated using the spatial analyst function in ArcMap version 9.1
Downslope elevation	Downslope elevation change, calculated as the difference between a cell's elevation (m) and the lowest elevation
Downslope neighbors	Number of cells in a roving 3 _ 3 window that have a lower elevation than the center cell; a measure of slope concavity or convexity
Sediment transport	Sediment transport capacity index (Burrough and McDonnell 1998)
Network index	Minimum wetness index value encountered along a flowpath (Lane et al. 2004)
Vegetation type	Vegetation maps for Big Bend National Park and the Maderas del Carmen Protected Area (Poulos 2007)
Landsat ETM+	
Band 1	Band 1 (blue, 0.45–0.52 mm)
Band 2	Band 2 (green, 0.53–0.61 mm)
Band 3	Band 3 (red, 0.63–0.69 mm)
Band 4	Band 4 (near-infrared, 0.78–0.90 mm)
Band 5	Band 5 (midinfrared, 1.55–1.75 mm)
Band 7	Band 7 (midinfrared, 2.09–2.35 mm)
EVI	Enhanced vegetation index (Liu and Huete 1995)
Brightness	Soil brightness index from tasseled cap transformation
Greenness	Green vegetation index from tasseled cap transformation
Wetness	Wetness index from tasseled cap transformation

Appendix C. Mean summary statistics for fuel models derived from the cluster analysis of fuel characteristics for sample plots (n=200) for BIBE. Adapted from Table 2 in Poulos (2009).

Fuel Type	**1**	**2**	**3**	**4**
Fine woody debris				
Shrub loading (kg ha $^{-1}$)	10,557.1	588.9	2,597.3	1,184.6
Forb loading (kg ha^{-1})	2.1	23.0	16.3	0.0
Grass loading (kg ha^{-1})	442.0	3721.4	1213.0	0.0
Litter depth (cm)	0.0	0.0	0.3	2.8
Litter loading (kg ha^{-1})	2,225.6	1440.4	2,741.6	7,251.2
Duff depth (cm)	0.0	0.0	0.4	8.8
Duff Loading	1367.4	1506.2	5,444.6	33,205.6
Coarse woody debris				
1-hr	2,582.4	183.7	801.2	1,860.6
10-hr	3,77.5	293.9	995.1	4,359.4
100-hr	3,64.9	276.6	762.8	1,624.5
1000-hr	739.4	314.3	3,814.7	3,002.6
Logs ha-^{1}	20.9	17.9	117.6	58.7
Volume (m2 ha^{-1})	9.4	4.0	48.5	38.3
Basal area (m^2 ha^{-1})				
Live	9.7	6.3	21.4	11.2
Standing dead	0.9	0.2	5.5	1.2
Crown bulk density (kg m^{-3})	0.72	0.076	0.088	0.088
Standing dead trees ha^{-1}				
5-10 cm	6.5	1.2	9.3	10.7
11-15 cm	12.5	2.1	14.9	18.4
16-20 cm	15.6	4.3	23.3	13.8
21-25 cm	10.1	1.4	17.3	4.1
26-30 cm	15.2	0.0	11.1	0.0
31-35 cm	3.3	0.0	5.8	5.7
>35 cm	0.0	0.0	0.0	5.4
Live trees ha^{-1}				
0-5 cm	472.5	669.7	3,491.3	569.0
6-10 cm	161.2	105.3	363.6	157.6
11-15 cm	151.7	82.3	274.2	209.4
16-20 cm	103.4	49.4	230.9	137.1
21-25 cm	72.5	31.6	156.4	116.0
26-30 cm	47.4	27.0	81.0	106.0
31-35 cm	24.2	21.4	49.4	74.0
>35 cm	8.2	16.0	37.2	15.2

Appendix D. Mean environmental and spectral characteristics of each fuel model type identified via cluster analysis. Reproduced from Table 3 in Poulos (2009). Means reported here include sites in the Maderas del Carmen Protected Area (MCPA) in Mexico.

Variable	**Fuel Type**			
	1	**2**	**3**	**4**
Elevation (m)	2097.3	2021.6	1967.6	2087.6
Slope (º)	19.09	20.15	18.21	20.60
North aspect	0.15	0.00	-0.04	0.24
East aspect	0.04	-0.03	0.11	0.04
Convexity	0.81	0.25	0.22	-0.70
Downslope neighbors	2.98	6.56	2.87	3.41
Downslope elevation	7.4	11.04	6.59	11.9
Sediment transport	14.49	14.78	10.48	19.29
Network index	5.82	4.56	5.90	4.49
PRR	18529	18228	17902	17616
Relative elevation	97.51	96.01	97.74	96.36
Shade relief	0.48	0.49	0.50	0.48
Topographic position 450m	17.64	3.13	-2.39	-19.15
Topographic position 150 m	-2.35	-1.89	0.41	3.38
Wetness Index	6.36	6.16	6.57	6.16
Band 1	62.6	68.7	68.7	53.1
Band 2	79.0	78.3	76.9	65.7
Band 3	59.4	97.1	91.7	81.7
Band 4	160.8	150.0	150.9	153.5
Band 5	18.1	16.8	18.9	14.9
Band 7	4.4	4.6	4.6	3.9
Brightness	117.7	116.5	110.7	105.1
Greenness	160.1	140.6	157.6	166.5
Wetness	132.9	128.8	131.7	135.8

Appendix E. Mean fuel characteristics for BIBE. Adapted from Table 4 in Poulos (2009).

Fuel characteristic	**BIBE**
Shrub loading (kg ha $^{-1}$)	3112.2
Forb loading (kg ha^{-1})	14.5
Grass loading (kg ha^{-1})	1709.4
Litter depth (cm)	0.2
Litter loading (kg ha^{-1})	6443.5
Duff depth (cm)	0.4
Duff loading	11124.6
1-hr	1006.5
10-hr	1013.0
100-hr	640.1
1000-hr	2249.0
Crown bulk density (kg m^{-3})	0.082
Logs ha-^{1}	232.7
Volume (m2 ha^{-1})	27.8
Basal area (m^{2} ha^{-1})	
Live	15.8
Standing dead	2.6
Standing dead trees ha^{-1}	
5-10 cm	15.0
11-15 cm	24.8
16-20 cm	26.2
21-25 cm	17.3
26-30 cm	12.2
31-35 cm	8.7
>35 cm	25.4
Live trees ha^{-1}	
0-5 cm	1401.3
6-10 cm	240.1
11-15 cm	259.3
16-20 cm	193.6
21-25 cm	140.6
26-30 cm	104.6
31-35 cm	52.8
>35 cm	85.9

Appendix F. Plant list for spring communities in BIBE. An * indicates exotic species (adapted from Bartel 2002). CLAR = Claro 2 Spring, DESE = Desert Spring, GRIG = Grigsby Spring, and SERE = Serendipity Spring.

Scientific Name	Common Name	CLAR	DESE	GRIG	SERE
Abutilon wrightii	Wright's abutilon	x			
Acacia constricta	whitethorn acacia			x	
Acacia greggii	catclaw acacia				
Adiantum capillus-veneris	maidenhair fern	x			x
Argyrochosma microphylla	small-leaf false cloak fern	x			
Aloysia gratissima	whitebrush			x	
Andropogon glomeratus	bushy bluestem	x	x		
Aristida purpurea	purple threeawn			x	
Aristida ternipes	spidergrass	x			
Artemisia dracunculus	tarragon			x	
Artemisia ludoviciana	white sagebrush			x	
Astragalus emoryanus	Emory's milkvetch			x	
Astragalus mollissimus	wooly locoweed			x	
Astrolepis integerrima	hybrid cloakfern			x	
Baccharis salicifolia	seepwillow, mule-fat			x	
Baccharis salicina	willow baccharis	x	x	x	x
Bahia absinthifolia	hairyseed bahia			x	
Boerhavia linearifolia	narrowleaf spiderling				
Bothriochloa barbinodis	cane bluestem				
Bothriochloa laguroides	silver beardgrass	x		x	
Bouchea spathulata	spoonleaf	x			
Bouteloua curtipendula	sideoats grama			x	
Brickellia laciniata	splitleaf brickelbush	x			
Calibrachoa parviflora	seaside petunia		x		
Carex microdonta	littletooth sedge	x			
Centaurium arizonicum	Arizona centaury	x	x		x
Cerastium axillare	Trans-Pecos chickweed			x	
Cheilanthes alabamensis	Alabama lipfern	x			
Cheilanthes eatonii	Eaton's lipfern			x	
Chromolaena bigelovii	Bigelow's thoroughwort	x			
Cirsium undulatum	wavyleaf thistle	x			
Cladium mariscus	swamp sawgrass	x			
Commelina erecta	erect dayflower			x	
Condalia viridis	green condalia				x
Corydalis curvisiliqua	Curvepod fumewort			x	
*Cynodon dactylon**	Bermudagrass		x		
Cyperus elegans	sticky flatsedge				
Cyperus laevigatus	smooth flatsedge		x		
Cyperus odoratus	fragrant flatsedge		x		

Scientific Name	Common Name	CLAR	DESE	GRIG	SERE
Dalea frutescens	black dalea			x	
Dalea pogonathera	bearded dalea				
Descurainia pinnata	Western tansymustard			x	
Diospyros texana	Texas persimmon			x	
Draba cuneifolia	wedgeleaf draba			x	
*Echinochloa crus-galli**	barnyardgrass				
Eleocharis geniculata	Canada spikesedge		x		
Eleocharis palustris	common spikerush				
Eleocharis rostellata	beaked spikerush	x			
Epipactis gigantea	stream orchid				
Eragrostis intermedia	plains lovegrass	x		x	
Erigeron modestus	plains fleabane	x			
Eriogonum jamesii	James' wild buckwheat			x	
Eriogonum tenellum	tall wild buckwheat			x	
Euphorbia dentata	toothed spurge	x			
Eysenhardtia texana	Texas kidneywood	x			
Fallugia paradoxa	Apache plume			x	
Fraxinus cuspidata	fragrant ash				
Fraxinus greggii	Gregg's ash			x	
Froelichia arizonica	Arizona snakecotton			x	
Fuirena simplex	western umbrella-sedge	x	x		
Funastrum torreyi	soft twinevine			x	
Gaura coccinea	scarlet gaura			x	
Glandularia quadrangulata	beaked mock vervain			x	
Gutierrezia sarothrae	broom snakeweed			x	
Gymnosperma glutinosum	gumhead	x			
Hedeoma nana	dwarf false pennyroyal			x	
Helenium elegans	pretty sneezeweed	x			
Heliomeris longifolia	longleaf false goldeneye	x			
Heliotropium curassavicum	seaside heliotrope		x		
Hesperidanthus linearifolius	slimleaf plainsmustard			x	
Heteropogon contortus	tanglehead	x			
Heterotheca fulcrata	rockyscree false goldaster			x	
Hymenoclea monogyra	singlewhorl burrobrush			x	
Imperata brevifolia	satintail				
Ipomoea costellata	crestrib morning-glory	x			
Isocoma pluriflora	southern goldenbush		x		
Janusia gracilis	slender janusia	x			
Juncus interior	inland rush	x			
Juncus nodosus	knotted rush	x	x		
Juncus scirpoides	needlepod rush		x		
Juncus tenuis	slender rush		x		

Scientific Name	Common Name	CLAR	DESE	GRIG	SERE
Juncus torreyi	Torrey rush				
Lappula occidentalis	flatspine stickseed			x	
Larrea tridentata	creosotebush		x		x
Lepidium lasiocarpum	shaggyfruit pepperweed			x	
Leptochloa dubia	green sprangletop	x			
Lesquerella purpurea	rose bladderpod			x	
Linum rupestre	rock flax	x			
Lobelia berlandieri	Berlandier's lobelia	x			
Lobelia cardinalis	cardinal flower	x			
Lythrum californicum	California loosestrife	x			
Machaeranthera pinnatifida var. *chihuahuana*	Chihuahuan tansyaster			x	
Machaeranthera tanacetifolia	Tahoka-daisy				
Marrubium vulgare	horehound			x	
Matelea producta	Texas milkvine			x	
Maurandella antirrhiniflora	roving sailor			x	
Mecardonia procumbens	baby jump-up	x			
Mimulus guttatus	seep monkeyflower	x	x		
Mirabilis sp.	four o'clock sp.			x	
Mortonia sempervirens	Rio Grande saddlebush				
Morus microphylla	Texas mulberry			x	
Muhlenbergia polycaulis	cliff muhly	x			
Muhlenbergia rigens	deergrass	x			
Muhlenbergia tenuifolia	mesa muhly	x			
Muhlenbergia utilis	aparejograss				
Nama sp.	fiddleleaf			x	
Nasturtium officinale	watercress				
Notholaena standleyi	star cloak fern			x	
Nothoscordum bivalve	crow-poison	x			
Nuttallanthus texanus	Texas toadflax			x	
Oenothera brachycarpa	shortfruit evening primrose			x	
Oenothera kunthiana	Kunth's evening primrose	x			
Oligomeris linifolia	lineleaf whitepuff		x		
Panicum hirticaule	roughstalk witchgrass				
Panicum lanuginosum	Mexican panicgrass	x			
Parietaria pensylvanica	Pennsylvania pellitory			x	
Parthenium confertum	Gray's feverfew	x			
Paspalum pubiflorum	hairyseed paspalum				
Pellaea ovata	ovateleaf cliffbrake			x	
Penstemon havardii	Big Bend penstemon	x			
Perityle vaseyi	Vasey's rockdaisy				
Phacelia congesta	blue curls			x	

Scientific Name	Common Name	CLAR	DESE	GRIG	SERE
Phaseolus pedicellatus	Sonoran bean			x	
Poa bigelovii	Bigelow bluegrass			x	
Polygala alba	white milkwort	x			
*Polypogon monspeliensis**	rabbitfoot grass		x		x
*Polypogon viridis**	beardless rabbitsfoot grass	x			
Populus fremontii	Fremont's cottonwood	x			
Porophyllum scoparium	shrubby poreleaf			x	
Prosopis glandulosa	honey mesquite		x		x
Quercus pungens	pungent oak			x	
Ribes aureum	golden currant				
Salazaria mexicana	bladdersage				
Salix nigra	black willow	x		x	
Samolus ebracteatus	limewater brookweed	x			x
Scutellaria potosina var. *tessellata*	Mexican skullcap	x			
Setaria grisebachii	Grisebach bristlegrass	x		x	
Setaria leucopila	plains bristlegrass			x	
Setaria parviflora	knotroot bristlegrass	x			
Silene laciniata	cardinal catchfly				
*Sorghum halepense**	Johnsongrass				
Sphaeralcea angustifolia	narrowleaf globemallow				
Sporobolus airoides	alkali sacaton				x
Stenaria nigricans	diamondflowers	x		x	
Tetraneuris scaposa	stemmy four-nerve daisy			x	
Thelesperma megapotamicum	green threads			x	
Thymophylla pentachaeta	fiveneedle pricklyleaf	x		x	
Toxicodendron radicans	poison ivy	x			
Tradescantia brevifolia	Trans-Pecos spiderwort	x			
Tragia amblyodonta	dog-tooth noseburn			x	
Trichloris crinita	false Rhodes grass		x		
Tripsacum dactyloides	eastern gamagrass				
Trixis californica	American trixis			x	
Typha domingensis	southern cattail	x	x		
Verbesina encelioides	golden crownbeard				
Vicia ludoviciana	deerpea vetch			x	
Vitis arizonica	canyon grape			x	
Vulpia octoflora	sixweeks fescue			x	
*Xanthium strumarium**	cocklebur		x		

Appendix G. Rotifer species identified in the Walsh et al. (2005) survey.

