National Park Service
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Natural Resource Stewardship and Science

Bandelier National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/BAND/NRR—2015/1000

ON THIS PAGE
View of Upper Alamo Canyon, 2009
Photography by: National Park Service

ON THE COVER
View across Burnt Mesa, Bandelier National Monument
Photography by: Dale Coker

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Editors

Brian Jacobs[1]

Barbara Judy[1]

Stephen Fettig[1]

Kay Beeley[1]

Collin Haffey[2]

Catherin Schwemm[3]

Jean Palumbo[4]

Lisa Thomas[4]

[1]Bandelier National Monument
15 Entrance Road
Los Alamos, NM 87544

[2] Jemez Mountain Field Station, USGS
at Bandelier National Monument
15 Entrance Road
Los Alamos, NM 87544

[3]Institute for Wildlife Studies
P.O. Box 1104
Arcata, CA 955184

[4]Southern Colorado Plateau Network
National Park Service
USGS Flagstaff Science Center
2255N. Gemini Drive
Flagstaff, AZ 86001

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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.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

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Note: Appendices are not printed as part of this report, but are instead appended as files on a CD.

Executive Summary

The Natural Resource Condition Assessment (NRCA) Program, administered by National Park Service (NPS) Water Resources Division, aims to document current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. The NRCA for Bandelier National Monument (NM) began in 2010 but was interrupted in June of 2011 by the Las Conchas Fire, which burned over 60% of the monument.

This assessment includes a description of selected resources and, when possible, reference conditions, current condition and trends, and factors that affect current conditions or are likely to affect future conditions. It addresses biological integrity at the landscape scale, as well as for communities and species of management concern. Recent drought and concomitant tree mortality, perhaps foreshadowing a predicted future warmer, drier climate, and the modern history of large severe fires are a focus of the report. Air quality, water quality and hydrology, and natural sounds are also addressed.

Bandelier NM protects over 33,000 acres of rugged but beautiful canyon and mesa country, as well as evidence of a human presence going back over 11,000 years. Petroglyphs, cavate dwellings carved into the soft rock cliffs, and standing masonry walls throughout the landscape are a record of a culture that survives in the surrounding communities.

The landscape of Bandelier NM has changed dramatically over the last century. Heavy grazing, prior to and during early federal management of the monument, effectively excluded fire in a system that had previously included frequent, low-severity surface fire. Subsequent national fire suppression policy and the timing of favorable wet climate windows in the American Southwest allowed land managers to manage ecosystem processes and created a semblance of stability across much of the landscape of the monument for most of the 20th century. Fire exclusion promoted dramatic increases in upland forest density and fuel loading during the early and mid-20th century. Subsequent large and severe crown fires burned over large areas of the monument, converting many forested areas into savannas, shrublands, or grasslands.

In the summer of 2010, scientists from the staff of Bandelier NM and the Southern Colorado Plateau Network (SCPN) of NPS convened a scoping workshop to begin work on the Bandelier NRCA. Collectively, the park natural resources staff and collaborating U.S Geological Survey (USGS) scientists brought over one hundred years of experience and knowledge about the park to this effort (see Chapter 3). At the end of two days of lengthy discussions, prioritization exercises, and decision-making, a list of focal resources emerged which provided direction for setting indicators and measures of resource condition. The final list included twenty-three resources grouped under five main categories: air and climate; geology and soils; water; and biological integrity (see Table 4-1). During the initial scoping, the group also decided that the assessment would develop a quantified and spatially explicit description of recent vegetation change within the monument using the wealth of vegetation data that had been collected by NPS, USGS, and collaborating scientists. Given recent drought-induced tree mortality and repeated catastrophic wildfire impacts over the last several decades, the time was right to synthesize current knowledge of broad-scale vegetation patterns in Bandelier NM.

The resulting vegetation analysis indicated drastic vegetation change within Bandelier NM between 1981 and 2004. Woodlands and savanna with juniper as the canopy dominant have expanded. Immediately upslope, the most striking change was the complete loss of mature piñon from piñon-juniper woodlands. Further upslope a continuing contraction and fragmentation of ponderosa pine stands was evident, with increased shrub dominance in the understory. Ponderosa pine-mixed conifer stands have been replaced by ponderosa pine-shrub communities.

The full impact of the Las Conchas Fire on ponderosa pine and mixed conifer forests has not yet been assessed. Nor are the long-term effects or recovery times known for wildlife communities that depend on forested habitats, such as breeding bird communities. The Las Conchas Fire had substantial physical impacts on both Capulin Creek and the Rito de los Frijoles, greatly altering stream morphology, destroying riparian vegetation, and decimating aquatic macroinvertebrate communities. Given the scale and severity of the Las Conchas Fire, the recovery time for the monument's aquatic systems is uncertain.

Many of the rare plant species occurring in Bandelier NM are associated with mesic forested or riparian habitats that have since been severely altered by the Las Conchas Fire. Overall, their current condition within the monument is poor. The last breeding Mexican spotted owls (MSO) within Bandelier NM were observed in 2002. The Las Conchas Fire destroyed most potential MSO breeding habitat in the monument. Likewise, although less is known about their population biology and distribution, Jemez Mountain salamanders—typically found in mixed conifer forests—are likely declining within the monument.

Since the 1990s natural resource management at Bandelier NM has focused on documenting soil erosion rates in piñon-juniper woodlands and developing restoration treatments to foster the recovery of herbaceous understory vegetation. These efforts have not only improved the ecological integrity of piñon-juniper communities, but have also helped to stabilize archeological sites. More than 75% of the known pre-contact archeological sites within Bandelier NM occur within piñon-juniper communities. Most of these sites have experienced adverse effects related to soil erosion and lack of post-fire vegetation recovery. Erosion management and long-term monitoring of restoration response and erosion rates should continue. Research has begun to assess the role of biological soil crusts in degraded and restored piñon-juniper woodlands, as a next step in the multi-decade campaign to stabilize erosion with the monument.

Bandelier Wilderness is designated as a Class 1 area under the Clean Air Act. However, in the most recent assessments, many of the criteria for air quality fell within the "moderate concern" category, including visibility, ozone, and nitrogen deposition. The Clean Air Act bestows an "affirmative responsibility" on federal land managers to protect Class 1 areas from the adverse effects of air pollution. In section 169A, "Congress hereby declares as a national goal the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class 1 Federal areas in which impairment results from manmade air pollution."

Bandelier NM serves as a harbinger of the types of changes projected for the American Southwest as a result of anthropogenic climate warming. The recent decadal drought, fires, and insect outbreaks have resulted in a landscape much different from one that would be familiar to the park's namesake. This assessment will help guide future goals and direction as the monument resource management focus transitions to preserving key ecological processes and basic ecological capital, and fostering incremental landscape adaptation in the face of a hotter and drier climate.

Contributors

All natural resource staff in the Bandelier National Monument Division of Resources Management provided their expertise directly as NRCA chapter authors, Chapter 4 section authors, supporting contributors, and/or chapter and section reviewers. Craig Allen was involved with the Bandelier staff in all phases of the project; his careful scientific review and attention to scholarship in the last stage of writing were vital contributions. Collin Haffey's writing skills were put to use on various writing and editing assignments in the final months of the project.

Matt Bowker and David Smith's report, *Assessment of Vegetation Change in Bandelier National Monument, a "Barometer of Change in the National Park System"*, formed the basis of the sections on forest and woodland vegetation change in Chapter 4. The unpublished report is included in its entirety in Appendix B.

The Southern Colorado Plateau Network contributed to the report preparation in several ways. Steve Monroe and Stacy Stumpf wrote the water quality and aquatic macroinvertebrate section in Chapter 4; Steve also contributed to the riparian sections. Jean Palumbo and Sonya Daw edited the document and formatted the final publication within InDesign.

Barbara Judy, Lisa Thomas and Cathy Schwemm served as project managers for the Bandelier NRCA and contributed to its writing. Barbara Judy and Lisa Thomas also served as reviewers.

List of Contributors

Name and position	Organization
Craig Allen, Research Ecologist	Jemez Mountain Field Station, USGS
Kay Beeley, GIS Specialist	Bandelier National Monument
Matthew Bowker and David Smith	Northern Arizona University
Sonya Daw, Writer/Editor	Southern Colorado Plateau Network
Stephen Fettig, Wildlife Biologist	Bandelier National Monument
Collin Haffey, Pathways Ecologist Intern	Jemez Mountain Field Station, USGS
Brian Jacobs, Botanist	Bandelier National Monument
Barbara Judy, Chief of Resources	Bandelier National Monument
Stephen Monroe, Hydrologist	Southern Colorado Plateau Network
Jean Palumbo, Writer/Editor	Southern Colorado Plateau Network
Catherin Schwemm, NRCA Ecologist	Institute for Wildlife Studies
Stacy Stumpf, Aquatic Ecologist	Southern Colorado Plateau Network
Lisa Thomas, Program Manager	Southern Colorado Plateau Network
Laura Trader, Fire Ecologist	Bandelier National Monument

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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. 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, the status of resource stewardship planning, and science, the identification of high-priority indicators, the availability of data and the 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. All NRCAs have several characteristics in common:

1. They address a subset of natural resource issues in each park, not all resources. The resource topics are selected by a team of park staff and outside experts based on a variety of criteria, including legal status, management need, and available data.
2. They assess current condition by comparing various measures of present-day status with ecological reference measures that describe past and/or desired conditions.
3. NRCA products are intended to include a substantive spatial component, when relevant, providing data and analyses in spatial presentation and GIS data formats that can be incorporated in future planning and management efforts.
4. They are organized around ecological indicator frameworks, and conform to national guidelines and standards. Specifically, the products include descriptions of indicator resources, definitions of reference conditions, descriptions of data and analysis methods used, evaluations of level of confidence for each assessment, identification of information gaps and research needs, and references.

Although the primary objective of NRCAs is to report on current conditions compared to reference conditions and values, NRCAs also report on trends, when possible and relevant (i.e., when the underlying data and methods support such reporting). Factors that influence resource conditions, such as past activities or conditions that provide a helpful context for understanding current conditions, may also be included.

The methodology for NRCAs typically involves an informal synthesis of scientific data and information from multiple and diverse sources, with a level of rigor and statistical repeatability that varies by resource, depending on available data and expertise. The credibility of an NRCA results 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, and should be adequately documented. There is a close connection with the NPS Inventory and Monitoring (I&M) program: NRCAs utilize I&M data whenever possible, and can potentially contribute to the I&M program by providing current condition estimates and establishing reference conditions and/or baseline values for vital sign indicators.

NRCAs do not establish management targets for study indicators; that process occurs within the realm of park planning and management activities. NRCA products can, however, help park managers define short-term workload priorities, frame data and study needs for important park resources, and communicate 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. The condition analyses and data sets developed for NRCAs will also be useful for park-level climate-change studies and planning efforts.

For more information on the NRCA program, visit:
http://nature.nps.gov/water/nrca/index.cfm

Chapter 2: Park Resource Setting/Resource Stewardship Context

2.1 Introduction

2.1.1 Enabling legislation/ Administrative history/Cultural significance

Located in Los Alamos County, New Mexico, the 33,997-acre Bandelier National Monument (NM) contains one of the largest concentrations of prehispanic archeological sites in the American Southwest. Within the monument are more than 3,000 sites, most associated with the Ancestral Pueblo period and dating from AD 1100 to 1550. These sites consist of large villages containing up to 400 rooms, hundreds of small farming hamlets, cliff houses, and scatters of artifacts. Major sites include Frijolito, Yapashi, Tyuonyi, Long House, San Miguel, Painted Cave, and Tsankawi. The park and the surrounding area also contain a high concentration of a unique architectural form called cavates (cliff houses that have been carved out of the soft volcanic tuff bedrock).

Adolph F. Bandelier, a pioneer in the study of Southwest history and ethnology, visited Frijoles Canyon in October 1880 and was the first person to record the existence of many of the major archeological sites in the area. He was guided by inhabitants of Cochiti Pueblo, who have direct ancestral ties to the sites in Frijoles Canyon. Bandelier's scientific and popular writings brought the area to public attention. In the late 1890s the archeological remains in the region were first proposed for protected status under the names of "Pajarito National Park or Cliff Cities National Park." This park proposal, spearheaded by Edgar L. Hewett, included a much larger tract than the current monument boundaries. To further his proposal, Hewett assisted in the development of the Antiquities Act, which became law in 1906, permitting the president to create national monuments "to preserve historic and prehistoric structures and objects of historic or scientific interest" (Antiquities Act, section 2). Bandelier NM was established by presidential proclamation on February 11, 1916, named after Adolph Bandelier, who died in 1914.

Bandelier's original 22,352 acres were administered by the US Forest Service from 1916 until the National Park Service assumed responsibility in 1932. Over time, lands have been added to the monument, and the current boundaries include approximately 33,997 acres. Congress designated 23,267 acres of the monument as wilderness in 1976.

Bandelier NM is a remarkably rich and significant cultural resource site, and its natural setting has affected these resources throughout its history. Ancestral Puebloan communities were established where natural resources were abundant, and the conditions of those natural resources are now affecting the persistence of the evidence of those communities, especially the erosion resulting from past grazing practices and the

Fishing in El Rito de los Frijoles, 1940.

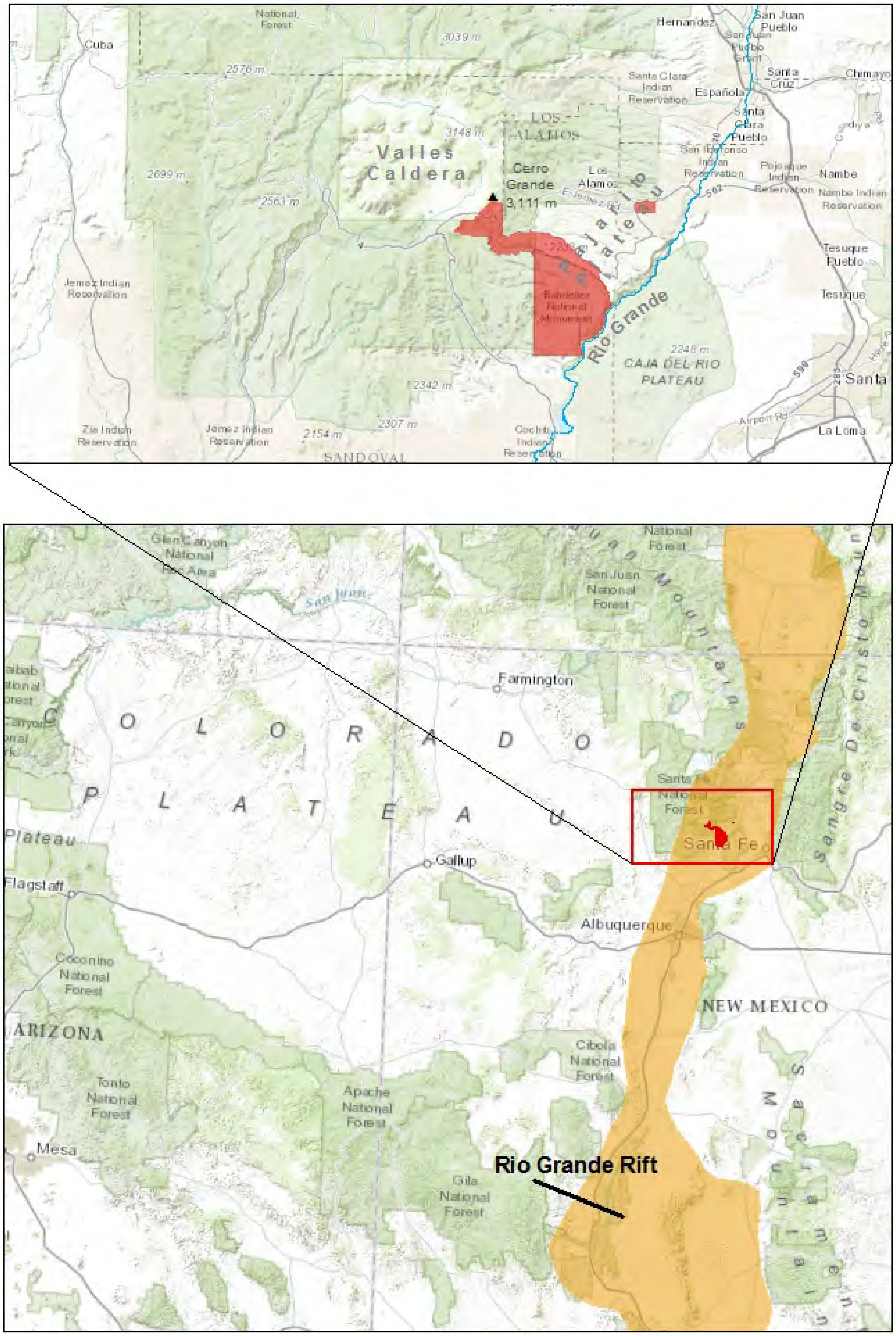


Figure 2-1. Bandelier National Monument is located on the Pajarito Plateau in north central New Mexico.

lack of post-fire vegetation recovery. Because this NRCA is necessarily focused on natural resources, we will not be addressing the cultural contribution of the monument. The reader is directed to several valuable sources for additional information on the human history of the monument, beginning with the "Bandelier National Monument Archaeological and Historic District – National Register Nomination Form" (NR66000042, updated

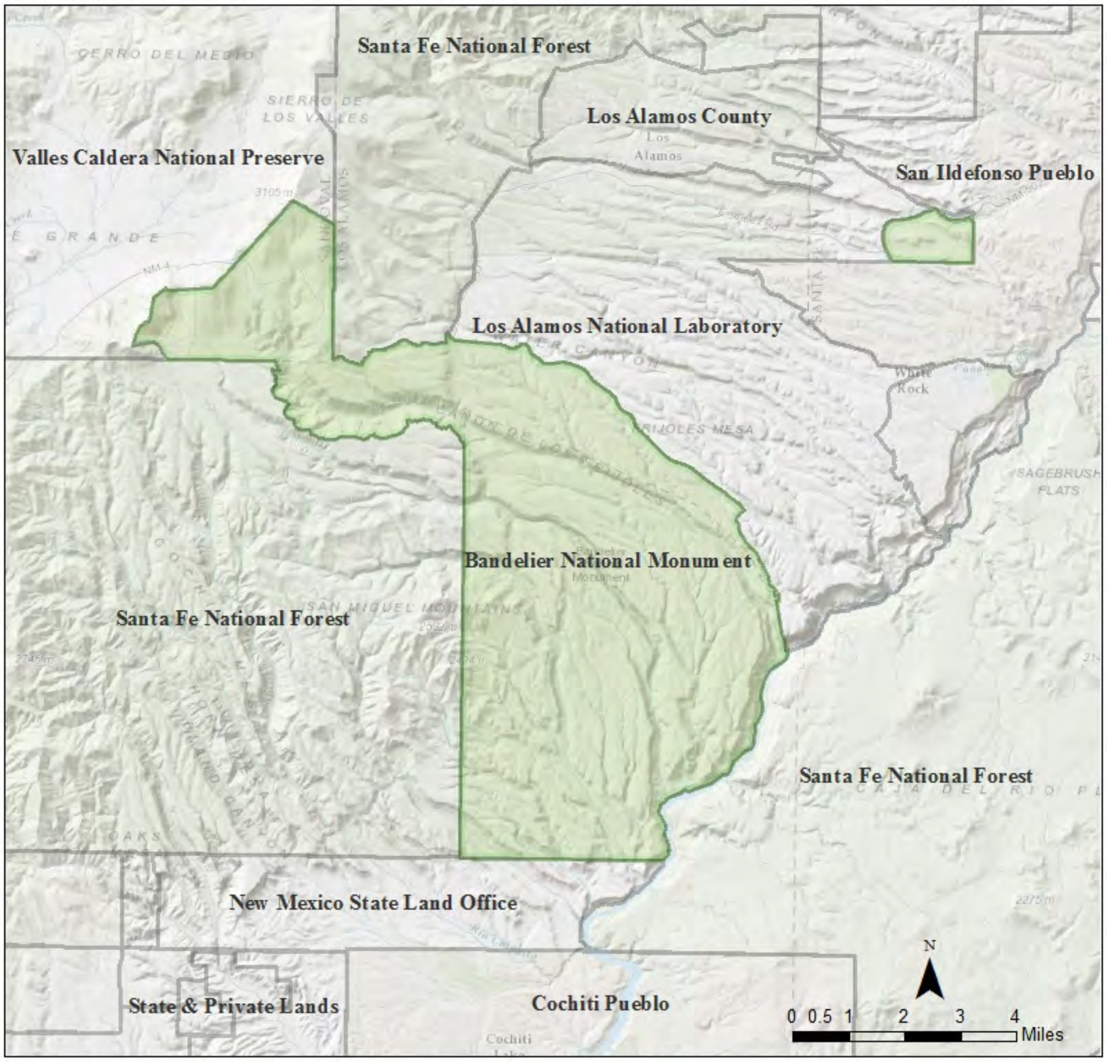


Figure 2-2. Map of public and private lands surrounding Bandelier National Monument.

2014).

2.1.2. Geographic setting

Bandelier NM is located along the southern portion of the volcanic Pajarito Plateau on the southeastern flank of the Jemez Mountains in north-central New Mexico (Figure 2.-1). The Pajarito Plateau is composed of volcanic ash and lava flows ejected from the Valles Caldera in a series of eruptions, the last of which occurred approximately 50,000 years ago (NPS 2014). Erosion has carved the plateau into a series of deep canyons that extend from the edge of the Valles Caldera to the Rio Grande. Of these, Capulin, Alamo, Frijoles, and other smaller canyons are within the monument boundaries. Bandelier NM is bounded on the north along the plateau by Los Alamos National Laboratory (LANL); to the northwest and west by the Jemez District of the Santa Fe National Forest (SFNF); in the northwest corner by Valles Caldera National Preserve (VCNP), and to the south by Cañada de Cochiti land grant and the Rio Grande in White Rock Canyon.

Within the park, there is a long elevational gradient that extends from 1600 m (5,300 ft) at the Rio Grande in the bottom of White Rock Canyon to 3,109 m (10,199 ft) at the summit of Cerro Grande in the Sierra de los Valles (which forms the natural boundary with Valles Caldera). The long elevational gradient, in combination with the geologic, topographic, and soils diversity provides the framework for a wide variety of ecosystem types and complex vegetation patterns.

2.1.3 Surrounding lands/Adjacent ownership

The monument is surrounded by public land managed by federal agencies with a range of mission directives (Figure 2-2). Northwest of the monument is the Valles Caldera National Preserve (89,000 acres/~36,000 ha), federally-owned lands that are at present managed by a public trust. The preserve was re-designated as a unit of the National Park Service by the 113th Congress in December 2014 and will transfer to the Department of Interior in 2015. The area is open to regulated public use and hunting is permitted. To the northeast is Los Alamos National Laboratory (LANL) and the Township of Los Alamos. LANL includes 26,500 acres (~10,700 ha) of open space lands and federal facilities, though use of the land is highly restricted and mostly closed to the public. The remainder of the lands surrounding the monument are primarily within Santa Fe National Forest, including 5,200 acres (~2,100 ha) of the Dome Wilderness directly adjacent to the western boundary of Bandelier Wilderness.

2.1.4 Visitation statistics

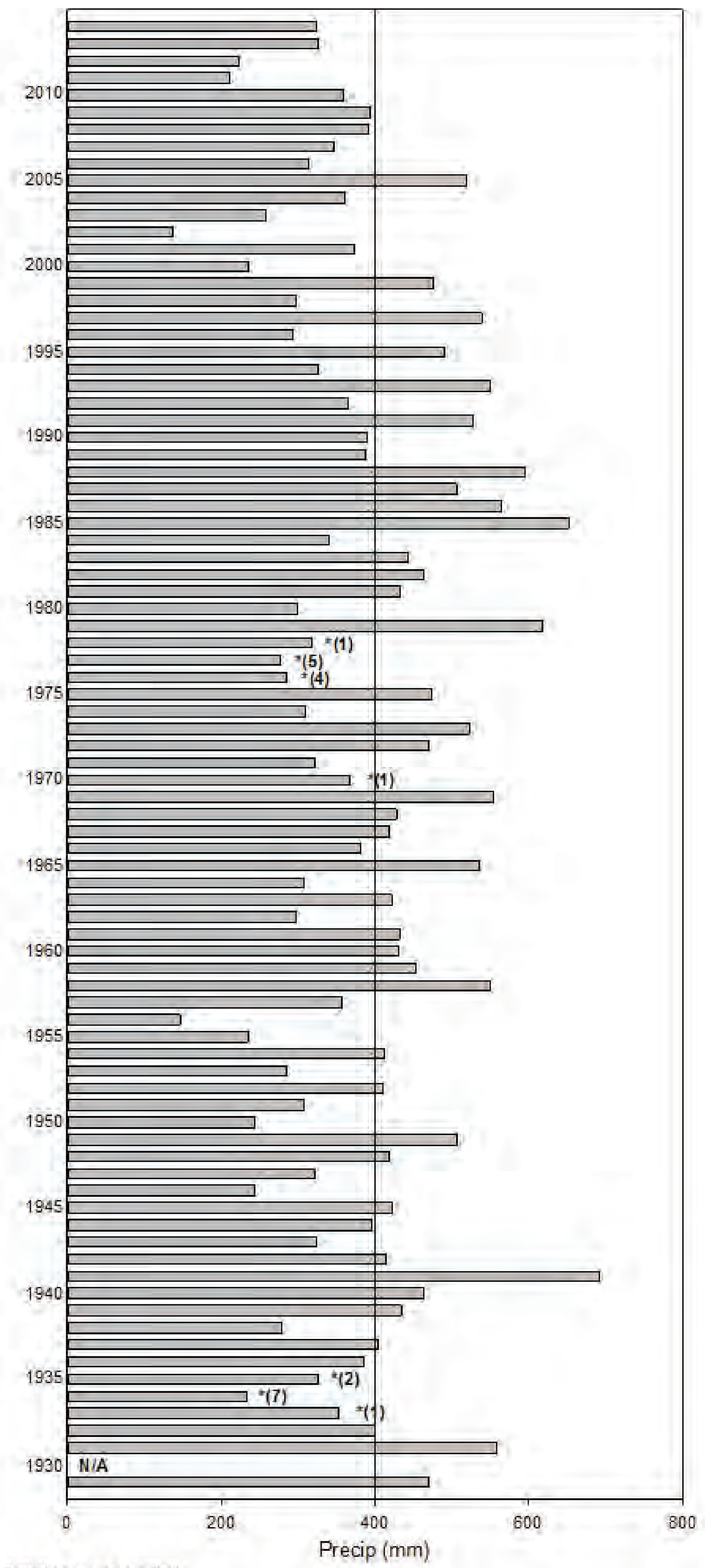
Recorded visitation at Bandelier NM has ranged in recent years from 234,896 (in 2010) to 126,682 (in 2013). During 2010, about 750 people were issued backcountry camping permits. During 2013, about 265 people were issued backcountry camping permits. Camping trips in Bandelier Wilderness generally average one to two nights. Wilderness day use is estimated to be higher than overnight camping use, but since permits are not required for day users the exact number of visitors is unknown. Since the 2011 Las Conchas Fire, visitor use in the wilderness has changed. For example, the southwest corner of the monument is less accessible to hikers due to fire and flood effects, resulting in reduced visitation to Capulin Canyon and Painted Cave. The wilderness portion of Frijoles Canyon, an always a popular destination for day hikers and campers, has received much less use in the past three years due to effects from the fire and subsequent flooding. (Reference: NPS IRMA Park Visitor Statistics and Interpretation Division Backcountry Permit records.)

2.2 Physical resources and processes

2.2.1 Climate

The climate of Bandelier NM is characterized by cool-to-cold, dry winters, and warm, wet (monsoonal) summers. Average monthly temperatures range from lows of -7° to -4°C (20 to 25°F) in December and January, to highs of 30° to 32°C (85 to 90°F) in June. The mean daily temperature extremes range between -10 °C and 6°C (14° and 43°F) in January and 13°C and 30 °C (55° and 86°F) in June, considered the coldest and warmest months of the year, respectively. The coldest recorded daily temperature at nearby Los Alamos was -27.2 °C (-17°F) and the warmest 35 °C (95°F).

Mean annual precipitation is about 427 mm, as recorded at the fire lookout tower near park headquarters (Figure 2-3) (unpublished weather records on file at Bandelier NM). Winter precipitation is delivered principally as snow by low-pressure systems that sweep from west to east across the Southwest, and coalesce with moisture from the Pacific Ocean or the Gulf of Mexico. Winter precipitation is generally followed by a seasonal dry period during the months of May and June. This dry period is defined as much by the increased potential evapotranspiration that accompanies increased day length, solar radiation, and temperatures, as by decreased precipitation. The spring dry period is usually relieved by the onset of the Mexican monsoon; this weather pattern typically delivers at least 40% of the annual precipitation during July through September, and is associated mostly with short-duration, high-intensity thunderstorms. Each summer, as high pressure becomes entrenched off the coast of Baja California, low pressure in the Southwest feeds Pacific moisture across the region, fueling the development of afternoon thunderstorms. The magnitude, frequency,



* (# of missing months)
398 mm average based on 1925-2012 record, excluding missing months

Figure 2-3. Water year precipitation for the period 1929–2014 from the Firetower weather station. The average water year total for the period 1929–2012 is 15.67. Years with missing months are indicated with *(n) with the number of missing months in parentheses.

and tracking of individual large, intense thunderstorm cells during this period can account for large year-to-year variability in annual rainfall and also variability between local areas. The subject of climate and climate change in New Mexico and Bandelier NM are addressed in detail in Enquist and Gori (2008), Fisichelli (2013), Gonzalez (2014), and in Chapter 5 and Appendix A of this report.

2.2.2 Fire

Historically, fire and climate were the primary environmental components that maintained ecosystem diversity at Bandelier NM. Frequent surface fires (6–15 year intervals) in most communities promoted relatively open woodlands of ponderosa pine and mixed conifer forest systems. Cycles of wet and dry periods allowed vegetation to build up during years with above-average precipitation, while dry periods limited recruitment and supported low-intensity lightning-caused fires that further limited recruitment of woody species (Allen 1989). Fire suppression and grazing have now largely eliminated surface fires, and tree densities have increased substantially as a result (Touchan et al. 1996).

High fuel loads, combined with drought conditions have led to a series of increasingly catastrophic fires in the Jemez Mountains over the last 30 years that have destroyed large areas of mature forest and have had numerous detrimental secondary impacts (e.g., exotic plant species expansion, post-fire floods). The 1977 La Mesa Fire burned 15,000 acres (60 km^2), and the 1996 Dome Fire burned 16,500 acres (67 km^2). The Cerro Grande Fire in 2000 originated as a controlled burn but eventually spread to 43,000 acres (194 km^2); while most recently the Las Conchas Fire in 2011 burned over 150,000 acres (600 km^2) and was the largest fire in New Mexico's history. The cumula-

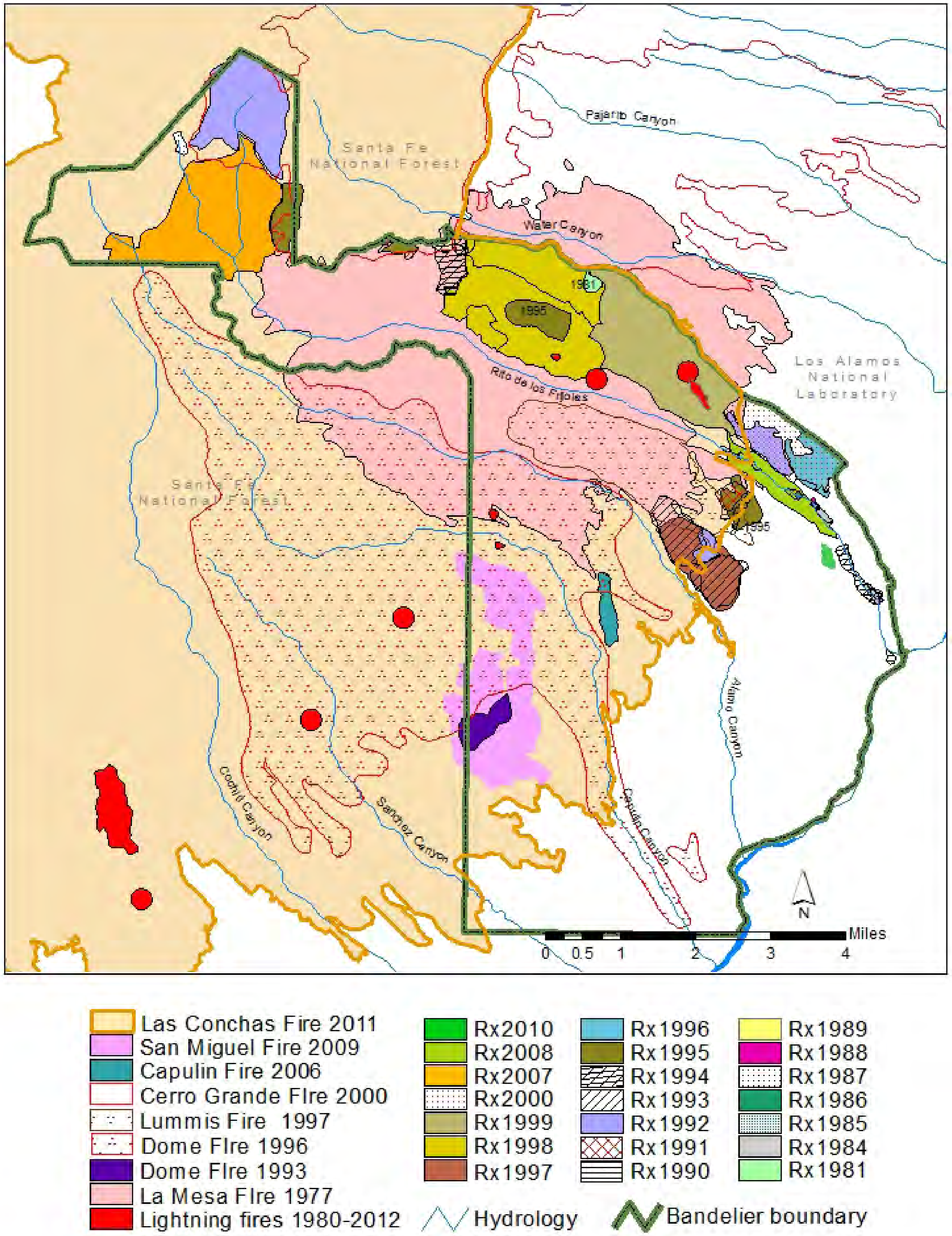


Figure 2-4. Fires greater than 10 acres within and adjacent to Bandelier National Monument for the period 1909–2011. The "Rx" indicates management-ignited fires.

tive result of these events is that there is now almost no forested area of the monument that has not burned in the last 20 years (Figure 2-4). Fire will be a recurring theme throughout this document, and conservation implications discussed in Chapter 5.

2.2.3 Geology

Geologically, Bandelier NM is located on the southeastern flank of the Jemez Mountains, which lie at the intersection of the Jemez lineament and the Rio Grande rift. The Jemez lineament is a chain of volcanic centers extending from Arizona to Colorado, and the Rio Grande rift is a crack in the earth's crust extending from the Rocky Mountains of central Colorado to Chihuahua, Mexico. This geologic interface was the site of a series of volcanic events related to tectonic movements beginning some 16 million years B.P., culminating in two massive explosions that led to the formation of the Toledo and Valles Calderas at 1.61 and 1.23 million years ago, respectively (Spell et al. 1993). The Toledo eruption ejected an estimated 396 km^3 of rock and ash, while the Valles eruption produced about 292 km^3. By comparison, Mt. Saint Helens erupted 25 km^3 and Krakatoa 18 km^3 of new material.

The Valles and Toledo eruptions cumulatively deposited the 300-meter thick Bandelier Tuff in two distinct layers that now dominate the Bandelier NM landscape as part of Pajarito Plateau (the lower Otowi and upper Tshirege members, respectively). The most recent eruption, El Cajete at 50–60,000 B.P., covered the local landscape with many meters of pumice, much of which was subsequently eroded and reworked, leaving pumice patches predominately on east-facing slopes and deep alluvial deposits on lower slopes (Wolff et al. 1996). Along the western boundary of the park lie the San Miguel Mountains, which are comprised of older Tertiary and andesitic and rhyolitic volcanics along with sedimentary sandstones of the Santa Fe Group and Galisteo Formation. The south-to-north trending Parajito Fault Zone ranges from the base of the San Miguel Mountains northward, distinctively separating the Pajarito Plateau from the San Miguel Mountains and the rim country to the west known as Sierra de los Valles and its associated mesas (Sawyer Mesa, Mesa del Rito). The Sierra de los Valles are made up of dacites associated with Cerro Grande and Sawyer Dome, along with rhyolites of Rabbit Mountain. In contrast, the Pajarito Plateau is bounded to the east by White Rock Canyon, a deep gorge containing the Rio Grande that has extensive exposures of Tertiary mafic lava beds.

2.2.3.1 Terrain and watershed characteristics

Topographically, the layered volcanic rocks of the Pajarito Plateau provide a structural control that has led to a series of deeply incised southeast-trending, steep-walled canyons (Frijoles, Lummis, Alamo, Hondo, Capulin, Medio, and Sanchez) alternating with broad mesa tablelands. The tablelands themselves are moderately incised with small drainages that create an undulating topography of small canyons and intervening "interfluves," particularly at the lower, distal ends of the mesas. Conversely, the upper portions of the mesas are flatter and are bounded by the structurally uncontrolled slopes of the San Miguel Mountains and Sierra de los Valles. Along the plateau escarpments and canyon sides there is a distinctive banding of cliffs, rock outcrops, and rubble zones that reflect the stratigraphy of the various members of Bandelier Tuff and other volcanic rocks. Conspicuous are the dramatic pink-to-orange cliffs of the Tshirege Member of Bandelier Tuff that can be over 250 m (820 ft) tall.

The canyon and valley bottoms can contain relatively broad floodplains (100–200 m; 325-650 ft) filled with deep sediments delivered by perennial, intermittent, and ephemeral streams. Frijoles Canyon and Alamo canyons together occupy 9,062 ha (22,392 acres), and Frijoles Canyon contains the only consistently perennial stream, El Rito de los Frijoles. The smaller Hondo, Capulin, Medio, and Sanchez Canyons together account for 4,087 ha (10,099 ac), and have intermittent zones of perennial waters. These drainages join the Rio Grande within White Rock Canyon, which in turn forms the eastern boundary of the monument. The Rio Grande, with its headwaters in the San Juan Mountains of southwestern Colorado, can deliver high discharges, particularly with spring snowmelt (>140 cms, 5,000 cfs), along with significant sediment deposition. While the gorge confines the river on a broad scale, there are floodplain deposits on both sides of the river that are up to 130 m (427 ft) across and support riparian and wetland vegetation. The Rio Grande is impounded 20 km south of the park boundary at Cochiti Lake reservoir. Reservoir filling began in 1972, and the pool at different times has extended up into White Rock Canyon through the monument and into the adjacent tributary canyons some 13 km (eight miles). This has created an identifiable high-water zone as high as 30 m (98 ft) up slopes above the current Rio Grande and side canyon floodplains.

2.2.4 Soils

A first-order soil survey by the Natural Resources Conservation Service (NRCS) was recently completed for Bandelier NM and made available in digital form (Hibner 2005). Thirty-nine soil map units were described and delineated at a 1:24,000 scale, and these are generally organized in broad terrain groups and along an elevation gradient. The map units are made up of various combinations of 34 soil series (and variants) from a wide variety of soil families. At the lowest elevations in White Rock Canyon and surrounding areas are a suite of units that represent the bordering escarpments, mesas and plateaus along with the bottom-land floodplains of the Rio Grande and immediate tributaries. These soils are variously derived from basalt, sedimentary bedrock, or alluvium.

Lower-elevation soils of the plateaus and mesas are derived from colluvium, slope alluvium, or eolian-deposit parent materials over rhyolitic Bandelier Tuff residuum. This group includes moderately developed soils (halplustalfs) of plateau tops (Canuela, Hackroy, and Nyjack series); weakly developed shoulder and backslope soils (ustorthents and ustipsamments) of the Palatka, Zacaton (south facing), and Abrojo (north facing) series, and rock outcrops. In contrast, this group also includes Armenta and Adornado soils that are derived from rhyolitic El Cajete pumice, which overlays the Bandelier Tuff. These soils are deeper (haplustolls), and have comparatively better developed but coarser surface horizons (sandy and gravelly loams). At similar elevations are soils of the inter-plateau canyons and valleys. These include Navajita and Piojillo soils of the lower colluvial toe slopes of canyon sides, along with alluvial soils of valley floors and floodplains (Totavi, Espiritu/Petegral, and Metate).

Mid-elevation mesa tops and slopes of the Pajarito Plateau are represented by a similarly structured group of soil units. Rotado and Tocal soils are relatively deep Paleustalfs and Haplustalfs, respectively, that are derived from rhyolytic tuff and occupy the summits of the interfluves. The shallower Urioste (Ustorthents) and Cymery (Haplustepts), along with rock outcrops, characterize shoulders and backslopes of the canyons. El Cajete pumice soils are represented again by the Adornado series on the plateau tops and the Cajete Series on the slopes. A cooler version of Metate occupies the alluvial terraces of the valley bottoms.

The highest-elevation plateau soils typically occur above the Parajito Fault Zone at greater than 2,300 m (7,500 ft). Tschicoma, Hoxoh, and Jemez are the deeper soils of the plateau summits and summit toeslopes (Argiustolls, Haplustolls, and Haplustalfs, respectively). Shallow Cymery, Urioste, and Estaban soils occupy the slopes, along with rock outcrop. Above the plateaus lie the mountain soils with Mapache and Lucito occupying the lower slopes and Casey the upper slopes and summits of the Sierra de los Valles; Wauquie and Laventana are andesitic soils found on the slopes of the San Miguel Mountains. Tschicoma and Tranquilar soils occupy small valley footslopes and floors,

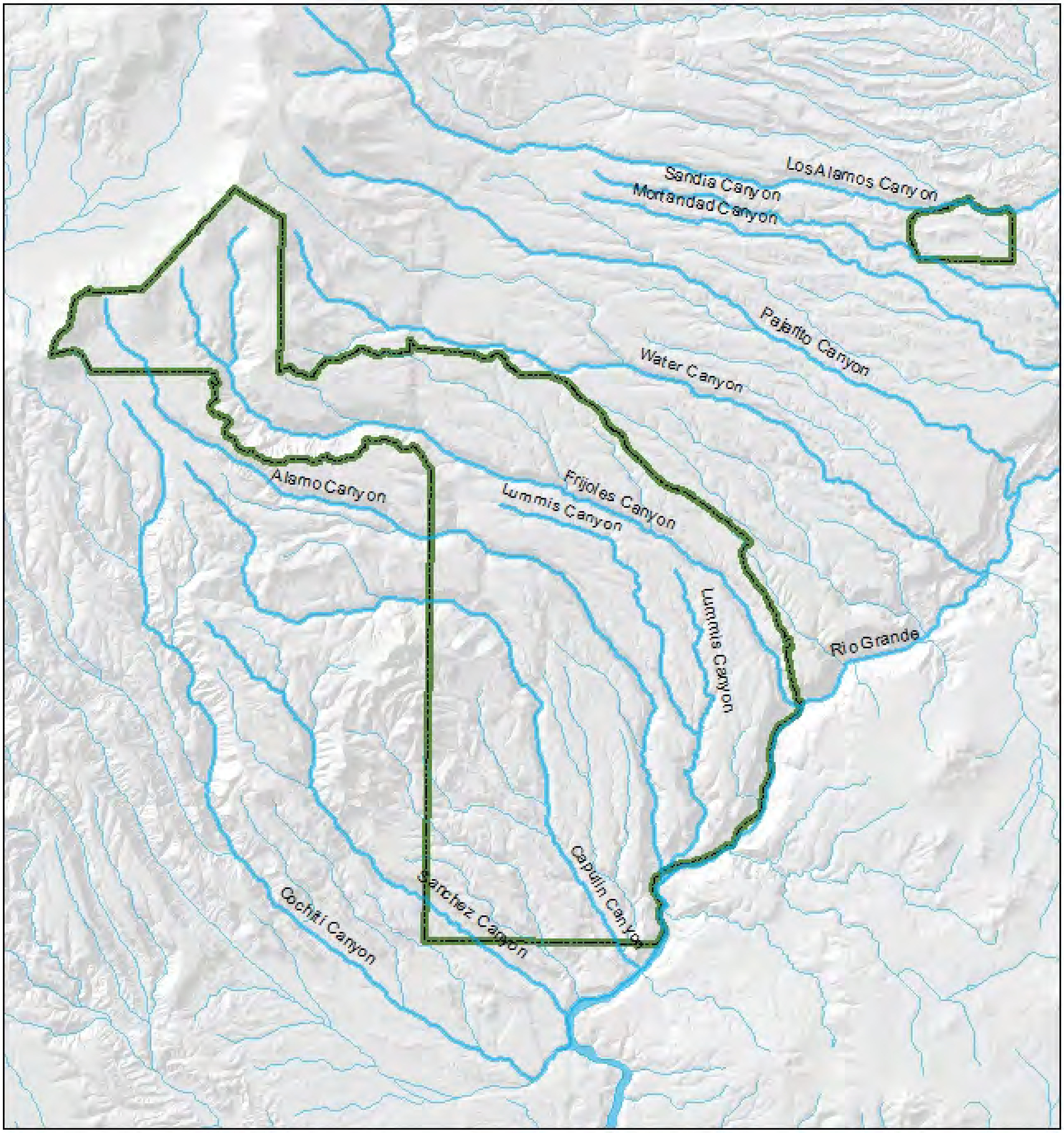


Figure 2-5. Map showing the canyons and drainages of Bandelier National Monument and adjacent lands, with the major canyons and perennial streams labeled.

respectively.

(A detailed soils description is included in Hibner 2005 and NPS 2007.) Erosion is addressed in section 4.01.

2.2.5 Hydrology and water quality

Bandelier NM is located in the Rio Grande-Santa Fe subwatershed (HUC 13020201) within the much larger Rio Grande watershed (Figure 2- 5). The monument contains significant freshwater resources, including springs, perennial and ephemeral streams, wetlands, and groundwater. Partial water sources for streams in the park are springs and seeps at relatively high elevations near the north and west borders of the park, however, most of the flowing water originates on Santa Fe National Forest and Valles Caldera National Preserve lands outside park boundaries. Of note are the two perennial streams in the monument—the Rito de los Frijoles and Capulin Creek. Both flows can become partially subsurface during very dry years. The southeastern boundary of the monument is the Rio Grande River. All water courses in the park generally flow northwest to southeast.

The quality of the freshwater resources in Bandelier NM is of concern to managers (Weeks 2007), and impacts come from two primary sources. Potential for airborne legacy waste deposition from LANL is monitored by LANL, the New Mexico Environment Department Water Quality Division, and by NPS. More recently, the landscape-scale Cerro Grande Fire and the Las Conchas Fire have led to substantial erosion that may have accelerated (temporarily) the leaching of toxics from surface sources, but which have also degraded water quality by increased sedimentation. Water quality is addressed in section 4.11.

2.3 Significant biological resources

2.3.1 Vegetation communities

The Jemez Mountains support a diversity of ecosystems sculpted by variations in elevation, soil type, topography, climate and fire history. A vegetation map for Bandelier NM was completed in 2011 (Muldavin et al. 2011; Figure 2-6), that delineates and describes the vegetation communities in detail; this chapter provides only brief descriptions of the most common plant community types. Much of the vegetation documented in the 2011 map was damaged or destroyed in the Las Conchas fire, however, and a thorough discussion of those impacts is presented for pinyon-juniper woodland, and ponderosa pine and mixed conifer forests in Chapter 4 and Appendix B.

2.3.1.1 Rio Grande corridor

The boundary at the Rio Grande includes the lowest elevations (4,000 ft/1219 m) of the monument. As a natural community, the riparian ecosystem along the Rio Grande has experienced enormous change during the last century, due largely to water impoundments and flow management, both upstream and downstream of the park, but also as a consequence of domestic grazing and exotic vegetation.

2.3.1.2 Montane grasslands

Montane grasslands typically occur in clearings between 7,500 and 10,199 ft (2286–3109 m) and can include many herbaceous species. Prior to 1900, historic high fire frequencies and vigorous grass competition maintained largely treeless grasslands. In the Jemez Mountains there is evidence that with fire suppression during the last 130 years conifers have invaded these high montane grassland sites, creating young forests and savannas rather than open grasslands and meadows.

2.3.1.3 Mixed-conifer/aspen forests

At the higher elevations in the monument (6500–10,170 ft/1980–3100 m) mixed-conifer communities can include Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), aspen (*Populus tremuloides*), Engelmann spruce (*Picea engelmannii*), blue spruce (*Picea pungens*), and limber pine (*Pinus flexilis*) as well as ponderosa pine (*Pinus ponderosa*). Over the last 125 years, the structure and composition of mixed conifer forests have changed dramatically. Fire suppression in the 20th century allowed the development of dense sapling understories in many mixed conifer forests, with tree regeneration dominated by Douglas-fir and white fir.

2.3.1.4 Ponderosa pine forests

At somewhat lower elevations (5,800–10,000 ft/1,770–3,050 m) ponderosa pine forests occur generally below or interspersed among the mixed-conifer forests. Ponderosa pine vegetation communities can be described as forest, woodland or savanna, depending on canopy density, but generally have ponderosa as the dominant overstory species. Ponderosa pine forests across the southwestern U.S. are threatened by several factors, but primarily by changes in fire regimes that have

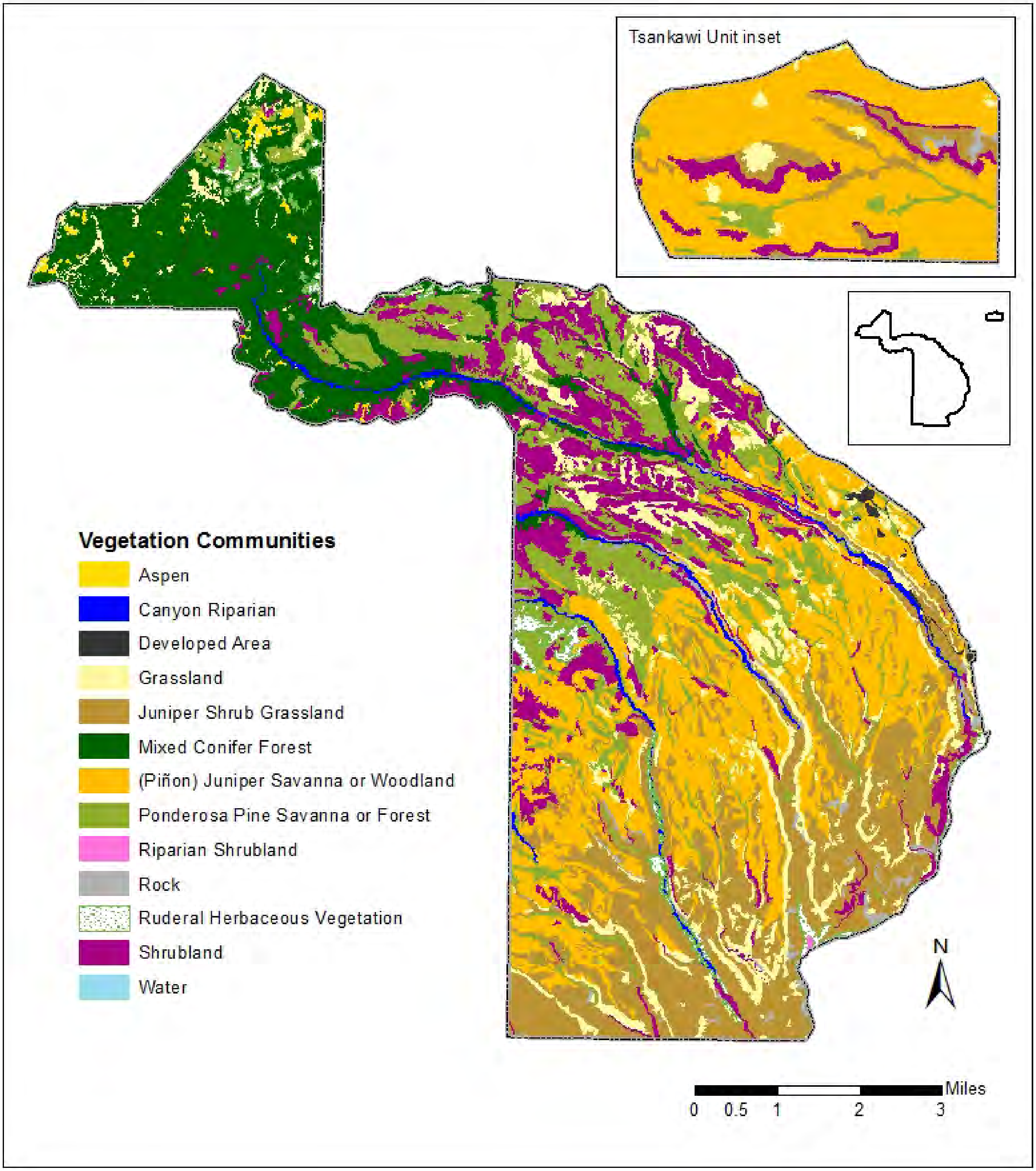


Figure 2-6. Vegetation map showing dominant vegetation types of Bandelier National Monument as of spring 2011, before the Las Conchas Fire burned approximately 60% of the park (Muldavin et al. 2011).

led to unnaturally high tree densities, and by interacting impacts of climate change and drought.

2.3.1.5 Piñon -juniper woodlands

Piñon-juniper woodlands are located in lower warm/dry areas from about 5,350–7,400 ft/1,630–2,260 m, and, at some sites, intergrade with shrub and grassland vegetation. The ecology and distribution of piñon-juniper communities have changed profoundly during the last century, and these changes are particularly apparent in the Jemez Mountains region. Under some conditions, the density of piñon pine (*Pinus edulis*) and juniper (*Juniperus* ssp.) species has increased dramatically, due to the combined effects of fire suppression and grazing. Grazing has reduced or eliminated the herbaceous understory that historically carried low-intensity fires and regulated piñon and juniper abundance; and the absence of fires has allowed trees to survive and mature in greater numbers than would have occurred with natural fire regimes.

In other areas, previous piñon-dominated woodlands recently have been decimated by the related impacts of drought and beetle infestation. Between 2002 and 2003, over 90% of the mature piñons in the monument and on the Pajarito Plateau were killed by a combination of these factors. At present the remaining mature piñons occur only at cooler upper elevations or in localized moister microsites.

The loss and degradation of the piñon–dominated woodland communities are likely permanent changes; soil loss, increasing temperatures, catastrophic fires and the absence of seeds are all factors that impede both natural and human-assisted restoration. Piñon –juniper systems are addressed in section 4.06 and Appendix B.

2.3.2 Vertebrate wildlife

2.3.2.1 Mammals

The diverse plant communities within Bandelier NM support a variety of wildlife species. Two extirpated species and 59 extant species of mammals have been documented at the park (Bogan et al. 2007). Fifteen bat species are known to occur, and of those the spotted bat (*Euderma maculatum*) and big free-tailed bat (*Nyctinomops macrotis*) are of special interest to the park and the state. Mule deer (*Odocoileus hemionus*) and elk (*Cervus canadensis*) are more abundant in the park today than prior to Euro-American arrival. Bighorn sheep (*Ovis canadensis*) had been previously extirpated from the park; New Mexico Game and Fish Department released fifty Rocky Mountain bighorn sheep into Cochiti Canyon in August 2014. Bandelier NM is part of the historic range of the gray wolf (*Canis lupus*) and the grizzly bear (*Ursus arctos*), although neither animal currently exists within the park boundaries.

2.3.2.2 Birds

170 bird species have been documented in Bandelier NM. The 2014 State of the Birds report identified western forest birds that need conservation efforts, as well as common birds in steep decline (NABCI 2014). The report identifies Yellow-Watch-List species which are birds with small populations restricted to a small range, or birds that are more widespread but with troubling declines and high threats. For Bandelier NM, these species include: band-tailed pigeon (*Patagioenas fasciata*), flammulated owl (*Otus flammeolus*), Mexican whip-poor-will (*Antrostomus arizonae*), rufous hummingbird (*Selasphorus rufus*), Lewis's woodpecker (*Melanerpes lewis*), olive-sided flycatcher,(*Contopus cooperi*), pinyon jay (*Gymnorhinus cyanocephalus*), Virginia's warbler (*Oreothlypis virginiae*), Cassin's finch (*Haemorhous cassinii*), evening grosbeak (*Coccothraustes vespertinus*). On the list of common birds in steep decline and regularly occurring in the monument are common nighthawk (*Chordeiles minor*), Wilson's warbler (*Cardellina pusilla*), and pine siskin (*Spinus pinus*).

2.3.2.3 Reptiles and amphibians

A 2002–2003 inventory of the park (Nowak and Persons 2008) observed 17 species of reptiles and amphibians, with an estimated inventory completeness of 65%. There are 44 species known or expected to occur in Bandelier NM. The Jemez Mountains salamander (*Plethodon neomexicanus)* has undergone range-wide declines in recent decades and is listed as threatened by the state of New Mexico. Further information about the Jemez Mountains salamander can be found in section 4.15

2.3.3 Threatened/Endangered species

Threatened and endangered species, such as Mexican spotted owls (*Strix occidentalis lucida*) and Jemez Mountain salamanders, can be found in the Bandelier Wilderness, as well as delisted and monitored animal species such as the peregrine falcon (*Falco peregrinus*) and bald eagle (*Haliaeetus leucocephalus*).

2.3.3.1 Mexican Spotted Owl (*Strix occidentalis lucida*)

Status: Threatened. Mexican spotted owls (MSO) are federally threatened, and until the summer of 2011 several of the major canyons within Bandelier NM were known to have suitable nesting and/or roosting habitat for the birds (Personal communication, Stephen Fettig). Though no owls have been observed during annual surveys since 2002, it was hoped that nesting birds were either going undetected or would return. The Las Conchas fire of 2011 likely destroyed any remaining habitat by removing all of the standing trees that MSO may have been using for roosting and protection. MSO are addressed in section 4.14.

2.3.3.2 Jemez Mountain Salamander (*Plethodon neomexicanus)*

Status: Endangered. The Jemez Mountain salamander is the only endemic amphibian in the Colorado Plateau region, and was listed as federally endangered throughout its range in 2013. Critical habitat was designated in USFS lands west of the monument in mixed conifer forests at elevations between ca. 7,500 to 10,500 feet, where downed trees and sufficient ground litter provide important microhabitat. The Las Conchas Fire (2011) affected much of the known salamanders in Bandelier NM; although these fossorial animals were underground and almost certainly survived the fire itself, the varying fire severities and associated alterations in vegetative habitat had unknown effects on affected populations of this terrestrial salamander. Salamanders are addressed in section 4.15.

2.3.3.3 Bald eagle (*Haliaeetus leucocephalus*)

Status: Delisted, monitored. Bald eagles winter in Bandelier NM, and winter roosting and fishing habitats are located near canyon mouths and along the Rio Grande River.

2.3.3.4 The New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus)*

Under study by the U.S. Fish and Wildlife Service (USFWS) for Endangered status. Under such designation, portions of the monument might be designated as critical habitat.

