National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sunset Crater Volcano National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/SCPN/NRR—2018/1837

ON THIS PAGE
Desert globemallow. Photo Credit: NPS

ON THE COVER
A view of yellow sunflowers with Sunset Crater Volcano in the background. Photo Credit: NPS

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Natural Resource Report NPS/SCPN/NRR—2018/1837

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December 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Baril, L., P. L. Valentine-Darby, K. Struthers, P. Whitefield, K. Anderson, and M. Brunson. 2018. Sunset Crater Volcano National Monument: Natural resource condition assessment. Natural Resource Report NPS/SCPN/NRR—2018/1837. National Park Service, Fort Collins, Colorado.

NPS 039/149831, December 2018

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program, administered by the National Park Service's (NPS) Water Resources Division, aims to provide documentation about current conditions of important park natural resources through a spatially explicit, multidisciplinary synthesis of existing scientific data and knowledge. The workshop for the Flagstaff Area National Monuments (NM) NRCAs, which includes Walnut Canyon, Wupatki, and Sunset Crater Volcano, was held from May 17 - 19, 2016. This NRCA report is for Sunset Crater Volcano NM.

Sunset Crater Volcano was established as a national monument in 1930 to preserve Sunset Crater Volcano and surrounding volcanic features, including the Bonito Lava Flow, ice cave, cinder fields, spatter cones, lava tubes, and squeeze-ups (NPS 2015a). The relatively young age of the volcanic eruption provides an excellent opportunity for scientists to study the ecologic succession of soils and plants in an arid and largely barren environment (NPS 2015a).

For Sunset Crater Volcano NM's NRCA, park staff selected nine natural resource topics for condition assessments and an evaluation of habitat connectivity between the three Flagstaff Area NMs. Sunset Crater Volcano NM's resources were grouped into four broad categories: landscapes, air and climate, geology and soils, and biological integrity, which included vegetation resources. Most of the assessments resulted in a good or moderate concern condition rating, with two conditions of unknown for the unique vegetation resources.

Like many national parks, the resources at Sunset Crater Volcano NM face many threats due to an ever-increasing human population within and surrounding cities, such as Flagstaff, Arizona, and increasing temperatures and erratic precipitation events due to climate change. The Flagstaff Area NM's proactive science program will become even more important in influencing resource conditions and identifying necessary adaptations in a rapidly changing environment.

Acknowledgements

Natural resources staff in the Flagstaff Area NM's Science and Resource Management Division participated in the development and reviews of this report's condition assessments. Lisa Leap, Division Chief of Resources; Paul Whitefield, Natural Resource Specialist; Mark Szydlo, Biologist; and Michael Jones, GIS Specialist provided their expertise as chapter and assessment reviewers and as information facilitators assisting with the development of indicators, measures, reference conditions, and maps, as needed. Paul Whitefield served as primary author of the Volcanic Resources condition assessment. Paul Whitefield also contributed significantly to the assessment development process, providing an overview of the regional resource-context and significance to the monument's resources.

Phyllis Pineda Bovin, National Park Service Intermountain Region Natural Resource Condition Assessment Coordinator, and Donna Shorrock, former National Park Service Intermountain Region Natural Resource Condition Assessment Coordinator, assisted with overall project facilitation and served as peer review managers. Jeff Albright, National Park Service Natural Resource Condition Assessment Program Coordinator, provided programmatic guidance. To all of the additional reviewers listed in Appendix B and contributors who are listed within each Chapter 4 assessment, we thank you. Your contributions have increased the value of Sunset Crater Volcano NM's NRCA report.

Sunrise over Sunset Crater Volcano. Photo Credit: NPS.

Chapter 1. NRCA Background Information

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

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

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

Although the primary objective of NRCAs is to report on current conditions relative to logical forms

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

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

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

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

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

NRCAs Strive to Provide...

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

of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs. Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

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

An NRCA is intended to provide useful science-based information products in support of all levels of park planning. Photo Credit: NPS.

Important NRCA Success Factors

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

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

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

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

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

NRCA Reporting Products...

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

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations* ***(near-term operational planning and management)***
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values*

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

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

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

Sunset Crater Volcano vent. Photo Credit: NPS / C. Schelz.

Chapter 2. Introduction and Resource Setting

2.1. Introduction

2.1.1. Enabling Legislation/Executive Orders

Sunset Crater Volcano National Monument (NM) was established on May 26, 1930 to preserve Sunset Crater Volcano and surrounding volcanic features, including the Bonito Lava Flow, ice cave, cinder fields, spatter cones, lava tubes, and squeeze-ups (NPS 2015a). The relatively young age of the volcanic eruption provides an excellent opportunity for scientists to study the ecologic succession of soils and plants in an arid and largely barren environment (NPS 2015a). The monument's unique resources and values are described in its three significance statements as follows (text excerpted from NPS (2015a)):

> Most Recent Eruption- Erupting roughly 900 years ago, Sunset Crater Volcano is the youngest of 600 volcanoes within northern Arizona's San Francisco Volcanic Field.
>
> Geology- The monument's display of plate tectonics, volcanism, and pristine eruption features provides excellent opportunities for science, education, and interpretation in the context of regional and global geology.
>
> Community- This catastrophic event profoundly affected the life of people in the region and left a unique archeological and ethnographic record of human response, adaptation, and recovery. Sunset Crater Volcano and its impressive features continue to be significant to contemporary American Indian tribes.
>
> Ecology-A 100-square-mile cinder and ash blanket smothered all life nearest the volcano, resulting in ecologic succession and a unique assemblage of plants in a largely barren landscape. The fresh volcanic terrain provides an unparalleled opportunity to study eruption dynamics, change, and recovery in an arid climate.

Additional fundamental and other important resources and values are identified for the monument in its Foundation Document (NPS 2015a), which further expand on the themes related to its purpose and significance statements.

2.1.2. Geographic Setting

Sunset Crater Volcano NM, which is co-administered with Walnut Canyon and Wupatki NMs, collectively referred to as Flagstaff Area National Monuments, is located in northern Arizona's Coconino County. It is approximately 32 km (20 mi) northeast of downtown Flagstaff, Arizona and encompasses 1,230 ha (3,040 ac) (NPS 2015a). It is located off of U.S. Highway 89 via Loop Road, which connects to Wupatki NM northeast of Sunset Crater Volcano NM (Figure 2.1.2-1). Lands surrounding the national monument consist largely of the Coconino National Forest, managed by the U.S. Forest Service (USFS).

Population

Arizona is the fourth fastest growing state in the U.S. based on projected percent change in population size from 1995 to 2025 (U.S. Census Bureau 2016a). The population estimate for Coconino County was 139,097 in July 2015, with an increase of 3.5% since April 2010, and the population of Flagstaff was an estimated 70,320 in July 2015, with a 6.4% increase since April 2010 (U.S. Census Bureau 2016b).

Climate

The climate of the U.S. Southwest is most influenced by its location between the mid-latitude and subtropical atmospheric circulation regimes. This creates the typical southwestern climate of dry, sunny days, with low annual precipitation. Rain comes in July-September from monsoon storms that originate in the Pacific Ocean and the Gulf of Mexico, and in November-March from winter storms that originate in the Pacific Ocean (Sheppard et al. 2002). The Colorado Plateau, where the monument is situated, is an arid region with irregular rainfall, periods of drought, warm to hot growing seasons, and long winters with freezing temperatures (Davey et al. 2006).

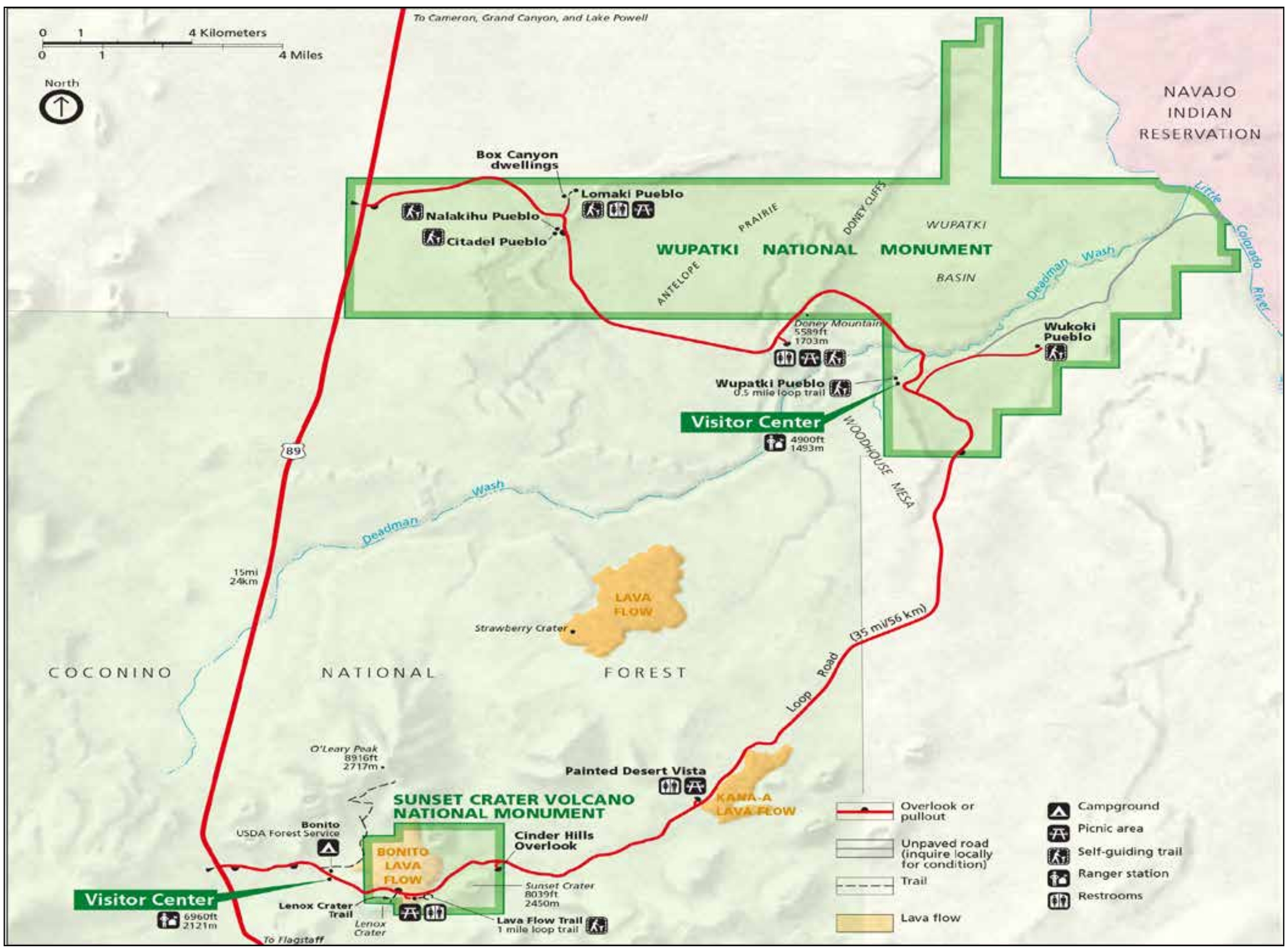


Figure 2.1.2-1. Sunset Crater Volcano NM is located off of Arizona Highway 89, approximately 32 km (20 mi) northeast of downtown Flagstaff, Arizona. Figure Credit: NPS (2015).

The National Weather Service Cooperative Observer (COOP) Network station, 28329, is located in the Coconino National Forest just west of the monument's western boundary. The data record at the COOP station spans from 1969 - present (2018) and is located at an elevation of 2,127.5 m (6,979 ft). Figures 2.1.2-2 and 2.1.2-3 show the temperature and precipitation graphs from data collected over the period of record at the COOP station, with a rising daily minimum temperature and the highest annual precipitation occurring in 2015 since 1969 (Climate Analyzer 2018).

2.1.3. Visitation Statistics

Monthly visitation data for Sunset Crater Volcano NM are available from 1934-2017 (NPS Public Use Statistics Office 2018). The total number of Sunset Crater Volcano NM visitors each year ranged from a low of 2,500 (in 1934) to a high of 597,942 (in 1992). The months with the highest average number of visitors over the recording period of 1979-2017 were June-August (Figure 2.1.3-1).

2.2. Natural Resources

A brief summary of the natural resources at Sunset Crater Volcano NM is presented in this section. For additional information, please refer to Chapter 4 assessments and cited reports within the summaries below.

2.2.1. Ecological Units, Watersheds, and NPScape Landscape-scale

Ecological Units

Sunset Crater Volcano NM is located in the Colorado Plateau Ecoregion, which includes portions of Arizona, Utah, Colorado, and New Mexico. The entire area encompasses 9.3 million ha (22.9 million ac) and is characterized by desert scrub and shrublands. Elevations reach as high as 2,804 m (9,200 ft) throughout the ecoregion. The elevation at Sunset Crater Volcano NM ranges between 2,076 – 2,441 m (6,810 - 8,010 ft) and spans the Semi-Desert Grassland/Shrub Steppe, Pinyon-Juniper Woodland and Ponderosa Pine (*Pinus ponderosa*) Forest life zones (Figure 2.2.1-1) NPS SCPN 2017). The Sunset Crater cinder cone, rising 300-m (985-ft) above the surrounding landscape, and

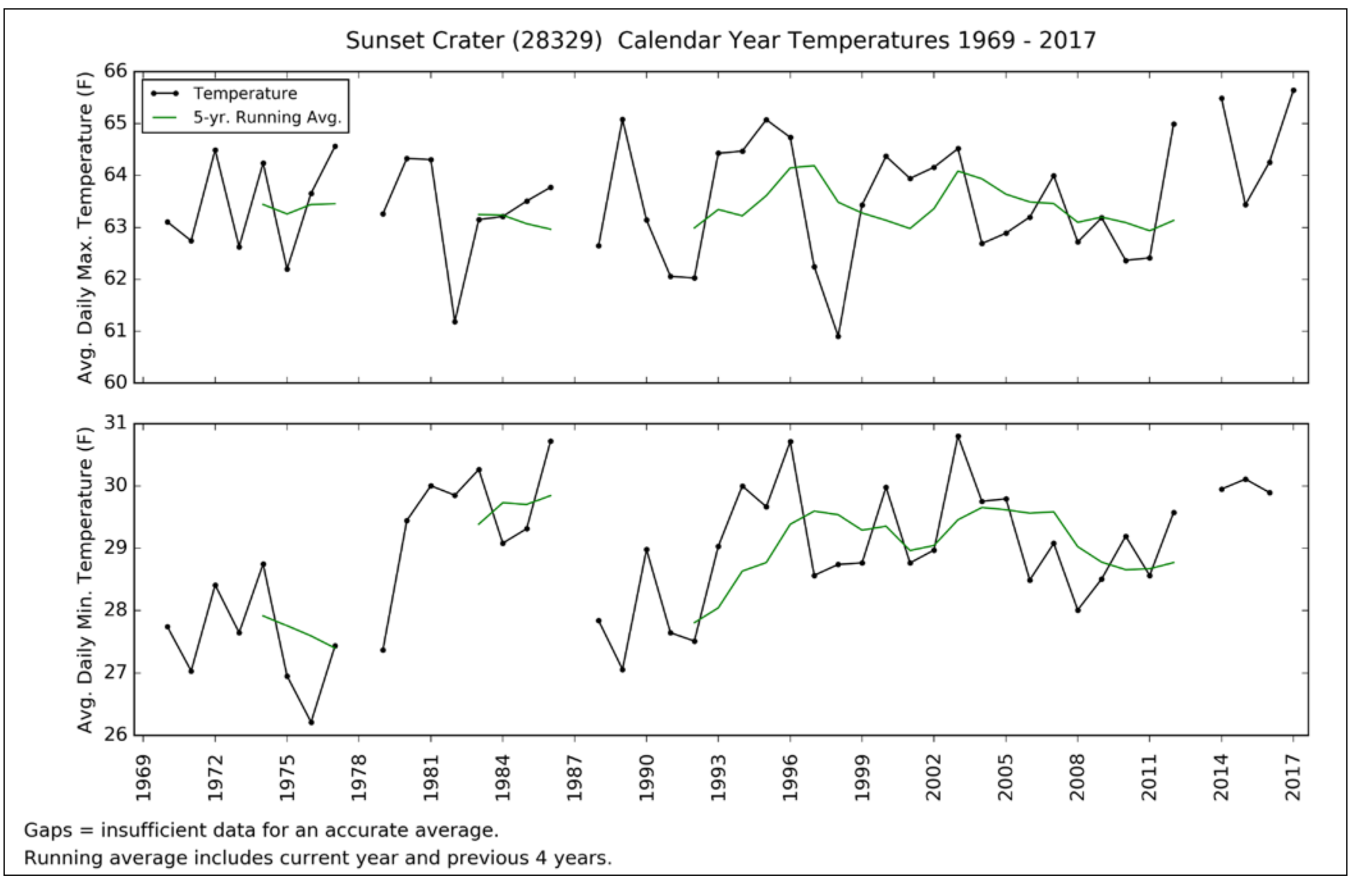


Figure 2.1.2-2. Average daily maximum (top) and minimum (bottom) temperatures (1969 - 2017). Figure Credit: Climate Analyzer (2018).

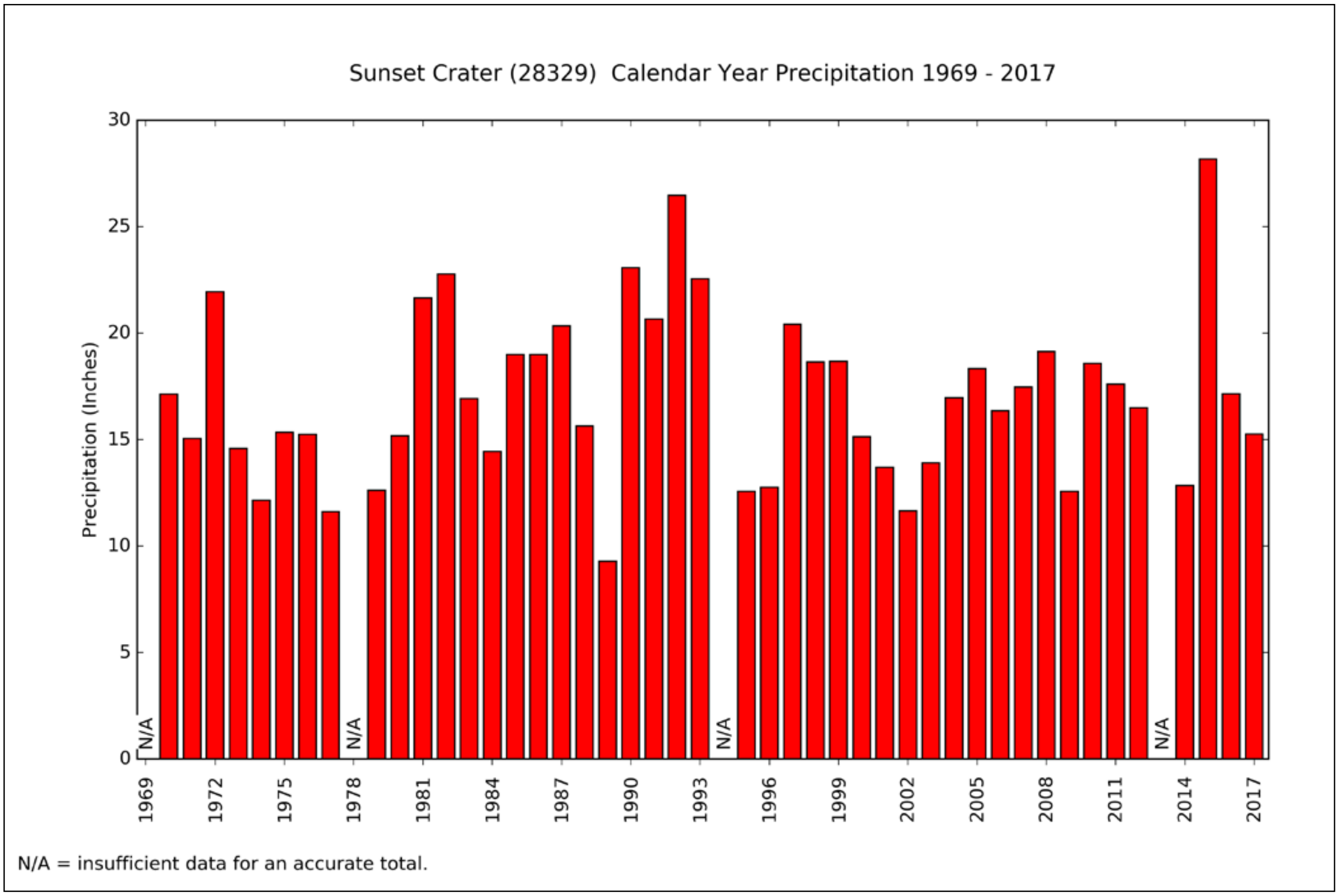


Figure 2.1.2-3. Annual average precipitation (1969 - 2017). Figure Credit: Climate Analyzer (2018).

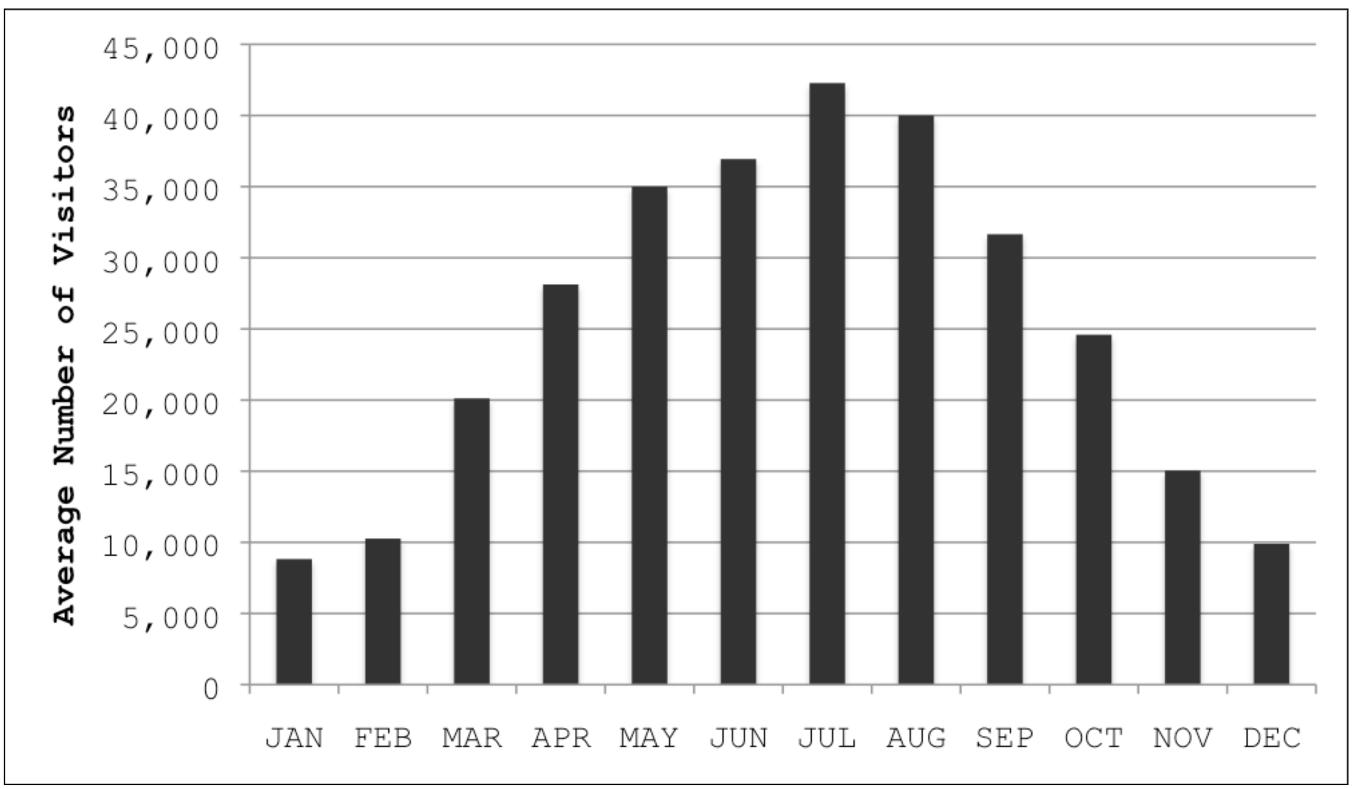


Figure 2.1.3-1. Average number of visitors by month to Sunset Crater Volcano NM from 1979-2017.

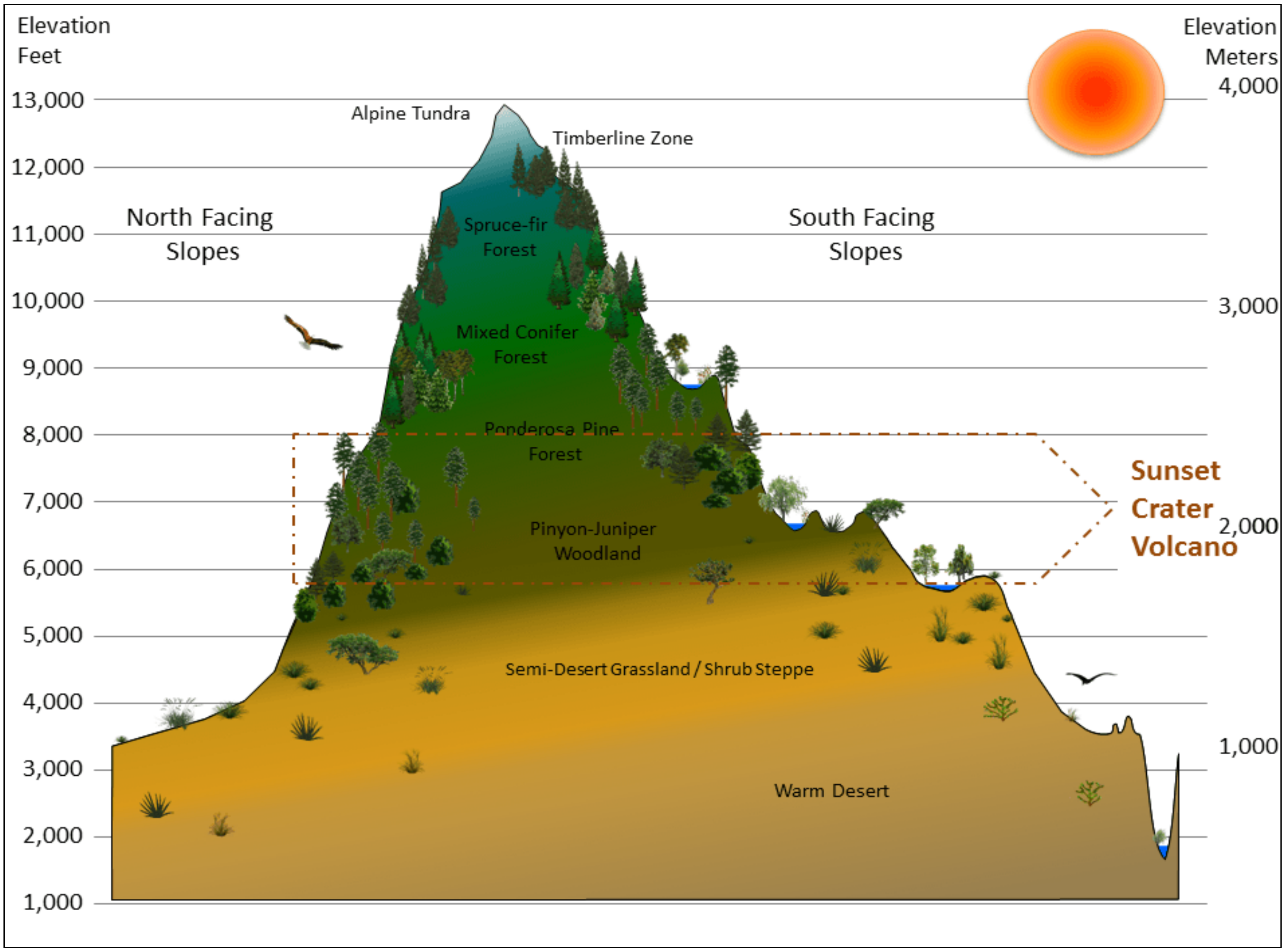


Figure 2.2.1-1. Sunset Crater Volcano NM spans three life zones. Figure Credit: NPS SCPN (2017b).

the Bonito Lava Flow are the major geologic features at the monument.

Watershed Units

The national monument is located in two watersheds. Fifty-eight percent of the monument is within the Doney Park watershed, which covers an area of 170.5 km^2 (42,133 ac), and 42% of the monument is located in the Upper Kana-a-Wash watershed (U.S. Geological Survey [USGS 2014]) (Figure 2.2.1-2). The Upper Kana-a-Wash watershed is a little smaller and encompasses a total area of 157 km^2 (38,801 ac). The monument only occupies 4.2% and 3.3% of each of the watersheds, respectively.