Taxa	(continued)
Adineta vaga	*Lecane hamata*
Anuraeopsis fissa	*Lecane inermis*
Aspelta imbuta	*Lecane lateralis*
Brachionus bidentatus	*Lecane luna*
Brachionus dimidiatus	*Lecane papuana*
Brachionus urceolaris	*Lecane perpusilla*
Cephalodella catellina	*Lecane pyriformis*
Cephalodella compacta	*Lecane rudescui*
Cephalodella doryphora	*Lecane tenuiseta*
Cephalodella forficula	*Lecane thalera*
Cephalodella gibba	*Lepadella ovalis*
Cephalodella gracilis	*Lepadella patella*
Cephalodella cf. mira	*Lepadella pumilo*
Cephalodella sterea	*Lindia anebodica*
Cephalodella tenuiseta	*Macrochaetus sericus*
Cephalodella vacuna	*Monommata arndti*
Cephalodella vitella	*Monommata enedra*
Collotheca coronetta	*Mytilina mucronata*
Collotheca gracilipes	*Philodina megalotrocha*
Collotheca ornata	*Plationus patulus*
Collotheca cf. paradoxa	*Platyias quadricornis*
Colurella colurus compressa	*Polyarthra dolichoptera*
Colurella obtusa	*Proales daphnicola*
Colurella uncinata	*Ptygura brevis*
Dicranophorus haueri	*Ptygura crystallina*
Dipleuchlanis elegans	*Ptygura longicornis*
Epiphanes senta	*Squatinella mutica*
Euchlanis dilatata	*Trichocerca collaris*
Euchlanis lyra	*Trichocerca marina*
Euchlanis triquetra	*Trichocerca similis*
Filinia longiseta	*Trichocerca tenuidens*
Filinia cf. novaezealandiae	*Wierzejskiella vagneri*
Itura viridis	
Lecane cf. abanica	
Lecane bifurca	
Lecane bulla	
Lecane closterocerca	
Lecane furcata	

Appendix H. NPS Certified Bird Species List for Big Bend National Park (NPS 2011). Birds are listed in taxonomic order per the most current Check-list of North American Birds (AOU 1998) and the Fifty-third Supplement to the American Ornithologists' Union Check-List of North American Birds (AOU 2012).

Common Name	Scientific Name	Occurance	Status
Ducks, Geese and Swans (Anatidae)			
Black-bellied Whistling-Duck	*Dendrocygna autumnalis*	Occasional	Vagrant
Greater White-fronted Goose	*Anser albifrons*	Occasional	Vagrant
Snow Goose	*Chen caerulescens*	Uncommon	Resident
Ross's Goose	*Chen rossii*	Rare	Resident
Canada Goose	*Branta canadensis*	Rare	Resident
Tundra Swan	*Cygnus columbianus*	Rare	Resident
Wood Duck	*Aix sponsa*	Uncommon	Resident
Gadwall	*Anas strepera*	Common	Resident
American Wigeon	*Anas americana*	Common	Resident
Mallard	*Anas platyrhynchos*	Uncommon	Resident
Blue-winged Teal	*Anas discors*	Common	Resident
Cinnamon Teal	*Anas cyanoptera*	Common	Resident
Northern Shoveler	*Anas clypeata*	Common	Resident
Northern Pintail	*Anas acuta*	Uncommon	Resident
Green-winged Teal	*Anas crecca*	Common	Resident
Canvasback	*Aythya valisineria*	Occasional	Resident
Redhead	*Aythya americana*	Rare	Resident
Ring-necked Duck	*Aythya collaris*	Common	Resident
Lesser Scaup	*Aythya affinis*	Uncommon	Resident
Bufflehead	*Bucephala albeola*	Common	Resident
Common Goldeneye	*Bucephala clangula*	Rare	Resident
Hooded Merganser	*Lophodytes cucullatus*	Rare	Resident
Common Merganser	*Mergus merganser*	Rare	Resident
Red-breasted Merganser	*Mergus serrator*	Occasional	Resident
Ruddy Duck	*Oxyura jamaicensis*	Rare	Resident
New World Quail (Odontophoridae)			
Scaled Quail	*Callipepla squamata*	Common	Breeder
Gambel's Quail	*Callipepla gambelii*	Rare	Unknown
Montezuma Quail	*Cyrtonyx montezumae*	Rare	Breeder
Patridges, Grouse, Turkeys and Old World Quail (Phasianidae)			
Wild Turkey	*Meleagris gallopavo*	Rare	Resident
Loons (Gaviidae)			
Common Loon	*Gavia immer*	Occasional	Resident
Grebes (Podicipedidae)			
Least Grebe	*Tachybaptus dominicus*	Rare	Resident
Pied-billed Grebe	*Podilymbus podiceps*	Common	Breeder

Common Name	Scientific Name	Occurance	Status
Eared Grebe	*Podiceps nigricollis*	Rare	Resident
Cormorants (Phalacrocoracidae)			
Neotropic Cormorant	*Phalacrocorax brasilianus*	Rare	Vagrant
Double-crested Cormorant	*Phalacrocorax auritus*	Rare	Resident
Darters (Anhingidae)			
Anhinga	*Anhinga anhinga*	Occasional	Vagrant
Pelicans (Pelecanidae)			
American White Pelican	*Pelecanus erythrorhynchos*	Rare	Migratory
Brown Pelican	*Pelecanus occidentalis*	Rare	Vagrant
Bitterns, Herons and Allies (Ardeidae)			
American Bittern	*Botaurus lentiginosus*	Uncommon	Resident
Least Bittern	*Ixobrychus exilis*	Rare	Migratory
Great Blue Heron	*Ardea herodias*	Common	Breeder
Great Egret	*Ardea alba*	Uncommon	Migratory
Snowy Egret	*Egretta thula*	Uncommon	Migratory
Little Blue Heron	*Egretta caerulea*	Rare	Migratory
Tricolored Heron	*Egretta tricolor*	Rare	Migratory
Reddish Egret	*Egretta rufescens*	Occasional	Vagrant
Cattle Egret	*Bubulcus ibis*	Common	Migratory
Green Heron	*Butorides virescens*	Common	Breeder
Black-crowned Night-Heron	*Nycticorax nycticorax*	Uncommon	Breeder
Yellow-crowned Night-Heron	*Nyctanassa violacea*	Rare	Migratory
Ibises and Spoonbills (Threskiornithidae)			
White Ibis	*Eudocimus albus*	Rare	Vagrant
White-faced Ibis	*Plegadis chihi*	Common	Migratory
Roseate Spoonbill	*Platalea ajaja*	Occasional	Vagrant
New World Vultures (Cathartidae)			
Black Vulture	*Coragyps atratus*	Common	Breeder
Turkey Vulture	*Cathartes aura*	Abundant	Breeder
Ospreys (Pandionidae)			
Osprey	*Pandion haliaetus*	Uncommon	Migratory
Hawks, Kites, Eagles and Allies (Accipitridae)			
Swallow-tailed Kite	*Elanoides forficatus*	Occasional	Migratory
White-tailed Kite	*Elanus leucurus*	Occasional	Migratory
Mississippi Kite	*Ictinia mississippiensis*	Uncommon	Migratory
Bald Eagle	*Haliaeetus leucocephalus*	Occasional	Vagrant
Northern Harrier	*Circus cyaneus*	Uncommon	Resident
Sharp-shinned Hawk	*Accipiter striatus*	Uncommon	Resident
Cooper's Hawk	*Accipiter cooperii*	Common	Breeder
Northern Goshawk	*Accipiter gentilis*	Occasional	Vagrant

Common Name	Scientific Name	Occurance	Status
Common Black-Hawk	*Buteogallus anthracinus*	Rare	Breeder
Harris's Hawk	*Parabuteo unicinctus*	Uncommon	Breeder
Red-shouldered Hawk	*Buteo lineatus*	Rare	Breeder
Broad-winged Hawk	*Buteo platypterus*	Rare	Migratory
Gray Hawk	*Buteo plagiatus*	Uncommon	Breeder
Short-tailed Hawk	*Buteo brachyurus*	Occasional	Vagrant
Swainson's Hawk	*Buteo swainsoni*	Uncommon	Migratory
White-tailed Hawk	*Buteo albicaudatus*	Occasional	Vagrant
Zone-tailed Hawk	*Buteo albonotatus*	Common	Breeder
Red-tailed Hawk	*Buteo jamaicensis*	Abundant	Breeder
Ferruginous Hawk	*Buteo regalis*	Uncommon	Resident
Rough-legged Hawk	*Buteo lagopus*	Rare	Resident
Golden Eagle	*Aquila chrysaetos*	Rare	Breeder
Rails, Gallinules and Coots (Rallidae)			
Yellow Rail	*Coturnicops noveboracensis*	Occasional	Vagrant
King Rail	*Rallus elegans*	Occasional	Vagrant
Virginia Rail	*Rallus limicola*	Uncommon	Migratory
Sora	*Porzana carolina*	Common	Resident
Purple Gallinule	*Porphyrio martinicus*	Occasional	Migratory
Common Gallinule	*Gallinula galeata*	Rare	Migratory
American Coot	*Fulica americana*	Common	Breeder
Cranes (Gruidae)			
Sandhill Crane	*Grus canadensis*	Uncommon	Migratory
Stilts and Avocets (Recurvirostridae)			
Black-necked Stilt	*Himantopus mexicanus*	Uncommon	Migratory
American Avocet	*Recurvirostra americana*	Uncommon	Migratory
Lapwings and Plovers (Charadriidae)			
Killdeer	*Charadrius vociferus*	Common	Breeder
Sandpipers, Phalaropes and Allies (Scolopacidae)			
Spotted Sandpiper	*Actitis macularius*	Common	Resident
Solitary Sandpiper	*Tringa solitaria*	Uncommon	Migratory
Greater Yellowlegs	*Tringa melanoleuca*	Uncommon	Migratory
Willet	*Tringa semipalmata*	Rare	Migratory
Lesser Yellowlegs	*Tringa flavipes*	Rare	Migratory
Upland Sandpiper	*Bartramia longicauda*	Rare	Migratory
Whimbrel	*Numenius phaeopus*	Rare	Migratory
Long-billed Curlew	*Numenius americanus*	Rare	Migratory
Dunlin	*Calidris alpina*	Occasional	Migratory
Baird's Sandpiper	*Calidris bairdii*	Uncommon	Migratory
Least Sandpiper	*Calidris minutilla*	Uncommon	Migratory

Common Name	Scientific Name	Occurance	Status
Pectoral Sandpiper	*Calidris melanotos*	Rare	Migratory
Western Sandpiper	*Calidris mauri*	Uncommon	Migratory
Long-billed Dowitcher	*Limnodromus scolopaceus*	Rare	Migratory
Wilson's Snipe	*Gallinago delicata*	Uncommon	Migratory
American Woodcock	*Scolopax minor*	Occasional	Vagrant
Wilson's Phalarope	*Phalaropus tricolor*	Rare	Migratory
Gulls, Terns and Skimmers (Laridae)			
Black-legged Kittiwake	*Rissa tridactyla*	Occasional	Vagrant
Bonaparte's Gull	*Chroicocephalus philadelphia*	Rare	Migratory
Laughing Gull	*Leucophaeus atricilla*	Rare	Migratory
Franklin's Gull	*Leucophaeus pipixcan*	Rare	Migratory
Ring-billed Gull	*Larus delawarensis*	Uncommon	Migratory
Least Tern	*Sternula antillarum*	Rare	Vagrant
Black Tern	*Chlidonias niger*	Occasional	Migratory
Forster's Tern	*Sterna forsteri*	Rare	Migratory
Pigeons and Doves (Columbidae)			
Rock Pigeon	*Columba livia*	Rare	Breeder
Band-tailed Pigeon	*Patagioenas fasciata*	Uncommon	Breeder
Eurasian Collared-Dove	*Streptopelia decaocto*	Common	Breeder
White-winged Dove	*Zenaida asiatica*	Abundant	Breeder
Mourning Dove	*Zenaida macroura*	Common	Breeder
Inca Dove	*Columbina inca*	Common	Breeder
Common Ground-Dove	*Columbina passerina*	Common	Breeder
Ruddy Ground-Dove	*Columbina talpacoti*	Occasional	Vagrant
White-tipped Dove	*Leptotila verreauxi*	Occasional	Vagrant
Cuckoos, Roadrunners and Anis (Cuculidae)			
Yellow-billed Cuckoo	*Coccyzus americanus*	Common	Breeder
Black-billed Cuckoo	*Coccyzus erythropthalmus*	Occasional	Migratory
Greater Roadrunner	*Geococcyx californianus*	Abundant	Breeder
Groove-billed Ani	*Crotophaga sulcirostris*	Rare	Breeder
Barn Owls (Tytonidae)			
Barn Owl	*Tyto alba*	Rare	Resident
Typical Owls (Strigidae)			
Flammulated Owl	*Psiloscops flammeolus*	Rare	Breeder
Western Screech-Owl	*Megascops kennicottii*	Uncommon	Breeder
Eastern Screech-Owl	*Megascops asio*	Rare	Breeder
Great Horned Owl	*Bubo virginianus*	Common	Breeder
Northern Pygmy-Owl	*Glaucidium gnoma*	Rare	Migratory
Ferruginous Pygmy-Owl	*Glaucidium brasilianum*	Occasional	Vagrant
Elf Owl	*Micrathene whitneyi*	Common	Breeder

Common Name	Scientific Name	Occurance	Status
Burrowing Owl	*Athene cunicularia*	Uncommon	Breeder
Long-eared Owl	*Asio otus*	Rare	Resident
Short-eared Owl	*Asio flammeus*	Rare	Resident
Northern Saw-whet Owl	*Aegolius acadicus*	Occasional	Vagrant
Goatsuckers (Caprimulgidae)			
Lesser Nighthawk	*Chordeiles acutipennis*	Abundant	Breeder
Common Nighthawk	*Chordeiles minor*	Uncommon	Migratory
Common Poorwill	*Phalaenoptilus nuttallii*	Common	Breeder
Mexican Whip-poor-will	*Antrostomus arizonae*	Uncommon	Breeder
Swifts (Apodidae)			
Chimney Swift	*Chaetura pelagica*	Occasional	Migratory
White-throated Swift	*Aeronautes saxatalis*	Abundant	Breeder
Hummingbirds (Trochilidae)			
Magnificent Hummingbird	*Eugenes fulgens*	Rare	Breeder
Blue-throated Hummingbird	*Lampornis clemenciae*	Common	Breeder
Lucifer Hummingbird	*Calothorax lucifer*	Uncommon	Breeder
Ruby-throated Hummingbird	*Archilochus colubris*	Rare	Migratory
Black-chinned Hummingbird	*Archilochus alexandri*	Abundant	Breeder
Anna's Hummingbird	*Calypte anna*	Common	Resident
Costa's Hummingbird	*Calypte costae*	Rare	Resident
Broad-tailed Hummingbird	*Selasphorus platycercus*	Common	Breeder
Rufous Hummingbird	*Selasphorus rufus*	Common	Migratory
Calliope Hummingbird	*Selasphorus calliope*	Rare	Migratory
Broad-billed Hummingbird	*Cynanthus latirostris*	Rare	Migratory
Berylline Hummingbird	*Amazilia beryllina*	Occasional	Vagrant
Violet-crowned Hummingbird	*Amazilia violiceps*	Occasional	Vagrant
White-eared Hummingbird	*Hylocharis leucotis*	Rare	Resident
Trogons (Trogonidae)			
Elegant Trogon	*Trogon elegans*	Occasional	Vagrant
Kingfishers (Alcedinidae)			
Belted Kingfisher	*Megaceryle alcyon*	Uncommon	Migratory
Green Kingfisher	*Chloroceryle americana*	Rare	Migratory
Woodpeckers and Allies (Picidae)			
Lewis's Woodpecker	*Melanerpes lewis*	Rare	Migratory
Red-headed Woodpecker	*Melanerpes erythrocephalus*	Rare	Vagrant
Acorn Woodpecker	*Melanerpes formicivorus*	Common	Breeder
Golden-fronted Woodpecker	*Melanerpes aurifrons*	Abundant	Breeder
Williamson's Sapsucker	*Sphyrapicus thyroideus*	Rare	Resident
Yellow-bellied Sapsucker	*Sphyrapicus varius*	Uncommon	Resident
Red-naped Sapsucker	*Sphyrapicus nuchalis*	Common	Resident
Ladder-backed Woodpecker	*Picoides scalaris*	Abundant	Breeder