2.3.4 Species of concern

2.3.4.1 Peregrine falcon (*Falco pereginus*)

Due to impacts from DDT, peregrine falcons were one of the first animals in the U.S. to be listed under the Endangered Species Act in the late 1960s. The primary strategies for peregrine recovery were to raise birds in captivity that would be free of DDT then to release them into protected habitat after the chemical was banned (USFWS 1984). Since that time peregrine falcon populations have recovered extremely well, and the species was officially removed from the Endangered Species list in 1999 (Mesta 1999). However, USFWS requires continued monitoring until at least 2015 (unless populations decline in which case additional action will be taken; USFWS 2003). Consequently NPS still considers breeding peregrines to be a species of concern.

Suitable nesting areas for peregrine falcons occur in and immediately adjacent to the monument, and include piñon-juniper woodlands and ponderosa pine and mixed conifer forests. The 2006 annual surveys indicated the presence of an occupied nest in the park. The Peregrine Falcon Habitat Management plan identifies three management zones that surround suitable nesting ledges and describes visitor use and management that will prevent impacts, particularly to breeding falcons.

2.3.4.2 American Pika (*Ochotona princeps*)

Pikas are small lagomorphs (rabbit family) distributed across most of the high altitude regions of western North America that have been proposed for listing. Though found at high elevations, pikas do not hibernate and spend much of the relatively short, high-altitude summer foraging and collecting vegetation for winter use. Interacting, multiple effects of climate change (e.g., declining precipitation, higher temperatures, less snowfall), now appear to be significantly reducing the number of supportive sites needed to maintain functioning metapopulations of pikas. Pikas are addressed in section 4.18.

2.3.4.3 Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*)

This species may have been extirpated many decades prior to the Las Conchas Fire as a result of introducing non-native rainbow, brown and brook trout into all the major park streams, but was certainly lost following the fire in 2011 and associated extreme floods. Trout are addressed in section 4.12.

2.3.4.4 Grama-grass cactus (*Sclerocactus papyracanthus*)

The status of this species in Bandelier NM is undetermined; it was documented in the late 1980s but has been rarely seen since then. Grama-grass cactus is a small, relatively short-lived species that is often cryptic in its habitat and similar in appearance to the grama grass (*Bouteloua* spp.) with which it is often associated. Grama-grass cactus is distributed across New Mexico and adjacent portions of Arizona and Texas at elevations between about 5,000 and 7,510 ft (1,525–2,290 m). Grama-grass cactus is included in section 4.07.

2.3.4.5 Yellow lady's slipper (*Cypripedium parviflorum* var. *pubescens*)

The yellow lady's slipper orchid is extremely rare in the Jemez Mountains and is known from only a few localities, though it is widely distributed across North America. It occurs in relatively open and grassy mixed conifer forests of upper elevation, mesic canyons, on well watered benches, seeps, and bogs on the north facing sides (Personal communication, Brian Jacobs). This species tolerates shade to nearly full sun conditions in fairly open sites within riparian-associated forest communities, meadows and clearings, however, many of the populations documented in the monument prior to the Las Conchas Fire in 2011 were located near small spot fire locations from the 1977 La Mesa Fire (Personal communication, Brian Jacobs). Yellow lady's slipper is included in section 4.07.

2.3.4.6 Cerro hawthorn (*Crataegus erythropoda*)

This hawthorn is an uncommon, but locally abundant, small tree of well-watered upper canyon areas. This species is found only in the Rocky Mountain states of Colorado, Arizona, New Mexico, Wyoming and Utah, and in the Jemez Mountains is found between about 7,000–8,000 ft (2,130–2,440 m) in elevation. In Bandelier NM it occurs in upper Frijoles Canyon. The global status of this species is generally secure, though it may have been extirpated from Bernalillo and Sandoval counties in New Mexico. Prior to 2011 it was uncommon in the monument, but locally abundant in moist areas of upper canyons. Though directly impacted by the 2011 and 2013 flood events, re-sprouting by several individuals has subsequently been observed (Personal communication, Brian Jacobs). Cerro hawthorn is included in section 4.07.

2.3.5 Internal streams and aquatic resources

2.3.5.1 Capulin Creek and Rito de los Frijoles

The Capulin Creek watershed is a designated wilderness area, managed for recreational use within the boundary of Bandelier NM. The upper reaches of the watershed outside of the park boundary are managed for recreation and timber harvest by the U.S. Forest Service. In 1996 the Dome Fire burned several thousand acres in the Capulin Creek watershed. On 26 June 2011, the Las Conchas Fire ignited and ultimately burned approximately 60% of the land within Bandelier NM, including the majority of the upper portions of Capulin Creek. All canopy and understory vegetation was burned, and subsequent flooding by a large event on 21 August 2011 drastically changed the geomorphology of Capulin Creek within the park.

Rito de los Frijoles is a perennial stream flowing eastward from the Sierra de los Valles to the Rio Grande. The upper reaches of the watershed are a designated wilderness area, managed for recreational use within park boundaries. The Bandelier NM visitor center and numerous archeological sites are located near the stream in the lower portion of the watershed, resulting in high levels of visitor use. In 1977 the La Mesa Fire burned about 6070 ha (15,000 acres) in and near the Rito de los Frijoles watershed. The 2011 Las Conchas Fire burned a large portion of the upper portion of the Rito de los Frijoles watershed. A large flood event on 21 August 2011 significantly affected channel morphology and physical habitat of Rito de los Frijoles. See section 4.10 for information on the Rito de los Frijoles and Capulin Creek riparian communities

2.3.5.2 Aquatic macroinvertebrates

Aquatic macroinvertebrates serve as the primary food base for many aquatic vertebrates, function as the primary processors of energetic inputs in low order streams like those found in Bandelier NM, and are consequently important indicators of ecosystem health. Communities of aquatic macroinvertebrates in streams are commonly monitored alongside physical and chemical properties of water because of their potential to provide additional indications of water quality and overall hydrologic condition (Brasher et al. 2011). The Southern Colorado Plateau Network has been monitoring Capulin Creek and Rito de los Frijoles since 2009. (See section 4.11 for more information on aquatic macroinvertebrates.

2.3.5.3 Native fish

Historical information on native fish occurring in the creeks that are within the park is lacking. Native Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*) populations were extirpated from Capulin Creek by large flood events following the Dome Fire. The New Mexico Department of Game and Fish, Bandelier NM, and the Santa Fe National Forest collaborated to reintroduce this species to Capulin Creek in 2006. The Las Conchas Fire in 2011 and subsequent flooding extirpated all fish from both Capulin Creek and Rito de los Frijoles.

2.4 Relevant regional or landscape scale natural resource information

2.4.1 Elk

Elimination of top predators, and the intentional maintenance by the state of New Mexico of a large herd of elk (*Cervus canadensis*) for hunting purposes, have resulted in a population of elk that is imposing substantial impacts on vegetation. Elk utilize all lands on the plateau, and can have especially potent impacts on shrubs and aspen, particularly post-fire (personal communication, S. Fettig). The role of elk in monument ecosystems is discussed in section 4.17.

2.4.2 Cochiti Reservoir

The Rio Grande River forms the eastern boundary of Bandelier NM from the mouth of Frijoles Canyon on the north to a point midway between Alamo and Capulin Canyons to the south, approximately six river miles (10 km). About 12 miles (20 km) upstream of Frijoles Canyon, the Rio Grande enters White Rock Canyon (WRC), a deeply cut gorge of relatively recent geologic origin, and the river remains within this canyon system until it emerges downstream at the Cochiti Reservoir Dam some 6 miles below the park's southern boundary. Numerous ecological impacts resulted when the dam was constructed and the reservoir filled, including the extirpation of a native plant population (an orchid, *Epipactis gigantea*), and the impairment of several perennial springs that stopped flowing when they were covered with sediment (Personal communications, Brian Jacobs). Seasonal inundation and drawdown of the reservoir continues to support the establishment of weedy species along the perimeter of the lake and riparian areas upstream. Riparian systems upstream of Cochiti are addressed in section 4.10.

2.5 Threats/stressors to important park resources

A comprehensive discussion of threats and stressors to park resources can be found in Chapter 4. Excerpted below are the most critical and encompassing of these impacts.

2.5.1 Climate change

The topic of climate change and changes in the size and intensity of wildland fires is greater than can be addressed here, but is arguably the greatest ecological threat to systems and species at Bandelier NM and across the Colorado Plateau. The cumulative effects of climate change on natural resources and physical processes at the park are incorporated in nearly every topic in Chapter 4, and addressed further as a management concern in Chapter 5.

2.5.2 Fire history and ecology

Fire has played an essential role in shaping and maintaining the vegetation communities and landscapes in Bandelier NM and the Jemez Mountains. Many factors, including climatic conditions, a high occurrence of lightning strikes, availability of surface fuels and flammable vegetation, and topography make fire one of the dominant natural disturbance processes in this region. Most of the vegetation communities and wildlife that have persisted through time here have evolved under the influence of frequent fire. However, natural fire processes, to which vegetation communities and species in the region have adapted, have been altered in multiple ways through human actions, and now climate change.

2.5.3 Park-wide vegetation change

At the scale of the entire monument, there are four tightly-linked phenomena responsible for most change that has occurred in recent decades: 1) climate change, 2) fire, 3) drought/insect outbreak, and 4) past land use. Other factors that strongly affect particular ecosystems in the park, such as elk herbivory or persistent accelerated erosion, are discussed in later sections.

2.5.4 Erosion in piñon-juniper woodlands

Accelerated rates of soil erosion within large portions of the semi-arid piñon-juniper woodland zone were first identified as a management issue in the 1970s in connection with early soil mapping and efforts to control a feral burro (*Equus asinus*) population (Earth Environmental Consultants 1978, Chong 1992). However, it was not until the mid-1980s when park-wide archeological survey efforts began to systematically document erosional impacts to cultural sites.

2.5.5 Nonnative plants

In Bandelier NM, exotic species comprise approximately 15% of all the plant species found within the park, however <5% (e.g., ~40 of ~800 taxa) are considered invasive (NPS 2006). And of those, only about 10-12 species are both high risk and easy to treat. Several species are considered nuisance species in that they are common and fairly wide-ranging, usually in disturbed areas, but they are either weak competitors or treatment on a large scale is not practical. The most challenging management species are those that are so invasive that they are ubiquitous across the landscape and very difficult to constrain.

2.6 Resource stewardship

2.6.1 Management directives, planning guidance and research related to natural resources

2.6.1.1 General/Resource Plans

Master Plan (NPS 1977). The importance of "ethnographic, scientific and educational" values at Bandelier NM was defined and articulated in the 1977 *Master Plan*. The goals of protecting and interpreting the ruins and preserving the park's natural setting were identified as the two primary purposes of the monument.

Resource Management Plan and Environmental Assessment for Bandelier National Monument (NPS 1988). The plan called for landscape ecology research and actions, including inventory of monument flora;

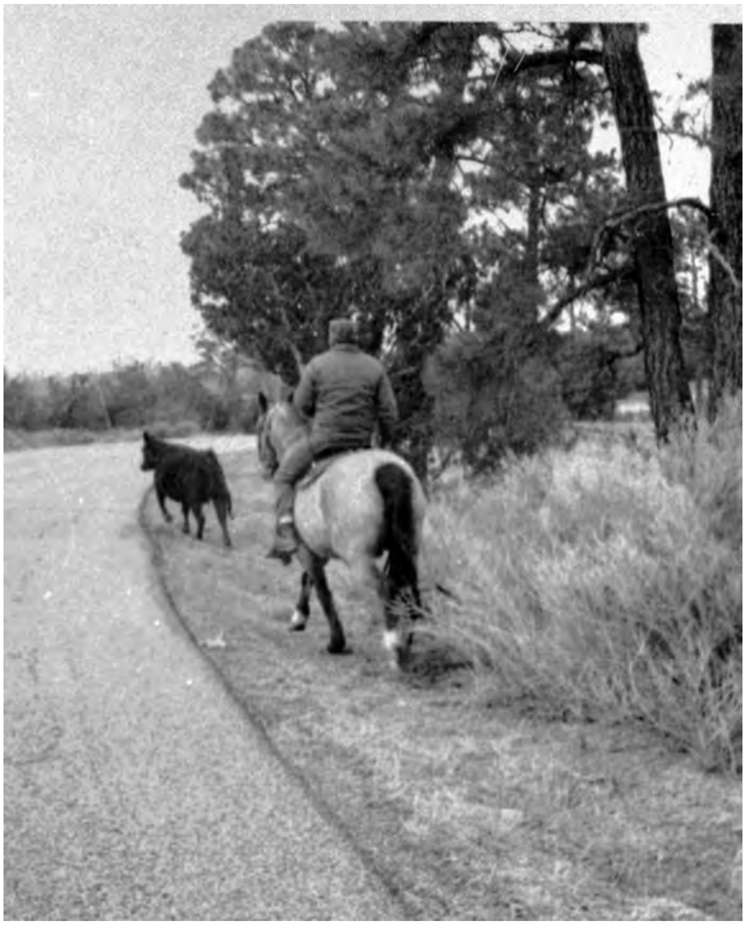
a paleo-environment study of the entire monument; management of burros, cattle and native ungulates; and focus on fire management as a key tool, among other areas of management focus.

Statement for Management (NPS 1990). This update of the park's *Master Plan* addressed the need for managing cultural and natural resources; providing for management-oriented scientific study of issues related to soils erosion and effects of fire suppression on vegetation; and documenting changes resulting from human activities.

Resource Management Plan (NPS 1995). Natural resource management goals and objectives specified in the document were to:

- preserve, protect, interpret and manage the cultural and natural resources of the park within naturally functioning ecosystems, consistent with cultural resource preservation
- provide the means and opportunity for people to study, understand, and enjoy the resources of the monument without unduly compromising the resources or ethnographic values
- restore and sustain natural ecosystem conditions and processes unimpaired from human influence to the degree practicable given landscape and cultural resource constraints
- carry out a wilderness management program which preserves and restores resource conditions and values defined by law and policy and is compatible with cultural resource management objectives
- preserve a comprehensive natural resource base for its value to promote scientific and educational interest

At the time the most critical resource issues were 1) loss of naturally-functioning ecosystems resulting in increased erosion, 2) large-scale vegetation change and loss or alteration of natural processes (predation, fire), and 3) a lack of scientific data, and increasing human activities and external development.



Moving cattle on Monument Road, Bandelier National Monument, 1973. NPS photo

Fire Management Plan (NPS 2005). The purpose of the monument's Fire Management Plan (FMP) was to describe fire and resource management goals and objectives and to provide a framework for incorporating those goals when making fire and fuels management decisions. Specifically, the use of wildland fire was described as the "practice of allowing a naturally ignited wildland fire to burn in a predefined geographic area, under specific prescription parameters, to accomplish fire and resource management goals and objectives". Ironically, as of fall 2014, there is very little area left in the monument that has not been burned in large wildfires or prescribed burns since 1996 (including the Las Conchas Fire of 2011, which alone burned over 60% of the park), and the manner in which the FMP will be applied in the future is uncertain. The FMP is currently (2014) being revised.

2.6.1.2 Specific Resource/Restoration Plans

An Environmental Assessment to Decide How to Eliminate Feral Cattle from Bandelier NM (NPS 1994b) evaluated a range of alternatives and adopted direct reduction by shooting as the proposed action. This plan has been implemented as needed since its adoption in 1994, including as recently as 2009. The plan was challenged in federal court by the New Mexico Livestock Board, who asserted a financial loss following cattle reduction in 1994. A federal magistrate denied the claim by the NM Livestock Board, clearing the way for monument staff to continue implementing feral cattle removal.

Integrated Pest Management Plan, Bandelier National Monument (Jacobs 1994). This administrative document explains the integrated pest management policy at Bandelier NM. Program components and pesticide use and responsibilities are included. The listing of pests include ants, bears, bees, feral cats, cockroaches, coyotes, feral dogs, clothing moths, poison ivy, raccoons, skunks, mice, packrats, squirrels, chipmunks, ticks, feral cattle, and feral burros. For each pest listed there is a description of its biology, impacts, action threshold, and control methods.

Bandelier National Monument Peregrine Falcon Habitat Management Plan (NPS 1994a). Peregrine falcons were delisted in 1999 under the Endangered Species Act. Bandelier NM continues to follow the Peregrine Falcon Habitat Management Plan because across New Mexico this falcon continues to show signs of low breeding success. Productivity (number of young per adult pair) has declined over the 2001–2013 period. Productivity was below 0.9 young per adult pair in 2013 with 1.1 young per adult pair being the minimum rate needed to maintain the state-wide population over the long-term.

The monument's Peregrine Falcon Habitat Management Plan sets disturbance limits for breeding habitat within the park. Disturbance limits are identified on maps as concentric polygons around the most suitable nesting habitats. The largest concentric polygons apply early in the breeding season (starting March 1 each year) when the birds are most sensitive to disturbance. Inner polygons apply later in the breeding season, when young are in the nests. Disturbance limits apply to number and duration of use of all aircraft and motorized equipment, and number of people in walking groups. A critical aspect of the plan is that all nesting habitats are managed as if occupied, unless field observations demonstrate a lack of occupancy at specific sites.

Water Resources Management Plan (Mott 1999). This administrative document presents water resources issues within the context of the monument's setting. Bandelier NM was established to preserve what remains of the area's once thriving Ancestral Puebloan culture. Springs, streams, and riparian zones allowed these ancient agrarians to flourish in an otherwise harsh landscape. The occurrence of water over a wide range of elevations and microclimates continues to support the monument's diverse assemblage of plants and animals, and provides the visitor from today's world a different manner of sustenance.

Biological Assessment Bandelier National Monument Fire Management Plan (NPS 2004). This Biological Assessment (BA) was prepared to meet the requirements of Section 7 of the Endangered Species Act, as amended (ESA) (19 USC 1536 [c], 50 CFR 402), and to assess the effects of implementation of the proposed alternative of the EA on federally listed, proposed or candidate species or their critical habitat that are known to be or could be present within Bandelier NM. This BA integrates research and documentation on federally listed species in the park and the protection measures developed as a collaborative effort of biologists and managers with the NPS and the USFWS.

Vegetation Management Plan (NPS 2002). This administrative document explains the vegetation management policy at Bandelier NM. Vegetation management is a component of many diverse activities planned or on-going at the park. A variety of routine activities, such as road and trail maintenance, hazard tree mitigation and developed landscape maintenance, can be considered vegetation management actions. Prescribed fire, exotic plant control, rare plant management, ruins stabilization and disturbed site revegetation are other management actions which can affect vegetation. Since vegetative systems are dynamic, changes occur in the absence of management actions as well; no action or, alternatively, suppression of 'natural forces', such as wildfire, can allow significant changes to occur. A vegetation management plan provides a context for these diverse activities, prescribes actions, and assigns responsibilities. It also enables park managers to assess the cumulative effects of vegetation management actions park-wide. Through vegetation management planning, managers can understand the vegetation dynamics within their park and coordinate short-term actions to achieve long-term goals.

Exotic Plant Management Plan (NPS 2006). This administrative document explains the exotic plant management policy at Bandelier NM. Written by park botanist Brian Jacobs and approved by Superintendent Darlene Koontz, the plan acknowledges that introduced species already established within the park are likely to become naturalized components of the local flora. Park management seeks to minimize the impacts of these immigrants and contain their spread, but complete eradication is in most instances impractical. At Bandelier NM, primary efforts will be focused on those 'targeted' species which can be effectively controlled or contained using mechanical and/or limited chemical methods.

Bandelier National Monument Final Ecological Restoration Plan and Environmental Impact Statement (NPS 2007). The purpose of the *Ecological Restoration Plan* is to direct efforts to re-establish healthy, sustainable vegetative conditions within the piñon-juniper woodland and to mitigate accelerated soil erosion that threatens cultural resources. This plan evaluates two options for reversing the problems identified above and includes the No Action alternative as a baseline for present management conditions. The primary goal in the Preferred Alternative is to re- establish healthy, sustainable, grass dominated plant communities within the piñon-juniper woodland to help stabilize soils and cultural resources.

Bandelier National Monument Acoustic Monitoring Report (NPS 2014). In 2011, the Natural Sounds and Night Skies Division received a request to collect baseline acoustical data at Bandelier NM. During the months of February and June, 2012, four acoustical monitoring systems were deployed for 28 and 35 days, respectively.

The goal of the technical assistance request was to complete a baseline soundscape inventory throughout the park, especially in the much-visited Frijoles Canyon portion of the park. The results of this inventory will be used in conjunction with a visitor soundscape survey to establish indicators and standards of soundscape quality that will support the park in developing a comprehensive approach to soundscape management planning. This project will develop a Soundscape Desired Condition for the park's pending Foundation for Planning and Management document, provide an impact assessment threshold for development projects within the canyon, and assist the park in assessing potential effects from ongoing and proposed air tourism and helicopter overflights related to park operations.

Pending ~2017 - Fisheries Management Plan. Monument staff have requested assistance from regional subject matter experts to develop a Fisheries Management Plan for the perennial streams in Frijoles and Capulin canyons. Topics to be addressed in the plan include fish management and restoration conditions.

2.6.1.3 Resource Stewardship Strategy

Each national park is directed to develop a Resource Stewardship Strategy (RSS) as part of the park management planning process. Indicators of resource condition, both natural and cultural, are selected by the park. After each indicator is chosen, a target value is determined and the current condition is compared to the desired condition. The completion of this NRCA is the first step in completing an RSS for the monument. Management plans will then be developed to outline actions to be taken over the next 15 to 20 years that will help achieve or maintain the desired condition(s) for each indicator. The RSS will be a multi-disciplinary effort, incorporating a variety of information from different sources.

Pending 2015 – Resource Stewardship Strategy, with Climate Change Vulnerability Assessment. Monument staff has requested assistance from regional and national program staff to carry out an RSS. As preplanning for the RSS, Bandelier NM managers have undertaken development of a Foundation Document (completion scheduled for June 2015; contact Greg Jarvis). In addition, the monument is scheduled for a State-of-the-Park Workshop in March 2015 (contact Jim Haskell). Cumulatively, these advance efforts will have identified key resources and issues and compiled the information required for the development of the RSS. The park is in an excellent position to undertake this planning effort given several decades of research and monitoring which have characterized existing conditions, trends, recent disturbances, and likely trajectories. Much of this is compiled and documented in the NRCA along with emerging issues and challenges that will provide the basis for a comprehensive RSS. Finally, since about 1995 the park has experienced a series of extreme climate events and associated ecological disturbances which, if properly addressed within the context of an RSS, could provide rationales for coherent (proactive versus reactive) management going forward.

2.6.2 Status of supporting science

2.6.2.1 History of the Natural Resource Program and the Bandelier Ecology Group

The natural resource program at Bandelier National Monument was formalized in the mid-to-late 1970s with the development of John Lissoway as the Monument's first natural resource management specialist and, with the strong support of the regional science office in Santa Fe, initiated a number of basic inventory and monitoring efforts. The La Mesa wildfire in 1977 and subsequent post-fire flooding in Frijoles watershed, along with acquisition of the Cerro Grande lands for upper watershed protection, also stimulated additional research work.

Management concerns about soil erosion and feral burro impacts in lower elevation woodland communities, and the potential for catastrophic crown fire in upland forests were major drivers for targeted research, including fire history reconstructions to support the prescribed fire program. Much of the early fire-related work was subsequently documented in the La Mesa symposium proceedings, including the beginnings of integrated natural-cultural efforts.

The resource program began to gain critical mass during the 1980's with an influx of outside researchers (including Brian Jacobs and Craig Allen), and particularly in 1990 with the arrival of a strongly supportive superintendent, Roy Weaver, who then hired a dynamic chief of resource management, Charisse Sydoriak, in 1991 when John Lissoway became the first full-time fire management officer at Bandelier. As part of this critical mass, the park hired Craig Allen as an ecologist in 1989, Kay Beeley as a biologist/GIS specialist in 1992, Brian Jacobs as park botanist/vegetation specialist in 1992, Stephen Fettig as wildlife biologist in 1994, and Laura Trader in 1995 as fire ecologist with the Bandelier fire monitoring program begun in 1992.

By the early 1990s a core staff was in place at the park, and Weaver and Sydoriak continued to develop an integrated natural/cultural/fire resource management program throughout the 1990s, until the Cerro Grande fire brought a close to that chapter of park history. Brian served as the Bandelier NM Botanist until his retirement in December 2014 (see the inset for a description of

Brian Jacobs, botanist, began working in Bandelier National Monument in 1986. He retired in December 2014.

Brian Jacobs retires

Throughout his career at Bandelier National Monument, Brian Jacobs has engaged in both landscape scale research and management of the natural resources in effective ways that have fundamentally improved the current and future condition of the park's ecosystems. Beginning in the late 1980s, with the first comprehensive flora of Bandelier, Brian established a key foundation for all subsequent vegetation studies and management activities. He managed the field collections from the flora in an on-site herbarium, which served as a resource well outside the boundaries of the monument and is now on permanent loan in the regional herbarium collection of the Museum of Southwest Biology at the University of New Mexico and available online from the University of Wyoming.

Brian Jacobs will likely be remembered for his key role in the extraordinary project to ecologically restore large portions of the park's piñon-juniper woodlands. He both contributed vital research on piñon-juniper woodlands and was instrumental in overseeing implementation of the project across the woodland portions of Bandelier. He lined up and oversaw related research activities of graduate students (Richard Gatewood and Brian Hastings), and sizable grants to analyze, treat and monitor the affected woodland landscape between 2002-2012.

Brian's research on piñon-juniper woodlands helped distinguish the age of piñon-juniper stands based on growth characteristics such as size of individuals, and stand and canopy structure. This research contributed to a management framework for different "types" of piñon-juniper and has helped conserve the unique ecosystem across much of the Colorado Plateau. In Bandelier, through years of testing potential approaches, Brian determined that herbaceous ground cover could be markedly improved and soil erosion rates greatly reduced, simply by thinning relatively young piñon-juniper trees (and lopping and scattering their stems as a coarse woody mulch), thereby promoting a more resilient woodland closer to historic pattern and process conditions.

Overall, Brian's contributions to Bandelier supported natural patterns and processes in the ecosystems of Bandelier and adjoining landscapes. He worked on his own and with the NPS Exotic Plant Management Team to eradicate backcountry exotic plants (particularly Tree of Heaven (*Ailanthus altissima*), toadflax (*Linaria vulgaris*), and Russian olive *(Elaeagnus angustifolia*)); he designed and implemented the highly successful rehabilitation of several miles of and old logging and fire road on Burnt Mesa, now an attractive and popular hiking trail; he made many contributions to the park's fire management program, ranging from major inputs into various fire management plans to supervising the multi-park NPS fire monitoring program for a number of years; he was the main architect and driver of Bandelier's current vegetation management plan; and for over 20 years he was the main park liaison for all things hydrological, from gaging stations to water quality studies, including development of a well-regarded water resource management plan for Bandelier.

Brian also focused his energy on studying landscape changes across Bandelier, including the effects of severe drought since ca. 2000, numerous fires, and the ecological restoration project. He partnered with colleagues to acquire diverse data on vegetation and geomorphic changes across the monument through multiple approaches, ranging from plot-level monitoring to remote sensing. For example, in 2014 he initiated a study with researchers from the USGS Canyonlands Field station on the ecological role of microbiotic crusts in semi-arid piñon-juniper woodlands, and their potential to promote or impede vascular plant community recovery after historic landuse.

Brian's contributions to Bandelier National Monument typically were undertaken quietly but substantively in his thoughtful and understated manner, characterized with extraordinary competence and effectiveness. His durable legacy, including valuable research studies implemented, development of long-term natural resource monitoring programs and associated data collected and archived, creation of high-quality management documents, and careful implementation of ecologically-based land management actions, will remain hugely important far into Bandelier's future.

his contributions), while Craig, Kay, Steve, and Laura are still working at Bandelier.

In 1993 the ecologist position was transferred to the new National Biological Survey (NBS), but Craig Allen remained based at Bandelier as a research ecologist, continuing to work directly together with Kay Beeley as the "Bandelier Ecology Group". Dr. Allen was a core partner in building the 1990s resource program. Informed by the solid foundation of his 1989 dissertation work on ecological changes in the Jemez Mountains landscape he identified critical natural resource issues (e.g. soil erosion in piñon juniper woodlands and impacts on cultural resources, stand structure and fire hazards in upland forests, alteration of natural flow regimes on Rio Grande by the U.S. Army Corps of Engineers, elk overpopulation and historic grazing impacts, negative impacts on park resources from activities on adjacent lands) and worked with park management to garner additional support for the program and recruit/build a credible staff.

With the addition of vegetation, GIS, fire, and wildlife expertise to the park's natural resource program, Bandelier's capacity and efforts to address a number of outstanding issues increased markedly during the 1990s, while continuing to build the information base and attract outside researchers. By 1995 the NBS became part of the U.S. Geological Survey, and since then Craig has led the USGS Jemez Mountain Field Station and with Kay the Ecology Group at Bandelier, providing the park with a stable ecology program and expertise which has supported core monitoring efforts while fostering an active research program with numerous external collaborators. USGS ecologist Collin Haffey joined the team near the end of the NRCA project. The long-term synergy between the USGS field station and NPS resource management staff allowed for great strides throughout the past two decades, despite the programmatic setbacks incurred in the aftermath of the Cerro Grande wildfire event. Collectively, this group holds over 125 years of resource management, monitoring and research experience in the Bandelier landscape.

2.6.2.2 NPS Inventory and Monitoring Program

With a mission to improve overall park management through expanded use of scientific knowledge, the Inventory and Monitoring (I&M) Program was established to collect, organize and provide natural resource data, as well as information derived from data through analysis, synthesis and modeling (NPS 2011).

The primary goals of the I&M Program are to:

- Inventory the natural resources under NPS stewardship to determine their nature and status
- Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other altered environments
- Establish natural resource inventory and monitoring as a standard practice throughout the National Park System that transcends traditional program, activity, and funding boundaries
- Integrate natural resource inventory and monitoring information into NPS planning, management, and decision making
- Share NPS accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives (NPS 2011)

To realize these goals, 270 parks with significant natural resources were organized into 32 regional networks. Bandelier NM is part of the Southern Colorado Plateau Network, which also serves eighteen additional parks. Through a rigorous multi-year, interdisciplinary scoping process, each network selected a number of important physical, chemical, and/or biological elements and processes for long-term monitoring. These ecosystem elements and processes are referred to as 'vital signs', and their respective monitoring programs are intended to provide high-quality, long-term information on the status and trends of those resources.

SCPN conducts long-term monitoring of a number of vital signs in Bandelier NM (Thomas et al. 2006). Network staff monitors aquatic macroinvertebrates and water quality in Capulin Creek and in El Rito de los Frijoles. They monitor upland vegetation and soils in the pinyon-juniper woodlands and work in conjunction with the Bandelier Fire Effects Program to monitor the mixed conifer forest. Through a cooperative agreement with Northern Arizona University, they also monitor upland bird communities in the mixed-conifer forest. The network's Land Surface Phenology project uses Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data to monitor the phenology and condition of vegetation and snow cover in all SCPN parks, including Bandelier NM.

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Chapter 3: Study Approach

The Bandelier National Monument (NM) Natural Resource Condition Assessment (NRCA) project was coordinated by the Southern Colorado Plateau Network (SCPN). In January of 2010 the program managers of the Southern and Northern Colorado Plateau Networks hired Cathy Schwemm as a term GS-11 Ecologist to assist both networks with coordination of NRCA projects. The NRCA Ecologist was later funded through a cooperative agreement but continued to perform similar functions throughout the project. In addition, the Bandelier NM staff provided substantial input to the project, including project definition and direction, data summaries and analysis, GIS support, writing, and review. An outside cooperator was funded to focus on the topic of highest priority, and this work also was reviewed by the SCPN program manager, the Bandelier NM staff, and Craig Allen, Jemez Mountain Field Station, U.S. Geological Survey (JMFS-USGS).

3.1 Preliminary scoping

The preliminary scoping workshop was held in July 2010 at Bandelier NM Headquarters in Los Alamos NM. The group that was convened for the initial scoping continued their substantive involvement over the course of the NRCA project. The NRCA team included Bandelier staff Kay Beeley (GIS Specialist), Brian Jacobs (Botanist), Barbara Judy (Resources Management Chief), Laura Trader (Fire Ecologist), and Stephen Fettig (Wildlife Biologist), as well as Craig Allen (JMFS-USGS Research Ecologist). Lisa Thomas (SCPN Program Manager) and Cathy Schwemm (NRCA Ecologist) provided project coordination with able assistance from Barbara Judy. The scoping workshop was held over two days and began with an introduction by SCPN on the general goals and process for completing the NRCA. The remainder of the time was devoted to developing a preliminary list of focal resource topics. To achieve this, the group first constructed a complete list of all possible natural resource topics, but did not attempt to prioritize the topics or identify data sources. The group then discussed how appropriate each topic was for the NRCA, whether the resource was of high concern for management and/or legal reasons, what types of data were currently available and how complete and usable the relevant datasets were, and finally what the relative priority level might be for each topic.

Prioritizing topics was difficult, but necessary for several reasons. First, NRCA guidelines state very clearly that the NRCAs will focus on, '…a subset of important natural resources in national parks.' Given the funding levels for NRCAs and the complexities of national park ecosystems, it is not possible to include all natural resources at the level of assessment required (nor is it probably useful). The group discussed at length how each potential topic would be addressed within the guidelines of the NRCA and whether it was appropriate to include a given topic, perhaps at the expense of something else. It was sometimes difficult to accept that some topics would be considered of moderate or low priority, even though such a designation did not probably indicate that the resource itself was of low priority, only that it might not benefit as greatly from a higher level of attention as might something else.

By the end of the two-day meeting the team had completed the first draft list of resource topics (Table 3-1) and priority levels, and incorporated this list into the NPS Ecological Framework (described below). For various reasons, this list changed somewhat over the course of the project. For example NRCA guidelines generally discourage including visitor and human use issues, so the group agreed to eliminate those topics. The final list (i.e. the Table of Contents for Chapter 4) is presented within the Ecological Framework format (Table 3-2).

NRCA funding for the Bandelier project was sufficient for the park staff to work cooperatively with an outside investigator to address one or two priority topics at a higher level of analysis than was possible without this fund-

Table 3-1. First draft list (July 2010) of all potential topics for the Bandelier National Monument Natural Resource Condition Assessment, herein sorted by priority. Items in bold were identified as being currently monitored or researched at some level.

Element	Management priority	Project priority	Data availability	Level of data summarization	Comments/ data availability
Elk impacts on woody vegetation (aspen)	high	high	high	medium	Multiple data sources are individually summarized; political implications; establishing reference conditions an important and non-trivial task; put BAND data in order first.
Historic spatial patterns of fire	high	high	high	medium	Complete record for 1932 thru 1996 exists, so data since 1996 need to be digitized and updated; spatial patterning of fire and insect outbreaks of interest; fire effects data could be incorporated.
Rio Grande corridor ecosystem	high	high	medium	low	Data are from multiple sources outside NPS, including USFWS and Corps; water holding episodes have resulted in sediment accretion, creating habitat for riparian vegetation, SW willow flycatchers, etc.
Large-scale ecosystem change	high	high	high	medium	Would qualitatively summarize large-scale ecosystem changes over past several decades, and assess changes in relation to natural vs. human-caused drivers, particularly climate; numerous independent lines of anecdotal or semi-quantitative information; find a cooperator to synthesize BAND and Jemez data (possibility to include Forest Service and Valles Caldera NP).
Erosion in pinon-juniper communities	high	medium	high	high	Data are only from a few sites; representative?
Invasive plants (cheatgrass)	high	medium	low	low	Not clear where data would come from: fire effects? I&M? Veg. map?
LANL contaminant impacts on park resources	medium	medium	high	medium	It will likely be difficult to get access to most of the data that would be needed to assess potential impacts to park.
Peregrine falcons	medium	medium	high	high	Summarize BAND population demographics and assess how they relate to statewide decline in productivity; lowest PEFA reproduction in 15 years.
Vegetation change	high	medium	high	high	This is currently being done in PJ; expand to other communities?
Water quality (DDT, cattle, NPS)	medium	medium	high	Low	Water quality impacts come from LANL, DDT site, cattle and NPS; this is important but may not be appropriate for this project.
Jemez Mountain salamander	medium	low	medium	medium	The species is a priority, but much work is being done elsewhere.
High elevation mammals (pikas, bushy-tailed woodrats, red-backed vole)	low	low	low	low	Ongoing research, data availability will increase in coming years.
Bighorn habitat	medium	low			Many outstanding questions regarding a potential re-introduction, so not sure how we would address this issue.
Non-native fish	low	low	high	high	Not a high project priority.
Mexican spotted owl	medium	low	high	high	Could be part of a multi-park assessment; birds have not been seen in the park for about 6 years; 4 occupied territories in the 1990s – Steve speculates that canyons are drier, less preferred as habitat.
Mountain meadows	medium	low	medium	medium	tree encroachment in montane meadows;

Table 3-1. (*continued*) First draft list (July 2010) of all potential topics for the Bandelier National Monument Natural Resource Condition Assessment, herein sorted by priority. Items in bold were identified as being currently monitored or researched at some level.

Element	Management priority	Project priority	Data availability	Level of data summarization	Comments/ data availability
Migratory birds (Grace's warbler)	medium	low	low	medium	This is a national species of conservation concern, but not enough data to consider here; 50% decline in Grace's warblers, a ponderosa pine species.
Wilderness values (viewshed/ night sky/soundscapes)	medium	low	low	low	A soundscape project will begin in FY11, and night skies are being assessed by I&M and NPS night sky program.
Scenic values (Jemez Mtn trail/scenic byway)	medium	low	low	low	Important, but not appropriate for this project.
Bats	low	low	low	low	Mexican freetail bat population – intermittent use of BAND caves would be more appropriate as a multi-park assessment.

ing. Because this opportunity was available, it was important to identify resource topics that were not only amenable to such an approach but that were also of high importance to the park. In the case of Bandelier NM, after developing the draft resource topic list, park staff determined that describing vegetation changes in response to large-scale impacts of wildfire, climate change and ungulate herbivory were their highest priorities for more extensive data analysis and synthesis.

After the meeting, several follow-up conference calls were held with the NRCA Ecologist, SCPN Program Manager, and Bandelier NM and USGS staff participating in the project to better define the resource topics and goals of the project.

3.2 Study design

3.2.1. Ecological framework, reference conditions, reporting areas

3.2.1.1 Ecological framework

The group incorporated the NPS Ecological Monitoring Framework (Fancy et al. 2009) to identify and then synthesize the natural resource topics, indicators, and measures that would be emphasized in the study. This framework was selected due to the tight integration of the framework with the NPS Inventory and Monitoring program from which much of the data used in the NRCA would originate. Further, an element of each assessment is the identification of data needed to better determine current conditions. If there were areas where data gaps seemed important, this information could potentially be incorporated more easily into future I&M program reviews if the topics were organized using this framework.

3.2.1.2 Reference conditions

Reference conditions were developed separately for each topic. Generally the process utilized to develop relevant reference conditions was to first conduct a literature search to determine what types of measures had been or were being used to evaluate similar resources. Discussions were usually then conducted with local knowledge experts, and existing NRCA documents examined to compare references conditions applied to similar resources in other NPS units. In some cases determining reference conditions

Table 3-2. Final list of selected topics organized within the NPS Ecological Monitoring Framework (Fancy et al. 2009). Changes are highlighted in bold with comments.

Level 1 Category	Level 2 Category	BAND Elements
Geology and Soils	Geomorphology	**Erosion in piñon-junipe**r - removed, included in Vegetation Change Assessment (Bowker and Smith)
Water	Water quality	Water quality
Biological Integrity	Invasive species	**Cheatgrass** - removed, separate topic, included in Vegetation Change Assessment Exotic fish **Elk and deer** removed, separate topic
	Infestations and disease	**Widespread vegetation mortality** due to beetle outbreaks; included in Vegetation Change Assessment **Bats/white-nosed syndrome** - removed as a topic for the NRCA
	Focal communities	Aspen Mountain meadows **Migratory landbirds** - priority increased in response to BAND Species of Concern effort **Bats** - removed as a topic for NRCA **Bighorn sheep habitat** - priority increased in response to BAND Species of Concern effort
	At-risk biota	**Jemez Mtn. salamander** - priority increased in response to BAND Species of Concern effort and fire **High-elevation mammals** - focused changed to picas only **Peregrine falcons** - included with raptors Mexican spotted owls **River otters** - added as part of BAND Species of Concern effort **Lynx** - added as part of BAND Species of Concern effort **Mountain lion** - added as part of BAND Species of Concern effort
Human Use	Point source human effects	**LANL contamination** - removed as separate topic, included as threat to water quality **Contamination dynamics** - removed as separate topic, included as threat to water quality
	Visitor and recreation use	**Wilderness values** - removed, not a natural resource
Landscapes and Ecosystem Processes	Fire and fuel dynamics	**Historic fire patterns** - included in larger topic of Fire History and Ecology
	Landscape dynamics	**Large-scale vegetation change** - ultimately included piñon-juniper, ponderosa pine, and mixed conifer vegetation types Rio Grande riparian ecosystem upstream of Cochiti Reservoir **Riparian zone stability** - included in Rito de Frijoles and Capulin Riparian
	Viewscape	**Scenic values** – Jemez Mountain Trail - removed, not a natural resource

was straightforward, for example if a recovery plan had been developed for an endangered species. Conversely, in many cases, particularly for complex ecological processes such as large-scale vegetation change, there currently are no quantified reference conditions available. The process for determining reference conditions (or reasons why they are unavailable or unquantified) is included within each topic section in Chapter 4.

3.2.1.3 Reporting areas

As the project developed we determined that the use of reporting areas would not enhance the project. The two primary influences on park resources and processes at present - catastrophic fire and climate change – are acting across all park systems and management areas.

3.2.2. General approach and methods

Specific elements were approached differently, but in general the NRCA Ecologist and Bandelier NM and USGS staff approached each element in the following manner. First, all NPS, USGS, or other relevant participants were asked to contribute their expertise. In addition the group communicated with any cooperators or researchers recommended by staff or identified from published or unpublished literature. If a resource had been identified during I&M scoping, all supporting documentation for that process was examined. Then a thorough literature search was conducted, first for the specific resource in the park, then for the resource or process in other regions, and then for any restoration, management, or research efforts that might provide information on methods incorporated to assess similar resources.

3.2.3 Components included in each analysis

Per the NPS NRCA guidelines, each assessment includes the following elements:

1. **Background**. This section describes the resource and generally why it was selected for inclusion in the project. It includes threatened or endangered status if appropriate, biological and ecological descriptions and contexts, relevance to the NPS mission, and relationship to specific park planning and management efforts. If known, threats to the resource or process are included in this section.
2. **Reference conditions**. The measures used to evaluate the condition of the resource are defined here. If no clear science-based measures appear to exist and alternate evaluation methods were utilized, those are also described here. The absence of any valid reference is noted here as well.
3. **Data and methods**. This section can include references to both existing data and methodologies evaluated as well as specific assessment methods incorporated for the NRCA.
4. **Resource condition and trend**. This section summarizes what is known about the resource in relation to the described reference conditions.
5. **Level of confidence**. In some cases very little is known about the status of the resource, the conditions that should be used to make the assessment, or both. This section evaluates the level of confidence the team had in making the assessment.
6. **Data gaps/Research needs/Management recommendations**. This section varies in length and scope. In some cases there are clear recommendations for further research or data that would be needed to have a high confidence in making an assessment. If the team had specific management recommendations to improve the state of the resource those may be included here as well.
7. **Sources of expertise**. Subject matter experts not identified elsewhere are listed here.
8. **Literature cited**. Each section is followed by a complete list of citations. In addition, as part of the final product, a database of all references included in the full document will be delivered to NPS.

3.2.4 Project challenges and changes

In the fall of 2011, oversight of the NCPN/SCPN NRCA projects by the NRCA Ecologist was suspended due to an unanticipated funding issue. In October of 2011, FY 2012 budgets were uncertain; neither the NRCA Program, the Intermountain Regional Office Resource Management Division, nor the Inventory and Monitoring Program were willing to take the risk of renewing the term NRCA Ecologist position until FY 2012 NRCA funding levels were established. Consequently, the term position expired. In the summer of 2012 funding for a similar coordinating position was established through a cooperative agreement with the Institute for Wildlife Studies. Through this agreement, Cathy Schwemm renewed her role as the coordinating NRCA Ecologist.

In the spring of 2011, Matt Bowker, with the U.S. Geological Survey Colorado Plateau Field Station, was identified as an appropriate cooperator to analyze and synthesize a broad array of vegetation data for for the park. Later that summer an Interagency Agreement was initiated to fund the data analysis and synthesis work. The following year, Matt Bowker accepted an assistant professorship at NAU. Because the original agreement was between NPS and USGS, it took over six months for USGS and NPS to find a solution to continuing Matt Bowker's involvement in the project. Ultimately, he was rehired as a USGS employee to complete his work on this project, but these administrative issues delayed his work.

The catastrophic Las Conchas Fire, ignited on June 26, 2011, ultimately burned over 60% of the monument. Both the fire and the subsequent floods and soil erosion that followed had immense impacts on park resources, many of which are described in sections of Chapter 4. The disturbances caused by these events not only altered the ecology of many park systems, but required all NPS and USGS personnel involved in the NRCA to divert their workloads dramatically toward the post-fire response. When the NRCA project re-started in the summer of 2012, the NRCA Ecologist and NPS and USGS staff reviewed the direction of the project in light of fire and flood impacts.

Midway through the NRCA process the Bandelier NM staff decided to increase the number of species of management concern that would be addressed in the NRCA report. This was in part because they were already engaged in a systematic review and assessment of these species. This added some additional work and time to the project but did not fundamentally change the focus or direction.

In the fall of 2014, with the news that Barbara Judy would be leaving her post at Bandelier, Lisa Thomas and Barbara Judy scheduled a close-out workshop on November 5th and 6th 2014. The Bandelier team, including Craig Allen and JMFS-USGS Pathways Intern, Collin Haffey, re-convened to review the remaining work for Chapter 4 and to complete Chapter 5 of the NRCA report. Lisa Thomas provided a final content review of Chapters 4 and 5 following completion of the BAND team's work.

3.3. Literature cited

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Chapter 4: Natural Resource Conditions

Chapter 4 is organized thus: (1) big-picture landscape-scale disturbance dynamics and parkwide vegetation change; (2) conditions in the major park ecosystems, starting with high elevation montane meadows and descending to the Rio Grande River and (3) condition of wildlife communities and species within Bandelier National Monument (NM).

The individual topics are also organized within the National Park Service (NPS) Ecological Monitoring Framework. Table 4-1 provides a roadmap to the Chapter 4 resource topics within this framework. Appendix D provides a more comprehensive list of species of management concern.

The Bandelier NM staff added an additional resource category to the topics covered in Chapter 4—Species of Management Interest—to cover species that are not directly managed by the monument, but have been of recurring interest to internal or external conservation partners in recent decades. These are species that historically may have occurred on or near Bandelier NM, but are probably not integral to park ecosystem function.

Table 4-1. Chapter 4 resource topics organized within the NPS Ecological Monitoring Framework.

Level 1	Level 2	Resource – Section
Air and Climate	Air quality	Air quality – 4.23
	Climate and climate change	Climate and climate change at Bandelier NM – Appendix A
Geology and Soils	Soil erosion	Erosion in piñon-juniper – 4.06-1
	Riparian geomorphology	Rio Grande Corridor and associated riparian vegetation – 4.09
		Rito del los Frijoles, Capulin Creek and associated riparian vegetation – 4.10
Water	Hydrology	Rio Grande Corridor and associated riparian vegetation– 4.09 Rito del los Frijoles, Capulin Creek and associated riparian vegetation – 4.10
	Water quality	Rito del los Frijoles, Capulin Creek and associated riparian vegetation – 4.11
Biological Integrity	Communities of concern	Montane grasslands – 4.03 Mixed conifer forest – 4.04 Ponderosa pine woodlands – 4.05 Piñon-juniper woodlands – 4.06 Rio Grande Corridor and associated riparian vegetation – 4.09 Rito del los Frijoles, Capulin Creek and associated riparian vegetation – 4.10 Native fish – 4.12 Landbirds – 4.13
	Species of management concern	American Pika - 4.18 Aspen – 4.04-1
	Species of management concern: At-risk biota	Rare plant species – 4.07 Mexican Spotted Owl – 4.14 Jemez Mountain Salamander – 4.15
	Species of management concern: Apex predators	Mountain lion – 4.16
	Species of management concern: Over-abundant species	Elk and deer – 4.17
	Invasive species	Nonnative plant species – 4.08
Ecosystem Pattern and Processes	Landscape dynamics	Fire history and ecology – 4.01 Parkwide vegetation change – 4.02
	Natural Sounds	Soundscape – 4.22

Ecosystem Pattern and Processes • Landscape Dynamics

4.01 Fire History and Ecology

4.01.1. Description

Fire has played an essential role in shaping and maintaining the vegetation communities and landscapes in Bandelier NM and the Jemez Mountains. Many factors, including climatic conditions, a high occurrence of lightning strikes, availability of surface fuels and flammable vegetation, and topography make fire one of the dominant natural disturbance processes in this region. Most of the vegetation communities and wildlife that have persisted through time here have evolved under the influence of frequent fire. However, natural fire processes, to which vegetation communities and species in the region have adapted, have been altered in multiple ways through human actions and now climate change. The term 'fire regime' is used to describe attributes, such as the frequency, intensity, extent, season, and duration, of naturally occurring fires as they would typically burn in a particular vegetation community or landscape.

The role of fire as an ecosystem driver is discussed in the following four sections, in relation to landscape-scale vegetation change, and in relation to three specific ecosystems—piñon-juniper woodlands, ponderosa pine forests and mixed conifer forests.

Climate

The warm, semi-arid southwestern environment contributes to fire occurrence in Bandelier NM and the Jemez Mountains. In May and June, before the onset of the summer monsoonal rains, temperatures near 100° F are possible and humidity is often extremely low. Strong southwesterly winds are also a common occurrence in the spring, and precipitation totals during this period are often less than half an inch. When fires start in May or June fire extents can be relatively large (Snyderman and Allen 1997). Conversely, the number of fire ignitions is highest in summer months (July, August, and September) when thunderstorms are more frequent; 86% of historic fires recorded in Bandelier were the result of lightning strikes Figure 4-1a (Allen 1984). Fire extents in the summer are generally smaller than in the spring because fuel moisture during these months tends to be higher as a result of monsoon storms Figure 4-1b.

The El Niño-Southern Oscillation (ENSO) phenomenon also has significant effects on precipitation and fire occurrence in Bandelier NM and the Jemez Mountains. ENSO involves fluctuating ocean temperatures: the El Niño or warm phase, where ocean temperatures are warmer than normal, causes enhanced precipitation across the southern U.S., while during the La Niña or cool phase, less precipitation falls (NOAA 2013). Higher precipitation levels stimulate the production of fuels, such as grasses, forbs, and shrubs, allowing these fuels to become more abundant and continuous. In the subsequent La Niña years, these fuels lose moisture and become available for fire ignition and spread (Touchan et al. 1995). Accordingly, major fire years in the Southwest were historically associated with drought conditions that followed periods of precipitation (Touchan et al. 1996).

Numerous sources reveal a long history of frequent low intensity surface fires that burned through continuous herbaceous understories to create relatively open woodlands and savannas in this region, as well as the occurrence of infrequent mixed-severity or stand-replacing fires. While Ancestral Puebloans certainly used fire and likely reinforced the frequent, low intensity fire regime, abundant lightning ignitions appear sufficient to explain most prehistoric fire patterns (Allen 2002a).

The pre-settlement forest structure and fire regime in the Bandelier NM area and the Jemez Mountains was maintained until about the 1880s, when railroads that linked New Mexico with other parts of the U.S. brought millions of sheep and cattle (Allen 2002b). The sheep and cattle overgrazed the land, removing the herbaceous vegetation and fine fuels that had previously carried surface fire.

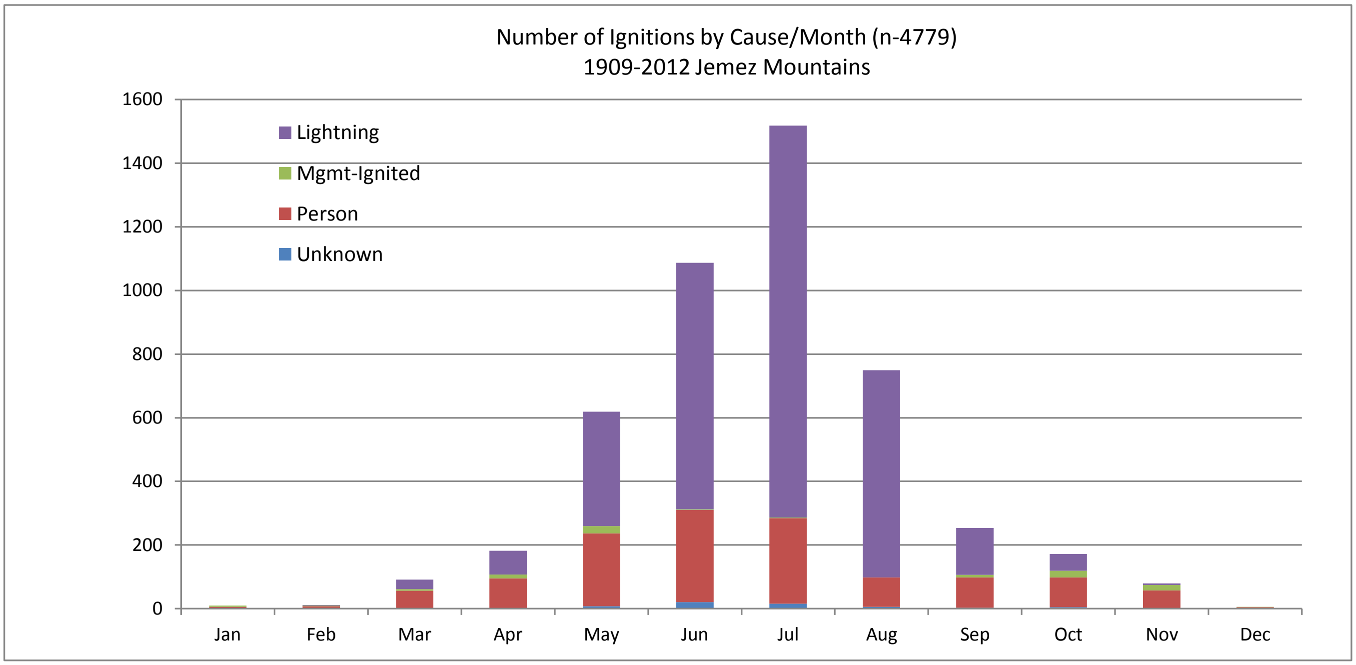

Figure 4-1a. Number of ignitions per month, by type, in the Jemez Mountains, New Mexico, from 1909–2012. Note the large number of ignitions occurring in June and July due to pre-monsoonal dry lightning storms.

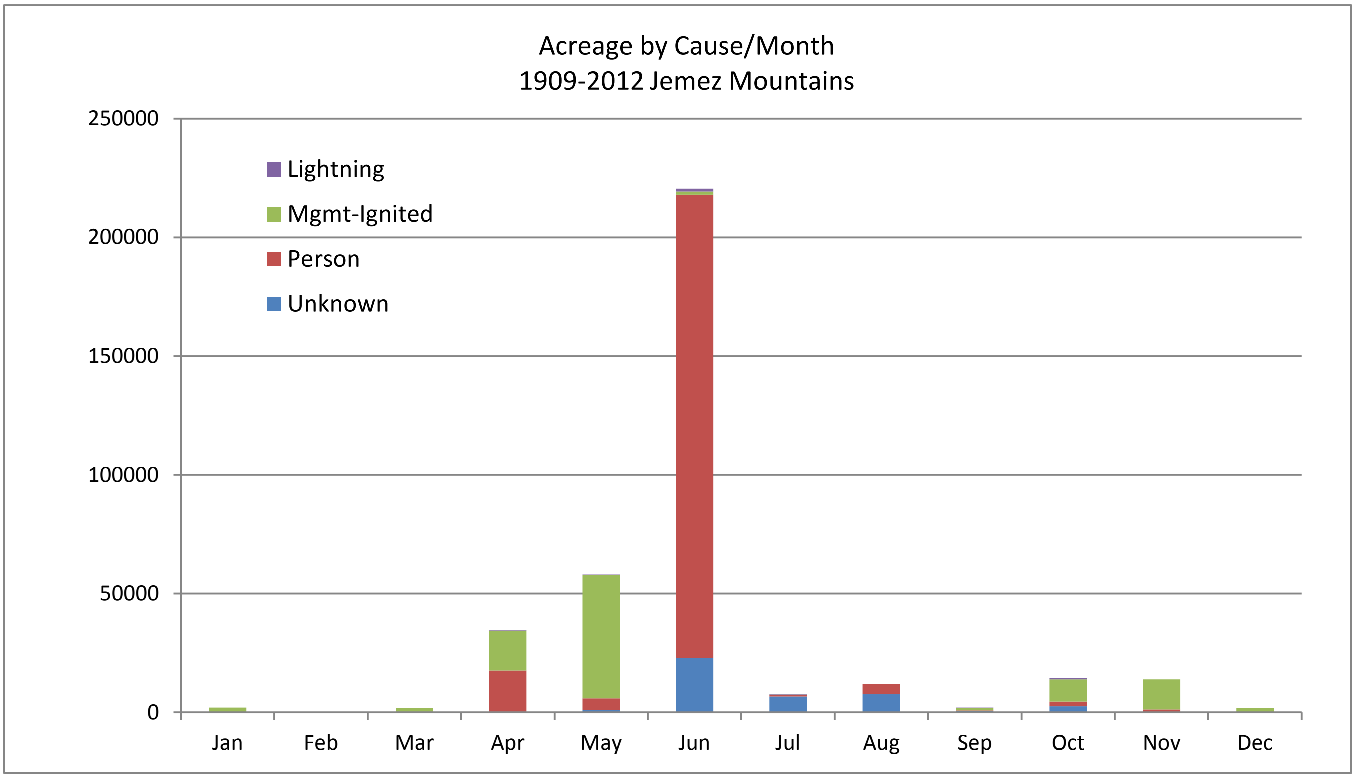

Figure 4-1b. Cumulative acres burned per month, by type of ignition, in the Jemez Mountains, New Mexico, from 1909–2012. Notable large fires burning May and June account for the majority of acres burned. Natural ignitions account for relatively few acres burned, in large part due to successful fire suppression. Human-caused ignitions that occur during seasonally dry conditions when natural ignitions are rare can often result in fires that exhibit unnaturally extreme fire behavior and severity.

In addition, widespread and effective fire suppression efforts began in the early 1900s, resulting in the near cessation of fire (Figure 4-2a).

Over the last century or so, the forest structures and fire regimes that once existed have been greatly altered, producing significant ecological effects on the fire prone-landscape (Potter and Foxx 1978; Allen 1989). Most notably, increased tree densities have resulted in 'crown fires' which can travel in the canopy across the forest at high speed and intensity, in stark contrast to the low intensity surface fires of the past. Fires of this type are now becoming more frequent in ponderosa pine forests, where large stand replacing fire events were once anomalous. The large amounts of surface fuels and compacted litter and duff can burn with high intensity and severity, causing a longer residence time (the amount of time fire burns in a location), and increasing the potential for lethal fire temperatures and deleterious effects on soil properties and vegetation adapted to less intense fires.

The absence of frequent, low intensity surface fire has altered and degraded the forests in Bandelier NM and the Jemez Mountains in many ways. The full range of tree age classes that existed historically has been replaced by extremely high densities of saplings and and mid-story trees. The high tree density also renders the forests more susceptible to disease and insect infestations, causing widespread mortality in trees. The forests no longer have an open canopy structure, limiting light penetration to the forest floor and causing herbaceous plant cover productivity and diversity to decrease. Forest fuels, such as branches, twigs, pine cones, and dead vegetation, have been accumulating to extremely high levels.