NPScape Landscape-scale

Most of the monument's natural resources (e.g., viewshed, night sky, volcanic features, cinder terrain, vegetation, wildlife, etc.) are affected by landscape-scale processes, and this broader perspective often provides more comprehensive information to better understand resource conditions. Studies have shown that natural resources rely upon the larger, surrounding area to support their life cycles (Coggins 1987 as cited in Monahan et al. 2012), and most parks are not large enough to encompass self-contained ecosystems for the resources found within their boundaries. This is especially important to Sunset Crater Volcano's natural resources due to the increasing population and developments surrounding Flagstaff, AZ that fragment what is currently intact natural areas. When feasible, landscape-scale indicators and measures were included in the condition assessments to provide an ecologically relevant, landscape-scale context for reporting resource conditions. NPS NPScape metrics were used to report on these resource conditions, providing a framework for conceptualizing human effects (e.g., housing densities, road densities, etc.) on landscapes (NPS 2014a,b). A more comprehensive evaluation of habitat and resource connectivity for

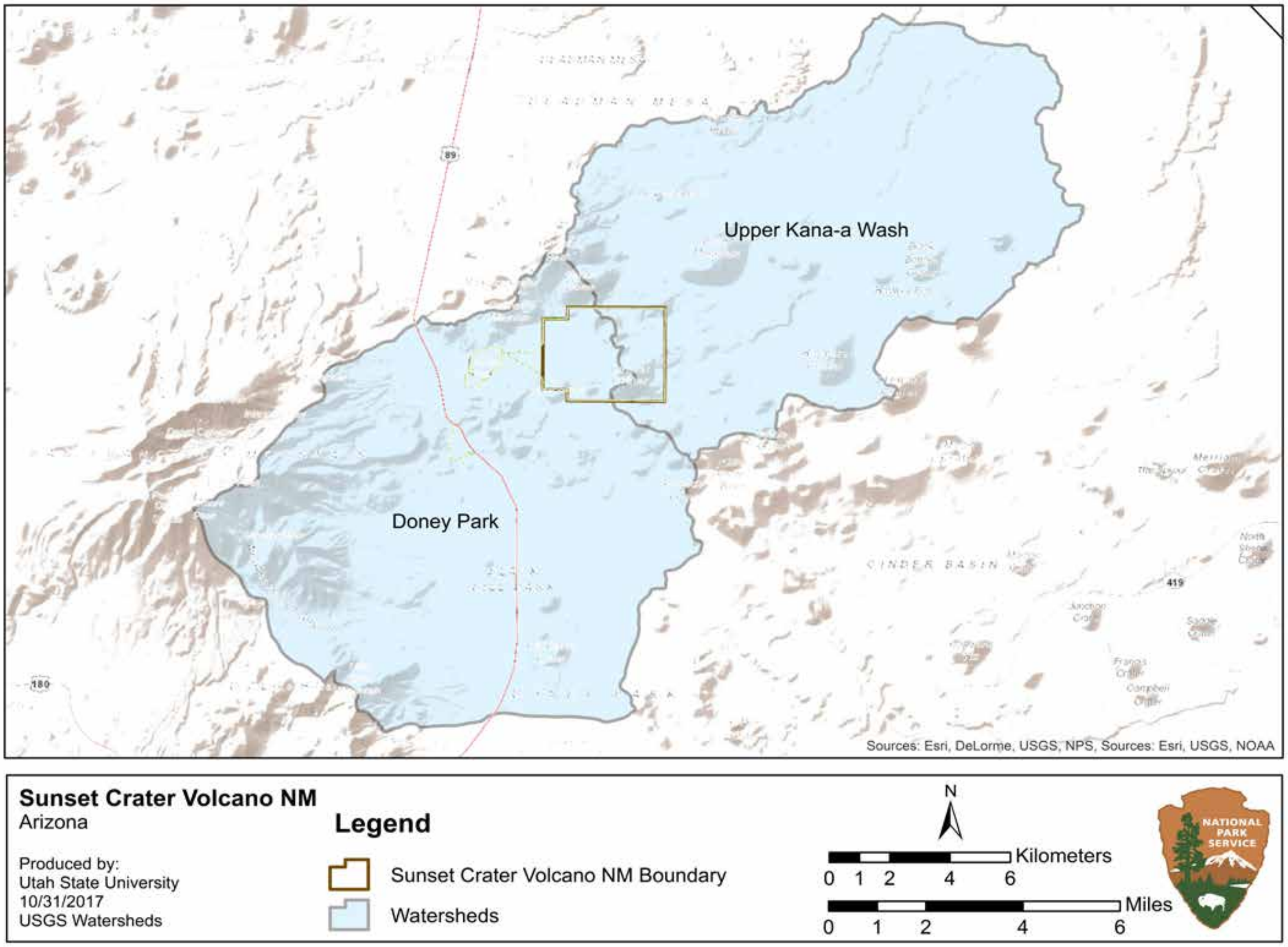


Figure 2.2.1-2. Sunset Crater Volcano NM is located within two watersheds.

selected wildlife species between the Flagstaff Area NMs is presented in Chapter 5 of this report.

2.2.2. Resource Descriptions

Viewshed

The monument was established in 1930 to protect the significant geological resources from the volcanic eruption that occurred about 900 years ago. The stark landscape of the cinder cone, Bonito Lava Flow, and associated volcanic cinder terrain create scenery that attracts visitors to the national monument. Viewsheds are considered an important part of the visitor experience at national parks and features on the visible landscape influence the enjoyment, appreciation, and understanding of the park. Vistas of native vegetation and natural landscape features dominate most of the monument's viewshed, with much of the surrounding rural landscape exhibiting low housing and road densities.

Night Sky

Dark night skies are considered an aesthetic in national parks and offer an experiential quality that is also integral to natural and cultural resources (Moore et al. 2013). Historically, American Indian's observation of the sun, moon and stars was essential for planning festivals and activities such as when to start planting and when to harvest (Aveni 2003). In an estimated 20 national parks, stargazing events are the most popular ranger- led program (NPS 2010a). But the values of night skies go far beyond visitor experience and scenery. The photic environment affects a broad range of species, is integral to ecosystems, and is a natural physical process (Moore et al. 2013). In 2016, Sunset Crater Volcano NM was designated an International Dark Sky Park by the International Dark Sky Association (IDA), a non-profit organization dedicated to preserving dark night skies around the world (IDA 2016). In addition, the city of Flagstaff, AZ was designated as the world's first International Dark

Sky Community due to its progressive outdoor lighting policy enacted in 1958— the world's first outdoor lighting ordinance (IDA 2016).

The NPS Natural Sounds and Night Skies Division (NSNSD) scientists conducted an assessment of Sunset Crater Volcano NM's night sky condition from two locations. The results were used to evaluate the night sky condition at the monument and to support the IDA application (NPS 2016a).

Soundscape

According to a majority of members of the American public surveyed, opportunities to experience natural quiet and the sounds of nature is an important reason for having national parks (Haas and Wakefield 1998). Baseline acoustical monitoring data for Sunset Crater Volcano NM were collected by park natural resource staff. An acoustical monitoring system was deployed at one location within the national monument during the months of July and August 2010. These data, along with results from a sound model developed by Mennitt et al. (2013), were used to evaluate the soundscape condition at the monument.

Air Quality

Two categories of air quality areas (Class I and II) have been established through the authority of the Clean Air Act of 1970 (42 U.S.C. §7401 et seq. (1970)). Like most NPS areas, Sunset Crater Volcano NM is designated as a Class II airshed. One air quality monitoring station is located within the required distance from the monument to derive trends for visibility. To date, three plants in the national monument are known to be ozone sensitive species (Bell in review).

Vegetation

There is a diversity of vegetation within the monument and the surrounding environment (consisting of the Coconino National Forest, including large areas of unvegetated beds of cinder or lava and rock outcrops, grassy meadows, open tree stands, and dense forests (Hansen et al. 2004). Woodlands (with relatively open forest canopies) are the predominate vegetation type in the national monument and surrounding area (Hansen et al. 2004), with ponderosa pine being the most common tree species, followed by pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*; Hansen et al. 2004). Ponderosa pine woodlands are usually found on cinder soils within the monument, and can be found on most landforms, except at the highest elevations and on the driest, south-facing slopes (Hansen et al. 2004). Canopy cover in the ponderosa pine woodlands within Sunset Crater NM is relatively sparse compared to other ponderosa pine associations throughout their range due to limits on tree establishment and growth rates in the volcanic environment (Hansen et al. 2004). The ponderosa pine communities within the monument tend to have little to no understory cover. Pinyon pine and juniper trees are more common (mixed with ponderosa pine) in the eastern and northern portions of the national monument (NPS 2009).

Douglas-fir (*Pseudotsuga menziesii*), quaking aspen (*Populus tremuloides*), and southwestern white pine (*Pinus strobiformis*) within Sunset Crater Volcano NM are of particular interest because of their limited occurrence within the national monument. They generally depend upon cooler and more mesic (wet) conditions in order to establish and survive than the other tree species within the monument, making them more sensitive or vulnerable to disturbances and threats. Sunset Crater beardtongue (*Penstemon clutei*) is a perennial herb endemic to the volcanic soils of the northeastern San Francisco Volcanic Field, including the national monument. The range of Sunset Crater beardtongue is approximately 350 km^2 (135 mi^2), but the population is disjunct (Springer et al. 2010). The larger of the two subpopulations is centered on the Cinder Hills OHV (off-road vehicle) area south of the monument, but the park provides protected habitat for this rare plant.

Wildlife

Data for wildlife topics are lacking for Sunset Crater Volcano NM and are listed as data gaps for birds, mammals, and herpetofauna. To date, a total of 34 mammals have been documented in the monument, including two non-native species, domestic sheep (*Ovis aries)*, and elk (*Cervus canadensis)*. The native Arizona or Merriam's elk (*Cervus canadensis merriami*) was hunted to extinction in the early 1900s. The Rocky Mountain elk (*Cervus canadensis nelsoni*) was introduced in 1913. The two species play very similar roles in the ecosystem unlike the other non-natives that are mentioned in this report. Only one species on the monument's NPSpecies list, Brazilian (or Mexican) free-tailed bat (*Tadarida brasiliensis*), is listed as a species of Greatest Conservation Need (SGCN) in the state (Arizona Game and Fish Department [AGFD] 2012).

Five herpetofauna species have been documented in the monument (noted as present), with an additional eight species that may occur (probably occur or unconfirmed). No non-native herpetofauna species have been observed, and no SGCN species have been identified at the monument. The monument's NPSpecies list for birds includes 103 confirmed species. An additional 12 species are considered probably present and 10 species remain unconfirmed. Only two non-native species, European starling (*Sturnis vulgaris*) and house sparrow (*Passer domesticus)* have been recorded. Ten species have been identified as SGCN by AGFD (2012).

2.2.3. Resource Issues Overview

Like many places, the Southwest is already experiencing the impacts of climate change. The predictions are that the Southwest will likely continue to become warmer and drier with continued climate change (Garfin et al. 2014, Monahan and Fisichelli 2014). The Southern Colorado Plateau is vulnerable to the impacts of climate change due to its semi-arid climate.

According to Kunkel et al. (2013), the historical climate trends (1895-2011) for the Southwest (including the states of Arizona, California, Colorado, Nevada, New Mexico, and Utah) have seen an average annual temperature increase of 0.9°C (greatest in winter months) and more than double the number of four-day periods of extreme heat. Future climate predictions (Kunkel et al. 2013) for 2070-2099 (based on climate patterns from 1971-1999) estimate temperatures could rise between 2.5°C and 4.7°C.

Monahan and Fisichelli (2014) assessed the magnitude and direction of changes in climate for Sunset Crater Volcano NM for 25 variables including temperature and precipitation between 1901-2012 (historical range of variability (HRV)). Results for extreme climate were defined as experiencing either <5th percentile or >95th percentile climates relative to the HRV. The results for the extreme climate variables at Sunset Crater Volcano NM were as follows:

- Three temperature variables were "extreme warm" (annual mean temperature, mean temperature of the warmest quarter, and maximum temperature of the warmest month).
- No temperature variables were "extreme cold."
- Three precipitation variables were "extreme dry" (annual precipitation, precipitation of the driest month, precipitation of the driest quarter).
- No precipitation variables were "extreme wet."

The results for the temperature of each year between 1901-2012, the averaged temperatures over progressive 10-year intervals, and the average temperature of 2003-2012 (the most recent interval) are shown in Figure 2.2.3-1. The blue line shows temperature for each year, the gray line shows temperature averaged over progressive 10-year intervals (10-year moving windows), and the red asterisk shows the average temperature of the most recent 10-year moving window (2003–2012). The most recent percentile is calculated as the percentage of values on the gray line that fall below the red asterisk. The results indicate that recent climate conditions have already begun

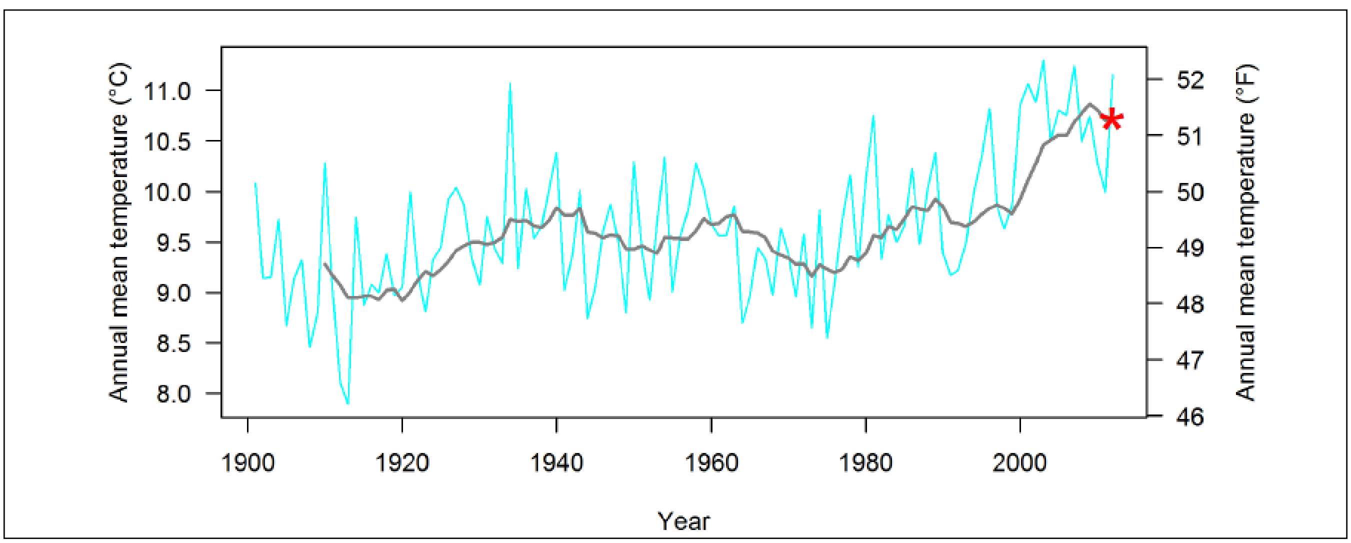


Figure 2.2.3-1. Time series used to characterize the historical range of variability and most recent percentile for annual mean temperature at Sunset Crater Volcano NM (including areas within 30-km [18.6-mi] of the park's boundary). Figure Credit: © Monahan and Fisichelli (2014).

shifting beyond the HRV, with the 2003-2012 decade representing the warmest decade on record. Garfin et al. (2014) expect more sustained extreme heat and fewer and less extreme cold periods. Overall, it's likely that future climate change will increasingly affect all aspects of park resources and operations (Monahan and Fisichelli 2014).

Prein et al. (2016) report that the western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall. Since 1974 there has been a 25% decrease in precipitation; however, this is a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016). However, surface water is almost non-existent within the monument and the rugged volcanic terrain, such as the Bonito Lava Flow, are so inhospitable that they likely provide little habitat for wildlife. In addition, the high daytime temperatures, high permeability in the deep cinders, low nutrient concentrations, low water-holding capacity, and sediment mobility by water, wind, and gravity limit plant growth and ecological succession in the volcanic cinder terrain of Sunset Crater Volcano NM. The related slow rates of soil development further limit the rate of ecological succession.

Drought, high temperatures, bark beetle infestations, and uncontrolled or severe wildfire are threats to the vegetation that does exist in the monument. These are threats, particularly to all trees and ecosystem components within the forests, but they may be of particular concern for the older, larger conifer trees growing in the monument.

Unregulated off-road vehicle activity may negatively affect Sunset Crater beardtongue, especially with repeated use, but there are no studies that address this potential threat. Other potential threats include herbivory, and hybridization with cultivated *Penstemon* species (Glenne 2003 as cited in Springer et al. 2010). But of all the stressors on beardtongue, climate change has the most potential to influence this species (Krause et al. 2015, Krause no date).

Even though backcountry use is not permitted in the national monument (NPS 1996), and the majority of visitors are concentrated along road corridors at pullouts, visitor centers, and interpretive exhibits rather than dispersed across the park, landscape-scale threats such as climate change and associated drought and high temperature conditions will likely have the most significant impacts to the natural resources.

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

In addition to NPS staff input based on the monument's purpose, significance, and fundamental resources and values, and other potential resources/ecological drivers of interest, the NPS Washington-level programs guided the selection of key natural resources for this condition assessment. This included Southern Colorado Plateau Inventory and Monitoring (I&M) Network (SCPN) Program, I&M NPScape Program for landscape-scale measures, Air Resources Division for air quality, and the Natural Sounds and Night Skies Program for the soundscape and night sky assessments.

<u>SCPN I&M Program</u>

In an effort to improve overall national park management through expanded use of scientific knowledge, the 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 2011a). 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; and
- share NPS accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives (NPS 2011a).

To facilitate this effort, 270 parks with significant natural resources were organized into 32 regional networks. Sunset Crater Volcano NM is part of the SCPN, which includes 18 additional parks. Through a rigorous multi-year, interdisciplinary scoping process, SCPN 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. Sunset Crater Volcano NM's land surface phenology was selected for monitoring by SCPN (NPS SCPN 2014).

Park Planning Reports

Natural Resource Condition Assessments

The structural framework for NRCAs is based upon, but not restricted to, the fundamental and other important values identified in a park's Foundation Document or General Management Plan. NRCAs are designed to deliver current science-based information translated into resource condition findings for a subset of a park's natural resources. The NPS State of the Park (SotP) and Resource Stewardship Strategy (RSS) reports rely on credible information found in NRCAs as well as a variety of other sources (Figure 2.3.1-1).

Foundation Document

Foundation documents describe a park's purpose and significance and identify fundamental and other important park resources and values. A foundation document was completed for Sunset Crater Volcano NM in 2015 and was used to identify some of the primary natural features throughout the monument for the development of its NRCA.

State of the Park

A State of the Park (SotP) report is intended for non-technical audiences and summarizes key findings of park conditions and management issues, highlighting recent park accomplishments and activities. NRCA condition findings are used in SotP reports, and each Chapter 4 assessment in this report includes a SotP condition summary.

Resource Stewardship Strategy

A Resource Stewardship Strategy (RSS) uses past and current resource conditions to identify potential management targets or objectives by developing

Figure 2.3.1-1. The relationship of NRCAs to other National Park Service planning reports.

comprehensive strategies using all available reports and data sources including NRCAs. National Parks are encouraged to develop an RSS as part of the park management planning process. Indicators of resource condition, both natural and cultural, are selected by park staff. After each indicator is chosen, a target value is determined and the current condition is compared to the desired condition. An RSS has not been completed for Sunset Crater Volcano NM.

2.3.2. Status of Supporting Science

The amount of available data and reports varied depending upon the resource topic. The existing data used to assess condition of each indicator and/or to develop reference conditions are described in each of the Chapter 4 assessments. In addition to the data obtained from the SCPN I&M and research conducted by other scientists and programs, subject matter experts, Paul Whitefield and Kirk Anderson, served as authors for the volcanic resources and recent volcanic terrain condition assessments, respectively. Additional Washington level programs, including I&M NPScape, Climate Change Response Program, Natural Sounds and Night Skies, and Air Resources Divisions provided a wealth of information to inform conditions for the monument's selected natural resources.

Flagstaff Area National Monuments' NRCA scoping meeting was held on May 17-19, 2016. Photo Credit: NPS.

Chapter 3. Study Scoping and Design

Sunset Crater Volcano National Monument (NM) Natural Resource Condition Assessment (NRCA) was coordinated by the National Park Service (NPS) Intermountain Region Office, Utah State University, and the Colorado Plateau Cooperative Ecosystem Studies Unit through task agreements, P14AC00749 and P15AC01212.

The NRCA process was a collaborative effort between the Flagstaff Area NMs' (Sunset Crater Volcano, Wupatki, and Walnut Canyon) staff, Southern Colorado Plateau Inventory and Monitoring Network staff, Intermountain Region NRCA Coordinator, and the NRCA team from Utah State University. Dr. Kirk Anderson, with the Museum of Northern Arizona, was selected as the subject matter expert for the park's volcanic cinder terrain condition assessment through the Colorado Plateau Cooperative Ecosystem Studies Unit task agreement P14AC00921. Paul Whitefield, Flagstaff Area NMs' Natural Resource Specialist, was selected as the subject matter expert for the park's unique volcanic features condition assessment.

3.1. Preliminary Scoping

Preliminary scoping for Sunset Crater Volcano NM's NRCA project began in March 2015. Paul Whitefield, submitted a draft list of natural resource topics based on the 'key [natural] resources and values identified in the park's Foundation Document (NPS 2015a). Paul Whitefield and Michael Jones, Flagstaff Area NMs' GIS Specialist, compiled reports and data sets pertaining to the preliminary list of natural resources, and Donna Shorrock, NPS IMR NRCA Coordinator (former) facilitated the process of uploading the park's information to USU's ftp site. Science writers from USU reviewed these reports and data sets and developed draft indicators, measures, and reference conditions, which served as the primary discussion guide during the on-site NRCA scoping workshop.

The workshop was held over a three day period from May 17-19, 2016 at the Flagstaff Area NMs' headquarters in Flagstaff, Arizona. The initial list of natural resource topics submitted by the park were reviewed, discussed, and refined by scoping workshop attendees (listed in Appendix B). Through discussions, meeting participants reviewed and refined the draft indicators, measures, and reference conditions for each resource topic. Some topics were omitted and some key resources were identified and selected as focal resources for the condition assessment. Additional datasets and reports were identified and incorporated into the revised assessment approach. Park staff also identified important concerns, issues/stressors, and data gaps for each natural resource topic. The final list of selected natural resources and their associated indicators, measures, threats/stressors, and data gaps are discussed in each Chapter 4 assessment.

3.2. Study Design

3.2.1. Indicator Framework, Focal Study Resources and Indicators

Sunset Crater Volcano NM's NRCA utilizes the NPS Inventory & Monitoring (I&M) Program's "NPS Ecological Monitoring Framework" (NPS 2005). This framework was endorsed by the National NRCA Program as an appropriate framework for listing resource components, indicators/measures, and resource conditions. Additionally, Flagstaff Area National Monuments' natural resource files, Southern Colorado Plateau Inventory and Monitoring Network's (SCPN) Vital Signs Plan (Thomas et al. 2006), and the RM-77 NPS Natural Resource Management Guideline (NPS 2004) are all organized similarly to the I&M framework.

Each NRCA report represents a unique assessment of key natural resource topics that are important to each park. For the purposes of Sunset Crater Volcano NM's NRCA, nine focal resources were selected for assessment, which are listed in Tables 3.2.1-1 -3.2.1-4. This list of resources does not include every natural resource at the park, but represents the natural resources and processes that were of greatest significance to park staff at the time of this effort. Each resource's threats and stressors were discussed and are presented in Table 3.2.1-5. Additional resources considered important, but listed as data gaps, are presented in Table 3.2.1-6.

Staff gave thought to identifying focal resource topics which have been consistently identified in legacy planning documents and literature, possess knowledge bases that are sufficient for establishing baseline condition, are indicative of overall ecologic and biotic integrity, have also been identified by stakeholders as focal resources on adjacent lands, or where resource trend may be increasingly understood as the NPS SCPN progresses with vital signs monitoring (Thomas et al. 2006). Staff were also interested in including some focal resources which may be vulnerable to degradation and possible loss due to climate change.

Table 3.2-1-1. Sunset Crater Volcano NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for landscapes patterns and processes.

Resource	Indicators	Measures
Viewshed	Scenic and Historic Integrity	Conspicuousness of Non-contributing Features
	Scenic and Historic Integrity	Extent of Development
Night Sky	Sky Brightness	All-sky Light Pollution Ratio
	Sky Brightness	Vertical Maximum Illuminance
	Sky Brightness	Horizontal Illuminance
	Sky Brightness	Zenith Sky Brightness
	Sky Quality	Bortle Dark Sky Scale
Soundscape	Sound Level	% Time Above Reference Sound Levels
	Sound Level	% Reduction in Listening Area
	Audibility of Anthropogenic Sounds	% Time Audible
	Geospatial Model	L_{50} Impact

Table 3.2.1-2. Sunset Crater Volcano NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for air and climate.

Resource	Indicators	Measures
Air Quality	Visibility	Haze Index
	Ozone	Human Health
	Ozone	Vegetation Health
	Wet Deposition	Nitrogen
	Wet Deposition	Sulfur
	Wet Deposition	Mercury
	Wet Deposition	Predicted Methylmercury Concentration

Reference conditions were identified with the intent of providing a benchmark to which the current condition of each indicator/measure could be compared using existing research and documentation. When a quantifiable reference for a given measure was not feasible, an attempt was made to include a qualitative reference to provide some context for interpreting current resource condition.

Table 3.2.1-3. Sunset Crater Volcano NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for geology and soils.

Resource	Indicators	Measures
Recent Volcanic Cinder Terrain	Cinder Cone Morphology	Cone Slope Angles
	Cinder Cone Morphology	Hc/Wc
	Cinder Cone Morphology	Cd/Cw
	Cinder Cone Morphology	Rill Length
	Cinder Cone Morphology	Rill Density
	Cinder Cone Morphology	Trail Networks
	Lava Flow Morphology	Surface Roughness
	Lava Flow Morphology	Trail Networks
	Soil Formation	% Organic Matter
	Soil Formation	O Horizon Thickness
	Soil Formation	Total Organic Carbon
	Soil Formation	Total Soil Nitrogen
	Soil Formation	% Silt + Clay ("Loess")
	Soil Formation	Soil Aggregate Stability
	Primary Ecological Succession	Colonization Of Flow Edges And Niches On Flow
	Primary Ecological Succession	Islands Of Fertility
Volcanic Features	Volcanic Landforms	Estimated Percentage of Persistent Surface Alteration
	Volcanic Eruption Features	Relative Percentage of Altered Inventoried Eruption Features

Table 3.2.1-4. Sunset Crater Volcano NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for biological integrity.

Resource	Indicators	Measures
Ponderosa Pine Forest	Ponderosa Pine-Pinyon-Juniper Vegetation Occurrence	Total Area Covered within National Monument
	Fire Regime	Departure from Natural Historical Fire Regime: Fire Regime Condition Class
	Status / Health of Trees	Extent of Conifer Mortality
Sensitive Trees	Species Occurrence	Presence/Absence of Douglas-fir
	Species Occurrence	Presence/Absence of Quaking Aspen
	Species Occurrence	Presence/Absence of Southwestern White Pine
Sunset Crater Beardtongue	Prevalence	Presence/Absence
	Population Structure	# Plants/Life Stage
	Response to Disturbance	Prescribed Fire
	Response to Disturbance	Root Trenching
	Response to Disturbance	Salvage Logging

3.2.2. Reporting Areas

The primary focus of the reporting area was within the national monument's legislative boundary; however, some of the analyses encompassed areas beyond the park's boundary. Certain aspects of natural resources assessed at the landscape level included viewshed, night sky, soundscape, and habitat connectivity. Data and reports for the night sky and soundscape assessments were provided by the NPS Natural Sounds and Night Skies Division. USU completed both the viewshed and habitat connectivity analyses, augmenting condition reporting using the NPS NPScape Program datasets and Area of Analysis for the viewshed and 30-km boundaries (NPS 2015b).

3.2.3. General Approach and Methods

The general approach to developing the condition assessments included reviewing literature and data and/or speaking to subject matter expert(s) for each of the focal resource topics, and when applicable, analyzing existing data to provide new interpretations for condition reporting. Following the NPS NRCA guidelines (NPS 2010b), each Chapter 4 assessment included six sections briefly described below.

The background and importance section of the NRCA report provided information regarding the relevance of the resource to the national monument using existing project proposals or descriptions previously developed by park staff for various planning documents.

Table 3.2.1-5. Resource condition assessment topic threats and stressors.