Common Name	Scientific Name	Occurance	Status
Northern Flicker	*Colaptes auratus*	Common	Breeder
Caracaras and Falcons (Falconidae)			
Crested Caracara	*Caracara cheriway*	Rare	Vagrant
American Kestrel	*Falco sparverius*	Common	Breeder
Merlin	*Falco columbarius*	Uncommon	Resident
Aplomado Falcon	*Falco femoralis*	Occasional	Unknown
Peregrine Falcon	*Falco peregrinus*	Common	Breeder
Prairie Falcon	*Falco mexicanus*	Rare	Breeder
Tyrant Flycatchers (Tyrannidae)			
Tufted Flycatcher	*Mitrephanes phaeocercus*	Occasional	Vagrant
Olive-sided Flycatcher	*Contopus cooperi*	Uncommon	Migratory
Greater Pewee	*Contopus pertinax*	Occasional	Vagrant
Western Wood-Pewee	*Contopus sordidulus*	Common	Migratory
Eastern Wood-Pewee	*Contopus virens*	Rare	Migratory
Yellow-bellied Flycatcher	*Empidonax flaviventris*	Occasional	Migratory
Willow Flycatcher	*Empidonax traillii*	Uncommon	Migratory
Least Flycatcher	*Empidonax minimus*	Common	Migratory
Hammond's Flycatcher	*Empidonax hammondii*	Uncommon	Migratory
Gray Flycatcher	*Empidonax wrightii*	Common	Migratory
Dusky Flycatcher	*Empidonax oberholseri*	Common	Migratory
Cordilleran Flycatcher	*Empidonax occidentalis*	Common	Breeder
Black Phoebe	*Sayornis nigricans*	Abundant	Breeder
Eastern Phoebe	*Sayornis phoebe*	Common	Resident
Say's Phoebe	*Sayornis saya*	Abundant	Breeder
Vermilion Flycatcher	*Pyrocephalus rubinus*	Abundant	Breeder
Dusky-capped Flycatcher	*Myiarchus tuberculifer*	Rare	Breeder
Ash-throated Flycatcher	*Myiarchus cinerascens*	Common	Breeder
Great Crested Flycatcher	*Myiarchus crinitus*	Rare	Migratory
Brown-crested Flycatcher	*Myiarchus tyrannulus*	Uncommon	Breeder
Great Kiskadee	*Pitangus sulphuratus*	Occasional	Vagrant
Sulphur-bellied Flycatcher	*Myiodynastes luteiventris*	Occasional	Vagrant
Piratic Flycatcher	*Legatus leucophaius*	Occasional	Vagrant
Tropical Kingbird	*Tyrannus melancholicus*	Uncommon	Breeder
Couch's Kingbird	*Tyrannus couchii*	Rare	Breeder
Cassin's Kingbird	*Tyrannus vociferans*	Common	Breeder
Thick-billed Kingbird	*Tyrannus crassirostris*	Occasional	Breeder
Western Kingbird	*Tyrannus verticalis*	Common	Breeder
Eastern Kingbird	*Tyrannus tyrannus*	Rare	Migratory
Scissor-tailed Flycatcher	*Tyrannus forficatus*	Uncommon	Migratory
Becards, Tityras and Allies (Tityridae)			
Rose-throated Becard	*Pachyramphus aglaiae*	Occasional	Vagrant

Common Name	Scientific Name	Occurance	Status
Shrikes (Laniidae)			
Loggerhead Shrike	*Lanius ludovicianus*	Common	Breeder
Vireos (Vireonidae)			
White-eyed Vireo	*Vireo griseus*	Rare	Migratory
Bell's Vireo	*Vireo bellii*	Abundant	Breeder
Black-capped Vireo	*Vireo atricapilla*	Uncommon	Breeder
Gray Vireo	*Vireo vicinior*	Common	Breeder
Yellow-throated Vireo	*Vireo flavifrons*	Uncommon	Migratory
Plumbeous Vireo	*Vireo plumbeus*	Common	Migratory
Cassin's Vireo	*Vireo cassinii*	Uncommon	Migratory
Blue-headed Vireo	*Vireo solitarius*	Uncommon	Migratory
Hutton's Vireo	*Vireo huttoni*	Common	Breeder
Warbling Vireo	*Vireo gilvus*	Common	Breeder
Philadelphia Vireo	*Vireo philadelphicus*	Rare	Migratory
Red-eyed Vireo	*Vireo olivaceus*	Common	Migratory
Yellow-green Vireo	*Vireo flavoviridis*	Rare	Vagrant
Jays and Crows (Corvidae)			
Pinyon Jay	*Gymnorhinus cyanocephalus*	Occasional	Migratory
Steller's Jay	*Cyanocitta stelleri*	Occasional	Vagrant
Blue Jay	*Cyanocitta cristata*	Rare	Vagrant
Western Scrub-Jay	*Aphelocoma californica*	Uncommon	Resident
Mexican Jay	*Aphelocoma wollweberi*	Common	Breeder
Clark's Nutcracker	*Nucifraga columbiana*	Occasional	Vagrant
Chihuahuan Raven	*Corvus cryptoleucus*	Uncommon	Resident
Common Raven	*Corvus corax*	Abundant	Breeder
Larks (Alaudidae)			
Horned Lark	*Eremophila alpestris*	Rare	Migratory
Swallows (Hirundinidae)			
Purple Martin	*Progne subis*	Rare	Migratory
Tree Swallow	*Tachycineta bicolor*	Uncommon	Migratory
Violet-green Swallow	*Tachycineta thalassina*	Common	Breeder
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	Common	Breeder
Bank Swallow	*Riparia riparia*	Uncommon	Migratory
Cliff Swallow	*Petrochelidon pyrrhonota*	Common	Breeder
Cave Swallow	*Petrochelidon fulva*	Uncommon	Breeder
Barn Swallow	*Hirundo rustica*	Common	Breeder
Chickadees and Titmice (Paridae)			
Mountain Chickadee	*Poecile gambeli*	Occasional	Vagrant
Black-crested Titmouse	*Baeolophus atricristatus*	Common	Breeder
Verdins (Remizidae)			
Verdin	*Auriparus flaviceps*	Common	Breeder

Common Name	Scientific Name	Occurance	Status
Bushtits (Aegithalidae)			
Bushtit	*Psaltriparus minimus*	Common	Breeder
Nuthatches (Sittidae)			
Red-breasted Nuthatch	*Sitta canadensis*	Rare	Migratory
White-breasted Nuthatch	*Sitta carolinensis*	Uncommon	Breeder
Pygmy Nuthatch	*Sitta pygmaea*	Occasional	Vagrant
Creepers (Certhiidae)			
Brown Creeper	*Certhia americana*	Uncommon	Resident
Wrens (Troglodytidae)			
Rock Wren	*Salpinctes obsoletus*	Common	Breeder
Canyon Wren	*Catherpes mexicanus*	Common	Breeder
House Wren	*Troglodytes aedon*	Common	Migratory
Winter Wren	*Troglodytes hiemalis*	Rare	Resident
Sedge Wren	*Cistothorus platensis*	Occasional	Vagrant
Marsh Wren	*Cistothorus palustris*	Common	Resident
Carolina Wren	*Thryothorus ludovicianus*	Uncommon	Resident
Bewick's Wren	*Thryomanes bewickii*	Common	Breeder
Cactus Wren	*Campylorhynchus brunneicapillus*	Abundant	Breeder
Gnatwrens and Gnatcatchers (Polioptilidae)			
Blue-gray Gnatcatcher	*Polioptila caerulea*	Abundant	Breeder
Black-tailed Gnatcatcher	*Polioptila melanura*	Abundant	Breeder
Dippers (Cinclidae)			
American Dipper	*Cinclus mexicanus*	Occasional	Vagrant
Kinglets (Regulidae)			
Golden-crowned Kinglet	*Regulus satrapa*	Rare	Resident
Ruby-crowned Kinglet	*Regulus calendula*	Abundant	Resident
Thrushes (Turidae)			
Eastern Bluebird	*Sialia sialis*	Common	Breeder
Western Bluebird	*Sialia mexicana*	Uncommon	Migratory
Mountain Bluebird	*Sialia currucoides*	Rare	Migratory
Townsend's Solitaire	*Myadestes townsendi*	Common	Resident
Veery	*Catharus fuscescens*	Occasional	Migratory
Gray-cheeked Thrush	*Catharus minimus*	Rare	Migratory
Swainson's Thrush	*Catharus ustulatus*	Uncommon	Migratory
Hermit Thrush	*Catharus guttatus*	Common	Migratory
Wood Thrush	*Hylocichla mustelina*	Rare	Migratory
Clay-colored Thrush	*Turdus grayi*	Occasional	Vagrant
Rufous-backed Robin	*Turdus rufopalliatus*	Occasional	Vagrant
American Robin	*Turdus migratorius*	Common	Migratory
Varied Thrush	*Ixoreus naevius*	Rare	Vagrant

Common Name	Scientific Name	Occurance	Status
Aztec Thrush	*Ridgwayia pinicola*	Occasional	Vagrant
Mockingbirds and Thrashers (Mimidae)			
Gray Catbird	*Dumetella carolinensis*	Uncommon	Resident
Curve-billed Thrasher	*Toxostoma curvirostre*	Abundant	Breeder
Brown Thrasher	*Toxostoma rufum*	Uncommon	Resident
Long-billed Thrasher	*Toxostoma longirostre*	Rare	Vagrant
Crissal Thrasher	*Toxostoma crissale*	Common	Breeder
Sage Thrasher	*Oreoscoptes montanus*	Uncommon	Resident
Northern Mockingbird	*Mimus polyglottos*	Abundant	Breeder
Starlings (Sturnidae)			
European Starling	*Sturnus vulgaris*	Rare	Resident
Wagtails and Pipits (Motacillidae)			
American Pipit	*Anthus rubescens*	Common	Migratory
Sprague's Pipit	*Anthus spragueii*	Rare	Resident
Waxwings (Bombycillidae)			
Cedar Waxwing	*Bombycilla cedrorum*	Uncommon	Migratory
Silky-flycatchers (Ptilogonatidae)			
Phainopepla	*Phainopepla nitens*	Uncommon	Breeder
Olive Warbler (Peucedramidae)			
Olive Warbler	*Peucedramus taeniatus*	Occasional	Vagrant
Longspurs and Snow Buntings (Calcariidae)			
Chestnut-collared Longspur	*Calcarius ornatus*	Uncommon	Migratory
Smith's Longspur	*Calcarius pictus*	Occasional	Migratory
Snow Bunting	*Plectrophenax nivalis*	Occasional	Vagrant
Wood-Warblers (Parulidae)			
Ovenbird	*Seiurus aurocapilla*	Uncommon	Migratory
Worm-eating Warbler	*Helmitheros vermivorum*	Rare	Migratory
Louisiana Waterthrush	*Parkesia motacilla*	Rare	Migratory
Northern Waterthrush	*Parkesia noveboracensis*	Uncommon	Migratory
Golden-winged Warbler	*Vermivora chrysoptera*	Rare	Migratory
Blue-winged Warbler	*Vermivora cyanoptera*	Rare	Migratory
Black-and-white Warbler	*Mniotilta varia*	Common	Migratory
Prothonotary Warbler	*Protonotaria citrea*	Rare	Migratory
Swainson's Warbler	*Limnothlypis swainsonii*	Rare	Migratory
Crescent-chested Warbler	*Oreothlypis superciliosa*	Occasional	Resident
Tennessee Warbler	*Oreothlypis peregrina*	Rare	Migratory
Orange-crowned Warbler	*Oreothlypis celata*	Common	Resident
Colima Warbler	*Oreothlypis crissalis*	Common	Breeder
Lucy's Warbler	*Oreothlypis luciae*	Uncommon	Breeder
Nashville Warbler	*Oreothlypis ruficapilla*	Common	Migratory

Common Name	Scientific Name	Occurance	Status
Virginia's Warbler	*Oreothlypis virginiae*	Rare	Migratory
MacGillivray's Warbler	*Geothlypis tolmiei*	Common	Migratory
Mourning Warbler	*Geothlypis philadelphia*	Rare	Migratory
Kentucky Warbler	*Geothlypis formosa*	Rare	Migratory
Common Yellowthroat	*Geothlypis trichas*	Common	Breeder
Hooded Warbler	*Setophaga citrina*	Uncommon	Migratory
American Redstart	*Setophaga ruticilla*	Common	Migratory
Cape May Warbler	*Setophaga tigrina*	Rare	Migratory
Cerulean Warbler	*Setophaga cerulea*	Rare	Migratory
Northern Parula	*Setophaga americana*	Common	Migratory
Tropical Parula	*Setophaga pitiayumi*	Rare	Resident
Magnolia Warbler	*Setophaga magnolia*	Rare	Migratory
Bay-breasted Warbler	*Setophaga castanea*	Rare	Migratory
Blackburnian Warbler	*Setophaga fusca*	Rare	Migratory
Yellow Warbler	*Setophaga petechia*	Common	Migratory
Chestnut-sided Warbler	*Setophaga pensylvanica*	Rare	Migratory
Blackpoll Warbler	*Setophaga striata*	Rare	Migratory
Black-throated Blue Warbler	*Setophaga caerulescens*	Uncommon	Migratory
Palm Warbler	*Setophaga palmarum*	Rare	Migratory
Pine Warbler	*Setophaga pinus*	Rare	Migratory
Yellow-rumped Warbler	*Setophaga coronata*	Abundant	Resident
Yellow-throated Warbler	*Setophaga dominica*	Uncommon	Migratory
Prairie Warbler	*Setophaga discolor*	Rare	Migratory
Grace's Warbler	*Setophaga graciae*	Rare	Migratory
Black-throated Gray Warbler	*Setophaga nigrescens*	Uncommon	Migratory
Townsend's Warbler	*Setophaga townsendi*	Common	Migratory
Hermit Warbler	*Setophaga occidentalis*	Uncommon	Migratory
Golden-cheeked Warbler	*Setophaga chrysoparia*	Rare	Migratory
Black-throated Green Warbler	*Setophaga virens*	Uncommon	Migratory
Fan-tailed Warbler	*Basileuterus lachrymosus*	Occasional	Vagrant
Rufous-capped Warbler	*Basileuterus rufifrons*	Occasional	Resident
Canada Warbler	*Cardellina canadensis*	Rare	Migratory
Wilson's Warbler	*Cardellina pusilla*	Common	Migratory
Red-faced Warbler	*Cardellina rubrifrons*	Rare	Resident
Painted Redstart	*Myioborus pictus*	Common	Breeder
Slate-throated Redstart	*Myioborus miniatus*	Occasional	Vagrant
Yellow-breasted Chat	*Icteria virens*	Common	Breeder
Emberizids (Emberizidae)			
Green-tailed Towhee	*Pipilo chlorurus*	Common	Resident
Spotted Towhee	*Pipilo maculatus*	Abundant	Breeder
Rufous-crowned Sparrow	*Aimophila ruficeps*	Common	Breeder
Canyon Towhee	*Melozone fusca*	Abundant	Breeder