In recent decades, a number of unusually large and intense fires have burned across the the monument landscape. The La Mesa Fire of 1977 burned 14,250 acres; the Dome Fire of 1996 burned 16,500 acres; the Cerro Grande Fire in 2000 burned 43,000 acres; and the Las Conchas Fire in 2011 burned 156,593 acres, becoming the second largest fire in New Mexico history (Figure 4-2b).

4.01.2 Reference conditions

Fire-scar chronologies show frequent and widespread fire in the forests of the Jemez Mountains before the 1890s (Allen 2002a). Fire activity (perhaps including multiple ignition points) in Bandelier NM and the Jemez Mountains commonly occurred over extensive areas in some drought years, such that networks of fire-scarred trees record many years where fires burned widely across watersheds in the monument (Allen 1989, 1994, 2007), throughout most of the Jemez Mountains (Allen et al. 1998, Allen 2002a), and even across most mountain ranges in the Southwest (Swetnam et al. 1999).

The fire season was generally in the spring and summer, when climatic and fuel conditions were conducive to fire ignition: fall fires were uncommon (Allen 2002a). Fire duration varied widely, depending on variables such as precipitation, slope, aspect, and elevation. In persistent drought conditions, some fires in ponderosa pine forests could burn for months.

Fire-scar chronologies indicate significant spatial variation in past fire regimes (Allen 2004) which can be summarized for the 3 major forest/woodland ecosystems.

Mixed conifer forest

Prior to the 20th century, the mixed conifer forest experienced frequent fires with a fire return interval of approximately 4–9.7 years. Most fires were low intensity surface fires, but small, patchy crown fires also occurred in mesic mixed conifer forest sites outside Bandelier NM(Touchan et al. 1996).

Ponderosa pine forest/woodland

In the 400 years prior to the 20th century, ponderosa pine forests experienced frequent fires, most of which were low-intensity surface fires (Allen et al. 1995; Touchan et al. 1996). The fire return interval during this period was approximately 5–15 years. Fire frequency tended to be reduced at low-elevation sites and in sites that are topographi-

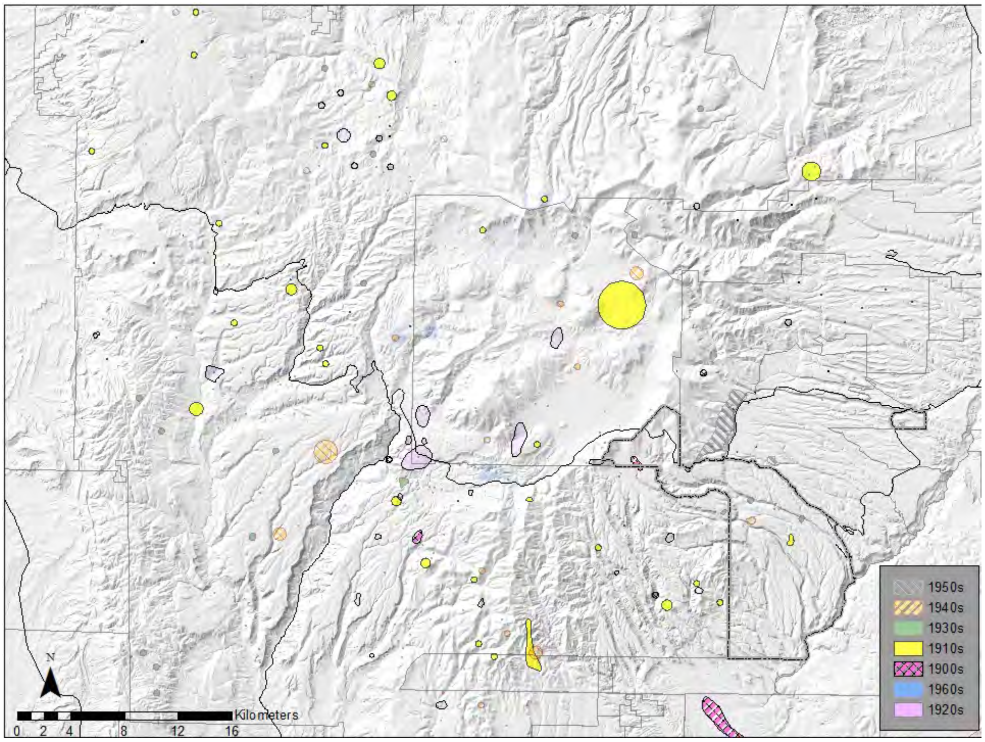

Figure 4-2a. Fires that occurred in the Jemez Mountains, New Mexico, by decade, from the 1900s to the 1960s. Bandelier NM boundary is in the lower right section. A period of high grazing numbers and successful fire suppression occurred from 1909–1969, and very few acres burned during this period. The circles represent the relative area of only those fires that had acreage records.

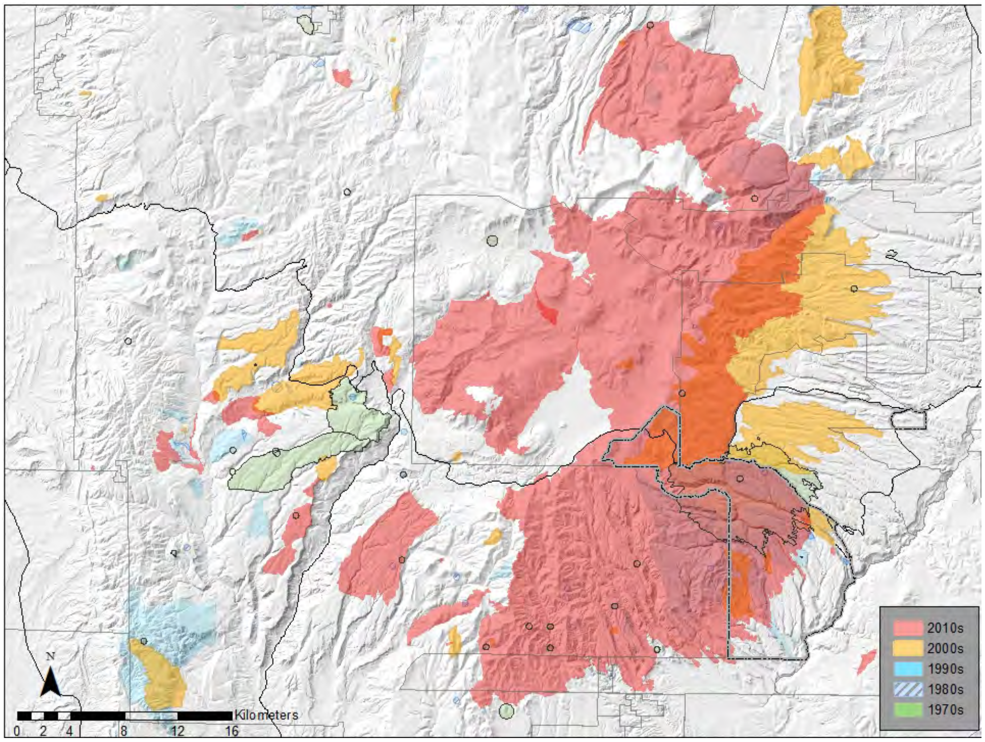

Figure 4-2b. Fires that occurred in the Jemez Mountains, New Mexico, by decade, from the 1970s to the 2010s. Bandelier is in the lower right section. After decades of effective fire exclusion, forest fuels became overly dense which resulted in a modern fire history of large fires with unprecedented severity both in size and degree. Large portions of the landscape, particularly around Bandelier NM, have effectively been reset. Understanding the trajectory of these post-fire landscapes is a high research priority for the monument.

cally isolated from the larger ponderosa pine forest matrix.

Piñon-juniper woodland

In contrast to our current knowledge of past fire regimes in the ponderosa and mixed conifer forests, the historical fire regime of the piñon-juniper woodland is not completely known and not without controversy (Bowker and Smith 2014). The fire history is difficult to know because piñyon pine and juniper trees are poor preservers of fire scars from which to reconstruct past fire cycles. Understanding the role of fire in the piñon-juniper woodlands is further complicated by the diversity of piñon -juniper community types that occur across the monument landscape. These include piñon-juniper savannas, piñon-juniper-oak communities, and most commonly, persistent piñon-juniper woodlands. At higher elevations, piñon-juniper woodland intersperses with, and, in some sites, has recently replaced ponderosa pine savanna. While some literature suggests frequent surface fire (Gottfried et al. 1995; Jacobs and Gatewood 1999), evidence is sparse and mostly from ponderosa pine stands near piñon-juniper stands (Bowker and Smith 2014). Patchy stand-destroying crown-fires are well-documented in piñon-juniper woodlands from elsewhere in the region (Romme et al. 2009). Pre-1900 disturbance regimes in piñon-juniper savanna are not well understood.

4.01.3 Data and methods

Numerous methods have been used to investigate historic fire conditions. Information gathered from packrat middens and pollen deposits support the concept of a long history of fire on the landscape by providing evidence that ponderosa pine (*Pinus ponderosa*), a fire evolved species, has existed in the southwestern U.S. region for approximately 8,000 to 11,000 years (Anderson 1989). Charcoal deposits provide evidence of continuous fire activity extending back at least 9,000 years (Brunner-Jass 1999, Allen et al. 2008). Core samples taken from bogs contain material that is approximately 9,000 to 15,000 years old, revealing a long history of high frequency fire activity for the past 9,000 years with an unusual gap in fire activity after 1880 (Allen et al. 2008).

Dendrochronological (tree-ring) analysis of fire scarred wood shows that, for many centuries prior to 1900, fires burned frequently and were widespread in these landscapes (Allen 2002a). Researchers have dated over one thousand sampled trees, logs, and stumps from more than fifty locations in the monument and the Jemez Mountains, thereby developing well replicated information regarding fire occurrence patterns, fire seasonality, and precipitation as far back as 1600 A.D (Allen 1989, Touchan et al. 1996, Morino et al.1998, Allen 2002a, Falk 2004, Margolis et al. 2007, Dewar 2011). For example, fire scar samples from multiple ponderosa pine sites in the Jemez Mountains recorded 1,858 fire events and 221 different fire years over a 400-year period, with an average fire return interval (or average number of years between fire events) ranging from 5-16 years (Touchan et al. 1996). Fire scar samples collected in ponderosa pine forests in Bandelier NM documented 113 separate fire years between 1480 and 1899, with widespread fires occurring every 5-15 years (Allen et al. 1995).

Historic records and journals also support the notion that natural fire was extensive in the Southwest. For example in 1875, Joseph Rothrock, a botanist with the expedition called the Wheeler Survey (predecessor of the U.S. Geological Survey), wrote of the region just south of Gallup, New Mexico: "… at an altitude of about 8,000 ft. above the sea, was a fine, open, park-like region with a large growth of yellow pine (*Pinus ponderosa*) and fir covering the hillsides. A diversified herbaceous vegetation was out in the most brilliant colors, beautifying alike the woods and open grounds. … Good forage was abundant" (Rothrock 1875).

Finally, aerial and ground based photography of landscape conditions in the monument and the Jemez Mountains demonstrate that fire was ubiquitous and played a major role in shaping and maintaining vegetation communities throughout the area. Repeat photography studies (Allen 1984 & 1989, Hogan and Allen 2000) show the vegetative and forest conditions as they existed under the influence of frequent fire, and also illustrate the striking expansion of local forests into previously open environments as well as the densification of some forests stands in the absence of periodic fire.

4.01.4 Condition and trend

Recent warm and dry climatic conditions are important drivers of increased forest drought stress and more high severity fire activity in the Southwest (Williams et al. 2010, 2013), including Bandelier NM and the Jemez Mountains.

In general, disruption of fire regimes during the 20th century has left many western forests susceptible to uncharacteristic wildfire. However, re-establishment of forest structure and fire regimes that predominated prior to European settlement can restore ecosystem function (Hurteau, Bradford, Fulé, Taylor, & Martin, 2013), mitigate destructive crown fire (Allen et al., 2002; Covington et al., 1997) and convey greater resiliency in the face of climate warming (Stephens et al., 2013). In most forests characterized by high-frequency low-severity fire regimes, ecological restoration entails mechanical thinning, followed by reintroduction of low-intensity fires that consume overabundant fuels, speed nutrient cycling, and encourage the reestablishment of a grass-dominated herbaceous understory, with multiple benefits to biodiversity. Wildfire alone may result in a forest structure that is subsequently more amenable to the reestablishment of historical fire regimes, with its concomitant benefits to ecosystem structure and function. However, recurrent fire also may have detrimental impacts on high-frequency low-severity fire regime ecosystems. In extreme cases, a single high-severity burn may cause near complete tree mortality over large areas, such as was the case in portions of the 2000 Cerro Grande (Allen et al. 2002) and 1996 Dome (USDI 1996) fires. Subsequent reburning of such areas can further eliminate seed trees and soil seed banks, reduce soil organic matter, encourage post-fire establishment of shrub and grass communities, and lead to long-term conversion of forest to non-forested ecosystem types—exemplified by extensive reburning by the 2011 Las Conchas Fire (Allen, 2012). Thus, the impacts of multiple, recurrent fires may have strikingly different long-term effects on the future of southwestern U.S. forests, depending on the influences of multiple factors, including initial forest composition and structural characteristics, fire size and intensity, fire return intervals, site characteristics, and climate.

Combinations of fire and drought are hypothesized to interact non-linearly, potentially pushing currently forested systems beyond thresholds that, once crossed, exceed the capacity of some ecosystems to recover (Allen, 2007; Williams et al. 2013), resulting in conversion to novel vegetative communities. Once across such resiliency thresholds, additional fires may drive positive feedback loops, perpetuating novel communities and establishing new fire regimes (Parks et al. 2013; Thompson et al. 2007; van Wagtendonk et al. 2012). Research that addresses the new fire regime characteristics and resiliency of emerging novel ecosystems is important as managers in fire-prone areas already face questions about appropriate burn frequencies and their influences on sustaining or encouraging desired ecosystem characteristics, as ongoing climate change makes restoration of previous forest conditions less likely.

4.01.5 Level of confidence

High level of confidence for history; moderate-to-low level of confidence for future projections.

4.01.6 Data gaps/Research needs/ Management recommendations

It will be important to understand the patterns and drivers that sustain more resilient forests following multiple fires. Resilience in forests of the Southwest is often defined from the perspective of single species or groups of species, and rarely assessed at the landscape level. We define landscape resilience in forests once dominated by surface fire (e.g., ponderosa pine) as resistance to widespread crown fire that allows for the incremental adaptation of understory and overstory vegetation to warming climate conditions. Fire has been a key tool for returning ecosystems to a resilient and adaptive state.

We provide the following recommendations:

- Continue with planned fuels treatments and restoration efforts of extant forests.

- Monitor disturbed landscapes to identify indications of ecosystem trajectory (such as changed fire regime and successional patterns).Identify areas where subsequent fires may have detrimental effects on landscape trajectories and develop a wildfire management strategy that aims to reduce fire impact to those areas. Likewise, identify areas where subsequent fires would have beneficial effects on ecosystem processes and develop strategies to allow, or encourage, wildfire into these areas.
- Consider experimental management techniques to alter trajectories based on information from monitoring and research.

4.01.7 Sources of Expertise

Craig Allen, Matthew Bowker, Terelene Foxx, Laura Trader, and Tom Swetnam

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4.02 Parkwide Vegetation Change

Introduction

Bandelier NM is rather unique for a monument of its size in that several decades of vegetation data are available, some of which is from long-term repeatedly measured studies. The park is also located adjacent to a National Laboratory with substantial research infrastructure, which has produced additional environmental observations over the same multi-decadal timespan. Thus, in many ways, the monument has already been serving as a barometer of change. During the initial project scoping for this Natural Resource Condition Assessment, park staff identified synthesis and analysis of a substantial body of vegetation data, collected by park staff and collaborating researchers for a variety of purposes, as an important area of focus for the NRCA.

In 2011, NPS entered into an Interagency Agreement with Matt Bowker, U.S. Geological Survey, Southwest Biological Science Center to conduct a synthesis and analysis of Bandelier NM vegetation data. With a focus on 3 major ecosystems within the park (piñon-juniper woodlands, ponderosa pine forests, and mixed conifer / aspen forests) the project's objectives were to

1. evaluate the direction of landscape-scale vegetation change that has occurred in recent decades
2. identify the primary drivers of observed change
3. suggest, to the extent possible, the likely direction of future change.

In 2014, Matt Bowker, assisted by David Smith, and in consultation with Craig Allen, Brian Jacobs, Stephen Fettig, Laura Trader, and Jim DeCoster, completed a report of his findings. *Assessment of Vegetation Change in Bandelier National Monument, a "Barometer of Change" in the National Park System* is a first attempt at compiling several of the most information rich datasets available for Bandelier NM and surroundings, and synthesizing these to assess the condition and trajectory of the park's major ecosystems, and possibly the future trajectory of southwestern woodlands and forests. The Bowker and Smith report forms the basis for this section, and for the sections on mixed conifer forests (4.04), ponderosa pine forests (4.05), and piñon-juniper woodlands (4.06), covering the major park ecosystems. A portion of their analysis was directed specifically toward aspen recovery following fire in relation to elk herbivory—those results are included in section 4.04-1 Aspen. Their full report is provided in Appendix B of this document.

4.02.1 Description

Bandelier NM encompasses vegetation communities ranging from semi-arid woodlands to subalpine forests and meadows (Muldavin et al. 2011). In total, 55 distinct plant communities are mapped in the park, which can be roughly divided into three major zones based upon dominant plant communities: mixed conifer / aspen forests, ponderosa pine forests, and piñon-juniper woodlands.

Vegetation changes can be simultaneously rapid and occur over a large spatial extent. A severe drought occurred in the 1950s across much of southwest North America, causing widespread tree mortality (Betancourt et al. 1993, Marshall 1957). The low elevation ponderosa pine forests within Bandelier NM died during the drought, resulting in a 2 km upslope retreat of ponderosa pine (Allen and Breshears 1998). The retreat of the pines released piñon-juniper woodlands from competition and those species co-dominated the low elevation mesa tops until the early 2000s. At the turn of the century a drought, driven by warmer than average temperatures, decimated the piñon population by killing over ninety percent of the mature piñon pine (Breshears et al., 2005). The low elevation mesa tops are now dominated by drought resistant one-seed juniper, and although piñon pine seedlings are present across much of the pre-drought range, few ponderosa seedlings are found in the pre-1950 range of the species.

4.02.1.1 Major drivers of change in Bandelier National Monument

At the scale of the entire monument, there are four tightly-linked phenomena responsible for most of the change that has occurred in recent decades: 1) climate change, 2) fire, 3) drought/insect and disease outbreaks, and 4) past land use. Other factors that strongly affect particular ecosystems, such as elk herbivory or persistent accelerated erosion, are discussed in later sections.

Before discussing these drivers of change individually, it is worth viewing them as a linked complex of the following interacting change agents (Figure 4-3; cf. Allen 2007):

1. Climate change, a pervasive force, modifies soil moisture and vapor pressure deficit, which leads to plant drought mortality (Breshears et al. 2005, Williams et al. 2013).
2. Climate change modifies distributions of some bark beetles (Bentz et al. 2010).
3. Warmer and drier conditions favor fire (Williams et al. 2010).
4. Drought stress leads to greater susceptibility of some tree species to bark beetle attack (Wallin et al. 2004).
5. Both drought- and beetle-killed plants contribute to fuel load.
6. Greater fuel load creates larger and more intense fires.
7. Accumulated fine fuel load has been strongly reduced by past grazing, and fire suppression activities, which results in fire exclusion and buildup of woody fuels (Allen 2004).

Climate change. Climate change influences vegetation both directly and indirectly. Recently, Williams et al. (2013) developed a forest drought-stress index, using a comprehensive tree-ring data set representing the past one thousand years. They found the index to be equally influenced by warm season vapor pressure deficit and cold season precipitation (together explaining 82% of the forest drought-stress index). These two parameters are likely to change in the near future. All available models converge on a

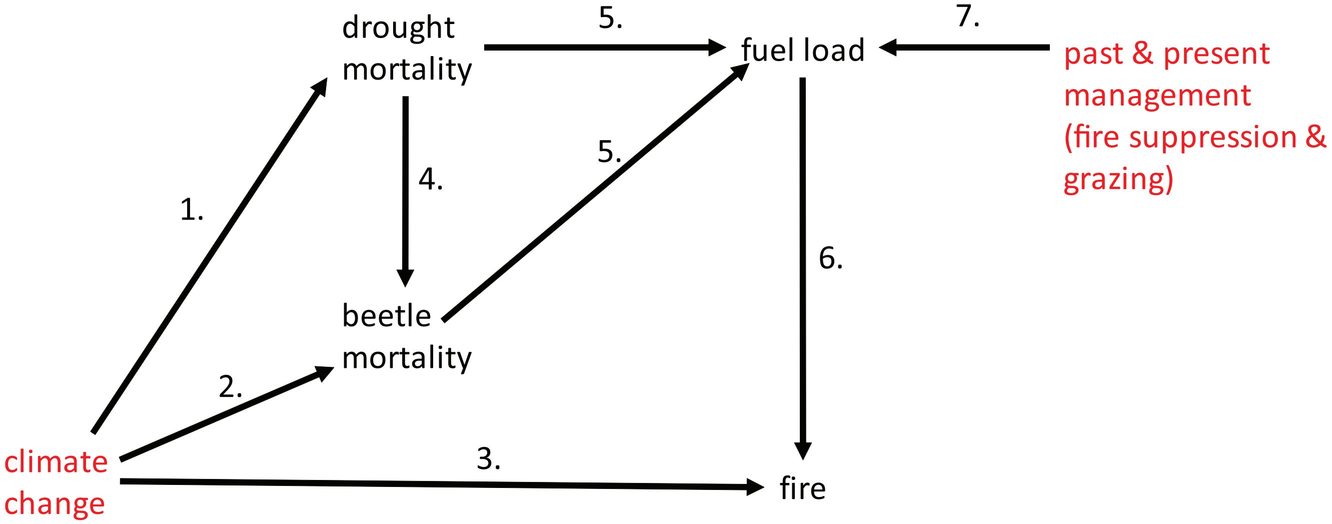

Figure 4-3. Linked drivers of vegetation change in Bandelier National Monument and the southwestern U.S. Climate change and past and present management have and continue to exert a variety of direct and indirect effects on forests and woodlands. See text for explanation.

scenario where northern New Mexico will experience warming (Karl et al. 2009). Precipitation projections are much less certain and likely to vary among models, although reduced spring precipitation is predicted by a consensus model (Karl et al. 2009). Both of these changes can be expected to influence soil moisture and therefore drought mortality directly, and indirectly affect fire susceptibility (Figure 4-3). Williams et al. (2010, 2013) project that by 2050, forest drought stress values will routinely be equal to or more extreme than mega-droughts seen in the 1200s and the 1500s. This suggests that areas currently occupied by Southwestern forests will, to a large degree, no longer be forest habitat. Breshears et al. (2011) argue that such climate change impacts on vegetation communities may not be gradual, incremental and homogenous (e.g. a small mortality rate every year). Rather, climate change impacts on ecosystems may be “big, fast, and patchy”. Climate change-linked drought and fire have already caused high mortality in 18% of southwestern forests (Williams et al. 2010). Such impacts give managers and stakeholders few options and little time to respond to climate change-driven vegetation change, such as the mass tree mortality events now being observed globally (Allen et al. 2010).

Fire suppression and subsequent large-scale crown fire. Fire is a part of the evolutionary environment of most of the forest, woodland and savanna types within Bandelier NM (Allen 1989, Moore et al. 1999, Touchan et al. 1996). It is well demonstrated that two phenomena— livestock reduction of fine fuels, and fire suppression—coincide with a shift to less frequent fire cycles (Touchan et al. 1996). We consider fire here as a stressor and a driver of vegetation change because the scale of recent fires has been unusual (Figure 4-4). The 1977 La Mesa Fire burned 6354 ha in 1977. The 1996 Dome fire burned 6677 ha, and was followed shortly by the 1997 Lummis Fire which burned another 865 ha. The Cerro Grande fire of 2000 burned 16,909 ha. Most recently, the Las Conchas fire burned 63,250 ha in 2011. These fires are occurring at higher frequency and intensity and at increasing spatial scale. Fire severities varied within these fires, but each fire had areas of significant stand replacement.

Drought and insect outbreaks. Periodically, severe droughts may be associated with pulse mortality of overstory trees (Allen 1998; Breshears et al. 2005, 2011). One such drought occurred in 2002. It caused major mortality to *Pinus ponderosa* and *P. edulis*, especially in lower elevations, but also impacted *Pseudotsuga menziesii* and *Abies concolor* at higher elevations (Muldavin et al. 2011). Primarily mature trees were affected rather than saplings. This extreme drought was not the driest on record, but was the most impactful in centuries. The severity of die-back events has been linked to the fact that warming climate interacts with drought to induce mass mortality. This was hypothesized by Breshears et al. (2005), and experimentally tested by Adams et al. (2009) using *Pinus edulis*. Using 50 years of tree ring data from multiple species along an elevation gradient in Arizona, Adams and Kolb (2005) found that growth rates were related to both water availability and temperature, and that species in the hotter and drier parts of their range were more sensitive to these influences (i.e. their growth tracked climate more closely than conspecifics from higher sites). Insects, such as bark beetles and the fungi they disperse, cause mortality of water stressed trees because water stress can inhibit defense mechanisms, such as production of resins (Wallin et al. 2004, Negron et al. 2009). Our data cannot distinguish between temporally congruent drought mortality episodes and bark beetle outbreaks; thus we treat them as a tightly-linked stressor complex.

4.02.2 Reference conditions

At the scale of the entire monument we can make three broad generalizations about historical reference conditions. First, most of the ecosystems have a tree canopy component. It is not thought that large shrublands and grasslands without trees were abundant on the landscape. Second, in most ecosys-

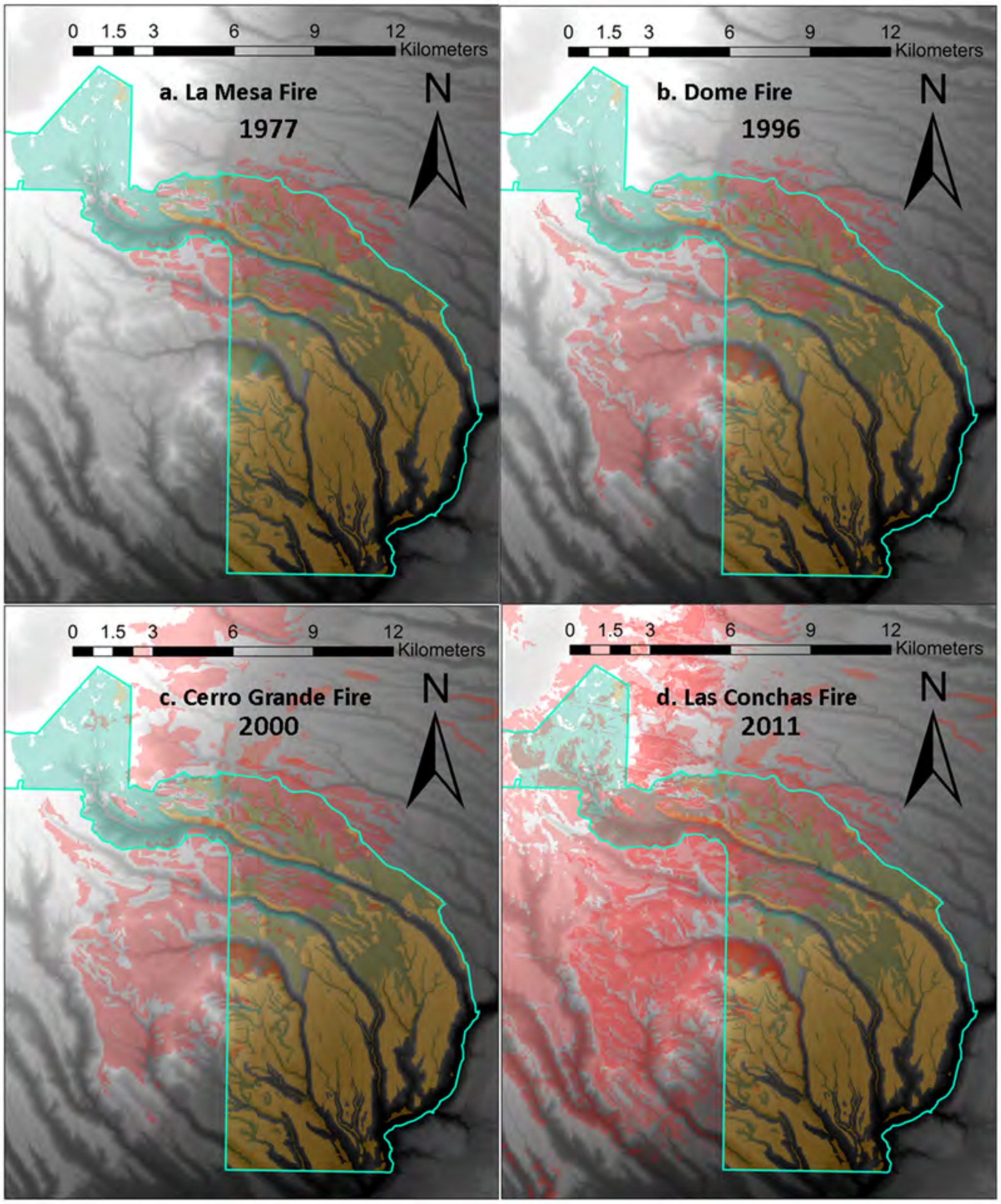

Figure 4-4. Cumulative footprint of medium and high severity wildfires in the distributions of the mixed conifer-aspen forest zone (blue green), ponderosa pine forest zone (drab green), and piñon-juniper woodland zone (orange), since 1977. Light red shades indicate a high or medium severity burn. Darker red shades indicate areas where high or medium severity burns have occurred twice.

tems it is thought that woody canopy cover increased through the 20th century, and under a more natural disturbance regime, forests would be less dense. Nearly a century of fire suppression has allowed many forests and woodland stands to attain unusually thick canopies, sometimes at the expense of understory herbaceous biomass. Finally, although fine scale shifting mosaics of different forest and woodland types would be expected, based upon normal disturbance and succession cycles, there should be no major directional shifts in the distribution of major vegetation types. At the scale of the entire monument, a vegetation trajectory toward an overall decrease in tree canopy cover, without loss of a tree component from the various ecosystems, and without a directional shift in the broad distribution patterns of the major ecosystem types, would approach reference conditions.

4.02.3 Objectives of vegetation analysis, data sources, and methods

Two vegetation maps have been produced in recent decades, encompassing most or all of Bandelier NM. Allen (1989, hereafter `Allen') produced a map (resolution 1.5 ha) based upon aerial imagery from 1981. Muldavin et al. (2011, hereafter `Muldavin et al.') produced a map using supervised automated digital processing, assisted by multispectral imaging techniques at a resolution of 0.5 ha. This map was based upon 2004 imagery.

The two maps used a different system of map units. Allen developed a system that consisted of 43 forest and woodland types and 23 additional patch types, identified primarily by the dominant tree component with additional understory information. Muldavin et al. collected a series of ground plot surveys which they analyzed using multivariate statistical methods and classified into a system consistent with the guidelines of the National Vegetation Classification Standard that identified 95 plant associations in Bandelier NM. To facilitate comparisons among the two maps, both were reduced to their

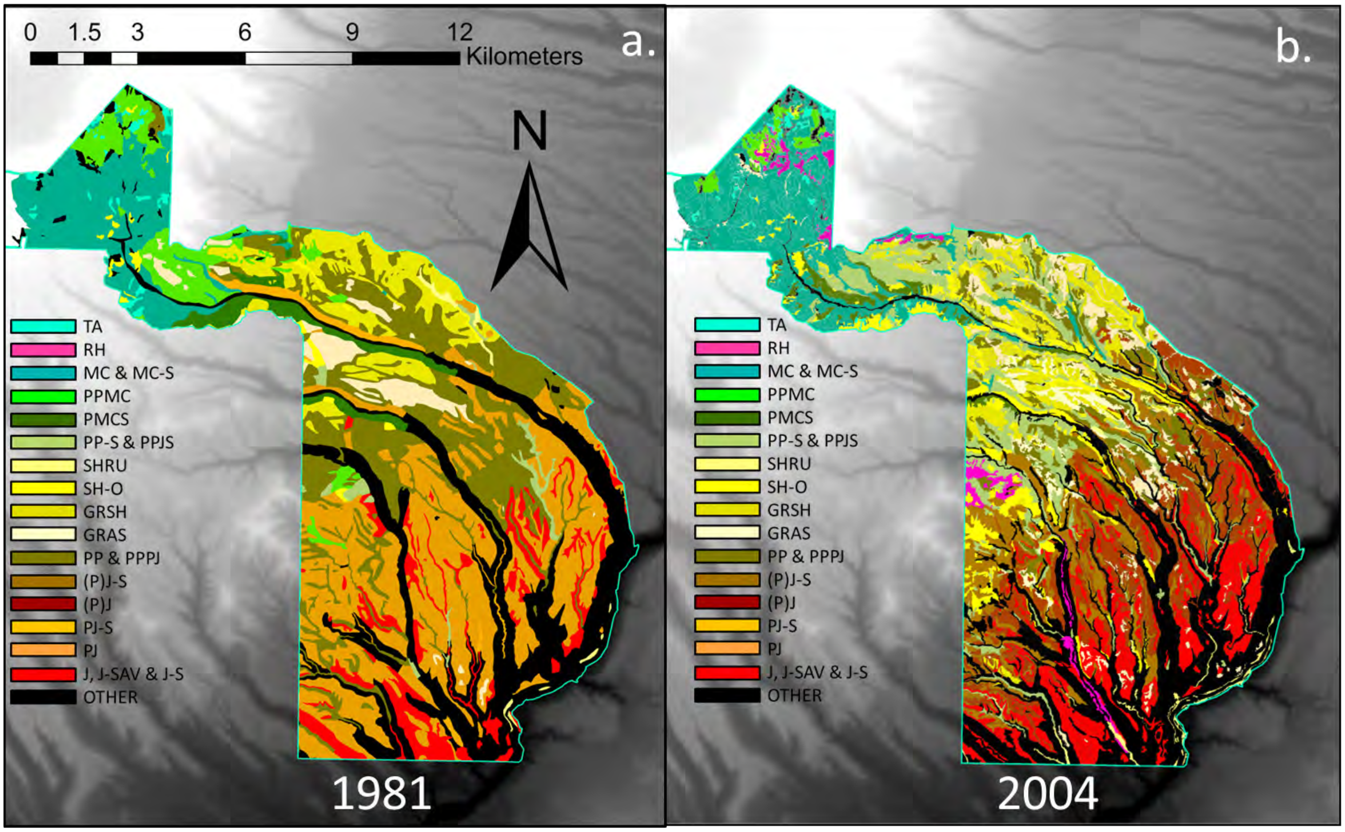

Figure 4-5. Change in spatial distribution of major vegetation map units from 1981–2004. a.1981, modified from Allen (1989). b. 2004, modified from Muldavin et al. (2011).

LEGEND

TA - Quaking Aspen Woodland/Forest

RH – Ruderal Herbaceous

MC – Mixed conifer Woodland/Forest

MC-S – Mixed conifer-Shrubland

PPMC – Ponderosa Pine/Mixed Conifer Woodland

PMCS – Ponderosa Pine/Mixed Conifer Shrubland

PP-S & PPJS – Ponderosa Pine Shrubland & Ponderosa Pine /Juniper Shrubland

SHRU -Shrubland

SH-O – Oak Shrubland

GRSH – Grassland/Shrubland

GRAS - Grassland

PP & PPPJ – Ponderosa Pine & Ponderosa Pine/Piñon-Juniper Woodland

(P)J-S – Juniper Shrubland (previously with piñon)

(P)J – Juniper Woodland (previously with piñon)

PJ-S –Piñon-Juniper Shrubland

PJ – Piñon-Juniper Woodland

J, J-SAV & J-S - Juniper Woodland, Juniper Savanna & Juniper Shrubland intersection, and the Muldavin et al. map was reclassified to conform to the Allen map (complete details of this process are provided in Bowker and Smith 2014). Although this translation was imperfect, most major Muldavin et al. units corresponded reasonably well to major Allen units. Comparisons of the Allen and Muldavin et al. vegetation maps are reported here and in the 3 following sections.

In addition to the spatial comparison of the maps, two point datasets associated with each of the maps, respectively, were used to estimate where and to what degree canopy cover has changed since the 1980s. The Allen data were analyzed in three ways to estimate canopy cover during the 1980s: 1) using the existing map attribute estimating canopy cover at the spatial scale of polygons; 2) applying an inverse distance weighting interpolation technique (Franke 1982) to the point data; and 3) by averaging the two methods. The three analyses of the Allen data were compared with the Muldavin et al. data to quantify cover change from the 1980s to post-2003; positive values indicate canopy loss, and negative values indicate canopy gain.

4.02.4 Condition and trend

4.02.4.1 Map analysis

Vegetation has changed drastically in 23 years between the 1981 and 2004 imagery (Figures 4-5 and 4-6). At the lowest elevations of the monument, it appears that woodlands and savannas, with *Juniperus* as the canopy dominant, are expanding. This pattern appears independent of any changes to other species, such as *Pinus edulis*. Further upslope, the most striking difference in vegetative dominance to have occurred is the complete loss of mature *P. edulis* as a co-dominant species due to drought and beetle mortality. This change occurred in association with the 2002 drought. These former *P. edulis*-dominated or co-dominated stands have shifted to *Juniperus* woodlands via subtraction of *P. edulis* rather than migration of *Juniperus*. Although *P. edulis* is retained mostly as saplings, it can no longer be said to be a co-dominant. Further upslope, there is a clear shrinkage and fragmentation of stands with *Pinus ponderosa* as the dominant, or co-dominant with *P. edulis*. Grass-dominated stands expanded at the apparent expense of *P. ponderosa* coverage.

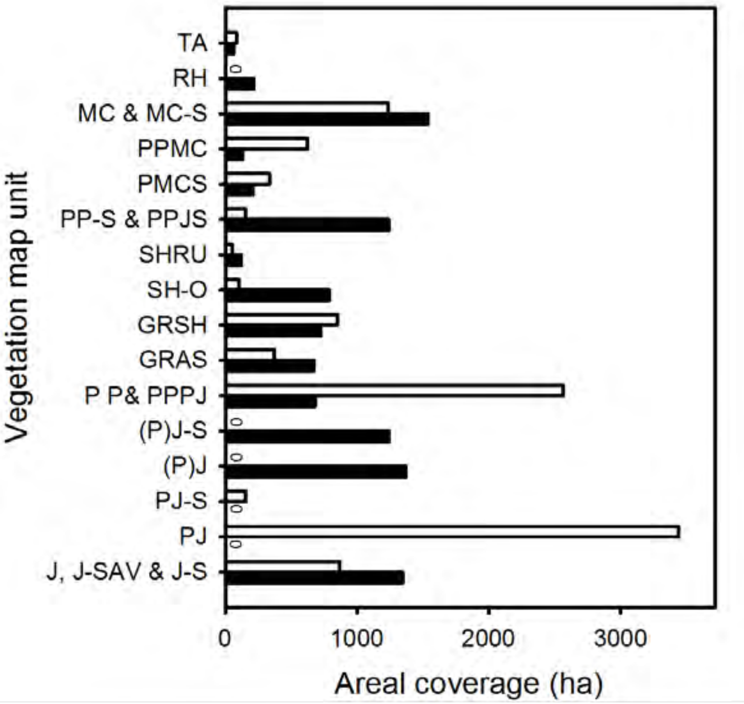

Figure 4-6. Change in total area of coverage of major vegetation map units from 1981 (white bars) – 2004 (black bars). See Figure 4-5 on page 48 for definition of vegetation codes..

Many *P. ponderosa* stands also seem to be gaining a shrubby understory. Across Bandelier, but particularly in the middle elevations where *P. ponderosa* was dominant, shrubs are becoming more prevalent, and the coverage wherein shrubs are a major component has more than tripled (Figure 4-7). It is difficult to ascribe such a large pattern to differences in vegetation classification or mapping. Allen (1989) was very cognizant of the distinctiveness of communities with and without shrub components in the 1981 imagery, devoting several map units to making this distinction. Compared to *P. ponderosa*, growth-ring widths of the shrub *Quercus gambelii* are less sensitive to interannual changes in drought severity (Adams and Kolb 2005), providing one possible reason for shrub proliferation

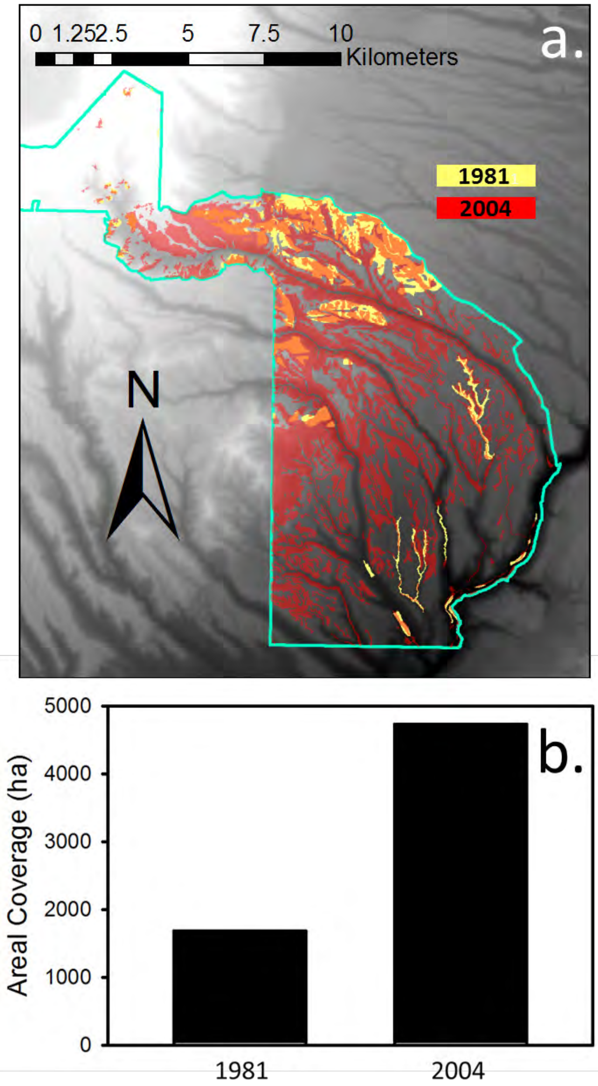

Figure 4-7. Expansion of plant communities with a shrub component (J-S, PJ-S, SH-O, SHRU, PP-S, PPJS, PMCS, MC-S) from 1981–2004. a. Spatial distribution of shrubs as a major community component. b. Areal coverage of shrubs as a major community component. See Figure 4-5 on page 48 for definition of vegetation codes..

in the middle elevations of the monument. Another major reason might pertain to the ability of *Q. gambelii* to resprout after fire (Abella 2008, Strom & Fule 2007). Some portions of the monument have experienced repeated fires in the last few decades.

At the highest elevations the spatial distribution of mixed conifer-dominated stands has declined by probably less than one third (Figures 4-5 and 4-6). (However, changes resulting from the recent Las Conchas Fire are not captured in this analysis.) Mixed conifer stands with *P. ponderosa* as a component may be increasing, as are shrubs overall. Finally, it is difficult to draw conclusions about *Populus tremuloides* stands; they appear to represent a shifting mosaic, as would be expected for a species associated with disturbance, but do not strongly change in coverage on the landscape from the earlier map to the later one.

4.02.4.2 Canopy cover analysis

The analysis of canopy cover change supports the conclusions discussed above. Averaged over the whole extent of our analysis, the monument appears to have lost between 14 –15% canopy cover. The lower elevation mesa tops, almost without exception, indicate some degree of canopy loss, generally about 30%, but some areas were even greater. These areas were dominated by piñon-juniper woodlands and ecotones of this ecosystem.

The area within the boundary of the La Mesa Fire (at a higher elevation) is experiencing canopy gain, usually less than 20%, indicating that there is some slow recovery of forest canopy after about 30 years. Still higher in elevation in the mixed conifer/aspen forests, the overall pattern is one of very heterogeneous net loss. Near complete loss of canopy is estimated for the upper portions of the canyon, and further north in areas which were burned by the Cerro Grande Fire as well as outside the fire perimeter.

4.02.4.3 Synthesis

There are several clear directional changes in the spatial distribution of focal vegetation communities. At higher elevations, *Pinus edulis* has declined dramatically, leaving these areas dominated by juniper. The lower boundary of *P. ponderosa* forests has shifted upslope and these forests have become increasingly fragmented, colonized by shrubs, or otherwise altered. *P. ponderosa*-mixed conifer stands appear to have been replaced by *P. ponderosa*-shrub communities, but otherwise mixed conifer forests have not strongly shifted in their spatial location.

The loss of distinctive overstory species, directional shifts of some major ecosystem types, proliferation of former subdominants, and drastic or outright loss of some dominant species on the landscape indicate that the ecosystems of the monument are largely well outside of desired conditions. Given that these recent vegetation shifts are directly or indirectly driven by climate change, it is likely that similar patchy, big, fast transformations will continue to occur on the monument landscape. The role of climate change in driving vegetation changes across the landscape is discussed in detail in Bowker and Smith 2014.

4.02.5 Level of confidence

There are inherent difficulties in making comparisons between two maps that were produced by different researchers using different techniques. While some error can be attributed to methods, (and many of these are discussed in detail in the appendices), confidence in the assessment of the broadest and strongest patterns is high.

4.02.6 Data gaps/Research needs/ Management recommendations

Bowker and Smith suggest management of fuel conditions within the remaining stands that have not been burned intensely may yet discourage similar events from occurring.

4.02.7 Sources of expertise

Matt Bowker, Dave Smith and Craig Allen

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4.03 Montane Grasslands

4.03.1 Description

Montane grasslands are found in a distinctive landscape pattern on upper, south-facing slopes (5–40%) with moderate to high solar exposure on nearly all of the larger summits and ridge crests in the Jemez Mountains above 9500 ft (2900 m) feet, including the slopes of Cerro Grande within Bandelier NM (Allen 1984 & 1989; Coop and Givnish 2007a) (Figure 8).

Primarily grasslands, these communities are dominated by the large bunchgrasses Thurber fescue (*Festuca thurberi*) and oatgrass (*Danthonia parryi*) (Allen 1984; Muldavin et al. 2011). Kentucky bluegrass (*Poa pratensis*) dominates some patches within these grasslands and may represent the legacy of historic livestock grazing (Moir 1967). Along with the dominant grasses, forbs can be common and diverse. Soils of montane grasslands are relatively deep mollisols with significant eolian inputs. These soils are well-developed, indicating the long-term presence of grassland vegetation on these sites and possible feedback mechanisms (Allen 1984; Coop and Givnish 2007).

The topographic situations of montane grasslands are consistent with the idea that fires were important to their long-term maintenance, and confirmed by fire-scar records of high frequency surface fires pre-1900 from old trees adjoining these grasslands (Allen 1989, Dewar 2012). While the climatic conditions of montane grasslands are clearly suitable for conifer establishment and growth, natural fires at relatively high frequencies, but low intensities, acted to rejuvenate existing meadows by burning pedestaled grass clumps and killing conifer regeneration (Allen 1984 & 1989; Coop and Givnish 2008; Dewar 2012).

Figure 4-8. Montane meadow. NPS photo.

4.03.1.1 Threats

The loss of montane meadows and grasslands (Figure 4-9) reduces biodiversity and other ecosystem services provided by grassland and herbaceous systems (Patton and Judd 1970, Kremer et al. 2014), so the observed occurrence of woody species encroachment and associated loss of herbaceous open spaces is of concern (Dyer and Moffett 1999, Moore and Huffman 2004, Vankat 2013, Kremer et al. 2014). Trees are common in areas adjacent to these grasslands, so the decrease in grassland/forb cover at high elevations indicates the increasing effects of factors that promote woody species persistence (Kremer et al. 2014).

In particular, prior to 1900, historic high fire frequencies and vigorous grass competition acted to maintain largely treeless grasslands (Allen 1984 & 1989). In the Jemez Mountains there is abundant documentation that, with fire suppression since 1900, conifers have invaded sites, creating high montane savannas where there used to be open grasslands and meadows (Allen 1984 & 1989; Swetnam et al. 1999; Coop and Givnish 2007a, Dewar 2012). Encroaching tree overstories suppress grasses and forbs and eventually displace them as tree densities increase, needle litter accumulates, and mature canopies close (Allen 1984). Recent large-scale wildfires have reversed some historic encroachment, killing trees primarily along the forested grassland boundaries. However, mechanical reductions are still required to remove well-established, large diameter trees scattered at lower densities in grassland interiors.

Overgrazing by many sheep from the 1880s to about 1920 caused failure of the previous surface fire regime, yet precluded conifer establishment (Allen 1984, 1989). Subsequent reductions in sheep numbers apparently allowed conifers to establish in degraded grasslands where appropriate seed sources existed. Moist spring weather may have promoted pulses of tree establishment. Increasing temperatures may also be supporting increased rates of tree establishment (Dyer and Moffett 1999, Coop and Givnish 2007b).

Because the persistence of montane grasslands is largely dependent on fairly frequent but low intensity fires, fire condition is extremely relevant to determining the condition of these systems. The current fire regime of the Jemez Mountains is very different from what it was pre-settlement, and has diverged even further in the last several decades. This topic is discussed at length in other sections of this report.

Geographic patterns of montane grassland occurrence in the Jemez Mountains and specifically in Bandelier NM was best documented through aerial photographs (Allen 1984 & 1989), though these only captured changes since 1935, well after grazing and fire suppression had begun.

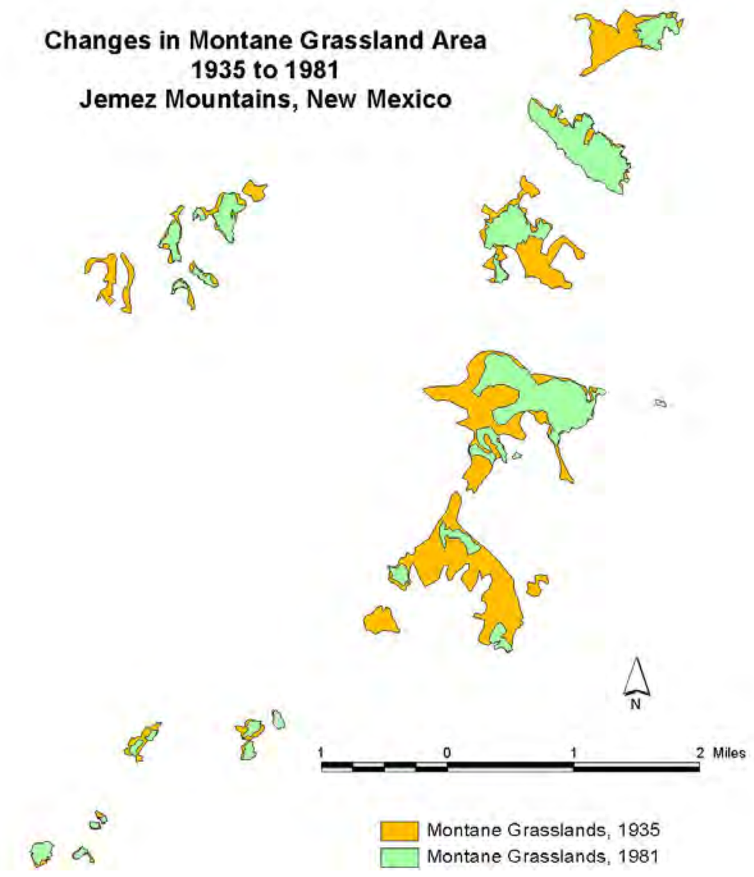

Figure 4-9. Changes in montane grassland area, 1935–1981, Jemez Mountains, New Mexico.

4.03.2 Reference conditions

Many higher elevation south-facing mountain slopes were dominated by montane meadows prior to the effects of fire suppression and historical grazing.

4.03.3 Data and methods

In his Masters thesis, Allen used historic photo analysis, tree cores, and soil analysis to examine historic conditions of montane grasslands (Allen, 1984). Allen (1989) identified grassland and meadow vegetation types using GIS and fieldwork.

Montane grasslands were also identified by Muldavin et al. (2011). Allen compared vegetation changes (including montane grasses) from 1935–1981, however no rigorous comparison has been made between Allen's delineations and that of Muldavin et al. (2011).

In fall of 1983 twelve permanently-marked photopoints were established in the upper portions of the Cerro Grande montane grassland to visually document changes (4–6 photos/pt, including the cardinal directions). These have been visited periodically and rephotographed (on file with Bandelier Ecology Group).

4.03.4 Condition and trend

Change analysis using historic air photos clearly reveals recent conifer tree invasion of Jemez montane grasslands, with an 85% decrease in open grassland area on Cerro Grande, from 110 ha in 1935 to 17 ha in 1981 (Allen 1989). Overall, in the southeastern portion of the Jemez Mountains, open montane grassland area decreased 55%—from 554 ha in 1935 to 250 ha in 1981. Several small montane grasslands present in 1935 have disappeared, while the larger grasslands have been fragmented (Allen 1989).

Encroachment continued through the mid-1990s until the Cerro Grande (2000) and Las Conchas (2011) fires removed additional trees (personal communications with Brian Jacobs and Craig Allen), although neither of these fires killed many mature invasive trees in the interior of the meadows. The fires also rejuvenated existing grasses by burning pedestaled clumps, decadent with dead growth, and promoting forb growth, though mechanical reductions are still required to remove well established large diameter trees scattered at lower densities in meadow interiors (Brian Jacobs, personal communication, Halpern et al. 2012). Ironically most of the trees that have invasively infilled the ancient montane grassland have survived the recent fires, while the adjoining upper slope old-growth forests were completely killed by the Cerro Grande and especially Las Conchas fires. For several years, from the mid-1980s to the early 1990s, there was sporadic management cutting to harvest trees (mostly small) that were expanding into upper slope montane grasslands on Cerro Grande. Management fires have also been utilized during the past several decades to remove mature invading trees, which has had limited but important effects on preserving grassland areas (Craig Allen, personal communication, NPS unpublished GIS data).

4.03.5 Level of confidence

The level of confidence for this analysis is high for changes occurring up to the present.

4.03.6 Data gaps/Research needs/ Management recommendations

A proposal to girdle larger trees and leave them standing to fall naturally in coming years was suggested as a minimally invasive approach to incrementally address the encroachment issue without the negative aesthetic impacts of cutting, or environmental concerns associated with herbicides. This would partially mitigate heavy fuel loads which could sterilize soils locally when burned. Prescribed fire could be used in concert with these practices to maintain herbaceous open spaces within mostly forested systems.

An NAU graduate student is inventorying montane meadows using Southern Colorado Plateau Network vegetation monitoring methods. Results will be available in 2016.

4.03.7 Sources of expertise

Craig Allen, Esteban Muldavin, Division Leader, New Mexico Heritage Program.

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4.04 Mixed Conifer / Aspen Forest

This is a brief summary of the information provided by Bowker and Smith (2014) in Appendix B. The data used, analysis methods, and all references are included therein. The information below is mostly interpreted or taken directly from that report.

4.04.1 Description

The Mixed Conifer / Aspen vegetation type is a mosaic of distinct forest types that differ in both overstory and understory components. Within this group, forest stands, including significant amounts of aspen (P*opulus tremuloides*), are of particular interest for both their aesthetic and ecological value. Aspen stands will be discussed separately in section 4.04-1.

Muldavin et al. (2011) described five mixed conifer alliances within Bandelier NM. On north aspects at the highest elevations, dense Engelmann spruce forests occur in the Jemez Mountains, but occupy minimal area within the boundaries of the park, particularly after recent high-severity fires. In the elevation zone between 2130 and 2750 m, forests are co-dominated by mid-elevation conifers (Douglas-fir, white fir, blue spruce, ponderosa pine, southwestern white pine, limber pine). Muldavin et al. describe two distinct mixed conifer forest groups within this zone that reflect an inherent moisture gradient. Which tree species dominate a site is a function of site conditions and disturbance history. For example, white fir and blue spruce (shade tolerant but fire intolerant) dominate mesic sites. In contrast, Douglas-fir (less shade tolerant, more fire resistant and drought tolerant) is more common on dry sites with the potential for higher fire frequency (Muldavin et al. 2011).

Over the last 125 years, the structure and composition of local mixed conifer forests have changed dramatically (Allen 1984, 1989, 2002). Fire suppression in the 20th century allowed the development of dense sapling understories in many mixed conifer forests, with tree regeneration dominated by Douglas-fir and white fir, and also aspen and ponderosa pine in some areas.

4.04.2 Reference conditions

Mixed conifer forest includes a mosaic of forest types in various stages of disturbance. Old-growth stands tend to be uneven-aged and contain multiple species and age classes, with an open structure and patchy understory.

On south-facing sites in Bandelier NM, such as much of the headwaters area of the Rito de los Frijoles, dry mixed conifer forests generally experienced frequent, low-intensity surface fires, with a mean fire interval of about 10 years before 1900, and crown fires rare or absent (Allen 1989). In mesic mixed conifer forest—largely absent on Bandelier but found elsewhere in northern New Mexico forests – past fire regimes included a mixed-severity fire regime with a combination of surface fires and patchy crown fires of low frequency, which generally corresponded with periods of drought (Touchan et al. 1996; Margolis et al. 2007; Margolis & Swetnam, 2013). Mesic mixed conifer crown fire gaps would be expected to become aspen stands if the species was locally present prior to fire. With post-1900 suppression of surface fires, both xeric and mesic mixed conifer forest understories in-filled with high densities of tree regeneration, particularly aspen and pine species initially, in the then-open forest stands, but later, increasingly dominated by shade-tolerant Douglas-fir and white fir regeneration as stands densified. With the long-term absence of fire, overstory aspen stands have gradually in-filled and been overtopped by conifer species, until fire or other disturbances allow aspen regeneration again.

4.04.3 Data and methods

Numerous methods and data sets were included in Bowker and Smith's analysis. A vegetation map based upon 1981 imagery was used to delineate the former location of various types of mixed conifer forest and aspen stands (Allen 1990). Available maps of fire severity were overlayed on the 1981 distribution of Mixed Conifer / Aspen forests to illustrate the cumulative footprint of moderate to high severity fire since 1977.

Two vegetation maps, Allen (1989) and Muldavin et al. (2011)), were compared to detect changes in vegetation cover over time. See section 4.02.3 (p. 11) for an explanation of the two different maps and how they were compared. See also section 4.04-1.4 Condition and trend for analysis of elk exclosure and refuge plot data to determine the relative impacts of browsing on aspen growth and regeneration. See Bowker and Smith (2014) for detailed descriptions of data and methods.