Resource	Threats / Stressors / Data Gaps
Viewshed	Regional development, associated view and light pollution - effects on most nocturnal species are not well understood
Night Sky	New visitor activities (e.g., casinos)
	Increasing dust and smog due to climate change
	Regional development, associated view and light pollution - effects on most nocturnal species are not well understood
Soundscape	Regional development and anthropogenic noises
	Effects of noise on most species are not well understood
Air Quality	Increasing dust from various sources (e.g., local industry, USFS Forest-wide Materials Quarry, climate change, etc.)
	USFS prescribed burns and increasing frequency of wildfires in the southwest
	Lack of vegetation monitoring for potential ozone impact
Recent Volcanic Cinder Terrain	Timber extraction
	Recreation, including trail systems
	Facility and infrastructure developments
Volcanic Resources	Impacts from increasing visitation, if coupled with insufficient communications to visitors
	Unmanaged cross-country hiking
	Off-road vehicle use
	Understanding of permanence versus resilience of trampling impacts on volcanic cinder substrates
Ponderosa Pine Forest	Uncontrolled or severe wildfire
	Pests/Disease
	Climate change (e.g., drought) and effects may be of particular concern for older, larger coniferous trees
	Lack of repeatable stand data to determine trend
	Improved documentation of any widespread mortality events that occur in the future
Sensitive Trees	Very vulnerable to extirpation - limited distribution and population
	Increased fire and drought due to climate change
	Pests/disease
	Lacking fire history data
	No current data on Southwestern white pine, may be a future study along the north slope
	No stand data for any of the species
Sunset Crater Beardtongue	Resource is a data gap; not well understood
	Unregulated off-road vehicle activity
	Herbivory, and hybridization with cultivated *Penstemon* species
	Climate model suggests Sunset Crater beardtongue is very susceptible to climate change

The data and methods section of the assessment described the existing data sets and methodologies used for evaluating the indicators/measures for current condition.

The reference conditions section listed the good, moderate concern, and significant concern definitions used to evaluate the condition of each measure.

The condition and trend section provided a discussion of the condition and trend, if available, for each indicator/measure based on the reference condition(s). Condition icons were presented in a standard format consistent with *State of the Park* reporting (NPS 2012a) and served as visual representations of condition/trend/level of confidence for each measure that was evaluated. Table 3.2.3-1 shows the condition/trend/confidence level scorecard used to describe the condition for each assessment, and Table 3.2.3-2 provides examples of conditions and associated interpretations.

Circle colors conveyed condition. Red circles signified that a resource was of significant concern; yellow circles signified that a resource was of moderate condition; and green circles denoted that a measure was in good condition. A circle without any color, which was often associated with the low confidence symbol-dashed line, signified that there was insufficient information to make a statement about condition; therefore, condition was unknown.

Table 3.2.1-6. Additional resource data gaps identified during scoping workshop.

Resource	Notes
Birds	Need point count routes
Mammals	Establish bat monitoring station in the future
Herpetofauna	Limited information for park

Arrows inside the circles signified the trend of the indicator/measure. An upward pointing arrow signified that the measure was improving; double pointing arrows signified that the measure's condition was currently unchanging; a downward pointing arrow indicated that the measure's condition was deteriorating. No arrow denoted an unknown trend.

The level of confidence in the assessment ranged from high-low and was symbolized by the border around the condition circle. Key uncertainties and resource threats were also discussed in the condition and trend section for each resource topic.

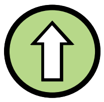
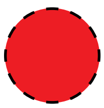
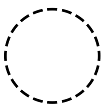
The sources of expertise included individuals who were consulted and/or provided a review and were listed in this section, along with the writer(s) who drafted the assessment.

An external drive was included in the final report with copies of all literature cited unless the citation was from a book or a URL was provided.

Table 3.2.3-1. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

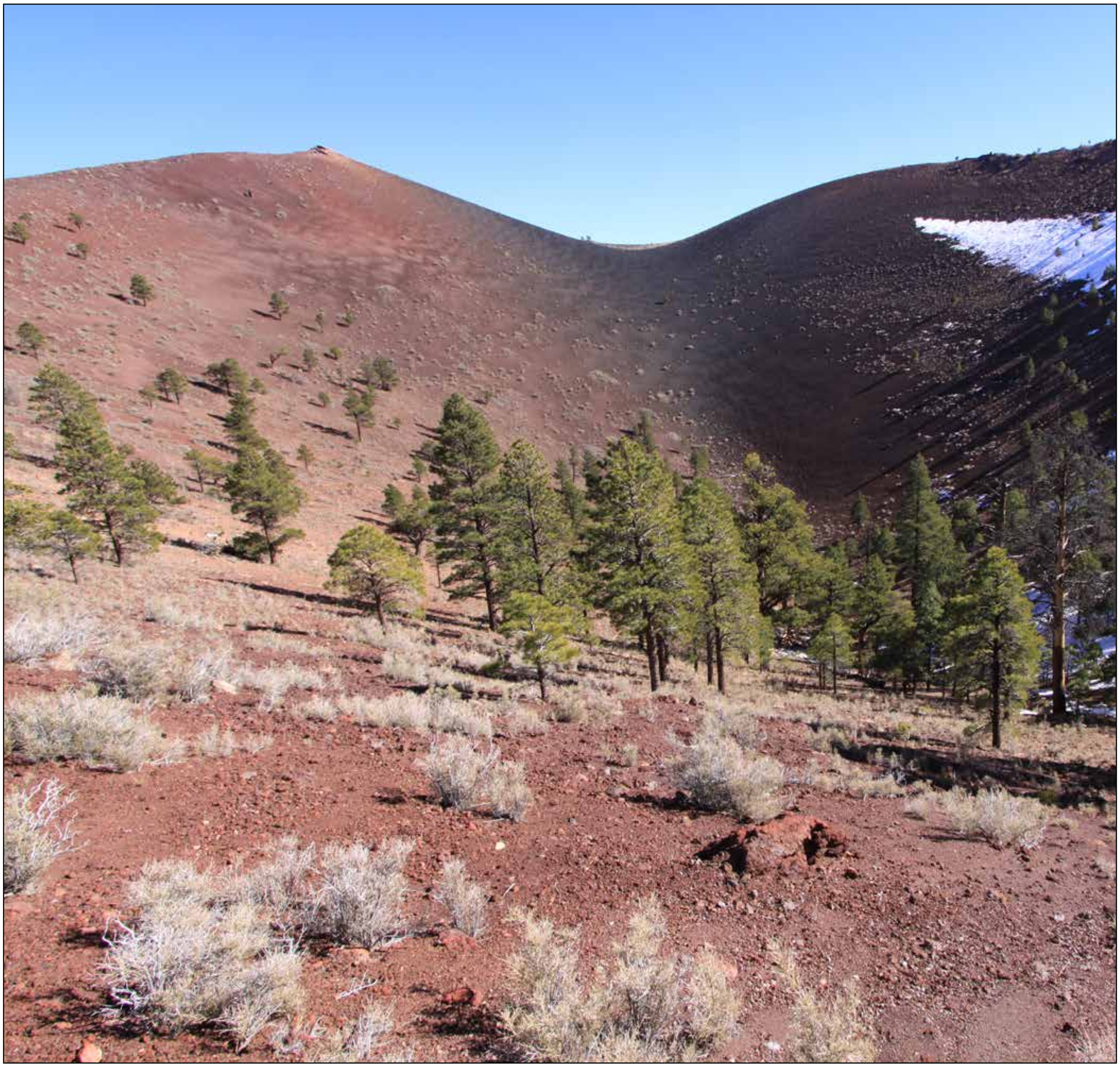
Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in good condition.		Condition is Improving.		High
	Resource warrants moderate concern.		Condition is unchanging.		Medium
	Resource warrants significant concern.		Condition is deteriorating.		Low
	An open (uncolored) circle indicates that current condition is unknown or indeterminate; this condition status is typically associated with unknown trend and low confidence.				

Table 3.2.3-2. Example indicator symbols and descriptions of how to interpret them.

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

Chapter 4. Natural Resource Conditions

Chapter 4 delivers current condition reporting for the nine important natural resources and indicators selected for Sunset Crater Volcano NM's NRCA report. The resource topics are presented following the National Park Service's (NPS) Inventory & Monitoring Program's NPS Ecological Monitoring Framework that is presented in Chapter 3.



Sunset Crater vent. Photo Credit: NPS / C. Schelz.

4.1. Viewshed

4.1.1. Background and Importance

The conservation of scenery is established in the National Park Service (NPS) Organic Act of 1916 ("… to conserve the scenery and the wildlife therein…"), reaffirmed by the General Authorities Act, as amended, and addressed generally in the NPS 2006 Management Policies sections 1.4.6 and 4.0 (Johnson et al. 2008). Although no management policy currently exists exclusively for scenic or viewshed management and preservation, parks are still required to protect scenic and viewshed quality as one of their most fundamental resources. According to Wondrak-Biel (2005), aesthetic conservation, interchangeably used with scenic preservation, has been practiced in the NPS since the early twentieth century. Aesthetic conservation strove to protect scenic beauty for park visitors to better experience the values of the park. The need for scenic preservation management is as relevant today as ever, particularly with the pervasive development pressures that challenge park stewards to conserve scenery today and for future generations.

Sunset Crater Volcano National Monument (NM) preserves a 1,229 ha (3,038 ac) area that is completely surrounded by the Coconino National Forest (NPS 1996). The monument was established in 1930 to preserve the 1,000 year-old Sunset Crater cinder cone and surrounding black lava fields that illustrate the region's dramatic past (Figure 4.1.1-1). The now extinct volcano erupted sometime between AD 1064 and 1180, covering the monument in a thick layer of volcanic cinder deposits (Thornberry-Ehrlich 2005). The eruption drove local inhabitants from the region, but by about A.D. 1225 members of the Sinagua, Cohonina, and Kayenta peoples recolonized the region surrounding the monument (NPS 1996). Approximately half of the monument's landscape is comprised of barren cinder fields, while Ponderosa pine (*Pinus ponderosa*) woodlands represent the dominant vegetation type (Hansen et al. 2004).

<u>Visitor Experience</u>

Viewsheds are considered an important part of the visitor experience at Sunset Crater Volcano NM, and features on the visible landscape influence a visitor's enjoyment, appreciation, and understanding of the monument. The monument's wilderness setting and proximity to a large urban community "offers spectacular views of undisturbed volcanic landscapes, cinder dunes, and lava flows" (NPS 2015). These views represent much more than just scenery; they represent a way to better understand the connection between self and nature. Visitors to the monument are provided opportunities to immerse themselves in the wilderness where experiences become more remote from anthropogenic sights and sounds, offering an

Figure 4.1.1-1. Sunset Crater Volcano with the San Francisco Peaks in the background. Photo Credit: NPS.

opportunity to literally "visualize" their connection to nature and past geologic forces.

Inherent in virtually every aspect of this assessment is how features on the visible landscape influence the enjoyment, appreciation, and understanding of the monument by visitors. The indicators we use for condition of the viewshed are based on studies related to perceptions people hold toward various features and attributes of viewsheds.

4.1.2. Data and Methods

In general, there is a wealth of research demonstrating that people tend to prefer natural landscapes over human-modified landscapes (Zube et al. 1982, Kaplan and Kaplan 1989, Sheppard 2001, Kearny et al. 2008, Han 2010). Human-altered components of the landscape (e.g., roads, buildings, power lines, and other features) that do not contribute to the natural scene are often perceived as detracting from the scenic character of a viewshed. Despite this generalization for natural landscape preferences, studies have also shown that not all human-made structures or features have the same impact on visitor preferences. Visitor preferences can be influenced by a variety of factors including cultural background, familiarity with the landscape, and their environmental values (Kaplan and Kaplan 1989, Virden and Walker 1999, Kaltenborn and Bjerke 2002, Kearney et al. 2008).

While we recognize that visitor perceptions of an altered landscape are highly subjective, and that there is no completely objective way to measure these perceptions, research has shown that there are certain landscape types and characteristics that people tend to prefer over others. Substantial research has demonstrated that human-made features on a landscape are perceived more positively when they are considered in harmony with the landscape (e.g., Kaplan and Kaplan 1989, Gobster 1999, Kearney et al. 2008).

Kearney et al. (2008) showed that survey respondents tended to prefer development that blended with the natural setting through use of colors, smaller scale, and vegetative screening. These characteristics, along with distance from non-contributing features and movement and noise associated with observable features on the landscape, are discussed below.

Scenic and historic integrity is defined as the state of naturalness or, conversely, the state of disturbance created by human activities or alteration (U.S. Forest Service (USFS 1995). This aspect of the assessment focuses on the features of the landscape related to non-contributing human alteration/development.

Key Observation Points

Three key observation points were selected by NPS staff (Table 4.1.2-1, Figure 4.1.2-1). The three locations were used to qualitatively evaluate viewshed condition using GigaPan panoramas and to quantitatively evaluate condition using viewshed analysis overlaid with NPScape housing and road densities. These locations were chosen based on viewsheds that are accessible to the public, are located upon a prominent landscape feature, are inclusive of natural resources, and include scenic views (NPS, M. Szydlo, Biologist, email message, 9/2/2016). The three locations used in this assessment include one site (Bonito Park) located outside of the monument to the west and two sites located inside the monument at Lava Trail and Cinder Hills Overlook.

Five observations points were originally chosen by NPS staff but two of the locations did not offer additional insight into the monument's viewshed because they were located in proximity to one another and offered limited viewsheds. However, we included the panoramic images for these two locations in Appendix C.

Conspicuousness of Non-Contributing Features

GigaPan Images

We used a series of panoramic images to portray the viewshed from an observer's perspective. These images were taken from each key observation point using a Canon PowerShot digital camera and the GigaPan Epic 100 system, a robotic camera mount coupled with stitching software (Figure 4.1.2-2).

Table 4.1.2-1. Key observation points used to assess Sunset Crater Volcano NM's viewshed condition.

Site Location	Image Date	Coordinates - Easting, Northing (UTM NAD83 12N)
Bonito Park	12/15/2016	449533/3914422
Lava Trail	12/15/2016	452512/3913222
Cinder Hills Overlook	12/15/2016	455478/3914348

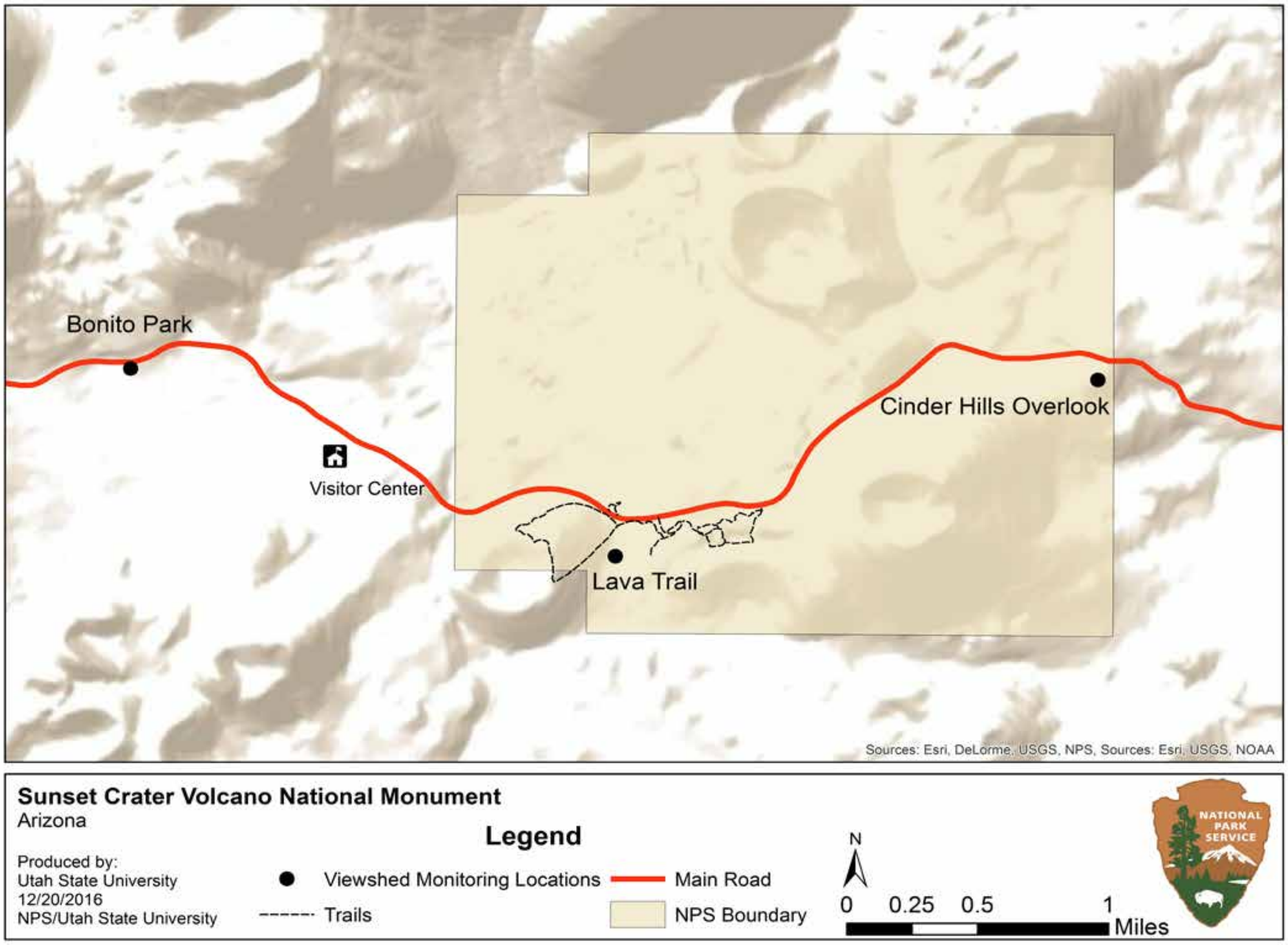


Figure 4.1.2-1. Locations of 2016 viewshed monitoring locations at Sunset Crater Volcano NM.

Figure 4.1.2-2. The GigaPan system takes a series of images that are stitched together using software to create a single panoramic image.

A series of images were automatically captured and the individual photographs are stitched into a single high-resolution panoramic image using GigaPan Stitch software (http://www.omegabrandess.com/GigaPan). The GigaPan images provided a means of assessing the non-contributing features on the landscape and qualitatively evaluating the viewshed condition based on groups of characteristics of man-made features as follows: (1) distance from a given key observation point, (2) size, (3) color and shape, and (4) movement and noise. A general relationship between these characteristics and their influence on conspicuousness is presented in Table 4.1.2-2.

Distance

The impact that individual human-made features have on perception is substantially influenced by the distance from the observer to the feature(s). Viewshed assessments using distance zones or classes often define three classes: foreground, middle ground, and background (Figure 4.1.2-3). For this assessment, we have used the distance classes that have been recently used by the National Park Service:

- *Foreground* = 0-½ mile from key observation point
- *Middle ground* = ½-3 miles from key observation point
- *Background* = 3-60 miles from key observation point.

Over time, different agencies have adopted minor variations in the specific distances use to define these zones, but the overall logic and intent has been consistent.

The foreground is the zone where visitors should be able to distinguish variation in texture and color, such as the relatively subtle variation among vegetation patches, or some level of distinguishing clusters of tree boughs. Large birds and mammals would likely be visible throughout this distance class, as would small or medium-sized animals at the closer end of this distance class (USFS 1995). Within the middle ground there is often sufficient texture or color to distinguish individual trees or other large plants (USFS 1995). It is also possible to distinguish larger patches within major plant community types (such as riparian areas), provided there is sufficient difference in color shades at the farther distance. Within the closer portion of this distance class, it may be possible to see large birds when contrasted against the sky, but other wildlife would be difficult to see without the aid of binoculars or telescopes. The background distance class is where texture tends to disappear and colors flatten. Depending on the actual distance, it is sometimes possible to distinguish between major vegetation types with highly contrasting colors (for example, forest and grassland), but any subtle differences within these broad land cover classes would not be apparent without the use of binoculars or telescopes, and even then, may be difficult.

Size

Size is another characteristic that may influence how conspicuous a given feature is on the landscape, and how it is perceived by humans. For example, Kearney et al. (2008) found human preferences were lower for man-made developments that tended to dominate the view, such as large, multi-storied buildings) and were more favorable toward smaller, single family dwellings. In another study, Brush and Palmer (1979) found that farms tended to be viewed more favorably than views of towns or industrial sites, which ranked very low on visual preference. This is consistent with other studies that have reported rural family dwellings, such as farms or ranches, as quaint and contributing to rural character (Schauman 1979, Sheppard 2001, Ryan 2006), or as symbolizing good stewardship (Sheppard 2001).

We considered the features on the landscape surrounding Sunset Crater Volcano NM as belonging to one of six size classes (Table 4.1.2-3), which reflect

Table 4.1.2-2. Characteristics that influence conspicuousness of human-made features.

Characteristic	Less Conspicuous	More Conspicuous
Distance	Distant from the observation point	Close to the observation point
Size	Small relative to the landscape	Large relative to the landscape
Color and Shape	Colors and shapes that blend into the landscape	Colors and shapes that contrast with the landscape
Movement and Noise	Lacking movement or noise	Exhibits obvious movement or noise

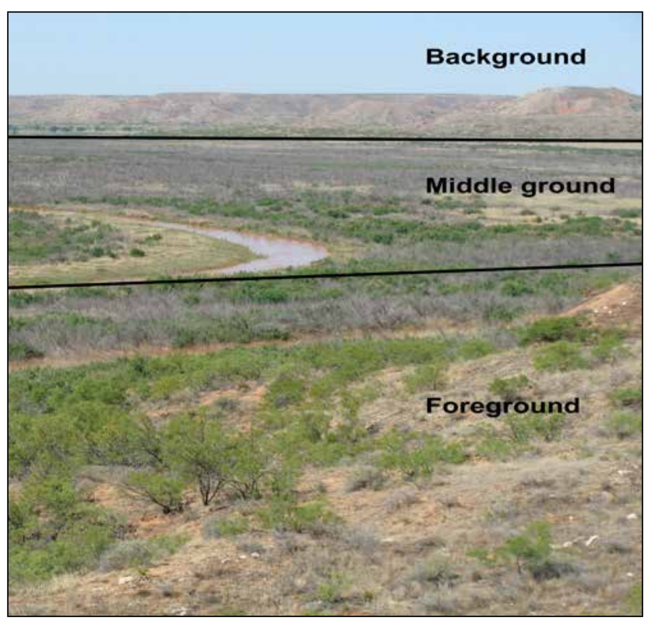


Figure 4.1.2-3. An example of foreground, middle ground, and background distance classes.

Table 4.1.2-3. Six size classes used for conspicuousness of human-made features.

Size	Low Volume	Substantial Volume
Low Height	Single family dwelling (home, ranch house)	Small towns, complexes
Substantial Height	Radio and cell phone towers	Wind farms, oil derecks
Substantial Length	Small roads, wooden power lines, fence lines	Utility corridors, highways, railroads

the preference groups reported by studies. Using some categories of perhaps mixed measures, we considered size classes within the context of height, volume, and length.

Color and Shape

Studies have shown that how people perceive a human-made feature in a rural scene depends greatly on how well it seems to fit or blend in with the environment (Kearney et al. 2008, Ryan 2006). For example, Kearney et al. (2008) found preferences for homes that exhibit lower contrast with their surroundings as a result of color, screening vegetation, or other blending factors (see Figure 4.1.2-4). It has been shown that colors lighter in tone or higher in saturation relative to their surroundings have a tendency to attract attention (contrast with their surroundings), whereas darker colors (relative to their surroundings) tend to fade into the background (Ratcliff 1972, O'Connor 2008). This is consistent with the findings of Kearney et al. (2008) who found that darker color was one of the factors contributing to a feature blending in with its environment and therefore preferred. Some research has indicated that color can be used to offset other factors, such as size, that may evoke a more negative perception (O'Connor 2009). Similarly, shapes of features that contrast sharply with their surroundings may also have an influence on how they are perceived.

This has been a dominant focus within visual resource programs of land management agencies (Ribe 2005). The Visual Resource Management Program of the BLM (BLM 2016), for example, places considerable focus on design techniques that minimize visual conflicts with features such as roads and power lines by aligning them with the natural contours of the landscape. Based on these characteristics of contrast, we considered the color of a feature in relative harmony with the landscape if it closely matched the surrounding environment, or if the color tended to be darker relative to the environment. We considered the shape of a feature in relative harmony with the landscape if it was not in marked contrast to the environment.

Movement and Noise

Motion and sound can both have an influence on how a landscape is perceived (Hetherington et al. 1993), particularly by attracting attention to a particular area of a viewshed. Movement and noise parameters can be perceived either positively or negatively, depending on the source and context. For example, the motion of running water generally has a very positive influence on perception of the environment (Carles et al. 1999), whereas noise from vehicles on a highway may be perceived negatively. In Carles et al.'s 1999 study, sounds were perceived negatively when they clashed with aspirations for a given site, such as tranquility. We considered the conspicuousness of the impact of movement and noise to be consistent with the amount present (that is, little movement or noise was inconspicuous, obvious movement or noise was conspicuous).

Hierarchical Relationship among Conspicuousness Measures

The above-described characteristics do not act independently with respect to their influence on the conspicuousness of features; rather, they tend to have a hierarchical effect. For example, the color and shape of a house would not be important to the integrity of the park's viewshed if the house was located too far away from the key observation point. Thus, distance becomes the primary characteristic that affects the potential conspicuousness. Therefore, we considered potential influences on conspicuousness in the context of a hierarchy based on the distance characteristics having the most impact on the integrity of the viewshed, followed by the size characteristic, then both the color and shape, and movement and noise characteristic (Figure 4.1.2-5).

<u>Extent of Development</u>

The extent of development provides a measure of the degree to which the viewshed is altered from its natural (reference) state, particularly the extent to which intrusive or disruptive elements such as structures and roads may diminish the "naturalness" of the view (USFS 1995, Johnson et al. 2008).

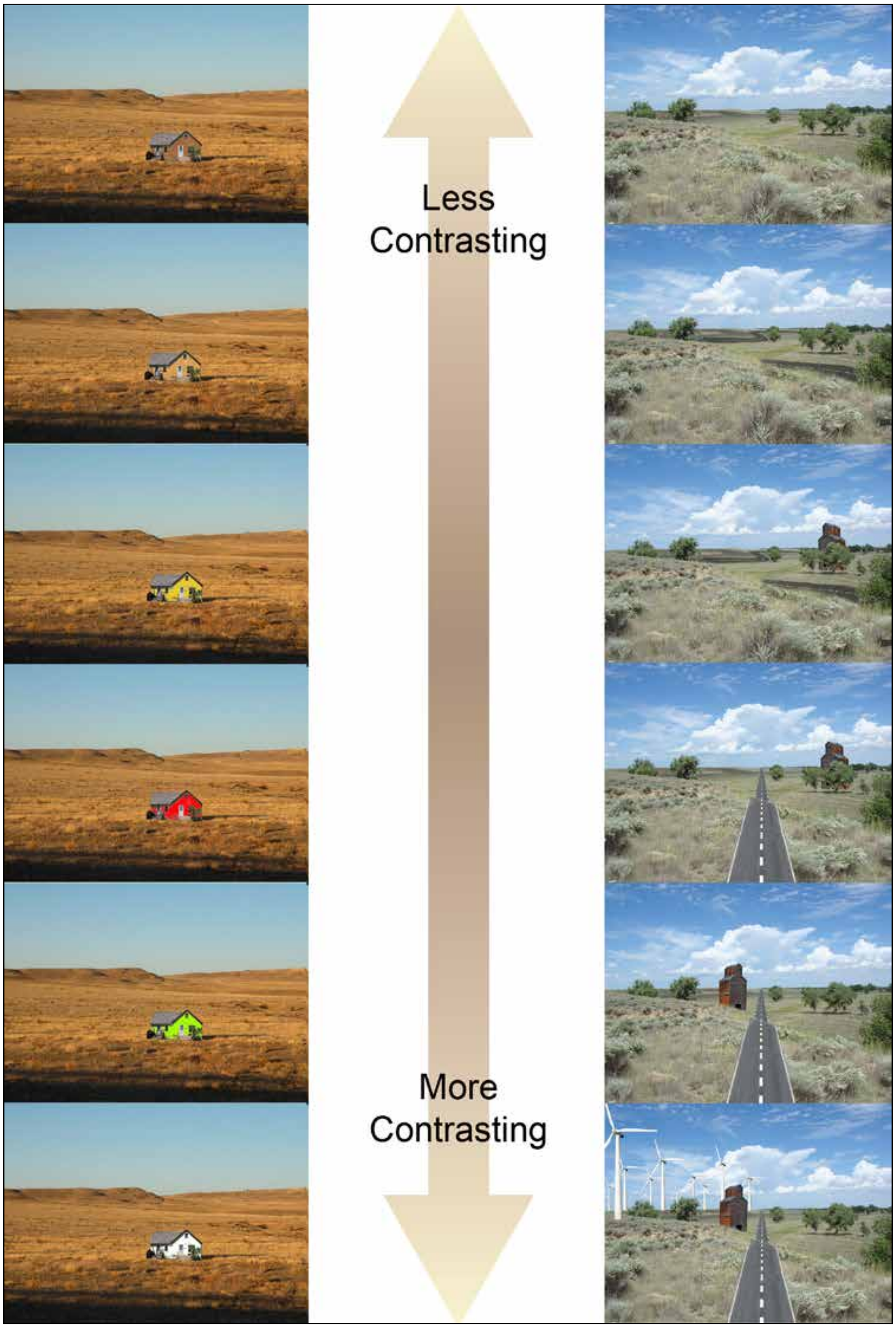


Figure 4.1.2-4. Graphic illustration of how color (left) and shape (right) can influence whether features are in harmony with the environment, or are in contrast.