Common Name	Scientific Name	Occurance	Status
Cassin's Sparrow	*Peucaea cassinii*	Uncommon	Breeder
Chipping Sparrow	*Spizella passerina*	Common	Resident
Clay-colored Sparrow	*Spizella pallida*	Uncommon	Resident
Brewer's Sparrow	*Spizella breweri*	Common	Resident
Field Sparrow	*Spizella pusilla*	Rare	Resident
Black-chinned Sparrow	*Spizella atrogularis*	Common	Breeder
Vesper Sparrow	*Pooecetes gramineus*	Common	Resident
Lark Sparrow	*Chondestes grammacus*	Common	Resident
Black-throated Sparrow	*Amphispiza bilineata*	Abundant	Breeder
Bell's Sparrow	*Artemisiospiza belli*	Uncommon	Resident
Lark Bunting	*Calamospiza melanocorys*	Common	Resident
Savannah Sparrow	*Passerculus sandwichensis*	Common	Resident
Grasshopper Sparrow	*Ammodramus savannarum*	Uncommon	Resident
Baird's Sparrow	*Ammodramus bairdii*	Uncommon	Migratory
Le Conte's Sparrow	*Ammodramus leconteii*	Rare	Resident
Fox Sparrow	*Passerella iliaca*	Rare	Resident
Song Sparrow	*Melospiza melodia*	Uncommon	Resident
Lincoln's Sparrow	*Melospiza lincolnii*	Common	Resident
Swamp Sparrow	*Melospiza georgiana*	Common	Resident
White-throated Sparrow	*Zonotrichia albicollis*	Uncommon	Resident
Harris's Sparrow	*Zonotrichia querula*	Occasional	Vagrant
White-crowned Sparrow	*Zonotrichia leucophrys*	Abundant	Resident
Golden-crowned Sparrow	*Zonotrichia atricapilla*	Occasional	Vagrant
Dark-eyed Junco	*Junco hyemalis*	Common	Resident
Yellow-eyed Junco	*Junco phaeonotus*	Occasional	Vagrant
Cardinals, Piranga Tanagers and Allies (Cardinalidae)			
Hepatic Tanager	*Piranga flava*	Uncommon	Breeder
Summer Tanager	*Piranga rubra*	Common	Breeder
Scarlet Tanager	*Piranga olivacea*	Rare	Migratory
Western Tanager	*Piranga ludoviciana*	Common	Migratory
Flame-colored Tanager	*Piranga bidentata*	Rare	Migratory
Northern Cardinal	*Cardinalis cardinalis*	Abundant	Breeder
Pyrrhuloxia	*Cardinalis sinuatus*	Abundant	Breeder
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	Rare	Migratory
Black-headed Grosbeak	*Pheucticus melanocephalus*	Common	Breeder
Blue Grosbeak	*Passerina caerulea*	Common	Breeder
Lazuli Bunting	*Passerina amoena*	Uncommon	Migratory
Indigo Bunting	*Passerina cyanea*	Common	Resident
Varied Bunting	*Passerina versicolor*	Common	Breeder
Painted Bunting	*Passerina ciris*	Common	Breeder
Dickcissel	*Spiza americana*	Uncommon	Migratory

Common Name	Scientific Name	Occurance	Status
Blackbirds (Icteridae)			
Red-winged Blackbird	*Agelaius phoeniceus*	Uncommon	Resident
Eastern Meadowlark	*Sturnella magna*	Common	Resident
Western Meadowlark	*Sturnella neglecta*	Uncommon	Resident
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	Common	Migratory
Rusty Blackbird	*Euphagus carolinus*	Rare	Vagrant
Brewer's Blackbird	*Euphagus cyanocephalus*	Common	Migratory
Common Grackle	*Quiscalus quiscula*	Rare	Migratory
Great-tailed Grackle	*Quiscalus mexicanus*	Uncommon	Breeder
Bronzed Cowbird	*Molothrus aeneus*	Uncommon	Breeder
Brown-headed Cowbird	*Molothrus ater*	Common	Breeder
Black-vented Oriole	*Icterus wagleri*	Occasional	Vagrant
Orchard Oriole	*Icterus spurius*	Common	Breeder
Hooded Oriole	*Icterus cucullatus*	Common	Breeder
Bullock's Oriole	*Icterus bullockii*	Common	Breeder
Baltimore Oriole	*Icterus galbula*	Rare	Migratory
Scott's Oriole	*Icterus parisorum*	Common	Breeder
Fringilline, Cardueline Finches and Allies (Fringillidae)			
House Finch	*Haemorhous mexicanus*	Abundant	Breeder
Purple Finch	*Haemorhous purpureus*	Rare	Migratory
Cassin's Finch	*Haemorhous cassinii*	Rare	Migratory
Red Crossbill	*Loxia curvirostra*	Rare	Migratory
Pine Siskin	*Spinus pinus*	Common	Migratory
Lesser Goldfinch	*Spinus psaltria*	Common	Breeder
American Goldfinch	*Spinus tristis*	Uncommon	Migratory
Evening Grosbeak	*Coccothraustes vespertinus*	Occasional	Vagrant
Old World Sparrows (Passeridae)			
House Sparrow	*Passer domesticus*	Common	Breeder

References:

7th Edition, AOU Checklist of North & Middle American Birds; American Ornithologists' Union. 1998. Check-list of North American Birds, 7th ed. American Ornithologists' Union, Washington, D.C.

American Ornitologists' Union. 2013. Fifty-fourth supplement to the American Ornithologists' Union *Checklist of North American Birds*. Auk 130:558-571.

Appendix I. Number of species and individuals observed on the Big Bend National Park Christmas Bird Count from 1965-1980; surveys were not conducted in 1966, 1974, or 1975.

Species	1965	1967	1968	1969	1970	1971	1972	1973	1976	1977	1978	1979	1980
Tundra Swan					3								
Gadwall			5										
American Wigeon			2										2
Mallard					1							13	
Blue-winged Teal	4											5	
Northern Shoveler					1		1						
Northern Pintail		32										5	
Green-winged Teal	3	16	34	38		5					9	97	12
Canvasback			2										
Redhead							1						
Ring-necked Duck	2	1	52		1								
Lesser Scaup	1												
Scaled Quail		6	3	70	23	1	14	34	50	48	68	7	27
Least Grebe					1						1		
Pied-billed Grebe													1
Eared Grebe			1										
Great Blue Heron		2	1	1					3	1		1	1
Green-backed Heron						1	1		1	1			
Black Vulture	4	8	6	2	3	2	4	5	2				
Black-shouldered Kite											1		
Northern Harrier						1	1		1	5	1	2	2
Sharp-shinned Hawk		1	1	1	1	1	1			1	2		2
Cooper's Hawk		1	1	2		2			4	2	3	1	2
Red-tailed Hawk		1	1	3	1	3	3	6	4	8	9	6	7
Ferruginous Hawk									1		1		
American Kestrel	2	4	2	3	3	2	2	1	2	2		1	5
Prairie Falcon				1						1			
Sora		1	2	5		3	3	2	1	3	3	3	1
American Coot			3	4	3	2	2	3			4		2
Sandhill Crane										5			
Killdeer	15	21	14	20	7	4	3	8	2	3	4	3	12
Spotted Sandpiper	3	2	5	20	2	6	3	1	4	8	5	9	11
Western Sandpiper				2									
Least Sandpiper		11	2	11			1	11					

Species	1965	1967	1968	1969	1970	1971	1972	1973	1976	1977	1978	1979	1980
Common Snipe		7	1	10	2	2	1		1	2		1	5
White-winged Dove				4	43	19	12	13	77	281	43	35	70
Mourning Dove	34	11	36	18	16	13	12	1	11	12	3	18	17
Inca Dove								2	5	5	10	16	3
Common Ground-Dove		3	5	12				3			1		
Greater Roadrunner	1	3	6	8	7	6	7	4	4	6	11	3	11
Eastern Screech-Owl/Western Screech-Owl		2	1	2			1						
Great Horned Owl	2		2			2	7	1		3	1		2
Long-eared Owl			1				2						
Common Poorwill							1						
White-throated Swift			26		45			4		50	265	4	20
Anna's Hummingbird						2	2						
Rufous Hummingbird						5							
Belted Kingfisher		1		2	1			2				3	2
Yellow-bellied Sapsucker	2	9	2	2	4	2	2	2	13	4	3	5	11
Ladder-backed Woodpecker	2	11	4	17	14	23	24	2	14	13	11	20	11
Northern Flicker	4	21	14	8	5	7	9	6	8	5	6	3	7
Dusky Flycatcher				1			1						
Black Phoebe	6	15	14	35	12	13	9	9	18	13	17	15	30
Eastern Phoebe	2	4	4	1	3	1	2		7	2	1	7	3
Say's Phoebe	8	9	14	15	10	11	11	15	21	19	19	12	32
Vermillion Flycatcher	2	7	3	5	2	3	3	1		3	4	4	1
Ash-throated Flycatcher			2	2		1	1		1	1		7	1
Cassin's Kingbird							1						
Thick-billed Kingbird						1							
Eastern Kingbird								2					
Loggerhead Shrike	6	6	13	11	6	4	9	8	20	22	12	12	24
Gray Vireo										1			1
Solitary Vireo											1		
Gray-breasted Jay									1				
Chihuahuan Raven	2								4	4			
Common Raven		3	4	9	2	5	9	2	6	8	14	13	14
Horned Lark			27										
Tree Swallow											13		
Northern Rough-winged Swallow	37	29	41	57	24	1		12		2	2		6
Verdin	1	17	12	14	11	23	13	7	16	23	32	11	17
Brown Creeper	1	2					2					12	

Species	1965	1967	1968	1969	1970	1971	1972	1973	1976	1977	1978	1979	1980
Cactus Wren	3	1	1	6	11	3	12	2	13	4	3	7	7
Rock Wren	3	13	19	58	26	16	29	16	39	50	16	72	54
Canyon Wren		2	5	10	6	4	2	2	1	1	7	2	
Carolina Wren		1	1			1		1					
Bewick's Wren		7	10	18	5	6	2	5	12	4	7	6	20
House Wren		2	2	4	1	2	2	2	2			5	
Winter Wren		2		1			1			1	2	8	
Marsh Wren		18	6	6	4	29	25	6	7	7	15	11	9
Golden-crowned Kinglet			2					2					
Ruby-crowned Kinglet	9	57	31	33	40	92	81	19	38	43	67	62	52
Blue-gray Gnatcatcher		5	1			1		1	6	4	2	16	12
Black-tailed Gnatcatcher	4		20	26	30	23	27	12	30	29	51	12	37
Eastern Bluebird	1	17		12	4	9		5				19	
Mountain Bluebird								12					
Swainson's Thrush												1	
Hermit Thrush		1	6	13	3	11	7	1	2	2	2	4	7
American Robin		2		2	2		3	2				25	
Northern Mockingbird	6	110	32	65	28	43	120	33	10	40	9	27	8
Sage Thrasher		1		2	2	4	6	2		2		1	1
Brown Thrasher			1	1	1	1				2	1	1	
Curve-billed Thrasher	2		5	6	8	6	20	3	21	7	11	2	9
Crissal Thrasher			1		1		2	1			2		4
European Starling							1						6
American Pipit		8	11	17	4	25	2	44	5		28	12	18
Cedar Waxwing		3		2	1							10	
Phainopepla						2					5	2	1
Orange-crowned Warbler		17	6	11	15	30	11	5	8	5	7	11	6
Yellow-rumped Warbler	14	182	33	42	17	128	168	34	28	25	33	149	43
Black-and-white Warbler									1			7	
Common Yellowthroat		4	2	13	2	8	43	1	5	6	4	8	3
Wilson's Warbler										1			
Western Tanager													1
Green-tailed Towhee		2	4	8	2	13	4	4	1	6		4	4
Rufous-sided Towhee	2	4	4	6	2	18	5	1	1	3	1	10	
Canyon Towhee	4			2	9	1	2	3	17	8	15	3	
Cassin's Sparrow				3		3			4				1
Rufous-crowned Sparrow		1		3					5	8	7	2	3

Species	**1965**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1976**	**1977**	**1978**	**1979**	**1980**
Chipping Sparrow		18	4	130		16	20	6	2	42		11	4
Clay-colored Sparrow				10		7						12	
Brewer's Sparrow			8	26		10	2		8	18		11	
Field Sparrow				1		4				4			1
Vesper Sparrow		1		4									
Lark Sparrow										1		1	
Black-throated Sparrow	4	4	76	32	30	30	72	49	174	350	49	94	184
Lark Bunting			2	3		29							
Savannah Sparrow			4	2		1				20		12	
Le Conte's Sparrow										6			
Fox Sparrow						1							
Song Sparrow		3	5	3	4	3		3	2	23	3	17	2
Lincoln's Sparrow		5	1	3	1	3	4	1	6	24	2	33	2
Swamp Sparrow		19	3	8	5	8	8	1	3	5	3	3	4
White-throated Sparrow		1		2		2						29	
White-crowned Sparrow	3	18	9	88	15	35	6	19	38	128	4	12	80
Dark-eyed Junco		6		1		6	2	10		32		42	
Northern Cardinal	1	28	14	34	14	9	9	5	2	15	13	20	23
Pyrrhuloxia	24	77	38	80	65	84	79	54	140	139	30	77	63
Varied Bunting												1	
Eastern Meadowlark		8											
Western Meadowlark	3	26						18			1		
Rusty Blackbird			1			1		3					
Brewer's Blackbird													15
Brown-headed Cowbird								4					
Scott's Oriole												1	
House Finch	35	18	43	180	20	99	40	10	91	71	84	40	143
Pine Siskin					34		5	4			46		
Lesser Goldfinch		1		4		2	2		20	6	1	10	
American Goldfinch				1		1	9		2	1			
House Sparrow			1	12	15		1			25	24	22	21
Boat-tailed Grackle/Great-tailed Grackle				8									
Number of Species	**39**	**70**	**75**	**82**	**64**	**78**	**74**	**68**	**63**	**74**	**67**	**80**	**69**
Number of Individuals	**262**	**960**	**781**	**1418**	**684**	**1007**	**1015**	**573**	**1046**	**1735**	**1135**	**1301**	**1223**

Appendix J. Number of species and individuals observed on the Big Bend National Park Christmas Bird Count from 1981-1995.