4.04.4 Condition and trend

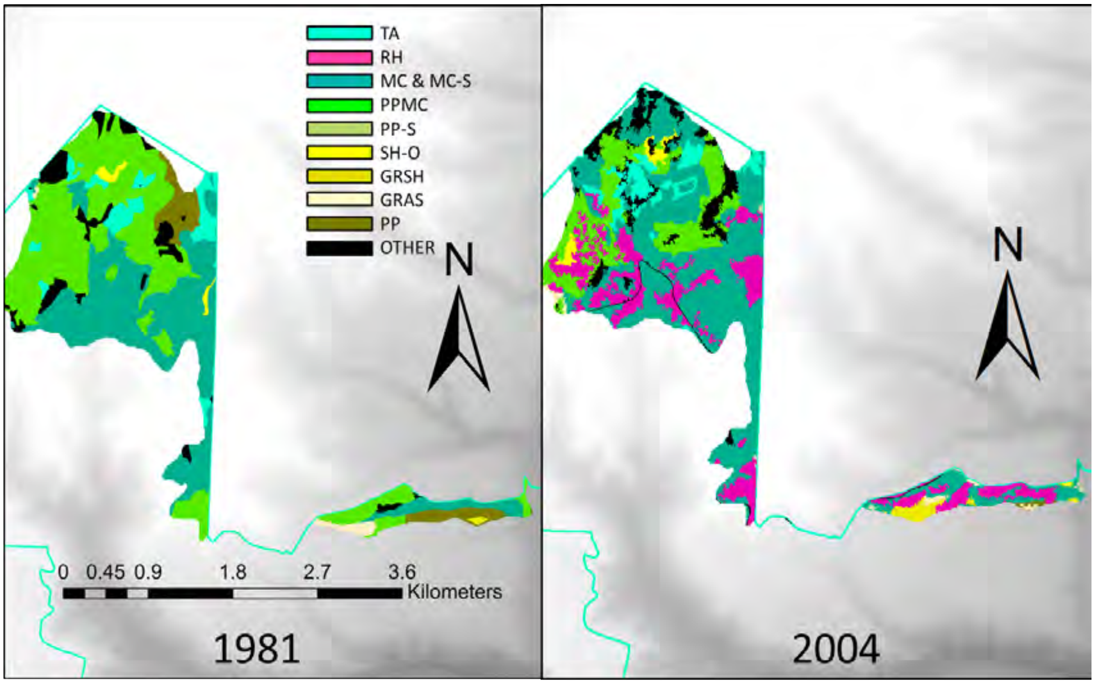
Vegetation change, specifically in the mixed conifer zone of Bandelier NM, is largely driven by fire, herbivory, and drought and drought-associated insect and disease outbreaks. After about a century of fire suppression and relatively few fires, large and often intense fires have been strongly impacting the mixed conifer/aspen forests of the park. The current millennium has been characterized by “mega-fires” in the region. The 1977 La Mesa Fire, 1996 Dome Fire, and 2001 Cerro Grande Fire all burned mixed conifer/aspen forests within Bandelier NM (Figure 4-4, p. 47). Each of these fires burned moderately to intensely in patches, opening canopies in patches up to hundreds of hectares in size. The scale of these openings was reasonably close to historical conditions of the mixed conifer/aspen forests within the park. The Las Conchas Fire was much larger and followed only 10 years after Cerro Grande. Virtually the entire southern half of the 1981 distribution of Mixed Conifer / Aspen forests was impacted by Las Conchas (Figure 4-4). The scale of this event is clearly outside of historical conditions. The cumulative outcome of these fires is that more than half of the 1981 distribution of Mixed Conifer / Aspen has experienced at least moderate severity fire.

It is too early for substantial data to be available to track the long-term response of the recent Las Conchas Fire in mixed conifer forests. However it is possible to observe change among major cover types from 1981–2004 within the Cerro Grande Fire perimeter. About 40% of areas mapped as mixed conifer by Allen (1989), retained this cover type following the Cerro Grande Fire, and approximately 25% best matched a ponderosa pine/mixed conifer/shrub community, perhaps signaling a transition to fire- adapted species. One notable fire disturbance-linked community type that does not appear to be increasing is aspen. After the Cerro Grande Fire, ruderal herbaceous communities comprised about 25% of the former area of communities mapped as mixed conifer within the burn perimeter. Spatially, the overall trends are the apparent decline in total coverage of ponderosa pine/mixed conifer communities, the increase in ruderal herbaceous vegetation, and a decline in contiguous patches of similar community types (Figure 4-10).

However, most impacts of the Cerro Grande Fire within Bandelier NM were actually low intensity, so we cannot attribute all vegetation change within this time period to the fire, which occurred in 2000. Another important event was the 2002–2004 drought-induced pulse of tree mortality which affected many white fir and Douglas-fir trees within portions of Bandelier’s mixed conifer forests, though less dramatically than the extreme mortality of piñon in the park’s lower-elevation woodlands.

Finally, saplings and suckers of aspen are extremely palatable to elk, and following fire, aspen recovery can be suppressed and even nearly eliminated due to elk herbivory (Kay 1990, Kay 1997, Kay and Bartos 2000, Wooley et al. 2008).

The recent post-fire trajectories of mixed conifer or aspen forests in Bandelier do not seem to be toward proliferation of aspen clones. Aspen is a difficult community type to map unless it is a pure stand. Relatively pure stands could be expected to increase



LEGEND
TA - Quaking Aspen Woodland/Forest
RH – Ruderal Herbaceous
MC – Mixed conifer Woodland/Forest
MC-S – Mixed conifer-Shrubland
PPMC – Ponderosa Pine/Mixed Conifer Woodland
PP-S & PPJS – Ponderosa Pine Shrubland
SH-O – Oak Shrubland
GRSH – Grassland/Shrubland
GRAS - Grassland
PP & PPPJ – Ponderosa Pine

Figure 4-10. Vegetation communities within the Cerro Grand Fire perimeter as mapped based on 1981 imagery (Allen 1990) and 2004 imagery (Muldavin 2011).

after stand-opening fires, which in small patches likely allowed pre-1900 recruitment of some current mature aspen groves. However, other current aspen groves in Bandelier reflect early 1900s infilling into glades, small openings, and canopy gaps in formerly much more open mixed conifer forests due to post-1900 suppression of historic surface fires, just as associated conifer species regeneration similarly infilled these stands. Between the 1981 and 2004 maps, aspens were mapped as neither gaining nor losing total area within the area of the 2000 Cerro Grande Fire; rather they show a shifting mosaic on the landscape, gaining area in some places while losing a similar amount in others. As discussed in the separate section on “Aspen”, there is evidence that browsing herbivory on aspen by ungulates (elk and deer) is suppressing recent post-fire aspen regeneration in portions of Bandelier’s mixed conifer forests. One clear change between the two maps is the new ruderal herbaceous communities, which would be expected in a fire-disturbed environment for this ecosystem type. According to Muldavin et al. (2011) these are dominated by Pascopyrum smithii along with Bouteloua spp. and a high diversity of forbs. We cannot yet determine if these ruderal patches will eventually be colonized by trees (aspen or conifers), as these patches are still young and there are insufficient data available currently to determine longer-term trends. It also appears as though a finer-scaled heterogeneity is emerging (Figure 10), although this observation may be influenced by a slightly smaller grain size used in the Muldavin (2011) map compared to the Allen (1989) map.

4.04.5 Level of confidence

The level of confidence for this analysis is moderate to high.

4.04.6 Data gaps/Research needs/ Management recommendations

Research needs are to update the park vegetation map to reflect post-Las Conchas Fire vegetation, monitor post-disturbance ecosystem recovery, and investigate potential fire management actions to contribute to ecosystem resilience. These are all discussed in more detail in chapter 5.

4.04.7 Sources of expertise

Matthew Bowker and David Smith

4.04.8 Literature cited

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Biological Integrity • Species of Management Concern

4.04-1 Aspen

Portions of this section are a summary of information provided by Bowker and Smith (2014). Their full report is provided in Appendix B.

4.04-1.1 Description

Quaking Aspen (*Populus tremuloides*), is the most widely distributed native tree in North America and the only aspen species in western North America (DeByle and Winokur 1985, Jones 1985, Worrall 2013). Vegetation communities dominated by aspen have numerous ecological and human values including high biological diversity (Chong et al. 2001), means by which they can indicate greater ecological health of a region (White et al. 1998), importance as wildlife habitat, ability to yield high-quality water in greater volume than other forest types in similar settings, ability to function as fire mediators in highly flammable coniferous forests (Fechner and Barrows 1976; DeByle and Winokur 1985), and the generally high value that humans place on the visual contribution of aspen stands in western landscapes.

The reproductive biology of aspen is of biological interest and greatly affects their current ability to persist. In the West, aspen does not typically regenerate from seed; aspen seeds are very sensitive to drying and need to stay wet for extended periods of time as well as in contact with mineral soil during early seedling growth. Intermittent dry conditions, or insufficient contact between the roots and mineral soil lead to seedling death (Quinn and Wu 2001; Turner et al. 2003). However, abundant aspen regeneration by seed can occur, particularly after fires when mineral soils are widely exposed (e.g., Turner et al. 2003).

In contrast, aspen vigorously reproduce vegetatively from existing clones (Barnes 1996). A clone is specifically defined as a group of individual stems and the associated root system that has been vegetatively propagated from a single seedling, called an 'ortet'. Many living aspen clones may be ancient, for example it has been proposed that most extant aspen clones in western North America established by 10,000 years ago (Mitton and Grant 1996), and the long-lived root systems of these clones make aspen one of the oldest living life forms on earth (Mitton and Grant 1996).

There is a long history of concern about browsing on aspen across the western United States (Sampson 1919; Leopold et al. 1947; Beetle 1962; Basile 1979; Mueggler 1988; Mueggler 1989; Krebill 1972; Murie 1994; Mueggler and Bartos 1997; Kay and Bartos 2000; Ripple and Larsen 2001), including in national parks (Wright and Thompson 1935; McLaren and Peterson 1994; White et al. 1998; Baker et al. 1997; Ripple and Larsen 2000).

Historic rise and recent declines of aspen

Aspen regeneration and succession are closely linked with historical and current fire regimes. Thus the story of recent aspen declines needs to be prefaced with an understanding of historical aspen expansions. Based on extensive fire-scar studies (Allen 1989), over at least the last 400 years, the dry mixed conifer and ponderosa pine forests of Bandelier NM were characterized by frequent surface fires (approximately 10-year mean fire intervals) with less common, patchy mixed-severity fires. With the advent of fire suppression by 1900, aspen began to expand due to release from this fire regime. Over the last century or so, the forest structures and fire regimes that once existed have been greatly altered, producing significant ecological effects on the fire prone-landscape (Foxx and Potter 1978; Allen 1989). Most notably, increased tree densities have resulted in 'crown fires", which can travel in the canopy across the forest at high speed and intensity, in stark contrast to the low intensity surface fires of the past. The patterns of aspen forest structure that emerged by the late 1900s were just as altered by fire suppression as the rest of the mixed conifer forests, with infilling of gaps by aspen sprouts that no longer were killed or thinned by frequent landscape-scale fires.

Although it is the most widespread tree species in North America (Worral et al. 2013), *Populus tremuloides* is generally declining in the western U.S. (Kay 1990, Kay 1997, Kulakowski et al. 2013, Schier 1975), with trends varying from place to place. Declines may be caused by a variety of factors. First, without fire, *Populus tremuloides* generally cannot compete with conifers. In some ecosystems, such as spruce-fir forest or high elevation, mesic mixed conifer forest, where long fire intervals allow conifers to close canopies and build high fuel loads, fire suppression throughout the 20th century largely omitted the fire-caused openings that typically provide opportunities for *Populus tremuloides* clones to proliferate. However, this sort of fire regime characterizes very little of the Monument landscape, as its high elevation forests are southerly in aspect and were connected as part of high-frequency firesheds pre-1900 (Allen 1989, Touchan et al. 1996,Morino et al. 1998). Secondly, herbivore populations in the Southwest have seen a substantial increase in the last century due to predator suppression, increase in ground water availability in the form of cattle tanks (Binkley et al. 2006), and re-introduction efforts (Truett 1996). Now when fires occur, herbivory can constrain the growth of new ramets (Kay and Bartos 2000, Binkley et al.2006). Sheppard and Fairweather (1994) estimate some 10-15 years of protection from herbivores might be necessary to allow an aspen ramet to attain a sufficient size to make it safe from herbivory. Finally, in recent years, the so-called "Sudden Aspen Decline" has led to mass mortality of mature *Populus* clones. Recently researchers have asserted the cause to be the combination of severe drought and warm temperatures (Anderegg et al. 2013, Worral et al. 2013). While this is a concern regionally, thus far in Bandelier NM there are no such cases of unexplained death of mature aspens (Stephen Fettig, personal communication), though it remains a possibility in the future.

History of elk and aspen in or near Bandelier National Monument

Elk were not abundant before the 20th century. Despite, or because they were relatively easy for Native Americans to hunt, they appear only relatively scarcely in archaeological records regionally in the Southwest (Truett 1996) and locally in the Jemez Mountains (Allen 2004). Mexican gray wolves and grizzly bears inhabited the local area until extirpation in the 1930s, and likely played some role in reducing elk numbers. Another predator, the cougar, has been the target of eradication efforts throughout the 20th century but has persisted in low numbers. Although the elimination of these predators was likely a boon for elk, human hunting pressure and limited surface water were probably greater constraints. Another difference between the 19th century and now is that elk are not naturally a forest species. They prefer open areas where they feed on herbaceous plants and can see their predators form a distance. With the advent of the rifle, elk can be killed from a distance and, therefore, they have found an advantage in spending greater amounts of time under forest cover in areas with hunting. Consequently elk are browsing forest species more heavily. A reference state would ideally be significantly after Puebloan occupation, before large-scale introduction of livestock and fire suppression and during a period of time when elk were present in low densities.

There is no reason to believe that aspens did not regenerate well after high-frequency watershed-wide fires in the Bandelier NM landscape prior to 1900, as they have been shown to do so when not constrained by other factors, like herbivory (Patton & Avant 1970). Aspens were much less likely to have been constrained by elk herbivory because elk are believed to have been a relatively minor species (<3% of large mammals) in the western U.S. before Euro-American settlement since they are poorly represented in archaeological and paleontological records (Allen 2004). This contrasts strongly with the current situation in which there has been major concern about elevated levels of elk herbivory cross the West (Murie 1944, Beetle 1962, Basile 1979), and a paucity of aspen regeneration for much of the 20th century (Ripple & Larsen 2001). Rocky Mountain elk (*Cervus canadensis*) were native in the Jemez Mountains until extirpated by about 1900 (Bailey 1931). This same subspecies was reintroduced to the Jemez Mountains in 1948 with elk from Yellowstone National Park, and in 1964-65 with elk from the Jackson Hole, Wyoming area (Allen 1996). The main difference between the pre-1900 and current role of elk in the ecosystem is based on population numbers (See section 4.17).

4.04-1.2 Reference conditions

Aspen is not browsed at a level that suppresses stand development.

4.04-1.3 Objectives of data analysis, data sources and methods

2001 through 2006 elk exclosure data.
Five elk exclosures were established in mixed conifer forests to track the influence of elk herbivory on aspen recovery, in addition to impacts on higher trophic levels. For each of the five exclosures and their adjacent controls, surveys counted the number of aspen individuals, and their frequency by height class. One pair of plots was burned in the 2000 Cerro Grande Fire. Bowker and Smith (2014) used a paired repeated measures design to examine the impact of elk herbivory on aspen growth following the Cerro Grande Fire.

Aspen and shrub recovery, random plots in Cerro Grande Fire vicinity; 2002 and 2005 data.
Maximum height and number of growing tips of aspen and elk herbivory-susceptible shrub species were measured in one set of random plots in 2002 (mostly located within the Cerro Grande Fire boundary) and in another set of random plots in 2005 (mostly located outside the Cerro Grande Fire boundary). Between 1992 and 2004, 3 distinct but similar studies were conducted that manipulated piñon-juniper canopy cover (Chong 1993; Jacobs and Gatewood 1998; and Loftin 1999). Bowker and Smith (2014) used classification and regression trees to model aspen height, and percentage of tips browsed as a function of spatial coordinates, elevation, pre-fire vegetation type, slope, aspect, and whether or not a site was located within the Cerro Grande Fire.

2006 aspen recovery in "refuge" plots in the Cerro Grand Fire vicinity; 2006 data.
During the collection of the previous dataset, it was observed that palatable saplings and shrubs appeared to be refuged by on-site elements, such as downed logs or rocks. This dataset focused on characterizing the properties of sites in which *Populus tremuloides* or elk-susceptible shrubs may be refuged from elk browsing. Field crews searched the entire Cerro Grande burn area looking for examples of an aspen or shrub that may be benefiting from a refuge element. When such a case was located, crews marked and sampled a 100 m^2 plot centered on the refuged individual or individuals. A total of 115 plots were sampled in this way. Bowker and Smith used classification and regression trees to model aspen height and cover as a function of refuge site characteristics.

Pooled data.
Bowker and Smith (2014) pooled the above data to produce maps of percent aspen browsing in 2002 and 2005, and maximum aspen height in 2006. All of these data were plotted through time as a simple means of gauging park-wide aspen recruitment and the impact of elk browsing.

4.04-1.4 Condition and trend

Aspen is currently decreasing in abundance because of the lack of successful regeneration on uplands with level or moderate slopes that are not protected from elk browsing.

Bowker and Smith (2014) found clear evidence that elk herbivory constrains aspen growth (Figure 4-11). In the first five years following the Cerro Grande Fire, elk exclosures and nearby controls did not have clearly different numbers of aspens. The numbers of aspens were highly variable among the different exclosure-control pairs, and in some pairs the exclosure had a greater number of sprouts, while in others control plots had more sprouts. This variability likely results from three linked factors:

- whether the plot burned
- the degree of shading in the understory
- soil temperature fluctuations due to different degrees of canopy closure

This suggests that the ability of aspen to initially resprout in an area, as suckers from roots of a surviving clone, is not clearly reduced by elk in this dataset. Elk browsing and debarking of mature aspens could reduce sprouting vigor, but these data account only for exclusion of such impacts since 2000.

Regardless of their numbers, aspen individuals are currently subject to intense herbivory which constrains their size. On average, saplings were constrained to around 40 cm in height and did not show an upward growth trend. Inside exclosures, aspens were clearly becoming larger over time and the growth rate increased at each increment. In 2006, they had attained a height about 4 times that of their elk-affected counterparts. While in the short-term, this herbivory does not seem to result in mortality of aspens, it is reasonable to assume that a long-term continuation of this pattern would eventually result in the depletion of energy reserves and death of these stems as observed in two 10-acre areas within Bandelier NM and elsewhere (Lindroth &and St. Clair 2013). Perhaps most interesting was the fact that fire intensity and elk exclusion seem to interact. In Figure 11c, we can see that control plots have similar, small aspen heights regardless of fire intensity. But, when protected from herbivory, the burned plot had aspens sprouts nearly double the size of the unburned plots. This suggests that aspen are well-equipped to recover from fire as long as they are not constrained by herbivory. These results are not surprising, and are in line with several other studies of the elk-aspen interaction in

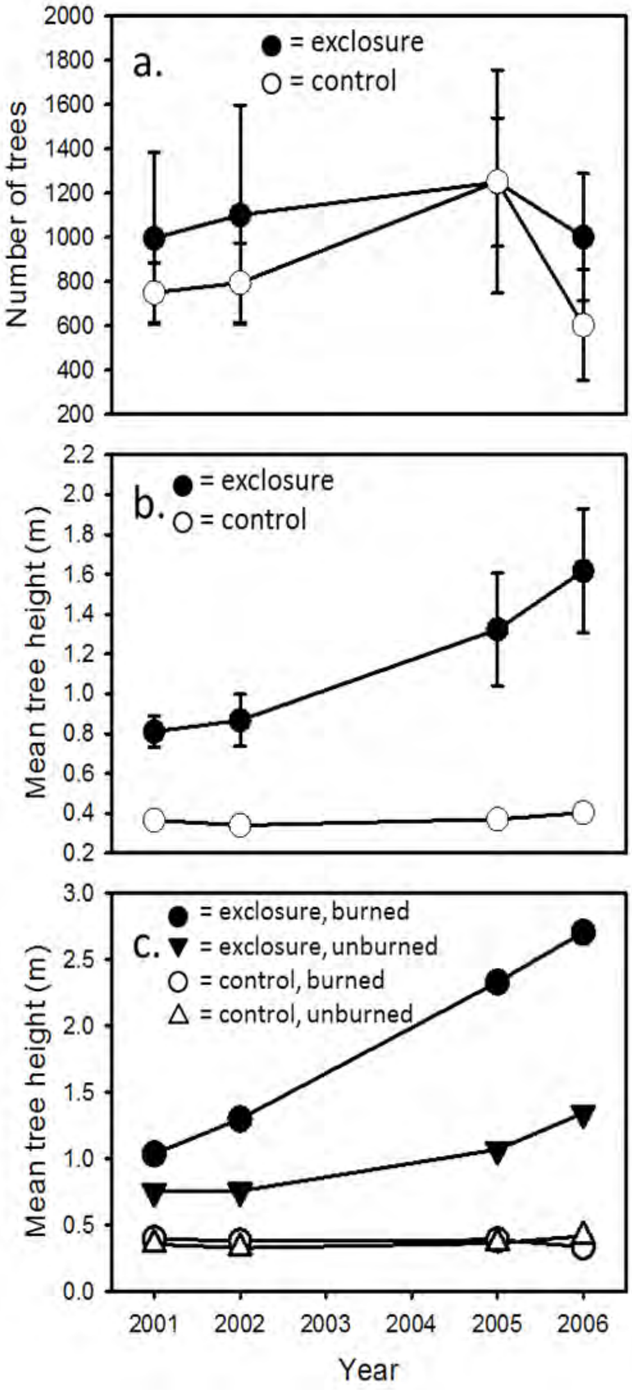

Figure 4-11. Number and mean height of aspen stems inside elk exclosures and in control plots outside of exclosures over five years. a. None of the considered factors affected number of aspen stems (Exclosure: F=1.6, P=0.26 Time: F=1.3, P=0.39), b. Mean aspen height was much greater inside exclosures, increased over time inside exclosures, and increased most inside burned exclosures (Exclosure: F=137277, P<0.0001; B × E : F=57.2, P=0.0003; Time: F= 160.0, P 0.0001; E × T: F=8.9, P=0.10), c. Illustration of the B × E interaction.

western North America.

Several of Bowker and Smith's analyses focused on the variation in indicators of elk herbivory on aspen across the landscape. They wished to determine which were the strongest influences upon intensity of herbivory, and whether these could be predictively modeled. Three datasets were available, dating from 2002, 2005, and 2006, that were pertinent to the recovery from the Cerro Grande Fire. In 2002 and 2005 there were direct observations of browsed tissue on aspen, supplemented with information on maximal sapling height, which would be expected to be under the influence of elk herbivory, but also influenced by climate and soil characteristics. In 2006, two indirect indicators of elk activity were available: aspen maximal height and cover.

Perhaps the most striking conclusion that can be drawn from this set of analyses is that elk herbivory has a strong spatial component, regardless of the year. Krantz (2001) compiled elk observations in Valles Caldera National Preserve in 2001, and found that the Rincon area of Valle Grande consistently had the largest number of elk, numbering in the hundreds for most observations. This result is attributed to the fact that it is a large area with considerable forest edge. Valles Caldera elk prefer to spend the night in open areas and spend days under tree cover, so the Rincon area attracts large numbers of animals. This demonstrates that the natural distribution of elk is highly variable spatially, and that there can be consistent hotspots of elk activity in a given year.

The spatial pattern of elk browsing indicators in Bandelier NM may be demonstrating something similar. Interestingly, in 2002, it was the far eastern edge of the northern portion of the monument which experienced the greatest herbivory. However, the northernmost portion of this area exhibited the smallest aspen heights. In 2005, models were much poorer in explanatory power (not shown: % browsing R2 = 0.05; maximum height R2 = 0.18) but the % browsing model indicates the greatest browsing north of the monument in lower lying areas, i.e. Valle Grande. Also in 2005, the smallest maximal tree heights were observed in the Bandelier NM portions of the Cerro Grande Fire area, but were about twice as large east of the park boundary. The 2006 aspen height data suggests more northerly locations had shorter aspens, and that in between 3967997N and 3968536N, no aspens were observed. Again this suggests a spatial heterogeneity in herbivore pressure. Some places experience much greater herbivory than other locations, and this patterning may shift from year to year (Wolf 2003).

4.04-1.5 Level of confidence

High; this is a highly researched topic across the western U.S.

4.04-1.6 Data gaps/Research needs/ Management recommendations

Trophic cascades associated with the loss of key predators has been shown to be an urgent global issue known to specifically be acting in U.S. national parks (Estes et al. 2011). The loss of large predators in the 1900s has left a characteristic signal in reduced tree growth rates at Isle Royal National Park (McLaren and Peterson 1994) and recruitment failure at Yellowstone National Park (Beschta and Ripple 2009). The monument's studies of aspen supports the synthesis provided by Estes et al. (2011).

Two management recommendations surface clearly from our current scientific understanding. First, land management planning efforts need to address the cascading ecosystem changes when consumers such as ungulate increase with the loss or continued absence of predators (Estes et al. 2011). Through planning efforts (e.g. compliance with NEPA), managers should seek to educate the public regarding the ecological role of apex predators and how their loss threatens biodiversity (Estes et al. 2011). Second, the best management solution is likely the restoration of an effective predation regime (Estes et al. 2011)—clearly not an easy task.

Management considerations in the face of climate change

Beschta et al. (2012) summed up the topic, saying that if effective adaptions to the adverse effect of climate change are to be accomplished on western public lands, large-scale reduction or cessation of ecosystem stressors associated with ungulate use are crucial. Active ecosystem management, including the elimination of non-climate in situ threats, such as herbivory, are important in the face of climate change (Welch 2005).

The park should conduct monitoring to determine regeneration of unprotected aspen stands within the footprint of the Las Conchas Fire.

4.04-1.7 Sources of expertise

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4.04-1.8 Literature cited

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4.05 Ponderosa Pine Forest and Woodland

This is a brief summary of the information provided by Bowker and Smith (2014) in Appendix B. Detailed descriptions of ponderosa pine forest ecology, the data used, analysis methods, and all references are included therein. The information below is mostly interpreted or taken directly from that report.

4.05.1 Description

Ponderosa pine (*Pinus ponderosa*; 'ponderosa') vegetation communities can be described as forest, woodland or savanna, depending on canopy density, but generally have ponderosa as the dominant overstory species. Ponderosa pine forests across the southwestern U.S. are threatened by several factors, primarily changes in fire regimes that have led to unnaturally high tree densities, and the interacting impacts of climate change and drought (Negron et al. 2009, Wallin et al. 2004), factors that are described in detail in Bowker and Smith (2014) and explained briefly below.

4.05.1.1 Climate

One of the most important expressions of climate change is increasing warm drought periods (Williams et al. 2012). The western U.S. is currently experiencing the warmest temperatures observed in a millennium (Intergovernmental Panel on Climate Change [IPCC] 2007), and models strongly suggest climate scenarios wherein northwestern New Mexico will very likely experience continued warming, possibly along with less spring precipitation (Karl et al. 2009).

Within Bandelier NM, the 1950s drought and associated bark beetle outbreak killed mesatop ponderosa pines across a several kilometer band along its lower elevational distribution over a brief 5-year timespan Figure 4-12 (Allen and Breshears 1998). Regionally, in the years following the 2002 drought many individuals or even entire stands died (Breshears et al. 2005; Gitlin et al. 2006).

4.05.1.2 Fire

Fire patterns in southwestern ponderosa pine forests have changed considerably over the last several centuries. Until about the late 1800s, fires were common, but remained mostly on the ground (rather than burned in the crowns of trees). Fire behavior was driven by forests that had fewer trees and a greater understory of grasses and shrubs that maintained surface fires and minimized long-term damage to mature trees (Allen 1989, Allen et al. 1995). The average fire return interval was about 5–15 years, which limited survival of all but a few tree cohorts (Figure 4-13).

With the introduction of grazers (cattle and sheep), much of the herbaceous understory was consumed or trampled, fires were routinely suppressed, and ponderosa pine forests across the southwest grew thicker and older. The result was much higher tree densities, a situation that greatly increases the potential for crown and high intensity fires that kill large trees which would otherwise

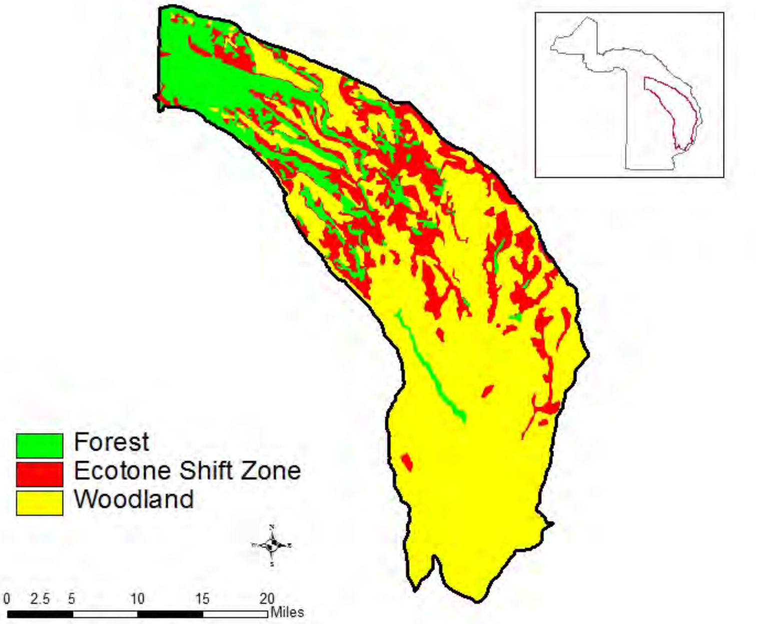

Figure 4-12. Changes in vegetation cover, 1954–1963, in the study area at Bandelier National Monument, showing persistent ponderosa pine forest (green), persistent piñon-juniper woodland (yellow), and the ecotone shift zone (red) where forest changed to woodland.

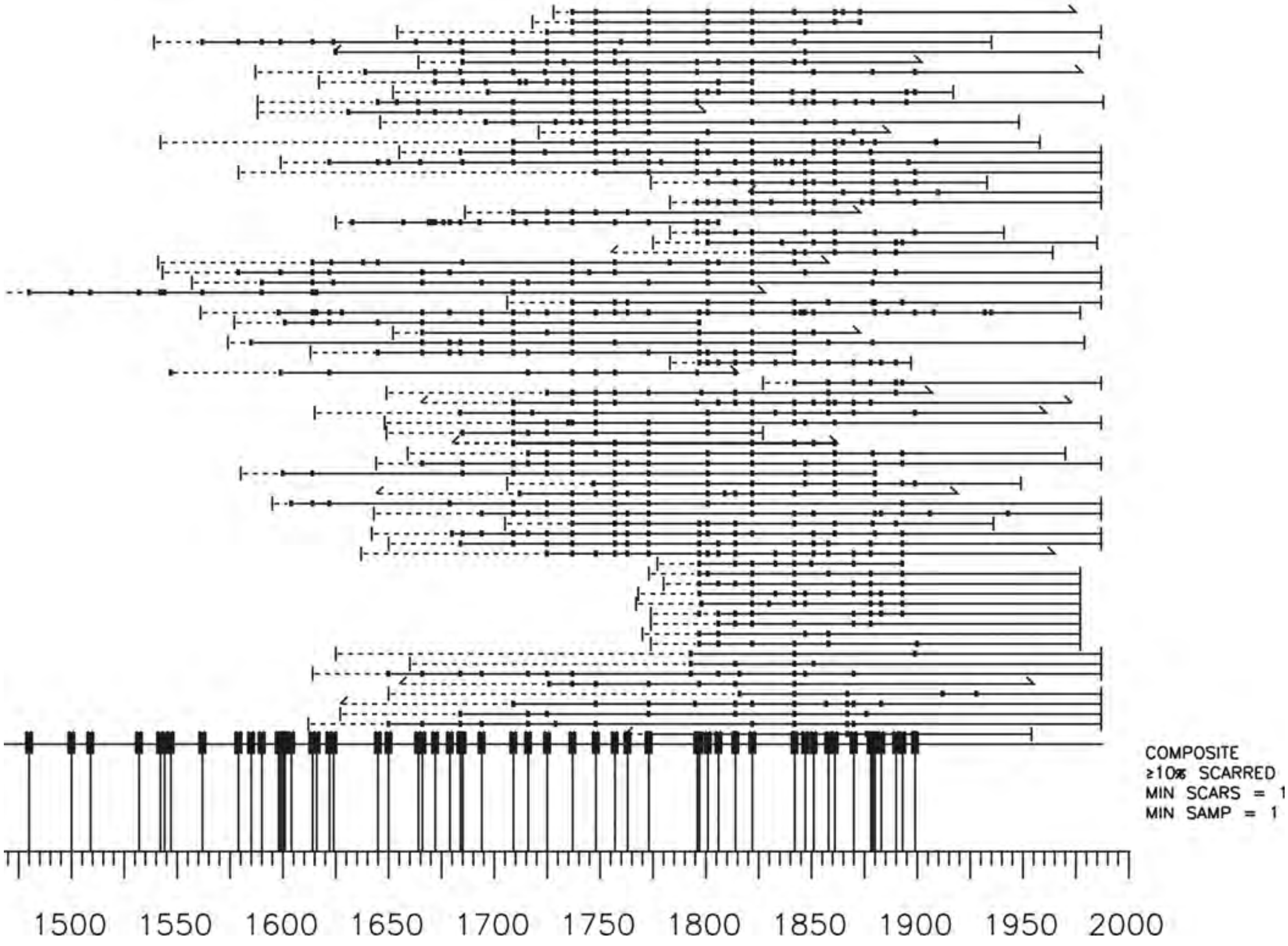

Figure 4-13. Fire scar chronology for samples collected in Frijoles Canyon. The horizontal lines depict individual tree lifespans. The dots along the lines represent recorded fire scars. Many trees record fire in the same year. Fires burned at a regular interval until after 1900.

survive low intensity surface fires (Potter and Foxx 1978, Allen 1989, Moore et al. 1999, Allen et al. 2002). In addition, exotic grasses (particularly cheatgrass, *Bromus tectorum*, and other brome species) are now permanently present in the seed bank of many southwestern forests or areas adjacent to them, and following fires, can now outcompete many native herbaceous species (Korb et al. 2003, Barclay et al. 2004, McGlone et al. 2009).

Fire is a part of the evolutionary environment of the ponderosa pine forest (Moore et al. 1999). However, fires in recent decades have been dissimilar to the surface fires that occurred from ca. 1500–1900, and can be characterized as having a much greater extent of high-severity fire effects. Since the 1970s, several major crown fires have occurred in and around Bandelier N. M. The 1977 La Mesa Fire (6,354 ha), the 1996 Dome Fire (6,677 ha), the 1997 Lummis Fire (607 ha), the 2000 Cerro Grande Fire (16,909 ha), and the catastrophic 2011 Las Conchas Fire (63,250 ha) all burned at least some ponderosa pine forests (Figure 4-14a), with the La Mesa, Dome and Las Conchas impacting ponderosa pine forests most severely(Figure 4-14b). These large, stand-replacing

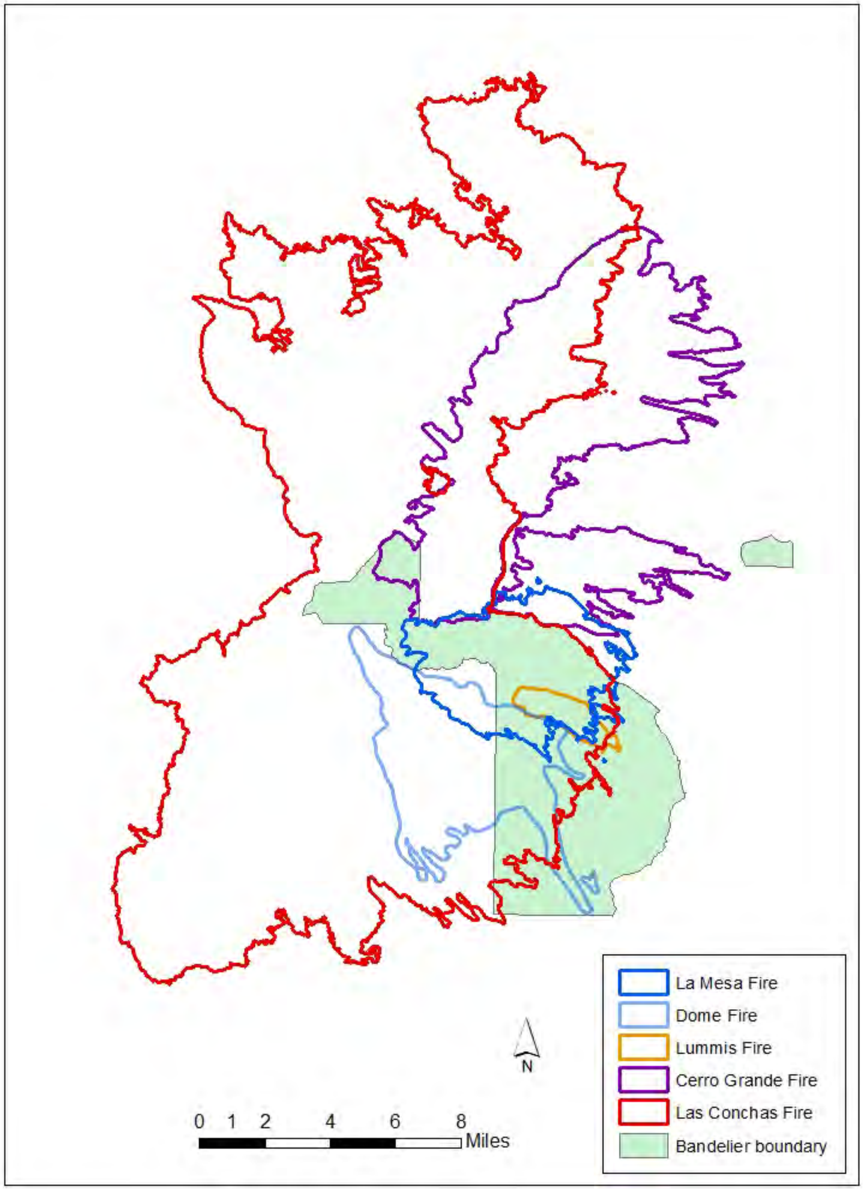

Figure 4-14a. Bandelier National Monument and outlines of 1997 La Mesa Fire, 1996 Dome Fire, 1997 Lummis Fire, 2000 Cerro Grande Fire and 2011 Las Conchas Fire.

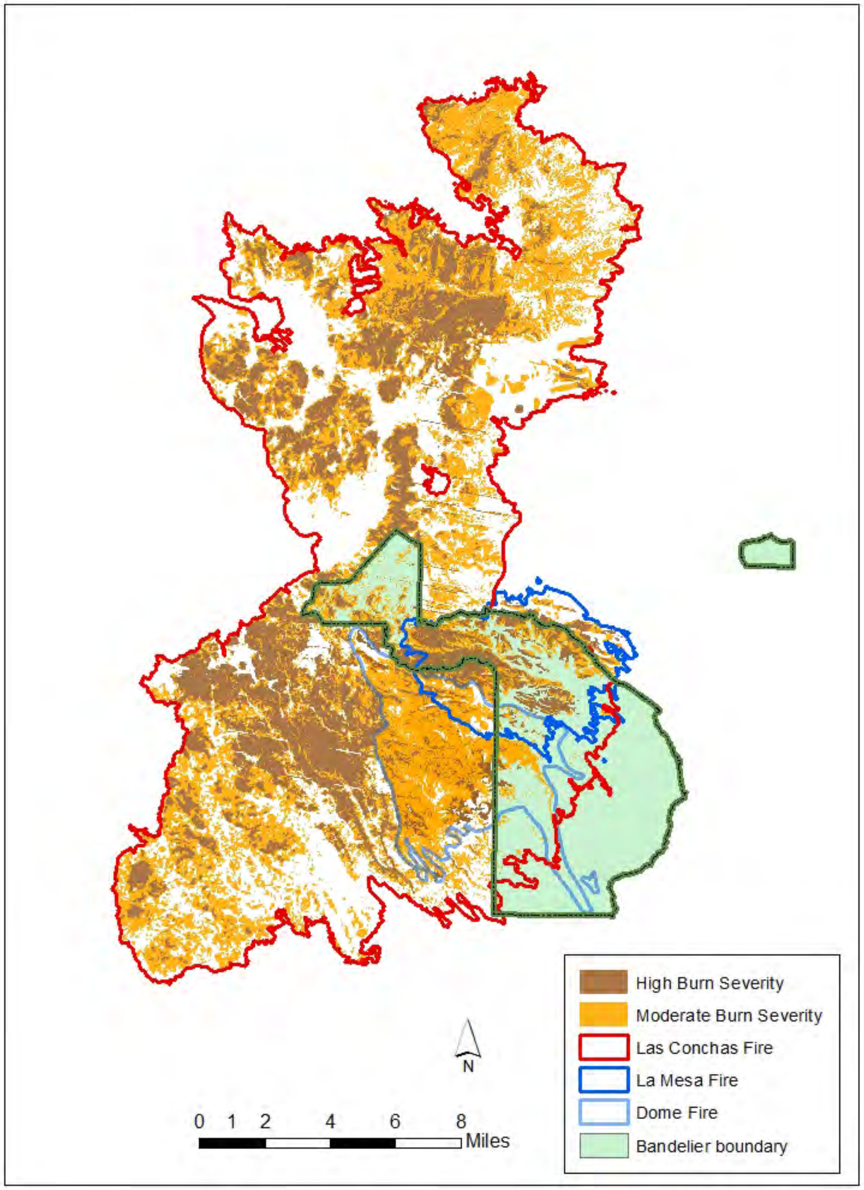

Figure 4-14b. Bandelier National Monument and the areas of high and moderate burn severity for the three fires (1997 La Mesa Fire, 1996 Dome Fire and 2011 Las Conchas Fire) that represent areas of tree cover loss.

fires were a result of over a century of fire suppression and fuel build-up interacting with warmer temperatures brought about by recent climate trajectories.

As has occurred elsewhere in the region, 20th century fire suppression resulted in rapid recruitment of ponderosa pine saplings, resulting in "doghair thickets" of small diameter trees. One local example of old-growth ponderosa pine densities, and subsequent stand thickening, comes from the Monument Canyon Research Natural Area of Santa Fe National Forest to the west of Bandelier NM. This stand displayed a two-tiered tree distribution with an old-growth density of 100 stems/ha and an understory thicket of saplings and poles with a tree density of 21,500 stems/ha (Allen 1989). Similar stand conditions and high fuel loads were evident in the area burned by the 1977 La Mesa Fire which converted the heart of the monument's ponderosa pine forest into grasslands (Allen 1989).

The historical fire regimes of ponderosa pine forests in the Jemez Mountains have been relatively well reconstructed using tree-ring methods and charcoal (Touchan et al. 1996, Allen 2002, Anderson et al. 2008). Prior to the 1860s, Utes, Apaches and Navajos using the Jemez Mountains area were a deterrent to settlement by Euro-Americans (Allen 2004). Shortly afterward, in the 1870s and 1880s, livestock were introduced in large numbers into what is now Bandelier NM, at very high stocking rates (Allen 2004). The grazing pressure diminished fine herbaceous fuels, curtailing the spread of fire and the size of fires. The previously high-frequency fires were further curtailed by the adoption of fire suppression policies in the early 20th century. Long-term fire scar records confirm that this omission of fire since the late 1880s in the Jemez Mountains is an anomaly. The fire regime can be tracked over periods of centuries rather than just a window of time just before the 20th century. Touchan et al. (1996) and Allen (2002), documented the last 500 years of burn scars, and provide strong evidence of a near complete cessation of fire by around AD 1900. In the 400 years prior to the 20th century, ponderosa pine forests experienced frequent fires, most of which were low-intensity surface fires. The fire return intervals were largely about 5–15 years. Large crown fires were absent from ponderosa pine forests in local and regional fire scar records (Swetnam and Baisan 1996).

4.05.2 Reference conditions

An extensive body of research has addressed the definition of reference conditions for southwestern ponderosa pine forests in general (e.g. Covington and Moore 1994, Fule et al. 1997, Moore et al. 1999 Swetnam et al. 1999). The conclusions from these studies are that prior to European settlement, ponderosa pine communities were mostly open canopied forests and savannas, with tree densities ranging from 8–25 trees per hectare (Fule et al. 1997, Allen et al. 2002, Woolsey 1911). Understories included native grasses and shrubs, such as *Quercus gambelii*— compositions maintained by frequent, low-intensity surface fires (Allen et al. 1995; Abella 2008).

In the Jemez Mountains, open ponderosa pine forests covered the middle and upper portions of the Pajarito Plateau 125 years ago. By 1900, heavy livestock grazing had degraded the grassy understory, leading to de facto fire suppression, which was later continued as 20th century fire suppression policy (Allen 1989).

4.05.3 Objectives of vegetation analysis, data sources, and methods

The data used and all analysis methods are described in detail in Bowker and Smith 2014 (Appendix B).

4.05.3.1 Vegetation maps

Two vegetation maps, Allen 1989 (`Allen') and Muldavin et al. 2011 (`Muldavin'), were compared to detect changes in vegetation cover over time. The Allen map was based upon 1981 imagery while the Muldavin map was based upon 2004 imagery. To facilitate comparisons among the two maps, both were reduced to their intersection and the

Muldavin map reclassified to conform to the Allen map (complete details of this process provided in Bowker and Smith 2014). Although this translation was imperfect, most major Muldavin units corresponded reasonably well to major Allen units. For ponderosa pine, Muldavin's eight types were reduced to Allen's four types (Bowker and Smith 2014).

4.05.3.2 Fire maps

Fire severity maps for each of the fires mentioned above (or fire perimeter, only if severity was not available), were spatially oriented with the vegetation maps. Multiple methods were used to compare seeded vs. unseeded, and variable fire intensities with vegetation composition to analyze changes in cover of various functional groups (forbs, grasses, shrubs, subshrubs and trees).

4.05.3.3 Fire effects monitoring plot data

Fire monitoring plots were established to examine shifts in vegetation characteristics after prescribed burns, mechanical thinning, and wildfire. This analysis used only data from plots representative of various types of ponderosa pine stands, or former ponderosa pine stands. Plots were defined as being from one of four areas: upper elevation ponderosa, low elevation ponderosa, previous ponderosa (area of La Mesa Fire) and the area of mechanical thinning. Burned plots were surveyed before a prescribed burn, immediately after the burn, and at one, two, five, and 10 years after the burn. Similar to burned plots, thinned plots were surveyed immediately before and after thinning.

4.05.3.4 Post-Dome Fire transects

In 1996, following the Dome Fire, an emergency seeding operation was initiated on the Santa Fe National Forest (SFNF) portion of the burn, but not on the monument's portions. In 1997, 49 vegetation sampling transects were established in and around the burn, ten in the park and the remainder in SFNF. Transects were located to sample areas that varied in pre-fire forest type, elevation, fire intensity, and seeding treatment. At each location, herbaceous vegetation was sampled using line-intercept methods, and tree regeneration counted within a plot centered around the transect (Barclay et al. 2004). All of the plots were measured in 1997 and 1998, the park's plots were re-measured in 2002, and the SFNF plots were re-measured in 2008.

4.05.3.5 Data analysis

PerMANOVA (Anderson 2001) was used to statistically test for differences in the overall cover composition of functional groups. Using the same community matrix, non-metric multi-dimensional scaling (NMDS) (McCune and Grace 2002) was used to graph functional group composition across fire intensities (high, moderate and unburned) and seeding (seeded vs. unseeded). An ANOVA was used to evaluate changes in cover of individual functional groups, species richness, total live canopy, and specifically for *Bromus tectorum* and *B. inermis*.

4.05.4 Condition and trend

Vegetation change in the ponderosa pine zone of Bandelier NM is largely driven by fire and associated invasive species impacts, and by drought and associated pathogen outbreaks. After about a century of fire suppression and relatively few fires, large, and often intense, fires are strongly impacting the ponderosa pine forests of Bandelier NM (Figure 4-4, p. 49). The 1977 La Mesa Fire had a major effect on the distribution of ponderosa pine forests (Potter and Foxx 1978, Allen 1989). Within Bandelier NM, nearly all of the area that experienced at least moderate severity burns, was mapped from 1981 air photos as vegetation types other than ponderosa pine forests—usually grasslands or shrublands (Allen 1989). Since it is known that most of the burned areas were ponderosa pine forests, this observation suggests a fire-triggered type conversion. Most of these areas have still not reverted back to ponderosa pine forests based on more recent 2004 mapping.

The 1996 Dome Fire impacted ponderosa pine forests, but mostly forest outside of the Bandelier NM boundary on the national forest side. Within the park, west of Capulin

Canyon, a sizable block (~ 1km^2) of contiguous ponderosa pine forests experienced moderate to high intensity fire (Fig. 4-2b, p. 39).

The 1997 Lummis Fire was almost entirely within ponderosa pine habitat, including some areas previously converted during the La Mesa Fire). This fire occurred in the largest remaining contiguous block of ponderosa pine forest remaining in the monument, and its perimeter encompassed more than half of that block. The Las Conchas Fire was a much larger fire, but its impacts on ponderosa pine forests within the monument were smaller, perhaps because of the fuel consumption effects of other recent fires (Figure 2d). On adjacent National Forest lands, many ponderosa pine and former ponderosa pine stands that were impacted by the Dome Fire reburned in Las Conchas.

In summary, ponderosa pine forests with herbaceous understories have been greatly reduced in coverage on the monument landscape by high severity fires since 1977, and are becoming increasingly fragmented (Figure 4-15). Shrubs appear to be emerging as either dominant species or major community components, along with grasses. Shrublands or shrub-grassland associations, in which shrub species re-sprout after fire, are common in various parts of the U.S. and the world. It seems likely that increasing fire frequency would perpetuate these community types and constrain recruitment of *Pinus ponderosa*.

Bowker and Smith (2014) used the Post-Dome Fire transect data (transects were primarily in ponderosa pine, but ranged from mixed conifer forest to piñon-juniper woodland) and fire monitoring plot data to examine the components of ponderosa pine community structure and composition that changed with fire. They observed that species richness was highest at moderate burn severities. Their analysis also suggested that total vegetative cover differed across burn severities, such that cover was highest in unburned plots and lowest at high burn severities. In examining canopy cover of individual functional groups, they found significant differences in the cover of forbs, shrubs, and trees across burn severities. Tree cover in unburned sites was approximately 58%, but

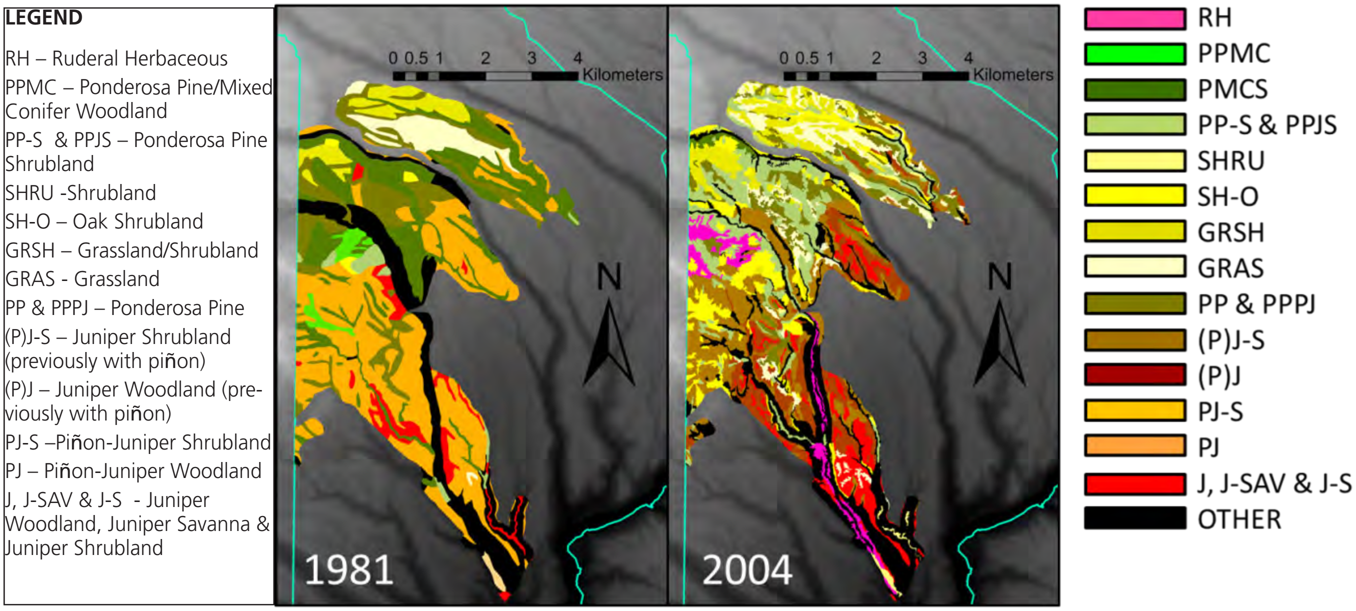

Figure 4-15. Vegetation communities within the Dome (1996) and Lummis (1997) fire perimeters as mapped based on 1981 imagery (Allen 1990) and 2004 imagery (Muldavin 2011).

only 3% and 1% respectively, in moderate severity and high severity burn sites. Shrub, forb and grass covers in moderately or severely burned sites were roughly two-fold that of unburned sites.

Over the past several decades, there have been major transformations in the distribution and vegetation structure of the ponderosa pine forests of Bandelier NM. Some of these changes have been induced by deliberate human action (thinning, prescribed burning and seeding), while others have been brought about by inadvertent human perturbation (climate change and wildfire). Wildfire in particular has had the greatest impact, resulting in fragmentation of the ponderosa pine forests, and establishment of large grassland patches. Wildfire has also promoted shrubs, both as a dominant species, and as an understory subdominant. As climate change increasingly favors fires, it can be expected that their frequency and magnitude will continue increasing (Williams et al. 2010).

The recent fires were the outcome of changing climate and fuel and canopy conditions brought about by a century of fire suppression. Since canopy cover and the continuity of ponderosa pine forests has already changed so much, we can expect that future fire behavior and outcomes could be different. Grassland patches are likely to experience frequent low intensity fire, but are being colonized by shrubs which will change their fire behavior. Shrublands and forests with shrub understories are likely to experience moderate to high intensity fire. If trees are part of the community or adjacent to these communities, the fire may be capable of jumping to tree crowns. The major shrubs (oak and locust) are fire resprouters. While we are seeing significant departure from historical vegetation conditions which formerly supported a surface fire regime, one positive aspect is that a more crown fire-resilient vegetation type is emerging. These scenarios would logically lead to a future where grasses and shrubs become more prevalent and promote their own persistence by modifying fire behavior and fuel characteristics. It would seem that ponderosa pine may have a lesser role in the resulting systems. If future climate conditions include multi-decadal wet spells between drought episodes, ponderosa pine may persist, but perhaps at lower densities, especially in shrub dominated portions of the landscape.

Major drought events, such as that of 2002 (Breshears et al.2005), are another force influencing vegetation dynamics. As stated elsewhere in this report, the future will very likely be characterized by increasingly warm, and therefore more severe droughts (Adams et al. 2009, Williams et al. 2010). It is clearly a factor which reduces the probability of the persistence of ponderosa pine stands (Allen & Breshears 1998, Gitlin et al. 2006). Less well understood are its effects on the recruitment of shrubs and exotic grasses. In the fire monitoring plots, shrub cover increased consistently each year from 1993 to 2000, resulting in an approximately 18-fold increase in shrubs. After the drought of 2002, shrub cover decreased to 1993 levels, consistent with observations of shrub canopy diebacks that year (Brian Jacobs and Craig Allen, personal communication).

In the remaining ponderosa pine stands that have withstood crown fire and drought, management activities may alter the successional course. Prescribed burning and mechanical thinning reduced overstory tree density by about 50 and 40%, respectively, from undisturbed controls. The reduction in overstory trees is consistent with historical conditions, and would likely avert or reduce the extent of crown fire runs in the future, allowing the persistence of ponderosa pine as a major community member. Interestingly, in contrast to wildfire, we did not find an influence of prescribed burning or thinning on shrub or understory herbaceous cover vegetation, suggesting that the treatments have not thinned the overgrown forests sufficiently to restore pre-1900 surface fire conditions.

In this ecosystem, which is so prone to change, desired conditions should be viewed as a moving target. The extent, abundance, and continuity of ponderosa pine woodland have been compromised, and the best guess at the future is a continuation of this trend; an increasing "shrubification" and an increasing presence of exotic grasses. This future does depend on which management actions are undertaken. There is some evidence that thinning and prescribed burning could slow this trend, by reducing the probability of crown fire in the remaining stands, and by removing the force which converts forests to shrublands—high-severity fire.

4.05.6 Data gaps/Research needs/ Management recommendations

- Generally, post-fire seeding is not likely to lead to desirable long-term vegetation outcomes and is not effective in reducing erosion. Seeding results in increased cover of exotic species that persists indefinitely.
- There is some evidence that thinning and prescribed burning could slow the process of conversion from forests to shrub and grasslands by reducing the probability of crown fires in remaining stands. See discussion of forest management under Jemez Mountain salamander.
- Climate change scenarios strongly indicate that northwestern New Mexico will experience continued warming and possibly less spring precipitation (Karl et al. 2009), conditions that will continue to inhibit, through various mechanisms, the regrowth of ponderosa forests. This increases the importance of landscape-wide conservation measures targeted at ponderosa pine forests.

4.05.7 Sources of expertise

Matthew Bowker, David Smith, and Stephen Fettig

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4.06 Piñon-Juniper Woodland

This is a summary of the information provided by Bowker and Smith (2014) in Appendix B. More in-depth descriptions of piñon-juniper woodland ecology, the data used, and analysis methods, are included therein. The information below is mostly interpreted or taken directly from that report.

4.06.1 Description

Piñon-juniper woodlands occur on nearly 40 million ha in North America (Romme et al. 2010) and include many different community types. In all cases, however, they occur in semi-arid climates, usually at medium elevations (~1200 –2500m), and contain at least one *Pinus* species and a *Juniperus* species. In Bandelier NM, until recently, piñon-juniper woodlands were dominated by *Pinus edulis* and *Juniperus monosperma*, with *Juniperus deppeana* either a subdominant or co-dominant in local areas (Muldavin et al. 2011). While a variety of woodland types that occur in Bandelier NM can be described as piñon-juniper (described in detail in Bowker and Smith 2014), most piñon-juniper woodlands in the monument best fit the persistent woodland type.

4.06.1.1 Climate

One of the most important expressions of climate change is increasingly warm drought periods (Adams et al. 2009). The western U.S. is currently experiencing the warmest temperatures observed in a millennium (IPCC 2007), and models strongly suggest climate scenarios wherein northwestern New Mexico will very likely experience continued warming, possibly along with less spring precipitation (Karl et al. 2009).

In the Southwestern U.S., piñon pine is susceptible to mass mortality during drought (Allen and Breshears 1998, Breshears et al. 2005, Gitlin et al. 2006). The impact of the 2002 drought across the Bandelier NM landscape provides a stark example. While major mortality of ponderosa pine and some impacts to Douglas-fir and white fir were observed, the 2002 drought decimated piñon pine, with over 90% mortality of mature trees. This has resulted in substantial transformations in vegetation community distribution and canopy cover on the landscape (Bowker and Smith 2014). *Juniperus monosperma*, the most common co-dominant of *Pinus edulis* in the monument, is more drought-tolerant than piñon but also experienced stand-level mortality during the recent drought periods (Bowker et al.2012, Brian Jacobs and Craig Allen, personal communications and unpublished data from Bandelier NM plots and transects).