We assessed the extent of development using Geographic Information System (GIS) analysis. The analysis provides a spatial and quantitative assessment of the housing and road developments within the monument's Area of Analysis (AOA), which we identified as a 97 km (60 mi) area surrounding the monument.

Viewshed Analysis

Viewshed analyses were conducted to evaluate areas that were visible and non-visible from a given observation point using ArcGIS Spatial Analyst Viewshed tool. USGS' National Elevation Datasets (NED) at 1/3 arc-second resolution (approximately 10 m / 32.8 ft resolution) (USGS 2016c) were used to

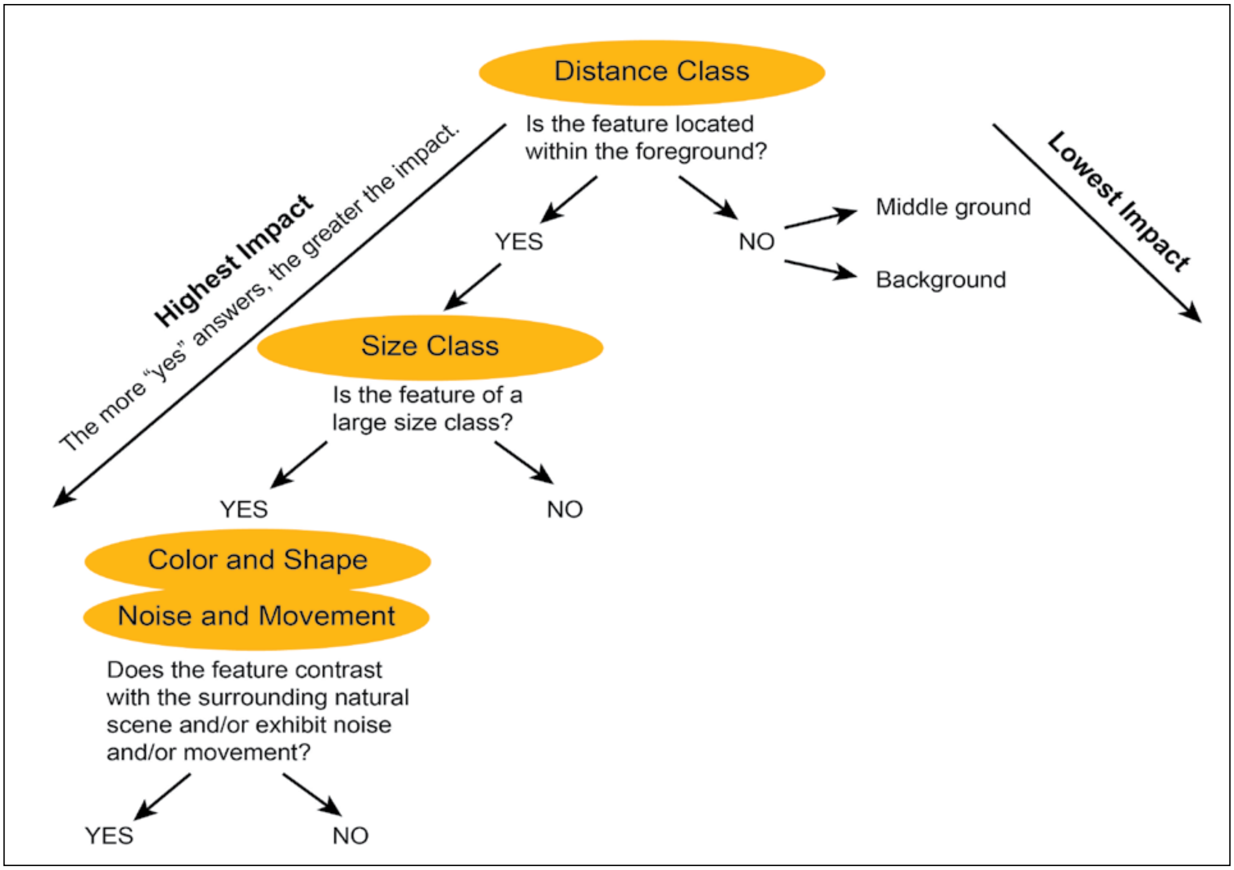


Figure 4.1.2-5. Conceptual framework for hierarchical relationship of characteristics that influence the conspicuousness of features within a viewshed.

create the viewshed AOA from each of the three key observation points; these AOAs were subsequently combined to create composite viewsheds based on all three points. Composite viewsheds are a way to show multiple viewsheds as one, providing an overview of the visible/non-visible areas across all observation points used as the input. The analysis assumed that the viewsheds were not hindered by non-topographic features such as vegetation; the observer was at ground level viewing from a height of 1.68 m (5.5 ft), which is the average height of a human; and visibility did not decay due to poor air quality. Additional details are listed in Appendix D. The composite viewshed was overlaid with the housing density and road density output (described below) to determine the areas with houses or roads most likely to be visible from the monument.

NPScape Data

NPScape is a landscape dynamics monitoring program that produces and delivers GIS data, maps, and statistics that are integral to understanding natural resource conservation and conditions within a landscape context (NPS 2016c, Monahan et al. 2012). NPScape data include seven major categories (measures), two of which will be used in the viewshed condition assessment: housing and roads. These metrics were used to evaluate resource conditions from a landscape-scale perspective.

NPScape data are consistent, standardized, and collected in a repeatable fashion over time, and yet are flexible enough to provide analyses at many spatial and temporal scales. Data are further described in the sections that follow.

Housing Density

The NPScape 2010 housing density metrics are derived from Theobald's (2005) Spatially Explicit Regional Growth Model, SERGoM 100 m (328 ft) resolution housing density rasters. SERGoM forecasts changes on a decadal basis using county specific population estimates and variable growth rates that are location-specific. The SERGoM housing densities are grouped into six classes as shown in Table 4.1.2-4. NPScape's housing density standard operating

Table 4.1.2-4. Housing density classes.

Grouped Housing Density Class	Housing Density Class (units / km^2)
Urban-Regional Park	Urban-Regional Park
Commercial / Industrial	Commercial / Industrial
Urban	>2,470
	1,235 - 2,470
Suburban	495 - 1,234
	146 - 495
Exurban	50 - 145
	25 - 49
	13 - 24
	7 - 12
Rural	4 - 6
	1.5 - 3
	<1.5
	Private undeveloped

procedure (NPS 2014a) and toolset were used to clip the raster to the monument's AOA then to recalculate the housing densities.

Road Density

ESRI's North America Detailed Streets road features (2014) were used to calculate the road density within the monument's AOA. The Feature Class Code values in the dataset are used to identify road types. According to NPScape's road density standard operating procedure (NPS 2014b), "highways are defined as interstates (FCC: A10-A19) or major roads (FCC: A20-A38, excluding ferry routes). All roads include all road features from the source data regardless of FCC value (excluding ferry routes). New road density rasters, feature classes, and statistics were generated from these data.

4.1.3. Reference Conditions

We used qualitative reference conditions to assess the scenic and historic integrity of Sunset Crater Volcano NM's viewshed, which are as presented in Table 4.1.3-1. Measures are described for resources in good condition, warranting moderate concern or significant concern.

4.1.4. Condition and Trend

Conspicuousness of Non-contributing Features

GigaPan images were collected from the three key observation locations in December 2016. The stitched images are shown in Figures 4.1.4-1, -2, and -3. From the Bonito Park vantage point the monument is visible when looking from northeast to southeast. In the first frame looking north to east the paved road leading into the monument is visible in the foreground, but this non-contributing feature is not conspicuous since the road corridor follows the contours of the landscape and is relatively narrow (Figure 4.1.4-1). However, vehicles traveling along the road corridor would increase this feature's conspicuousness as a result of visual interruption and noise. Natural vegetation dominates the viewshed in this direction with grasslands in the foreground and ponderosa pine in the middle ground and background; however, much of the background is blocked by natural features located in the middle ground. From east to south Sunset Crater is visible in the background and is the dominant landscape feature in this direction. Grasslands occur in the foreground with ponderosa pine in the middle ground and background. Power lines and the road corridor

Table 4.1.3-1. Reference conditions used to assess the viewshed at Sunset Crater Volcano NM.

Indicator	Measures	Good	Moderate Concern	Significant Concern
Scenic and Historic Integrity	Conspicuousness of Non-contributing Features	The distance, size, color and shape, and movement and noise of the noncontributing features blend into the landscape.	The distance, size, color and shape, and movement and noise of some of the noncontributing features are conspicuous and detract from the natural and cultural aspects of the landscape.	The distance, size, color and shape, and movement and noise of the noncontributing features dominate the landscape and significantly detract from the natural and cultural aspects of the landscape.
	Extent of Development	Lack of or inconspicuous noncontributing features; road and housing densities are low.	Noncontributing features exist in some areas of the viewshed, with some conspicuousness; road and housing densities are moderate, with minor intrusion on the viewshed.	Noncontributing features intrude prominently on the landscape and are highly conspicuous; road and housing densities are high.

Figure 4.1.4-1. Panoramic views in each direction from the Bonito Park key observation point in Sunset Crater Volcano NM (from top: north to east, east to south, south to west, and west to north).

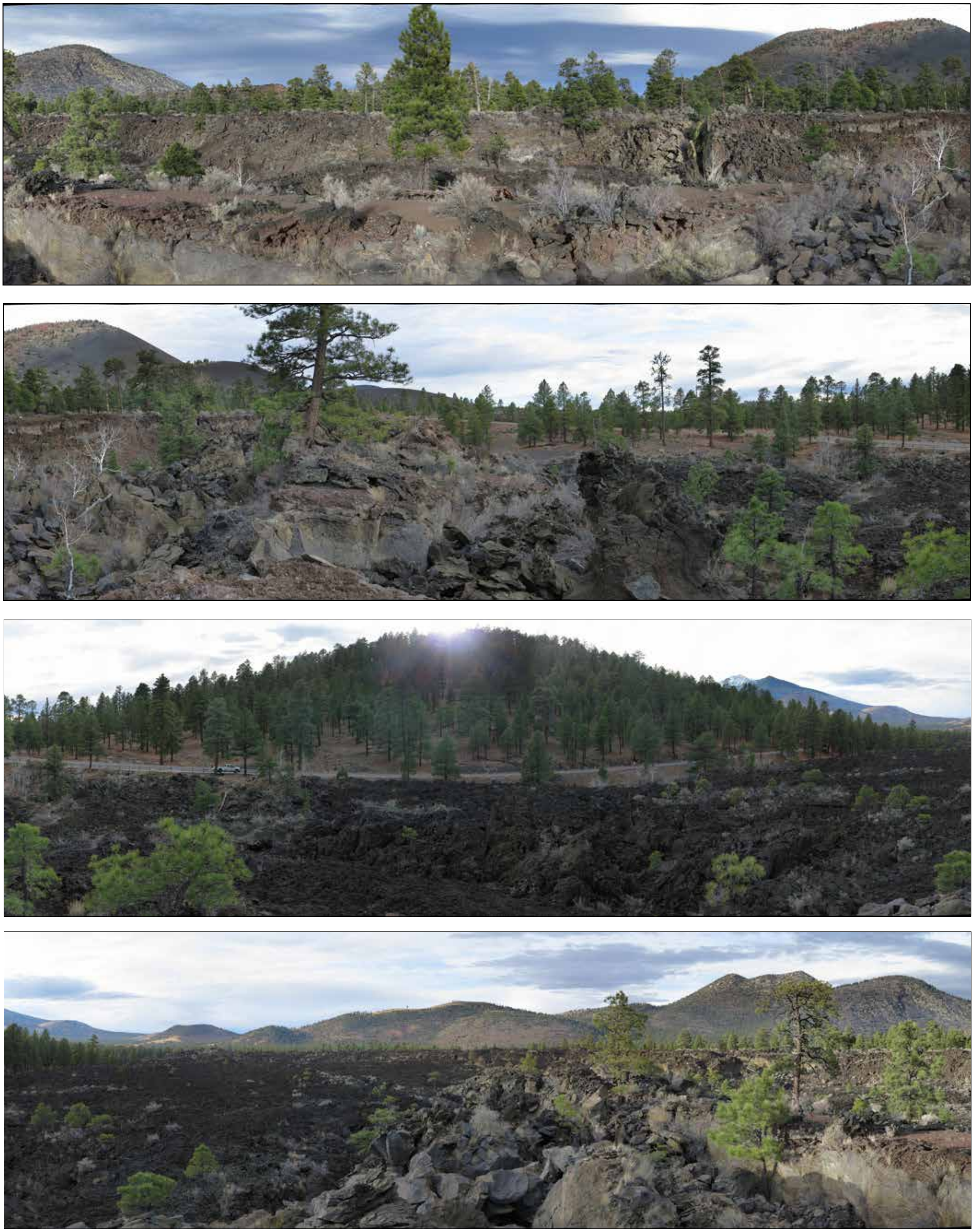


Figure 4.1.4-2. Panoramic views in each direction from the Lava Trail key observation point in Sunset Crater Volcano NM (from top: north to east, east to south, south to west, and west to north).

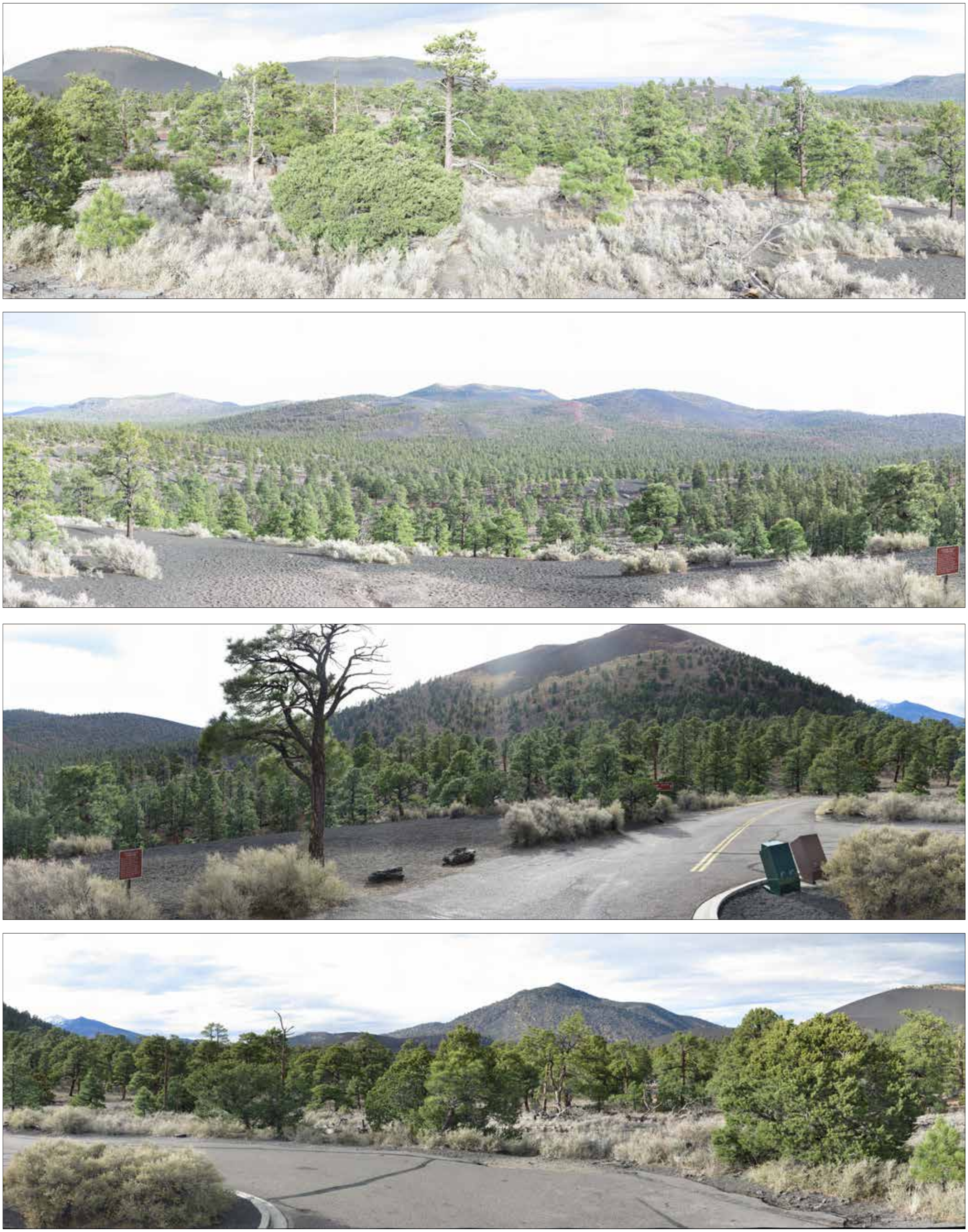


Figure 4.1.4-3. Panoramic views in each direction from the Cinder Hills Overlook key observation point in Sunset Crater Volcano NM (from top: north to east, east to south, south to west, and west to north).

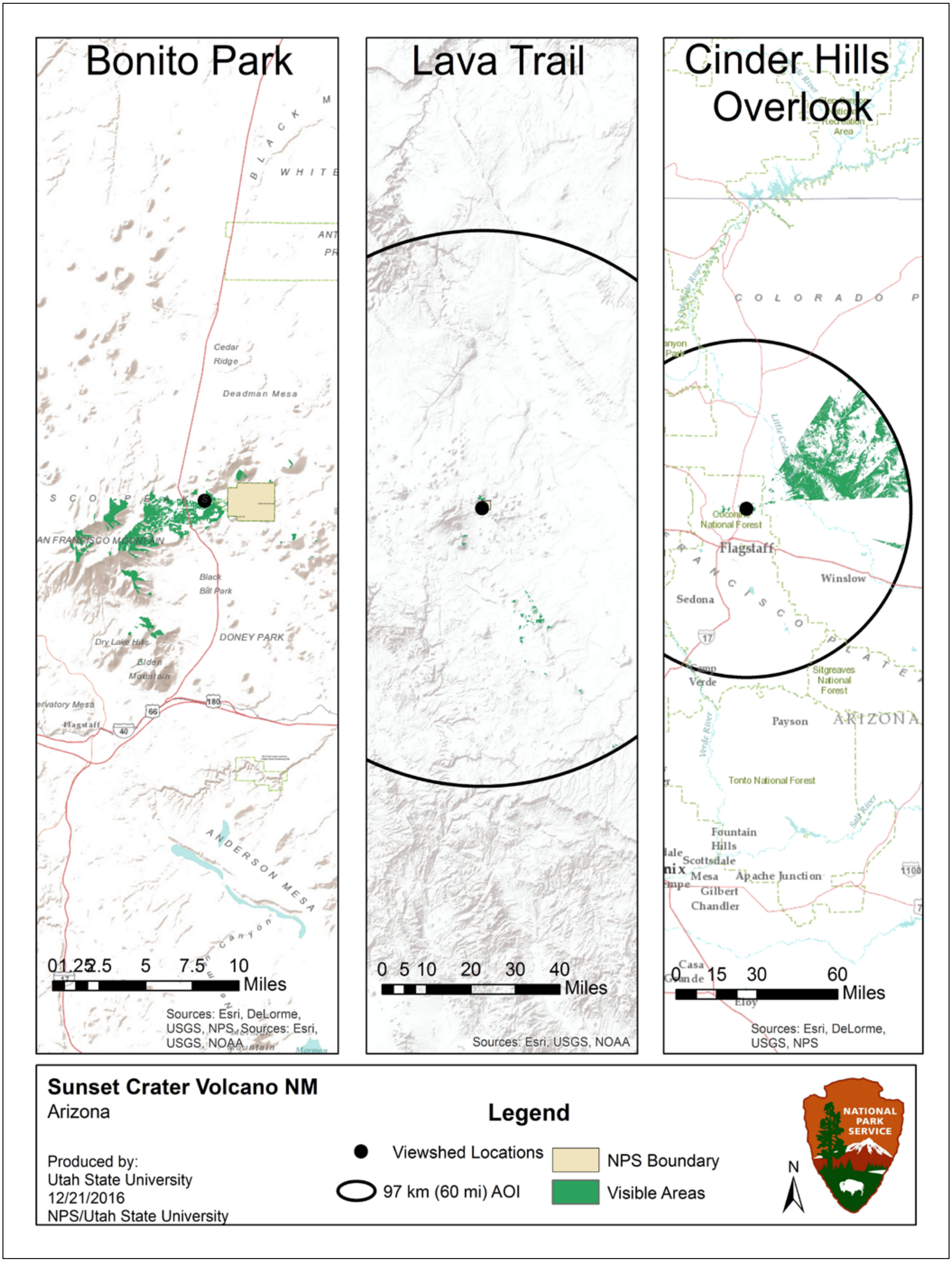


Figure 4.1.4-4. Visible areas from each of the three key observation locations in Sunset Crater Voclano NM.

were the two non-contributing features in the middle ground; however, they are not conspicuous, especially in the absence of traffic. From south to west there are no visible non-contributing features. Grasslands and scattered trees dominate the foreground, whereas ponderosa pine dominates the middle ground and background. The San Francisco Peaks are visible in the background toward the west. This view does not include the monument. From west to north, the road is again visible in the viewshed, but it is not conspicuous unless there is traffic. There are garbage and recycling receptacles along the road as well as road signs and two interpretive signs, but the interpretive signs were designed to blend well with the landscape in terms of color and size. Furthermore, the sign was installed to provide context for the visitor when viewing the Bonito Lava Flow and Sunset Crater. The San Francisco Peaks are also visible in the background; however, much of the background is blocked by natural features located in the middle ground. Overall, the viewshed is good from this vantage point.

From the Lava Trail observation location, the road is visible to two of the viewsheds, however, as with the Bonito Park location, the road follows the natural contour of the landscape and is not visible along its entire length (Figure 4.1.4-2). The only other non-contributing feature at this location was the interpretive footpath, which blends well with the natural surroundings and allows visitors to better understand the monument's unique geology via the signed interpretive trail. In the foreground and middle ground the sparsely vegetated lava flow is the dominant landscape feature. The middle ground is composed of ponderosa pine woodlands and when visible, sparsely vegetated cinder hills in the background. Much of the background, however, is effectively blocked by natural features. Since the road corridor, and especially the footpath, blend well with the natural landscape, the viewshed from this vantage point is good.

The Cinder Hills Overlook location was located at the eastern end of the monument and offers the best vantage point for the farthest views of the three locations (Figure 4.1.4-3). From north to east cinder soils with shrubs and ponderosa pines are visible in the foreground. In the middle ground barren cinder hills are dominant, but portions of the road corridor and power lines are also visible. The viewshed in the background extends for some distance and while developments may be visible, they were not evident in the panoramic image. The view from east to south is similar except that the viewshed does not extend nearly as far. An interpretive NPS sign describing the viewshed is visible in the foreground. From south to west a paved road, an interpretive sign, and trash receptacles are visible in the foreground. Because these non-contributing features are in the foreground, they are conspicuous. Natural vegetation and landscape features dominate both the middle ground and background. The San Francisco Peaks are visible in the background. The view from west to east provides a similar view with a paved pullout in the foreground and natural landscape features in the middle ground and background with views of the San Francisco Peaks. The viewshed is considered good from this location.

The viewshed analyses were generally consistent with the panoramic images. Figure 4.1.4-4 shows the area and extent that should be visible from each key observation location. The figure shows only the areas that should be visible from each observation location rather than the entire AOA since the viewsheds for each observation location were relatively narrow. The analysis reveals that Cinder Hills Overlook has the largest viewshed, while Bonito Park has the smallest viewshed. At Bonito Park the largest viewshed was to the west and south, but it only extends for approximately 16 km (10 mi). This is consistent with the GigaPan images. At Lava Trail the viewshed was narrow but extended for 97 km (60 mi) to the southeast; however, the panoramas show that the view is best toward the southwest. It is important to note that the viewshed analysis does not account for vegetation, which may obscure the view in some locations. Furthermore, the panoramic images collected at Lava Trail look as though they were taken from a depression in the landscape, which may also account for the apparent discrepancy. Finally, the viewshed analysis for Lava Trail is very small and scattered. The Cinder Hills Overlook viewshed analysis indicates that the view to the northeast is the least obstructed and this is consistent with the GigaPan images. The viewshed in this direction extends at least 97 km (60 mi). Overall, the viewshed analysis indicates a generally narrow view from all three locations, but the view extends to approximately the edge of human vision (97 km [60 mi]) in some places and the sources of obstruction were natural landscape features. The GigaPan images show few non-contributing features and that native vegetation dominated these viewsheds. Therefore, we consider the condition for this measure to be good. Confidence is medium since the viewshed analysis was based on modelled data and while photographs can be revealing, they do not account for movement associated with traffic or other factors that may influence visitors' perceptions of viewshed.

Extent of Development

The composite viewshed based on the three key observation locations is shown in blue in Figures 4.1.4-5 and 4.1.4-6. This analysis reveals that areas to the north and east of the monument are most visible, while areas to the south and west are the least visible. Based on data compiled in NPScape (Budde et al. 2009 and Monahan et al. 2012), housing densities surrounding the monument are low (Table 4.1.4-1). The majority (69%) of all housing consists of private undeveloped lands and densities less than 1.5 units/km^2 (22%). Most of the development within the viewshed is rural (Figure 4.1.4-5). The viewshed analysis was calculated out to 97 km (60 mi) since this is the area most likely visible to the average observer (USFWS 1995). The white spaces within this boundary indicate no census data; thus, housing densities could not be calculated for these areas. However, these data originate with the U.S. Census Bureau and units with unknown densities were probably not reported, which likely indicates undeveloped areas. Total road density within the 97 km (60 mi) AOA surrounding the monument was 0.74 km/km^2. Figure 4.1.4-6 shows road density by various classes. Road density within the monument's viewshed is less dense than it is elsewhere in the AOA and is representative of a relatively rural landscape since there are few areas with a high density of roads.

Overall Condition, Trend, Confidence, and Key Uncertainties

Based on this assessment, the viewshed condition at Sunset Crater Volcano NM is good (Table 4.1.4-2). There were few non-contributing features in the monument's viewshed as observed from the three key observation locations, and those that were present blended relatively well with the natural landscape. The composite viewshed shown in blue in Figures 4.1.4-5

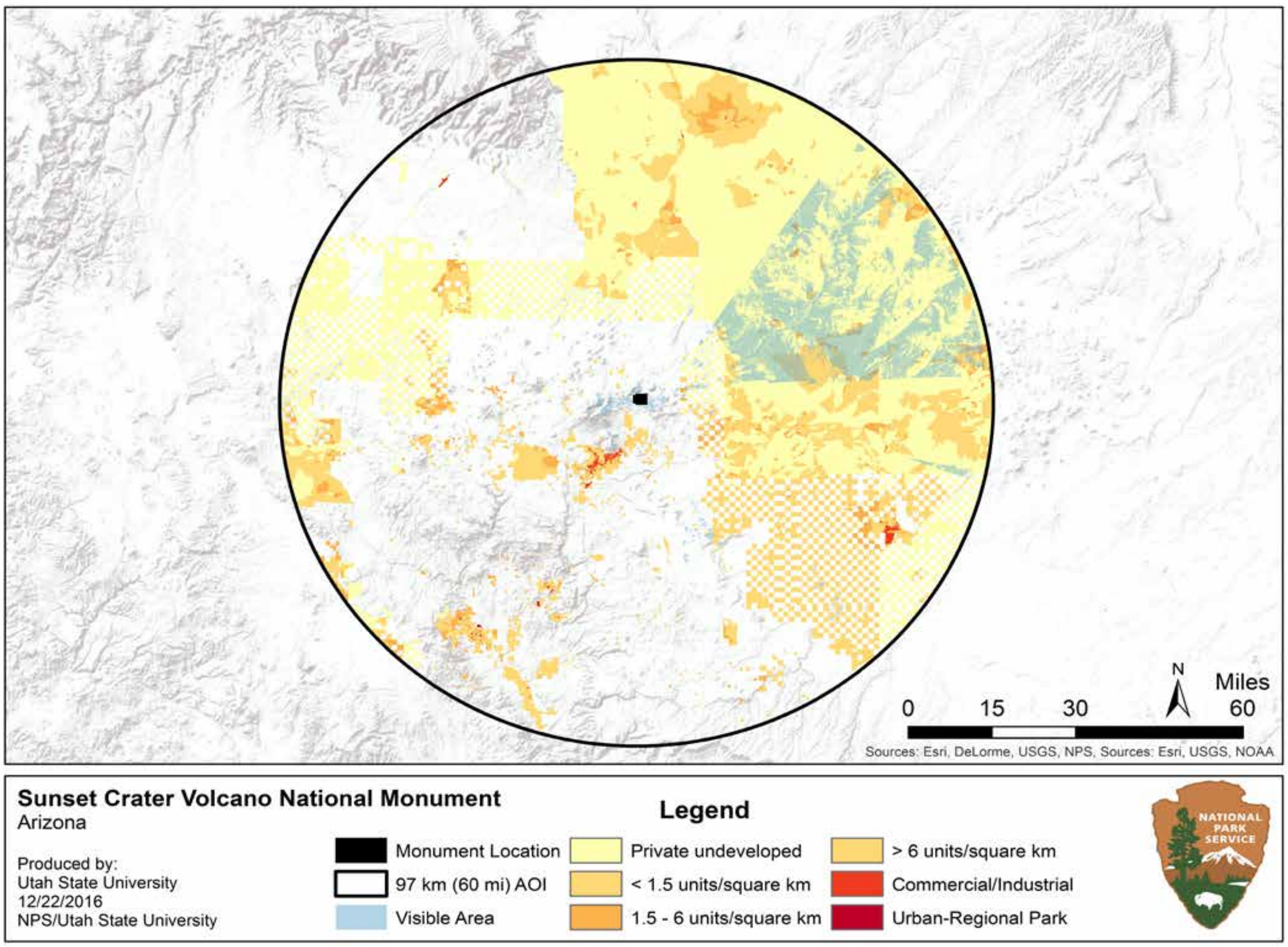


Figure 4.1.4-5. Housing density and visible areas in and around Sunset Crater Volcano NM.