Species	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Canada Goose															8
Wood Duck		5		2											
Gadwall		1		9					1						6
American Wigeon				1					5						
Mallard				1						2					1
Blue-winged Teal		4						2							
Cinnamon Teal													2		
Northern Shoveler			1												
Northern Pintail				1					1						
Green-winged Teal	1	10		17				10		5	20	4	19		
Ring-necked Duck			11	1								1	2		1
Lesser Scaup		1													
Bufflehead				1										1	
Scaled Quail		15	94		9	41		31	199	13	30	65	186	12	3
Pied-billed Grebe				1			1	1				2	2		
American Bittern													1		
Great Blue Heron		2	3	3	2	1		1		2	3		2	2	5
Great Egret															1
Black-crowned Night-Heron					1										
Black Vulture	2							1	9	5					
Turkey Vulture			5												
Northern Harrier	1	2	3	2	3			1	3		4	1	2	1	
Sharp-shinned Hawk		1	1		1		2				1	1	3	1	2
Cooper's Hawk	2		1	2	1	3			1	1	1	2	2		
Northern Goshawk			1												
Harris's Hawk					3	2			2			1			1
Red-shouldered Hawk									1						
Red-tailed Hawk	9	3	11	5	5	6	4	6	9	3	3	10	23	6	7

Species	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
American Kestrel	3		1	2	2	2		1	2		3	1	2	1	
Merlin							1						1		
Peregrine Falcon				1				1		1					
Prairie Falcon															1
Virginia Rail				1									1		
Sora		8			1	1	3	1	2			1	1		
American Coot		1		1			2	3	4	2	1	3	3	2	2
Sandhill Crane				22											
Killdeer	6	8	12	10	4	8	3	1	11	4	7	2	3	7	4
Spotted Sandpiper	1	8	5	6	6	4	5	13	13	11	5	4	3	3	9
Western Sandpiper		6													
Least Sandpiper			9					1	2		7				
Common Snipe	3	4	6	3	1	3		1	3	2	3			2	1
Rock Dove							1								
White-winged Dove	13	24	28	68	45	46	14	11	104	5	83	53	41	21	17
Mourning Dove	10	17	13	16	11	5	3	15	4	3	112	48	8	47	13
Inca Dove	8	14	1	8	7	10	7	30	74	3		14	21	5	9
Common Ground-Dove											14				
Ruddy Ground-Dove								1							
Greater Roadrunner	12	8	9	2	5	5	4	5	7	9	3	3	57		10
Western Screech-Owl													3		2
Great Horned Owl	1	3	2		2	3	2	1	3	2		1	5	1	
White-throated Swift					1	258	136	262	240			125	420	400	337
Anna's Hummingbird			1		2										
Belted Kingfisher	1	2	1	3			1	1			4	1			2
Golden-fronted Woodpecker			1		3	6	8	7	27	7	11	9	24	5	14
Yellow-bellied Sapsucker	10	1	2	2	1		2	13	4	5		2	7		3
Red-naped Sapsucker				1	1	1			4		1	6	12	1	
Ladder-backed Woodpecker	13	9	26	7	11	9	12	9	25	9	14	11	25	5	9
Northern Flicker	4	2	14	1	8	1		1	12	9		1	3	1	1

Species	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Tufted Flycatcher												1			
Gray Flycatcher													4		
Black Phoebe	13	14	17	10	13	12	6	9	27	9	18	13	27	21	22
Eastern Phoebe	19	10	4	1	6	3		12	6	4		4	7	4	3
Say's Phoebe	11	7	15	10	15	22	6	12	38	21	12	8	33	9	10
Vermillion Flycatcher	3	7	3	1	2	5	6	1	8		1	6	4	1	6
Ash-throated Flycatcher	1	6	4	2	2	3	1	4	3		8	6	2	3	3
Loggerhead Shrike	11	7	11	7	11	17	4	16	32	2	18	17	25	11	9
Solitary Vireo	3														
Eastern Solitary Vireo											1				
Chihuahuan Raven		1										1			
Common Raven	10	10	9	16	19	12	9	17	35	10	23	23	36	11	15
Horned Lark		1													
Tree Swallow													1		
Northern Rough-winged Swallow				4	11						4	3	8	22	13
Black-crested Titmouse					1										
Verdin	13	17	27	10	17	27	13	16	41	12	1	5	63	14	36
Brown Creeper	11								4						
Cactus Wren	3	5	9	2	1	3		4	7	1	14	3	27	2	2
Rock Wren	85	25	5	6	43	33	23	21	30	11	33	55	58	21	33
Canyon Wren	1	5	3	5	6	10	2	3	3	3	1	26	18	13	8
Carolina Wren													2		1
Bewick's Wren	15	6	14	2	3	15	1	3	6	1	3	5	25	6	3
House Wren	2	5		1	1		2	2	2		2	4	3		
Winter Wren	1	1			1										
Marsh Wren	25	17	4	8	18	12	8	3	4	3	9	4	5	3	9
Golden-crowned Kinglet	2								5						
Ruby-crowned Kinglet	102	127	66	17	49	52	35	45	86	8	35	51	134	33	59
Blue-gray Gnatcatcher	8	21	7		1	19	2	3	23		8	23	16	3	17
Black-tailed Gnatcatcher	30	32	29	9	23	5		15	30	8	8	25	71	10	28

Species	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Eastern Bluebird		2		6			12	5			3	14		4	
Western Bluebird	12							2		12					
Mountain Bluebird	4													5	
Hermit Thrush	7	18	3	8	1	3	1						8		
American Robin	13	1	2	2			1	4							
Northern Mockingbird	30	29	17	17	21	49	7	26	21	11	35	32	19	17	4
Sage Thrasher	2	1					3		2					3	
Brown Thrasher					1						2	1	1		
Curve-billed Thrasher	3	2	4	1	3	3	1	6	13	3		4	26		5
Crissal Thrasher			1		1			2	2				3		3
European Starling				2									13		
American Pipit	4	4	21	17	4	37	52	8	18	12	3	4	23	52	8
Cedar Waxwing			30	2	6		12	13							2
Phainopepla	4	7		1	2	2				1					1
Orange-crowned Warbler	12	33	7	8	5	23	2	6	11	3	11	20	21	1	15
Nashville Warbler				1											
Yellow-rumped Warbler	118	126	30	111	84	125	63	24	57	19	100	37	73	10	36
Yellow-throated Warbler											1				
Common Yellowthroat	4	5	3	1	4	5	1	7	9	5		7	24	1	11
Summer Tanager						1									
Green-tailed Towhee	5	6	4	6	1	17	3	7			8	2	4	2	1
Spotted Towhee						6		2		4	2	1			3
Rufous-sided Towhee	8	13	2		8										2
Canyon Towhee	14	2	15	6	3			3	16	7	4	3	33	1	7
Rufous-crowned Sparrow	10	47	4	2					9	6	2		25		
Chipping Sparrow	125	255		2	59	83	19	9		2	44	42			12
Clay-colored Sparrow		82				3	20	2							
Brewer's Sparrow	1	178			4	255	37	35				2			
Field Sparrow		1	2	1	1		1	9			2				
Black-chinned Sparrow								1							1

Species	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Vesper Sparrow				1	1				1		4				
Lark Sparrow								1							
Black-throated Sparrow	196	153	99	27	59	84	31	76	199	56	138	188	341	54	105
Sage Sparrow													1	1	2
Lark Bunting	1				1	5					442		1	42	
Savannah Sparrow	1			2				3							4
Fox Sparrow		2			2	2						1			
Song Sparrow	25	2	3	4	7	1	1	7	6	5	1	2	6	10	12
Lincoln's Sparrow	7	29	2	5	4	9	2	5	6		3	2		4	5
Swamp Sparrow	2	9	4	1		6	1		3	6	2	2	7	9	6
White-throated Sparrow	4	5			2	2					1	1		2	
Harris's Sparrow									1						
White-crowned Sparrow	9	121	20	299	36	146	9	168	43	25	25	16	25	100	15
Dark-eyed Junco	75	2		2		1				2	2	5	1		7
Northern Cardinal	1	28	28	21	26	9	9	14	12	2	15	7	27	12	16
Pyrrhuloxia	23	90	24	35	52	151	63	81	61	16	53	32	77	114	21
Blue Grosbeak		1										1			
Indigo Bunting											1				
Painted Bunting					1										
Red-winged Bunting															2
Western Meadowlark													28		
Great-tailed Grackle				12											
Cassin's Finch									1						
House Finch	21	172	125	31	83	140	14	65	100	10	27	44	80	59	1
Pine Siskin		50			12									18	
Lesser Goldfinch	2	3	2	1	2	8	1	3	1						
American Goldfinch		49		14	20		60	12				3	4		
House Sparrow	28	24	3	34	26	22	19	2	1	2		2	3		
Number of Species	**71**	**80**	**67**	**80**	**78**	**64**	**60**	**76**	**70**	**55**	**65**	**73**	**77**	**59**	**72**
Number of Individuals	**1240**	**2035**	**944**	**994**	**921**	**1863**	**774**	**1225**	**1755**	**405**	**1460**	**1130**	**2327**	**1232**	**1053**

Appendix K. Number of species and individuals observed on the Big Bend National Park Christmas Bird Count from 1996-2010.

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Canada Goose				1											
Wood Duck									1		1	1			
Gadwall				2	8		10		41	2	4	11		26	4
American Wigeon				2		1									
Mallard	10			5	32	6	21	14		9	3				
Mexican Duck					6	5	3	15	38	3	7	4	3	13	
Blue-winged Teal			3		4						3				
Cinnamon Teal			11	1						3					
Northern Shoveler				5	2	3						2			
Green-winged Teal	4	5	20	51	33	12	7	7	83	15	6	14	6	19	4
Ring-necked Duck	12		7	8	2				22		3	2		1	3
Lesser Scaup		4							7						
Common Merganser													1		
Ruddy Duck			1	1											
Scaled Quail		9	195	16	5	15	16	10	2	1	43	15	31		22
Least Grebe													1		
Pied-billed Grebe			2	2	1	1	2		1	4	9	3	1	5	2
Eared Grebe								1							
American Bittern										1	1				
Least Bittern		1													
Great Blue Heron	2	1	7	2	2	4	5	1	3	1	2	1	1	2	3
Great Egret												1			
Green Heron					1				1						
Black-crowned Night-Heron	1														
Black Vulture		4			14	4	6	7	19		32	8	1	5	9
Turkey Vulture											1				
Northern Harrier					3	3		3				1		4	
Sharp-shinned Hawk	2	1	3	1	1	2	2	1	1	3	1	1	1	1	

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Cooper's Hawk			1			1	1	4	1	2	3	1		3	1
Harris's Hawk	1														
Red-tailed Hawk	3	5	4	1	3	5	8	2	8	1	3	4	1	7	3
Golden Eagle		2						1	2						
American Kestrel	2	2	2				1	1						3	2
Merlin					1										
Peregrine Falcon					1	1	1		2			1			
Prairie Falcon						1									
Virginia Rail									1						
Sora	1	3					1		1	2	2		1	5	
American Coot		4	6	8	5	6	10	1	5	4	9	8	3	7	3
Killdeer	1	12	14	9	13	10	10	5	7	14	4	4	3		2
Spotted Sandpiper	6	9	21	22	7	11	9	6	26	2	6	3	7	5	9
Least Sandpiper			21	15	15	10	4				1				
Dunlin			1												
Wilson's Snipe									4	4	4		2	1	2
Common Snipe			2	3	1	5	2								
Rock Dove	26	15	1												
Eurasian Collared-Dove												7		4	
White-winged Dove	37	26	22	6	14	39	28	6	40	23	63	28	28	78	56
Mourning Dove	4	22	1	3	4	10	8	45	1	55				14	13
Inca Dove	17	12	19	6		4	3	37	10	18	3			4	11
Common Ground-Dove		2		4		2		5	3	4	7		4	4	
Greater Roadrunner	12	10		9	23	15	19	14	14	8	24	6	6	16	12
Groove-billed Ani			20										1		
Western Screech-Owl		1		3	3	1	1	1			1				
Great Horned Owl	1		2				2	2		1	1		1	1	
Burrowing Owl			1											1	
White-throated Swift	237	29	490		361	116		160		1330	49	150	110	550	
Anna's Hummingbird	1	1						1		1			1	1	1

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Rufous Hummingbird									1						
Belted Kingfisher			1		3		2				1	1	1	2	
Green Kingfisher			2	1	2	1		1			1				
Golden-fronted Woodpecker	24	15	21	14	22	13	10	16	20	10	25	24	17	13	22
Yellow-bellied Sapsucker	2	1	5	1		3		8	4	3	4	7	1	1	
Red-naped Sapsucker	3	2		9	9	4	5	1	14	5	3	9	4	5	4
Ladder-backed Woodpecker	8	16	9	12	28	20	22	19	17	18	12	15	6	13	8
Northern Flicker	3	2	1	2	11	11	4	12	8	6		3	4	2	8
Gray Flycatcher		1		1	1					1	1	1		1	
Dusky Flycatcher												1			
Black Phoebe	9	22	25	25	35	19	24	26	50	15	31	16	17	27	11
Eastern Phoebe	5	4	2	8	8	9	4	9	14	6	9	4	10	31	9
Say's Phoebe	11	18	31	13	29	6	14	8	13	8	11	10	5	19	11
Vermillion Flycatcher	3	12	10	8	6	3	2	7	9	10	14	14	8	18	4
Ash-throated Flycatcher	1	1	1		1			3	4	4	1	1		1	1
Loggerhead Shrike	12	17	24	9	9	11	16	13	12		10	6	8	7	12
Bell's Vireo													1		
Gray Vireo					1										
Plumbeous Vireo				2			1								1
Blue-headed Vireo				2											
Hutton's Vireo					2										
Warbling Vireo								1							
Mexican Jay										2					
Chihuahuan Raven							1		1						
Common Raven	17	19	19	29	27	17	28	25	9	19	30	17	12	21	14
Tree Swallow														1	
Northern Rough-winged Swallow	1	1	2	4	4	13			88	28	18	6		1	
Black-crested Titmouse						2					2				
Verdin	23	12	35	21	40	19	15	17	22	8	20	22	10	19	18
Bushtit										4			1		

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Red-breasted Nuthatch							2								
White-breasted Nuthatch														1	
Brown Creeper								1	2				1		1
Cactus Wren	7	2	4	7	5	3	3	1	3		8	4	6	4	9
Rock Wren	21	56	23	50	21	20	29	26	38	23	28	26	9	27	17
Canyon Wren	19	4	4	4	1	2	6	3	3	6	2	6	1	4	1
Carolina Wren												1		1	
Bewick's Wren	6	1	8	17	9	12	7	7	11	2	8	4	8	10	4
House Wren		1	2	2	1	1		3		3	2			6	
Winter Wren												1		1	1
Marsh Wren	19	14	13	15	12	4	13	9	29	9	11	25	5	8	3
Golden-crowned Kinglet												3		2	
Ruby-crowned Kinglet	47	59	73	70	80	70	48	152	217	48	64	71	32	55	25
Blue-gray Gnatcatcher	11	16	14		1	7		17	2	3	18	12	3	56	23
Black-tailed Gnatcatcher	32	36	62	44	63	19	25	39	54	22	37	57	16	46	16
Eastern Bluebird		6	2			18			5						1
Western Bluebird				5	4	4		1						8	
Mountain Bluebird														6	
Hermit Thrush	1	2		6	3	9	4	5	10	6	2	2	3		
American Robin				12		42		19		5		3		42	2
Gray Catbird				2											
Northern Mockingbird	23	31	20	23	6	26	15	12	12	12	33	27	22	48	20
Sage Thrasher		1		2		1		1			4	1		3	
Brown Thrasher				1	1									2	1
Curve-billed Thrasher	5	5	8	5	5	5	5	3	3		6	4		1	4
Crissal Thrasher	1			3	5	1	2	6	8	2	5	8	4	5	4
European Starling									1						
American Pipit	31	34	36	2	28	8	8	8	5	23	10	11	15		14
Cedar Waxwing				6	1	33		2		67		6			15
Phainopepla			2	2		1	5					1	1		1