4.06.1.2 Fire

In addition to variation in species composition, piñon-juniper woodlands can differ fundamentally in disturbance regimes. The natural fire regime of these ecosystems is not completely known because, unlike larger fire-resistant species, such as ponderosa pine, piñons and junipers often do not survive fire, so tree-ring data commonly are unavailable for use in reconstructing fire histories. Understanding the role of fire in the piñon-juniper woodlands of Bandelier NM is complicated by the diversity of piñon-juniper community types that occur across the landscape. These include juniper savannas, piñon-juniper savannas, piñon-juniper -oak communities, and most commonly, persistent piñon-juniper woodlands.

At higher elevations, piñon-juniper woodland intersperses with, and in some sites, has recently replaced ponderosa pine savanna. Some have suggested that a major herbaceous understory component historically existed in piñon-juniper communities of the region and that surface fires may have preserved this condition (Gottfried et al. 1995, Jacobs & Gatewood 1999). However, evidence is sparse and mostly from ponderosa pine stands near piñon-juniper stands (cf. Allen 1989).

Patchy stand-destroying crown-fires are well-documented in piñon-juniper woodlands from elsewhere in the region (Romme et al. 2009). Pre-1900 disturbance regimes in piñon-juniper savanna are not well understood. Piñon-juniper woodlands have been less affected by fire than other ecosystems, but large areas of piñon-juniper have been lost in recent fires, particularly in the 1996 Dome Fire and the 2011 Las Conchas Fire.

Persistent erosion has also had substantial negative impacts on piñon-juniper communities in Bandelier NM. Overgrazing and the resulting loss of the herbaceous understory likely accelerated this process (Allen 1989, Miller and Wigand 1994, Brockway et al. 2002). High erosion rates create a positive feedback loop, whereby herbaceous plants cannot colonize the unstable surface, and because there are few plants in between trees, erosion is unchecked.

The past conditions of the piñon-juniper woodlands are characterized by change, and can be coarsely reconstructed based on historical or archaeological evidence. Significant portions of piñon-juniper woodlands may have been cleared on the monument's mesa tops during the period of Ancestral Puebloan settlement (Allen 2004). The period of abandonment coincided with a megadrought in the 1500s. Both settlement and mega-drought could be viewed as likely triggers of ecological state transition. Recovery and regrowth from this event must have occurred during the cool period known as the Little Ice Age.

It is known that the ecosystems that grew back from these earlier perturbations were woodlands with a substantial grass cover, as noted in the Ramon Vigil Land Grant of 1877 and later adjacent Land Grants surveyed by the General Land Office (Allen 2004). This land grant and the resettling of nomadic Native Americans onto reservations around the 1860s marked the introduction of large scale livestock grazing (Allen 2004), since the Navajo, Apache and Utes had previously served as a deterrent to Euro-American use of the area.

Although livestock had certainly been introduced earlier, their numbers have not been documented and cannot be estimated well, but are thought to be much lower than after the 1860s. Thus, the period from 1860–1870 is one of the better periods to use as a reference to compare current conditions to because it is over 300 years after occupation by Ancestral Puebloans, yet just before the introduction of large livestock herds. The introduction of livestock quickly compromised herbaceous plant cover, as stocking rates were an order of magnitude greater than what would be considered carrying capacity today (Foxx and Tierney 1984) By 1913, grass cover was described by the General Land Office as "scant", compared with descriptions from 30-40 years before as "excellent" or "fine" growth of grass (Allen 2004).

One major result of a degraded herbaceous layer was erosion. The creation of the national monument in 1916, and the transition to management by the National Park Service in 1932 led to the termination of commercial ranching in Bandelier NM, but trespassing or feral livestock has remained a problem (Allen 2004). Erosion and hydrological impacts lingered after the cessation of commercial grazing. As early as 1938 the inability of the soil to retain moisture was noted by the General Land Office (Allen 2004). A 1948 internal park memorandum described the large extent of the problem and suggested means to correct it. High erosion rates may have been further accelerated by the 1950s drought which resulted in vegetation mortality. Accelerated erosion has persisted up to the present as possibly the foremost management issue in the piñon-juniper woodlands.

The sharp decrease in herbaceous vegetation corresponds with a cessation of fires in the general area. An oft-stated belief is that because this major herbaceous component had previously existed in the understories of piñon-juniper communities in the park and nearby, surface fire may have preserved a relatively open canopied configuration (Gottfried et al. 1995, Jacobs and Gatewood 1999). The fire history is difficult to know with certainty because piñon-juniper woodlands are poor preservers of fire scars from which to reconstruct past fire cycles. The evidence for frequent surface fire is indirect but comes from two lines of reasoning:

1. Most individual trees are young, whereas older trees are more widely scattered (Jacobs et al. 2008). Since woodlands generally become thick without maintenance by fire, this implies the presence of fires, which did not destroy whole stands, i.e. low intensity surface fire.
2. A frequent fire cycle is well established for directly adjacent and interfingered ponderosa pine savannas (Allen et al. 1995), and it is reasonable to believe that these fires carried into piñon-juniper stands with herbaceous understories. This series of events may have led to thickening tree canopies, which reinforce a more closed woodland rather than an open grassy woodland. Jacobs et al. (2008) use a predictive model to conclude only about a third of the monument's current piñon-juniper woodlands were recently encroached savannas. The other two-thirds likely were persistent woodlands that may have thickened in the past century and which did not have a frequent-fire regime.

4.06.2 Reference conditions

Prior to historic grazing, Colorado piñon pine (*Pinus edulis* Engelm.) – one-seed juniper (*Juniperus monosperma* (Engelm.) Sarg.) woodlands were largely restricted to unproductive (e.g. steeper and rocky) settings adjoining and interspersed with the (swales, pumice patches, and gentle mesa) locations dominated by ponderosa savanna (Allen 1989, Gottfried et al. 1995, Jacobs et al. 2008). Age-class and observational data suggest the historic woodland component was relatively open canopy, but mostly persistent in nature (sensu Romme et al. 2009) with sparse understories and only supporting patchy crown fire (Jacobs et al., 2008).

4.06.3 Objectives of vegetation analysis, data sources, and methods

Bowker and Smith incorporated the literature on known ecosystem dynamics, expert knowledge, and ecological principles to develop an a priori state-and-transition model for the park's piñon-juniper ecosystems (Figure 16). They then used hierarchical cluster analysis of data from the watershed-scale thinning study to validate the existence of the proposed states (Figure 17).

Between 1992 and 2004, three distinct but similar studies were conducted that manipulated piñon-juniper canopy cover (Chong 1993; Jacobs and Gatewood 1998; and Loftin 1998). The goal of the analysis was to determine the relative importance of interannual climate variability, overstory reduction and slash redistribution, ground surface manipulations, age of treatments, and fire on the relative functional group composition of the understory. Bowker and Smith pooled data from the three studies and analyzed it using regression tree models.

Bowker and Smith used a dataset from 46 monitoring plots established in piñon-juniper woodland in 2008–2010 by the Southern Colorado Plateau Network to examine the relationship between soil aggregate stability (a negative index of erodibility; low scores indicate high erodibility) and factors thought to contribute to soil stability. These factors include mechanical thinning, canopy closure, total biocrust cover, total litter cover, and cover of major plant functional groups (forb, annual grass, perennial grass, and shrub).

Bowker and Smith used two Bandelier NM datasets: 1) line intercept vegetation data collected in 1999 and 2003 from nine 300 m long transects (so-called JRM LTER transects); and 2) erosion bridge measurements of microtopographic soil surface changes from the same nine transects (plus two additional erosion transects measured annually, 1999-2007), to examine possible relationships between vegetation structure and erosion. They used perMANOVA and non –metric multidimensional scaling (NMDS) for the analysis.

4.06.4 Condition and trend

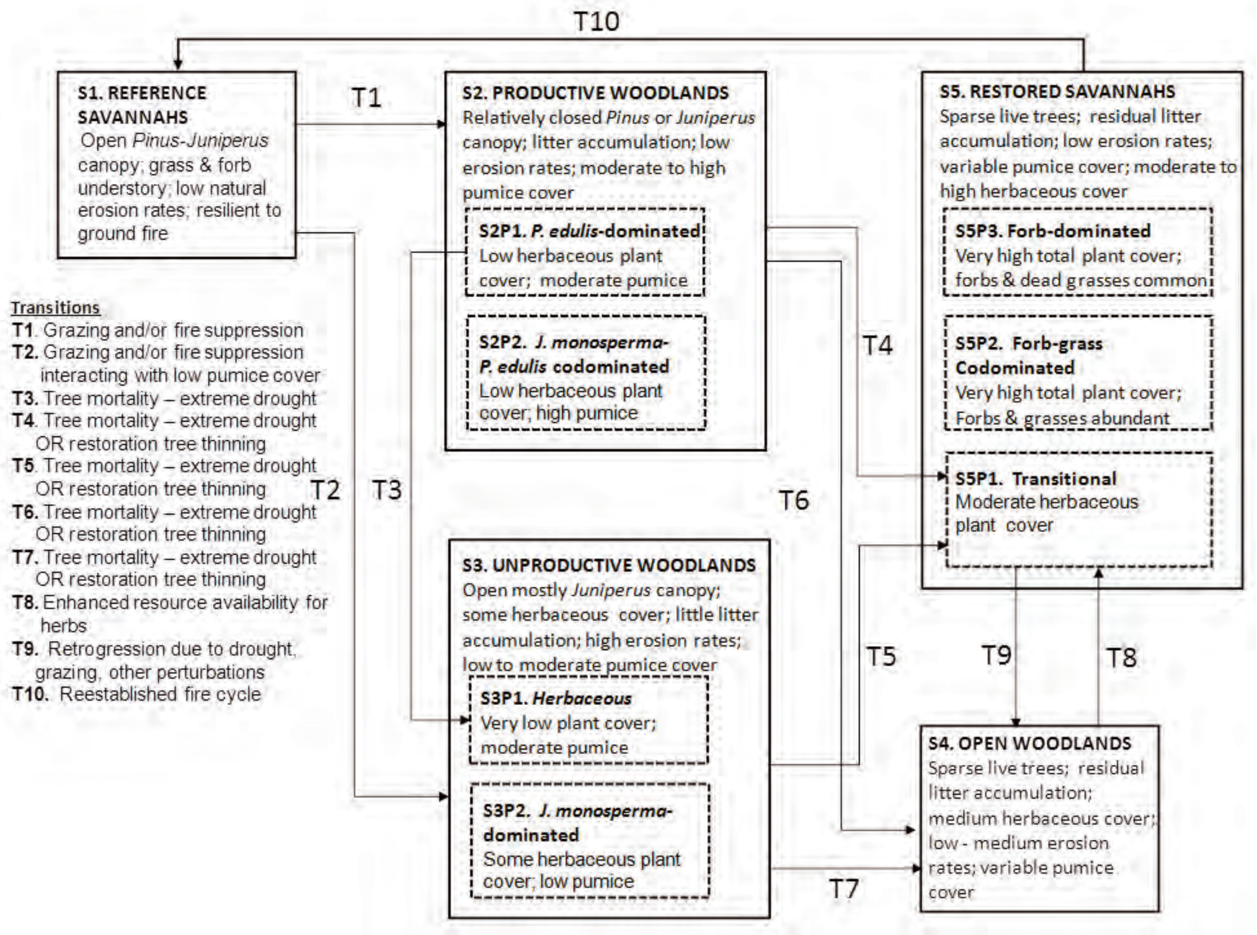

Figure 4-16. State-and-transition diagram for piñon-juniper mesa tops. Solid boxes represent ecosystem states. Dashed boxes indicate phases within states. Arrows indicate transitions. In some cases, phases within the reference state are not connected to any others by arrows; this is our method of representing spatial variants of the reference state that are determined by abiotic factors, or cases where we simply do not have a strong hypothesis for the relationship among phases.

The trajectory of piñon-juniper woodlands in Bandelier NM has diverged from reference conditions. However, it is important to note that these woodlands are heterogeneous, and not all sites have the potential to support the same desired outcome. Woodlands would have interfingered with ponderosa pine savannas which may have played a large role in spreading frequent fire to grassier, open piñon-juniper woodlands and savannas. Highly productive persistent woodlands would have been subject to low frequency crown fire. Generally speaking, many of the woodlands and savannas recently supported too much tree canopy compared to desired conditions, and some of them support much less herbaceous cover than desired. The current woodlands can be thought of as a mosaic of persistent, unproductive woodlands (averaging 21% or less tree canopy cover, up to 45% bare ground cover, and < 5% herbaceous cover), persistent productive woodlands (averaging 38% or more tree canopy cover, 17% or less bare ground cover, and < 5% herbaceous cover), open woodlands (20% tree cover, 55% litter cover), and thinning-induced savannas which have the potential to support surface fire (averaging 7% or less tree cover, and up to 32% herbaceous cover).

The first characteristic, overgrown canopy, is reversing due to three drivers: 1) intentional canopy reductions (thinning), 2) fire, and

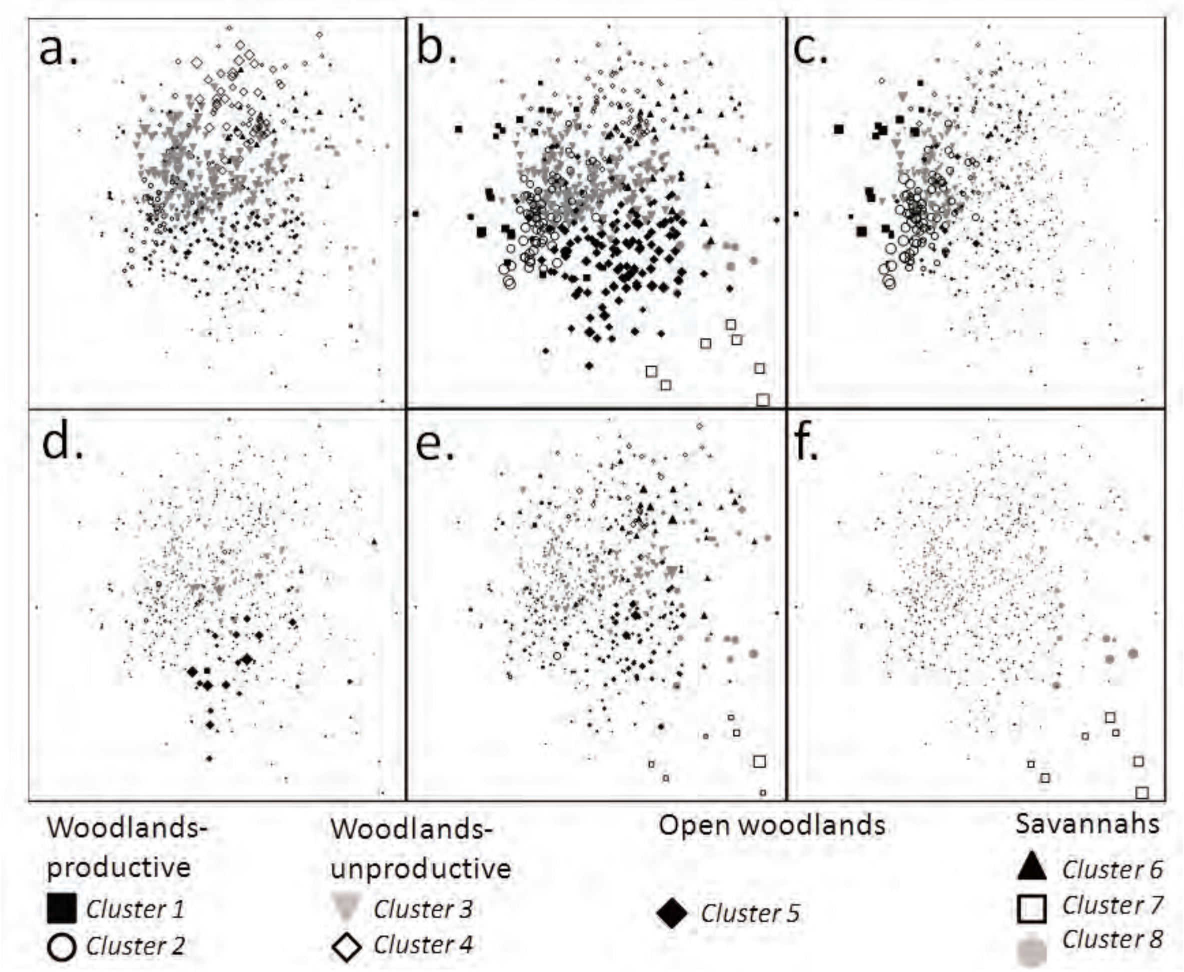

Figure 4-17. Diagrams showing six versions of the same non-metric multidimensional ordination with symbols coding for the eight clusters found in our cluster analysis. In each panel a point is a transect in a given time point; the position of each point is identical in all panels. The panels differ in that the size of symbols is scaled proportionally to a particular element of the community that is characteristic of one or more clusters. (a.) Symbols are scaled according to percent cover of bare ground, which is especially high in clusters 3 and 4. (b.) Symbols are scaled according to percent cover of litter, which is high in clusters 1, 2, 5 and 7. (c.) Symbols are scaled according to live *P.edulis* cover, which is high in clusters 1, 2, and to a lesser extent 3. (d.) Symbols are scaled according to dead *P. edulis* cover, which is high in cluster 5. (e.) Symbols are scaled according to live forb cover, which is high in clusters 6, 7 and 8. (f.) Symbols are scaled according to dead grass cover, which is high in cluster 7.

3) drought-induced dieback and mortality of trees. Thinning may induce ecosystem state transitions which are favorable, but are probably best applied to situations where the large majority of trees are younger rather than older. Stands that are primarily young are likely stands that have thickened relatively recently, and would change in a desired trajectory if thinning was applied. These areas are more likely to be former savannas or former open grassy woodlands (Jacobs et al. 2008). There are also situations where thinning is not highly likely to promote a transition, i.e. unproductive woodlands. This was actually expected to some degree. The watershed-scale thinning study attempted to avoid such areas by selecting mesatops with favorable soil types, gentle slopes, and little exposed bedrock. However, individual transects were heterogeneous mosaics of productive and unproductive types. Treatments were applied uniformly, regardless of individual transect characteristics, in the process, treating some unproductive

woodlands. This allows us to experimentally demonstrate that less productive woodlands are less responsive to canopy treatment.

There is comparatively little data on the effects of fire in piñon-juniper woodlands of Bandelier NM and environs, though various fires have burned woodlands in the park since 1996, including the Dome Fire of 1996, the 2005 Capulin Fire, the 2011 Las Conchas Fire, and various other wildfires and prescribed burns. Thinning and drought mortality make stand destroying crown fires less likely in the future because affected canopies are less continuous. The 1996 Dome Fire encompassed thousands of hectares of piñon-juniper woodlands, apparently creating some conversions to shrublands, grasslands or ruderal herbaceous cover (Figure 4-15, p. 78). However most fire-impacted stands within the Dome Fire boundary in the Bandelier NM fire atlas remained as woodlands, and apparently did not experience crown fire, though that would be the expected normal outcome of a fire in a piñon-juniper woodland. Another dataset mapping fire severity does not include most of the woodlands in question, suggesting that burning had been low severity or patchy, allowing the woodlands to persist. Another reason why there may have been relatively little conversion of woodlands to other vegetation types is that a large proportion of these woodlands in question are co-dominated by *Juniperus deppeana* and *Quercus undulata*, both resprouters post-fire. These dominant species are atypical of most of the woodlands in the park. Virtually all of these stands lost mature piñon pine between 1981 (before the fire) and 2004 (after the fire), but these transformations were almost certainly due to the drought rather than the fire.

Drought mortality in the tree canopy is the most problematic of these three drivers. Piñon-dominated woodlands in Bandelier NM and on the Pajarito Plateau recently have been decimated by the related impacts of

Figure 4-18. Landscape transformation associated with a die-off of piñon pine trees triggered by a global change-type drought. Piñon pine trees, evergreen when alive, (left) exhibiting reddish-brown foliage indicating mortality (October 2002); (right) after they have lost their needles, exposed gray trunks of standing dead tree carcasses remain (May 2004). Almost all of the surviving green trees in (b) are junipers. (Breashears et al. 2008)

drought and beetle infestation; between 2002 and 2003, over 90% of the mature piñons were killed by a combination of these factors (Figure 4-18). Despite the fact that canopy has been reduced overall, we cannot confidently say that the woodlands are moving closer to desired conditions because mature individuals of the previously co-dominant *Pinus edulis* have been lost. The future of this species is uncertain within Bandelier NM. Currently it persists in the understory as saplings established before the early 2000s mortality pulse, but because future climate is likely to bring increasingly severe and warm droughts (Williams et al. 2013), it is not clear that this species will rebound (Adams et al. 2009). Just as troubling are observations of substantial *Juniperus monosperma* mortality since 2003 in portions of the monument, documented in multiple park data sets (e.g., PJ demography plots, LTER transects, SCPN plots). If both species are lost, affected stands will effectively undergo a shift in growth form dominance to grasslands and/or shrublands.

The second major element of these ecosystems is the understory and its control over accelerated erosion (Davenport et al. 1996). The effect, at the scale of a whole watershed, of a thinning and slash redistribution study on promotion of understory herbs is well documented (Chong 1993, Hastings et al. 2003, Jacobs 2002, Loftin 1999). We interpret successful promotion of understory using slash redistribution as an ecosystem state change—a transition to a structural and functionally distinct ecosystem.

This state change is very much in line with the desired conditions of more open woodlands with herbaceous understories. Our examination of long-term transects confirms that greater development of a grassy understory is associated with less emitted sediment. In our analysis of the SCPN monitoring plots, greater soil aggregate stability seems to be promoted by greater canopy cover, despite that thicker-canopied woodlands tend to yield more sediment in erosion events (Hastings et al. 2003). Though this was not the expected result, it likely indicates that most sediment yield in the park is regulated more by the connectivity of patches which can intercept and store runoff (Davenport et al. 1996) than by the erodibility of soil per se.

In general, the literature and our analyses of existing data indicate that: 1) herbaceous understories can be promoted by slash redistribution, though this does not always happen, 2) erosion is reduced by herbaceous understories and slash, and 3) promotion of herbaceous understories and reduction of erosion are consistent with desired trajectories for the piñon-juniper ecosystem.

Since a large proportion of the park's piñon-juniper woodlands have undergone thinning and slash redistribution, can the understory stratum of these woodlands be said to be on a desired trajectory? There are reasons to be optimistic, but recent drought conditions cast some doubt on the permanence of older treatments, and whether similarly successful results will continue to be replicable. Bowker and Smith (2014) demonstrate that understory productivity is just as tightly controlled by climate as by overstory reduction and slash redistribution. A fortuitous redistribution of slash during a wetter than average period is most likely to promote understory production because two constraints (adequate moisture, and unstable soil surfaces) are simultaneously omitted.

However for reasons poorly understood, wet years in the recent past seem to lead to lesser understory production. Long-term transects suggest that established herbaceous understories can be compromised by extreme drought, and that, proportionately, grasses may experience more cover loss than the tree canopy (Figure 4-19). Other results from the small-scale thinning plots of Jacobs and Gatewood (1999) seem to directly conflict with this observation. Most of the grass species would be able to rebound from a drought die-back due to vegetative growth from surviving patches, but it is not known how resilient these herbs are to repeated drought events which may be more com-

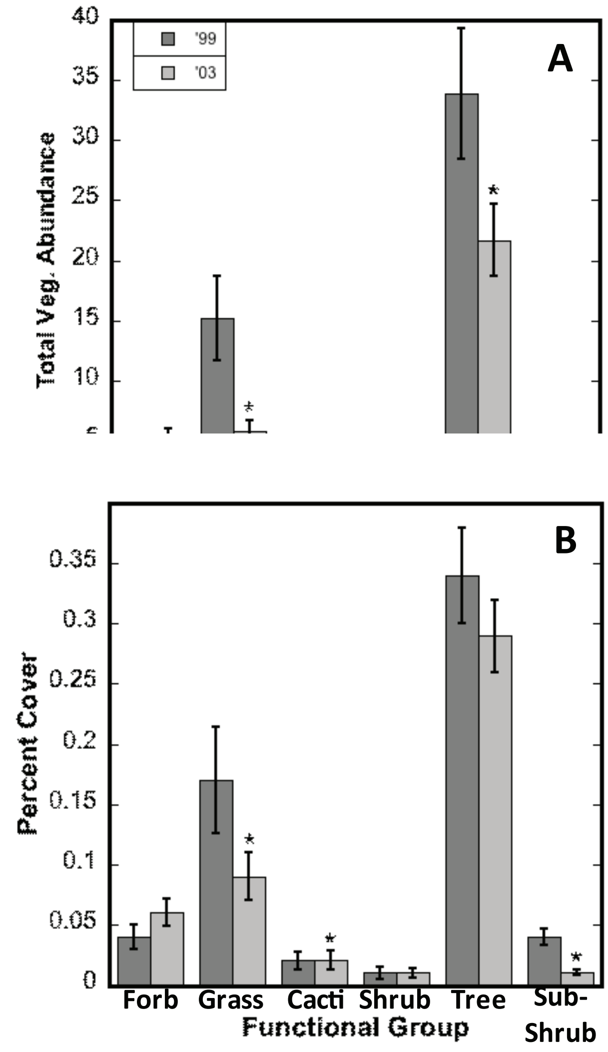

Figure 4-19. Bar graphs showing the mean and standard error for total (A) and percent (B) abundance of individual functional groups. Asterisks denote significant differences between years. Even though it is difficult to tell from the graph, the percent cacti is different in the two years (means are .0186 and .0249 for 1999 and 2003, respectively).

mon in the future (Karl et al. 2009). Some short-lived forbs produce large quantities of long-lived seed in favorable years, thus may retain considerable resiliency. As drought eliminates more and more canopy, the understory will become increasingly important. Since herbaceous plants are less long-lived, and leave less recalcitrant residues, we can expect an emerging dynamic ecosystem that varies strongly from wet years to dry years. We would conjecture that very high herbaceous biomass would be possible in wet years, whereas much reduced cover and accelerated erosion could characterize drought years.

4.06.5 Level of confidence

Reference conditions are poorly understood due to successive intensive human uses, high confidence for last approximately 300 years of history and moderate confidence for trajectory.

4.06.6 Data gaps/Research needs/ Management recommendations

- Develop fire management recommendations for treated piñon-juniper woodland areas to promote grassy understory and maintain open canopy.
- Continue SCPN monitoring of piñon-juniper woodlands.
- Develop remote sensing monitoring methods to track post-treatment vegetation response.

4.06.7 Sources of expertise

Matthew Bowker and David Smith

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4.06-1 Erosion in Piñon-Juniper Woodlands

4.06-1.1 Description

Accelerated rates of soil erosion within large portions of the semi-arid piñon-juniper woodland zone of Bandelier NM (occurring primarily in mesa-top settings between 1830–2135 m [6000-7000 ft] elevation) were first identified as a management issue in the 1970s in connection with early soil mapping and efforts to control a feral burro (*Equus asinus*) population (Earth Environmental Consultants 1978, Chong 1992). However, it was not until the mid-1980s that park-wide archaeological survey efforts began to systematically document erosional impacts to cultural sites. At the same time, a graduate student researcher (later the park ecologist) articulated the erosional problem in piñon-juniper systems (Allen 1989); and these and other efforts cumulatively presented the widespread impacts that erosion was having on park resources.

In the early 1990s, long-term monitoring of vegetation and erosion within the woodland zone was initiated. The goal was to determine whether erosion was accelerating or the systems were still recovering from prior landuse impacts. A number of focused research efforts were also initiated to quantify rates of runoff and erosion within woodlands (Wilcox et al. 1994, 1995a, 1995b, 1996a, 1996b; Wilcox et al. 2002), assess methods to mitigate runoff and erosion (Chong 1993, Chong 1994, Hastings et al. 2003, Jacobs 1999, Jacobs and Gatewood 1999, Jacobs et al. 2002b), and reconstruct historical vegetative and soil conditions (Allen and Breshears 1998, Allen 2004, Julius 1999,). Several collaborative efforts attempted to provide ecohydrologic frameworks linking observations and data, arguing that the spatial arrangement and critical threshold of effective cover within an area could be used to model hydrologic response in degraded woodland systems (Davenport el al. 1998).

From 2007–2010, nearly 5,000 acres (constituting about ½ of the total woodland acreage within the park, and representing nearly all of the woodland area deemed favorable for mechanical restoration treatments, minus several hundred acres of uncut control) were mechanically treated using a thinning-slash restoration method. This method was developed and tested at several scales, including within a 100-acre paired watershed study area (ref; Hastings et al. 2003). Results from these studies demonstrated that mechanical thinning and slash treatments increase understory cover by 3-fold, while reducing runoff and sediment yields by 1–2 orders of magnitude (Hastings et al. 2003, Jacobs et al. 2002b).

History

Most researchers agree that prior to Euro-American settlement the region of the Jemez Mountains now occupied by Bandelier NM was predominantly an open woodland system that was abandoned around 1600 after several hundred years of intense human occupation by Ancestral Pueblo farmers. For the next 200 hundred years, until around 1800, the area recovered in part, and presumably both tree and herbaceous understory cover increased in many locations. In ponderosa pine communities, conditions were somewhat different, as a frequent surface fire regime may have kept productive grassy savanna areas more open and woodlands restricted to shallow rocky soil locations (Bowker and Smith 2014).

Arguably the biggest changes to the landscape took place when Euro-Americans arrived in the area. Spanish colonists in the 1600s brought sheep, cattle, goats, horses, and burros, along with tools such as metal axes. What had been small-scale use of the Bandelier NM area for livestock changed dramatically with when the railroad arrived at Buckman in the 1880s and very heavy grazing ensued, promoted at the federal level. This quickly proved unsustainable. The railroad also turned what had been sporadic timber collection into a full-fledged industry, though the inaccessible terrain on the southern part of the plateau to some extent limited the exploitation of the lands that would became the monument. Even so, the combination of grazing and logging proved devastating for the fragile soils of the Pajarito Plateau, and began a cycle of erosion that continues to this day. Research indicates that a pattern of increasing woodland cover reinforced initial grazing impacts on the understory and facilitated initiation of accelerated surface runoff and soil erosion.

An intense multi-year drought during the mid-1950s shifted the distribution of ponderosa pine communities several kilometers up-mesa, representing a shift up in elevation at the lower end of ponderosa distribution. This shift is now thought of as a tipping point when ecohydrologic degradation processes in the woodland (piñon-juniper) system became self-reinforcing (Allen and Breshears 1998, Bowker and Smith 2014d). During the 1970s, a feral burro population was likely a contributing factor in woodland soil erosion (Allen 1989). In the 1990s large populations of elk and deer further increased soil erosion (Chong 1992). More recently a dry period that began around 1996 and intensified with several severe multi-year droughts (2000–2004, 2010-present) resulted in widespread mortality of piñon (exceeding 90%). However, there has been a piñon seedling response in many locations.

Finally, fire has become a more common disturbance in regional woodlands with increased severity and extent. Consequently, post-burn woodlands are initially somewhat sterile and may be more vulnerable to weed invasion and accelerated erosion. However, prior mechanical treatments may prime the systems response to burning and promote post-fire recovery of the understory (Jacobs and Gatewood 2002a).

4.06-1.2 Reference conditions

Erosion levels were likely low due to large amounts of herbaceous cover in a landscape dominated by savanna type woodland with piñon-juniper and ponderosa pine trees. A rough estimate of pre-grazing erosion rates can be inferred from treated areas where sediment production was reduced by an order of magnitude relative to untreated control (Hastings et al, 2003).

4.06-1.3 Data and methods

Surface runoff and soil erosion has been assessed by a variety of methods and at several spatial scales. The most reliable methods are based on direct measurements of vegetative cover, precipitation, and runoff and sediment transport using instrumented watersheds with line transects, rain gauges, flumes, and sediment traps. Integrated ecohydrologic measures have been collected primarily at two study sites located on the mesa immediately south of park headquarters. These provide comparative data across multiple spatial scales within untreated woodlands (Frijolito Experimental Watershed) and across matched treatment-control areas (Paired Watershed Study). Data collected within these discrete study areas are then incorporated into predictive models that can infer hydrologic condition indirectly using measures of effective soil cover.

Vegetation cover (% of total) by species was collected for basal intercept and canopy overstory along permanent line transects. Sediment production (kg-ha) was estimated using sediment traps for defined contributing areas (i.e. 0.1-ha microwatersheds).Runoff (cfs) was estimated using instrumented flumes for defined contributing areas (i.e. 0.3-ha microwatersheds). Detailed data and methods for individual studies are documented in the cited references.

4.06-1.4 Condition and trend

After the 1950s drought, through the mid-1990s, piñon-juniper woodlands increased in both extent and density, in part facilitated by an unusually wet period during the 1980s. By the time long-term monitoring efforts were initiated in the early 1990s, average woodland tree densities exceeded 1000 stems/ha, compared to forest age reconstructions that suggested tree densities were <250 stems/ ha prior to 1850 (Julius 1999). Higher tree densities were accompanied by a generally sparse herbaceous understory cover.

Recent measures of runoff and erosion suggest that rates are highly accelerated because extrapolated over time, current rates yield unsustainable levels of sediment production. For example, at measured soil-loss rates of ~10 mm/decade (Wilcox 1994), the existing soil resource in these locations, which is less than 10 cm, could be eliminated within one century.

The long-term benefits of landscape-scale woodland restoration treatments in the face of developing warmer and drier conditions are unclear. Recent accelerating climate-induced changes in woodland overstory include increased fire activity and near complete loss of mature piñon. Partial, but ongoing and progressively more expansive die-off of juniper overstory due to drought stress suggests that type conversion of this system to more of a scrubland (sparse grass and shrub cover with scattered trees) could happen within 20-50 years (Bowker and Smith 2014).

4.06-1.5 Level of confidence

Historical reference conditions are inferred from a number of lines of evidence, but these are mostly indirect and confidence is generally fair to poor. Measurements of soil erosion are highly variable from year to year and driven by the relative strength of summer monsoonal patterns with a few large events producing most of the observed erosion in a given year. Hydrologic measures are extremely scale dependent, with the response mediated by antecedent conditions and subject to threshold effects. Current conditions and response to restoration treatment are well documented for a few well-studied locations, but future trends are highly speculative relative to anticipated effects of climate change on this system.

4.06-1.6 Data gaps/Research needs/ Management recommendations

- Reconstruct the temporal and spatial patterns of recent drought-beetle induced tree mortality.
- Characterize ecohydrologic system response to cumulative effects of mechanical thinning, drought, and fire disturbance.
- Implement long-term monitoring of the restoration response using remote sensing methods to complement ground based (erosion and vegetation) measurements.
- Conduct research to assess the role of biological soil crusts in degraded and restored semi-arid woodland systems.

Going forward, we are developing new methods to remotely sense understory response to restoration treatment at landscape scales using satellite imagery which would support monitoring of the woodland soils and embedded cultural resources. Monitoring of the entire 5,000-acre treatment footprint will allow management to determine spatial and temporal patterns of treatment response and identify locations which may benefit from supplemental treatment.

4.06-1.7 Sources of expertise

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4.06-1.8 Literature cited

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4.07 Rare Plant Species

4.07.1 Description

Five plant species of management concern have been identified by monument staff because they require monitoring due to their restricted distribution and/or existing threats to their persistence in the park (Brian Jacobs, personal communication). At present, no federally-listed species occur in the park, but several are (or have been) identified by the State of New Mexico as endangered, or by NatureServe as imperiled or vulnerable (http://www.natureserve.org). See Appendix D for a complete list of species of management concern for Bandelier NM.

All of the mesic species (yellow ladyslipper, rattlesnake orchid, grape fern, wood lily and cerro hawthorn) have been significantly impacted by recent fire, flood, and drought events, to the point where source material (seeds, spores, rhizomes and bulbs) may now be extremely rare, or even extirpated within the park. In addition, the historic riparian landscape where these species were once found has been permanently altered. Consequently, in establishing reference conditions for these species, managers should consider that many sites that once supported them are now in the very early stages of secondary successional processes. It may or may not be reasonable to consider long-term measures of abundance and distribution that fall within the historic ranges of variation noted for each species. For the near-term, the park may simply want to document the presence or absence of each as riparian systems recover. Reference conditions for the single xeric species (grama grass cactus) are likewise problematic due to the absence of existing information on current or historic populations.

Regardless of current ecological condition, negative anthropogenic impacts (e.g. from grazing, recreation, collecting) to habitats where populations of these species are currently or have historically been found, would indicate some level of impairment.

4.07.2 Reference conditions

All of these species were likely present in appropriate settings, but locally rare even prior to Euro-American contact primarily due to restricted habitat requirements

4.07.3 Data and methods

Data exist for the abundance or distribution of the species described below. In addition, previous surveys have been conducted and local botanists and park staff are generally familiar with historic locations and the general number of individuals that were present at each site in past years.

Data from surveys conducted in the late 1980s for grama grass cactus in the Tsankawi Unit of the park, and from ladyslipper and grape fern surveys in the 1990s, are available in Bandelier NM. Plot data collected during the pilot study for the Southern Colorado Plateau Network (SCPN) integrated riparian protocol (Scott and Reynolds 2007) in Capulin Canyon did not include observations of any of the mesic species of concern. Plot data collected for the park's vegetation map (Muldavin et al. 2011) likewise did not include any of these species. All other information on abundance and location comes from park staff observations.

4.07.4 Condition and trend

<u>Greater or large yellow ladyslipper (*Cypripedium parviflorum* var. *pubescens*)</u>

Description

Cypripedium parviflorum var. *pubescens* (yellow ladyslipper) is an orchid that produces one or two bright yellow flowers between May and August. Plant height ranges from 10–50 cm, and the large, showy lip petal of the flower is between 15 and 55 mm long. The species can reproduce

both vegetatively from rhizomes, (so that individual plants observed growing close together are likely one clone), and sexually (Deller). Reproduction by seed is rare, however, because seeds are very small and dependent on mycorrhizal fungi for germination, and because seedlings that do emerge rarely survive (Deller). Rhizomes may be viable below ground even though they do not produce flowers every year (Deller).

Distribution

Greater yellow ladyslipper is widely distributed throughout North America, occurring across much of Canada and in 42 of the lower 48 states. In New Mexico it has been documented in both the Jemez and the Sangre de Cristo Mountains at elevations between 1,830 and 2,900 meters (Coleman 2002).

Ecology

This species tolerates shade to nearly full sun conditions in fairly open sites within riparian-associated forest communities, meadows and clearings. Individual plants are found in generally mesic conditions but not directly adjacent to water, and prefer neutral to slightly acidic soils. Many of the populations documented in the monument prior to the Las Conchas Fire in 2011 were located near small spot fire locations from the 1977 La Mesa Fire (Brian Jacobs, personal communication).

Status

NatureServe assesses the global status of this species as secure and the national status as apparently secure, though there are currently few documented occurrences of large and secure populations anywhere in North America (NatureServe). The species is classified by NatureServe as imperiled in New Mexico where it was previously listed as endangered. It is listed by Los Alamos National Laboratory (adjacent to the park) as a sensitive species (Hathcock et al. 2010). Extirpation of two populations has been documented in Arizona and populations in New Mexico and Arizona are considered to be in decline. In Bandelier NM most, if not all, of the known populations were likely destroyed by floods and debris flows in 2011 and 2012. Some individual clones may have survived in areas above flood zones, but if so their locations are at present unknown and it will likely be some time until they can be discovered (Brian Jacobs, personal communication).

Threats

The high-intensity fires and post-fire floods and debris flow events that followed the Las Conchas Fire in 2011 destroyed much of the riparian habitat upon which this species depends. While occasional low-intensity fires may provide areas of open habitat for ladyslippers, the extreme fires that have occurred recently have probably eliminated most, if not all, of the previously documented occurrences of this plant along Capulin and Frijoles creeks (Brian Jacobs, personal communication). Because flowering individuals re-sprout from rhizomes and sexual reproduction is rare, significant re-establishment from seed is unlikely for this species. Continued drought may further restrict population growth if it alters the mesic environment this plant requires.

Condition and trend

The current condition of this species in the park is poor; the 2011-2012 floods probably destroyed or buried most of the existing individuals, source populations are extremely limited, and habitat has been altered or lost. Trend is a steep decline precipitated by the events of 2011-2012.

Rattlesnake Orchid (*Epipactis gigantea Douglas* ex Hook.)

Description

Epipactis gigantea is an erect perennial reaching anywhere from 30 centimeters to one meter in height. Its stems have wide or narrow lance-shaped leaves 5 to 15 centimeters long and inflorescences of two or three showy flowers near the top. Each flower has three straight sepals which are light brownish or greenish with darker veining, each one to two centimeters long. The fruit is a hanging capsule 2 or 3 centimeters long which contains thousands of tiny seeds.

Distribution

Widespread and locally abundant in suitable habitats, native to western North America from British Columbia to central Mexico

Ecology

This plant grows in wet areas in a variety of wetland settings; including riverbanks, hot springs, and meadows.

Status

Populations of this species are widespread and abundant across western U.S. but local populations have been impacted by recent widespread fire and flood disturbance. NatureServe assesses the status of this species as secure nationally and it is has no protected status in New Mexico.

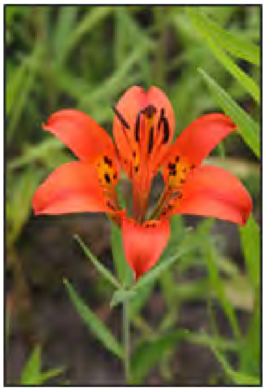
Threats

Spring habitats within White Rock Canyon were destroyed during reservoir holding events during the mid-1980s. Recent high-intensity fires and post-fire floods and debris flow events have subsequently degraded much of the riparian habitat upon which this species depends. Continued drought may further restrict population growth if it alters the mesic environment this plant requires.

Resource condition and trend

The current condition of this species in the park is poor; the 2011-2012 floods likely destroyed or buried most of the existing individuals, source populations are extremely limited, and habitat has been altered or lost. Current population trends are on a steep decline.

Wood Lily (*Lilium philadelphicum* var. *andinum*)



Description

The wood lily is a geophytic monocot that flowers from June to August. A single stalk grows up to 0.5 meters and produces one to three orange-red flowers.

Distribution

This species is distributed across most of Canada and much of the eastern, midwestern, and Rocky Mountain regions of the U.S. It is rare, however, in New Mexico and Colorado, and absent from Utah and Arizona. In New Mexico it is patchily distributed in only four or five counties. In the Jemez Mountains it ranges from 2,130 to 2,440 meters in elevation, and in the monument is found only in upper Frijoles Canyon.

Ecology

In the southwest this lily prefers moist, open understory habitats in mixed conifer riparian forests and higher mountain meadows. Periodic low-intensity fires may enhance habitat by providing openings in forests canopies.

Status

NatureServe assess the global and national status of this species as secure. In New Mexico it is assessed as vulnerable, and was previously listed by the state as endangered. Wood lilies were formerly common in the upper Frijoles riparian zone but few individuals have been observed since the events of 2011 (B. Jacobs).

Threats

Similar to the species described above, recent fires and floods in riparian zones have likely extirpated most of the previously known wood lily populations. If populations do re-establish, threats noted to wood lily populations in other locations have included woody encroachment and risk from collectors.

Condition and trend

The condition of this species in Bandelier NM is currently poor. As with the ladyslipper and the grape fern, the riparian habitats upon which wood lilies depend have been greatly altered and existing populations largely destroyed. Given their much higher reproductive rates from seed, wood lilies may be more likely than ferns or orchids to re-establish if conditions are good. Trend is a steep decline, precipitated by the events of 2011-2012.

Cerro hawthorn (*Crataegus erythropoda*)

Description

This shrub or small tree grows to a maximum height of about five meters. Plants have dark green leaves and thorny branches. Clusters of white flowers are produced in late spring, and the fruit (berries) are palatable to birds and rodents. Due to its relatively low stature in riparian woodlands, individual hawthorns also provide important habitat for songbirds and other small vertebrates. The species is often cultivated, and appears to have a fairly wide range of drought and wind tolerance in urban settings.

Distribution

This species is only found in the Rocky Mountain states of Colorado, Arizona, New Mexico, Wyoming and Utah. In the Jemez Mountains it is found between about 2,130–2,440 meters in elevation, and within Bandelier NM it occurs in upper Frijoles Canyon.

Ecology

Cerro hawthorn is found in relatively open, well-drained sites within riparian woodlands. It is not found where there is a closed canopy above it.

Status

NatureServe assesses the global status of this species as secure. It is assessed as vulnerable in Colorado, Arizona and New Mexico, and critically imperiled in Wyoming and Utah. It may have been extirpated from Bernalillo and Sandoval counties in New Mexico. Prior to 2011 it was uncommon in the monument, but locally abundant in moist areas of upper canyons (NPS 2007). Though directly impacted by the 2011 and 2013 flood events, re-sprouting by several individuals has subsequently been observed (B. Jacobs).

Threats

Relatively little seems to be known regarding the status of this species in the wild or threats to it throughout its range. Many individuals in the Frijoles drainages were either damaged or killed in the Las Conchas Fire, though re-sprouting is occurring. Minimal published information is available on the ability of this species to recover from fire. Populations in New Mexico seem to be scattered, and the general lack of information on the species has been identified as a concern.

Condition and trend

The condition of this species in the park is likely poor, given that it was only known from riparian sites that were both burned and flooded in 2011. The number of surviving individuals is likely quite low. Without surviving reproductive individuals, significant population growth in the short term is unlikely. Trend is likely a steep decline precipitated by the events of 2011-2012, though it was probably historically rare.

Gramma Grass Cactus (*Sclerocactus papyracanthus*)

Description

This small cactus is a perennial, but relatively short-lived species that grows only to about 8 cm in height. Small, white flowers are produced in April or May, but during the remainder of the year the plant is cryptic, covered with papery-like spines, making the plant appear similar to the gramma grass (Bouteloua spp.) with which it is often associated.

Distribution

Gramma grass cactus is distributed across New Mexico and adjacent portions of Arizona and Texas at elevations between about 1,525 and 2,290 meters.

Ecology

This species prefers open sites in fine, sandy clay loams on basaltic canyon rims and mesa tops, usually in piñon-juniper woodlands and desert grassland habitats. In Bandelier NM, the plant is found at lower elevations in open and grassy piñon-juniper habitats (NPS 2007) but basalt exposures and associated soils that this plant prefers are relatively rare in the main park unit (B. Jacobs).

Status

NatureServe assesses this cactus as critically imperiled in Texas, imperiled in Arizona, and apparently secure in New Mexico, though it may have been extirpated from Cibola and Grant counties. This is inherently a cryptic species within the habitats where it is found. (This species was reported as occurring fairly frequently during the SCPN upland vegetation monitoring in 2009 [DeCoster and Swan 2011], however, in 2013 these occurrences were field-checked and found to represent a mixture of Echinocereus and Escobaria species. The identification of this species in the upland vegetation plots has since been corrected. Sclerocactus papyracantha has only been encountered in one plot [42] during upland monitoring from 2008 to 2010). A project to enhance a population of this cactus in the monument was undertaken in 1989 when hundreds of individual plants were transplanted to the park's Tsankawi unit (from a salvaged site outside the park), however, none of the plants survived after five years.

Threats

Current threats to this species within the park are unknown. Given likely habitats that exist in exposed soils, erosion may be a factor. In other locations the species is at risk from cattle grazing and off-road activities, but these impacts are not a factor in the park.

Condition and trend

The status of this species in the park is generally unknown. Assuming that plants were historically common prior to grazing but are now rarely observed, the condition is likely poor. The trend is unknown.

Grape or Rattlesnake Fern (*Botrychium virginianum*)

Description

This small deciduous fern grows to about 30 cm in height. The plant produces two leaf types: a single sterile leaf which is pinnately divided into subleaflets and appears early in the spring and lasts through the summer, and a shorter, fertile leaf which produces sporangia and is short-lived compared to the sterile leaf. Wind-dispersed (anemochorous) spores are released during the early summer.

Distribution

Grape ferns are widely distributed across North America and exist often at relatively high elevations.

Ecology

In Bandelier NM, this fern is found in habitats similar to those described for the ladyslipper: shady to mostly-sunny open patches and bogs in riparian mixed conifer forests. Prior to the 2011 floods it was only known to occur in one bog location that was subsequently destroyed (Brian Jacobs, personal communication).

Status

NatureServe assesses the global and national status of this species as secure. The status of the species in New Mexico is unknown, but it is listed as critically imperiled in California, Arizona and Colorado. Known locations for this species in the park were inundated by the post-fire floods and debris flows in 2011 and 2012, likely extirpating grapefern from the park. Targeted surveys in 2013 have found no occurrences remaining (B. Jacobs).

Threats

Catastrophic high-intensity fires and associated floods, such as those that have occurred recently have probably eliminated the populations that previously existed along Frijoles creeks (B. Jacobs). Like the ladyslipper orchid, the absence of a source population for this species greatly reduces the likelihood of short-term re-colonization at historic sites. Because spore producing plants are particularly dependent on moist habitat conditions, continued drought may also impede establishment in this species.

Condition and trend

The current condition of this species in the park is poor, though it may have always been rare. The riparian habitats in which this fern was found have been greatly altered or destroyed and there is no regional source population. Trend is a steep decline precipitated by the events of 2011-2012.

4.07.5 Level of confidence

Confidence in the presence or absence of the mesic species at likely locations is fairly high given the existing knowledge of park staff and ongoing monitoring efforts. Confidence in the status of the riparian species in relation to successional processes, however, will probably be very low for the foreseeable future. Confidence in the condition or trend of grama grass cactus populations is low.

4.07.6 Data gaps/Research needs/ Management recommendations

The park botanist conducts annual informal walking surveys of existing sensitive plant populations and potential habitat primarily to assess habitat condition, numbers of individuals and reproductive status at known locations, and to opportunistically census presence of new individuals in potential habitat. If status of any of these species was elevated to federally listed, the park would work with the Natural Heritage Program of New Mexico and the USFWS to conduct more formal assessments of suitable habitat and population status.

4.07.7 Sources of expertise

Brian Jacobs, Megan Swan

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Web Sites

NatureServe: http://www.natureserve.org (accessed July-August 2013)

Cypripedium parviflorum var. *pubescens*

http://plants.usda.gov/core/profile?symbol=cypap3

Botrychium virginianum

http://eol.org/pages/597549/overview

http://www.natureserve.org/explorer/servlet/NatureServe?searchName=Botrychium%20virginianum

Lilium philadelphicum var. *andinum*

http://nmrareplants.unm.edu/droplist/liland.htm:

Crataegus erythropoda

http://pick4.pick.uga.edu/mp/20q?search=Crataegus+erythropoda&guide=Trees&flags=not_no:#http://nmrareplants.unm.edu/droplist/craery.htm

Sclerocactus papyracanthus

http://plants.usda.gov/core/profile?symbol=SCPA10

http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=242415297

4.08 Nonnative Plants

4.08.1 Description

Exotic or non-native plant species are those that are not naturally a component of pre-Euro-American settlement ecosystems. However not all exotic species necessarily pose a threat to existing communities. For management purposes exotic species can be categorized by their degree of invasiveness— ecologically how well they out-compete native species— and/or how well they can be controlled. For example, while non-native ornamental species are often easily controlled if needed, they usually do not compete well with native species, and so pose little threat to native populations. Such species consequently may be of lower management concern than those that are more aggressive and survive unaided under natural conditions.

In Bandelier NM, exotic species comprise approximately 15% of all the plant species found within the park. However, <5% (e.g. ~40 of ~800 taxa) are considered invasive (NPS 2006). Of those, only about 10-12 species are both high risk and easy to treat. Several species are considered nuisance species in that they are common and fairly wide-ranging, usually in disturbed areas, but they are either weak competitors or treatment on a large scale is not practical. The most challenging management species are those that are so invasive that they are ubiquitous across the landscape and very difficult to constrain. The common and widespread exotic plant species found in the monument are listed in Table 4-2 along with basic information about their ecology and status, if known.

Post-disturbance conditions, in particular those that result from large wildfires, often facilitate the expansion of exotic grasses and other invasive species (Keeley 2006; Balch et al. 2013). Additional factors, such as pre-fire landcover, fire intensity, elevation and climate, also affect post-fire abundance of exotic species (Keeley and McGinnis 2007; Fornwalt et al. 2010; Sherrill and Romme 2012; Shive et al. 2013). *Bromus* species have invaded and now dominate many arid-ecosystems across the west, further altering natural fire regimes (D'Antonio and Vitousek 1992). *Bromus tectorum* (cheatgrass), *B. inermis* and *B. japonicas* are present in the monument.

4.08.2 Reference condition:

No nonnative plants present.

4.08.3 Data and methods

At present, information on exotic species distribution and abundance comes from 1) the Exotic Plant Management Team (EPMT) work that is conducted annually, 2) anecdotally from park staff and cooperators, and 3) incidentally from upland vegetation monitoring. Post-Las Conchas Fire data on vegetation have been collected but are not yet available.

4.08.4 Condition and trend

Bromus tectorum (cheatgrass), *B. inermis* and B. *japonicas* are present in Bandelier NM, and appear to be increasing in distribution. Cheatgrass has expanded across the lower elevations of the park, likely facilitated by both drought and fire conditions of recent decades (B. Jacobs). The other two species are less abundant but possibly increasing as well. Given the enormous impacts of recent fires, these species should be of particular concern to managers.

Several additional weed populations (e.g., *Cirsium vulgare*, *C. arvense, Carduus nutans, Cardaria draba*), around the main headquarters and visitor service areas have been largely extirpated by EPMT efforts (B. Jacobs). Fire impacts have prevented most work from being conducted in the riparian corridors, so very little is known about invasive plant changes in those areas.

Fires in the southwest are probably going to increase with changing climate. Along with predicted increasing temperatures and continued drought conditions in this region, the potential for additional invasions and persistence of exotic species is high (Hurteau et al. 2014).

4.08.5 Level of confidence:

The level of confidence for this analysis is low to moderate.

4.08.6 Data gaps/Research needs/ Management recommendations

- Additional surveys for noxious species in riparian and burn areas should be conducted.
- The use of remote sensing data, now available at relatively finer scales than used previously, could be considered for detecting new invasions (He et al. 2011).
- All prescribed fire plans and wildfire management and recovery actions should consider the potential for post-fire invasive species impacts, as well as the ability to couple fire impacts to invasives with re-introduction and/or facilitation of native propagation (Keeley 2006; Keeley and McGinnis 2007).

4.08.7 Sources of expertise

Brian Jacobs

4.08.8 Literature cited

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Table 4-2. Common and widespread nonnative plant species found in Bandelier National Monument, their location, and status post-Las Conchas Fire (LCF), if known; website provided if available. Organized according to type of nonnative species.

Scientific name common name	Type	Locations in Bandelier NM	Comments/post-LCF status, if known
Invasive non-native plants for which there is an effective suppression method			
Ailanthus altissima[a] Tree of Heaven	woody	Lost Canyon (approx. 2 acres), and previously extirpated from historic orchard	often reproduces by root sprouting so is often difficult to treat; highly adapted to disturbance; early successional species following fire but can persist in shade once established; treated in Lost Canyon area by EPMT in 2013
http://www.fs.fed.us/database/feis/plants/tree/ailalt/all.html			
Elaeagnus angustifolia[b] Russian olive	woody	Rio Grande Corridor and scattered swales; lower tributary canyons and mouths (and associated willow patches) including Frijoles, Lummis, and Alamo; Developed District	common and spreading throughout the southwest
http://www.fs.fed.us/database/feis/plants/tree/elaang/all.html			
Ulmus pumila[b] Siberian elm	woody	RGC and roadsides; lower tributary canyons and mouths (and associated willow patches) including Frijoles, Lummis, and Alamo; Developed District	reproduces by seed and root sprouting
http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5410128.pdf			
Tamarix ramosissima[c] salt cedar/tamarisk	woody	RGC; lower tributary canyons and mouths (and associated willow patches) including Frijoles, Lummis, and Alamo.	resprouts from root meristem after fire (Drus 2013);
http://www.fs.fed.us/database/feis/plants/tree/tamspp/all.html			
Linaria vulgaris[a] butter and eggs (yellow toadflax)	perennial forb	RGC, and Capulin mesa; lower tributary canyons and mouths (and associated willow patches) including Frijoles, Lummis, and Alamo	infestations are expanding in New Mexico (USFS 2012); treated on Capulin Mesa by EPMT in 2013
http://www.fs.fed.us/database/feis/plants/forb/linspp/all.html http://www.invasivespeciesinfo.gov/plants/toadflax.shtml			
Cirsium arvense[a] Canada thistle	perennial forb	RGC; lower tributary canyons and mouths (and associated willow patches) including Frijoles, Lummis, and Alamo.	can produce new shoots from roots; treated along the Highway 4 corridor by EPMT in 2013
http://www.fs.fed.us/database/feis/plants/forb/cirarv/all.html			
Lepidium latifolium[a] peppergrass	perennial forb	RGC; lower tributary canyons and mouths (and associated willow patches) including Frijoles, Lummis, and Alamo.	
Centaurea repens Russian knapweed	perennial forb	RGC; lower tributary canyons and mouths (and associated willow patches) including Frijoles, Lummis, and Alamo	reproduces from seeds and vegetative buds on roots
http://www.colostate.edu/Depts/CoopExt/TRA/knapweed.html			
Invasive non-native plants for which there is currently no effective suppression method			
Bromus tectorum[b] cheatgrass	annual grass	widely distributed at lower elevations, expanding into canyons and possibly burned areas post-LCF	winter annual, so abundance dependent on winter-spring rainfall; expanding, especially in post-fire areas
http://www.fs.fed.us/database/feis/plants/graminoid/brotec/all.html			
B. japonicas Japanese brome	annual grass	widely distributed in disturbed areas near horse corral, developed park areas, Rio corridor, and lower canyon slopes	
http://www.fs.fed.us/database/feis/plants/graminoid/brojap/all.html			

Table 4-2. Common and widespread nonnative plant species found in Bandelier National Monument, their location, and status post-Las Conchas Fire (LCF), if known; website provided if available. Organized according to type of nonnative species (*continued).*

Scientific name **common name**	**Type**	**Locations in Bandelier NM**	**Comments/post-LCF status, if known**
B. inermis smooth brome	perennial grass	roadsides, Dome Fire area	spreading vegetatively
http://www.npwrc.usgs.gov/resource/plants/exoticab/pipebrom.htm			
Widespread nuisance species			
Cirsium vulgare[b] bull thistle	biennial forb	local patches in Cerro burn area; disturbed or burned meadow areas along Hwy 4	treated along the Highway 4 corridor by EPMT in 2013
Carduus nutans[a] musk thistle	biennial forb	roadside, Hwy 4	post-fire invader (Floyd-Hanna et al. 1993); reproduces only from seed; treated along the Highway 4 corridor by EPMT in 2013
Kochia scoparia kochia	annual forb	RGC and disturbed sites	
Kali tragus Russian thistle/ tumbleweed	annual forb	disturbed sites	
Taraxacum officinale dandelion	perennial forb	riparian, canyons, and lawns	
Verbascum thapsus mullein	biennial forb	disturbed and recently burned areas	treated on Capulin Mesa by EPMT in 2013
Chenopodium glaucum goosefoot	annual forb	disturbed and recently burned areas	
Poa pratensis blue grass	perennial grass	riparian, lawns, developed canyon area; persisting where planted	
Non-native plants (including ornamentals) that do not currently pose a risk to ecosystem health			
Euphorbia esula[a] leafy spurge	perennial forb	near Corral Hill (~0.10 acre)	substantial root systems
Cardaria draba[a] hoary cress	perennial forb	horse corral	treated within the horse corral area and along the Highway 4 corridor by EPMT in 2013;
Melilotus officinalis yellow sweet clover	annual/biennial forb (legume)	roadsides	
Juglans nigra black walnut	ornamental; woody	historic orchard and Frijoles Creek	
Coronilla [securigera] varia crown vetch	ornamental; perennial forb (legume)	residential area	
Lathyrus latifolius sweet pea	ornamental; perennial forb (legume)	residential area	
Salvia pratensis meadow clary	ornamental; perennial forb	roadside, Hwy 4	
Mentha arvensis spearmint	ornamental; perennial forb	lower Frijoles Creek	
Althea rosea hollyhock	ornamental; perennial forb	roadside, Hwy 4	

[a] New Mexico (2009) Class A or B noxious weed species (limited or regional distribution)

[b] NPS Exotic Plant Management Team (EPMT)

[c] New Mexico Class C noxious weed species (widespread)

4 Rio Grande Corridor (RGC)

Water • Hydrology;

Geology and Soils • Geomorphology;

Biological Integrity • Communities of Concern

4.09 Rio Grande Corridor and Associated Riparian Vegetation

4.09.1 Description

The Rio Grande forms the eastern boundary of Bandelier NM from the mouth of Frijoles Canyon on the north to a point midway between Alamo and Capulin Canyons to the south, approximately six river miles. This section of the river is bordered to the east by the Caja del Rio, a basaltic upland managed by the Espanola District of the U.S. Forest Service (USFS) primarily for grazing and ORV recreation. The park does not manage the river system proper since the monument's boundary is defined as being the western-side of the active river channel. However, the park does manage its portion of the terrestrial riparian river corridor and participates as a principal stakeholder to influence how river flow and water holding events are managed by the upstream and downstream water managers, specifically the U.S. Army Corps of Engineers (ACE).