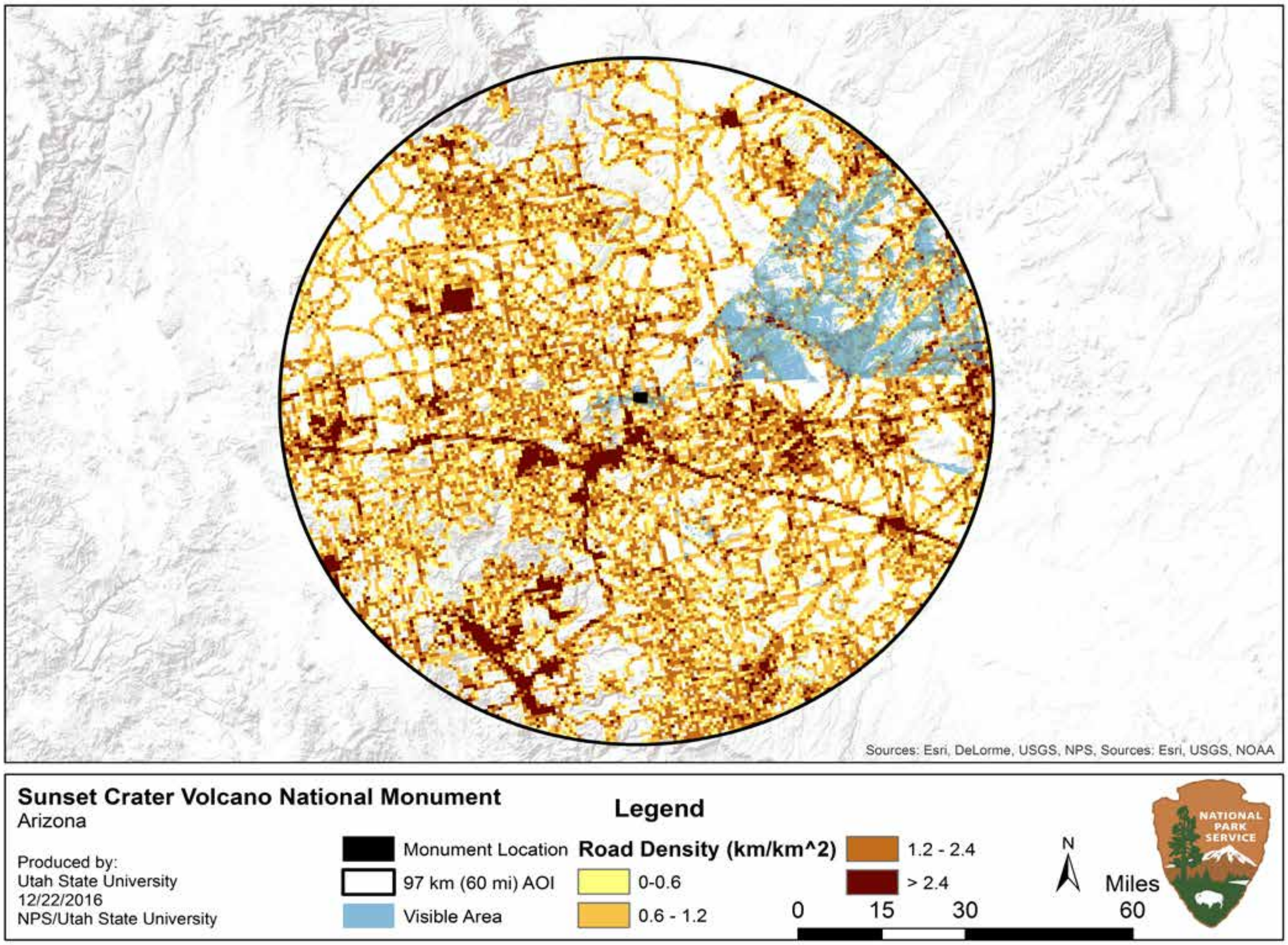


Figure 4.1.4-6. **Road density and visible areas in and around Sunset Crater Volcano NM.**

and 4.1.4-6 show that views to the south and west are blocked, but this was a result of natural features of the landscape. The housing and road density analyses show that the region surrounding the monument is mostly rural. This assessment represents baseline condition for Sunset Crater Volcano NM's viewshed; therefore, we could not report on trend. Both measures were assigned medium confidence. Factors that influence confidence level include age of the data (<5 years) unless the data are part of a long-term monitoring effort), repeatability, field data versus modeled data, and whether data can be extrapolated to other areas in the monument. We assigned medium confidence to the condition ratings because they were largely based on modeled data. Furthermore, the digital elevation model we used to determine visible areas from each vantage point was at 10 m (32.8 ft) resolution. Finer scale data would probably give a better indication of the areas visible. Lastly, we did not account for vegetation height in the viewshed analysis.

The GigaPan images support the viewshed analysis. The consistency between the GigaPan images and the corresponding viewshed analysis displayed in Figure 4.1.4-4 is somewhat difficult to see and would be best viewed digitally (e.g., GIS) to determine the visibility of specific geographic features. When zooming in using GIS the landscape features that block the viewshed or allow for a broad viewshed are more obvious and can be easily compared with the GigaPan images. The

Table 4.1.4-1. **Housing densities within a 97 km (60 mi) buffer around Sunset Crater Volcano NM.**

Density Class	Area (km^2)	Percent
Private Undeveloped	10940	69
< 1.5 units	3524	22
1.5 - 6 units	568	4
> 6 units	672	4
Commercial/Industrial	50	0.3
Urban-Regional Park	2	< 0.01
Total Area	15756	100

Table 4.1.4-2. Summary of viewshed indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Scenic and Historic Integrity	Conspicuousness of Non-contributing Features		Native vegetation and natural landscape features dominated the viewshed in each of the three locations as observed in the GigaPan panoramic images. Therefore, we consider the condition for this measure to be good. The viewshed analysis was consistent with the GigaPan images. Confidence is medium since the viewshed analysis was based on modelled data and while photographs can be revealing, they do not account for movement associated with traffic or other factors that may influence visitors' perceptions of viewshed. There were no data available to determine trend for this measure.
	Extent of Development		The housing and road density analyses show that the region surrounding the monument is mostly rural. Therefore, we consider the condition for this measure to be good. There were no data available to determine trend for this measure. Confidence in this condition rating is medium.
Overall Condition			There were few non-contributing features in the monument's viewshed as observed from the three key observation locations, and those that were present blended relatively well with the natural landscape. Housing density indicates the region is mostly rural, and road density is low. There were no data available to determine overall trend. Instead, these data serve as a baseline for which to make future comparisons. Confidence in this condition rating is medium since the majority of data used were based on models.

viewshed analysis should not be used for planning purposes until groundtruthed.

<u>Threats, Issues, and Data Gaps</u>
Potential threats to Sunset Crater Volcano NM's viewshed include development within the AOA, increased visitation to the monument, and atmospheric dust and smog as a result of climate change. According to the housing density analysis however, development within the monument's viewshed is not expected to change substantially over the next 50 to 60 years. Even by 2100, the analysis showed only a slight increase in development. It is important to keep in mind, however, that this prediction based on past development and may not reflect actual future development. Road density is also relatively low, especially within the monument's viewshed. Roads are usually associated with development. Since development is predicted to remain stable, road density is also likely to remain stable.

Increased visitation could impact viewshed to some extent, but backcountry use is not permitted (NPS 1996) and thus, the majority of visitors are concentrated along road corridors, at pullouts, visitor centers, and interpretive exhibits rather than dispersed across the backcountry. Furthermore, visitation has declined since peaking during the early to mid-1990s (NPS Public Use Statistics 2017). An additional threat to the monument's viewshed include pumice mining for industrial use and landscaping materials on the slopes of San Francisco Mountain, particularly as seen from the Lava Trail (Thornberry-Ehrlich 2005). However, this was not apparent in the GigaPan images.

Although development immediately surrounding the monument is low and is not expected to increase substantially, atmospheric dust and mineral aerosols have increased in the interior western U.S. by 500% over the late Holocene average (Neff et al. 2008). This increase is directly related to increased settlement and livestock grazing during the 19th century (Neff et al. 2008). Atmospheric dust can impact viewshed quality (refer to the Air Quality assessment for more details). Overall however, there are few potential threats to Sunset Crater Volcano NM's viewshed and its current condition is considered good.

4.1.5. Sources of Expertise
Assessment author is Lisa Baril, wildlife biologist and science writer, Utah State University. No outside experts were consulted for this assessment. Note that the measures and methods used for assessing the condition of Sunset Crater Volcano NM's viewshed are different from the measures/methods recommended by the NPS Visual Resources Program in the Air Resources Division under 2018 draft guidance that post-dates this viewshed assessment. Please contact the NPS Visual Resource Program for more information: visual_resources@nps.gov.

4.2. Night Sky

4.2.1. Background and Importance

Natural dark skies are a valued resource within the NPS, reflected in NPS management policies (NPS 2006), which highlight the importance of a natural photic environment to ecosystem function, and the importance of the natural lightscape for aesthetics. The NPS Natural Sounds and Night Skies Division (NSNSD) makes a distinction between a lightscape—which is the human perception of the nighttime scene, including both the night sky and the faintly illuminated terrain, and the photic environment—which is the totality of the pattern of light at night at all wavelengths (Moore et al. 2013).

Lightscapes are an aesthetic and experiential quality that is integral to natural and cultural resources. A 2007 visitor survey conducted throughout Utah national parks found that 86% of visitors thought the quality of park night skies was "somewhat important" or "very important" to their visit (NPS 2010a). Additionally, in an estimated 20 national parks, stargazing events are the most popular ranger-led program (NPS 2010a, Figure 4.2.1-1).

The value of night skies goes far beyond visitor experience and scenery. The photic environment affects a broad range of species, is integral to ecosystems, and is a natural physical process (Longcore and Rich 2004). Natural light intensity varies during the day-night (diurnal) cycle, the lunar cycle, and the seasonal cycle. Organisms have evolved to respond to these periodic changes in light levels in ways that control or influence movement, feeding, mating, emergence, seasonal breeding, migration, hibernation, and dormancy. Plants also respond to light levels by flowering, vegetative growth, and their direction of growth (Royal Commission on Environmental Pollution 2009). Given the effects of light on living organisms, it is likely that the introduction of artificial light into the natural light/darkness regime will disturb the normal routines of many plants and animals (Royal Commission on Environmental Pollution 2009), as well as diminish stargazing recreational opportunities offered to national park visitors.

In 2016, Sunset Crater Volcano NM was designated an International Dark Sky Park by the International Dark Sky Association (IDA), a non-profit organization dedicated to preserving dark night skies around the world (IDA 2016). Sunset Crater Volcano NM was designated along with Wupatki and Walnut Canyon National Monuments since all three monuments are managed jointly by the NPS as one unit. Thus, the Dark Sky Park designation was applied to all three simultaneously (IDA 2016).

Figure 4.2.1-1. Ranger preparing telescope for night sky viewing at Sunset Crater Volcano NM. Photo Credit: NPS.

Sunset Crater Volcano NM's designation was in part facilitated by the night sky stewardship of Flagstaff, AZ, which lies 21.8 km (13.5 miles) southwest of the monument. In 2001, the city was designated as the world's first International Dark Sky Community owing to its progressive outdoor lighting policy enacted in 1958— the world's first outdoor lighting ordinance (IDA 2016). The city is also home to Lowell Observatory and the U.S. Naval Observatory Flagstaff Station, both of which are active astronomical research facilities. In addition, the Lowell Observatory regularly hosts interpretive star gazing events that highlight the region's nocturnal lightscape. Sunset Crater Volcano NM also hosts public star parties where visitors learn about the importance of preserving dark night skies in the monument. Protecting the night sky resources at Sunset Crater Volcano NM benefits the natural resources, enriches the visitor experience, and has cultural significance (NPS 2015a).

4.2.2. Data and Methods

The NPS NSNSD goals of measuring night sky brightness are to describe the quality of the lightscape, quantify how much it deviates from natural conditions, and how it changes with time due to changes in natural conditions, as well as artificial lighting in areas within and outside of the national parks (Duriscoe et al. 2007). In this assessment, we characterize the night sky environment in Sunset Crater Volcano NM using four measures that quantify sky brightness and one measure that describes overall sky quality. The quantitative measures are all-sky light pollution ratio, vertical maximum illuminance, horizontal illuminance, and zenith sky brightness. These measures, which are described in detail below, provide information on various aspects of the observed photic environment and proportion of light pollution attributed to anthropogenic sources. We also include the Bortle Dark Sky Scale, which is a measure of sky quality as perceived by a human observer trained to determine the visibility of various celestial bodies and night sky features. Together, these five measures were used to assess the condition of this important park resource (Table 4.2.2-1).

NSNSD scientists conducted an assessment of Sunset Crater Volcano NM's night sky condition at two locations: Lava Flow Trailhead and Cinder Cone (Figure 4.2.2-1). Lava Flow Trailhead was monitored on 4 June 2004, 9 February 2005, 24 February 2006, 18 September 2006, and 13 March 2012. Cinder Cone was monitored on 15 October 2001. The Cinder Cone monitoring site was located outside the monument since access to the monument's cinder cone is not permitted, and choosing a high elevation site is important since it provides a much clearer view of the horizon to better characterize the conditions of entire night sky. Data collected during the assessment were used to support the IDA application. Ground-based measurements were collected under clear and moonless conditions. A CCD camera was used to assess the all-sky light pollution ratio, zenith sky brightness, maximum vertical illuminance, and horizontal illuminance. The Bortle Dark Sky Scale was used to evaluate night sky quality. In addition to these field-based data, the all-sky light pollution ratio was also modeled using satellite imagery from October 2015.

<u>All-sky Light Pollution Ratio</u>

The all-sky light pollution ratio (ALR) is the average anthropogenic sky luminance presented as a ratio over natural conditions. It is a useful metric to average the light flux over the entire sky (measuring all that is above the horizon and omitting the terrain). Recent advances in modeling the natural components of the

Table 4.2.2-1. Indicators and measures of the night sky and why they are important to resource condition.

Indicators	Measures	Description
Sky Brightness	All-sky Light Pollution Ratio, Vertical Maximum and Horizontal Illuminances, and Zenith Sky Brightness	The all-sky light pollution ratio describes light due to man-made sources compared to light from a natural dark sky. Vector measures of illuminance (horizontal and vertical) are important in describing the appearance of objects on the landscape and their relative visibility. The zenith is generally considered the darkest part of pristine skies. Understanding the lightscape and sources of light is helpful to managers to maintain dark skies for the benefit of wildlife and people alike.
Sky Quality	Bortle Dark Sky Scale	The Bortle Dark Sky classification system describes the quality of the dark night sky by the celestial bodies and night sky features an observer can see. Observing the stars has been an enjoyable human pastime for centuries.

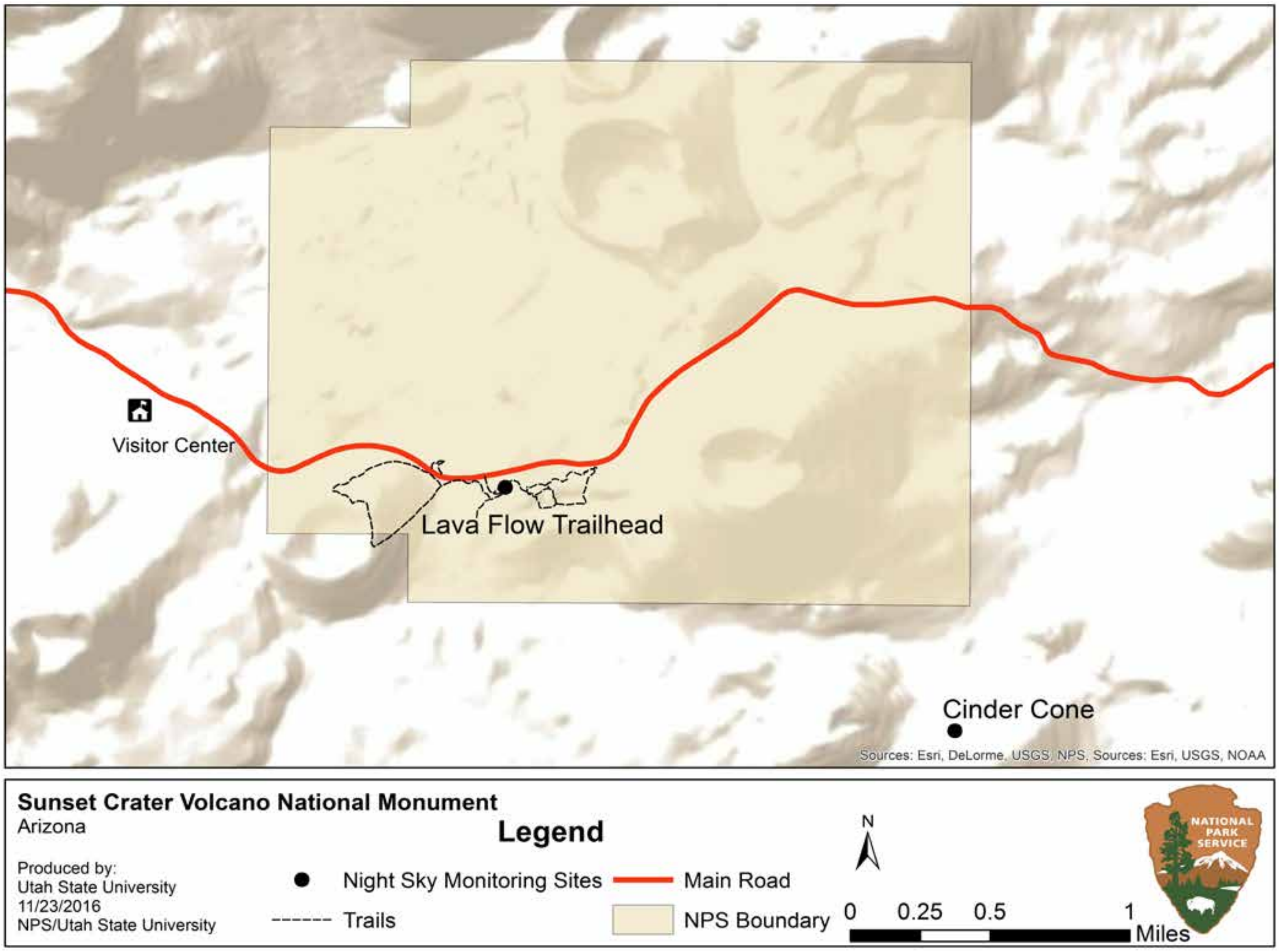


Figure 4.2.2-1. Location of night sky monitoring sites in Sunset Crater Volcano NM.

night sky allow separation of anthropogenic light from natural features, such as the Milky Way. This metric is a convenient and robust measure. It is most accurately obtained from ground-based measurements with the NPS Night Skies Program's photometric system, however, it can also be modeled with moderate confidence when such measurements are not available.

Modeled ALR data were based on 2015 National Aeronautics and Space Administration (NASA) Day/Night Band data collected by the Visible Infrared Imaging Radiometer Suite instrument located on the Suomi National Polar Orbiting Partnership satellite (NASA 2016). While modeled data provide useful overall measurements, especially when site visits cannot be made, they are less accurate than ground-based measurements.

A natural night sky has an average brightness across the entire sky of 78 nL (nanolamberts, a measure of luminance), and includes features such as the Milky Way, Zodiacal light, airglow, and other starlight. This is figured into the ratio, so that an ALR reading of 0.0 would indicate pristine natural conditions where the anthropogenic component was 0 nL. A ratio of 1.0 would indicate that anthropogenic light was 100% as bright as the natural light from the night sky.

Maximum Vertical and Horizontal Illuminance

The maximum sky brightness is typically found in the core of urban light domes (i.e., the semicircular-shaped light along the horizon caused by the scattering of urban light). The minimum sky brightness is typically found at or near the zenith (i.e., straight overhead). The integrated night sky brightness is calculated from both the entire celestial hemisphere as well as a measure of the integrated brightness masked at the apparent horizon to avoid site-to-site variations introduced by terrain and vegetation blocking. Vector measures of illuminance (horizontal and vertical) are important in describing the appearance of three-dimensional objects on the landscape and their relative visibility.

Vertical illuminance is the integration of all light striking a vertical plane from the point of the observer. In light-polluted areas, maximum sky brightness and maximum vertical illuminance will often measure the same area of sky, typically at the core of urban light domes. Vertical illuminance is an important metric when discussing night sky quality as it is easily noticeable to park visitors (since humans are oriented vertically). Even with dark conditions overhead, high vertical illuminance can hinder or inhibit dark adaptation of the eyes and cast visible shadows on the landscape. This is also an important ecological indicator, as many wildlife species base behavior on visual cues along the horizon. Horizontal illuminance is the amount of light striking a horizontal surface and is an important indicator of sky brightness (Cinzano and Falchi 2014). It is less sensitive in slightly impacted areas. This is because, even though the entire sky is considered, there is a rapid falloff in response to photons near the horizon, owing to Lambert's cosine law. At sites remote from cities, most of the anthropogenic sky glow occurs near the horizon.

For these two measures of illuminance we report the observed (artificial + natural) maximum vertical and horizontal illuminance. We also report the corresponding light pollution ratio (LPR) (i.e., proportion of light attributed to anthropogenic sources) (Duriscoe 2016). The light pollution ratio is useful since it is unit-less, allowing for comparison between measures (Duriscoe 2016). The LPR is also a more intuitive approach to understanding the contribution of artificial light sources for a particular area.

Zenith Sky Brightness

Sky brightness describes the amount of light observed in the night sky. This measure was calculated from the median pixel value of an approximately one degree diameter circle centered on the zenith and was collected using the CCD camera and is considered the darkest part of a pristine sky (NPS 2016a). As with maximum vertical and horizontal illuminance, we report the observed zenith sky brightness in addition to its corresponding LPR.

Bortle Dark Sky Scale

The Bortle dark sky scale was proposed by John Bortle (Bortle 2001) based on 50 years of astronomical observations. Bortle's qualitative approach uses a nine-class scale that requires a basic knowledge of the night sky and no special equipment (Bortle 2001, Moore 2001, White et al. 2012, Table 4.2.2-2). The Bortle scale uses both stellar objects and familiar descriptors to distinguish among the different classes. Another advantage of the Bortle scale is that it is suitable for conditions ranging from the darkest skies to the brightest urban areas (Moore 2001, Figure 4.2.2-2).

4.2.3. Reference Conditions

Table 4.2.3-1 summarizes the condition thresholds for measures in good condition, those warranting moderate concern, and those warranting significant concern. The ideal night sky reference condition, regardless of how it's measured, is one devoid of any light pollution. However, results from night sky data collection throughout more than 90 national parks suggest that a pristine night sky is very rare (NPS 2010a).

Sunset Crater Volcano NM is considered a non-urban NPS unit, or area with at least 90% of its property located outside an urban area (Moore et al. 2013). For non-urban NPS units and those containing wilderness areas, the thresholds separating reference conditions of good condition, moderate concern, and significant concern are more stringent than those for urban NPS units because these areas are generally more sensitive to the effects of light pollution.

Anthropogenic Light Ratio (ALR)

The threshold for night skies in good condition is an ALR <0.33 and the threshold for warranting moderate concern is ALR 0.33-2.00. An ALR >2.00 would warrant significant concern (Moore et al. 2013).

Maximum Vertical Illuminance

Although no thresholds for maximum vertical illuminance have been set at this time, the NPS Night Skies Program recommends a reference condition of 0.4 milli-Lux, since the average vertical illuminance experienced under the natural night sky on a moonless night is 0.4 milli-Lux (derived from Jensen et al. 2006, Garstang 1986, and unpublished NPS Night Skies Program data). Vertical illuminance can also be

Table 4.2.2-2. Bortle Dark Sky Scale.

Bortle Scale	Milky Way (MW)	Astronomical Objects	Zodiacal Constellations	Airglow and Clouds	Nighttime Scene
Class 1 Excellent Dark Sky Site	MW shows great detail, and appears 40° wide in some parts; Scorpio-Sagittarius region casts an obvious shadow	Spiral galaxies (M33 and M81) are obvious objects; the Helix nebula is visible with the naked eye	Zodiacal light is striking as a complete band, and can stretch across entire sky	The horizon is completely free of light domes, very low airglow	Jupiter and Venus annoy night vision, ground objects are barely lit, trees and hills are dark
Class 2 Typical Dark Site	MW shows great detail and cast barely visible shadows	The rift in Cygnus star cloud is visible; the Prancing Horse in Sagittarius and Fingers of Ophiuchus dark nebulae are visible, extending to Antares	Zodiacal band and gegenschein are visible	Very few light domes are visible, with none above 5° and fainter than the MW; airglow may be weakly apparent, and clouds still appear as dark voids	Ground is mostly dark, but object projecting into the sky are discernible
Class 3 Rural Sky	MW still appears complex; dark voids and bright patches and a meandering outline are visible	Brightest globular clusters are distinct, pinwheel galaxy visible with averted vision	Zodiacal light is easily seen, but band of gegenschein is difficult to see or absent	Airglow is not visible, and clouds are faintly illuminated except at zenith	Some light domes evident along horizon, ground objects are vaguely apparent
Class 4 Rural-Suburban Transition	MW is evident from horizon to horizon, but fine details are lost	Pinwheel galaxy is a difficult object to see; deep sky objects such as M13 globular cluster, Northern Coalsack dark nebula, and Andromeda galaxy are visible	Zodiacal light is evident, but extends less than 45° after dusk	Clouds are just brighter than the sky, but appear dark at zenith	Light domes are evident in several directions (up to 15° above the horizon), sky is noticeably brighter than terrain
Class 5 Suburban Sky	MW is faintly present, but may have gaps	The oval of Andromeda galaxy is detectable, as is the glow in the Orion nebula, Great rift in Cygnus	Only hints of zodiacal light may be glimpsed	Clouds are noticeably brighter than sky	Light domes are obvious to casual observers, ground objects are easily seen
Class 6 Bright Suburban Sky	MW only apparent overhead, and appears broken as fainter parts are lost to sky glow	Cygnus, Scutum, and Sagittarius star fields just visible	Zodiacal light is not visible; constellations are seen, and not lost against a starry sky	Clouds appear illuminated and reflect light	Sky from horizon to 35° glows with grayish color, ground is well lit
Class 7 Suburban-Urban Transition	MW may be just barely seen near the zenith	Andromeda galaxy (M31) and Beehive cluster (M44) are rarely glimpsed	Zodiacal light is not visible, and brighter constellations are easily seen	Clouds are brilliantly lit	Entire sky background appears washed out, with a grayish or yellowish color
Class 8 City Sky	MW not visible	Pleiades are easily seen, but few other objects are visible	Zodiacal light not visible, constellations are visible but lack key stars	Clouds are brilliantly lit	Entire sky background has uniform washed out glow, with light domes reaching 60° above the horizon
Class 9 Inner City Sky	MW not visible	Only the Pleiades are visible to all but the most experienced observers	Only the brightest constellations are discernible	Clouds are brilliantly lit	Entire sky background has a bright glow, ground is illuminated

Source: White et al. (2012).