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Orange-crowned Warbler	5	9	13	10	7	9	5	13	47	11	21	13	3	24	8
Northern Parula						1									
Yellow Warbler									1						1
Yellow-rumped Warbler	31	101	33	79	90	53	28	102	161	137	41	52	22	219	14
Black-throated Gray Warbler												1			
Common Yellowthroat	2	2	10	4	4	2	5	4	8	11	19	12	5	2	4
Hooded Warbler						1									2
Wilson's Warbler									1	1					
Green-tailed Towhee			1					5	3	8	8	2	1	7	2
Spotted Towhee			2	2		29	8	8	23	4	1	6	1	1	2
Rufous-sided Towhee	2														
Canyon Towhee	1	1	10	9	1	6	3	2	0	0	3	2	0	0	11
Cassin's Sparrow														1	
Rufous-crowned Sparrow		3	3	9	3	9	1		8				3	16	
Chipping Sparrow		7	6	3		8		65		8	4			20	
Clay-colored Sparrow				2				1	1	8	2			17	
Brewer's Sparrow		5	2	4		1		24		14	1		3	34	
Field Sparrow						2					15			9	
Black-chinned Sparrow						1									
Vesper Sparrow			2	1				8	1	30	1		4	35	
Lark Sparrow									2					1	
Black-throated Sparrow	11	128	130	79	64	167	37	69	35	27	70	39	51	100	50
Sage Sparrow				1		4				2					
Lark Bunting				4					2					10	2
Savannah Sparrow			20	2		2		17	3	24	3		2	272	7
Le Conte's Sparrow										2					
Fox Sparrow				3	1			1							
Song Sparrow		12	21	12	9	3	9	9	31	9	2	4		17	2
Lincoln's Sparrow			4		6	4	2	12	14	39	2			9	3
Swamp Sparrow	2		6	4	8	2	10	7	14	3	2	4		5	7

Species	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
White-throated Sparrow			5	1											
White-crowned Sparrow	8	9	71	145	43	92	26	52	267	33	28	12	201	288	84
Dark-eyed Junco				2		30		1	7					7	
Northern Cardinal	12	6	29	12	24	24	11	27	17	18	14	11	15	27	18
Pyrrhuloxia	17	40	80	12	52	40	11	43	66	61	29	36	19	116	47
Blue Grosbeak		1													
Red-winged Bunting			20						3		2		3		
Eastern Meadowlark				8		4	1				2				1
Western Meadowlark					1	3								3	
Great-tailed Grackle		3						1							
Brown-headed Cowbird									1						
Purple Finch		4									1				
Cassin's Finch			3												
House Finch	42	65	77	8	104	48	42	37	186	116	91	25	88	59	97
Pine Siskin						6									
Lesser Goldfinch	3	1	5	6			13	2	1			14	4	5	6
American Goldfinch						3	2			13		1			
House Sparrow	8	49	10	15	24			4						6	
Number of Species	**60**	**71**	**79**	**88**	**78**	**89**	**70**	**83**	**84**	**77**	**84**	**76**	**67**	**91**	**71**
Number of Individuals	**869**	**1037**	**1899**	**1062**	**1490**	**1284**	**714**	**1345**	**1936**	**2468**	**1089**	**940**	**870**	**2608**	**815**

Appendix L. Number of birds detected of each species in each habitat class in Big Bend National Park during 2010 Rocky Mountain Bird Observatory survey. Table reproduced from White (2011).

Species	Habitat Class		# of Birds Detected	
	Grassland	Riparian	Total	% of Total
black-throated sparrow	368	21	389	15%
cactus wren	231	1	232	9%
northern mockingbird	191	10	201	8%
pyrrhuloxia	199	2	201	8%
Bell's vireo	51	92	143	6%
yellow-breasted chat	26	86	112	4%
blue grosbeak	39	63	102	4%
mourning dove	51	32	83	3%
lesser nighthawk	68	6	74	3%
white-winged dove	1	68	69	3%
black-tailed gnatcatcher	59	8	67	3%
ash-throated flycatcher	47	10	57	2%
scaled quail	54	1	55	2%
brown-headed cowbird	25	29	54	2%
painted bunting	23	30	53	2%
rufous-crowned sparrow	50	1	51	2%
verdin	43	7	50	2%
northern cardinal	1	48	49	2%
turkey vulture	38	11	49	2%
Scott's oriole	38	-	38	2%
common yellowthroat	-	36	36	1%
house finch	22	7	29	1%
summer tanager	-	21	21	1%
Cassin's sparrow	19	-	19	1%
Chihuahuan raven	15	4	19	1%
Carolina wren	-	12	12	0%
canyon towhee	8	-	8	0%
canyon wren	1	7	8	0%
loggerhead shrike	8	-	8	0%
blue-gray gnatcatcher	6	1	7	0%
cliff swallow	3	4	7	0%
greater roadrunner	6	1	7	0%
ladder-backed woodpecker	2	5	7	0%
lesser goldfinch	-	7	7	0%
orchard oriole	7	-	7	0%
black phoebe	-	6	6	0%
brown-crested flycatcher	1	5	6	0%
common ground-dove	-	6	6	0%

Species	Habitat Class		# of Birds Detected	
	Grassland	Riparian	Total	% of Total
green-tailed towhee	5	-	5	0%
Say's phoebe	4	1	5	0%
Swainson's hawk	5	-	5	0%
Brewer's sparrow	4	-	4	0%
chipping sparrow	4	-	4	0%
crissal thrasher	4	-	4	0%
gray vireo	4	-	4	0%
northern rough-winged swallow	-	4	4	0%
western kingbird	4	-	4	0%
barn swallow	3	-	3	0%
curve-billed thrasher	3	-	3	0%
house sparrow	-	3	3	0%
Lucy's warbler	-	3	3	0%
golden-fronted woodpecker	-	2	2	0%
great horned owl	1	1	2	0%
hooded oriole	2	-	2	0%
rock wren	1	1	2	0%
varied bunting	2	-	2	0%
yellow-billed cuckoo	-	2	2	0%
yellow-rumped warbler	2	-	2	0%
Bewick's wren	1	-	1	0%
black-chinned hummingbird	1	-	1	0%
broad-tailed hummingbird	1	-	1	0%
common nighthawk	1	-	1	0%
indigo bunting	-	1	1	0%
mallard	-	1	1	0%
northern harrier	1	-	1	0%
peregrine falcon	-	1	1	0%
red-tailed hawk	1	-	1	0%
scissor-tailed flycatcher	1	-	1	0%
western wood-pewee	1	-	1	0%
Unidentified Bird	50	17	67	0%
Unidentified Sparrow	15	-	15	0%
Unidentified Hummingbird	-	3	3	0%
Unidentified Thrasher	2	-	2	0%
Unidentified Duck	-	1	1	0%
Unidentified Swallow	1	-	1	0%
Unidentified Warbler	-	1	1	0%
Total	**1,825**	**690**	**2,515**	**100%**

Appendix M. Number of birds detected of each species in each habitat class in Big Bend National Park during 2011 Rocky Mountain Bird Observatory survey. Table reproduced from White and Valentine-Darby (2012).

Species	Habitat class		# of birds detected	
	Grassland	Riparian	Total	% of total
Cactus Wren	220	--	220	8
Turkey Vulture	165	38	203	8
Black-throated Sparrow	174	15	189	7
Mourning Dove	66	70	136	5
White-winged Dove	18	103	121	5
Bell's Vireo	4	107	111	4
House Finch	73	16	89	3
Ash-throated Flycatcher	72	16	88	3
Verdin	54	9	63	2
Chihuahuan Raven	54	6	60	2
Chipping Sparrow	18	42	60	2
Pyrrhuloxia	59	1	60	2
Northern Mockingbird	33	23	56	2
Northern Rough-winged Swallow	3	39	42	2
Common Yellowthroat	1	40	41	2
Bank Swallow	--	40	40	2
Scott's Oriole	36	1	37	1
Curve-billed Thrasher	35	--	35	1
Rock Wren	33	2	35	1
Black-tailed Gnatcatcher	23	11	34	1
Northern Cardinal	7	23	30	1
Say's Phoebe	8	21	29	1
Yellow-breasted Chat	--	29	29	1
Brewer's Blackbird	--	27	27	1
Wilson's Warbler	2	24	26	1
Bewick's Wren	23	2	25	1
Great-tailed Grackle	5	20	25	1
Blue-gray Gnatcatcher	14	9	23	1
Summer Tanager	--	22	22	1
Rufous-crowned Sparrow	12	7	19	1
Greater Roadrunner	13	5	18	1
Scaled Quail	14	2	16	1
Yellow-rumped Warbler	3	12	15	1
Vesper Sparrow	8	6	14	1
Lesser Nighthawk	5	8	13	0
Mallard	--	12	12	0

Species	Habitat class		# of birds detected	
	Grassland	Riparian	Total	% of total
Canyon Wren	5	6	11	0
Canyon Towhee	10	--	10	0
Common Ground-Dove	--	10	10	0
Violet-green Swallow	--	10	10	0
Vermilion Flycatcher	--	8	8	0
Black-chinned Sparrow	4	3	7	0
Gray Vireo	7	--	7	0
Crissal Thrasher	4	2	6	0
Green-tailed Towhee	3	3	6	0
Loggerhead Shrike	6	--	6	0
Savannah Sparrow	5	1	6	0
Spotted Sandpiper	--	6	6	0
Cassin's Kingbird	--	5	5	0
Ladder-backed Woodpecker	2	3	5	0
Lark Bunting	5	--	5	0
Marsh Wren	--	5	5	0
Red-winged Blackbird	--	5	5	0
Western Kingbird	--	5	5	0
American Avocet	--	4	4	0
Brewer's Sparrow	3	1	4	0
Killdeer	--	4	4	0
Golden-fronted Woodpecker	1	2	3	0
Great Horned Owl	1	2	3	0
Red-tailed Hawk	2	1	3	0
Ruby-crowned Kinglet	--	3	3	0
Swainson's Hawk	3	--	3	0
White-crowned Sparrow	3	--	3	0
American Kestrel	2	--	2	0
Black Vulture	--	2	2	0
Black-headed Grosbeak	--	2	2	0
Common Raven	2	--	2	0
Horned Lark	2	--	2	0
Northern Shoveler	--	2	2	0
Western Meadowlark	2	--	2	0
American Coot	--	1	1	0
American Pipit	--	1	1	0
Black Phoebe	--	1	1	0
Brown-headed Cowbird	1	--	1	0
Burrowing Owl	1	--	1	0

Species	Habitat class		# of birds detected	
	Grassland	Riparian	Total	% of total
Cassin's Sparrow	--	1	1	0
Eastern Phoebe	--	1	1	0
Gray Hawk	--	1	1	0
Great Egret	--	1	1	0
Lesser Goldfinch	--	1	1	0
Northern Flicker	1	--	1	0
Northern Harrier	1	--	1	0
Sage Thrasher	1	--	1	0
Virginia's Warbler	--	1	1	0
Western Screech-Owl	--	1	1	0
Western Tanager	1	--	1	0
Winter Wren	--	1	1	0
Yellow Warbler	--	1	1	0
Unidentified Bird	98	47	145	6
Unidentified Cardinal	46	50	96	4
Unidentified Swallow	--	35	35	1
Unidentified Sparrow	18	8	26	1
Unidentified Myiarchus	--	12	12	0
Unidentified Blackbird	--	10	10	0
Unidentified Thrasher	8	--	8	0
Unidentified Corvid	3	4	7	0
Unidentified Duck	--	4	4	0
Unidentified Hummingbird	2	2	4	0
Unidentified Warbler	--	4	4	0
Unidentified Hawk	2	--	2	0
Unidentified Woodpecker	--	2	2	0
Unidentified Empidonax	--	1	1	0
Unidentified Flycatcher	1	--	1	0
Unidentified Oriole	--	1	1	0
Unidentified Tanager	1	--	1	0
Total	**1,512**	**1,095**	**2,607**	**100**

Appendix N. Number of birds detected of each species in each habitat class in Big Bend National Park during 2012 Rocky Mountain Bird Observatory survey. Table reproduced from White and Valentine-Darby (2013).

Species	Habitat class		# of birds detected	
	Grassland	Riparian	Total	% of total
Black-throated Sparrow	392	14	406	15
Cactus Wren	198	---	198	7
Bell's Vireo	50	142	192	7
White-winged Dove	33	145	178	7
Ash-throated Flycatcher	138	32	170	6
Yellow-breasted Chat	3	131	134	5
Turkey Vulture	100	13	113	4
Northern Cardinal	8	97	105	4
Pyrrhuloxia	85	5	90	3
Northern Mockingbird	79	10	89	3
Verdin	63	16	79	3
Mourning Dove	46	25	71	3
Scott's Oriole	49	---	49	2
Cliff Swallow	1	44	45	2
Common Yellowthroat	---	44	44	2
Rock Wren	32	11	43	2
House Finch	31	8	39	1
Black-tailed Gnatcatcher	35	1	36	1
Summer Tanager	---	34	34	1
Rufous-crowned Sparrow	30	1	31	1
Brewer's Sparrow	26	3	29	1
Chihuahuan Raven	26	1	27	1
Eurasian Collared-Dove	3	24	27	1
Crissal Thrasher	17	3	20	1
Green-tailed Towhee	15	3	18	1
Painted Bunting	---	17	17	1
Blue-gray Gnatcatcher	16	1	17	1
Ladder-backed Woodpecker	1	14	15	1
Common Raven	14	---	14	1
Greater Roadrunner	9	4	13	0
Scaled Quail	12	---	12	0
Mallard	---	11	11	0
Bewick's Wren	10	---	10	0
Curve-billed Thrasher	8	2	10	0
Loggerhead Shrike	10	---	10	0
Wilson's Warbler	---	10	10	0

Species	Habitat class		# of birds detected	
	Grassland	Riparian	Total	% of total
Brown-headed Cowbird	---	9	9	0
Canyon Towhee	9	---	9	0
Gambel's Quail	---	9	9	0
Lesser Nighthawk	4	4	8	0
Blue Grosbeak	---	7	7	0
Clay-colored Sparrow	---	7	7	0
House Wren	7	---	7	0
Northern Shoveler	---	6	6	0
Canyon Wren	2	3	5	0
Great Horned Owl	1	4	5	0
Hepatic Tanager	---	5	5	0
Brewer's Blackbird	---	4	4	0
Carolina Wren	---	4	4	0
Common Ground-Dove	---	4	4	0
Say's Phoebe	1	3	4	0
Yellow-rumped Warbler	---	4	4	0
Bank Swallow	---	3	3	0
Black Vulture	---	3	3	0
Black-chinned Hummingbird	---	3	3	0
Cassin's Sparrow	3	---	3	0
Vermilion Flycatcher	---	3	3	0
Belted Kingfisher	---	2	2	0
Black Phoebe	---	2	2	0
Black-chinned Sparrow	2	---	2	0
Blue-winged Teal	---	2	2	0
Gray Flycatcher	---	2	2	0
Gray Hawk	---	2	2	0
Killdeer	---	2	2	0
Peregrine Falcon	---	2	2	0
Phainopepla	1	1	2	0
American Coot	---	1	1	0
Barn Swallow	---	1	1	0
Common Nighthawk	---	1	1	0
Great Egret	---	1	1	0
Inca Dove	---	1	1	0
Northern Harrier	1	---	1	0
Northern Parula	---	1	1	0
Northern Rough-winged Swallow	---	1	1	0
Spotted Sandpiper	---	1	1	0

Species	Habitat class		# of birds detected	
	Grassland	Riparian	Total	% of total
Spotted Towhee	1	---	1	0
Warbling Vireo	---	1	1	0
Western Meadowlark	1	---	1	0
White-throated Sparrow	---	1	1	0
White-throated Swift	---	1	1	0
Yellow Warbler	---	1	1	0
Unidentified Bird	27	11	38	1
Unidentified Sparrow	26	8	34	1
Unidentified Blackbird	---	28	28	1
Unidentified Thrasher	17	---	17	1
Unidentified Dove	1	3	4	0
Unidentified Swallow	---	3	3	0
Unidentified Hummingbird	---	2	2	0
Unidentified Corvid	1	---	1	0
Unidentified Flycatcher	---	1	1	0
Unidentified Warbler	---	1	1	0
Unidentified Woodpecker	---	1	1	0
Unidentified Wren	---	1	1	0
Total	**1,645**	**1,037**	**2,682**	**100**

Appendix O. Number of birds detected of each species in each habitat class in Big Bend National Park during 2013 Rocky Mountain Bird Observatory survey. Table reproduced from White and Valentine-Darby (2014).