About 12 miles upstream of Frijoles Canyon, the Rio Grande enters White Rock Canyon, a deeply cut gorge of relatively recent geologic origin, and the river remains within this canyon system until it emerges downstream at the Cochiti Reservoir Dam some six miles below the park's southern boundary. White Rock Canyon is a scenic river corridor administered by several different federal, state, and local agencies including the Department of Energy's Los Alamos National Lab (LANL, White Rock Canyon Preserve), Espanola District-Santa Fe National Forest (SFNF), Los Alamos County Open Space, Bureau of Indian Affairs San Ildefonso Pueblo, and the Bureau of Land Management.

The river section within White Rock Canyon is generally well watered, although major reductions in spring runoff flow peaks have been imposed by upstream dam regulation, primarily on the Rio Chama, a major tributary which joins the Rio Grande just north of Espanola, NM. And although White Rock Canyon is not managed cooperatively, and several of the entities are not land management agencies per se, the unit is ecologically coherent and the habitat was identified by the New Mexico State Department of Game and Fish as having high potential for supporting reintroduction of extirpated desert bighorn sheep.

<u>Human Impacts to Rio Grande</u>

As a natural community, the riparian ecosystem along the Rio Grande has experienced enormous change during the last century, largely due to water impoundments and flow management, both upstream and downstream of the park, but also as a consequence of domestic grazing and exotic vegetation. Regional water usage has increased dramatically since the 1950s and water rights within the Rio Grande watershed are fully appropriated. Indeed portions of the Rio Grande south of Albuquerque routinely go dry during the summer months as water is variously diverted, consumed, and evaporated. However the major impacts to Bandelier NM have resulted from construction and management of flow and sediment impoundment structures, in particular the Cochiti Dam and Reservoir system.

In addition, within the last couple of years the city of Santa Fe established a water uptake and filtration plant several miles upstream of the park at Buckmans Crossing, where river water is pumped overland for domestic use by the capital city. In the summer of 2013, the town of Los Alamos announced plans to drill several new wells along the west rim of White Rock Canyon near the community of White Rock to extract shallow aquifer river water (technically San Juan Basin-Chama water) to supplement municipal water supplies and replace old deep aquifer well fields. Finally, feral cattle, probably escaped from the pueblo upstream or crossing from the Caja del Rio, have been a perennial problem and contribute to a degraded riparian zone. Periodically the park attempts to trap and/ or shoot feral cattle in collaboration with the NM state livestock board and under legal guidance of the 1995 feral cattle EA (NPS 1995); recent actions include those in 1995 and 2009.

Cochiti Dam and Reservoir

The Cochiti Dam, completed in 1977, created a flood and sediment control reservoir system which encompasses the entire river corridor within Bandelier NM. Operationally, this means that the reservoir is used to hold back spring runoff in excess of certain thresholds, but excess water is supposed to be evacuated within a 3-month period; however this authority was exceeded during the mid-1980s resulting in several extended water holding events at the maximum flood pool level (~5,460ft). These extended water holding events severely impacted the riparian corridor, initially killing all vegetation both native and exotic, depositing many feet of nitrogen-rich silt, extinguishing springs and seeps and their unique floras, and releasing a succession of exotic plant invasions post-flooding.

Prior to this water holding event the river corridor reportedly supported extensive patches of woody exotics, along with encroachment stands of one-seed juniper on river flats. The flooding eradicated these populations, along with the native understory vegetation. It was primarily the exotic species which recovered and expanded strongly in the aftermath of flooding with a host of new invasive species colonizing the nutrient-rich sediments. In the mid-2000s a major invasive plant control effort focused on three woody exotic species (e.g. Salt Cedar, Siberian elm, Russian Olive) allowed native willow and cottonwood a chance to regain ground along the reach that borders the monument.

Since the mid-1980s water holding, the park has been productively engaged with the ACE (responsible for river operations upstream and downstream, including Cochiti Dam) to promote the benefits of mimicking historic flow regimes (e.g., on channel morphology and cottonwood recruitment) by allowing short duration, high volume spring peak runoff, as well as to point out the negative impacts of long-term water holding events (e.g., on native vegetation,particularly recently colonized sediment bars and willow fly catcher nesting habitat).

Sedimentation

In addition to holding water, the Cochiti Dam and Reservoir traps large quantities of sediment within the affected portions of the river system—as the sediment builds upstream, the river becomes braided, creating a complex mosaic of bars and backwaters, with the bars commonly colonized by native willows. This has created some unique (although artificial) and high quality riparian habitat which, if not altered by future river operations, could support a host of sensitive species including southwestern willow fly catcher. A darker-side to the reservoir sediment storage is the buried contaminant plume originating from Los Alamos National Laboratory (LANL) just upstream of the monument park. Recently the Cochiti Pueblo and ACE have begun coring these sediments to assess levels of various contaminants in the sediment. This same environmental program is beginning to collect baseline vegetation data as well.

Recent fire events have contributed large amounts of sediment to a reservoir system already aggrading much faster than originally forecast due to the sediment inputs from degraded woodland systems. Whether the lifespan of the systems can be extended is an open question. Ironically the absence of sediment in flows below Cochiti Dam has promoted scouring and down-cutting of those reaches which degrades the riparian corridor, as well as habitat for the endangered silvery minnow.

4.09.2 Reference conditions

Reference conditions of the river system are not well documented but we can infer a relatively pristine system prior to 1850, when the hydrologic regime characterized by spring snow melt runoff would generate peaks exceeding 10,000cfs in the absence of upstream dams. Summer monsoonal events would have created temporary pulses in flow and sediment-turbidity, variability that is now greatly moderated by the presence of the dam. The riparian corridor would have supported stands of cottonwood at tributary canyon mouths where sediment fans accumulate and willow thickets along the banks, while scattered seeps and springs emerging at the base of steep canyon slopes would have supported unique floras, including hackberry overstory and sensitive flowering species (e.g., rattlesnake orchid and cardinal flower).

4.09.3 Data and methods

Available data are limited, but include hydrologic flow records from Otowi Gauging Station about 12 miles upstream from the park boundary. This information and a historical perspective are provided in the Cochiti Baseline Biological Report (Allen et al. 1993).

Almost no terrestrial vegetation data are available, aside from floristic reports and an early assessment of post-Cochiti Dam sediment bar formation. Time-series remote sensing reconstructions may offer the best option for assessing landscape scale changes. Baseline documentation of the emerging wetlands and deltas within the monument was provided by mapping efforts in 1996 and 1997 (Promislow 1996; Wechsler and Fettig 1997); more recent changes could be reconstructed using time-series orthoimagery and lidar.

4.09.4 Condition and trend

River flow regimes have been significantly altered from historical conditions. A combination of upstream water impoundments, loss of channel capacity, encroachments into the floodplain, and insufficient snowpack in most years constrain the ability to generate high spring runoff peaks, which are considered beneficial to river dynamics and riparian community health.

Sediment continues to accumulate within the reservoir system, and rates of deposition have spiked in recent post-fire years. While the life-span of this reservoir system is limited by sediment storage, passing sediment through the system is problematic, given the presence of contaminants from LANL. The sediment deltas, braided channels, backwaters, and lush riparian vegetation associated with reservoir deposits have created valuable riparian habitat which supports winter migratory birds, including water fowl and raptors.

Frijoles Spring, which was extinguished by sediment deposition for more than a decade has now re-emerged as a spring fed pond and marsh, although much of the supported wetland flora is exotic.

Recently there are fresh signs of trespass cattle in the park (creating trails, droppings, and impacting Frijoles Spring) despite an intact boundary fence. This situation suggests that the animals were able to walk around the fence in the river during low river levels during the winter of 2012-2013.

Although the magnitude of mid-1980s water holding events has not been repeated (due to a combination of dryer-warmer conditions, earlier snow melt runoff, increased water usage, reduced channel capacity, and more responsible reservoir management), and the system is progressing through a successional recovery phase, visual impacts will continue to be evident for many decades, while the impacts on springs and associated riparian floras and the promotion of exotic weed floras is a longer-term legacy.

Human demand for water in the region continues to increase, and with predicted drying and warming climatic trends, the prospects for additional resource impacts loom while ecological management of the river system become ever more constrained.

4.09.5 Level of confidence

Confidence in the changes of water flow is high due to the presence of gauging station records. Confidence in the assessment of the overall ecological integrity of the system is low to moderate given the absence of resource sampling or monitoring. Historical reference conditions are inferred from a number of lines of evidence, but these are mostly indirect and confidence is generally fair to poor.

4.09.6 Data gaps/Research needs/ Management recommendations

Acquisition of additional remote sensing products (e.g., ortho-imagery and LiDAR), and time-series change analysis to determine status and trends for riparian habitat would be helpful.

The park should continue to participate with other agencies and stakeholders (such as Cochiti Pueblo, ACE, LANL, SFNF) in the management of the river corridor to maintain as natural a flow regime as possible.

4.09.7 Sources of expertise

Brian Jacobs

4.09.8 Literature cited

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Water • Hydrology;

Geology and Soils • Geomorphology;

Biological Integrity • Communities of Concern

4.10 Rito de los Frijoles and Capulin Creek and Associated Riparian Vegetation

4.10.1 Description

Maintaining and protecting proper hydrologic function and natural riparian and aquatic communities of park streams is a priority management goal for Bandelier NM (Mott 1999, Weeks 2007). To function holistically, riparian ecosystems—the biological and structural elements of areas adjacent to streams and rivers—require both physical and ecological integrity. Physical characteristics of healthy riparian zones include intact floodplains, good water quality, sufficient flows, and in-stream structural components (e.g. sediment) that provide habitat for aquatic species and streamside communities (Poff et al. 1997, Bendix and Hupp 2000). Biological elements include native vegetation communities adapted to periodic flooding and appropriately diverse communities of aquatic-adapted and reliant species (Karr 1991, Dwire and Kauffman 2003).

Vegetation types occurring along Rito de los Frijoles (perennial) and Capulin Creek (perennial) are classified as Rocky Mountain Subalpine-Montane Riparian Forest and Woodland, with specific types of box elder-alder-cottonwood, white-fir-box-elder mixed, ponderosa pine-broadleaf mixed, ponderosa pine dry wash, and oneseed juniper dry wash (Muldavin et al. 2011). In Bandelier NM these are fairly narrow zones that include dominant species of ponderosa pine, thinleaf alder, box elder, narrowleaf cottonwood, mountain maple, gambel oak, beech, cherry, and New Mexico olive (Muldavin et al. 2011).

Riparian systems contribute to the overall diversity of regional landscapes, often supporting relatively higher numbers of rare or regionally restricted species (Sabo et al. 2005). In arid systems where water is naturally scarce, riparian systems also provide particularly critical connections between upland, riverine, and downstream communities (Wilcox et al. 2003, Osterkamp and Hupp 2010), but may be relatively more vulnerable to disturbance and climate change effects (Friedman and Lee 2002, Perry et al. 2012).

Disturbance and recovery

Several large wildfires and subsequent flood events since 1977, (most recently the massive Las Conchas Fire (LCF) of 2011; fires are summarized in section 2.2.2), have had substantial impacts, at multiple scales, on the biological communities and hydrologic processes in Capulin and Frijoles canyons in Bandelier NM (Mott 1999, Veenhuis 2002, Stumpf and Monroe 2012). Disturbance is a natural process in all ecosystems, including riparian zones (Lake 2000, Shafroth et al. 2002, Stanley et al. 2010), and periodic flooding is required for the persistence of many stream-associated species (Bornette et al. 2008). However, the events occurring in the monument over the last 30 years, while not always directly human-caused, have had increasingly cumulative negative impacts on natural and cultural park resources. Consequently, there has been concern that park ecosystems may have lost resilience and are now moving toward threshold states from which they may not recover (Dwire and Kauffman 2003, Jackson and Sullivan 2009, Bowker and Smith 2014). Moreover, ongoing and anticipated impacts of prolonged drought and climate change may hinder the recovery and successional processes in riparian systems following disturbance more than would otherwise be expected (Perry et al. 2012).

The primary impacts of the LCF on Capulin Creek and Rito de los Frijoles were the following:

1. Large portions of riparian vegetation communities suffered direct mortality from the fire, so much so that in some areas 100% of the riparian canopy was

lost (Stumpf and Monroe 2012). In Capulin Canyon, approximately 60% of the riparian zone was severely burned, and 40% was slightly to moderately burned. Linearly this translates to about 7 km severely burned and 3 km less so. For Frijoles Canyon, approximately 7.6 km of high severity impacts and 11.4 km of low to moderate severity affected the riparian zone (unpublished GIS analysis). Aerial photography shows near complete loss of vegetation along much of both streams.

2. The extreme reduction in live upland vegetation combined with reduced soil integrity substantially increased runoff during post-fire precipitation events. For example the post LCF peak flow in Frijoles Canyon on September 13, 2013 was three times as large as any previously recorded for that stream (Veenhuis 2002, NPS 2011). Flow in southwestern streams is highly variable and riparian ecosystems in the region are adapted to disturbance caused by large flood events. However, extreme flood events following landscape scale fires can be particularly destructive to riparian ecosystems because they typically transport large volumes of sediment and woody debris (Wilcox et al. 2003, Neary et al. 2005). Post-fire floods frequently result in deepening and widening of stream channels, conditions which in turn alter the attributes of the existing floodplain (Mott 1999, Friedman and Lee 2002, Veenhuis 2002, Neary et al. 2005). Flooding and peak flow events, particularly when large debris are transported, not only cause direct mortality to understory plants that may have survived the original fire, but may also bury or remove the existing seed bank (Yount and Niemi 1990).

Riparian ecosystems are resilient, and after fires, riparian plant communities often recover more rapidly than upland communities due to the moist conditions and because fire severity is often lessened in riparian zones (Dwire and Kaufman 2003, Pettit and Naiman 2007, Ellis 2001). However, ruderal species often establish in heavily disturbed sites, such as flood zones, more rapidly than native species (Bornette et al. 2008, Ringold et al. 2008). Most studies conducted in riparian ecosystems have determined that successional responses to large-scale disturbance can take from years to decades, and are dependent on multiple factors of geography, climate, and human activities (Fisher et al. 1982, Lake 2000, Lite et al. 2005). In addition to the direct loss of riparian forest stands due to fire and flooding, the absence of herbaceous and woody plants removes significant food and habitat resources for numerous vertebrate and invertebrate species (Bess et al. 2002, Lecerf et al. 2005).

Landforms and geomorphology

Stream channel morphology is defined by a complex series of interactions between hydrologic regimes and watershed geologic characteristics. Metrics used to describe channel morphology include substrate size, channel cross-sectional form, and planform of the channel and floodplain. These all influence a stream's habitat abundance and diversity, sensitivity and resilience to natural and human-induced disturbances, retention of surface and sub-surface water, sediment transport and retention, nutrient capacity, and connectivity both within the aquatic system and between the stream and adjacent uplands. Large floods such as those occurring in the streams at Bandelier NM, post LCF, periodically restructure stream channel morphology. Prior to the LCF, Rito de los Frijoles had been relatively unimpacted by disturbances for nearly thirty years, and the stream was in a relatively stable condition, supporting a healthy riparian ecosystem and aquatic communities with high abundance and diversity. Large flood events occurred in Capulin Canyon following the 1996 Dome Fire and at the time of the LCF, Capulin Canyon was in a state of transition. It is probable that the LCF and subsequent floods may have exacerbated geomorphic and vegetation changes in Capulin intiated by the Dome Fire (B. Jacobs pers. comm.).

Resource managers at Bandelier NM have observed noteworthy sediment displacement and landform change since the LCF, particularly in canyon settings that are characterized by steep slopes and fractured bedrock. Limited analysis of LiDAR datasets collected over Frijoles Canyon between 2010 and 2013 identified areas of canyon bottom sediment deposition of +/- 20–40m in severely burned portions of the canyon (Jacobs 2014). The unburned lower canyon also exhibited landform change, particularly near the Lower Falls of Frijoles Canyon that has seen major landslide and rockfall episodes since the 1930s. During the August 2011 major post-fire flood event, the toe of the slope below the falls was scoured by the stream and thin vertical bedrock blocks fell into and broke up in the stream channel. The site is poised to experience another major landslide and/or rock slope failure that could very easily obliterate the remaining remnants of the Falls Trail in this area.

Vegetation recovery

Succession processes after floods should facilitate the transition from essentially bare ground and buried vegetation to herbaceous emergence, woody species recovery (often from resprouting, Engelhardt et al. 2011), and culminating again in a riparian woodland. Riparian vegetation can be particularly resilient to long-term fire impacts, though response and recovery trajectories appear to vary depending on fire severity, availability of source populations, and climatic conditions in the immediate post-fire years (Ellis 2001, Dwire and Kaugman 2003). Characteristics that would be relevant in assessing vegetation community structure could include woody species diversity (Jackson and Sullivan 2009), tree cover (canopy area), woody species recruitment rates (either from seed or re-sprouting, Jackson and Sullivan 2008), population dynamics of dominant tree species, herbaceous species diversity, and exotic species abundance.

However, given how much the riparian zone has been altered by direct fire and flood impacts, and the likelihood that drought conditions may continue for the foreseeable future, consideration should be given to the validity of using past community conditions as a reference (Stoddard et al. 2006). For example, species that are more adapted to flooding and periodic inundation may become less common than more drought-tolerant taxa. Also, the potential for exotic species to proliferate in post-disturbance conditions is likely an undesired outcome with which managers should be concerned (Rindgold 2008).

4.10.2 Reference conditions

Landforms and geomorphology

In the context of the last 10,000 years, the recent flooding observed post-Las Conchas Fire is not unprecedented. The last hundred years, however, have been very quiet in terms of geomorphic stability, as a result of vegetation conditions due to fire suppression. For example, Reneau (2000) identified periods of rapid downcutting in Frijoles Canyon during the early Holocene (8000-10000 years ago).

Vegetation

The fairly narrow montane riparian zones along interior streams support well-developed and diverse forest or woodlands, including dominant species of ponderosa pine, thinleaf alder, box elder, narrowleaf cottonwood, mountain maple, Gambel oak, beech, cherry, and New Mexico olive. Periodic fires and floods result in patchy loss of riparian vegetation followed by succession.

4.10.3 Data and methods

Landforms and geomorphology

Staff observations, review of historic photographs, repeat photo points and repeat LiDAR all contribute to understanding of ongoing landform changes.

Measures of stream morphology, including substrate particle size, habitat type, and geomorphic channel unit, are all useful indicators of channel condition and are collected as part of the SCPN's aquatic macroinvertebrate monitoring program. These data have been collected from two sites on both Rito de los Frijoles and Capulin Creek for more than five years and provide a picture of these streams functional condition (Stumpf and Monroe (2009, 2010, 2011, 2012a, 2012b).

Streamflow

At present, there is one active streamflow gauge in Rito de los Frijoles and no gauges on other streams in Bandelier NM. The streamflow gauge on Rito de los Frijoles was destroyed by the flood on August 21, 2011. A new gauge was installed by the USGS at the same location and data from this station are available online at: (http://nwis.waterdata.usgs.gov/nm/nwis/uv/?site_no=08313350). Since the 2011 flood the accuracy of base flow data from this gauge has been poor due to high volumes of sediment moving through the system and numerous moderate to large flood events.

While only one streamflow gauge is currently active in the monument, there are data available from gauges that had been previously deployed in Rito de los Frijoles and Capulin Creek. Table 4-3 provides information about the gauges and the data available.

Vegetation

Very few data exist that quantitatively describe the historic riparian vegetation community structure of Capulin or Frijoles creeks. A small number of plots were established in riparian areas during the vegetation mapping project (Muldavin et al.2011) and there appear to be three within the Capulin riparian zone but none in the Frijoles area. SCPN estimates of riparian vegetation canopy cover at four sites, two on Rito de los Frijoles and two on Capulin Creek, as part of the network's aquatic macroinvertebrate monitoring program. The riparian canopy was dense at sites along both streams prior to the LCF, ranging from a low of 63% at Rito de los Frijoles to 99% at Capulin Creek. In the years since the LCF, no live riparian vegetation has been recorded at 3 of the 4 SCPN monitoring sites. SCPN's site on Rito de los Frijoles near the monument visitor center site did not burn during the LCF, but has seen a reduction in riparian cover most likely due to scouring. Cover at that site declined from an average of 75% prefire to 27% postfire.

Landforms

Staff observations, review of historic photographs, repeat photo points and repeat LiDAR all contribute to understanding of ongoing landform changes.

4.10.4 Condition and trend

Geomorphology and streamflow

Stream geomorphology data collected by SCPN since 2009 provided the following information:

- Substrate particle size. Gravel, silt, and cobbles were abundant channel substrate types prior to the LCF in both Capulin and Frijoles creeks. In the years since the fire and subsequent flooding sand and small gravel have become the dominant substrates.
- Habitat type. Prior to the LCF, aquatic macroinvertebrate habitat data collected at sites on Rito de los Frijoles and Capulin Creek showed a wide diversity of habitat types, including both substrate bottom materials and primary production materials (leaf packs, woody debris, vegetation and root wads). Post fire data show that the majority of those habitat types are no longer present. Since 2011 available habitat in these streams appropriate for aquatic macroinvertebrates ranged from 5% to 35%.
- Geomorphic channel units. Riffles, runs, and cascades were the most abundant geomorphic channel units found along Rito de los Frijoles and Capulin Creek prior to the LCF. The influx of large volumes of fine sediments since the fire has resulted in the burial or loss of gravel and cobble substrates and has greatly reduced the number of riffles and cascades in the streams. Long sandy runs are now the dominant geomorphic channel units present.

The LCF had substantial physical impacts on both Capulin Creek and the Rito de los

Frijoles (Stumpf and Monroe 2012), greatly altering stream morphology, at least for the short-term. Continued erosion and flood events can be expected for the next several years. Numerous flood events have occurred since the fire, the largest of these in July 2013, suggesting watershed conditions remain impaired (S. Monroe pers. comm.). However, assuming that upland conditions improve in coming years, peak flows and associated debris and high-flow impacts will decline. However, it is possible a prolonged reduction in streamflow resulting from climate changed-induced drought will have significant impacts on Capulin and Frijoles riparian systems (Lake 2000).

Vegetation

If the assessment was for present and standing conditions only, the current condition of riparian vegetation communities in Capulin and Frijoles canyons affected by recent fire and flood events is poor. However, what is of ecological importance is how well these sites are poised to recover. Capulin Canyon is in much worse shape following the LCF than Frijoles. This is probably due to the relatively short time since the Dome Fire, and because a greater percent of the Capulin watershed, including upper Capulin, burned at high severity, while upper Frijoles burned less severely.

Under historic regime conditions, fires and floods alone in these systems would likely support future healthy riparian forests following secondary succession (Scott and Reynolds 2007). But the severity of the impacts, along with the potentially stronger influences of prolonged drought and upland and landscape (watershed) responses to climate change (Bendix and Hupp 2000, Engelhardt et al. 2011), alter that scenario substantially. The potential for invasive species to quickly establish and affect successional trajectories is also a concern.

4.10.5 Level of confidence

The level of confidence in this assessment is moderate.

4.10.6 Data gaps/Research needs/ Management recommendations

- Monitoring of riparian zones to document recovery processes and detect introductions of invasive/exotic species.
- Aerial photography could greatly assist in documenting vegetation recovery.
- Monitor the rate of landform change using LiDAR.

Table 4-3. Data available from streamflow gauges on Capulin Creek and Rito de los Frijoles in Bandelier National Monument.

Stream	Station IDs	Location	History	Data available
Capulin Creek	USGS # 083133655	Capulin Canyon at Ranger Cabin	NPS station destroyed by the first post-Dome Fire flood 6/26/96; new gauge installed by USGS near the previous station so are considered one record.	4/85-6/96; 6/97-11/98; 7/97 upgraded to satellite system (DCP)
	USGS # 08313365	Capulin Canyon above Ranger Cabin	Crest-stage gauges to monitor streamflow after the Dome fire	7/96-11/98
Capulin Creek	USGS # 08313366	Capulin Canyon below Ranger Cabin	Crest-stage gauges to monitor streamflow after the Dome fire	7/96-11/98
Capulin Creek	USGS # 08313368	Capulin Canyon below Painted Cave	Crest-stage gauges to monitor streamflow after the Dome fire	7/96-11/98
*Rito de los Frijoles	USGS # 08313350	Rito de los Frijoles near VC	7/63-9/69 and 7/77-9/79: USGS, location upstream of VC. 10/79-present: USGS and LANL, site downstream of VC.	7/63-9/69; 7/77-present
Rito de los Frijoles	USGS # 08313300	Rito de los Frijoles near Los Alamos		1960-1963

*Data available at:
http://nwis.waterdata.usgs.gov/nm/nwis/uv/?site_no=08313350; http://wdr.water.usgs.gov/wy2012/pdfs/08313350.2012.pdf

- Continue operation of a discharge gauge on the Rito de los Frijoles.
- The known flood history within Frijoles Canyon and projected increase in extreme flood events should be fully valued by managers in future infrastructure development efforts.
- Repeat LiDAR over multiple years, with analysis, to assess how long accelerated landform changes continue once episodes of mass movement are underway.

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Brian Jacobs, Stephen Monroe

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Water • Water Quality

Biological Integrity • Communities of Concern

4.11 Water Quality and Aquatic Macroinvertebrates

4.11.1 Description

4.11.1.1 Background

Maintaining and improving surface water quality at Bandelier NM has been an important natural resource goal since the establishment of the park (Mott 1999, Weeks 2007). Under the National Park Service Organic Act (1916, 16 USC1), national park waters should remain unimpaired for future generations, and, in addition, Bandelier NM has identified surface waters as an important natural and cultural resource (Weeks 2007). Riparian vegetation, stream flow, channel morphology, stream water quality, and aquatic macroinvertebrate communities have all been identified as priority vital signs for monitoring in the monument by the Southern Colorado Plateau Network (SCPN) of the NPS (Thomas et al. 2006).

Aquatic macroinvertebrates serve as the primary food base for many aquatic vertebrates and they function as the primary processors of energetic inputs in low order streams, like the streams found in Bandelier NM. Consequently, they are important indicators of ecosystem health. Communities of aquatic macroinvertebrates in streams are commonly monitored alongside physical and chemical properties of water because of their potential to provide indications of water quality and overall hydrologic condition (Brasher et al. 2011).

This assessment will focus on the water quality and macroinvertebrate communities of the Capulin Creek and the Rito de los Frijoles ('Frijoles'), and associated upland catchment areas. These sites each have a substantial data record, and were selected for long-term monitoring by SCPN because of their history of impairment; the substantial impacts that have occurred to each as a result of recent large-scale disturbances; and because Rito de los Frijoles is the stream most accessible to visitors. A separate section of this report will address vegetation and physical properties of the two streams, and an overview of the two canyon systems is provided in Section 4.10.

4.11.1.2 Impacts on aquatic systems at Bandelier National Monument

Historic and continuing impacts to aquatic systems have made maintaining good water quality and protecting stream ecosystems a particular challenge for park managers (Mott 1999). Significant past impairments to surface water quality in the park include the use of organochlorides (e.g. DDT; Mott 1999); high nutrient loads resulting from human and livestock use in the watershed (Thomas et al. 2006); and the introductions of trace and heavy elements into the groundwater system by Department of Defense activities at the adjacent Los Alamos National Laboratory (LANL; Mott 1999, Weeks 2007).

In addition, a series of extreme wildfires that began in the 1970s, and associated post-fire floods have increased sedimentation, altered existing aquatic invertebrate communities, and damaged or destroyed streamside forest vegetation (Veenhuis 2002, Vieira et al. 2004, Stumpf and Monroe 2012b). Fire can have both direct and indirect impacts on riparian communities. Direct effects occur during the fire and consequent major runoff events (Neary et al. 2005), while indirect effects are a consequence of subsequent vegetative and geomorphologic changes (Minshall 2003, Oliver et al. 2012). Aquatic communities in Bandelier NM have repeatedly experienced both types of effects. Interactions between persistent drought conditions and continued introductions of contaminants (from both natural and anthropogenic sources), with repeated disturbance, may further limit the potential for long-term aquatic and riparian ecosystem recovery (Allen 2007, Weeks 2007).

4.11.1.3 Water quality standards

The state of New Mexico has developed statewide water quality standards and criteria for surface waters and specific additional criteria relevant to streams to meet requirements of the Federal Clean Water Act (NMED 2013). A water quality standard refers to a specific parameter and its associated designated use, in conjunction with a criterion, which is the numeric component against which a result is compared. For example, the standard for chronic mercury (the specific parameter) for aquatic life (designated use) is 0.77 µg/L (numeric criterion). For this assessment results of water quality core parameter measurement as well as other frequently sampled analytes are summarized and evaluated in Appendix E. The National Park Service does not have regulatory authority over waters in the U.S., or even the authority to make assessments for designated use. For a complete summary and explanation of water quality standards see Dyer and Monroe (2013).

4.11.1.4 Research and monitoring history

Water quality

Ongoing efforts to understand and protect aquatic ecosystem integrity in Bandelier NM have resulted in a substantial body of work describing data collection and summary efforts for hydrologic resources (Weeks 2007, Brown 2008). Specifically, the NPS Water Resources Division completed a comprehensive summary of existing surface water quality data for the monument (NPS 1997); Brown (2008) summarized and evaluated available water quality data for Bandelier NM and four other park units in the SCPN through 2004; and Macy and Monroe (2006) collected and presented water quality data for multiple SCPN parks, including Bandelier NM, in 2005 and 2006. See these existing data syntheses for detailed descriptions of data collection methods and data sources. For additional background information, the reader is directed to the above-mentioned references as well as Mott (1999), Appendix C in Thomas et al. (2006), Weeks (2007), Brasher et al. (2011), and Monroe et al. (in preparation). Water quality data for streams and springs in the monument and nearby areas are available at www.intellusnm.com. During the period since 2005 water quality data have been collected at the park by various agencies and contractors focused on issues that include an assessment of surface water quality in relation to state of New Mexico water quality standards, an NPS contracted study updating the status of previously detected high levels of DDT in Rito de los Frijoles, a sampling program designed by EPA and SCPN to establish baseline levels for potential contaminants that include pharmaceuticals, personal care products, waste indicators, and pesticides in Rito de los Frijoles. Brief summaries of each of these efforts are provided below.

In 2010 SCPN began monitoring water quality in two perennial streams in Bandelier NM —the Rito de los Frijoles and Capulin Creek. Reports and water quality data collected at the monument since 2005, are summarized in Table 4-4.

Aquatic macroinvertebrates

Previous studies investigating the aquatic macroinvertebrate community of streams at the monument have focused on relating community structure to water quality, researching biomonitoring techniques (Hopkins 1992, Stevens 1996), or examining the short-term (Pippin and Pippin 1980, Pippin and Pippin 1981, MacRury and Clements 2002) and long-term (Vieria et al. 2004) effects of large wildfires on community structure and recovery. In 2005 SCPN and USGS conducted a pilot study to determine the most appropriate methods for the long-term monitoring of aquatic macroinvertebrates at Bandelier NM (Brasher et al. 2010). SCPN began monitoring aquatic macroinvertebrates in Capulin Creek in 2007 and in the Rito de los Frijoles in 2009.

4.11.2 Reference conditions

The preferred status for water quality is a condition that minimizes the presence of contaminants associated with 20th century human activities.

Prior to the 20th century, abundant and diverse macroinvertebrate communities were likely present in monument streams, with local loss and recolonization following fire or flood events.

4.11.3 Data and methods

SCPN has been monitoring water quality at Bandelier NM since 2010. The objectives are to determine the status and trends of NPS core water quality parameters (water temperature, pH, specific conductance dissolved oxygen, turbidity, and discharge) and selected water quality constituents, including bacteria, nutrients, major elements, and trace metals (Appendix E) in relation to flow, season, and climatic conditions. There are currently five SCPN water quality monitoring sites in the monument, two on Capulin Creek and three on Rito de los Frijoles, each of which is sampled three to four times per year (Dyer and Monroe 2013).

Long-term annual monitoring of aquatic macroinvertebrates at Bandelier NM began in Capulin Creek in 2007 and in Rito de los Frijoles in 2009. SCPN is currently monitoring four sites, two each on Capulin and Frijoles creeks. Two sites on Rito de los Frijoles and one site on Capulin Creek are co-located with a water quality monitoring site. Detailed sampling methods are described in Brasher et al. 2011 and are based on the USGS NAWQA and the EPA EMAP programs. Sampling is conducted once each year in either September or October. Biological and physical habitat data are collected at each of the four sites (Brasher et al. 2011). Sampling includes both qualitative and quantitative methods; qualitative data provide a species list for each site, while quantitative samples result in estimates of abundance that can be spatially and temporally compared (Brasher et al. 2011, Stumpf and Monroe 2012b). The SCPN is currently using a broad suite of metrics to summarize key aquatic macroinvertebrate community characteristics (Brasher et al. 2011). These metrics describe:

- abundance/richness/diversity: total abundance, number of taxa, and Simpson's Diversity Index
- tolerance: percent of individuals and taxa sensitive to perturbation
- functional – feeding: actual and relative abundance of individuals and richness of taxa.
- composition: abundance and relative abundance of Ephemeroptera, Plecoptera and Tricoptera (EPT).
- habitat factors: (stream width, stream depth, discharge, water quality parameters

As of this writing the SCPN aquatic invertebrate monitoring program has collected six years of data for Capulin Creek, and four years of data for the Rito de los Frijoles. Six years is considered a minimum period needed to begin to assess the range of natural variability in community dynamics (Brasher et al. 2011). However, given the substantial disturbance caused by the Las Conchas Fire (LCF) and subsequent hydrologic events, Capulin and Frijoles creeks have experienced instability during the years since the fire. Several more years of sampling will be necessary to determine whether future communities will be similar to those that existed prior to 2011 (e.g. during the pilot study in 2005-2006 when abundance and diversity in Capulin creek appear to have been relatively high), or be markedly different.

4.11.4 Resource condition and trend

4.11.4.1 Water quality standards

Rito de los Frijoles in Bandelier NM is on New Mexico's 2012–2014 303(d) list of impaired waters for aluminum and DDT in fish tissue. Past sources of impairment have also included fecal coliform bacteria, temperature, turbidity, and radium 226 and 228. Some aspects of water quality in Bandelier NM had improved prior to the LCF in 2011; Capulin Creek was listed as impaired due to sedimentation and turbidity from 2002–2006 and is no longer listed. However, recent water quality data collected after the LCF indicate that the status of both streams will likely change due to large-scale inputs of sediment into the streams and increased temperatures caused by the complete loss of

Table 4-4. Reports of water quality data collected from streams at Bandelier National Monument since 2004, and aquatic macroinvertebrate data collected since 2005.

Collection years	Reference	Source
Water Quality		
	Macy and Monroe 2006	SCPN
2010	Dyer, Monroe and Lawrence 2012	SCPN
2011	Dyer and Monroe 2013	SCPN
2012–2013	In prep., data available from SCPN	SCPN
2004–2008	New Mexico Environment Department 2010	NMED
Macroinvertebrates		
2005-2006	Brasher et al. 2010	SCPN
2007	Stumpf and Monroe 2009	SCPN
2008	Stumpf and Monroe 2010	SCPN
2009	Stumpf and Monroe 2011	SCPN
2010	Stumpf and Monroe 2012	SCPN
2011	Stumpf and Monroe 2012	SCPN
2012–2013	In prep., data available from SCPN	SCPN

riparian vegetation.

New Mexico Environment Department Pajarito Plateau Water Quality Assessment

In 2006 the New Mexico Environment Department (NMED) conducted an assessment of surface water quality focused on streams flowing across the Pajarito Plateau, including three sites on Rito de los Frijoles and one in Lummis Canyon in Bandelier NM. The assessment covered the period 2004–2008 and included collection of water quality samples analyzed for trace metals, radionuclides, bacteria, ions, and PCBs. Among these analytes, aluminum was found to be in exceedance of state of New Mexico water quality standards in samples collected at Rito de los Frijoles (New Mexico Environment Department [NMEDNMED 2010).

DDT

During the 1950s and 1960s NPS applied DDT and other chlorinated hydrocarbons for pest control in lower sections of Frijoles Canyon. Chemicals also entered canyon aquatic and terrestrial ecosystems through the NPS drainage system or via leakage from storage containers (NPS 1995). Samples collected from Rito de los Frijoles in 1975 by the State of New Mexico showed high concentrations of DDT and subsequent studies also found evidence of contamination in sediment and fish tissue. A risk assessment and Environmental Analysis resulted in a ban on fishing in the affected reach of Rito de los Frijoles. Resampling for DDT in 2012 found concentrations similar to those identified in the 1990s (Baker 2013).

Bacteria

Water samples collected by NPS and others in the 1970s, 1980s, and 1990s from multiple sites on the Rito de los Frijoles identified high levels of fecal coliform at various times (NPS 1995). Some of the samples had fecal coliform levels in exceedance of established state of New Mexico water quality standards (New Mexico Water Quality Control Commission 1995). Generally coliform levels are higher during summer months when visitor use and water temperatures are both high, and at sites in the more heavily used portion of Frijoles Canyon (Mott 1999). Various researchers have suggested that the source of coliform could be point sources or ground water. Possible sources identified included spills at the lift station; spillovers at the horse corral due to heavy rain; a continuously leaking sewage pipe; leachate from unlined pit toilets at Ceremonial Cave; natural sources, such as the turkey vulture roost in the Frijoles riparian area; or washing of naturally occurring bacteria, and backcountry human and horse waste, into the stream by storm flows (Mott 1999).

In 2009 SCPN initiated regular collection of water samples for *E. coli* analysis at sites on Rito de los Frijoles and Capulin Creek in Bandelier NM. From 2009–2014, summer *E. coli* levels frequently exceeded New Mexico State water quality standards in lower Frijoles, while sites upstream and on Capulin Creek only occasionally experienced exceedances (Figure 4-20).

Water temperature

Water temperature data collected at 15-minute intervals with temperature loggers deployed in Rito de los Frijoles (unpublished data) by SCPN near the monument's visitor center during the period 8/1/2009 –8/13/2013 indicated regular exceedances of the New Mexico water quality criteria for the high-quality coldwater aquatic life designation currently applied to this stream (Figure 4-21). The number of water temperature exceedances per year has increased significantly since the LCF, probably due to greater solar radiation input to the stream caused by loss of vegetation resulting from the fire and subsequent flooding. While similar datasets do not exist for the Upper Crossing of Rito de los Frijoles or Capulin Creek, temperature measurements during periodic site visits indicate that temperature exceedances occur at these sites as well.

Contaminants of emerging concern

Beginning in 2011, SCPN has partnered with the United State Environmental Protection Agency (USEPA) to assess the occurrence of "contaminants of emerging concern" (CEC) in water sources in SCPN parks. Included in this project are approximately 250 analytes, consisting of pesticides, personal care products, pharmaceuticals and waste water indicators. For many of these contaminants, the risks of long-term, low-level exposure to human and ecosystem health are not known and the goal was to develop a baseline dataset documenting the occurrence of these contaminants. At Bandelier NM SCPN collected samples for CEC analysis from two sites in Rito de los Frijoles during 2011 through 2013. Eighteen contaminants were detected in samples collected near the visitor center, and 15 contaminants were detected in samples collected near the Wilderness Boundary. Results between the two sites were similar, and the most common detections were caffeine, flame retardants, and bisphenol A (BPA). Though the sources of these contaminants are unknown, they may be introduced into park surface water through wastewater treatment, recreational use of surface waters, atmospheric deposition, watershed runoff, or management actions, such as invasive plant treatments, park maintenance and landscaping.

Radionuclides

Runoff from areas burned by wildfire mobilizes high concentrations of ash and sediment, which potentially contain contaminants concentrated by the fire. Contaminants may be present naturally in the forest overstory, understory, and litter, or may have been transported by smoke generated by the fire. These contaminants could be a complex mix of particles, liquids and gaseous compounds, including polynuclear aromatic hydrocarbons, organic acids, particulate matter (PM), semi-volatile and volatile organic compounds and the inorganic fraction of particles. They could also be elevated levels of radionuclides (gross alpha emitters) or other radioactive contaminants of concern.

In order to assess radionuclide levels in Bandelier NM streams after the LCF, SCPN collected surface water and streambed sediment samples at two sites on the Rito de los Frijoles, at a site on Alamo Creek, and at a site on Capulin Creek in 2011 and 2012. These samples were analyzed for gross alpha, beta, gamma, isotopic uranium, and radium 226/228.

Of the analytes, only gross alpha and radium have New Mexico State drinking water criteria. None of the results from the four sites exceeded these criteria. Results for analysis

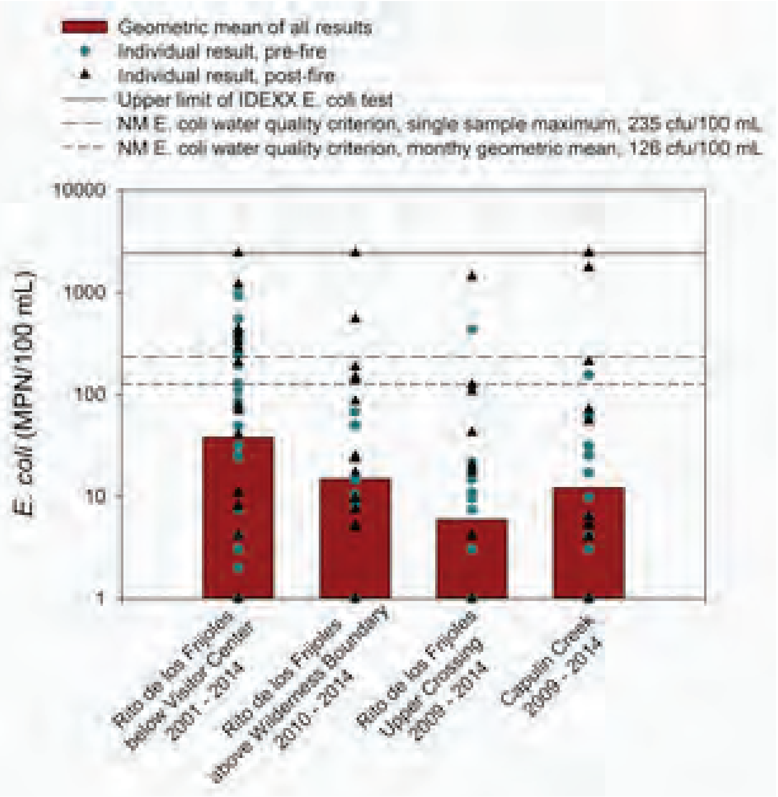

Figure 4-20. *E. coli*. Results of bacteria samples collected from Rito de los Frijoles and Capulin Creek in Bandelier, 2001–2014, showing *E. coli* counts and State of New Mexico water quality criteria.

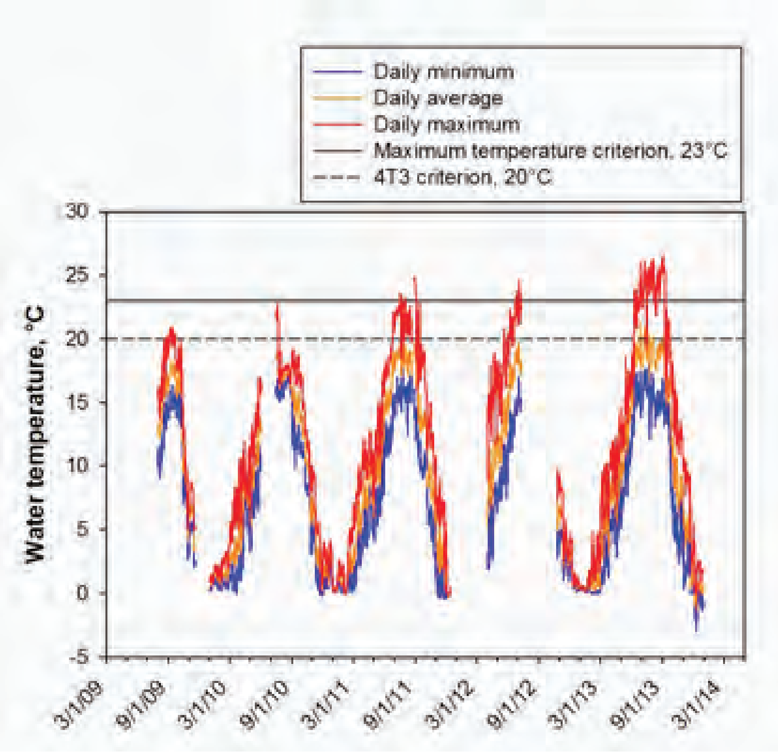

Figure 4-21. Water temperatures in Rito de los Frijoles at Bandelier National Monument from August 1, 2009 to March 1, 2014.

of water samples for gross alpha, beta, gamma, and isotopic uranium results were lower in the 2012 samples than in the samples collected during 2011. Conversely, levels of gross alpha, beta, and isotopic uranium in streambed sediment samples were higher in 2012 than they were in 2011.

4.11.4.2 Aquatic macroinvertebrates

Given the increase in catastrophic wildfire over the last several decades, we recognize that the SCPN monitoring record is not long enough to describe reference conditions for Bandelier NM streams. However, this six-year monitoring effort can be used to describe the condition of aquatic macroinvertebrate communities prior to and after the LCF. SCPN has collected 4 years of prefire data at Capulin Creek and 2 years of prefire data at Frijoles. Post-fire quantitative aquatic macroinvertebrate data exist for 2 years at Frijoles and for 1 year at 1 site on Capulin Creek. Data were not collected at CAP02 in 2011 or either site in 2012 due to a lack of appropriate habitat. The data presented in this section refer to quantitative samples collected at targeted riffle habitats.

Pre-fire condition

Prior to the LCF and subsequent floods, samples collected at SCPN monitoring sites were species rich and high in abundance. Average sample abundances from Rito de los Frijoles in 2009 and 2010 ranged from 688.0 individuals per sample to 760.6. In the 4 years preceding the LCF, 2007–2010, Capulin Creek sample abundance averaged from a low of 229.2 individuals per sample to a high of 757.0. Pre-fire taxa richness at SCPN sites on Frijoles Creek ranged from 27 to 30 taxa per sample. At sites on Capulin Creek, pre-fire taxa richness ranged from 13.4 to 31.6 taxa.

Pre-fire samples collected at sites on both streams possessed rich and diverse aquatic macroinvertebrate communities. At monitoring sites along Frijoles, the Simpson's Diversity Index averaged 0.87. At Capulin Creek pre-fire diversity was slightly lower, with an average Simpson's Diversity index of

0.80. Coleopterans (beetles) were the most abundant orders sampled at the Frijoles prior to the fire, averaging 244.10 individuals per sample. Sensitive taxa in the orders Ephemeroptera (mayflies) (159.25), Plecoptera (stoneflies) (52.85), and Trichoptera (110.30) were also found in high abundances at our sites on the Frijoles. Pre-fire samples collected from the SCPN sites at Capulin Creek were dominated by both Chironomids (midges), averaging 352.46 individuals per sample, ephemeropterans at 290.60, and plecopterans at 92.95 individuals per sample. Coleopterans (91.45), and trichopterans (72.92), while still present, were found in lower abundances at Capulin Creek.

Because of their sensitivity to disturbance, aquatic macroinvertebrate taxa are often monitored as barometers for change or stress in aquatic ecosystems. Prior to the 2011 disturbances, individuals categorized as intolerant to disturbance dominated samples collected at of SCPN's monitoring sites. The average abundance of intolerant individuals collected in samples at Frijoles Creek prior to the fire was 491.23. Moderately tolerant individuals averaged 209.23, followed by tolerant individuals at 1.30 individuals. A similar pattern of dominance was found in samples collected from Capulin Creek. Intolerant individuals dominated samples, averaging 387.98 individuals per sample. Moderately tolerant individuals averaged 156.65 individuals and tolerant abundance averaged 8.55 individuals.

Aquatic macroinvertebrates are grouped into functional groups based on specialized feeding appendages. Prior to the fire, samples collected from monitoring sites along Frijoles Creek were dominated by collector-gatherers, which averaged 540.68 individuals per sample. Scrapers and collector-filterers were also abundant, averaging 214.21 and 148.71 individuals per sample, respectively. Few predators (40.64) or shredders (37.45) were found at sites on Frijoles. Similar to Frijoles, samples from Capulin Creek were dominated by collector-gatherers, which averaged 180.63 individuals per sample. Mean total abundance for shredders (76.55), collector-filterers (72.09), scrapers (65.31), and predators (61.45) were considerably lower.

Post-fire condition

Impacts to aquatic macroinvertebrate communities have been recorded in the park from every fire/flood disturbance event of the previous three decades. Pippin and Pippin (1980) reported a 98% reduction in macroinvertebrates in Rito de los Frijoles following flooding after the La Mesa Fire, a condition Mott (1999) attributed, at least partially, to increased sedimentation. Vieira et al. (2004) found significantly greater change between time periods in the burned (Capulin) than in the unburned (Frijoles) stream after the Dome Fire, and likewise attributed this largely to habitat changes, such as the destruction of pool and riffle habitat (Mott 1999).

The Rito de los Frijoles and Capulin Creek aquatic macroinvertebrate communities appear at present to be in a period of considerable instability following the LCF and the hydrologic events that followed. Samples collected in 2011 and 2012 show that the aquatic communities of both streams have seen massive declines in abundance and shifts in community structure. Along Capulin Creek the loss of appropriate habitat has prevented SCPN from collecting quantitative samples at the lower monitoring site (CAP02) since 2010. Average abundance and richness values at SCPN monitoring sites plummeted to near zero in 2011 and 2012 (Figures 4-22 and 4-23).

While very few individuals of any taxa were found after the LCF, post-fire samples from monitoring sites on both streams show a change in aquatic macroinvertebrate community structure, with a shift in dominance to chironomids (midges) and non-chrionomid dipterans (flies). Post-fire sampling on both streams indicated that moderately tolerant taxa predominated. The dominant post-fire functional group in both streams was collector-gatherers.

Functional groups describe how energy is processed and turned into biomass, based on the structure of the aquatic macroinvertebrate community. Prior to the LCF, sites on both streams had healthy and diverse functional communities capable of processing much of the instream primary production and riparian inputs that flowed through the streams. Scrapers and collector-gatherers were among the most abundant individuals at all sites in the years leading up to the LCF. Scrapers are important because they can process primary production in the form of algae, bacteria, and fungi, while collector gatherers process fine particulate matter found on sediments and detritus. Another ecologically important group found in high abundance along Capulin Creek before the LCF was the shredders. Shredders are responsible for instream processing of live and dead plant materials. Like scrapers, the processing of macrophytes in the water column results in additional resources for both collector gatherer and filterer taxa. Scrapers have been absent from all samples collected at Capulin and Frijoles in the years since the LCF. Shredders have been found at RIT01, but in very low abundances since the fire. The loss of these taxa is ecologically significant because they are responsible for breaking down large pieces of organic matter instream. As a result of their absence, much of the organic matter created or deposited in these streams via riparian vegetation goes unused. An additional consequence of the loss of these groups is less resource availability for the generalist taxa in the collector filterer and gatherer groups. These results suggests that post-fire aquatic communities at SCPN monitoring sites are ill-equipped to process energetic inputs to the stream, a primary function of lower order or headwater streams. Additionally, these results align with those of Vieira et al. (2004), who found that specialized feeders, such as grazers and shredders, that appeared prior to the disturbance were absent in the years immediately following.

One factor that undoubtedly led to the depauperate conditions of the aquatic community at SCPN sites in Bandelier NM was the lack of bottom substrates available for foraging and habitat. Prior to the fire, gravel and cobble size particles dominated at Frijoles Creek (Figure 4-24) and gravels dominated at Capulin (Figure 4-25). Larger substrates provide surfaces that shelter organisms, as well as providing surfaces to cling to while feeding. After the repeated hydrologic events that have occurred along both streams, SCPN data show a shift from larger grained particles to finer grained particles, particularly sand. The overwhelming dominance of sand may be restricting the aquatic community to those organisms adapted to burrowing into softer surfaces. The loss of riparian vegetation in the moderately and severely burned sections of the streams also influences the stream conditions. Riparian vegetation contributes allochthonous inputs to the stream's trophic structure and also shades the streams, thus reducing water temperature.

A third factor influencing both substrate availability and riparian vegetation recovery is hydrologic condition. Previous studies of the aquatic macroinvertebrate communities at Bandelier NM following the La Mesa and Dome fires showed the vulnerability these populations have to large-scale hydrologic events that commonly occur as a result of high severity wildfires (Pippin and Pippin 1980, Vieira et al. 2004). However these studies also show how quickly richness, abundance, and density numbers can rebound in the months following disturbance. Vieira et al. (2004) found density values comparable to their pre-fire collections within in a year of the Dome Fire. These numbers were attributed to taxa whose adult stages have high rates of dispersal. Data collected from SCPN monitoring sites have not yet yielded signs of such a recovery following the LCF. Dipterans, which primarily accounted for the recovery in the Vieira study, have been found in extremely low numbers in samples collected since the LCF.

Differences in post-fire aquatic macroinvertebrate community recovery may be the result of greater hydrologic instability following the LCF in comparison to earlier fires. Large flow events carrying debris flows and depositing fine sediments continued to occur in 2013. These events can impede the recolonization of riparian vegetation and bury or move medium gravel and cobble substrates that are considered vital habitat (Cannon and Reneau 2000, Brasher et al. 2011). This lack of habitat and riparian vegetation undoubtedly affects community structure and diversity. Previous studies suggest that frequency and magnitude of hydrologic events may not diminish until vegetation recovery begins to occur in the watersheds (Veenhuis 2002).

The data collected by SCPN in the years following the LCF suggest that instream conditions are currently unfavorable for most aquatic macroinvertebrate taxa. Vieira et al. (2004) point out that studies from other watersheds around the country experiencing similar disturbance patterns indicate that pre-fire community structure may not be regained for 10 years or more following the fire. Given the scale and severity of the LCF, and the post-fire monitoring data collected thus far, it seems reasonable that recovery of the aquatic macroinvertebrate communities at Bandelier may take 10 years or more. The rate of recovery of the aquatic community will likely be dependent on how quickly hydrologic conditions stabilize and large flow events subside.

Condition and trend

The time to recovery (resilience) or to a new community state will depend on many factors, including future hydrologic conditions and the level of habitat degradation (Neary et al. 2005), and the availability of source populations (Fisher et al. 1982, Hall and Lombardozzi 2008, Vieira et al. 2011). For example, several short-term studies found rapid recovery of both abundance and diversity of riparian invertebrates, attributing this response in part to an influx of nutrients resulting from burned and downed material transported to stream habitats (Malinson and Baxter 2010). However, multiple studies also found that riparian systems within

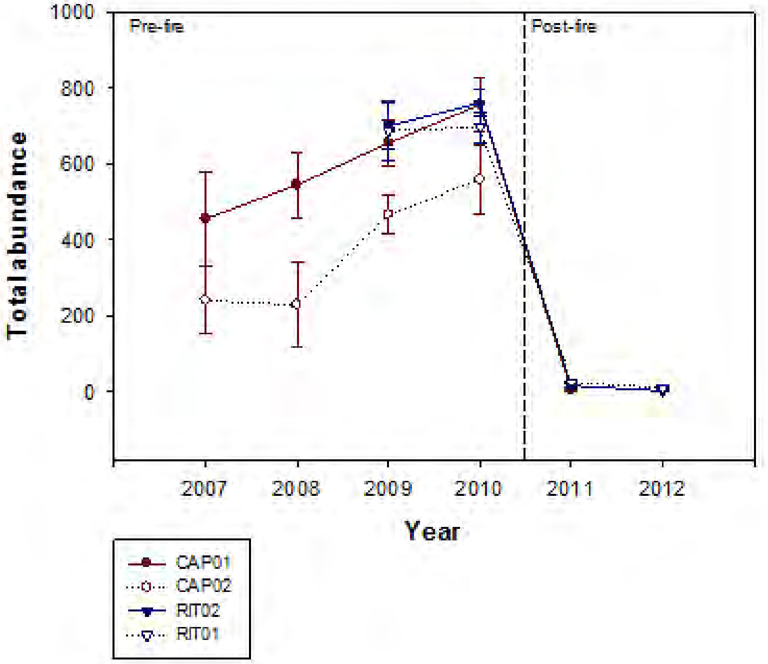

Figure 4-22. Site abundance. Average quantitative sample abundance of individuals collected from SCPN sites in Bandelier National Monument. No quantitative samples were collected from CAP01 in 2011, or CAP01 and CAP02 in 2012 due to a lack of appropriate habitat. Error bars represent +/- 1SE.

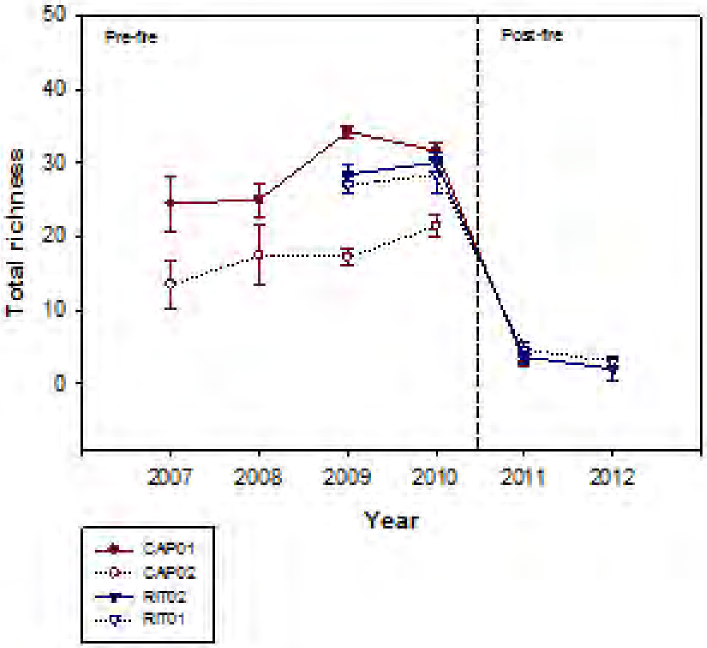

Figure 4-23. Taxa richness. Taxa richness of quantitative samples collected from SCPN sites in Bandelier National Monument. No qualitative samples were collected from CAP01 in 2011, or CAP01 and CAP02 in 2012 due to a lack of appropriate habitat. Error bars represent +/- 1 SE.