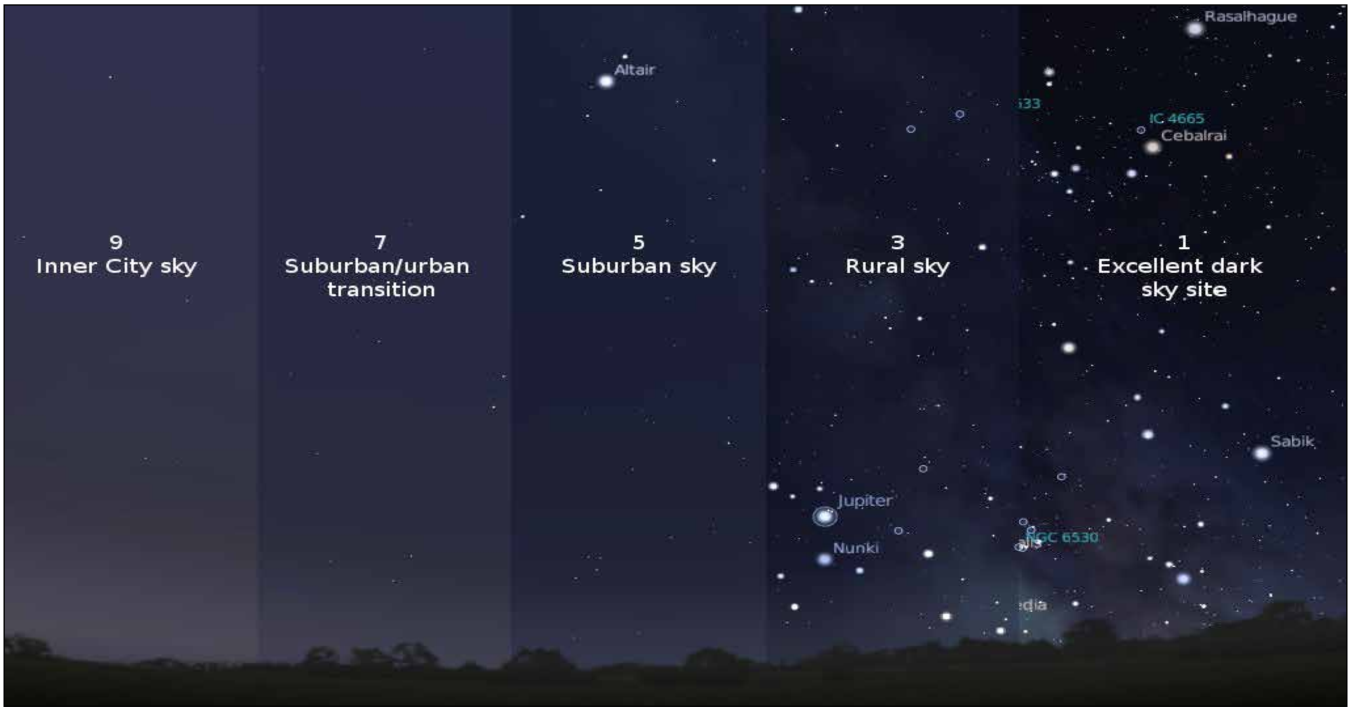


Figure 4.2.2-2. A graphic representation of the Bortle Dark Sky Scale (Bortle 2001). Figure Credit: NPS Natural Sounds and Night Skies Division.

expressed as a ratio to natural conditions, similar to ALR.

<u>Horizontal Illuminance</u>

As with maximum vertical illuminance, no thresholds for horizontal illuminance have been set at this time. The NPS Night Skies Program recommends a reference condition of 0.8 milli-Lux, since the average horizontal illuminance experienced under the natural night sky on a moonless night is 0.8 milli-Lux (Duriscoe 2016). Horizontal illuminance can also be expressed as a ratio to natural conditions, similar to ALR.

<u>Zenith Sky Brightness</u>

Reference conditions for night sky brightness can vary moderately based on the time of night (time after sunset), time of the month (phase of the moon), time of the year (the position of the Milky Way), and the activity of the sun, which can increase "airglow"—a kind of faint aurora. For the minimum night sky brightness measure, the darkest part of a natural night

Table 4.2.3-1. Reference conditions used to assess the night sky.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Sky Brightness	All-sky Light Pollution Ratio (ALR)*	ALR <0.33 (<26 nL average anthropogenic light in sky)	ALR 0.33-2.00 (26-156 nL average anthropogenic light in sky)	ALR >2.00 (>156 nL average anthropogenic light in sky)
	Maximum Vertical Illuminance	Thresholds have not been developed. A recommended reference is 0.4 milli-Lux.	Thresholds have not been developed. A recommended reference is 0.4 milli-Lux.	Thresholds have not been developed. A recommended reference is 0.4 milli-Lux.
	Horizontal Brightness	Thresholds have not been developed. A recommended reference is 0.8 milli-Lux.	Thresholds have not been developed. A recommended reference is 0.8 milli-Lux.	Thresholds have not been developed. A recommended reference is 0.8 milli-Lux.
	Zenith Sky Brightness (msa)*	≥21.60	21.20-21.59	<21.20
Sky Quality	Bortle Dark Sky Scale Class*	1-3	4	5-9

*National Park Service Natural Sounds and Night Skies thresholds for non-urban parks. Non-urban parks are those with at least 90% of their land located outside an urban area (Moore et al. 2013).

sky is generally found near the zenith. A value of 22.0 magnitudes per square arc second (msa) is considered to represent a pristine sky, though it may vary naturally by more than +0.2 to -0.5 depending on natural conditions (Duriscoe 2013). Lower (brighter) values indicate increased light pollution and a departure from natural conditions. The astronomical magnitude scale is logarithmic, so a change of 2.50 magnitudes corresponds to a difference of l0x; thus a 19.5 msa sky would be 10x brighter than natural conditions. Minimum night sky brightness values of 21.4 to 22.0 msa, are generally considered to represent natural (unpolluted) conditions (Duriscoe et al. 2007).

Bortle Dark Sky Scale

A night sky with a Bortle Dark Sky Scale class 1 is considered in the best possible condition (Bortle 2001); unfortunately, a sky that dark is so rare that few observers have ever witnessed it (Moore 2001). Non-urban park skies with a Bortle class 3 or darker are considered to be in good condition, class 4 warrants moderate concern, and class 5 warrants significant concern. At class 4 and higher, many night-sky features are obscured from view due to artificial lights (either within or outside the park). Skies class 7 and higher have a significantly degraded aesthetic quality that may introduce ecological disruption (Moore et al. 2013).

4.2.4. Condition and Trend

All-sky Light Pollution Ratio

Modeling data by the NPS Night Skies Program show a median ALR of 0.29 for the entire monument (Table 4.2.4-1). This is 29% brighter than average natural conditions. Figure 4.2.4-1 shows the modeled ALR for the region surrounding Sunset Crater Volcano NM and the extent of the light domes cast by cities located in the region. The light domes from Flagstaff, Arizona located 21.8 km (13.5 miles) to the southwest and Phoenix, Arizona located approximately 206 km (128 miles) to the south of the monument are visible from Sunset Crater Volcano NM and are the largest contributors of artificial sky glow in the monument.

The modeled ALR value was higher than the majority of ground-based measurements (Table 4.2.4-1). Ground-based ALRs varied from 0.16 to 0.28, which corresponds to a range of 16% to 28% brighter than average natural conditions. Figures 4.2.4-2, -3, -4, -5, -6, and -7 show the natural and anthropogenic light sources on the six monitoring dates. These data images are shown in false color with yellow, red, and white corresponding to brighter sky and blue, purple, and black corresponding to darker sky. Since all ALR measurements, modeled and ground-based, were less than 0.33, we consider this measure of sky brightness to be good. Confidence in this condition rating is high since it was based on six ground-based measurements and a modeled estimate. Data were collected at Lava Flow Trailhead during five nights over five years and during one night at the Cinder Cone site for an additional year of data. In total, there were six nights of monitoring from 2001 to 2012, which was insufficient to determine trend. However, these data suggest stable conditions for this measure of sky brightness.

Maximum Vertical Illuminance (milli-Lux)

Observed maximum vertical illuminance ranged from 0.52 to 0.70 milli-Lux. The corresponding LPR was estimated as 39% to 64% brighter than average natural conditions. All six measurements exceeded the NSNSD recommendation of 0.4 milli-Lux, however, since there are no thresholds for good condition, moderate concern, or significant concern, we did not assign a condition for this measure. Confidence is low due to lack of reference conditions. We could not determine trend based on the six sampling dates,

Table 4.2.4-1. Night sky measurements collected at Sunset Crater Volcano NM.

Location	Date	All-sky Light Pollution Ratio	Observed Maximum Vertical Illuminance (milli-Lux)	Observed Horizontal Illuminance (milli-Lux)	Observed Zenith Sky Brightness (msa)	Bortle Class
Park-wide	10/2015*	0.29	–	–	–	–
Cinder Cone	10/15/2001	0.28	0.68	1.02	15.26	3
Lava Flow Trailhead	6/20/2004	0.20	0.70	1.03	21.14	3
	2/9/2005	0.21	0.60	0.75	21.89	3
	2/24/2006	0.16	0.52	0.71	21.54	3
	9/18/2006	0.20	0.67	0.93	21.68	3
	3/13/2012	0.16	0.63	0.86	21.79	3

* Modeled median ALR data park-wide.

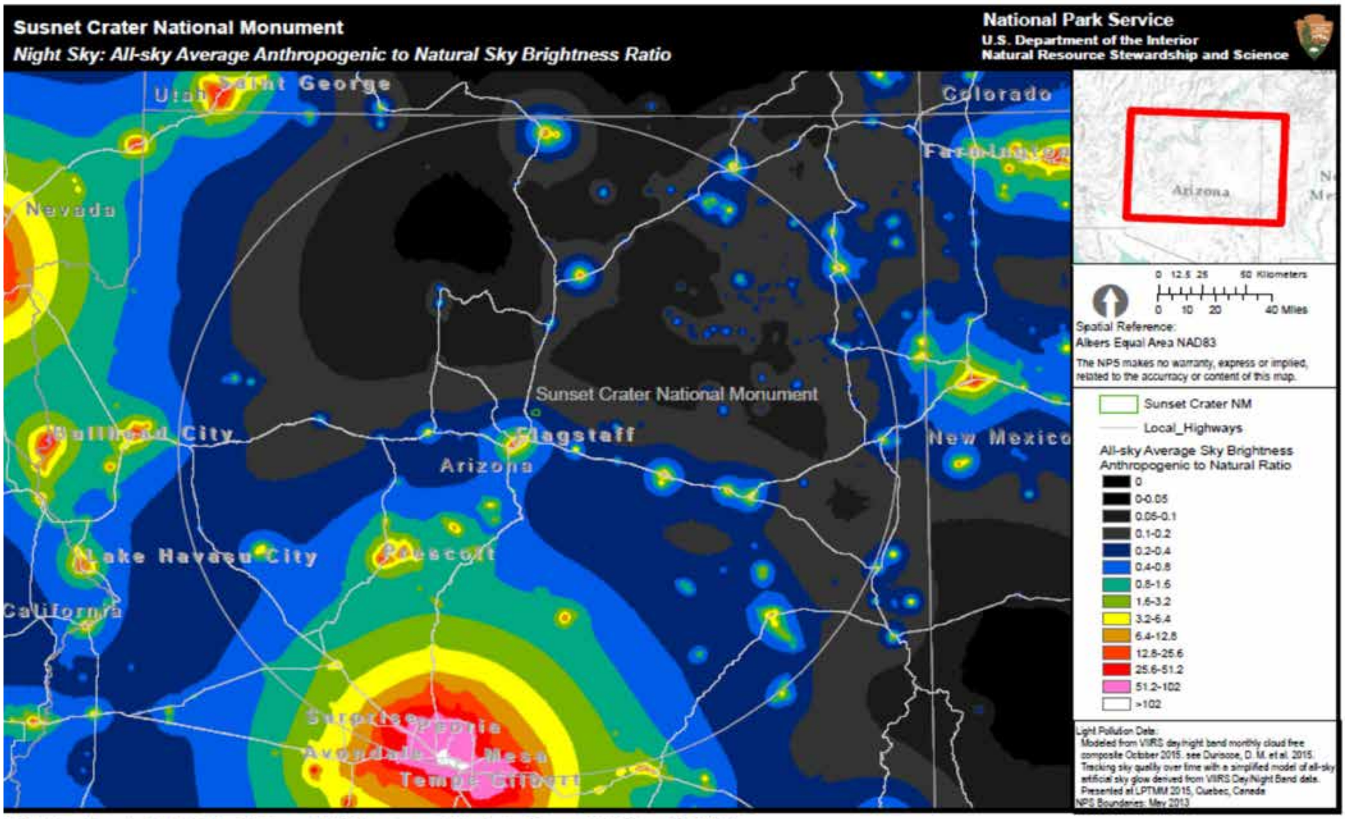


Figure 4.2.4-1. **Modeled ALR map for Sunset Crater Volcano NM. A 200 km ring around the park illustrates the distance at which anthropogenic light can impact night sky quality within the monument. Figure Credit: NPS Natural Sounds and Night Skies Division.**

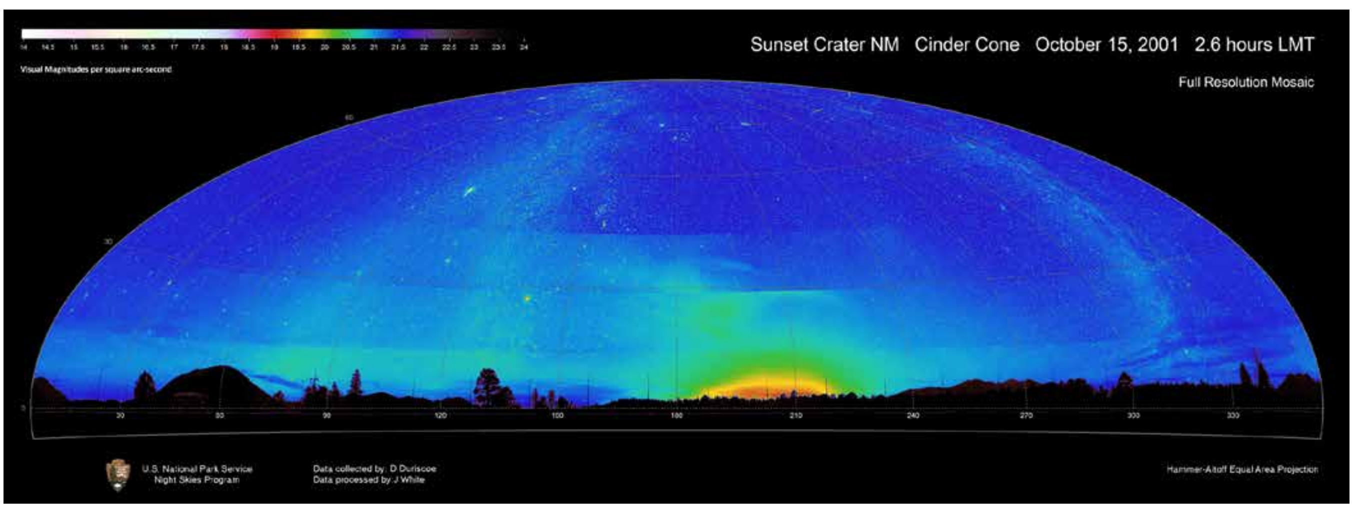


Figure 4.2.4-2. **Panoramic all-sky mosaic of all light sources on 15 October 2001 in Sunset Crater Volcano NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.**

but these data suggest stable conditions for maximum vertical illuminance.

<u>Horizontal Illuminance (milli-Lux)</u>

Observed horizontal illuminance ranged from 0.71 to 1.03 milli-Lux, which corresponds to an LPR of 8% to 14% brighter than average natural conditions. The NSNSD recommends a threshold of 0.8 milli-Lux, which was exceeded for four of the six measurements. However, since there are no thresholds for good condition, moderate concern, or significant concern, we did not assign a condition for this measure.

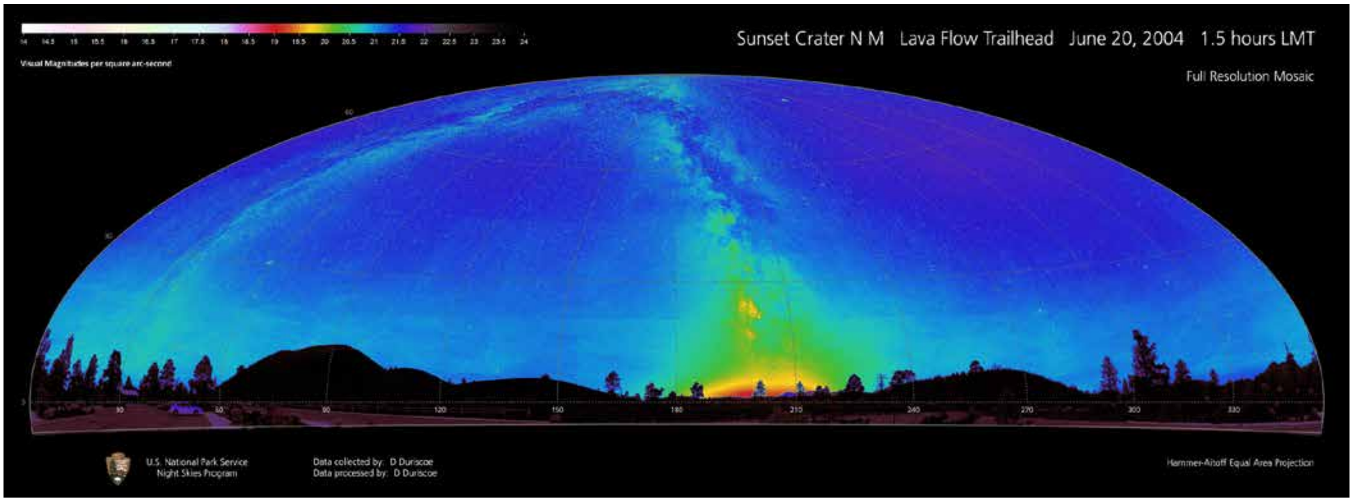


Figure 4.2.4-3. Panoramic all-sky mosaic of all light sources on 20 June2004 in Sunset Crater Volcano NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.

Figure 4.2.4-4. Panoramic all-sky mosaic of all light sources on 9 February 2005 in Sunset Crater Volcano NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.

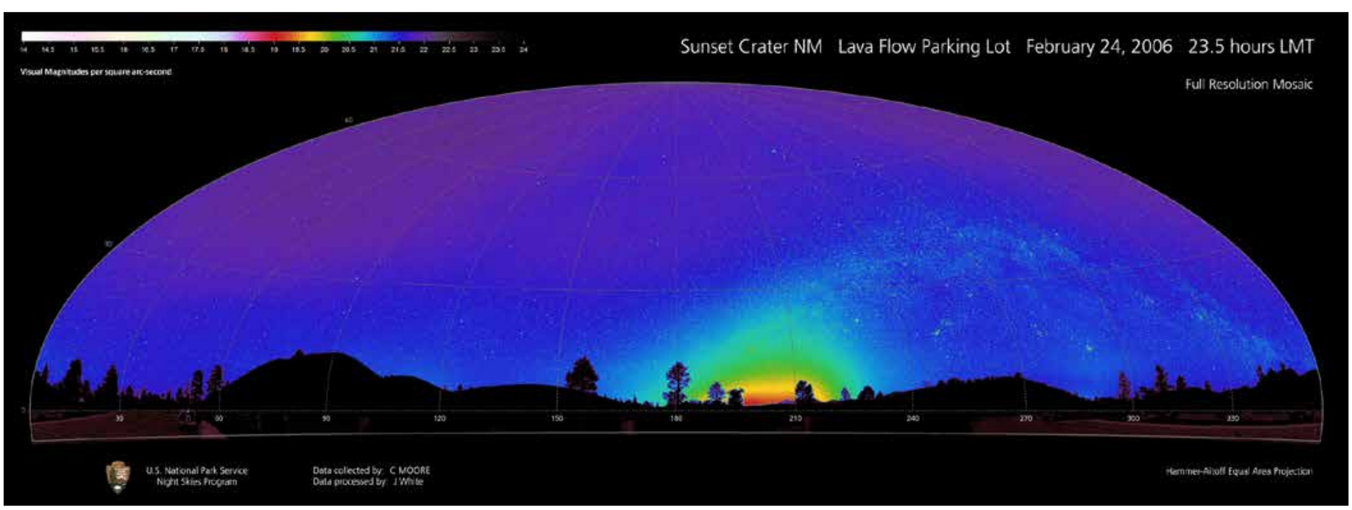


Figure 4.2.4-5. Panoramic all-sky mosaic of all light sources on 24 February 2006 in Sunset Crater Volcano NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.

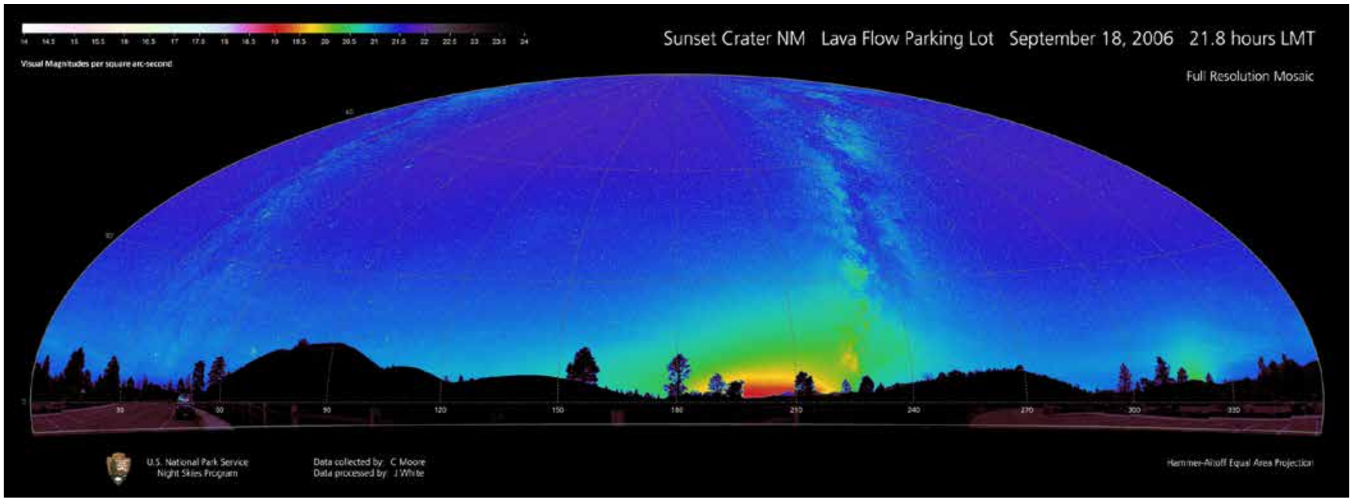


Figure 4.2.4-6. Panoramic all-sky mosaic of all light sources on 13 September 2006 in Sunset Crater Volcano NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.

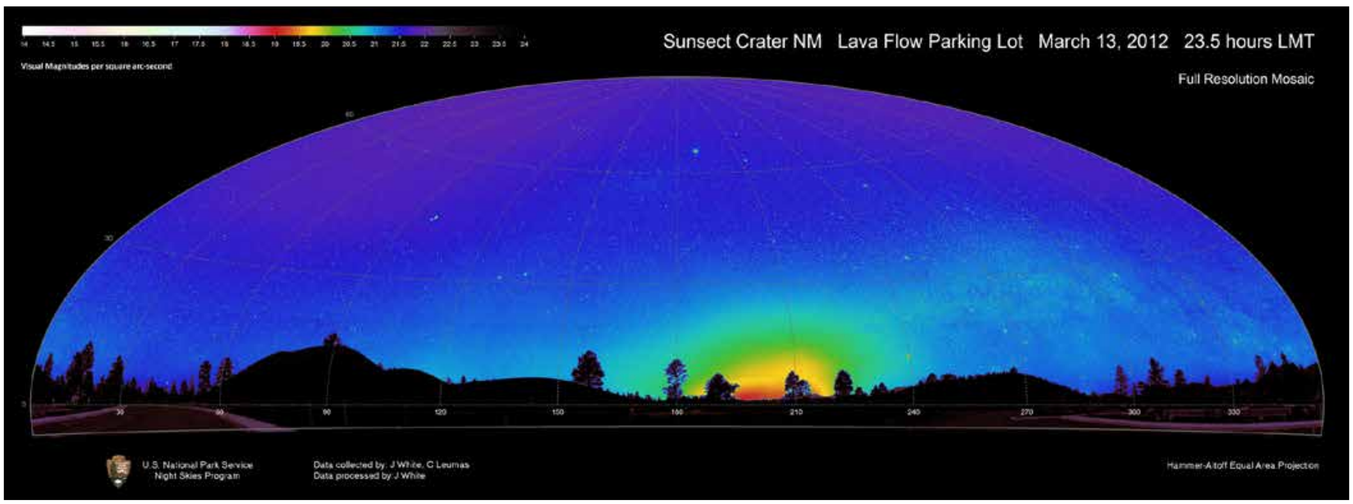


Figure 4.2.4-7. Panoramic all-sky mosaic of all light sources on 13 March 2012 in Sunset Crater Volcano NM. Light sources include natural and anthropogenic. Figure Credit: NPS Natural Sounds and Night Skies Division.

Confidence is low due to lack of reference conditions. We could not determine trend based on the six sampling dates, but these data suggest stable conditions for horizontal illuminance.

Zenith Sky Brightness (msa)

Zenith sky brightness varied from 21.14 to 21.89 msa at Lava Flow Trailhead. Data collected on 9 February 2005, 18 September 2006, and 13 March 2012 indicate good condition. Data collected on 20 June 2004 and 24 February 2006 warrant significant and moderate concern, respectively. Data collected at the Cinder Cone site on 15 October 2001 also indicate significant concern but this value appears to be an outlier. Since these data vary widely from good condition to warranting significant concern, we assigned an overall condition of moderate concern for this measure. The corresponding LPR measurements for zenith sky brightness ranged from 10% to 15% brighter than average natural conditions. We assigned high confidence to this condition rating since the data were collected in the field and as recently as March 2012 and are part of a time series. We could not determine trend based on the six sampling dates although these data indicate stable but highly variable conditions.

Bortle Dark Sky Class

NSNSD observers estimated the night sky quality to class 3 on all six monitoring dates, which corresponds to a rural sky. Under a Bortle Class 3 the Milky Way still appears complex and dark globular clusters are visible, but Zodiacal light is easily seen in addition to some light domes along the horizon. The Bortle Class designation is somewhat subjective depending on the observer, but was consistent on all nights of data collection. A Bortle Class 3 designation indicates good condition for this measure of sky quality. We assigned medium confidence to this condition rating since this measure is subjective and observer dependent. We could not determine trend based on the six sampling dates, but these data suggest stable conditions.

Overall Condition, Trend, Confidence, and Key Uncertainties

Overall, we consider the night sky at Sunset Crater Volcano NM to be good with an unknown trend and high overall confidence level in the condition rating. For a summary of indicators, measures, and their condition see Table 4.2.4-2. The overall condition rating and confidence level were based on the three measures for which condition thresholds have been developed. These measures were all-sky light pollution ratio, zenith sky brightness, and the Bortle Dark Sky Class designation.

Those measures for which confidence in the condition rating was high were weighted more heavily in the overall condition rating than measures with medium confidence. None of the measures were assigned low confidence. Factors that influence confidence level, include age of the data (<5 years unless the data are part of a long-term monitoring effort), repeatability, field data versus modeled data, and whether data can be extrapolated to other areas in the monument. Two of the three measures were given a high confidence level since the majority of data were collected in the field with data acquired as recently as 2012. The Bortle Dark Sky Scale, which is based on qualitative observations of the night sky, is somewhat subjective and was therefore, assigned medium confidence. Although the data used in this assessment spans about a 12-year period, data collection occurred on only six nights, which is insufficient to determine trend. However, over time, and in conjunction with other measurements, these data will provide a robust dataset with which to monitor and assess the night sky environment at Sunset Crater Volcano NM.

Regional and Local Context

Sunset Crater Volcano NM preserves a dark night sky rarely found in other regions, an attribute acknowledged by its designation as an International Dark Sky Park in 2016. Criteria for this designation are stringent and require a plan to preserve dark night skies (IDA 2016). To this end, monument staff are committed to long-term monitoring of night skies in addition to continuing outreach and education programs highlighting the monument's nocturnal landscape (NPS 2016a). In 2016, NPS staff purchased three basic Unihedron Sky Quality Meter devices to be shared among the three monuments and has created a data collection form to support long-term sky quality monitoring (NPS 2016a).