Species	Habitat class		# of birds detected	
	Grassland	Riparian	Total	% of total
Black-throated Sparrow	376	18	394	13
Mourning Dove	245	65	310	10
Bell's Vireo	33	166	199	6
Northern Mockingbird	171	17	188	6
Cactus Wren	161	--	161	5
White-winged Dove	32	129	161	5
Ash-throated Flycatcher	77	53	130	4
Pyrrhuloxia	115	14	129	4
Brewer's Sparrow	119	--	119	4
Northern Cardinal	--	88	88	3
Turkey Vulture	74	13	87	3
Rock Wren	54	6	60	2
Verdin	39	15	54	2
Yellow-breasted Chat	--	53	53	2
Yellow-rumped Warbler	2	51	53	2
House Finch	22	30	52	2
Scott's Oriole	39	5	44	1
Black-tailed Gnatcatcher	39	2	41	1
Common Yellowthroat	--	40	40	1
Cassin's Sparrow	38	--	38	1
Lark Bunting	31	--	31	1
Summer Tanager	1	30	31	1
Chipping Sparrow	19	8	27	1
Wilson's Warbler	--	26	26	1
Chihuahuan Raven	18	6	24	1
Scaled Quail	23	--	23	1
Common Raven	18	4	22	1
Green-tailed Towhee	19	2	21	1
Blue-gray Gnatcatcher	15	5	20	1
Rufous-crowned Sparrow	18	1	19	1
Canyon Towhee	18	--	18	1
Ladder-backed Woodpecker	8	9	17	1
Mallard	--	17	17	1
Eurasian Collared-Dove	--	16	16	1
Northern Rough-winged Swallow	--	15	15	0

Species	Habitat class		# of birds detected	
	Grassland	Riparian	Total	% of total
Common Ground-Dove	--	13	13	0
Brewer's Blackbird	--	12	12	0
Canyon Wren	2	10	12	0
Loggerhead Shrike	11	--	11	0
Cave Swallow	--	10	10	0
Barn Swallow	2	6	8	0
Bewick's Wren	7	--	7	0
Gadwall	--	7	7	0
Lincoln's Sparrow	--	7	7	0
Lucy's Warbler	--	7	7	0
Say's Phoebe	3	4	7	0
Black Phoebe	--	6	6	0
House Wren	1	5	6	0
Orange-crowned Warbler	1	5	6	0
Vermilion Flycatcher	--	6	6	0
Black Vulture	--	5	5	0
Great Horned Owl	--	5	5	0
Lark Sparrow	5	--	5	0
White-crowned Sparrow	3	2	5	0
Crissal Thrasher	2	2	4	0
Gambel's Quail	3	1	4	0
Swamp Sparrow	--	4	4	0
Black-chinned Sparrow	3	--	3	0
Blue-winged Teal	--	3	3	0
Curve-billed Thrasher	3	--	3	0
House Sparrow	--	3	3	0
Ruby-crowned Kinglet	--	3	3	0
Yellow Warbler	--	3	3	0
American Pipit	1	1	2	0
Cliff Swallow	1	1	2	0
Golden-fronted Woodpecker	--	2	2	0
Gray Hawk	--	2	2	0
Lesser Goldfinch	2	--	2	0
Lesser Nighthawk	--	2	2	0
Nashville Warbler	--	2	2	0
Savannah Sparrow	--	2	2	0
Western Kingbird	--	2	2	0
American Goldfinch	--	1	1	0
American Wigeon	--	1	1	0

Species	Habitat class		# of birds detected	
	Grassland	Riparian	Total	% of total
Brown-headed Cowbird	--	1	1	0
Cassin's Kingbird	--	1	1	0
Clay-colored Sparrow	1	--	1	0
Common Black-Hawk	--	1	1	0
Great Blue Heron	--	1	1	0
Killdeer	--	1	1	0
Marsh Wren	--	1	1	0
Northern Harrier	1	--	1	0
Prairie Falcon	1	--	1	0
Red-tailed Hawk	--	1	1	0
Spotted Towhee	1	--	1	0
Western Wood-Pewee	--	1	1	0
Unknown Bird	79	43	122	4
Unknown Sparrow	38	12	50	2
Unknown Raven	14	--	14	0
Unknown Warbler	--	9	9	0
Unknown Hummingbird	2	5	7	0
Unknown Dove	4	2	6	0
Unknown Hawk	3	--	3	0
Unknown Finch	1	--	1	0
Unknown Kingbird	--	1	1	0
Unknown Thrasher	1	--	1	0
Unknown Woodpecker	--	1	1	0
Total	**2020**	**1130**	**3150**	100

Appendix P. Taxonomic classification of benthic macroinvertebrates and counts for individual taxa collected in the Rio Grande in and near BIBE, Texas by Moring (2002). Number of individuals per taxon shown for each site. Subfamily and tribe names excluded. Table modified from Moring (2002).

Class	Order	Family	Genus or scientific name	Colorado Canyon	Santa Elena	Johnson Ranch	Boquillas	Black Gap
Turbellaria				0	0	1	0	0
Aphanoneura	Araeolaimida		*Aelosoma* sp.	2	0	0	0	0
Ostracoda				3	2	0	2	0
Bivalvia	Pelecypoda	Corbiculidae	*Corbicula fluminea*	0	0	0	0	8
		Sphaeriidae		1	0	0	0	0
			Sphaerium sp.	23	0	0	0	0
Gastropoda	Limnophila	Physidae		0	1	0	0	0
			Stenophysa sp.	3	0	4	43	13
Hirudinea	Pharyngobdellida	Erpobdellidae		0	0	0	0	1
Oligochaeta	Haplotaxida	Tubificidae	*Branchiura sowerbyi*	0	0	0	2	0
			Limnodrilus hoffmeisteri	1	47	35	3	2
		Lumbricidae	*Lumbricina*	1	0	0	0	1
		Enchytraeidae		0	0	0	1	1
		Naididae	*Nais pardalis*	23	0	0	0	0
			Paranais sp.	1	0	0	0	0
			Pristina breviseta	2	0	0	3	0
			Dero sp.	0	0	0	3	0
Arachnida	Acarina	Acari		0	0	1	0	0
Insecta	Ephemeroptera	Baetidae	*Callibaetis* sp.	0	0	1	0	0
			Camelobaaetidius sp.	0	0	0	0	1
			Fallceon quilleri	0	0	0	0	1
		Heptageniidae	*Neochoroterpes* sp.	32	51	11	35	33
		Leptophlebiidae		1	12	10	0	0
			Thraulodes sp.	15	5	6	7	19
			Thraulodes gonzalesi	18	16	0	15	41
			Traverella sp.	5	6	0	17	0
			Traverella presidiana	3	0	1	8	23

Class	Order	Family	Genus or scientific name	Colorado Canyon	Santa Elena	Johnson Ranch	Boquillas	Black Gap
		Tricorythidae	*Tricorythodes* sp.	44	20	10	6	10
	Odonata	Coenagrionidae	*Argia* sp.	3	3	1	9	9
		Calopterygidae	*Hetaerina americana*	1	0	0	0	1
		Gomphidae		6	1	5	0	1
			Erpetogomphus sp.	0	1	0	2	5
			Stylurus sp.	0	0	0	0	1
		Macromiidae	*Macromia* sp.	0	0	0	0	1
	Hemiptera	Belostomatidae	*Abedus* sp.	0	1	0	0	0
		Corixidae		2	14	33	18	44
			Trichocorixa sp.	1	3	7	2	20
		Naucoridae	*Ambryus* sp.	1	1	1	0	4
			Cryphocricos sp.	4	1	6	0	0
		Veliidae		1	0	0	6	0
			Trochopus sp.	0	0	0	0	1
	Megaloptera	Corydalidae	*Corydalus* sp.	6	3	2	0	0
	Trichoptera			0	0	1	0	0
		Glossomatidae		0	0	0	1	0
			Protoptila sp.	0	0	2	0	6
		Hydropsychidae		1	0	3	0	0
			Cheumatopsyche sp.	64	1	52	42	15
			Smicridea sp.	25	10	14	1	7
		Hydroptilidae		0	0	0	0	1
			Hydroptila sp.	2	0	1	2	2
			Mayatrichia sp.	89	58	19	0	6
			Ochrotrichia sp.	20	0	0	2	4
	Lepidoptera	Pyralidae	*Petrophila* sp.	9	0	5	1	5
	Coleoptera	Dytiscidae	*Laccophilus* sp.	0	0	0	1	0
		Hydrophilidae		0	0	1	0	0
		Elmidae	*Heterlimnius* sp.	0	0	2	2	0

Class	Order	Family	Genus or scientific name	Colorado Canyon	Santa Elena	Johnson Ranch	Boquillas	Black Gap
			Hexacylloepus sp.	0	0	0	0	1
			Microcylloepus sp.	0	0	0	2	1
			Microcylloepus pusillus	75	6	30	7	2
		Dryopidae	*Helichus* sp.	10	2	5	13	11
		Ceratopogonidae		1	0	0	1	0
			Hemerodromia sp.	2	0	1	2	0
		Ephydridae		0	3	0	0	0
		Simulidae		6	15	23	0	0
			Simulium sp.	0	48	256	1,075	159
			Cnephia sp.	423	745	336	0	682
		Tabanidae		1	1	0	0	0
		Chironomidae		0	0	0	0	1
			Ablabesmyia sp.	6	28	24		14
			Labrundinia sp.	13	2	3	2	1
			Thienemannimyia gr. sp.	1	0	0	12	58
			Thienemannimyia sp.	0	0	0	14	0
			Telopelopia okoboji	167	155	207	1	57
			Cricotopus bicinctus gr.	15	12	216	2	11
			Cricotopus sp.	42	11	86	4	61
			Cricotopus trifascia	0	0	0	9	2
			Nanocladius sp.	42	0	0	0	0
			Nanocladius distinctus	48	89	33	0	2
			Orthocladius rivicola gr.	4	13	14	0	12
			Orthocladius complex	6	4	5	7	0
			Parakiefferiella sp.	193	133	52	2	14
			Thienemanniella sp.	6	3	15	5	6
				0	0	0	1	0
			Chironomus sp.	12	21	38	19	18
			Cryptochironomus sp.	2	5	10	3	1

Class	Order	Family	Genus or scientific name	Colorado Canyon	Santa Elena	Johnson Ranch	Boquillas	Black Gap
			Dicrotendipes sp.	0	2	0	1	2
			Paralauterborniella nigrohalteris	15	0	0	9	3
			Polypedilum	6	0	3	4	47
			Polypedilum convictum	0	5	15	125	6
			Polypedilum scalaenum	44	48	114	3	26
			Polypedilum tritum	6	0	0	8	0
			Tanytarsus sp.	4	5	1	29	6

Appendix Q. Known Ephemeroptera and Trichoptera (E+T) from BIBE and Big Bend Ranch State Park, Texas. Collections are from the Rio Grande, local spring, and spring-fed stream locations unless otherwise noted. Table modified from Baumgardner and Bowles (2005).

Order Ephemeroptera		
	Family Baetidae	
		Acentrella ampla
		Baetis magnus (larvae)[1]
		Callibaetis montanus
		Callibaetis pictus (larvae, reared adults)
		Camelobaetidius kickapoo
		Camelobaetidius mexicanus (larvae)
		Fallceon quilleri (larvae)
	Family Caenidae	
		Brachycercus sp. (adults)
		Caenis bajaensis (larvae)
	Family Leptohyphidae	
		Tricorythodes explicatus (larvae)
		Tricorythodes minutus (larvae, reared adults)
	Family Leptophlebiidae	
		Choroterpes inornata (larvae, reared adults)
		Farrodes mexicanus (larvae)
		Neochoroterpes oklahoma (larvae, adults)
		Thraulodes gonzalesi (larvae, adults)
		Traverella presidiana (larvae, adults)
Order Trichoptera		
	Family Calamoceratidae	
		Phylloicus aeneus
	Family Glossosomatidae	
		Protoptila alexanderi
	Family Helicopsychidae	
		Helicopsyche borealis
		Helicopysche sp.
	Family Hydroptilidae	
		Alisotrichia arizonica
		Hydroptila angusta
		H. arctia
		H. icona
		H. protera
		Hydroptila sp. (larvae only)
		Leucotrichia limpia
		Mayatrichia acuna
		M. ayama

Order Ephemeroptera		
	Family Hydroptilidae	
		Neotrichla minutismella
		N. sonora
		Ochrotrichia boquillas
		O. capitana
		O. dactylophora
		O. spinulata
		O. tarsalis
		O. rothi
		Oxyethira aculea
		O. azteca
		Oxyethira sp.
	Family Hydropsychidae	
		Cheumatopsyche arizonensis[1]
		Cheumatopsyche campyla
		Cheumatopsyche lasia
		Smicridea fasciatella
		S. signata
	Family Leptoceridae	
		Nectopsyche gracilis
	Family Odontoceridae	
		Marilia flexuosa Ulmer or *M. mexicana*
		Marilia nobsca
	Family Philopotamidae	
		Chimarra adella
		C. angustipennis
		C. ridleyi
		C. utahensis
		Chimarra sp.[1]
		Wormaldia arizonensis
	Family Polycentropodidae	
		Polycentropus halidus

1 – Species found only in Big Bend Ranch State Park samples, not in BIBE.

Appendix R. Fish species that occur in the BIBE reach of the Rio Grande River as identified by Hubbs et al. (2008) and modified by BIBE staff. Status of the species is provided when known, abbreviations are as follows: "Native-Et" = Native, Extirpated; "Native-E" = Native, Extinct; "Native-R" = Native, Reintroduced.