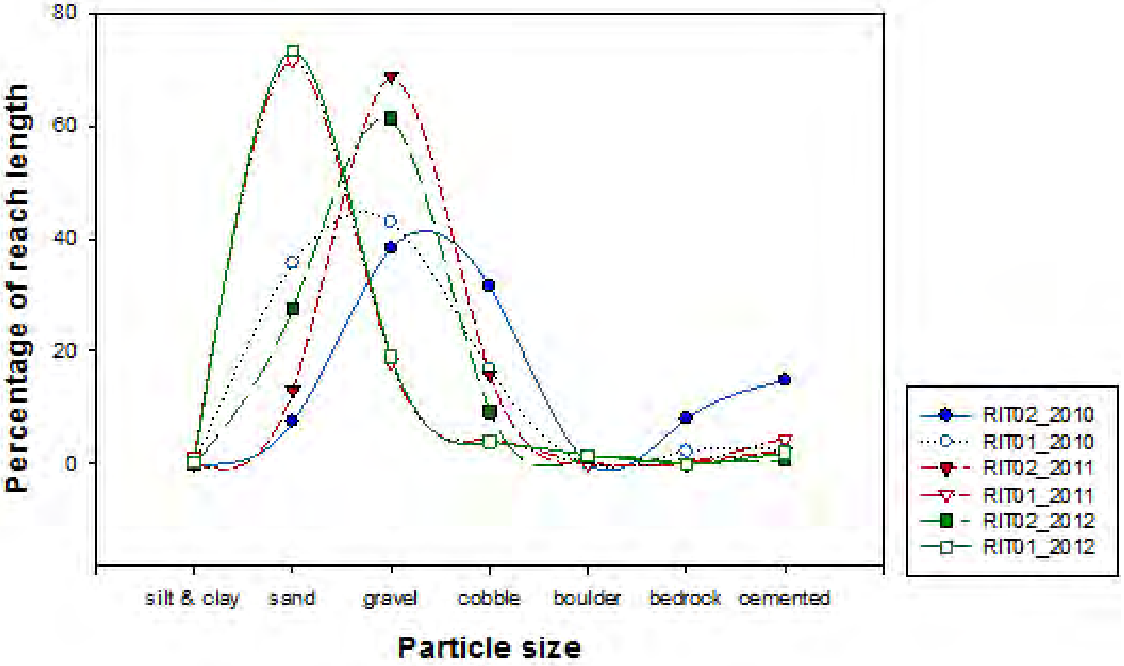

Figure 4-24. Physical habitat. Pre-Las Conchas Fire (2010) and Post- Las Conchas Fire (2011–2012) percentage of particle grain sizes found at RIT01 and RIT02 at the Rito de los Frijoles in Bandelier National Monument.

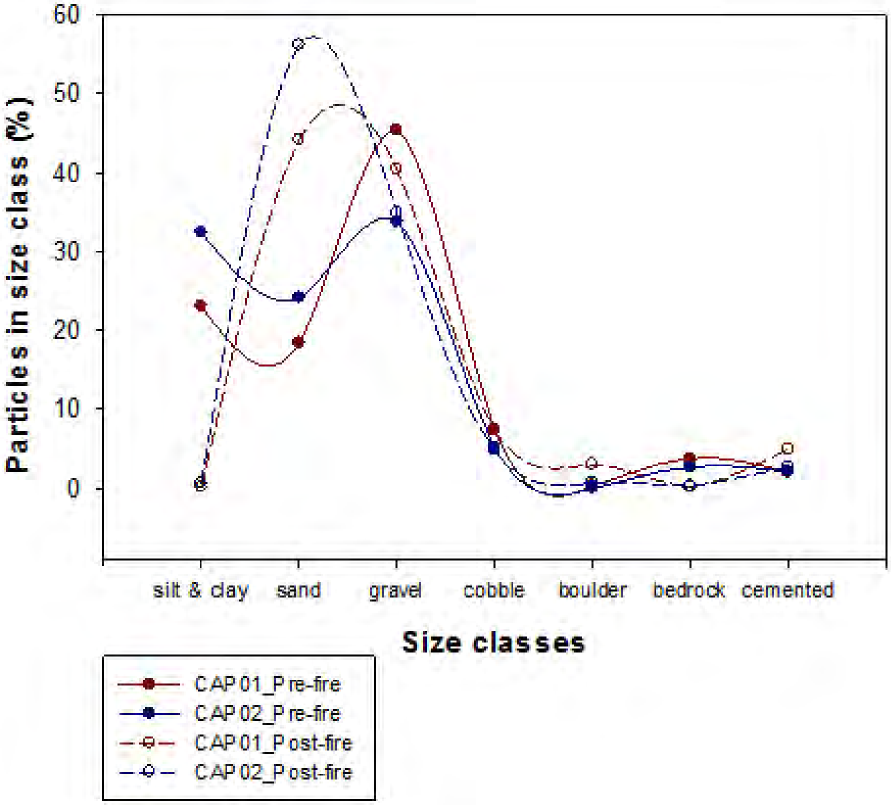

Figure 4-25. Physical habitat. Pre-Las Conchas Fire (2010) and Post- Las Conchas Fire (2011–2012) percentage of particle grain sizes found at CAP01 (red) and CAP02 (blue) at the Capulin Creek in Bandelier National Monument.

catchments that experienced high fire severity exhibited delayed or impaired ecosystem response (Minshall 2003). For example, the absolute abundance of invertebrates may increase long-term following disturbance (Malinson and Baxter 2010), though taxon diversity overall decreases and some functional groups are lost (Neary et al. 2005).

Many studies have found that generalists and tolerant species are relatively more common the first few years post-disturbance (Hall and Lombardozzi 2008, Oliver et al. 2012). Numerous studies have found that fine sediments, as those now predominant in both streams, provide poor quality habitat compared to pebble and cobble sediments, and that the pace at which habitat improves will be reflected in more rapid increases in both abundance and diversity (Vieira et al. 2004, Henne and Buckley 2005, Oliver et al. 2012).

Because of the ephemeral nature of stream invertebrates, (e.g. entire communities can be lost from a site in a matter of hours during catastrophic flooding (Neary et al. 2005), current conditions may have little or no relationship with past community structure and composition (Fisher et al. 1982). Succession as a valid concept for streams has been debated (Fisher et al. 1982), but clearly the recent fires—La Mesa (1978), Dome (1996), and Las Conchas (2011)—and subsequent floods at Bandelier NM have changed the macroinvertebrate communities in both streams substantially, at least in the near-term if not permanently.

4.11.7 Sources of expertise

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4.11.8 Literature cited

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Biological Integrity • Communities of Concern

4.12 Native Fish

4.12.1 Description

Fish habitats occur in montane streams at Bandelier NM. While park managers don't manage the Rio Grande, they are interested in habitat status of the river as it informs management considerations within the monument, (see section 4.09, 4.10 and 4.11) for related background information).

The New Mexico portion of the Rio Grande is thought to originally have hosted between 16 and 27 native species (Hatch 1985, Smith and Miller 1986, and Propst et al. 1987), three of which were endemic to the upper Rio Grande as far north as the Chama River—Rio Grande shiner (*Notropis jemezanus*), bluntnose shiner (*Notropis simus simus*), and Rio Grande silvery minnow (*Hybognathus amarus*). Noteworthy is the fact that the type locality for the Rio Grande shiner and the Rio Grande bluntnose shiner is the Rio Grande at Otowi Bridge (currently where New Mexico Highway 502 crosses the Rio Grande in Santa Fe County). Both species have been extirpated from the Rio Grande (Platania 1991). Today, there are no endemic fish species found in the Rio Grande in the reach along the Bandelier NM (Platania 1992). The silvery minnow is the only endemic fish species surviving in New Mexico, and is restricted to below Albuquerque and above Elephant Butte Reservoir (Bestgen and Platania 1991).

4.12.2 History of fish planting in Bandelier National Monument streams (Allen 1989)

New Mexico Department of Game and Fish records on file at Bandelier NM show that 36,750 brook trout (*Salvelinus fontinalis*), 82,740 rainbow trout (*Salmo gairdneri*), and 368,404 cutthroat trout (*Oncorhynchus clarkii virginalis*) of Yellowstone origin were planted in Frijoles Creek between 1912 and 1955. Alamo Creek received 13,000 brook trout, 4,000 rainbow trout, and 6,000 cutthroat trout between 1919 and 1931, while Capulin Creek received 10,500 brook trout, 17,000 rainbow trout, and 1,500 cutthroat trout between 1922 and 1931. Undocumented introductions of brown trout (*Salmo trutta*) have also occurred in these monument streams.

More recently, based on fish collecting (Platania 1992) at Bandelier NM on August 23, 1990 and August 13, 1991, brook, rainbow, and brown trout were found in Rito de los Frijoles.

In the spring of 1996, the Dome fire burnt 16,516 acres of Bandelier NM and the adjacent Dome Wilderness of the Santa Fe National Forest (Veenhuis 2002). Much of the fire was stand-replacing crown fire with debris flows which removed all fish from Capulin Creek. This was unprecedented in the watershed in the previous 330 years (Cannon and Reneau 2000),

On March 30, 2006, after watching the creek and macroinvertebrate populations slowly recover over ten years, a crew moved 100 Rio Grande cutthroat trout from Cañones Creek in the northern part of the Jemez Mountains on the Coyote Ranger District of the Santa Fe National Forest to Capulin Creek in Bandelier NM and the Santa Fe National Forest (Ferrell et al. 2006). Cutthroat trout from these waters had been tested for genetic purity and overall health and were determined to be the best donor population (personal communications between Stephen Fettig and Kirk Patten, 2006).

By 2009, Rio Grande cutthroat trout had reached a self-sustaining population, exceeding the population viability criteria of >500 adult fish or a total population of 2,500 individuals (Patten and Cook 2009). In 2011, post-Las Conchas Fire flooding in Capulin removed all fish from the creek (Stumpf and Monroe 2012).

Rio Grande cutthroat trout are one of 14 recognized subspecies of cutthroat trout native to western North America. Cutthroat trout are distinguished by the red-orange slashes in the gular folds below the jaw. Cutthroat trout once inhabited most cold-water streams throughout western North America. The Rio Grande cutthroat trout is considered the southernmost subspecies of cutthroat trout, and is differentiated from other cutthroat trout by the large spots that are concentrated towards the tail and colorful pink or orange hues on its belly and sides.

Most subspecies of cutthroat trout have suffered large declines within their native ranges. These declines have occurred primarily since the early 1900s due to exotic species introduction, habitat degradation, and over-harvesting (Duff 1996). Cutthroat trout thrive in clear mountain streams that provide clean spawning gravel, feeding and resting sites, and food in the form of aquatic and terrestrial invertebrates (Sublette et al. 1990). Ideal habitat conditions have been altered in many locations by human activities, including grazing, mining, logging, road building, and agriculture. Since the late 19th century, stocking of nonnative trout has been a common practice throughout the western states. Brook trout and brown trout out-compete the native cutthroats for prime habitat areas (Griffith 1988). Behnke (1992) describes a population of greenback cutthroat trout that was virtually replaced by brook trout in five years.

Rio Grande cutthroat trout populations currently occupy less than 10% of their original range (Stumpff and Cooper 1996). However, in October 2014, the U.S. Fish and Wildlife Service issued a 12-Month Finding on a Petition to List Rio Grande Cutthroat Trout as an Endangered or Threatened Species as Not Warranted (http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=E05D).

4.12.2 Reference conditions

It is possible, but not certain, that native cutthroat trout existed prehistorically in Frijoles Creek (Allen 1989). Historical information on native fish occurring within creeks internal to the park is lacking. Henderson and Harrington (1914) reported that fish were present in Rito de los Frijoles before 1900, and that fish were gone by 1914. Henderson and Harrington (1914) also referenced flooding and drying, as well as large volumes of debris coming into the creek, as possible reasons for fish vanishing from Rito de los Frijoles between 1900 and 1914.

4.12.3 Data and methods

Sampling was by electrofishing (Smith-Root Type VII, 12-volt backpack unit) and by small mesh seines and preserving (using 10% formalin) in the field for identification and analysis in the laboratory (Platania 1992). Specimens were subsequently transferred to 70% ethyl alcohol and catalogued into the Museum of Southwestern Biology's research collection of fish.

4.12.4 Condition and trend

Internal streams: condition good (non-native fish naturally removed), trend improving (habitat improving). As of the summer of 2014, the stream habitats had not yet stabilized to the point where there was sufficient macroinvertebrate presence to support native fish (See section 4.11 for more information).

4.12.5 Level of confidence

Knowledge of the historical condition of internal creeks is low; knowledge of current condition is high; understanding of whether Rio Grande cutthroat populations could survive long-term in monument creeks is moderately low.

4.12.6 Data gaps/Research needs/ Management recommendations

Creeks internal to the park lack historical baseline data.

Native fish of New Mexico montane streams are at high risk due to expected climate warming and drying in northern New Mexico, It is thought that the near perennial flowing waters of Rito de los Frijoles and Capulin Creek may be an important asset that can aid in regional conservation efforts. However, given the recent loss of large portions of the riparian overstory vegetation in Frijoles, Alamo, and Capulin Canyons, and projected climate warming, it is unclear whether any streams will be cold enough to support Rio Grande cutthroat populations into the future.

Viewing fish management in a regional context is especially important given the likelihood that large fires in the future will result in undesirable extirpations of native fish. Having well distributed populations is the best way of insuring the long-term survival of native fish. Bandelier NM can play an important role in these conservations efforts with the following steps:

1. Develop a fisheries management plan to support regional efforts to manage metapopulations of native fish species of conservation concern across land management agencies, with the goal of establishing multiple native fish species within the internal creeks of the park.
2. In support of this recommendation, park management should (a) work with SCPN to determine when there is sufficient food for native fish species, as network staff continue to monitor the recovery of aquatic macroinvertebrate populations, (b) work with the New Mexico Department of Game and Fish to conduct additional electrofishing surveys, prior to any potential transplants of native fish species, to establish a confidence level of essentially 100% that non-native fish will not interbreed with the transplanted native fish, (c) strictly follow NPS policies on fishing because cutthroat trout are 20 times easier to catch than brown trout (Behnke 1992), making them more susceptible to over harvesting, and (d) assess reintroduction of other non-trout native fish species (e.g., long-nose dace, Rio Grande chub, Rio Grande sucker dace), which may be more resilient to projected climate warming.

4.12.7 Sources of expertise

Stephen M. Fettig

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4.13 Landbirds

4.13.1 Description

Between 1967 and 2007, the average population of common birds across the United States declined steeply, falling 70 percent, from 17.6 million to 5.35 million individuals (Butcher and Niven 2007). These alarming findings document landbird declines which are persistent and based on 40 years of data across 550 bird species (Butcher and Niven 2007a). The analysis of DeSante and Kaschube (2009) further suggests that the observed declines are not something of the past, but an immediate and on-going cause of concern.

Furthermore, DeSante and Kaschube (2009) suggest that the declines are geographically extensive, based on data from 653 monitoring stations across North America. With 192 landbird species contributing to the observed average decrease of 1.77% in adult birds per year, this decline translates to a loss of more than 23% of the adult birds over the 15-year study. With overall landbird populations declining by nearly 2% per year, the prospect of losing another 23% of our birds in 15 years means the situation is critical. With more than 25% of the bird species for which we have reliable data showing significant and worrisome population trends, it is likely that further and irreversible declines of landbirds will occur within many national parks. This is especially worrisome because national parks and other public lands play a disproportionately large role in providing habitat for North American birds.

Partners in Flight (PIF) was founded in 1990 with broad public support as a result of widespread and alarming declines in North American birds (National Fish and Wildlife Foundation 1990). Birds stand out above other wildlife groups as perhaps the most highly valued and actively appreciated component of North America's biological diversity (Rich et al. 2004). In 2001 in the U.S. alone, 46 million birders spent $32 billion to observe, photograph or feed wildlife. The overall economic output of this activity was $85 billion (La Rouche 2003). More importantly, through consumption of pest insects, pollination of plants, dispersal of native seeds, and other services, birds contribute to the maintenance of ecosystems that also support human life.

In 2004, PIF published the North American Landbird Conservation Plan (Rich et al. 2004) that provided a continental synthesis of priorities and objectives to guide landbird conservation actions for 448 native landbirds that breed in the U.S. and Canada. The plan identified the priority species, research, monitoring, and management within Bird Conservation Region (BCR) 16, which includes Bandelier NM. The list of the priority species found at the park are listed in Table 4-5).

In 2009, the first State of the Birds report made it clear that birds are bellwethers of our natural and cultural health as a nation—they are indicators of the integrity of the environments that provide us with clean air and water, fertile soils, abundant wildlife, and the natural resources on which our economic development depends (U.S. Committee of the North American Bird Conservation Initiative [NABCI] 2009). At the same time the report made clear that in western forests, 38 obligate forest species collectively are showing a declining trend (NABCI 2009).

In 2010, the second State of the Birds report focused on climate change impacts. Climate change is producing new threats to birds and vegetation, which may be particularly severe in arctic and alpine regions. Birds are a vital element of every terrestrial habitat in North America. Conserving habitat for birds will therefore contribute to meeting the needs of other wildlife species and entire ecosystems (NABCI 2010).

The 2014 State of the Birds report identified western forest birds that need conservation efforts, as well as common birds in steep

Table 4-5. Status in Bandelier National Monument of bird species identified in the North American Landbird Conservation Plan (Rich et al. 2004) for Bird Conservation Region 16 and species that are found in the park.

Common name	Status at Bandelier National Monument
Dusky grouse	regular breeding species
Flammulated owl	breeding numbers have likely decreased greatly since 1980s
Spotted owl	likely no longer breeds at the park
Black swift	accidental
White-throated swift	characteristic species of the park's dry canyons
Calliope hummingbird	south-bound migrant
Rufous hummingbird	south-bound migrant
Lewis' woodpecker	mostly a very rare visitor to the park, usually during migration
Williamson's sapsucker	regular breeding species; likely to decline with the loss of snags and cavities for nesting
Red-naped sapsucker	regular breeding species; likely to decline with the loss of snags and cavities for nesting
Olive-sided flycatcher	rare breeding species
Willow flycatcher	very rare visitor to the park, usually during migration
Gray flycatcher	regular breeding species
Dusky flycatcher	regular breeding species
Pinyon jay	rare breeding species, may not be present every year, nomadic nature makes monitoring difficult
Clark's nutcracker	rare breeding species
Mountain bluebird	rare breeding species
Sage thrasher	accidental
Virginia's warbler	regular breeding species
Grace's warbler	regular breeding species
Green-tailed towhee	regular breeding species
Brewer's sparrow	migrant species
Cassin's finch	rare breeding species

Rich, T. D., C. J. Beardmore, H. Berlanga, P. J. Blancher, M. S. W. Bradstreet, G. S. Butcher, D. W. Demarest, E. H. Dunn, W. C. Hunter, E. E. Iñigo-Elias, J. A. Kennedy, A. M. Martell, A. O. Panjabi, D. N. Pashley, K. V. Rosenberg, C. M. Rustay, J. S. Wendt, T. C. Will. 2004. Partners in Flight North American Landbird Conservation Plan. Cornell Laboratory of Ornithology. Ithaca, NY.

decline (NABCI 2014). The report identifies Yellow-Watch-List species which are range restricted (small range and population), or are more widespread, but with troubling declines and high threats. For Bandelier NM these species include (see Table 4-9 for scientific names): band-tailed pigeon, flammulated owl, Mexican whip-poor-will, rufous hummingbird, Lewis's woodpecker, olive-sided flycatcher, pinyon jay, Virginia's warbler, Cassin's finch, and evening grosbeak. On the list of common birds in steep decline that regularly occur at Bandelier NM are common nighthawk, Wilson's warbler, and pine siskin.

4.13.1.1 Bird monitoring at Bandelier National Monument

The Southern Colorado Plateau Inventory and Monitoring Network (SCPN) completed bird community monitoring within piñon-juniper habitats in 2008, and within mixed conifer habitats in 2008, 2009, and 2012 (Holmes and Johnson 2012a, 2012b, 2014). The approach used variable circular plot (VCP) counts each sampling year, with 100 plots originally established in the mixed conifer forest. (See Appendix F for a discussion of the point count method for collecting avian data). In 2012, after the Las Conchas Fire, which burned approximately half of the mixed conifer bird sampling plots at high or moderate severity, the remaining habitat was assessed and sampling was conducted only in monitoring plots with no evidence of fire (unburned), or with low canopy burn severity—plots with little to no changes in vegetation structure.

A preliminary comparison of relative abundance between pre-fire (100) and post-fire unburned and low-severity burn (48) plots found that of the 9 most commonly detected species that increased after the fire, 7 were either long distance migrants (chipping sparrow, Hammond's flycatcher, warling vireo, western tanager, and western wood peewee) or species that move to lower elevations in the winter (hermit thrush and Williamson's sapsucker). This increase may have been due to the movement of individuals, upon arrival from their wintering grounds, from unsuitable burned territories to already occupied post-Las Conchas forest areas where foliage for nesting or tree sap was available. Just two of the species that increased postfire were resident species—the hairy woodpecker and pine siskin (Holmes and Johnson 2014).

Of the 9 most commonly detected species that decreased in mixed conifer habitat post-Las Conchas Fire, 6 were resident species (brown creeper, dark-eyed junco, mountain chickadee, northern flicker) or species that move to lower elevations and different habitats in winter (ruby crowned kinglet, yellow-rumped warbler). Three migrant species also decreased in abundance (Cordilleran flycatcher, house wren, violet-green swallow, Holmes and Johnson 2014). It is important to note, however, that these data are from only one year postfire and are likely not indicative of long-term patterns.

Within piñon-juniper habitats, bird banding data specific to Bandelier NM are consistent with broader trends pointing to large-scale declining bird populations. The data are from a juniper-woodland mesa-top sites south of the park's headquarters with methods following the national Monitoring Avian Productivity and Survivorship (MAPS) protocol (DeSante et al. 2007). The site was not treated in the restoration work of the first decade of the 2000s. The data show a decline in both the number and subspecies captured over six years. The decline is robust for scaling, based on effort measured in birds per net-hour (Table 4-6).

In 2010, the park began operating three MAPS stations following continent-wide protocols (DeSante et al. 2007). Data for 2010 through 2013 show low adult return rates (data not presented) and low reproduction rates (Table 4-7) (Fettig unpublished data).

4.13.1.2 Presidential directive to protect migratory birds

Executive Order 13186 of January 10, 2001, identified the responsibilities of federal agencies to protect migratory birds and required the NPS to sign a Memorandum of Understanding (MOU) with the U.S. Fish and Wildlife Service (USFWS) for the protection of migratory birds. Such an MOU was signed in 2010 and committed the NPS to evaluating migratory birds species identified in one or more of the following sources: (1) the USFWS periodic report Birds of Conservation Concern (www.fws.gov/migratorybirds); (2) federally-listed threatened and endangered bird species; (3) priority bird species documented in conservation plans completed under NABCI (Partners in Flight North American Landbird Conservation Plan, U.S. Shorebird Conservation Plan, North American Waterbird Conservation Plan, and North American Waterfowl Management Plan); and (4) listed as priority species or species of highest conservation concern in State Wildlife Action Plans. For Bandelier NM these references include Butcher et al. (2007), NMDGF (2006), NMPIF (2007), Norris et al. 2005), Rich et al. (2004), and USFWS (2008).

Table 4-8 lists bird species of concern which are regular breeding species with moderate or high abundances at Bandelier NM. In contrast, Table 4-9 lists bird species of concern which are accidental, rare, or migrants at the park. Because of the species abundances, investigations and management

Table 4-6. Bird capture rates by year at a Juniper-woodland mesa-top site at Bandelier National Monument (S. Fettig unpublished data). Note that the rate has been declining each year.

	2008	2009	2010	2011	2012	2013
Total birds banded	80	162	55	60	40	37
Total banding mornings	8	11	10	11	11	10
Total net hours (9–12 nets)	324.64	477.77	369.19	417.20	575.87	525.12
Birds banded per net hour	0.24	0.34	0.15	0.14	0.07	0.07
Total subspecies banded	20	24	19	16	18	15

Table 4-7. Number of hatch-year (HY) birds banded per 600 net-hours, for three sites (Alamo Drainage (ALDR), Frijoles East (FREA), and Frijoles West (FRWE)) at Bandelier National Monument from 2010 through 2013. Percent hatch-year birds is equal to hatch year birds banded divided by total birds banded.

Site/Year	2010	2011	2012	2013
Hatch-year birds banded				
ALDR	33	5	50	18
FREA	4	0	10	3
FRWE	24	0	58	9
Totals	**61**	**5**	**118**	**30**
Hatch-year birds/600 net hours				
ALDR	38.60	8.61	64.66	23.39
FREA	4.99	0.00	12.77	4.03
FRWE	27.68	0.00	76.18	11.36
Mean	**24.17**	**2.89**	**50.90**	**13.01**
All age birds banded				
ALDR	171	45	89	72
FREA	58	29	31	32
FRWE	132	48	129	249
Totals	**361**	**122**	**249**	**181**
Percent hatch-year birds				
ALDR	19.30	11.11	56.18	25.00
FREA	6.90	0.00	32.26	9.38
FRWE	18.18	0.00	44.96	11.69
Mean	**16.90**	**4.10**	**47.39**	**16.57**

actions directed at species in Table 4-9 are less likely to contribute to landscape-level conservation efforts than actions directed at species in Table 4-8.

4.13.2 Reference conditions

Populations of selected landbirds in prominent monument habitats maintain viable population levels.

4.13.3 Data and methods

Johnson and Wauer (1996) documented changes in bird communities using a line-transect method that mapped bird observations along one-mile routes in the footprint of the 1977 La Mesa Fire. Additional data for five of the transects extend into the 1990s (Wauer unpublished). Point count data with variable circular plot (VCP) distance sam-

Table 4-8. Birds identified as species of concern by existing published conservation plans, USFWS (2008), Rich et al. (2004), Butcher et al. (2007), Norris et al. 2005), NMDGF (2006), NMPIF (2007), that are regular breeding species with moderate or high abundances at Bandelier National Monument.

Standard English name	Scientific name	Habitats
White-throated swift	*(Aeronautes saxatalis)*	Canyon and cliffs
Broad-tailed hummingbird	*(Selasphorus platycercus)*	Higher elevation shrublands
Williamson's sapsucker	*(Sphyrapicus thyroideus)*	Higher elevation forest with snags
Hammond's flycatcher	*(Empidonax hammondii)*	Closed canopy forests
Dusky flycatcher	*(Empidonax oberholseri)*	Open canopy forests and shrublands
Plumbeous vireo	*(Vireo plumbeus)*	Forests across the park
Western scrub-jay	*(Aphelocoma californica)*	Open canopy forests and shrublands
Juniper titmouse	*(Baeolophus ridgwayi)*	Juniper woodlands
Western bluebird	*(Sialia mexicana)*	Open canopy forests and shrublands
Virginia's warbler	*(Oreothlypis virginiae)*	Shrublands
Grace's warbler	*(Setophaga graciae)*	Ponderosa forests

pling for some piñon-juniper habitats are available from 2008 (Holmes and Johnson 2012a). Additional point count data with VCP are available for mixed conifer forest for 2008, 2009, and 2012 with limited comparison of post Las Conchas Fire changes (Holmes and Johnson 2012a, 2012b; 2014). Park-wide data for landbirds are from Fettig (2004), who utilized Breeding Bird Atlas (BBA) sampling methods (Laughlin 1981, Kingery 1998, Fettig et al. 2002). Briefly, BBA observations are conducted within a 5 km x 5 km area, called a block. Observers develop a comprehensive species list by spending approximately 20-40 hours actively surveying a block during 5–10 visits throughout the breeding season. For each observation of a potential breeding bird, the species, breeding behavior, date, and cover type are recorded onto standard forms. MAPS constant-effort-bird banding data (DeSante et al. 2007) exist for six years (2008–2013) at one site within piñon-juniper woodlands and at three sites for five years (2010–2014).

4.13.4 Condition and trend

Reliable trend data are not yet available but reproductive rate information pooled across all species from MAPS stations suggests low reproduction in both piñon-juniper habitats and mixed conifer habitats.

4.13.5 Level of confidence

The level of confidence for the condition

Table 4-9. Birds, identified as species of concern by existing published conservation plans, USFWS (2008), Rich et al. (2004), Butcher et al. (2007), Norris et al. (2005), NMDGF (2006), NMPIF (2007), that are accidental, rare, migrant, etc. at Bandelier NM, and their status at the park.

Standard English name	Scientific name	Status at Bandelier NM
Dusky grouse	*(Dendragapus obscurus)*	Rare
Turkey vulture	*(Cathartes aura)*	Common, breeding is very difficult to confirm
Bald eagle	*(Haliaeetus leucocephalus)*	Rare, winter only
Northern harrier	*(Circus cyaneus)*	Accidental
Northern goshawk	*(Accipiter gentilis)*	Accidental
Swainson's hawk	*(Buteo swainsoni)*	Accidental
Zone-tailed hawk	*(Buteo albonotatus)*	Rare, probably no longer a breeding species
Ferruginous hawk	*(Buteo regalis)*	Accidental
Golden eagle	*(Aquila chrysaetos)*	Accidental
Peregrine falcon	*(Falco peregrinus)*	Rare
Prairie falcon	*(Falco mexicanus)*	Accidental
Western sandpiper	*(Calidris mauri)*	Accidental
Stilt sandpiper	*(Calidris himantopus)*	Accidental
Wilson's phalarope	*(Phalaropus tricolor)*	Migrant
Band-tailed pigeon	*(Patagioenas fasciata)*	Rare, breeding is very difficult to confirm
Yellow-billed cuckoo	*(Coccyzus americanus)*	Never has been documented at Bandelier
Flammulated owl	*(Psiloscops flammeolus)*	Rare
Northern pygmy-owl	*(Glaucidium gnoma)*	Rare
[Mexican] spotted owl	*(Strix occidentalis)*	Extripated
Black swift	*(Cypseloides niger)*	Accidental
Calliope hummingbird	*(Selasphorus calliope)*	Migrant, Common
Rufous hummingbird	*(Selasphorus rufus)*	Migrant, Common
Olive-sided flycatcher	*(Contopus cooperi)*	Rare breeding species
Willow flycatcher	*(Empidonax traillii extimus)*	Migrant, no breeding records
Gray vireo	*(Vireo vicinior)*	Never has been documented at Bandelier
Pinyon jay	*(Gymnorhinus cyanocephalus)*	Rare, may breed at Bandelier in some years
Sage thrasher	*(Oreoscoptes montanus)*	Migrant
Yellow warbler	*(Setophaga petechia)*	Migrant
Brewer’s sparrow	*(Spizella breweri)*	Migrant
Black-chinned sparrow	*(Spizella atrogularis)*	Accidental
Black-throated sparrow	*(Amphispiza bilineata)*	Accidental
Lincoln's sparrow	*(Melospiza lincolnii)*	Migrant
Lazuli bunting	*(Passerina amoena)*	Accidental
Bullock's oriole	*(Icterus bullockii)*	Rare breeding species
Cassin's finch	*(Haemorhous cassinii)*	Uncommon

and trend of landbirds at Bandelier NM is low, due to the lack of rigorous analysis of existing MAPS data. Large-scale vegetation changes associated with the Las Conchas Fire will affect population levels over coming decades. Definitive information will require targeted field work to answer management questions.

4.13.6 Data gaps/Research needs/ Management recommendations

The lack of local information on Grace's warblers is the most significant data gap. Breeding Bird Survey (BBS) data show sharp annual declines of 5.5% in New Mexico for Grace's warblers (a relatively easy to detect species) and an annual decline of 2.3% throughout western states. An analysis by Butcher and Niven (2007) suggests the species has declined an average of 1.93% per year over 40 years (1965–2005) in the U.S., a 54% decrease. Thus, the decline is persistent and appears to be range-wide in the U.S. SCPN bird community monitoring and MAPS stations at the monument should continue with integrated analyses linked to weather to provide information to management on likely causes of population changes. Unpublished data by Ro Wauer should be computerized and analyzed to provide additional historical information on bird numbers. Repeat breeding bird atlas work would provide park-wide spatial data with relative abundance information as well as specific information on level of breeding and links to habitats.

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4.14 Mexican Spotted Owl

4.14.1 Description

4.14.1.1 Ecology

The Mexican spotted owl (MSO; *Strix occidentalis lucida*) occupies primarily mixed conifer forests dominated by Douglas-fir, true fir and pine, or pine with an oak or other broad-leafed understory component. Their favored habitat is usually steep, forested canyons, often with rocky cliffs, perennial water and riparian vegetation (Gutierrez et al. 1995, U.S. Fish and Wildlife Service [USFWS] 1995, Willey 1993). The species prefers old growth forests but also occupies uneven-aged stands with complex vertical structure (Ganey and Balda 1989a).

Adult MSOs are highly faithful to breeding sites, with territory sizes in Arizona and New Mexico ranging from 7–11 square kilometers (Kroel 1991). In mixed conifer communities, breeding MSOs select sites with more mature Douglas-fir and pine canopy closure of 75% or more, and the presence of an oak understory (Seamans and Gutierrez 1995, Peery et al. 1999). In pine-oak habitat, territories may be located on more moderate slopes with 60% or greater canopy cover, and are less concentrated in canyon bottoms (Ganey et al. 2000). In steep-walled canyons, owls may also nest in cliff crevices (Gutierrez et al. 1995). In winter, lower-elevation piñon-juniper habitat may be used.

MSOs may forage and roost in a wider range of habitats than are used for nesting, but generally prefer sites with high canopy closure, live-tree basal area, available snags, and fallen logs (Ganey and Balda 1989b). Fledglings may depend on oak thickets for roosting and to avoid predator detection (Gutierrez et al. 1995). The majority of dispersing birds are juveniles (Arsenault et al. 1997), and nearly all isolated patches of mixed conifer or ponderosa pine in New Mexico and the southwest can be reached by dispersing owls (USFWS 1995). Dispersers have also established home ranges in piñon-juniper habitat (Ganey et al. 1998).

In Bandelier NM, Mexican spotted owls nest in canyons having a cool micro-environment and vegetation dominated by cool-moist species typical of mixed conifer forests. The majority of MSO habitat is located within the Bandelier Wilderness. Nesting-roosting zones cover approximately 2,800 hectares (6,900 acres or 20% of the park), have areas with steep slopes (>40%) in mixed conifer habitat types, and have been consistently monitored prior to any planned management action.

The prey base of the species in New Mexico is strongly affected by climatic variation. A recent study shows annual survival and reproduction of MSOs is positively correlated with previous year's precipitation (Seamans et al. 2002).

4.14.1.2 Status

MSOs were first reported at Bandelier NM in 1910. Management-related surveys began in 1985. As part of the park's 1998 Fire Management Plan, nine nesting-roosting zones (NRZs) and suitable nesting areas (SNAs) were created and mapped (Johnson 1998). Through formal consultation, the U.S. Fish and Wildlife Service approved the use of such designations. The park continues to manage all potential MSO habitat based on the 1998 NRZ and SNA definitions. Analysis of observations from 1977 to 1997 within the park and surrounding areas suggested that fire benefits MSOs, provided it occurs at intensities low enough to maintain essential characteristics of nesting habitat. Thus, in the 1998 Fire Management Plan, the park proposed treating NRZs with low intensity fire in an effort to reduce the threat of crown fires. Since then, 170 hectares (430 acres) of NRZ habitat have been treated with prescribed fire.

4.14.2 Reference conditions

The maximum number of occupied sites within Bandelier NM known prior to 2002 was three.

4.14.3 Data and methods

Mexican spotted owls are typically located by visiting potential habitat and looking for fresh signs (feathers and droppings). Nocturnal calling surveys are also used to elicit calls from owls, at least three times each season, if owls are not found in other ways.

4.14.4 Condition and trend

The last breeding MSOs in the monument were observed in 2002. No MSOs were detected by standard survey methods from 2003–2013. In 2011, the Las Conchas Fire destroyed most potential MSO breeding habitat in the park.

4.14.5 Level of confidence

The level of confidence for the condition and trend of MSO in Bandelier NM is high. The physical structure provided by trees in cool canyon settings is now gone because of the Las Conchas Fire of 2011. Our confidence is high that the owls are currently not breeding in the park.

4.14.6 Data gaps/Research needs/ Management recommendations

Recommendations to consider are (1) maintain large stands of mature and old-growth ponderosa pine and mixed conifer forest, particularly in areas with steep slopes; (2) protect and restrict activity in 243-hectare (600-acre) areas around known nest sites, or around roost sites if nest sites are unknown (U.S. Fish and Wildlife Service 1995, Peery et al. 1999) and (3) restore riparian habitats and restrict human use of appropriate riparian areas.

4.14.7 Sources of expertise

Stephen Fettig

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4.15 Jemez Mountain Salamander

4.15.1 Description

The Jemez Mountain (JM) salamander (*Plethodon neomexicanus*) is a federally endangered species restricted to the Jemez Mountains of northern New Mexico in Los Alamos, Rio Arriba, and Sandoval Counties, and around the rim of the collapsed Valles Caldera, with some occurrences within the caldera. The majority of salamander habitat is located on federally-managed lands, including the Santa Fe National Forest, Bandelier NM, Valles Caldera National Preserve, and Los Alamos National Laboratory, with some habitat located on tribal land and private lands (New Mexico Endemic Salamander Team [NMEST] 2000).

Relatively warm and wet environmental conditions suitable for salamander aboveground activity are likely influenced by snow infiltration and rain from summer thunderstorms (U.S. Fish and Wildlife Service [USFWS] 2012). When active above ground, the species is usually found under decaying logs, rocks, bark, moss mats, or inside decaying logs or stumps. The salamander's subterranean habitat appears to be deep, fractured, subterranean rock in areas with high soil moisture (NMEST 2000). Compacting soil makes the habitats unusable for JM salamanders. Thus, parking areas, hardened walking areas, and trails make habitat unusable. JM salamanders are normally found in mixed conifer communities, including areas dominated by Douglas-fir (*Pseudotsuga menziesii*), blue spruce (*Picea pungens*), Engelmann spruce (*Picea engelmannii*), ponderosa pine (*Pinus ponderosa*), and white fir (*Abies concolor*) with occasional aspen (*Populus tremuloides*), Rocky Mountain maple (*Acer glabrum*), New Mexico locust (*Robinia neomexicana*), ocean spray (*Holodiscus* sp.), and various shrubby oaks (*Quercus* sp.) (Degenhardt et al. 1996, Hathcock 2008, Whitford 1976, Williams 1973).

The JM salamander is strictly terrestrial, does not possess lungs, and does not use standing surface water for any life stage. Respiration occurs through the skin, which requires a moist microclimate for gas exchange. The absorption and conservation of substrate moisture is probably the most important factor in the ecology of this terrestrial salamander, as it is in other strictly terrestrial salamander species (Heatwole and Lim 1961). The species is rarely observed aboveground, and can only been found on the surface when environmental conditions are moist and temperatures warm (typically July through September; but occasional salamander observations have been made in May, June, and October (USFWS 2012). Snow infiltration and summer monsoon-generated thunderstorms provide needed environmental moisture (USFWS 2012).

The overall range-wide population size of the JM salamander is unknown because surveys tend to cover small areas (approximately 256 ft by 256 ft (200 m by 200 m). Like most plethodontid salamanders, monitoring population size or trends of the Jemez Mountains salamander is inherently difficult because of the natural variation associated with the species' behavior (Hyde and Simons 2001). For example, when the species is underground, individuals cannot be detected. The available data cannot be used to estimate population size or trends in the range-wide abundance of the salamander. Even though we are not able to estimate population trends, the number of surveys resulting in no salamander detections is increasing.

4.15.2 Reference conditions

As explained above, determining population sizes for JM salamanders is problematic because most of their lives are spent below ground. Instead, the amount of available habitat can be used as a proxy for population status. Critical habitat for an endangered species is defined by the USFWS as the specific areas within the geographical area occupied by the species which (a) are essential to the conservation of the species and (b) may require special management considerations or protection. For the JM salamander, the

Primary Constituent Elements (PCE; areas of potential habitat a species is known to use; USFWS 2013) include:

- elevations from 6,988 to 11,254 feet (2,130 to 3,430 meters)
- moderate to high tree canopy cover with greater than 50 % canopy closure that provides shade and maintains moisture and high relative humidity at the ground surface, and that
    - consists of the following tree species alone or in any combination: Douglas-fir; blue spruce; Engelmann spruce; white fir; limber pine; ponderosa pine; and aspen
    - has an understory containing New Mexico locust or oak
- ground surface in forest areas with structural features, such as rocks, bark, or moss mats that provide the species with food and cover
- underground habitat in forest or meadow areas containing interstitial spaces provided by
    - igneous rock with fractures or loose rocky soils
    - rotted tree root channels
    - burrows of rodents or large invertebrates

4.15.3 Data and methods

A complete overview of the available survey data and protocols for the Jemez Mountain salamander is reported in the USFWS 12-month finding (USFWS 2010). In summary, there are approximately 20 years of salamander survey data that provide detection information at specific survey sites for given points in time. However, like most plethodontid salamanders, monitoring population size or trends of the JM salamander is problematic due to the life history and behavior of the species (Hyde and Simons 2001). For example, when the species is underground, individuals cannot be detected, therefore, the probability of detecting a salamander is highly variable and dependent upon the environmental and biological parameters that drive above- and below-ground activities (Hyde and Simons 2001). Consequently population size estimates using existing data cannot be made accurately, and the available data cannot be used to estimate population size or trends in the range-wide abundance of the salamander.

Despite an inability to quantify population size or trends for the salamander, we can use information provided by qualitative data to make potential inferences. For example the number of surveys completed where no salamanders are detected is increasing. Disease has been implicated in the decline of many amphibians, and it is an unknown, but credible threat to the JM salamander. Cummer et al. (2005) reported chytridiomycete fungus (*Batrachochytrium dendrobatidis*) in an individual *P. neomexicanus* from Sierra Toledo on the Valles Caldera in Sandoval County. Since then at least one other individual has tested positive for *B. dendrobatidis*. Based on these inferences, the status of salamanders is likely variable across their range, and persistence may be at risk in some locations. For example, in places where the salamander was once considered abundant or common, it is now rarely detected or not detected at all (unpublished data, New Mexico Heritage Program). There also appears to be an increase in the number of areas with the above Primary Constituent Elements (PCE) where salamanders once were present, but have not been observed during more recent surveys (New Mexico Heritage Program 2010 unpublished data).

There are, however, two localities in the Valles Caldera National Preserve (VCNP) where JM salamanders are relatively abundant compared to other locations—Redondo Border located in the central portion of the VCNP, and on a slope in the northeast portion of the VCNP. Still, the number of individuals found at these two localities is at present far below the number noted in historical surveys (e.g. 659 individuals were captured in a single year in 1970 and 394 of those individuals were captured in a single month (Williams 1976). Currently, there is no known location where the number of salamanders observed is similar to that observed in 1970.

4.15.4 Condition and trend

The overall range-wide population size of the JM salamander is unknown, however, all qualitative information and observations suggest declining trends. Salamander populations are known to be susceptible to fire-related effects, including decreased forest humidity, desiccation of habitat, loss of microhabitat (such as downed logs and litter), erosion, and filling in (by runoff) of subterranean habitat utilized by salamanders (USFWS 2012). Post-fire management actions that have negatively impacted JM salamanders and their habitat include the mulching and reseeding of occupied habitat with soil-binding, non-native grasses.

4.15.5 Level of confidence

We are highly confident that JMS habitat is declining and that the overall population is likely following a similar trend. There are many aspects of the species' biology that are unknown, which limits the development of management recommendations.

4.15.6 Data gaps/Research needs/ Management recommendations

A great deal of JM salamander biology is unknown. Specific information on all subterranean aspects of the species' biology remains uninvestigated and would be valuable for developing monitoring protocols or recovery strategies. Currently there are no reliable monitoring methods for the JM salamander that do not disrupt or destroy their aboveground (under logs, rocks, moss mats) or subterranean habitats. Developing and implementing a monitoring protocol that can be used consistently across land management units would be valuable. If such a protocol was also robust with climate change forecasts, forest restoration treatments, and wildfire impacts, management options for promoting salamander resiliency would likely be greatly expanded. As summers become warmer and drier, and winter precipitation becomes more variable, it will be critical to maintain high percent cover of forest canopy in habitats most valuable to the salamander. High percent canopy cover provides shade and maintains moisture and relative humidity at the ground surface. Thus, significant fire management effort should be devoted to protecting forest canopy in areas of the park with north facing slopes and fractured-rock habitats or other rocky habitats that may contain small underground air pockets for salamander movement and overwintering. Surface habitats with bark, or moss mats, in addition to fractured-rock habitat, may be especially important for providing this species with food and cover.

4.15.7 Sources of expertise

Stephen Fettig

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Biological Integrity • Species of Management Concern - Apex Predator

4.16 Mountain Lion

4.16.1 Description

Mountain lions (*Puma concolor*; synonym: cougar) are ambush predators, unlike wolves which are short-distance pursuit predators. This hunting style conforms well to mountain lions being essentially solitary, with individual adults deliberately avoiding one another, except during the brief period of courtship (Nowak 1991, p.1205). These behaviors permit mountain lions to thrive in many habitats—at one time, mountain lions had the most extensive natural distribution of any mammal in the new world, except humans. However, mountain lions have been extirpated from much of eastern North America (Dixon 1982). By the early twentieth century, mountain lions appeared to have been eliminated everywhere in the United States north of Mexico except the mountainous part of the West and southern Texas and in Florida (Nowak 1991, p1206).

Their territorial nature means that mountain lions can be well-spaced across the landscape. When prey densities are low, mountain lion populations can survive at low densities. Individual territory sizes depend on terrain, vegetation, abundance of prey, gender, and whether a female has kittens or not. While mountain lions are relatively large in size, the species is not always the apex predator in its range. Mountain lions are known to yield to other predators, such as jaguar (*Panthera onca*), gray wolf (*Canis lupus*), black bear (*Ursus americanus*), and grizzly bear (*Ursus arctos*), a behavior that comports well with its solitary nature.

Solitary mountain lions typically are able to ambush a variety of ungulate prey including deer (*Odocoileus* sp., the most common food item for mountain lions in North America), elk (*Cervus canadensis*), moose (*Alces alces*), and bighorn sheep (*Ovis canadensis*). Estimates of deer kill frequency vary from about one every three days for a female with large kittens to one every 16 days for a lone adult (Lindzey 1987). Mountain lions are reclusive, usually avoiding people, with fatal attacks on humans (*Homo sapiens*) being rare. Attacks have trended upward in recent years as more people build homes and spend time in mountain lion habitats (Beier 1991, Chester 2006). New Mexico reported an attack in 2008, the first there since 1974 (New Mexico Department of Game and Fish [NMDGF] 2008).

4.16.2 Reference conditions

Mountain lions are present in the monument at unknown densities.

4.16.3 Data and methods

Approximately 64% of New Mexico's 315,194 km^2 (121,589 mi2) is considered mountain lion habitat (NMDGF 2010). NMDGF classifies mountain lion habitat as fair, moderate, good, and excellent based on the density of mountain lions. Excellent habitat has an adult cougar density of 3.0–4.0/100 km^2; good habitat has an adult cougar density of 1.2–1.7/100 km^2; moderate habitat has an adult cougar density of 0.6–0.9/100km^2; fair habitat has an adult cougar density of 0.4–0.5/100 km^2.

4.16.4 Condition and trend

New Mexico Game Management Unit 6, which includes Bandelier NM and includes all of Los Alamos County, parts of northern Sandoval County, northwestern Santa Fe county, and southern Rio Arriba County is roughly delineated by a circle that intersects the cities of Bernalillo, Cuba, Española, and Santa Fe (NMDGF 2011). Unit 6 contains approximately, 6,659 km2 of mountain lion habitat with an estimated population of 156–209 animals in 2011. Thus, Unit 6 is considered excellent mountain lion habitat (NMDGF 2011). If Bandelier NM has a mountain lion population in proportion to its area and is typical of unit 6, we would expect 4-6 cougars in the park. Given that mountain lion territories may cross park boundaries from neighboring agencies, the park may occasionally see additional animals.

4.16.5 Level of confidence

This assessment is based on currently available information (NMDGF 2011) and the level of confidence is high.

4.16.6 Data gaps/Research needs/ Management recommendations

Communication with the public should focus on the importance of predators for long-term healthy ecosystem function (Estes et al. 2011) and on the importance of predators in limiting or reducing grazing, as a climate change mitigation strategy (Welch 2005).

Managers should be aware that NMDGF may seek to protect bighorn sheep introduced west of the park in August 2013 by reducing mountain lion populations in some areas. NPS management policies do not support such reductions within the Bandelier NM. Park managers should undertake monitoring to establish population densities and be vigilant to possible reductions in mountain lion use of the park, if reductions are conducted on adjacent public lands.

4.16.6.1 Management considerations in the face of climate change

With wolves gone from the landscape, it is essential to maintain mountain lion populations as an essential ecosystem element. Any decrease in mountain lion populations is likely to exacerbate ungulate herbivory (Ripple and Beschta 2006; Estes et al. 2011) and a predator-prey imbalance (Berger and Wehausen 1991) and lead to a less stable situation in the face of increased climate variability (Welch 2005 p. 87; Martin and Maron 2012).

4.16.7 Sources of expertise

Stephen Fettig

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Biological Integrity • Species of Management Concern - Overabundant Species

4.17 Elk and Deer

4.17.1 Description

Elk (*Cervus canadensis*) are the largest ungulates in New Mexico. Elk were long believed to be a subspecies of the European red deer (*Cervus elaphus*), but evidence from a study of the mitochondrial DNA indicates that the two are distinct species (Ludt et al. 2004). The Merriam's Elk (*Cervus canadensis merriami*) is the extinct subspecies of elk once found in the arid lands of the southwestern United States, including southern New Mexico. Rocky Mountain elk (*Cervus canadensis nelsoni*) were native in the Jemez Mountains until extirpated due to overhunting by around 1900 (Bailey 1931).

Although elk were present prior to 1900, there is no evidence to suggest that elk were plentiful in the region during prehistoric or historic times (Allen 1996). In 1948 and again in 1964–1965, elk were reintroduced to the region and their population grew exponentially, reaching around 7000 individuals by 1991. Data from New Mexico Department of Game and Fish suggest that by the late 1980s or early 1990s, the Jemez Mountains population of reintroduced elk had grown to levels greater than were known since at least 1200 A.D. (Allen 1996).

During the 1990s, grazing and browsing by elk and livestock became a pressing issue of public concern in the Jemez Mountains. An interagency and citizen group called "Seeking Common Ground" struggled with this issue. Current information suggests that undesirable impacts on vegetation are visible in widely distant places across the Jemez Mountains of North Central New Mexico, including in Bandelier NM (Krantz 2001, Fettig 2001, Fettig 2002a, Fettig 2003a, and Fettig 2003b).

The Rocky Mountain National Park and Estes Park environments could also be used as reference areas. This park and adjacent mountain community are physically disrupted by the migration of the elk, ranging in size from calves to full-grown 700-pound adults. Several butterfly and plant species are harmed by over-browsing by elk, especially the aspen groves that the elk herd of perhaps 3,000 animals decimates in its search for food. The elk population, while taxing the common food resources, also adversely affects native species that share the same food supply, such as beaver.

Excerpt from Allen (1996).

Faunal remains in local archeological sites and historic information suggest that elk populations in the Jemez Mountains were low from ca. 1200 A.D. through ca. 1900 A.D., when they were extirpated from this region. Elk were reintroduced to the Jemez country in 1948 and 1964–1965, and their population apparently grew exponentially, reaching 1000 animals in the 1970s and about 7000 by 1991. Elk populations in Bandelier NM and adjoining areas increased rapidly after the 1977 La Mesa Fire. Winter use by elk in the La Mesa Fire area, occurring in the monument grew from about 100 animals in 1978 to around 1500 elk by 1992. The dramatic increase in the monument's elk herd (an annual growth rate of 21.3% and a 3.6 year population doubling time) was due in part to the creation of about 6000 hectares of grassy winter range in and around the park by the La Mesa Fire. Some of this local population increase reflects concentration of elk into this favorable wintering habitat from surrounding portions of the Jemez Mountains. Existing data are inadequate to determine whether elk populations are still growing rapidly in the Jemez Mountains. While annual aerial surveys since 1990 reveal no clear population trend, a variety of observations demonstrate increasing elk use of lower elevation areas. Negative resource impacts from today's high elk populations are beginning to be widely noted across the Jemez Mountains, especially in high-use portions of the Bandelier NM area. Affected resources range from plant communities to soils and even archeological sites. Given the large uncertainties associated with the current data on elk populations, care should be taken to avoid further population increases until the resource impacts of this new phenomenon (large numbers of elk) can be identified, desirable population levels identified (based to a significant degree upon ecological information and resource carrying capacities, as well as social considerations), and appropriate cooperative management strategies implemented.

4.17.2 Reference conditions

Prior to Euro-American arrival, elk and deer populations were low due to Native American hunting and occurrence of apex carnivores on the landscape.

4.17.3 Data and methods

In 2002 and 2005, field workers investigated the influences of browsing by elk on aspen sprouts and shrubs species at randomly selected sites from a universe predominantly located within Bandelier NM's Cerro Grande area, using the Alaska Pack extension to ArcView 3.3 (Alaska Region 2005). The selection universe overlapped slightly onto the neighboring Santa Fe National Forest and Valles Caldera National Preserve. The crew visited additional randomly selected sites outside of Bandelier NM in order to evaluate any potential similarities or differences for the effects of browsing vegetation adjacent to the park. These sites were specifically located on Mesa del Rito and Sawyer Meadow.

In 2006, a study took place in which a crew of 3–4, spaced out approximately 10-75 m apart to cover the target area and identify refuges, visually surveyed the high elevations (areas of approximately 2000 m or more, or approximately 8,800 or more ft). Refuges are defined as places where woody shrubs and aspen saplings are being protected from ungulate browse. These refuges or safe zones (Turner et al. 2003) consisted primarily of fallen trees, rocks, and other natural obstacles which inhibit ungulates from reaching the young trees.

In addition to aspen (*Populus tremuloides*) sprouts, the crew searched for shrubs species within each plot to evaluate browsing by elk. These species included: wild raspberry (*Rubus strigosus*), chokecherry (*Prunus virginiana*), red elderberry (*Sambucus microbotrys*), serviceberry (*Amelanchier utahensis*), mountain maple (*Acer glabrum*), dogwood (*Cornus stolonifera*), thimbleberry (*Rubus parviflorus*), ocean spray (*Holodiscus dumosus*), mountain mahogany (*Cerocarpus montanus*), cliffbush (*Jamesia americana*), ninebark (*Physocarpus monogynus*), barberry (*Berberis fendleri*), Gambel oak (*Quercus gambelii*), currant (*Ribes* sp.), wild rose (*Rosa* sp.), whortleberry (*Vaccinium myrtillus*), mock orange (*Philadelphus microphyllus*), mountain lover (*Paxistima nyrsinites*), New Mexico locust (*Robinia neomexicana*), buckbrush (*Ceanothus fendleri*), snowberry (*Synphoricarpos oreophilus*), and shrubby cinquefoil (*Potentilla fruticosa*). Additional information is available (Krantz 2001, Fettig 2001, Fettig 2002a, Fettig 2003a, and Fettig 2003b).

4.17.4 Condition and trend

Since 2000, fieldwork at Bandelier NM has examined the influence of browsing by elk on aspen sprouts and other woody shrubs within the park's mixed conifer forests (Fettig 2002b, Fettig 2003a, and Fettig 2003b). Results have shown widespread browsing of regenerating aspen sprouts. In 2002, fieldwork on randomly selected burned plots documented a clear decline in the density of regenerating sprouts within multiple aspen clones covering a total area of 8.3 ha (20 ac). The sprout density has declined from an estimated 6,000–8,000 stems/ha (2400-3200 stems/ac) to fewer than 300 stems/ha (120 stems/ac) with the mean stem height less than 0.5 m (1.6 ft) and all sprouts browsed. Such a low sprout density with 100% browsing during the growing season, and no live canopy-height trees means that clone survival is questionable. An additional 10.1 ha (25 ac) of regenerating aspen have similar stem heights but densities are over 6,000 stems/ha (2430 stems/ac). These higher stem densities suggest that near-term clone survival is not in question, even with no sprouts able to reach tree size due to browsing. From these observations we expect that some aspen clones have a relatively high chance of declining in spatial extent over the next few years. In other places the prognosis for clone survival is good, even while aspen sprouts are not able to grow into trees.

4.17.5 Level of confidence

Our level of confidence is high for this analysis—the data are spatially robust and supported by photographs which can be re-examined.

4.17.6 Data gaps/Research needs/ Management recommendations

Additional observations of shrubs not producing seed or fruits in burned and browsed settings leads to a management question, "What is the spatial distribution of woody shrubs able to reproduce under the current level of elk browsing?"

Managers should stay informed on Chronic Wasting Disease (CWD). CWD affects the brain tissue of infected elk and is similar in symptoms to bovine spongiform encephalopathy (BSE), commonly known as mad-cow disease (MCD). There is yet no evidence to conclude that elk CWD is transmutable to humans, and research concerning CWD effect on the ecosystem is underway. As of 2010, environmental and Chronic Wasting Disease problems in Estes Park, Colorado and on a greater scale throughout the Western U.S. and North America have local, state, and federal policy-makers searching for solutions.

4.17.6.1 Management considerations in the face of climate change

At their current densities within Bandelier NM and the Valles Caldera National Preserve, elk are likely to inhibit some vegetation responses to climate change by reducing tree establishment and shrub growth. Although the interaction effects of ungulate browsing with vegetation responses to climate change are not well understood, the removal of vegetative biomass by elk may increase soil temperatures and decrease soil moisture levels (Beschta et al. 2012; also see Appendix G, ecological impacts of grazing by livestock), thus perhaps exacerbating the impacts of warmer summers on stressed vegetation and related animal communities.

4.17.7 Sources of expertise

Craig Allen, Stephen Fettig

4.17.8 Literature cited

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4.18 American Pika

4.18.1 Description

4.18.1.1 Ecology

American pikas (*Ochotona princeps*) are small lagomorphs (rabbit family) that are distributed across most of the high altitude regions of western North America. There are currently five recognized subspecies of *O. princeps*. *O. p. saxatilis*, the Goat Peak pika, is endemic to the Jemez Mountains, and is marginally found at (or closely adjoining) Bandelier NM (Hafner and Smith 2010). A different species, the collared pika, *O. collaris*, ranges from southeast Alaska to northwestern Canada and is not sympatric with *O. princeps*.

Pikas inhabit talus fields and felsenmeers (fields of broken surface rocks) located near low-stature grasses and forbs. Such sites are located near or above tree-line in alpine habitats. However, the Goat Peak pika is found in felsenmeers well below alpine zones and often with trees adjacent to the felsenmeers. Pikas do not dig burrows, but rely on existing spaces between and under rocks for homes. However, they can enlarge their homes by digging. Pikas require rocky habitat near forage plants, and have specific temperature requirements. They are generally restricted to cool, moist habitats at high elevations. However, in the northern portion of their range they may be found near sea level.