Although the city of Flagstaff, Arizona (population 65,870) is located 21.8 km (13.5 miles) southwest of the monument, its light dome is visible within the monument. However, the city of Flagstaff, Arizona is a leader in preserving dark night skies and was the first community to receive the Dark Sky designation by the IDA in 2001 (IDA 2016). Lowell Observatory located within the city limits provides numerous educational opportunities for the local community to participate in star gazing events and learn about the importance of dark night skies for aesthetics, wildlife, human health, and as a cultural resource. Although the population of Flagstaff, AZ is expected to grow, city lighting ordinances will limit light pollution in the area, thereby contributing to the preservation of dark night skies in Sunset Crater Volcano NM.

Threats, Issues, and Data Gaps

Although Flagstaff, Arizona and Sunset Crater Volcano NM have implemented plans to preserve dark night skies, light pollution from the city and surrounding area may have unwanted effects on the monument's nocturnal landscape, especially if the Flagstaff area grows in population. Arizona is the fourth fastest growing state in the U.S. (NPS 2016a, U.S. Census Bureau 2016a). Continued growth of urban centers such as Phoenix, Arizona (population 1,445,632) may degrade Sunset Crater Volcano NM's dark night sky despite being 206 km (128 miles) away (NPS 2016a). The modeled ALR map shown in Figure 4.2.4-1 shows the influence of the Phoenix, Arizona metropolitan area light dome on the monument.

Effects of Artificial Lighting on Wildlife

Studies show that artificial lighting reduces nocturnal foraging by rodents, modifies patterns of communication among coyotes, stimulates nocturnal activity in birds that are normally diurnal, disorients insects and birds that migrate at night, and alters patterns of pollination by nocturnal moths (Longcore

Table 4.2.4-2. Summary of night sky indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Sky Brightness	All-sky Light Pollution Ratio (ALR)		The modeled ALR value was higher than the majority of ground-based measurements. Ground-based ALRs varied from 0.16 to 0.28, which corresponds to a range of 16% to 28% brighter than average natural conditions. Since all ALR measurements, modeled and ground-based, were < 0.33, we consider this measure of sky brightness to be good. Confidence in this condition rating is high since it was based on six ground-based measurements and a modeled estimate. In total, there are six nights of monitoring during 2001 to 2012, which was insufficient to determine trend. However, the data suggest stable conditions for this measure of sky brightness.
	Vertical Maximum Illuminance (milli-Lux)		The condition for this measure is indeterminate since condition class thresholds have not been developed by the NSNSD; however, all six measurements exceeded the recommended threshold of 0.4 milli-Lux developed by the NSNSD. We could not determine trend based on the six sampling dates, but the data suggest stable conditions. Confidence in this condition rating is low due to lack of reference values.
	Horizontal Illuminance (milli-Lux)		The condition for this measure is indeterminate since condition class thresholds have not been developed by the NSNSD; however, data from four of the six monitoring dates exceeded the recommended threshold of 0.8 milli-Lux. We could not determine trend based on the six sampling dates, but the data suggest stable conditions. Confidence in this condition rating is low due to lack of reference values.
	Zenith Sky Brightness (MSA)		Zenith sky brightness varied from 21.14 to 21.89 msa at Lava Flow Trailhead. Data collected on three dates indicate good condition, while data collected on the remaining two dates at Lava Flow Trailhead warrant significant or moderate concern. Data collected at the Cinder Cone site also indicate significant concern but may be an outlier. Since these data vary widely from good condition to warranting significant concern, we assigned an overall condition of moderate concern for this measure. We assigned high confidence to this condition rating since the data were collected in the field and as recently as March 2012 and are part of a time series. We could not determine trend based on the six sampling dates although the data indicate stable but highly variable conditions.
Sky Quality	Bortle Dark Sky Class		NSNSD observers estimated the night sky quality to class 3 on all monitoring dates, which corresponds to a rural sky. Under a Bortle Class 3 the Milky Way still appears complex and dark globular clusters are visible, but Zodiacal light is easily seen in addition to some light domes along the horizon. The Bortle Class designation is somewhat subjective depending on the observer, but was consistent on all nights of data collection. A Bortle Class 3 designation indicates good condition for this measure of sky quality. We assigned medium confidence to this condition rating since this measure is subjective and observer dependent. We could not determine trend based on the six sampling dates, but data suggest stable conditions.
Overall Condition			Sunset Crater Volcano NM's nocturnal landscape is in good condition. Two of the three measures for which thresholds have been developed met the threshold for good condition. Although field data were collected over a 12-year period (2001-2012), there were only six data points. Therefore, trend could not be determined. Confidence in this rating is high.

and Rich 2004). Despite these studies, the effects of artificial lighting are not well understood for most species. Sunset Crater Volcano NM protects habitat for several primarily nocturnal species including the western spotted skunk (*Spilogale gracilis*), pinyon mouse (*Peromyscus truei*), little brown bat (*Myotis lucifugus*), and western pipistrelle (*Pipistrellus hesperus*) (NPS 1996). Given the monument's designation as an International Dark Sky Park, the region has the potential to protect these and other species that depend on the nocturnal landscape.

4.2.5. Sources of Expertise

The NPS Natural Sounds and Night Skies Division (NSNSD) helps parks manage the night sky in a way that protects park resources and the visitor experience. They provide technical assistance to parks in the form of monitoring, data collection and analysis, and in developing baselines for planning and reporting purposes. For more information, see http://nps.gov/nsnsd.

Jeremy White and Li-Wei Hung, Natural Sounds and Night Skies Division, part of the NPS Natural Resource Stewardship and Science Directorate, provided information pertaining to night sky data collection methodology, interpretation of results, and comments on earlier drafts of this assessment.

Assessment author is Lisa Baril, biologist and science writer, Utah State University.

4.3. Soundscape

4.3.1. Background and Importance

Our ability to see is a powerful tool for experiencing our world, but sound adds a richness that sight alone cannot provide. In many cases, hearing is the only option for experiencing certain aspects of our environment, and an unimpaired acoustical environment is an important part of overall National Park Service (NPS) visitor experience and enjoyment, as well as vitally important to overall ecosystem health.

In a 1998 survey of the American public, 72% of respondents identified opportunities to experience natural quiet and the sounds of nature as an important reason for having national parks (Haas and Wakefield 1998). Additionally, 91% of NPS visitors "consider enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks" (McDonald et al. 1995) (Figure 4.3.1-1). Despite this desire for quiet environments, noise continues to intrude upon natural areas and has become a source of concern in national parks (Lynch et al. 2011).

A park's natural soundscape is an inherent component of "the scenery and the natural and historic objects and the wildlife" protected by the Organic Act of 1916. NPS Management Policies (§ 4.9) (2006) require preservation of parks' natural soundscapes and restoration of degraded soundscapes to natural conditions wherever possible. Additionally, the NPS is required to prevent or minimize degradation of natural soundscapes from noise (i.e., any unwanted sound). Although the management policies currently refer to the term soundscape as the aggregate of all natural sounds that occur in a park, differences exist between the physical sound sources and human perceptions of those sound sources. Physical sound resources (e.g., wildlife, waterfalls, wind, rain, and cultural or historical sounds), regardless of their audibility, at a particular location, are referred to as the acoustical environment, while the human perception of that acoustical environment is defined as the soundscape. Clarifying this distinction will allow managers to create objectives for safeguarding both the acoustical environment and the visitor experience.

In addition, sound plays a critical role for wildlife communication. Activities such as courtship, predation, predator avoidance, and effective use of habitat rely on the ability to hear with studies showing that wildlife can be adversely affected by intrusive sounds. While the severity of impacts varies depending on the species and other conditions, documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, separation of mothers and young, and interference with communication (Selye 1956, Clough 1982, USFS 1992, Anderssen et al. 1993, NPS 1994, Dooling

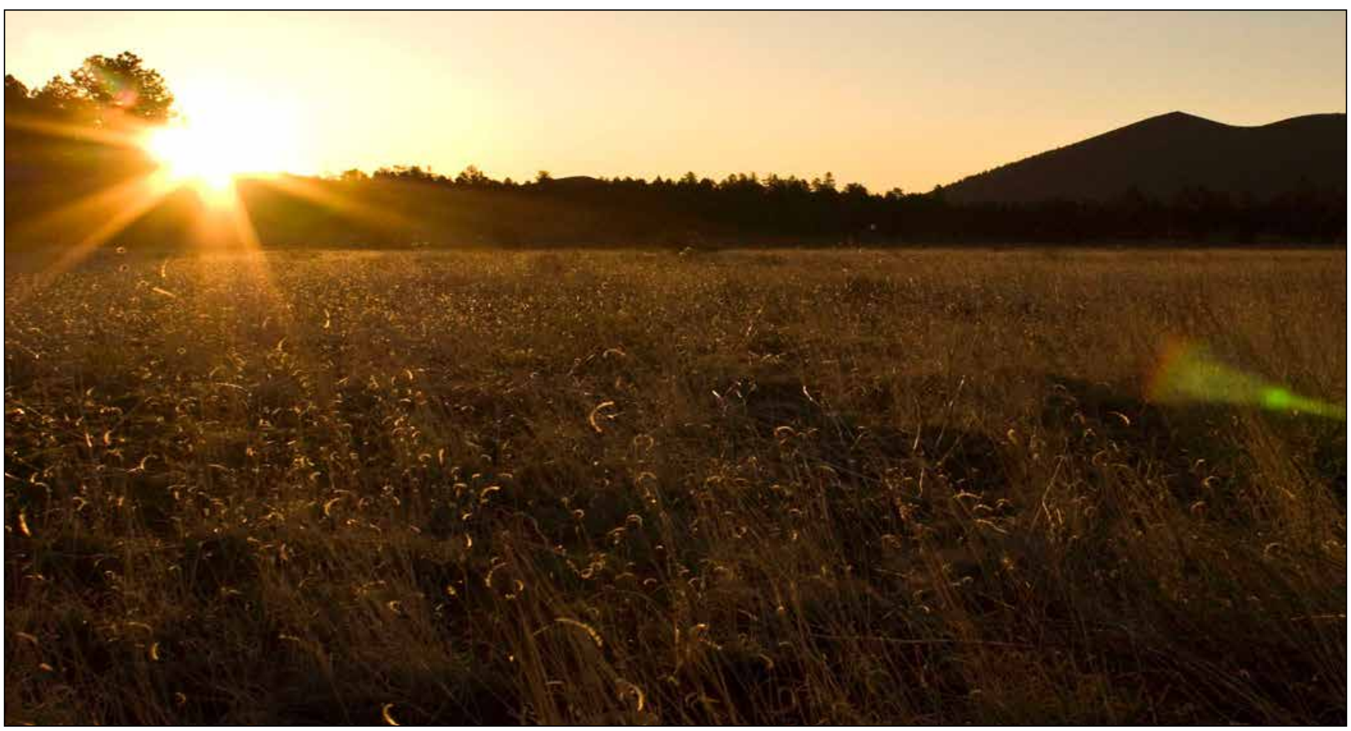


Figure 4.3.1-1. Sunrise at Sunset Crater Volcano NM provides solitude for park visitors. Photo Credit: NPS.

and Popper 2007, Kaseloo 2006). Researchers have also documented wildlife avoidance behaviors due to increased noise levels (Shannon et al. 2015, McLaughlin and Kunc 2013). An interesting recent publication showed that even plant communities can be adversely affected by noise because key dispersal species avoid certain areas (Francis et al. 2012).

Sunset Crater Volcano National Monument (NM) provides an increasingly rare opportunity for visitors to experience a natural soundscape. The monument's proximity to Flagstaff, Arizona provides a unique opportunity for park staff to engage visitors in appreciating and preserving the monument's natural soundscape through interpretive programs and guided hikes (NPS 2015a).

Sound Characteristics

Humans and wildlife perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air. Sound is measured in terms of frequency (pitch) and amplitude (loudness) (Templeton and Sacre 1997, Harris 1998).

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

The amplitude (or loudness) of a sound, measured in decibels (dB), is logarithmic, which means that every 10 dB increase in sound pressure level (SPL) represents a tenfold increase in sound energy. This also means that small variations in SPL can have significant effects on the acoustical environment. For instance, a 6 dB reduction in background noise level would produce a 4x increase in listening area (Figure 4.3.1-2). Changes in background noise level cause changes in listening opportunity. These lost opportunities will approach a halving of alerting distance and a 75% reduction of listening area for each 6 dB increase in affected band level (Barber et al. 2010).

SPL is commonly summarized in terms of dBA (A-weighted SPL). This metric significantly discounts sounds below 1,000 Hz and above 6,000 Hz to approximate the variation in human hearing sensitivity.

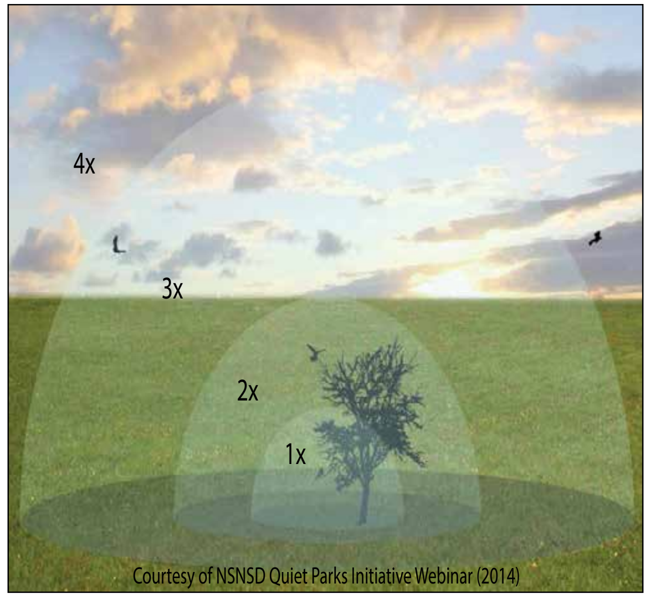


Figure 4.3.1-2. A 6 dB reduction in background noise level would produce a 4x increase in listening area. Figure Credit: © Ted E. Dunn.

4.3.2. Data and Methods

Baseline acoustical monitoring data for Sunset Crater Volcano NM were collected by park natural resource staff. An acoustical monitoring system was deployed at one location (characteristics of the monitoring location are summarized in Table 4.3.2-1) within the national monument during the months of July and August 2010 (Figure 4.3.2-1).

The monitoring location was approximately 0.4 mi (0.6 km) from the crater and 0.15 mi (0.2 km) from the Loop Road. The site was monitored for 20 days during July and August. The National Transportation Systems Center (Volpe Center) analyzed the data and produced a report (NPS 2013a), which was coordinated as part of a technical assistance request with the NPS Natural Sounds and Night Skies Division (NSNSD). The objectives were to characterize existing sound levels, establish a baseline for future monitoring, and estimate natural ambient sound levels in support of the

Table 4.3.2-1. Location characteristics of the acoustical monitoring site at Sunset Crater Volcano NM.

Location	Dates Deployed	Vegetation	Elevation
Sunset Crater Volcano	7/7/2010-8/6/2010 (20 days)	Bare Rock/ Sand/Clay	2,125 m (6,973 ft)

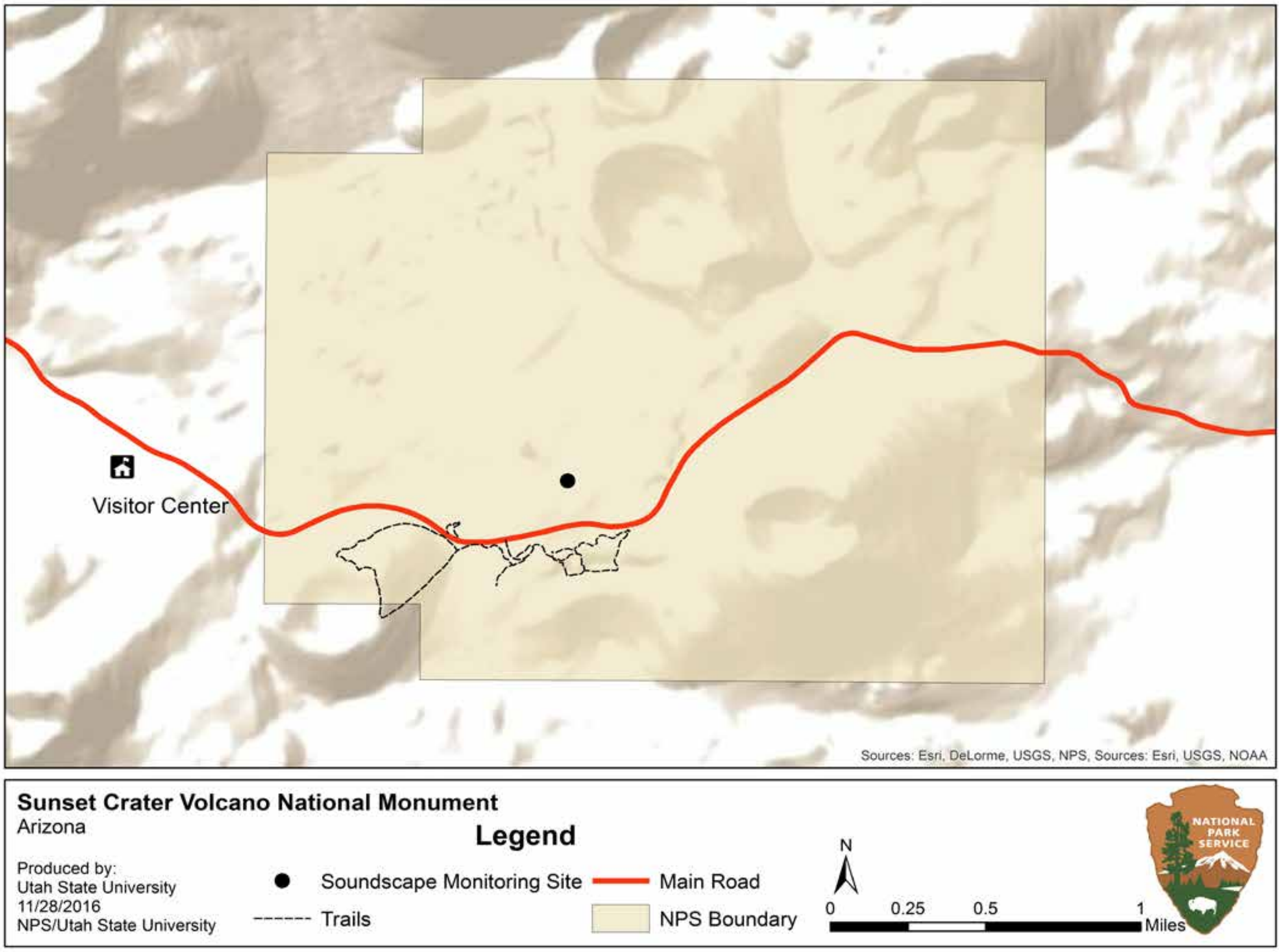


Figure 4.3.2-1. Location of the 2010 acoustical monitoring site at Sunset Crater Volcano NM.

potential development of an air tour management plan (NPS 2013a); however, the monument was exempted from producing an air tour management plan since fewer than 50 air tours are reported annually (FAA 2014).

<u>% Time Above Reference Sound Levels</u>

The percent time above reference sound levels is a measure of the amount of time that the sound level exceeds specified decibel values (NPS 2010). Research into the effects of noise on wildlife is rapidly developing, and observed responses to noise sources and sound levels have been found across a variety of species. In a literature review of the effects of noise on wildlife, Shannon et al. (2015) found that responses to noise can include "altered vocal behavior to mitigate masking, reduced abundance in noisy habitats, changes in vigilance and foraging behavior, and impacts on individual fitness and the structure of ecological communities." Of the organisms studied, wildlife responses were observed at noise levels as low as 40 dBA, and further, 20% of studies documented impacts below 50 dBA. Human responses to sound levels can serve as a proxy for potential impacts to other vertebrates because humans have more sensitive hearing at low frequencies than most species (Dooling and Popper 2007). Table 4.3.2-2 summarizes sound levels that relate to human health and speech, as documented in the scientific literature.

The first, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dBA can have adverse effects on blood pressure while sleeping (Haralabidis 2008). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third value, 52 dBA, is based on the United States Environmental Protection Agency's (U. S. EPA) speech interference threshold for speaking in a raised

Table 4.3.2-2. Sound level values related to human health and speech.

Sound Levels (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al. 2008)
45	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund et al. 1999)
52	Speech interference for interpretive programs (USEPA 1974)
60	Speech interruption for normal conversation (USEPA 1974)

Source: NPS (2013).

voice to an audience at 10 meters (32.8 feet) (U.S. EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter (3.3 feet). Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations. The NSNSD determined the percent of time sound levels were above these four decibel reference levels for both day (7:00 am to 7:00 pm) and night (7:00 pm to 7:00 am) (NPS 2010) at the Sunset Crater Volcano monitoring site.

<u>% Reduction in Listening Area</u>

A one decibel change is not readily perceivable by the human ear, but any addition to this difference could begin to impact listening ability. To assess the condition of the acoustic environment, it is useful to consider the functional effects that increases in sound levels might produce. For instance, the listening area, the area in which a sound can be perceived by an organism, will be reduced when background sound levels increase. Seemingly small increases in sound level can have substantial effects, particularly when quantified in terms of loss of listening area as previously shown in Figure 4.3.1-2 (Barber et al. 2010). Each 3 dB increase in the background sound level will reduce a given listening area by half.

Failure to perceive a sound because other sounds are present is called masking. Masking interferes with wildlife communication, reproductive and territorial advertisement, and acoustic location of prey or predators (Barber et al. 2010). However, the effects of masking are not limited to wildlife. Masking also inhibits human communication and visitor detection of wildlife sounds. In urban settings, masking can prevent people from hearing important sounds like approaching people or vehicles, and interfere with the way visitors experience cultural sounds or interpretive programs.

To determine the effect noise from air tours and other aircraft has on the natural soundscape at Sunset Crater Volcano we calculated percent reduction in listening area from the natural ambient sound level to each of three sound level categories: existing ambient, existing ambient without air tour noise, and existing ambient without all aircraft noise. Air tour noise is distinguished from other aircraft noise because low-level fixed wing/propeller aircraft present unique sound signatures that are indicative of air tour activity. However, it is possible that some portion of these events were categorized erroneously as air tours. These metrics were reported as the level of sound that was exceeded fifty percent of the time at a given location, or L_{50} (NPS 2013a).

Natural ambient sound level refers to all naturally occurring sounds and excludes all anthropogenic noise. Existing ambient sound level includes all sounds in a given area, natural and anthropogenic. Existing ambient sound level without air tour noise includes all sounds, natural and anthropogenic, minus noise from air tours. Existing ambient sound level without all aircraft noise includes all sounds, natural and anthropogenic, minus noise from all aircraft, including air tours, commercial jets, military overflights, and any other aircraft. Existing ambient sound levels were reported for both day (7:00 am to 7:00 pm) and night (7:00 pm to 7:00 am), while existing ambient sound levels without air tour noise and without all aircraft noise were reported for day only since this is when noise from aircraft is most likely to impact visitor enjoyment (NPS 2013a).

<u>% Time Audible</u>

Percent time audible is the amount of time that various sound sources are audible to humans with normal hearing. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore, percent time audible is a protective proxy for wildlife. The

NSNSD determined the percent time audible of sounds in each of four categories (three anthropogenic and one natural), as follows: fixed-wing aircraft and helicopters, other aircraft sounds, other human sounds, and natural sounds. Data were gathered via in-situ site visits and by audio recordings collected at Sunset Crater Volcano and analyzed later.

L_{50} Impact

The geospatial model estimated sound pressure levels for the continental United States by using actual acoustical measurements combined with a multitude of explanatory variables such as location, climate, landcover, hydrology, wind speed, and proximity to noise sources (e.g., roads, railroads, and airports). The 270 m (886 ft) resolution model predicts daytime sound levels during midsummer. Each square of color maps generated from this effort represents 270 m^2 (2,960 ft^2), and each pixel on the map represents a median sound level (L_{50}). It should be noted that while the model excels at predicting acoustic conditions over large landscapes, it may not reflect recent localized changes such as new access roads or development.

Model parameters useful for assessing a park's acoustic environment include the understanding of a) natural conditions, b) existing acoustic conditions including both natural and human-caused sounds, and c) the impact of human-caused sound sources in relation to natural conditions. The L_{50} impact condition demonstrates the influence of human activities to the acoustic environment and is calculated by zeroing all anthropogenic factors in the model and recalculating ambient conditions. It is effectively the difference between existing and natural condition.

4.3.3. Reference Conditions

Table 4.3.3-1 summarizes the condition thresholds for measures in good condition, those warranting moderate concern, and those warranting significant concern.

% Time Above Reference Sound Levels

We used decibel levels presented in Table 4.3.2-2 as thresholds to separate the three reference conditions displayed in Table 4.3.3-2 (U.S. EPA 1974, Berglund et al. 1999, and Haralabidis et al. 2008). If sound levels were below the World Health Organization's recommended maximum noise level in bedrooms (45 dBA), then we considered the condition to be good. If sound levels were above that which is expected to cause speech interference for interpretive programs, we considered the condition to warrant significant concern.

% Reduction in Listening Area

Sunset Crater Volcano NM is considered a non-urban park, or park with at least 90% of their land located outside an urban area. Parks outside an urban area are usually quieter and more susceptible to noise

Table 4.3.3-1. Reference conditions used to assess the sound levels at Sunset Crater Volcano NM.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Sound Level	% Time Above Reference Sound Levels	The majority of sound levels recorded were <45 dBA.	The majority of sound levels recorded were between 45 - 52 dBA.	The majority of sound levels recorded were >52 dBA.
	% Reduction in Listening Area*	Listening area was reduced by ≤ 30% over natural ambient sound levels.	Listening area was reduced by 30-50% over natural ambient sound levels.	Listening area was reduced by >50% over natural ambient sound levels.
Audibility of Anthropogenic Sounds	% Time Audible	Dominant sounds are consistent with the non-urban setting of the monument. Natural ambient sounds such as wind, birds singing, thunder claps, etc. dominate, but some sounds related to recreational activities, and/or traffic are also sometimes audible.	Dominant sounds are generally consistent with the park's non-urban setting, but noise occurs more frequently and noise from the adjacent highways, etc., begins to infiltrate the area.	A high percentage of the audible sounds heard are from noises such that the natural and/or cultural sense of place is compromised; therefore, the enjoyment of visitors is compromised.
Geospatial Model	L_{50} Impact*	≤ 1.5	1.5 - ≤ 3.0	>3

*National Park Service Natural Sounds and Night Skies thresholds for non-urban parks. Non-urban parks are those with at least 90% of their land located outside an urban area (Turina et al. 2013).

intrusions (Turina et al. 2013). Visitors likely have a greater expectation for quiet at non-urban parks and wildlife are likely more adapted to a noise-free environment. Therefore, the thresholds separating reference conditions for non-urban parks are more stringent than for those located in urban areas. A reduction in listening area of 30% would indicate good condition, while a more than 50% reduction in listening area would warrant significant concern (Turina et al. 2013).

% Time Audible

We considered this measure to be in good condition if the dominant sounds at Sunset Crater Volcano NM were natural. While some anthropogenic noise is expected, it generally does not interfere with the natural soundscape. In contrast, if the dominant sounds are from anthropogenic sources, then we consider this measure to warrant significant concern.

L_{50} Impact (Mennitt et al. 2013)

Reference conditions for this measure were developed by Turina et al. 2013 and are presented in Table 4.3.3-2. We used thresholds for non-urban parks, which are those with at least 90% of their land located outside an urban area (Turina et al. 2013).

4.3.4. Condition and Trend

% Time Above Reference Sound Levels

Figure 4.3.4-1 shows the percent time sound levels were above the reference sound levels at the monitoring site during day (7 a.m. - 7 p.m.) and night (7 p.m. - 7 a.m.) hours. The percent of time above reference sound levels declined with increasing sound levels, and the proportion of time reference sound levels were exceeded was low throughout the monitoring period. The 35 dBA sound level was exceeded only 5.5% of the time during the day and 1.6% of the time at night. At 45 dBA the proportion of time above reference sound levels was only 0.7% during the day and 0.06% at night. Sounds levels did not exceed 52 dBA at night and rarely exceeded 52 dBA during the day. These data show that day or night, sounds levels in Sunset Crater Volcano NM were low the majority of the time. Therefore, we considered this measure to be in good condition. Confidence in this condition rating is high, but since data were collected at this site for one season only, trend could not be determined.