Scientific name	Common name	Status
Scaphirhynchus platorynchus	shovelnose sturgeon	Native-Et
Atractosteus spatula	alligator gar	Native-Et
Lepisosteus oculatus	spotted gar	Native
Lepisosteus osseus	longnose gar	Native
Anguilla rostrata	American eel	Native-Et
Dorosoma cepedianum	gizzard shad	Native
Dorosoma petenense	threadfin shad	Introduced
Campostoma anomalum	central stoneroller	
Campostoma ornatum	Mexican stoneroller	Native
Cyprinella lutrensis	red shiner	Native
Cyprinella lutrensis blairi	Maravillas red shiner	Native-E
Cyprinella proserpina	Proserpine shiner	
Cyprinella venusta	blacktail shiner	Introduced
Cyprinus carpio	common carp	Introduced
Dionda argentosa	Manantial roundnose minnow	
Dionda diabolic	Devils River minnow	
Dionda episcopa	roundnose minnnow	Native
Hybognathus amarus	Rio Grande silvery minnow	Native-R
Macrhybopsis aestivalis	speckled chub	Native
Notropis amabilis	Texas shiner	
Notropis braytoni	Tamaulipas shiner	Native
Notropis buchanani	ghost shiner	
Notropis chihuahua	Chihuahua shiner	Native
Notropis jemezanus	Rio Grande shiner	Native
Notropis orca	phantom shiner	Native-E
Notropis simus pecosensis	Pecos bluntnose shiner	
Notropis simus simus	bluntnose shiner	Native-E
Notropis stramineus	sand shiner	
Pimephales promelas	fathead minnow	Introduced
Pimephales vigilax	bullhead minnow	Introduced
Rhinichthys cataractae	longnose dace	Native
Carpiodes carpio	river carpsucker	Native
Cycleptus elongatus	blue sucker	Native
Ictiobus bubalus	smallmouth buffalo	Native
Ictiobus niger	black buffalo	Introduced
Moxostoma austrinum	west Mexican redhorse	Native
Moxostoma congestum	gray redhorse	Native
Astyanax mexicanus	Mexican tetra	Native
Ameiurus melas	black bullhead	

Scientific name	Common name	Status
Ictalurus furcatus	blue catfish	Native
Ictalurus lupus	headwater catfish	Native-Et
Ictalurus punctatus	channel catfish	Native
Ictalurus sp.	Chihuahua catfish	Native
Pylodictis olivaris	flathead catfish	Native
Menidia beryllina	inland silverside	Introduced
Fundulus grandis	gulf killifish	
Fundulus zebrinus	plains killifish	Introduced
Lucania parva	rainwater killifish	
Gambusia affinis	western mosquitofish	Native
Gambusia amistadensis	Amistad gambusia	Native-E
Gambusia gaigei	Big Bend gambusia	Native
Gambusia geiseri	Largespring gambusia	
Gambusia senilis	blotched gambusia	
Gambusia speciosa	Tex-Mex gambusia	
Cyprinodon eximius	Conchos pupfish	Native
Cyprinodon pecosensis	Pecos pupfish	
Cyprinodon variegatus	sheepshead minnow	
Morone chrysops	white bass	Introduced
Morone saxatilis	striped bass	Introduced
Lepomis auritus	redbreast sunfish	
Lepomis cyanellus	green sunfish	Native
Lepomis gulosus	warmouth	Native
Lepomis macrochirus	bluegill	Native
Lepomis megalotis	longear sunfish	Native
Lepomis microlophus	redear sunfish	Introduced
Lepomis miniatus	redspotted sunfish	
Micropterus dolomieu	smallmouth bass	Introduced
Micropterus salmoides	largemouth bass	Native
Pomoxis annularis	white crappie	
Etheostoma grahami	Rio Grande darter	Native
Aplodinotus grunniens	freshwater drum	Native
Cichlasoma cyanoguttatum	Rio Grande cichlid	Native
Oreochromis aureus	blue tilapia	Introduced
Total Introduced		13
Total Native		32
Total Native and Extinct		4
Total Native and Extirpated		4
Reintroduced		1
Total		**53**

Appendix S. Reptile species documented in BIBE. Schmidly et al. (1996) and NPS (2011) document only the presence of species, while Prival and Goode (2005) reported the number of individuals of each species recorded during their survey.

Scientific Name	Common Name	Schmidly et al. (1996)	Prival and Goode (2005)	NPS 2011
Agkistrodon contortrix	Trans-Pecos copperhead	x	4	x
Anolis carolinensis	green anole			x
Apalone spinifera emoryi	Texas spiny softshell		7	x
Arizona elegans	Kansas glossy snake	x	7	x
Aspidoscelis inornata heptagramma	Trans-Pecos striped whiptail	x	34	x
Aspidoscelis marmorata	marbled whiptail	x	184	x
Aspidoscelis septemvittata septemvittata	Big Bend spotted whiptail	x	116	x
Aspidoscelis tesselata	common checkered whiptail		3	x
Bogertophis subocularis	Trans-Pecos rat snake	x	23	x
Coleonyx brevis	Texas banded gecko	x	38	x
Coleonyx reticulatus	reticulate banded gecko		3	x
Cophosaurus texanus scitulus	Chihuahuan greater earless lizard	x	178	x
Crotalus atrox	western diamondback rattlesnake	x	86	x
Crotalus lepidus	mottled rock rattlesnake	x	3	x
Crotalus molossus	black-tailed rattlesnake	x	27	x
Crotalus scutulatus	Mohave rattlesnake	x	11	x
Crotaphytus collaris	eastern collared lizard	x	6	x
Diadophis punctatus regalis	regal ringsnake	x		
Diadophis punctatus	ring-necked snake		3	x
Elaphe bairdi	Baird's ratsnake		2	x
Elaphe emoryi	Great Plains rat snake	x	1	x
Eumeces obsoletus	Great Plains skink	x	8	x
Eumeces tetragrammus brevilineatus	short-lined skink	x	8	x
Gambelia wislizenii	long-nosed leopard lizard	x	2	x
Gerrhonotus infernalis	Texas alligator lizard		3	x
Gopherus berlandieri	Berlandier's tortoise			x
Gyalopion canum	Chihuahuan hook-nosed snake			x
Hemidactylus turcicus	Mediterranean house gecko			x
Hypsiglena torquata janii	Texas nightsnake	x	28	x
Kinosternon flavescens	yellow mud turtle	x	24	x
Lampropeltis alterna	gray-banded kingsnake			x
Lampropeltis getula	desert kingsnake			x
Lampropeltis triangulum	Mexican milksnake			x
Leptotyphlops dissectus	Texas threadsnake			x
Leptotyphlops humilis segregus	Trans-Pecos threadsnake		1	x
Masticophis flagellum	western coachwhip	x	30	x

Scientific Name	Common Name	Schmidly et al. (1996)	Prival and Goode (2005)	NPS 2011
Masticophis taeniatus	central Texas whipsnake	x	6	x
Nerodia erythrogaster transversa	blotched watersnake		2	x
Phrynosoma cornutum	Texas horned lizard	x	1	x
Phrynosoma modestum	round-tailed horned lizard	x	9	x
Pituophis catenifer affinis	Sonoran gopher snake	x	6	x
Pseudemys gorzugi	Rio Grande cooter			x
Rhinocheilus lecontei	Texas long-nosed snake	x	12	x
Salvadora grahamiae grahamiae	mountain patch-nosed snake		2	x
Salvadora hexalepis deserticola	Big Bend patch-nosed snake	x	2	x
Sceloporus cowlesi	southwestern fence lizard		14	x
Sceloporus consobrinus	southern prairie lizard	x		
Sceloporus magister	twin-spotted spiny lizard	x	10	x
Sceloporus merriami	Big Bend canyon lizard	x	408	x
Sceloporus poinsettii	crevice spiny lizard	x	67	x
Sonora semiannulata	ground snake; variable groundsnake	x	8	x
Tantilla cucullata	Trans-Pecos black-headed snake		1	x
Tantilla hobartsmithi	southwestern black-headed snake	x	4	x
Terrapene ornata	desert box turtle			x
Thamnophis cyrtopsis	western black-necked garter snake	x	35	x
Thamnophis marcianus	checkered garter snake	x	4	x
Trachemys gaigeae gaigeae	Big Bend slider		4	x
Trachemys scripta	red-eared slider			x
Trimorphodon biscutatus vilkinsonii	Texas lyresnake		1	x
Urosaurus ornatus	Big Bend tree lizard	x	67	x
Uta stansburiana	side-blotched lizard	x	52	x

Appendix T. Sky quality photometric report for Emory Peak, 20 November 2003.

National Park Service Night Sky Program

Night Sky Quality Monitoring Report

PARK:	Big Bend National Park	**EQUIPMENT:**	Apogee, 35mm f/2, Bessel V		
SITE NAME:	Emory peak	**OBSERVERS:**	D Duriscoe, R Skiles, M Hersey		
LONGITUDE:	-103.30533	**AIR TEMP (°F):**	50		
LATITUDE:	29.246083	**REL HUMID (%):**	11		
ELEVATION (m):	2394	**WIND SP (mph):**	8		
DATE (UT):	November 20, 2003	**CCD TEMP (°C):**	-25		
TIME START (UT):	3:02:26	**EXP (seconds):**	10		
DATA QUALITY:	Very Good	**BORTLE CLASS:**	2	**ZLM:**	6.9

NARRATIVE: Extremely dark, virtually free of light polluiton. Zodiacal light strong, brightest feature in west/southwest, whole band seen curving from horizon to horizon. Several very small light domes from cities seen, including El Paso/Juarez, Del Rio, possibly Monterey, others. Lights from Study Butte/Terlingua seen as scattered, not bad. Chisos Basin lights most annoying. Some layered haze, also fairly bright airglow. Incredible detail in the Milky Way, sky as close to pristine as found anywhere in 48 states. Radio antenna causes vertical dark feature to southeast.

SKY BRIGHTNESS DATA

Data Set	Time (UT)	Extinction coefficient (mag/air-mass)	Std Err Y Extinction Regression (mags)	Zenith (mag/sq arc-sec)	Whole Sky (mags)	Sky Above 20° Altitude (mags)	Brightest (mag/sq arc-sec)	Darkest (mag/sq arc-sec)	Synthetic SQM
1st	Start 3:2:26 End 3:21:33	0.121	0.037	21.66	-7.33	-6.77	20.49	21.71	
2nd									
3rd									
4th									
5th									
6th									

1st SET LIGHT DOME DATA

City	Distance (km)	Azimuth	Brightness (mLUX)
Alpine	129	344.0	0.003
El Paso/Ciudad Juarez	411	314.0	0.004
Midland + Odessa	328 + 304	20 + 17	0.002
Del Rio	234	86.0	0.002
Terlingua + Presidio	26 + 109	290 + 289	0.010
Chihuahua	281	257.0	0.004
Total Anthropogenic Sky Glow (mLUX)			**0.073**

Appendix U. Sky quality photometric report for Emory Peak, 15 April 2007.

National Park Service Night Sky Program

Night Sky Quality Monitoring Report

Report date 13-May-10 by: D Duriscoe

PARK:	Big Bend NP	**EQUIPMENT:**	SBIG, 50mm f/2, 6084
SITE NAME:	Emory Peak	**OBSERVERS:**	D Duriscoe, K Magargal
LONGITUDE:	-103.30534	**AIR TEMP (°F):**	44
LATITUDE:	29.24606	**REL HUMID (%):**	32
ELEVATION (m):	2391	**WIND SP (mph):**	3
DATE (UT):	April 15, 2007	**CCD TEMP (°C):**	-20
TIME START (UT):	3:24:04	**EXP (seconds):**	12
DATA QUALITY:	Excellent	**BORTLE CLASS:**	2 **ZLM:** 7.4

NARRATIVE: Excellent night, fairly calm winds but seeing just good, quite a bit of twinkling going on with brighter stars, transparency very good, visibility 100+ miles in daytime. Layered haze seen east and west, west seems hazier. Zodiacal light and Venus dominate early evening, then the band seen irregularly between Cancer and Virgo, gegenschein fairly easy just left and above Spica. ZLM 7.4 with considerable effort, very intermittent, but 7.2 50% of the time seen (Dan). Airglow not strong but not a real dark night, seen especially to the east. to 15 degrees above horizon. Light domes of Del Rio and Presidio brightest but not much of a distraction at all. Midland/Odessa/Alpine seen as a band about 6 degrees wide but no more than 1 or 2 degrees tall and quite faint with bumps for individual cities. El Paso barely glimpsed, Chihuahua seen pretty easily, but fainter than Presidio and Del Rio. Del Rio seems brighter than 3 years ago, others about the same. Very little change in Terlingua/Study Butte, except for a bright reddish light apparently near the road intersection. Lights of Basin development not as bad as I remember, but 3 bright ones near the Restaurant are obvious, about as bright as Sirius each from this location. An exceptionally dark site considering all factors, still unmatched for remoteness from light polluting cities and towns. SQM 21.76 1st, 21.86 2nd. 21.87 beginning of 4th. By local midnight, gegenschein still not dramatic, city light domes seem dimmer, none brighter than 2nd or 3rd magnitude. As to Bortle class, ignoring Basin lights, class 2 based on limiting magnitude. No light dome is bright enough to be offensive. Seeing was not great, probably if steady air exists with good transparency, Class 1 (ZLM 7.5 or fainter) could conceivably be achieved at this site.

SKY BRIGHTNESS DATA

Data Set	Time (UT)	Extinction coefficient (mag/air-mass)	Std Err Y Extinction Regression (mags)	Zenith (mag/sq arc-sec)	Whole Sky (mags)	Sky Above 20° Altitude (mags)	Brightest (mag/sq arc-sec)	Darkest (mag/sq arc-sec)	Synthetic SQM
1st	Start 3:24:4 End 3:44:10	0.156	0.027	21.84	-6.94	-6.34	19.98	22.22	21.85
2nd	Start 4:26:9 End 4:46:17	0.162	0.031	21.90	-6.91	-6.30	20.82	22.19	21.88
3rd	Start 5:28:16 End 5:48:23	0.157	0.032	21.95	-6.90	-6.25	21.03	22.21	21.92
4th	Start 6:30:19 End 6:50:11	0.161	0.030	21.94	-6.96	-6.32	20.23	22.19	21.87
5th									
6th									

2nd SET LIGHT DOME DATA

City	Distance (km)	Azimuth	Brightness (mLUX)
Alpine	129	344.0	0.005
El Paso/Ciudad Juarez	411	314.0	0.010
Midland + Odessa	328 + 304	20 + 17	0.007
Del Rio	234	86.0	0.007
Terlingua + Presidio	26 + 109	290 + 289	0.027
Chihuahua	281	257.0	0.012
Total Anthropogenic Light (mLUX)			**0.199**

Appendix V. Light pollution ratios for Emory Peak, 15 April 2011.

Data Set Number	Local Mean Time at End (decimal hours)	Ratio of Anthropogenic Light to Natural Light								
		Sky Brightness					Illumination of the Land from Sky Glow			
		Hemispheric Illuminance			Luminance			Vertical Surface		
		Entire Sky	Sky Above 20° Altitude	Sky Within 30° of Zenith	Brightest Area	Darkest Area	Horizontal Surface	Mean	Maximum	Minimum
1	20.85	0.04	0.04	0.03	0.96	0.00	0.05	0.16	0.20	0.13
2	21.88	0.04	0.04	0.03	0.16	0.00	0.04	0.11	0.12	0.07
3	22.92	0.05	0.03	0.01	0.05	0.00	0.03	0.11	0.10	0.09
4	23.95	0.11	0.10	0.07	1.14	0.00	0.10	0.18	0.21	0.15

NPS 155/123937, February 2014

National Park Service
U.S. Department of the Interior

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