Found primarily above 1,600 m, pikas do not hibernate and spend much of the relatively short, high-altitude summer foraging and stockpiling vegetation for winter use in ‘haypiles’ (Conner 1983, Dearing 1996). Plant types selected for haypiles can be distinctly different from plants immediately consumed—summer foods appear to be chosen in relation to flowering times and nutritional value (Smith 1974, Huntly et al. 1986), while plants collected for storage are often high in phenols which can function as preservatives (Dearing 1996). Overwinter survival of pikas has been shown to be strongly dependent on the amount and quality of food collected and stored for the winter (Dearing 1997, Morrison et al. 2009).

Pikas have an unusually high resting body temperature. This adaptation allows them to survive cold temperatures at high elevations, but also requires that they avoid behaviors and/or environments that could lead to overheating (Smith 1974). Consequently both seasonal and diurnal behaviors are related to temperature. At lower elevation (warmer) sites, collecting and storing food for winter (called haying) begins earlier in the season and lasts later into the fall, (thus avoiding the hottest periods of the summer), and daily activity during warmer mid-day hours is reduced compared to at higher elevations (Smith 1974, Moyer-Horner 2010).

4.18.1.2 Threats and status

While pikas do occupy low elevation and anthropogenic sites, such as mine tailing piles and rock quarries (Beever et al. 2008, Simpson 2009, Rodhouse et al. 2010, Manning and Hagar 2011), it is largely accepted that the availability of appropriate habitat strongly determines pika distribution (Hafner 1994). The contraction of the pika’s range with general warming during the Holocene left isolated populations at high elevations separated by uninhabitable areas (Grayson 2005, Galbreath et al. 2009). Though pikas are relatively poor dispersers across non-suitable areas (Smith 1974, Aho et al. 1998, Jeffress et al. 2013), until recently the dynamics of source-sink habitats and metapopulations apparently sustained pikas across their range (Hafner 1994, Molainen et al. 1998, Kreuzer and Huntly 2003).

Interacting, multiple effects of climate change (e.g. declining precipitation, higher temperatures, reduced snowfall), now appear to be reducing the number of sites that support pikas in some places (Smith 1974, Molainen et al. 1998, Kreuzer and Huntly 2003, Beever et al. 2003, Morrison and Hik 2007, Beever et al. 2011, Erb et al. 2011, Stewart and Wright 2012, Jeffress et al. 2013).

Pika distribution is shrinking as a result, (Beever et al. 2003, Wolf et al. 2007, Calkins et al. 2012; though see Millar and Westfall 2010a, Millar and Westfall 2010b, and Wolf 2010 for discussion).

Pikas are found across the high mountain ranges of southern Colorado and Utah and northern New Mexico in appropriate talus habitat (Hafner 1994). In the Jemez Mountains they occur in most rocky areas above about 8,800 ft, including areas of the Valles Caldera National Preserve and Bandelier NM (Valles Caldera National Preserve [VCNP] 2013, Allen 1989, Hathcock et al. 2011). The Southern Colorado Plateau Network (SCPN) mammal inventory noted pika sign in 2003 and observed individual pikas in 2004 at high elevations on Cerro Grande (Bogan et al. 2007).

A petition to list American pikas as endangered or threatened within the Endangered Species Act was submitted to the U.S. Fish and Wildlife Service (USFWS) in 2007 by the Center for Biological Diversity (CBD; Wolf et al. 2007). CBD described rising temperatures resulting from global climate change as the primary threat to pika persistence. Increased summer temperatures as a result of climate change may have the potential to adversely affect some lower and mid-elevation pika populations of *Ochotona princeps princeps, O. p. fenisex, O. p. schisticeps* and *O. p. saxatilis* in the foreseeable future; however, this does not equate to a significant portion of the suitable habitat for any of the five subspecies or the species collectively. American pika can tolerate a wider range of temperatures and precipitation than previously thought (Millar and Westfall 2009, p. 17). The American pika has demonstrated flexibility in its behavior, such as using cooler habitat below the surface to escape hotter summer daytime temperatures, and physiology that can allow it to adapt to increasing temperature (Smith 2009, p. 4). Cooler temperatures below the talus surface can provide favorable thermal conditions for pika survival below relatively warm surface environments. In 2010 USFWS determined that listing at any level was not warranted, and that, based on existing climate and other models applied in their analysis (specifically Ray et al. 2010), there was not a threat to the species or the any subspecies now or in the foreseeable future (USFWS 2010).

As far as is known there are no available population estimates from any pika populations within the Jemez Mountains. Likewise presence/absence monitoring has not been conducted for sites that have previously been identified as occupied.

4.18.2 Reference conditions

Pikas are present at unknown population levels within Bandelier NM.

4.18.3 Data and methods

As far as is known there have been sporadic observations that indicate the presence of pika in the park in the past.

4.18.4 Condition and trend

New Mexico's Comprehensive Wildlife Conservation Strategy (CWCS) lists *O. p. saxatilis* as a subspecies of greatest conservation need, as well as vulnerable and state sensitive (New Mexico Department of Fish and Game [NMDGF] 2006), and Beever and Smith (2008) have assigned *O. p. saxatalis* a status of vulnerable. Largely as a response to climate change threats, NPS has initiated pika monitoring and research as a unique program ('Pikas in Peril') within the NPS Inventory and Monitoring Program (Garret et al. 2011).

Persistence of *O. p saxatilis* populations within New Mexico and across the southern Rocky Mountains appears to be good (Colorado Division of Wildlife [CDOW] 2009, Utah Division of Wildlife [UDW] 2009), though density and trend data are not available for populations in New Mexico (NMDGF 2009, U.S. Forest Service [USFS] 2009). Rock and grassland habitats where this species breeds at Bandelier NM are at low risk in the foreseeable future, even in the face of regional drying and increased fire frequencies. Furthermore, any behavioral adaptions to increased summer temperature, such as reducing activity during the warmest part of summer days, may be compensated for by increased length of the growing season or frost-free days. However, based on other status reviews (Beever and Smith 2008; NatureServe 2009), further monitoring may be wise for *O. p. saxatilis* in the Jemez Mountains of New Mexico to obtain information on the current status of this population of the subspecies.

4.18.5 Level of confidence

The level of confidence for this analysis is high.

4.18.6 Data gaps/Research needs/ Management recommendations

During SCPN's vital signs development, the monitoring of high elevation or "boreal" mammals was considered, but not selected. No demographic rate information or population size information is available for pikas at Bandelier NM. Currently there is no information that would suggest local populations of pikas are at risk; however studies in other areas have shown that populations can disappear without physical changes to habitat. Monitoring of the Goat Peak pika (*O. p. saxatilis*) at Bandelier NM could provide helpful information to regional land managers.

4.18.7 Sources of expertise

Stephen Fettig

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Biological Integrity • Species of Management Interest

Note: In contrast to Species of Management Concern, Species of Management Interest are not directly managed by monument managers, but have been of recurring interest by internal or external conservation partners in recent decades. They are reviewed here to summarize early or more recent discussions.

4.19 River Otters

River otters occur in the Rio Grande, but are not managed by Bandelier staff. They do not inhabit the internal streams of Bandelier NM and were not observed in the most recent mammal survey of the monument (Bogan et al. 2007).

4.19.1 Description

4.19.1.1 Biology

The river otter (*Lontra canadensis*) is a relatively large member of the weasel family (Mustelidae), with a combined body and tail length of between 90 and 140 cm (3–4.5 ft). River otters are much larger than American mink (*Neovison vison*), the only other aquatic carnivore in Colorado, and much smaller than beaver (*Castor Canadensis*; Rodentiae) with whom they are often sympatric. An adult river otter weighs between 5–14 kg (11–31 lb). Males have been known to range up to 50 miles. Females typically stay within three to 10 miles of their den.

River otters are well-adapted to freshwater habitats and cold climates—webbed feet with non-retractable claws facilitate swimming, capturing live prey and living in dens, a long, tapered tail propels the animal in the water, and two layers of fur provide critical insulation. All otters are carnivorous. River otters are primarily fish-eaters, but will also consume a variety of other small prey, such as crayfish, birds and small mammals.

Otters occasionally construct dens, but more commonly inhabit existing cavities in areas adjacent to calm waters, particularly beaver dens. Otters forage mostly during twilight and in the early morning hours and rest in their dens during the day. They appear to be adept at conserving energy, often sliding along snowbanks and mudflats in a fashion that appears playful but is most likely simply an efficient means of travel. Otters do not hibernate and are active throughout the winter, when they feed and travel under the ice. Breeding occurs throughout the winter beginning in December, and small litters of 1-3 pups are born between February and April.

4.19.1.2 Distribution

River otters historically ranged across North America, including Canada and all U.S. states (except Hawaii). Otter populations were decimated by the cumulative effects of fur trapping, habitat loss (stream and river impoundments) and water pollution, and were extirpated from Colorado and most of the Rocky Mountain and plains states by the early 20th century (Boyle 2006).

4.19.1.3 Status

Otters are considered a Sensitive Species by the USFS throughout Region 2 (includes Colorado). River otters have no other federal status, though NPS considers them a species of concern. The principle threats to river otters in Colorado are habitat destruction, particularly water development efforts that result in stream flow and channel morphology alteration, water pollution, and human settlement and recreational use along rivers and lakes (Boyle 2006).

According to the International Union of Conservation of Nature (IUCN, 2009) populations of otters currently occur in 1) the Rio San Pedro of Chihuahua, a tributary of the Rio Conchos entering the Rio Grande from the southeast, 2) the upper Rio Grande near the Colorado/New Mexico border, and 3) the middle Pecos River in southeastern New Mexico, which enters the Rio Grande from the west. These observations are corroborated by multiple observations by competent observers, and in the case of the first population, otter photos and sign. These populations are centered in areas with macrohabitats characterized by a river flowing through deep canyons or ancillary wetlands. Considerably more detailed survey work is needed to determine the full extent of the distribution of otters in the Rio Grande drainage. A genetic study is critically needed to determine the true taxonomic affiliation of these recently discovered populations. A moratorium on translocations should be put in place for the Rio Grande to conserve the native populations already existing.

4.19.1.4 River otter re-introduction efforts in New Mexico

Excerpt from D. Williams. Restoration begins in Rio Grande Basin in New Mexico Wildlife Vol. 53, No. 4, Winter 2008-2009.

"On Oct. 14, the magic of six federal and state agencies, one Indian Pueblo, several conservation organizations and many individuals came together with New Mexico's first release of wild river otters. It was the first time anyone had seen a wild otter in New Mexico waters since 1953, when one was caught in a Gila River beaver trap"….

River otters are highly social, playful, semi-aquatic members of the weasel family. They are believed to have once inhabited the Gila, upper and middle Rio Grande, Mora, San Juan and Canadian river systems. Early settlers occasionally mentioned otters in their journals, but references were infrequent, leading biologists to speculate that otter populations were small. In 2004, scat and tracks discovered in Navajo Lake indicated a few otters have migrated south from Colorado, one of many states that have reintroduced otters in the past 30 years.

Jim Stuart, the New Mexico Department of Game and Fish mammalogist, said river otters have thrived almost everywhere they have been reintroduced (personal communication).

"Putting otters in the Rio Grande Basin will be a good learning experience while we consider putting more in the Gila, and possibly other rivers," Stuart said. "Right now we don't know how many otters the Rio Grande system can support. The Upper Rio Grande was chosen as the first otter release site because of its reliable water flows, good food sources and relatively undisturbed habitat with little human activity. Adjacent lands are controlled by the U.S. Bureau of Land Management and Taos Pueblo, both supporters of otter restoration. A feasibility study conducted by the New Mexico River Otters Working Group and the Department of Game and Fish identified six suitable release sites: the Upper Rio Grande, the Rio Grande in White Rock Canyon, the Rio Chama from El Vado Dam to Abiquiu Lake, the Upper Gila River, Lower Gila River and the Lower San Francisco River. In 2006, the State Game Commission approved the study and directed the Department to initiate efforts to restore otters in the Upper Rio Grande and the Gila River."

"If future releases around the state are successful, limited trapping of otters may be possible," Stuart said. River otters currently are not on federal or state endangered or threatened species lists. "

"In New Mexico, otters are considered protected furbearers with no take allowed," he said. "It's quite possible that at a future date that we could see a harvest, but we'll have to wait and see."

He said historic records indicate otters were not numerous enough in New Mexico to provide trappers a good income.

In 1931, mammalogist Vernon Bailey, chief naturalist for the U.S. Bureau of Biological Survey, noted in his book, "Mammals of New Mexico," (1931) that otters were too uncommon to be of any marketing importance.

Whether New Mexico's river otter population ever reaches the numbers required to support limited hunting and trapping will depend upon the initial success of the New Mexico Friends of River Otters. The group is one of the state's largest, most diverse and dedicated organizations formed to support a single species. Members include Amigos Bravos, Taos Pueblo, Earth Friends Wild Species Fund, New Mexico Wildlife Federation, Center for Biological Diversity, Defenders of Wildlife, Four Corners Institute, Rio

Grande Chapter of the Sierra Club, Upper Gila Watershed Alliance, and the U.S. Bureau of Land Management. Melissa Savage, a member of the New Mexico Friends of River Otters, said the group is keeping its goals modest for now. "Our target is 60 otters—30 in the Rio Grande and 30 in the Gila," she said. "We think that's what it will take to really get them started." '

4.19.2 Reference conditions

River otters occur intermittently in the Rio Grande today and forage in Bandelier NM.

Due to the lack of sufficiently large fish populations as a food source. river otters most likely would not persist in the internal streams of the monument.

4.19.3 Data and methods

See Bogan et al. 2007

4.19.4 Condition and trend

River otters are making a remarkable comeback in many parts of their original range in the U.S.

4.19.5 Level of confidence

Level of confidence for this analysis is high.

4.19.6 Data gaps/Research needs/ Management recommendations

No recommendations at this time.

4.19.7 Sources of expertise

Stephen Fettig

4.19.8 Literature cited

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4.20 Lynx

4.20.1 Description

Canada lynx (*Lynx canadensis*) feed predominantly on snowshoe hares (*Lepus americanus*). They will also eat rodents and birds, and sometimes hunt larger prey, such as deer. Like many cats, they will eat carrion when it is available. They hunt both by ambush and by actively seeking out prey, varying their tactics depending on the available prey species. The lack of any documented snowshoe hare observations in the Jemez Mountains means that the presence of any sustained population of Canada lynx would be highly unlikely.

Until one radio collared animal from Colorado wondered onto the Valles Caldera, Canada lynx had never been documented in the Jemez Mountains (Bailey 1931).

4.20.2 Reference conditions

There are no faunal records indicating that lynx occurred in the Bandelier NM landscape during historic or prehispanic times.

4.20.3 Data and methods

n/a

4.20.4 Condition and trend

Canada lynx are not present at Bandelier NM and there are no verified observations for the park.

4.20.5 Level of confidence

The level of confidence for this analysis of the condition and trend of Canada lynx at Bandelier NM is very high.

4.20.6 Data gaps/Research needs/ Management recommendations

No management action is recommended.

4.20.7 Sources of expertise

Stephen Fettig

4.20.8 Literature cited

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4.21 Bighorn Sheep

4.21.1 Description

Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) occupy open, mountainous habitat, either above timberline, or in open canyons and slopes below forests and woodlands. The species is characterized by low reproductive rates, long life spans, and populations that can be bottom-up regulated by nutritional constraints (i.e., populations are limited by food availability) or top-down limited by predation (i.e., populations are limited primarily by mountain lion predation).

In the past 20 years, the state of New Mexico has made two attempts to start an interagency planning process for reintroduction of bighorn sheep into White Rock Canyon. The New Mexico Department of Game and Fish (NMDGF) assessed the post-Las Conchas Fire landscape in the vicinity of Cochiti Canyon and determined that post-fire vegetation conditions were favorable for reintroduction of bighorn sheep. An introduction location was selected that was reasonably distant from suburban sites and entirely within the boundary of the Santa Fe National Forest (SFNF), thus avoiding the interagency and domestic animal interaction issues that have characterized previous reintroduction efforts. Acting under a permit issued by SFNF, the department released fifty Rocky Mountain bighorn sheep into Cochiti Canyon in August 2014, captured from a high-elevation Sangre de Cristo population. Introduced animals represented a range of ages, both male and female. NMDGF will monitor this new population closely in coming years using their standard protocols.

Rocky Mountain bighorn sheep are thought to have never been widespread in New Mexico, with historical evidence for just four populations in Wheeler Peak, Pecos Wilderness, White Rock Canyon, and Manzano/Los Pinos Mountains (Bailey 1931, Leopold 1933). However, pre-Hispanic era populations are hypothesized to have been more widespread than recent historical accounting. In 2004, there were an estimated total of 950 Rocky Mountain bighorn sheep among three alpine and three low-elevation populations. In 2004 all three alpine populations were estimated to be > 100, and each of the three low-elevation populations were estimated to be < 100. Populations with more than 100 bighorn sheep have an increased probability of long-term persistence (Berger 1990) in New Mexico.

Two of three alpine populations are currently at carrying capacity and require trapping and removal to keep herds below carrying capacity (Hacker et al. 2000). Declines in the three low-elevation populations in New Mexico are associated with habitat loss resulting from fire suppression and livestock grazing (Huddleston-Lorton 2000), increased predation from mountain lions (*Puma concolor*) (Ahlm 2001, Huddleston-Lorton 2000, Rominger and Dunn 2000), train-strike kills (NMDGF files), and disease (Ahlm 2001). Other factors influencing bighorn sheep populations include: recreation use, roads, fences, exotic ungulates, poor range conditions, feral dogs, and illegal harvest.

Bighorn sheep have been extirpated from Bandelier NM. The species is known through scientific and archeological evidence to have existed in the park in historic and prehistoric times. Based on one skull in the Smithsonian Museum, the population of bighorn sheep in White Rock Canyon at the time of collection may have been intermediate in physical form between rocky mountain and desert bighorn sheep.

4.21.2 Reference conditions

Bighorn sheep were rare and concentrated on rocky steep slopes within White Rock Canyon.

4.21.3 Data and methods

See Ahlm (2001).

4.21.4 Condition and trend

Rocky Mountain sheep were extirpated from Bandelier NM around 1890. The NMGF reintroduced them into Cochiti Canyon in August 2014, and continues to monitor the population's status..

4.21.5 Level of confidence

The level of confidence for the condition and trend of Rocky Mountain bighorn sheep in the monument is very high.

4.21.6 Data gaps/Research needs/ Management recommendations

Based on discussions during the 1990s, there are many non-biological considerations to contemplate in any consideration of putting bighorn sheep back into White Rock Canyon.

NMDGF will have the primary responsibility for preventing nose-to-nose contact between wild sheep and domestic sheep and goats, unregulated hunting, and predation management. Bandelier NM may need to establish MOUs with American Indian pueblos to clarify what access tribes would have to animal parts (if any) for religious use.

Recommendations

1. The state of New Mexico needs to take a leading role in any establishment effort because they are in control of all source populations of bighorn sheep in New Mexico.

2. In the 1990s, potential impacts from bighorn sheep browsing were identified as an issue. This topic needs to be examined again in the light of fire-related habitat changes and expected warmer and dryer summers in the future.

4.21.7 Sources of Expertise

Stephen Fettig

4.21.8 Literature cited

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4.22 Natural Sounds

4.22.1 Description

Soundscapes are generally defined as the total amount of ambient noise in an area, measured in terms of frequency and amplitude (decibels; Ambrose and Burson 2004). Because national parks are often (perhaps wistfully) considered 'islands' of quiet (Lynch et al. 2011, Miller 2008), NPS has been working for several decades to establish baseline conditions and develop measuring and monitoring methods for soundscapes in national parks (Miller et al. 2008). Similar to the topic of light pollution, however, soundscapes have primarily been addressed in relation to visitor experiences (Rogers and Sovick 2001, Sovick 2001, Miller 2008, Lynch et al. 2011) with relatively little attention given to ecological and landscape-scale impacts of anthropogenic noise (Barber et al. 2011, Francis and Barber 2013).

'Soundscape ecology' is an emerging field within landscape ecology that attempts to connect ecological processes with human and natural sounds at landscape scales (Dumyahm and Pijanowski 2011b, Pijanowski et al. 2011, Traux and Barrett 2011). When evaluated ecologically, the impacts of anthropogenic sounds are most commonly considered in terms of effects on wildlife. (Marine studies are abundant, but herein only terrestrial systems will be discussed.) For example, studies have demonstrated the negative impacts of human-generated noise on birds (Dooling and Popper 2007, Slabbekoorn and Ripmeester 2008, Francis et al. 2009, Francis et al. 2011a), bats (Schaub et al. 2008), rodents (Shier et al. 2012), frogs (Barber et al. 2010, Bee and Swanson 2007), and invertebrates (Morley et al. 2014). Human noise is perhaps most detrimental to prey species because it can both mimic predator sounds and mask them (Landon et al. 2003, Chan et al. 2010, Brown et al. 2012).

The presence of roads and energy development facilities appear to have the greatest impacts on wildlife (as opposed to inputs such as overflights; Barber et al. 2011, Newman et al. 2014). Road noise can alter animal behavior, movement patterns, ability to find prey, and breeding processes (Reijnen and Foppen 2006, Bee and Swanson 2007, Barber et al. 2011, Siemers and Schaub 2011), while noises associated with energy development are often incessant, causing increased levels of chronic stress for animals near these sites (Bayne et al. 2008, Barber et al. 2009, Francis et al. 2011b, Blickley et al. 2012, Souther et al. 2014). Some species are able to adapt to long-term additions of noise in their environment but others are not (Barber et al. 2010). Research further suggests that due to the complex nature of sounds and the fact that impacts at individual and population scales translate up to ecosystem and process levels, ambient and pulsed noise levels perceived by wildlife should be addressed at multiple spatial and temporal scales (Slabbekoorn and Halfwerk 2009, Barber et al. 2011, Dumyahn and Pijanowski 2011a and b).

4.22.2 Reference Conditions

NPS policies direct that the absence of anthropogenic noise be the baseline against which impacts are measured, though there are places where human-generated noise is appropriate for the given purpose of a park (e.g. battle re-enactments at Gettysburg; Lynch et al. 2011). However, because the primary cultural resource protection mission of Bandelier NM is to preserve a period of human occupation wherein human noise was minimal, aside from occasional performances or demonstrations, natural quiet should be considered the reference condition for visitor experiences. Given the relative absence of information on the effects of noise on wildlife, measurements of anything over natural sounds should be considered ecologically undesirable.

4.22.3 Data and methods

Methods for measuring and monitoring sound are well-established; however, these are objective measures only, without a context of relevance to wildlife impacts (Miller et al. 2008, Villanueva-Rivera et al. 2011). In terms of human perception, a relatively high level of information on the local soundscape has been collected at the park, with methods described in Newman et al. (2014) and White (2014). Data collection methods included on- and off-site instruments as well as visitor surveys. As far as is known there have been no studies investigating the impacts of anthropogenic noise on wildlife at Bandelier NM.

4.22.4 Condition and trend

Bandelier NM is a relatively very quiet place, but the most common sources of noise at the park are aircraft overflights and vehicles (White (2014). Nothing is known regarding the ecological impacts of noise at any location in the park nor, the trend in noise levels across any time period.

4.22.5 Level of onfidence

the level of confidence for this analysis is low to moderate.

4.22.6 Data gaps/Research needs/ Management ecommendations

Data collected by White (2014) in 2012 could serve as a baseline against which to measure future noise levels, though again there is no information on wildlife impacts from conditions measured in 2012.

4.22.7 Sources of Expertise

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4.23 Air Quality

4.23.1 Background

The Clean Air ActT (CAA) requires that the air quality of national parks and '…other areas of special national or regional natural, recreational, scenic or historic value be preserved and protected' (42 U.S.C. §7470(2)). The CAA further designates 48 NPS units, including Bandelier NM, as "Class 1" areas, where special protections are provided for air quality and scenic views. Consequently, managers of Class 1 areas are required by the CAA as well as the Title 54 (54 USC 100101(a) et seq.), commonly known as the NPS Organic Act, and Management Policies to protect these values. The greatest existing threats to maintaining good air quality at Bandelier NM include regional and local sources of air pollution, such as power plants, oil and gas development, industrial facilities, agriculture, urban developments, and wild fire (NPS-ARD 2014).

4.23.2 Reference conditions

The NPS Air Resources Division (ARD) focuses on four indicators to evaluate air quality conditions and trends in national parks: visibility, ozone, nitrogen and sulfur deposition, and mercury and toxics deposition. Benchmarks have been established using regulatory standards and best available scientific evidence.

4.23.2.1 Visibility

Visibility is a human-centered concept that can also be valuable for assessing ecological impacts because it indirectly measures pollutant particles in the atmosphere from both natural and human-caused sources. The CAA established a national goal to return visibility to "natural conditions" in Class I areas, which are those conditions estimated to exist in a given area in the absence of human-caused visibility impairment. Visibility is often measured using deciview (dv) metric measures, and ARD recommends that mid-range visibility days should be < 2 dv above natural conditions (NPS-ARD 2014).

4.23.2.2 Ozone

Ozone is formed when nitrogen oxides from vehicles, power plants, and other combustion sources combine with volatile organic compounds from gasoline, solvents, and vegetation in the presence of sunlight. The National Ambient Air Quality Standard (NAAQS) for ozone is set by the U.S. Environmental Protection Agency (EPA), and is based on human health effects. The NPS ARD recommends a benchmark for good ozone condition of 60 parts per billion (ppb) or less, which is 80% of the human health-based NAAQS (NPS-ARD 2013).

In addition to being a concern for the health of park staff and visitors, long-term exposures to ground-level ozone can cause injury to ozone-sensitive plants . The W126 metric is a biologically relevant measure that focuses on plant response to ozone exposure and is a better predictor of vegetation response than the metric used for the human health standard. The W126 preferentially weighs the higher ozone concentrations most likely to affect plants and sums all of the weighted concentrations during daylight hours. The highest 3-month period that occurs during the growing season is reported in "parts per million-hours" (ppm-hrs). The NPS ARD recommends a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation.

4.23.2.3 Sulfur and Nitrogen

Sulfur (S) and nitrogen (N) compounds in the air can deposit into ecosystems and cause acidification, excess fertilization (eutrophication), and changes in soil and water chemistry (Allen and Geiser 2011).

Nitrogen, together with sulfur, can also acidify surface waters and soils, which can result in changes in community structure, biodiversity, reproduction, and decomposition (Bobbink et al. 2010; De Schrijver et al. 2011). NPS ARD recommends a nitrogen or sulfur wet deposition of less than 1 kilogram per hectare per year (kg/ha/yr) as condition to protect sensitive ecosystems (Ellis et al. 2013; NPS-ARD 2013).

4.23.2.4 Mercury and toxics

Mercury and other toxic pollutants (e.g., pesticides, dioxins, PCBs) accumulate in the food chain and can affect both wildlife and human health (Eagles-Smith et al. 2014). High mercury concentrations in birds, mammals, and fish can result in reduced foraging efficiency, survival, and reproductive success. Other toxic air contaminants of concern include pesticides (e.g., DDT), industrial by-products like PCBs, and emerging chemicals, such as flame retardants for fabrics (PBDEs). These pollutants enter the environment from historically contaminated soils, current day industrial practices, and air pollution.

The ARD does not currently assess the condition for mercury, as condition thresholds for mercury deposition have not been established. Environmental conditions play a significant role in the potential for mercury to accumulate in the food chain. Therefore, the ARD recommended condition, once developed, will take into account physical, chemical, and biological parameters.

4.23.3 Data and Methods

4.23.3.1 Condition methods

Air quality status assessments are based on current conditions compared to NPS ARD benchmarks for specific measures of visibility, ozone, and atmospheric deposition. NPS ARD uses six specific measures for three indicators to summarize current air quality conditions at the park (Table 4-10).

4.23.3.2 Overview

For each of the specific measures of air quality identified above, data from national air quality monitoring networks were reviewed and 5-year averages (2008–2012) were calculated for monitoring sites with at least 3 years of complete annual data. The Inverse Distance Weighted (IDW) interpolation method was then used to estimate 5-year average values for all locations in the contiguous U.S. The condition for Bandelier NM is the value derived from this national analysis at the geographic center of the park. The estimated 5-year averages (conditions) for the park were compared to established benchmarks to be assigned one of three status categories:

- Warrants Significant Concern,
- Warrants Moderate Concern, or
- Resource is in Good Condition.

4.23.3.3 Visibility

Visibility conditions are measured using Haze Index in deciviews (dv). Annual average measurements for visibility on mid-range days (40th to 60th percentile) were averaged over a 5-year period (2008–2012) and subtracted from the estimated natural visibility condition on mid-range days at each Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring site. The difference between current visibility and natural visibility conditions on mid-range days were interpolated for all IMPROVE locations with an Inverse Distance Weighted (IDW) estimation method to estimate 5-year average values for the contiguous U.S. The estimated current visibility condition for Bandelier NM is the value derived from this national analysis at the geographic center

Table 4-10. National Park Service indicators of air quality and specific measures. The W126 metric is a biologically relevant measure that focuses on plant response to ozone exposure.

Indicator of air quality	Specific measure
Visibility	Visibility on mid-range days minus natural visibility condition on mid-range days
	Vegetation health: 3-month maximum 12-hour W126
	Nitrogen wet deposition

of the park. A resulting condition greater than 8 dv is assigned a Warrants Significant Concern status. A current visibility condition from 2–8 dv is assigned Warrants Moderate Concern status. Resource is in Good Condition if the current visibility condition is less than 2 dv.

4.23.3.4 Ozone

Current condition for human health risk from ozone is measured using the 4th-highest daily maximum 8-hour ozone concentration in parts per billion (ppb). Annual 4th-highest daily maximum 8-hour ozone concentrations were averaged over a 5-year period (2008–2012) at all Clean Air Status and Trends Network (CASTNET) and Air Quality System (AQS) monitoring sites. For 5-year average calculations, annual ozone data must meet a 75% data completeness criterion, meaning that there must be 115 or more valid days within a year. Five-year averages were interpolated for all ozone monitoring locations with an IDW estimation method to estimate 5-year average values for the contiguous U.S. The estimated current ozone condition for human health risk at Bandelier NM is the value derived from this national analysis at the geographic center of the park. A resulting condition greater than or equal to 76 ppb is assigned a Warrants Significant Concern status. A current ozone condition from 61–75 ppb is assigned Warrants Moderate Concern status. Resource is in Good Condition if the current ozone condition is less than 2 ppb.

Current condition for vegetation health risk from ozone is measured using the maximum 3-month 12-hour W126 in parts per million hours (ppm-hrs). Annual maximum 3-month 12-hour W126 were averaged over a 5-year period (2008–2012) at all Clean Air Status and Trends Network (CASTNET) and Air Quality System (AQS) monitoring sites. Five-year averages were interpolated for all ozone monitoring locations with an IDW estimation method to estimate 5-year average values for the contiguous U.S. The estimated current ozone condition for vegetation health risk at Bandelier NM is the value derived from this national analysis at the geographic center of the park. A resulting condition greater than 13 ppm-hrs is assigned a Warrants Significant Concern status. A current ozone condition from 7–13 ppm-hrs is assigned Warrants Moderate Concern status. Resource is in Good Condition if the current ozone condition is less than 7 ppm-hrs.

4.23.3.5 Atmospheric deposition

Conditions of atmospheric deposition are based on wet deposition in kilograms per hectare per year (kg/ha/yr) only because dry deposition data are not available for most areas. Wet deposition for sites within the contiguous U.S. was calculated by multiplying nitrogen or sulfur concentrations in precipitation by a normalized precipitation amount. Annual nitrogen and sulfur wet deposition measurements were averaged over a 5-year period (2008–2012) at all National Atmospheric Deposition Program – National Trends Network (NADP-NTN) monitoring sites. Five-year averages were interpolated for all atmospheric deposition monitoring locations with an IDW estimation method to estimate 5-year average values for the contiguous U.S. The estimated current nitrogen and sulfur condition for the monument is the value derived from this national analysis at the geographic center of the park. A resulting condition greater than 3 kg/ha/yr is assigned a Warrants Significant Concern status. A current nitrogen or sulfur condition from 1–3 kg/ha/yr is assigned Warrants Moderate Concern status. Resource is in Good Condition if the current nitrogen or sulfur condition is less than less than 1 kg/ha/yr

4.23.3.6 Trend methods

Trends were computed from data collected over a 10-year period at on-site monitors. Trends were calculated for sites that have at least 6 years of annual data and an annual value for the final year of the 10 year period, i.e. 2012.

4.23.3.7 Visibility

Visibility trends were computed from the Haze Index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the Clean Air Act, which include improving visibility on the haziest days and allowing no deterioration on the clearest days. If the Haze Index trend on the 20% clearest days was deteriorating, the overall visibility trend was reported as deteriorating. Otherwise, the Haze Index trend on the 20% haziest days was reported as the overall visibility trend. Visibility monitoring data were retrieved from the BAND IMPROVE monitor (BAND1).

4.23.3.8 Ozone

Typically, annual 4th-highest daily maximum 8-hour average ozone concentrations (ppb) and maximum 3-month 12-hour W126 are used to calculate 10-year trends for ozone. However, no trend information was available for Bandelier NM because there were not sufficient on-site or nearby ozone monitoring data.

4.23.3.9 Atmospheric deposition

Wet deposition trends were evaluated using pollutant concentrations in precipitation (micro equivalents/liter) so that yearly variations in precipitation amounts do not influence trend analyses.

For sulfur wet deposition trends, sulfate concentrations measured in precipitation were trended over a 10-year period. For nitrogen wet deposition trends, total nitrogen in precipitation was estimated using molecular weight ratios to calculate the nitrogen portions of nitrate and ammonium. The resulting ratios were summed to estimate total nitrogen concentration in precipitation and trended over a 10-year period. Wet deposition monitoring data were retrieved from BAND NADP monitor (NM07).

4.23.4 Resource condition and trend

4.23.4.1 Visibility

The visibility condition at Bandelier NM does not meet the ARD recommended benchmark for good condition. Based on 2008–2012 estimated visibility data, visibility on mid-range days at the monument was 3.8 dv above estimated natural conditions (3.0 dv), and falls within the moderate concern category. On the haziest days, visual range has been reduced from approximately 120 miles (without the effects of human caused pollution) to 60 miles because of human caused pollution at the park. Severe haze episodes can occasionally reduce visibility to approximately 4 miles (IMPROVE 2013). During the last decade (2003–2012), visibility improved on the clearest days and remained relative unchanged on the haziest days at the BAND IMPROVE monitor (BAND1) (NPS-ARD 2014). However, visibility on the clearest days appears to have deteriorated over the last three years (2010–2012).

4.23.4.2 Ozone

Current condition for human health risk from ozone at Bandelier NM does not meet the ARD recommended benchmark condition. The estimated 4th-highest daily maximum 8-hour ozone concentration from 2008–2012 is at 66.1 ppb and falls within the moderate concern status category (NPS-ARD 2014). Bandelier NM lies within Los Alamos and Sandoval counties that meet the NAAQS ozone standard of an 8-hour average concentration of 75 parts per billion (ppb). For this reason, these counties are EPA-designated “attainment” area for ozone.

Current condition for vegetation health risk from ozone warrants moderate concern status category based on estimated W126 metric of 11.3 ppm-hrs for 2008–2012 (NPS-ARD 2015). A risk assessment that considered ozone exposure, soil moisture, and sensitive plant species concluded that plants in the park were at low risk of foliar ozone injury (Kohut 2007; Kohut 2004); however, estimated ozone concentrations and cumulative doses at the park are high enough to induce foliar injury to sensitive vegetation under certain conditions (Binkley et al. 1997).

4.23.4.3 Sulfur and nitrogen

Sulfur deposition is in good condition and nitrogen deposition condition warrants moderate concern at Bandelier NM in accordance with ARD benchmarks. During the period of study (2008–2013), estimated wet sulfur deposition at the park was 0.8 kg/ha/yr and estimated wet nitrogen deposition was 1.9 kg/ha/yr (NPS-ARD 2014). During the last decade (2003–2012), the trend in wet sulfur and nitrogen deposition in rain and snow remained relatively unchanged (no statistically significant trend) at the BAND NADP monitoring station (NM07) (NPS-ARD 2014).

Nitrogen deposition at Bandelier NM is at levels known to affect diversity of plants and lichens (Pardo et al. 2011), and ecosystems in the park were rated as having high sensitivity to nutrient-enrichment effects relative to other NPS units (Sullivan et al. 2011a; Sullivan et al. 2011b). Plants in arid ecosystems such as Bandelier NM are particularly vulnerable to changes caused by nitrogen deposition; for example, invasive grasses tend to thrive in areas with elevated nitrogen deposition, displacing native vegetation adapted to low nitrogen conditions (Brooks 2003; Schwinning et al. 2005; Allen et al. 2009). The 2011 Las Conchas Fire at Bandelier NM burned over 75% of the Frijoles Canyon watershed, further impacting the park's waterways and susceptibility to acidification and nutrient enrichment. In addition, weed density is known to increase in post-fire environments with higher soil N levels (Floyd-Hanna et al. 2004).

In addition to assessing wet deposition levels, critical loads can also be a useful tool in determining the extent of deposition impacts (i.e., nutrient enrichment) to park resources. A critical load is defined as the level of deposition below which harmful effects to the ecosystem are not expected.

Pardo et al. (2011) suggested a critical load of 3.0–8.4 kilograms nitrogen per hectare per year (kg N/ha/yr) to protect lichen and herbaceous vegetation in the North American Deserts ecoregion; and 2.5–17.0 to protect lichen, forest, and herbaceous vegetation in the Northwestern Forested Mountains ecoregion. To maintain the highest level of protection in the park, the lower end of this range would be an appropriate management goal. The estimated maximum 2010–2012 average for total nitrogen deposition in the North American Deserts ecoregion of Bandelier NM was 2.6 kg/ha/yr and 4.5 kg/ha/yr in the Northwestern Forested Mountains ecoregion (NADP 2014). Therefore, total deposition levels in the park are below ecosystem critical loads in the North American Deserts ecoregion and above ecosystem critical loads in the Northwestern Forested Mountain ecoregion, suggesting that in some parts of the park, lichen, forest, and herbaceous vegetation are at risk for harmful effects.

4.23.4.4 Mercury and other toxins

Landers et al. (2008) detected airborne toxics in passive air samples and vegetation (lichen, conifer needles) at Bandelier NM. Compared with concentrations at all 20 western national parks, concentrations detected in the park's air sampler were near the median. Pesticides detected included both current-use and historic-use. Baker (2013) also detected persistent toxic compounds, such as DDT, in the park soils at levels that may pose a health risk to humans and wildlife, including fish. The predicted concentrations of methylmercury (the toxic, bioavailable form of mercury) in surface waters at the park are moderate, as compared to other NPS units (USGS 2015).

4.23.5 Level of confidence

The degree of confidence in the condition and trends of visibility at Bandelier NM is high because there is an on- site visibility monitor. The degree of confidence in the condition and trends of ozone at the park is medium because there is not an on-site or nearby representative ozone monitor with enough data to calculate a trend. The degree of confidence in the condition and trends of sulfur and nitrogen at the park is high because there is an on-site wet deposition monitor.

4.23.6 Data gaps/Research needs/ Management recommendations

Data and planning priorities for improving air quality at Bandelier NM include:

- continued support for existing in-park air quality monitoring;
- increased monitoring of ozone;
- additional support for monitoring air quality and mitigating impacts during wildfire events;
- applied research to better understand air pollution impacts on sensitive park ecosystems, including the potential impact of mercury and other toxics;
- continued management direction that emphasizes efforts to protect air quality and minimize impacts to biota;

4.23.7 Sources of expertise

Colleen Flanagan Pritz, Ecologist, Air Resources Division: 303-969-2806

Ksienya Pugacheva, Natural Resource Specialist: 303-969-2524

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Chapter 5: Toward Ecosystem Integrity in a Warmer Drier Future: Don’t Panic!

5.1 State change

For centuries, people living and working within the current boundaries of Bandelier National Monument (NM) have both driven, and responded to, landscape change. Since the transfer of the land to National Park Service management, that fact has remained the same. Heavy grazing prior to and during early federal management of Bandelier initiated fire exclusion across most of the monument. Combined with a policy of active fire suppression and the timing of favorable wet climate windows, land managers were able to manage ecosystem processes and temporarily create an artificial semblance of stability across much of the landscape for most of the 20th century.

The fragility of this fabricated state became apparent when historical ecologists reconstructed fire histories from local sources and found that, at least since the 1500s until the 1890s, fires were frequently burning across the Jemez Mountains, including on the Bandelier NM. These frequent, low severity fires, left behind open forests with grassy understories (see section 4.01 Fire History & Ecology).

Fire exclusion has promoted dramatic increases in upland forest density and fuel loading during the early and mid-20th century. Subsequently, large and severe crown fires have burned over large areas, converting many forested areas into savannas, shrublands, or grasslands. Large patch sizes of high-severity burn areas may preclude natural tree seed recruitment for centuries, while shrub and grass understories, which now dominate many sites, will reinforce type conversion through altered disturbance regimes.

Surveys of archaeological site conditions, along with intensive ecohydrological research near the ancestral pueblo of Frijolito, provided evidence of other widespread landscape changes by revealing that late 20th century levels of soil erosion were much higher than in the past, likely a reverberation effect from historic grazing. Following the recognition of pervasive and accelerated erosion rates, managers initiated the piñon-juniper ecological restoration effort, which treated large portions of the low elevation mesa tops within Bandelier NM (see section 4.06-1 Piñon-Juniper Erosion).

In recent decades Bandelier resource managers have shifted management philosophy toward trying to preserve processes and basic ecological capital to foster incremental landscape adaptation to changing conditions; the piñon-juniper woodland restoration project is a strong example of this approach. Because of historical human intervention prior to the park’s establishment, many keystone ecosystem processes and species are missing or declining (see section Plant Species of Management Concern). Events like the early 2000s piñon mortality and the 2011 Las Conchas Fire have caused widespread and rapid ecosystem state change that have forced Bandelier land mangers into a reactive stance.

Following an ecosystem state change, many organisms strongly associated with or dependent on particular vegetation communities are at risk, as these systems reorganize into new states, degrade, and/or become more limited in extent, even though new ecosystem conditions will benefit some set of current and/or new species. The post-disturbance ecosystems (e.g., treeless landscapes) may follow successional trajectories that result in characteristics and processes that differ from the pre-disturbance ecosystem (e.g., forested landscapes), ranging from different habitat availabilities and fire regimes to altered hydrologic properties. Management intervention may be required to shift the post-disturbance trajectories away from undesirable landscape conditions. At Bandelier NM, where more than half of the park is congressionally-designated as wilderness, any such management actions would need to be considered within the context of the park's legislated purpose and with regard to wilderness values.

Many ecological systems within the monument are currently at high risk of rapid system shifts away from historical conditions due to cumulative impacts of recent drought-insect-fire-flood disturbance and ongoing climate warming. These risks are not spatially homogenous and the effects of disturbance interaction will likely be patchy. For example, in the aftermath of the 2011 Las Conchas Fire, it appears that upland forests and woodlands within the monument fared much better than those on adjacent national forest lands where large expanses are now treeless. This could be a result of many factors, such as multiple fires, daily fire behavior, or vegetation densities, all of which are associated with a high degree of randomness.

In short, if the Bandelier landscapes of the 20th century were defined by an illusion of artificial stasis brought on by management's aim for *control* of nature, the landscapes of the 21st century will be defined by substantial dynamic changes, with management aiming to foster ecological integrity and adaptive capacities of natural systems.

5.2 Future state

The American Southwest is projected to experience dramatic changes in temperature and precipitation patterns in response to increasing levels of anthropogenic CO_2, which, if realized, would fundamentally alter vegetation composition and structure within the park, probably through a series of severe disturbances not unlike what we have already been experiencing since 2000 (cf. Williams et al. 2013).

Recent climatic conditions for Bandelier NM are already shifting beyond the historical range of variability, with average annual temperature for the decade from 2003 to 2012 exceeding that of any other decade for all 10-year periods from 1901 to 2012 (Monahan and Fisichelli 2014; Appendix A). The ecological responses to recent climate change effects have been so profound that they likely constitute tipping points for many vegetation communities; i.e., the sort of ecological system changes anticipated in response to predicted patterns of warming and drying in the American Southwest, and beyond.

Future climate projections for the Southwest, including Bandelier NM, have been generated from multi-model averaged data by Kunkel et al. (2012). Mean annual temperature, compared with the 1971-1999 average, is projected to increase 3–5 °F by mid-century and 5–8 °F by the end of the century, depending on the greenhouse gas emissions scenario. Current greenhouse gas emissions are on a trajectory similar to the higher emissions scenarios (Peters et al. 2013). Warming by mid-century is projected for all seasons, with the greatest increases likely in summer. Wide agreement exists among individual climate models in the direction and magnitude of warming over the coming decades. Total annual precipitation may decrease slightly by mid-century (Kunkel et al. 2012); however, precipitation variability is likely to remain large over the coming decades, and there is greater uncertainty in precipitation than in temperature projections (Kunkel et al. 2012).

5.3 State of management

Bandelier serves as a potential harbinger of the types of changes projected for the Southwestern U.S. driven by anthropogenic global warming. The recent decadal drought, fires, and insect outbreaks have all created a landscape much different from one that would be familiar to the park's namesake. Under current conditions, agency managers need to fully realize that the window of opportunity for restoration of degraded systems is closing with each passing dry year. The rapid changes unfolding may preclude management actions beyond monitoring in the near term, as many ecological systems are simply overwhelmed and make adjustments to the new conditions. Although drought conditions and destructive fires have seemingly become the norm, it is likely that ocean currents will create conditions that result in a wetter period for the Southwest and Bandelier NM.

Managers should both prepare for a continuation of recent dry conditions AND contingently plan for wet conditions and be prepared to take advantage of what may be the last window to restore ecosystem processes or intervene in current ecosystem trajectories. Such planning will be more likely to succeed if managers can fundamentally change their management emphasis away from a traditional approach that attempts to maintain historical conditions toward one that incorporates promoting ecosystem integrity and resilience (NPS 2010). Generally, managing for ecological integrity (*sensu* Woodley et al. 1993, Woodley 2010) or resilience (*sensu* Holling and Gunderson 2002) means an ecosystem maintains its full complement of native species and the processes to ensure their survival, as well as the means to withstand and recover from disturbances caused by natural environmental or human factors.

Managing for such broadly defined goals as ecosystem integrity or resilience can be challenging, to say the least. Identifying key ecosystem characteristics or processes that lead to integrity or resiliency may provide an initial starting point for a discussion on management in an uncertain, and changing future. For example, managers could choose broad ecological integrity objectives with the intent of 1) relying on historical information for guidance but not as blueprint for future designs, and 2) maintaining landscape-scale adaptive capacity by retaining keystone species and ecosystem processes. Regardless of the exact details of future management strategies, Bandelier NM managers should seek to:

- document the changes occurring across our landscape
- promote constructive and transparent discussions about management strategies
- broaden resource management frameworks by integrating a range of disciplines, scales, and approaches
- engage in broad landscape-scale efforts across jurisdictions

Given the high likelihood of climate change to drive big, fast, and patchy landscape rearrangements (Breshears et al. 2011), managers should anticipate a quickening pace for acquiring and incorporating resource information as a basis for management action. Successful managers will confront and overcome bureaucratic constraints on management action. These are difficult challenges, but if not accomplished we will fall short of our NPS obligations to the public as caretakers of "America's Best Idea."

5.4 Opportunities for success

The authors of this report provide the following guiding recommendations for Resource Managers at Bandelier NM.

5.4.1 Facilitate conservation planning across a broader landscape and develop multi-partner, multi-agency approaches to resource management.

Conversations across jurisdictional boundaries are likely to yield positive outcomes for landscape conservation. As stressors become recognized at landscape scales, action on a similar scale would likely be appropriate. Without local relationships in place, it would be a much more difficult and slower process to react to problems as they arise. The separate agencies in the Jemez Mountains all have obligations that may be different on the edges but are all based around a similar core set of conservation principles. Fostering conversations and/or planning efforts around shared core management principles could go a long way to furthering, or healing, relationships with neighboring land management agencies.

5.4.2 Support a climate change vulnerability assessment for the Jemez Mountains landscape.

Use climate change vulnerability assessment planning efforts to theorize potential management actions. Search for proactive strategy options; identify affirmative steps and options for management action. Retrospectively analyze the previous decades of fire management efforts, BAER programs, and piñon-juniper restoration to learn from past successes and failures.

5.4.3 Initiate NPS Resource Stewardship Strategy planning efforts for Bandelier National Monument.

As a Resource Stewardship Strategy (RSS) is undertaken, we see the following lines of inquiry based on Parks Canada's approach to assessing ecological integrity (Woodley 2010), as helpful for getting that effort started:

- What are the status and trends of species and communities in the park and in the encompassing Jemez Mountains landscape?
- What are the status and trends in ecosystem processes (e.g., disturbance regimes, pollination)?
- Are ecosystem trophic levels intact? For example, is hunting of predators (or predator control) outside the park influencing predator populations and thereby ecosystems within Bandelier NM?
- Do biological communities exhibit an appropriate mix of age classes and spatial arrangements that will support native biodiversity?
- Are productivity and decomposition processes operating within acceptable limits?
- Are ecosystems cycling water and nutrients within acceptable limits?

5.4.4 Evaluate options to integrate the Resource Management and Fire Management programs.

A programmatic transition of fire management from hazard fuel reduction to more ecologically based objectives, using combinations of available restoration techniques, will require 1) focused research to refine restoration targets and methods; 2) coordinated application at landscape scales, and 3) validation by a companion monitoring component that enables an adaptive management approach. Methods, restoration targets, and supporting documentation for mechanical and other restoration treatments to thin mature tree size classes are available regionally, but have not been evaluated or adapted for local conditions. Modeling is a useful tool, especially if used retroactively with existing, local response data to refine expected outputs. At Bandelier, mechanical thinning techniques may be considered for forested systems to produce selected mortality in canopy components, while leaving heavy fuels vertical, at least in short term. Pre-treatment mechanical thinning and litter fuels treatments may also be useful for protecting old growth or high value, fire intolerant individuals. Using prescribed fire as a blunt but intelligent tool that restores appropriate stand structure across variable site conditions through time is a low intervention approach that is desirable for many natural areas. However, it may require longer time periods to reach historical structural densities; leaving the system vulnerable to crown fire during the interim period. Conversely, increasingly more frequent and larger scale occurrences of crown fire and other landscape scale disturbances (e.g., drought and associated disease/ insect outbreaks amplified by high stand densities) should be modeled to determine if longer term, less intrusive, restoration approaches are timely enough to meet management goals.

At Bandelier NM, focused restoration studies have primarily addressed lower elevation woodland communities. A ten-year research program documenting the effects of past land use, as well as testing proposed treatment options, won support for its uniquely interventionist restoration treatments from many environmental and wilderness advocates, including the original three proponents for establishment of the Bandelier Wilderness. Ecological restoration of the balance of Bandelier's vegetation communities, mostly higher-elevation forested areas, has been pursued primarily through the reintroduction of fire disturbance with the goal of providing some stability and ecosystem resistance (see Fulé et al. 2012). While the central role of fire in maintenance of these forested systems is well documented from a historical perspective, there is some question as to whether fire treatments alone will continue to constitute a viable, long-term restoration strategy. For example, during the past 37 years, nearly half of the park's ponderosa pine community has experienced destructive crown fire. Despite an active prescribed fire program for nearly 15 years, restoration of fire process and historic structure/composition to forested systems at Bandelier NM remains a challenging goal.

5.4.5 Be alert to the potential for nonnative plant species already present in the park to become major ecosystem stressors.

Bandelier NM has been extensively invaded by cheat grass, and smooth brome is poised to expand into the monument from the Santa Fe National Forest on the western boundary. If heating and drying trends continue in the region, the presence of these species within the monument may become more impactful. The legislatively-mandated Alamo Watershed Ecosystem Study of three watersheds adjacent to and within Bandelier NM may provide an opportunity to evaluate management actions for smooth brome. The study is intended to provide a unified vision and determine best ecosystem management practices for watersheds that are jointly managed by the Santa Fe National Forest and Bandelier National Monument. Investigation of cheat grass is ongoing at multiple locations throughout the American Southwest, reflecting the difficulty of controlling this damaging plant.

5.4.6 Develop opportunities for land management experiments and take advantage of available "natural experiments."

Given high levels of uncertainty in future landscape conditions, managers should work to design experiments to compare alternative management strategies in order to find potential solutions to challenges brought on by rapidly changing conditions. There is also potential to take advantage of ongoing "natural experiments" (e.g., between NPS and USFS strategies or differences between treated vs. untreated forest). To learn from such "natural experiments", the differing management treatments must be well-documented, and the managers involved must adopt a shared monitoring plan that includes pre-treatment data.

5.4.7 Interpret climate change-driven landscape changes and the human response to them, both past, present, and future.

The dynamic landscape of Bandelier NM provides a core story that is ripe to be shared through the monument's interpretive program, incorporating both current events and earlier climate stress events that reshaped human occupancy of the Jemez Mountains.

5.5 Addressing uncertainty

Ongoing learning about the landscape will be essential for successful resource management. It must include provision for real-time or near real-time information development at multiple scales, ranging from routine backcountry observations, to long-term plot-based monitoring and research, to remote sensing. There should be agency flexibility to ramp up monitoring for locations that exhibit rapid dynamic change.

5.5.1 Data gaps and research needs

Many data gaps in basic inventory, long-term monitoring, and research have been identified during this NRCA process. Closing these information gaps will be an important first step toward informed decision-making.

- **Investigate geomorphic and vegetation changes in Frijoles Canyon.** Analyze recently acquired LiDAR data and acquire/analyze multi-spectral remote sensing imagery to better understand recent changes in Frijoles Canyon. The wealth of LiDAR data collected for this canyon and watershed between 2010 and 2014 has created a promising research opportunity that would inform park managers on the pace and extent of geomorphic and vegetation change.

    - Acquire a complete time-series of remote sensing products from a consistent source (e.g., Landsat) with multi-spectral remote sensing imagery to track changes in physical landform and vegetation cover.
    - Analyze recently acquired LiDAR data to better understand recent changes in Frijoles Canyon where most of the LiDAR was taken.
- **Update the park vegetation map** to reflect changes since 2004 due to widespread drought, insect outbreaks, fire, and flood effects. During a multi-year drought from 2000 to 2004, over 95% of the mature piñon pine within the monument died, including the oldest trees which exceed 300 years in age. Mature piñon was nearly erradicatedfrom the woodland zone, essentially type converting the piñon-juniper zone where the majority of cultural resources are located to juniper woodland.

  In 2011 the Las Conchas Fire burned over 60% of the monument, severely altering monument vegetation. In addition to these natural disturbances, park management implemented a landscape-scale mechanical thinning restoration effort within the woodland zone to mitigate soil erosion issues between 2007 and 2010.

  Thus, a vegetation map of the park based on 2004 photography is now well out-of-date along with soils information based on 2000-era surveys. The timing and pattern of drought and fire induced vegetation and soil-hydrologic changes need to be fully documented and quantified to support effective management of this rapidly changing cultural landscape in order to inform activities to protect the embedded archeological resources.

  Status: development of an updated vegetation map is ongoing through a Cooperative Agreement with the University of New Mexico Natural Heritage Program.
- **Investigate potential for fire management actions to contribute to ecosystem resilience.** Ecological restoration of Bandelier's montane forests has been pursued primarily through the reintroduction of fire disturbance with the goal of providing some stability and ecosystem resistance. While the central role of fire in maintenance of these forested systems is well documented from a historical perspective, there is some question whether fire treatments alone continue to constitute a viable, long-term restoration strategy. For example, during the past 37 years, nearly half of the park's ponderosa pine community has experienced destructive crown fire, with limited prospects for conifer regeneration in some areas. Despite an active prescribed fire program for over 30 years, the restoration of fire as a natural process and of historic vegetation structures and compositions to forested ecosystems at Bandelier continues to be challenging in an increasingly dynamic global-change world.
- **Research poorly known groups** like: soil bacteria, earthworms, fungi, moths, pathogens, insects (e.g., native bees as pollinators), and non-vascular plants (e.g., mosses) and lichens).
- **Quantify predator population sizes** to track this key trophic layer.
- **Replicate breeding bird atlas data collection** from the early 2000s to provide documented spatial changes in breeding species with explicit connections to habitat types. (See Appendix F for information on bird demographic needs).
- **Monitor post-disturbance ecosystem recovery** to
    - Identify areas of potential post-disturbance landscape-scale type-conversion.
    - Assess suitability and timing of native fish reintroduction by monitoring riparian vegetation, channel geomorphology, water chemistry and macroinvertebrates.

    - Identify trajectory of piñon-juniper systems following ecological restoration, and drought mortality.
    - Assess effectiveness of wildfire fuels treatments and prescribed fire.
    - Detect exotic invasions in disturbed and successional areas.
- **Monitor plant phenology** to provide proxy for climate change and incorporate into national phenological networks. Plant-based phenology observations would complement SCPN land surface phenology monitoring using MODIS imagery.

5.6 Conclusions

As Bandelier NM approaches its centennial as a protected natural area and federally-designated wilderness, managers have come to recognize that its protected status neither heals nor hides the wounds of past land use; thus monument landscapes bear stark tribute to past mistakes and mismanagement. Although set aside and protected, it has sustained losses of ecological integrity, biological capital, component species, and connectivity. Even so, the application of restoration treatments in an attempt to repair past damage remains controversial because it challenges basic philosophical and legal tenets for land management in national parks and wilderness areas to let nature be 'free willed' or largely absent the effects of human intervention—including federal agency management. Among many environmental advocates, there is both concern and suspicion that if intensive, broad-scale restoration treatments can be justified and implemented in one natural area, then the door is open for all public land to become more vulnerable to both well-intentioned and potentially damaging management actions.

Understanding that these concerns are founded on previous adverse experience, we advise future managers to rely on the best available science as they weigh alternative management decisions and actions. The recent piñon-juniper woodland restoration project exemplifies the incorporation of decades of research and pilot treatments into developing a restoration strategy. It also demonstrates a philosophical shift toward fostering incremental landscape adaptation to changing conditions. Even if near-term management is tilted toward natural recovery of post-disturbance landscapes, those decisions should be made in an open and active decision-making framework.

With the pace of landscape changes likely to quicken, managers may not have the luxury of decades of research to support future management decisions. However, amidst the uncertainty of modeling system trajectories, the questions remain—what interventions are possible to foster resilience and reduce stressor impacts, and when do we have enough knowledge, even if it is far from complete, to act?

The best management strategies will incorporate all aspects of ecosystem understanding. Such a holistic approach will require integration of solid science, across all disciplines, at a landscape level. The benefit of exercises like a resource stewardship strategy or climate change vulnerability assessment is that they provide opportunities to develop multi-management possibilities and understand the tradeoffs that are inherent in integrated landscape scale management. Important ecosystem components of the Bandelier landscape are presented in Chapter 4 in a compartmentalized manner with the hope of simplifying complex systems. It would be a mistake to view any one component as isolated from the rest, and only by thinking of them as an integrated whole can we hope to avoid deleterious intervention and long-term landscape scars.

Maintaining the stability of core management principles will serve as a strong foundation from which to build successful resource management strategies as priorities shift with changing conditions. The landscape that comprises Bandelier National Monument, through its associated native cultures and post-Hispanic land-based cultures, has exemplified strong linkages between human and "natural" worlds for many centuries.

Moving forward, we must remember that both worlds are, and will remain, closely intertwined as we seek to steward a healthy and sustainable future.

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National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

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