% Reduction in Listening Area

Existing Ambient L_{50} dBA

Table 4.3.4-1 summarizes ambient daytime sound level data for the monitoring site. L_{50} represents the level of sound exceeded 50% of the time during the given measurement period. The daytime existing ambient L_{50} value was 28.7 dBA. At night existing

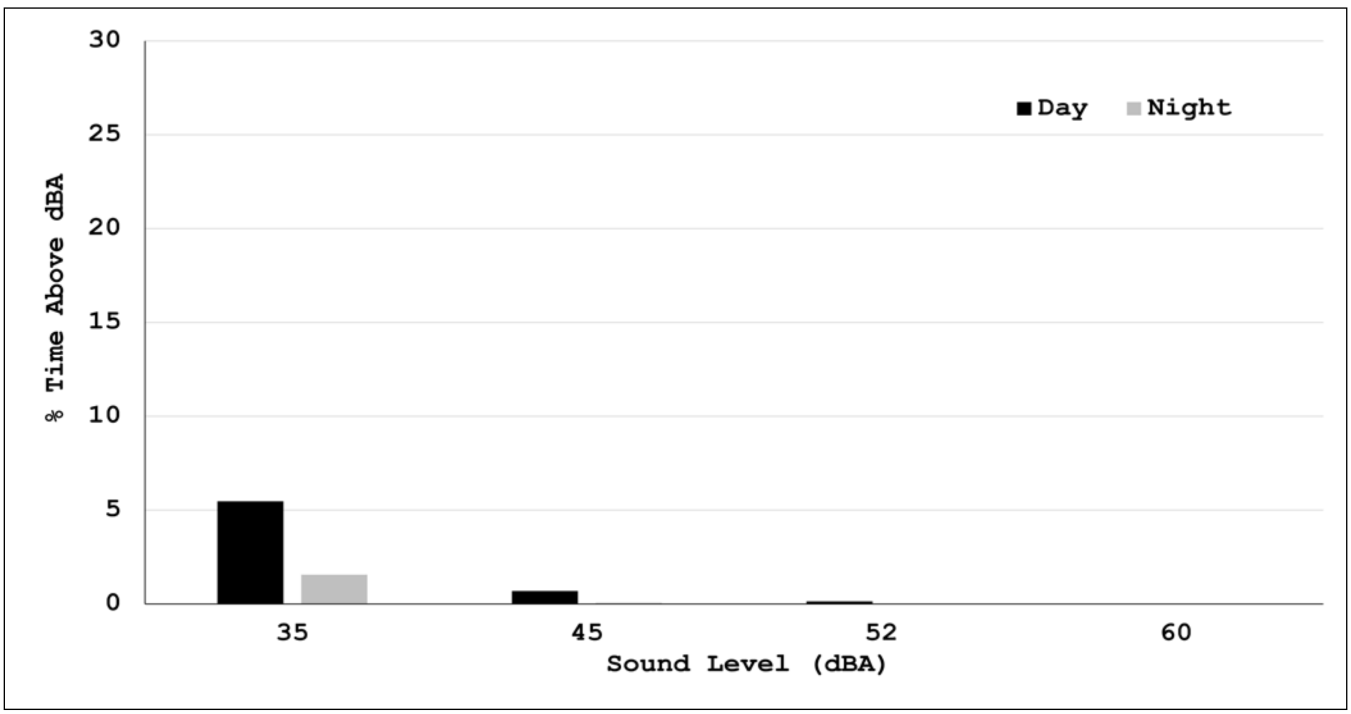


Figure 4.3.4-1. Percent time above reference sound levels at Sunset Crater Volcano NM.

Table 4.3.4-1. Ambient daytime (7:00 am to 7:00 pm) sound levels at Sunset Crater Volcano NM.

Site Location	Natural Ambient L_{50} (dBA)	Existing Ambient L_{50} (dBA)	Existing Ambient w/out Air Tours L_{50} (dBA)	Existing Ambient w/out All Aircraft L_{50} (dBA)
Northeast Rim	23.3	28.7 (71%)	27.5 (62%)	25.6 (41%)

Note: Percentages indicate reduction in listening area over natural ambient conditions.

ambient sound levels were lower at 18.9 dBA (data not shown in Table 4.3.4-1). Daytime values exceeded the baseline condition (median L_{NAT}) by 5.4 dBA, which corresponds to a reduction in listening area over natural ambient sound levels of 71%. Since the reduction in listening area was greater than 50% this measure warrants significant concern.

Existing Ambient L_{50} w/out Air Tour Noise
Existing ambient sound level without air tour noise was slightly lower than existing ambient values but still greater than natural ambient values (Table 4.3.4-1). At Sunset Crater Volcano NM, this measure exceeded natural ambient conditions by 4.2 dBA, which corresponds to a listening area reduction of 62%. By eliminating the air tour events, the listening area increased by 9 percentage points over existing ambient conditions. Although some sound signatures may have been erroneously categorized as air tours, these types of overflights are not common at Sunset Crater Volcano NM. Since 2013, 16 air tours have been reported over the monument (FAA 2014, 2015, 2016). Since the listening area was reduced by 62% over natural ambient sound levels, this measure warrants significant concern.

Existing Ambient L_{50} w/out All Aircraft
Compared with the other measures, existing ambient sound levels without all aircraft sound exhibited the lowest values except for natural ambient sound levels. The natural ambient sound level was exceeded by 2.3 dBA. This resulted in a listening area reduction of 41%. Since the listening area was reduced by less than 50% but more than 30%, the condition for this measure warrants moderate concern.

Overall Summary
Two of the three measures of reduction in listening area warrant significant concern, while the remaining measure warrants moderate concern. Removing aircraft noise from the data improved the listening area, but the listening area was still reduced by 41% without all aircraft noise, which suggests other sources of noise also contribute to reduction in listening area. Based on these data, the overall condition for reduction in listening area warrants moderate to significant concern at Sunset Crater Volcano NM. Confidence in this condition rating is high since these data were based on in situ field measurements and analysis in the lab by the Volpe Center. Since data were collected during one season only, we could not determine trend.

% Time Audible
A detailed analysis of audibility (Figure 4.3.4-2) found that natural sounds contributed about half (49%) of all sounds to the acoustical environment. Aircraft were audible 28% of daytime hours, while other human sounds (vehicles and voices) were audible 23% of daytime hours for a total of 51% of noise that can be attributed to anthropogenic sources. Noise from vehicles and aircraft has the potential to mask natural sounds that provide a sense of place and add to the natural character of the monument. Since the contribution of natural sounds and anthropogenic noise to the acoustical environment were about equal, we consider the condition for this measure to be of moderate concern. Since these data are based on in situ field measurements and analysis in the lab by the Volpe Center, confidence is high. Trend could not be determined based on these data.

L_{50} Impact (Mennitt et al. (2013)
Figure 4.3.4-3 shows the modeled mean impact sound level map for the monument. The modeled mean impact was 0.7 dBA above natural conditions but ranged from 0 dBA in the least impacted areas to 3.0 dBA in the most impacted areas. The map depicts the area most influenced by human-caused sounds (i.e., lighter areas). The existing and natural acoustic environment condition maps for the monument are included in Appendix E.

Summary statistics of the L_{50} values for the natural, existing, and impact conditions are provided in Table 4.3.4-2. Average values represent the average L_{50} value occurring within the monument boundary, and since

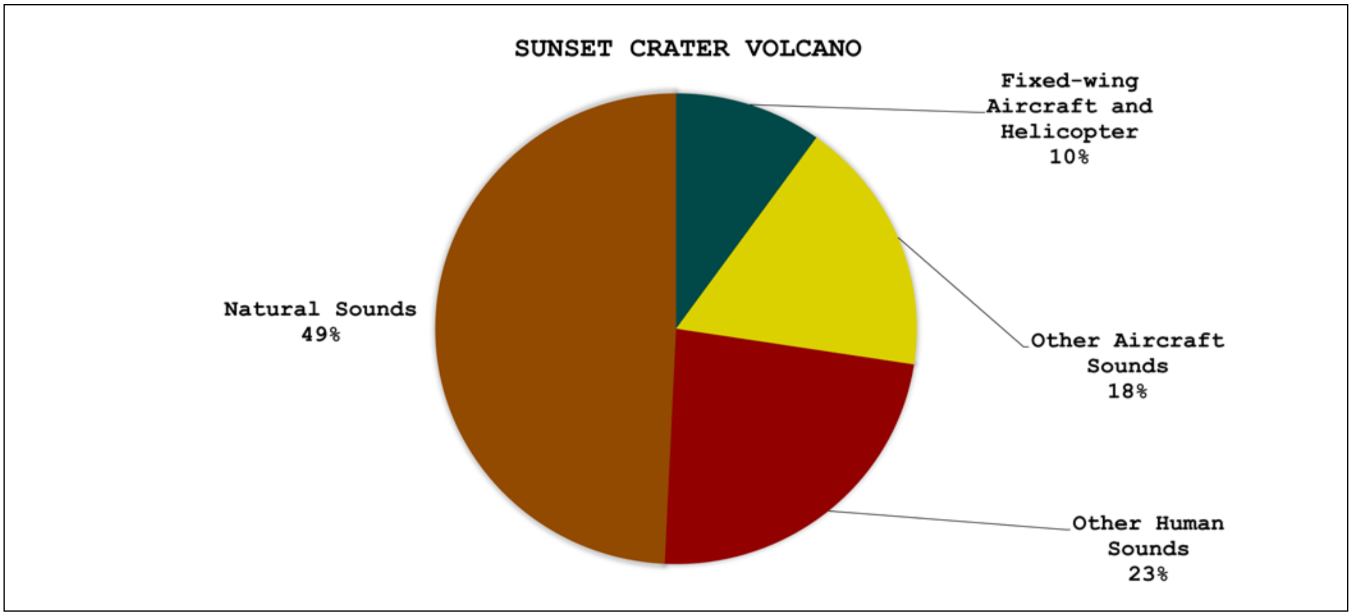


Figure 4.3.4-2. **Percent time various sounds were audible at the Sunset Crater Volcano NM monitoring site.**

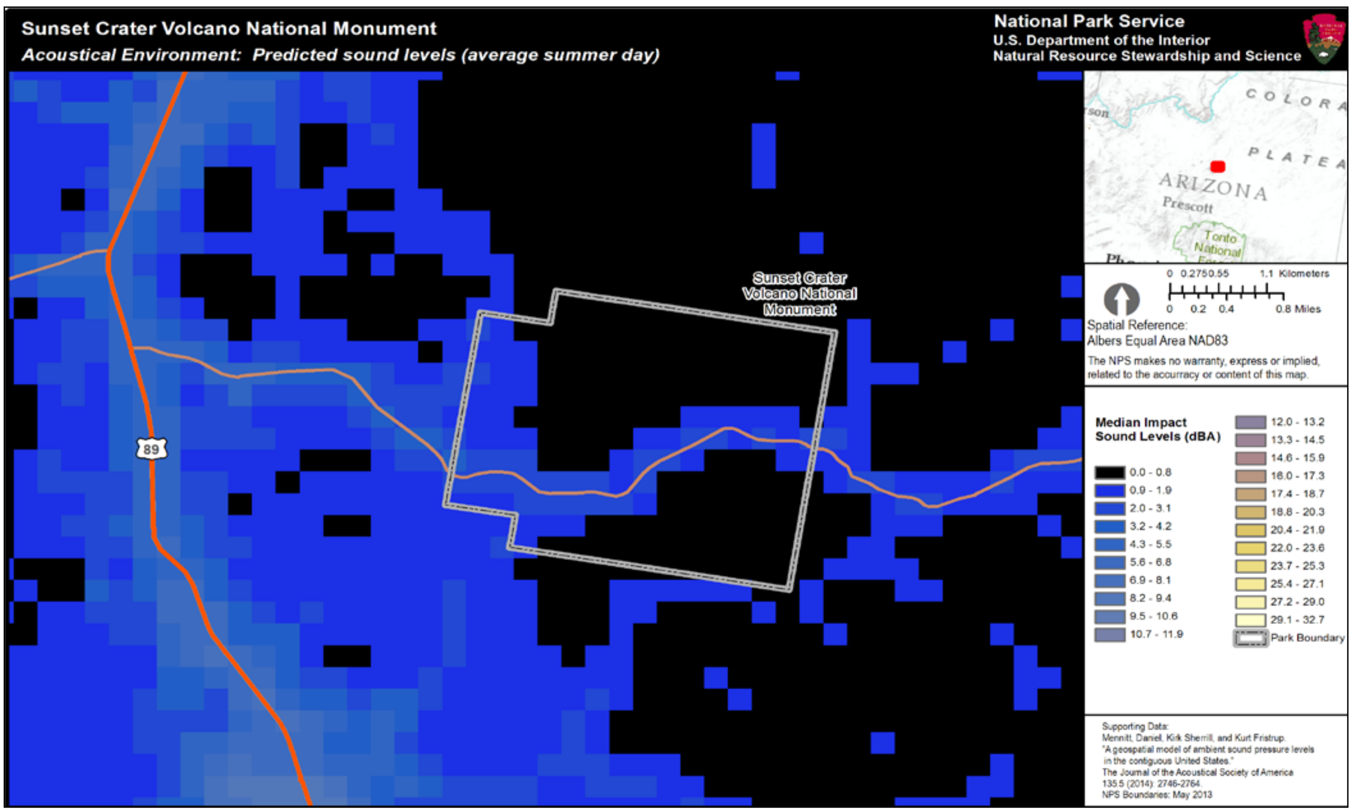


Figure 4.3.4-3. **The modeled L_{50} impact sound level at Sunset Crater Volcano NM. Lighter colors represent higher impact areas. Figure Credit: Emma Brown, NPS NSNDS.**

this value is a mean, visitors may experience sound levels higher and lower than the average L_{50}. A one decibel change is not readily perceivable by the human ear, but any addition to this difference could begin to impact a visitor's listening ability to hear natural sounds or interpretive programs.

Mennitt et al. (2013) suggest that in a natural environment, the average summertime L_{50}, which is the sound level exceeded half of the time (and is a fair representation of expected conditions) is not expected to exceed 41 dBA. However, acoustical conditions vary by area and depend on vegetation, landcover,

Table 4.3.4-2. Summary of the modeled minimum, maximum, and average L_{50} measurements in Sunset Crater Volcano NM.

Acoustic Environment Condition	Min. (dBA)	Max. (dBA)	Avg. (dBA)
Natural	28.9	30	29.5
Existing	29.2	32.7	30.1
Impact	0.0	3.0	0.7

Note: Data were provided by E. Brown, NPS NSNSD.

elevation, climate, and other factors (Mennitt et al. 2013). Any one place may be above or below this average depending on these and other variables. Mennitt et al. (2013) also state that "an impact of 3 dBA suggests that anthropogenic noise is noticeable at least 50% of the hour or more." The modeled median impact result for the monument was below 1.5 dBA, thus the L_{50} Impact was considered to be in good condition according to the reference thresholds developed by Turina et al. (2013). Since these data are modeled, confidence is medium. Trend could not be determined based on these data.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Overall, we consider the soundscape at Sunset Crater Volcano NM to range from good condition to warranting moderate concern. This condition rating was based on three indicators with a total of four measures, which are summarized in Table 4.3.4-3. Two of the four measures used to assess the soundscape were considered good. The remaining two measures either warranted moderate concern or were split between warranting moderate concern to warranting significant concern. The data showed that while sound levels rarely exceeded 35 dBA, noise was audible about 50% of the time at the monitoring location. In other words, noise events were not typically loud, but they were audible 50% of the time, probably because background sound levels were so low. Anthropogenic noise was attributed to aircraft, vehicles, and human voices. Although about half of all sounds were attributed to anthropogenic noise, the proportion of time decibels were above reference conditions was low at all four sound level values related to human health.

Those measures for which confidence in the condition rating was high were weighted more heavily in the overall condition rating than measures with medium confidence. None of the condition ratings were assigned low confidence. Factors that influence confidence in the condition rating include age of the data (<5 years unless the data are part of a long-term monitoring effort), repeatability, field data versus modeled data, and whether data can be extrapolated to other areas of the monument. Only one of the four measures, L_{50} impact, was given a medium confidence rating since it was based on modeled data. Although we assigned this measure medium confidence, the model provides a useful map of how sound may vary across the monument. The remaining measures were assigned high confidence since they were based on field data despite being six years old, although we acknowledge that these data may not reflect current condition. Since data were collected during one season (2010), we could not determine trend.

A key uncertainty is that these results may not fully represent typical sources of anthropogenic noise heard within the monument since data were collected during one season, and some sound signatures may be misidentified throughout the analysis process. Also, sound levels vary by time of day, with the weather, topography, and other factors (NPS 2013a). It is expected that a long monitoring period would capture this sort of variability. And finally, the information is already six years old (2010). It is expected that natural ambient conditions would remain constant from the 2010 monitoring period to the present, but existing ambient sound level (which includes natural and human-caused sounds) could have changed since the inventory was conducted. Continued monitoring will provide more information about how and if Sunset Crater Volcano NM's soundscape is changing.

Threats, Issues, and Data Gaps

In addition to the 16 air tours reported for 2013-2015, other aircraft noise, including military overflights and high altitude commercial aircraft, is a regular but rare disruption to the monument's solitude (NPS 1996). Sunset Crater Volcano NM is also in the line-of-sight route for low-level personal aircraft enroute from Flagstaff to Page, AZ and other communities in the Four Corners area, and also on the primary helicopter emergency medical transport route from Tuba City and Kayenta to Flagstaff Medical Center (NPS, P. Whitefield, Natural Resource Specialist, comments to draft assessment, September 2016).

Table 4.3.4-3. Summary of soundscape indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Sound Level	% Time Above Reference Sound Levels		Sound levels rarely exceeded 35 dBA day or night, which is below the World Health Organization's recommendation for maximum noise level in bedrooms; therefore, we considered this measure to be in good condition. Confidence in this condition rating is high, but since data were collected at this site for one month, trend could not be determined.
	% Reduction in Listening Area		Two of the three measures of reduction in listening area warrant significant concern while the remaining measure warrants moderate concern. Removing aircraft noise from the data improved the listening area, but the listening area was still reduced by 41% without all aircraft noise, which suggests other sources of noise also contribute to reduction in listening area. Based on these data, the overall condition for reduction in listening area warrants moderate to significant concern. The confidence in this condition rating is high since these data are based on in situ field measurements and analysis in the lab by the Volpe Center. Since data were collected during one season only, we could not determine trend.
Audibility of Anthropogenic Sounds	% Time Audible		Natural sounds were audible about half (49%) of the time during the monitoring period. Aircraft was audible 28% of daytime hours, while other human sounds (vehicles and voices) were audible 23% of daytime hours. Overall, anthropogenic noise was audible about 51% of the time during the monitoring period. Since natural sounds and anthropogenic noise were audible for a similar amount of time, we consider the condition for this measure to be of moderate concern. Since these data are based on in situ field measurements and analysis in the lab by the Volpe Center, confidence is high. Trend could not be determined based on these data.
Geospatial Model	L_{50} Impact		The modeled mean impact was 0.7 dBA above natural conditions but ranged from 0 dBA in the least impacted areas to 3.0 dBA in the most impacted areas. The modeled median impact result for the monument was below 1.5 dBA, thus the L_{50} Impact was considered to be in good condition Since these data were modeled, confidence is medium. Trend could not be determined based on these data.
Overall Condition			Overall, we consider the soundscape at Sunset Crater Volcano NM to range from good to moderate concern. Two of the four measures used to assess the soundscape were considered good. The remaining two measures either warranted moderate concern or were split between warranting moderate concern to warranting significant concern. Data showed that noise was audible about 49% of the time, but median sound levels rarely exceeded 35 dBA. Confidence is high for two of the three measures and medium for the remaining measure for an overall confidence of high. Trend could not be determined for one season of data.

Noise from Highway 89 and FS 545 interrupts the monument's natural sounds (NPS 1996). An estimated 50-60 vehicles travel along select portions of the monument's road every hour during July and August (NPS 2013a), and traffic volume is likely to increase as the population of Flagstaff, AZ rises. Approximately 70,320 people live in Flagstaff as of July 1, 2015 (U.S. Census Bureau 2016a). This is a 6.4% increase since April 2010 and the population is expected to increase (U.S. Census Bureau 2016a). Arizona is the fourth fastest growing state in the U.S. based on projected percent change in population size from 1995 to 2025 (U.S. Census Bureau 2016b). The off-road vehicle use area on the monument's south and east boundaries also significantly impacts the monument's natural soundscape (NPS 1996). Along the western boundary there is also a "haul" road that is a nearly constant source of noise from large trucks associated with mining activities in the region (NPS 1996).

In addition to influencing our experience of the landscape, human-caused noise and frequency can influence the behavior and ability of wildlife to function naturally on the landscape. With respect to the effects of noise, there is compelling evidence that wildlife can suffer adverse behavioral and physiological changes from noise and other human disturbances, but the ability to translate that evidence into quantitative estimates of impacts is presently limited (Shannon et al. 2015).

In a review of literature addressing the effects of noise on wildlife published between 1990 and 2013, wildlife responses to noise were observed beginning at about 40 dBA, and further, 20% of papers showed impacts to terrestrial wildlife at or below noise levels of 50 dBA (Shannon et al. 2015). Wildlife response to noise was found to be highly variable between taxonomic groups. Furthermore, response to noise varied with behavior type (e.g., singing vs. foraging) (Shannon et al. 2015). One of the most common and readily observed biological responses to human noise is change in vocal communication. Birds use vocal communication primarily to attract mates and defend territories, but anthropogenic noise can influence the timing, frequency, and duration of their calls and songs (Shannon et al. 2015). Similar results have been found for some species of mammal, amphibians, and insects, which also rely on vocal communication for breeding and territorial defense. Other changes include changes in time spent foraging, ability to orient, and territory selection (Shannon et al. 2015).

Several recommendations have been made for human exposure to noise, but no guidelines exist for wildlife and the habitats we share. The majority of research on wildlife has focused on acute noise events, so further research needs to be dedicated to chronic noise exposure (Barber et al. 2010). In addition to wildlife, standards have not yet been developed to assess the quality of physical sound resources (the acoustic environment), separate from human or wildlife perception. Scientists are also working to differentiate between impacts to wildlife that result from the noise itself or the presence of the noise source (Barber et al. 2010). Sunset Crater Volcano NM staff has continued to collect sound data to further evaluate changes in the monument's soundscape and possible effects anthropogenic noise may have on wildlife.

4.3.5. Sources of Expertise

The NPS Natural Sounds and Night Skies Division (NSNSD) scientists help parks manage sounds in a way that balances the various expectations of park visitors with the protection of park resources. They provide technical assistance to parks in the form of acoustical monitoring, data collection and analysis, and in developing acoustical baselines for planning and reporting purposes. For more information, see http://nps.gov/nsnsd.

Emma Brown, Acoustical Resource Specialist with the NSNSD, provided an NRCA soundscape template used to develop this assessment and the sound model statistics and maps.

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4.4. Air Quality

4.4.1. Background and Importance

Under the direction of the National Park Service's (NPS) Organic Act, Air Quality Management Policy 4.7.1 (NPS 2006), and the Clean Air Act (CAA) of 1970 (U.S. Federal Register 1970), the NPS has a responsibility to protect air quality and any air quality related values (e.g., scenic, biological, cultural, and recreational resources) that may be impaired from air pollutants.

One of the main purposes of the CAA is "to preserve, protect, and enhance the air quality in national parks" and other areas of special national or regional natural, recreational, scenic, or historic value. The CAA includes special programs to prevent significant air quality deterioration in clean air areas and to protect visibility in national parks and wilderness areas (NPS-Air Resources Division [ARD] 2012a) (Figure 4.4.1-1).

Two categories of air quality areas have been established through the authority of the CAA: Class I and II. The air quality classes are allowed different levels of permissible air pollution, with Class I receiving the greatest protection and strictest regulation. The CAA gives federal land managers responsibilities and opportunities to participate in decisions being made by regulatory agencies that might affect air quality in the federally protected areas they administer (NPS-ARD 2005).

Class I areas include parks that are larger than 2,428 ha (6,000 acres) or wilderness areas over 2,023 ha (5,000 acres) that were in existence when the CAA was amended in 1977 (NPS-ARD 2010). Sunset Crater Volcano National Monument (NM) is designated as a Class II airshed. However, it is important to note that even though the CAA gives Class I areas the greatest protection against air quality deterioration, NPS management policies do not distinguish between the levels of protection afforded to any unit of the National Park System (NPS 2006).

<u>Air Quality Standards</u>

Air quality is deteriorated by many forms of pollutants that either occur as primary pollutants, emitted directly from sources such as power plants, vehicles, wildfires, and wind-blown dust, or as secondary pollutants, which result from atmospheric chemical reactions. The CAA requires the U.S. Environmental Protection Agency (USEPA) to establish National Ambient Air Quality Standards (NAAQS) (40 CFR part 50) to regulate these air pollutants that are considered harmful to human health and the environment (USEPA 2017a). The two types of NAAQS are primary and secondary, with the primary standards establishing limits to protect human health, and the secondary

Figure 4.4.1-1. A view of the crater in Sunset Crater Volcano NM on a clear day. Photo Credit: NPS.

standards establishing limits to protect public welfare from air pollution effects, including decreased visibility, and damage to animals, crops, vegetation, and buildings (USEPA 2017a).

The NPS' ARD (NPS-ARD) air quality monitoring program uses USEPA's NAAQS, natural visibility goals, and ecological thresholds as benchmarks to assess current conditions of visibility, ozone, and atmospheric deposition throughout Park Service areas.

Visibility affects how well (acuity) and how far (visual range) one can see (NPS-ARD 2002), but air pollution can degrade visibility. Both particulate matter (e.g. soot and dust) and certain gases and particles in the atmosphere, such as sulfate and nitrate particles, can create haze and reduce visibility.

Visibility can be subjective and value-based (e.g., a visitor's reaction viewing a scenic vista while observing a variety of forms, textures, colors, and brightness) (Figure 4.4.1-2), or it can be measured objectively by determining the size and composition of particles in the atmosphere that interfere with a person's ability to see landscape features (Malm 1999). The Viewshed assessment of this report addresses the subjective aspects of visibility, whereas this section addresses measurements of particles and gases in the atmosphere affecting visibility.

Ozone is a gaseous constituent of the atmosphere produced by reactions of nitrogen oxides (NO_x) from vehicles, powerplants, industry, fire, and volatile organic compounds from industry, solvents, and vegetation in the presence of sunlight (Porter and Wondrak-Biel 2011). It is one of the most widespread air pollutants (NPS-ARD 2003), and the major constituent in smog. Ozone can be harmful to human health. Exposure to ozone can irritate the respiratory system and increase the susceptibility of the lungs to infections (NPS-ARD 2017a). Ozone is also phytotoxic, causing foliar damage to plants (NPS-ARD 2003). Foliar damage requires the interplay of several factors, including the sensitivity of the plant to the ozone, the level of ozone exposure, and the exposure environment (e.g., soil moisture). The highest ozone risk exists when the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions, particularly adequate soil moisture, foster gas exchange and the uptake of ozone by plants (Kohut 2004).

Ozone penetrates leaves through stomata (openings) and oxidizes plant tissue, which alters the physiological and biochemical processes (NPS-ARD 2012b). Once the ozone is inside the plant's cellular system, the chemical reactions can cause cell injury or even death (NPS-ARD 2012b), but more often reduce the plant's resistance to insects and diseases, reduce growth, and reduce reproductive capability (NPS-ARD 2012c).

Air pollutants can be deposited to ecosystems through rain and snow (wet deposition) or dust and gases (dry deposition). Nitrogen and sulfur air pollutants are commonly deposited as nitrate, ammonium, and sulfate ions and can have a variety of effects on ecosystem health, including acidification, fertilization or eutrophication, and accumulation of mercury or toxins (NPS-ARD 2010, Fowler et al. 2013). Atmospheric deposition can also change soil pH, which in turn, affects microorganisms, understory plants, and trees (NPS-ARD 2010). Certain ecosystems are more vulnerable to nitrogen or sulfur deposition than others, including high-elevation ecosystems in the western United States, upland areas in the eastern part of the country, areas on granitic bedrock, coastal and estuarine waters, arid ecosystems, and some grasslands (NPS-ARD 2017a). Increases in nitrogen have been found to promote invasions of fast-growing non-native annual grasses (e.g., cheatgrass [*Bromus tectorum*]) and forbs (e.g., Russian thistle [*Salsola tragus*] at the expense of native species (Brooks 2003, Allen et al. 2009, Schwinning et al. 2005). Increased grasses can increase fire risk (Rao et al. 2010), with profound implications for biodiversity in non-fire

Figure 4.4.1-2. A scenic view of Sunset Crater Volcano NM from O'Leary. Photo Credit: NPS.

adapted ecosystems. Nitrogen may also increase water use in plants like big sagebrush (*Artemisia tridentata*) (Inouye 2006).

According to the USEPA (2017b), in the United States, roughly two thirds of all sulfur dioxide (SO_2) and one quarter of all nitrogen oxides (NO_x) come from electric power generation that relies on burning fossil fuels. Sulfur dioxide and nitrogen oxides are released from power plants and other sources, and ammonia is released by agricultural activities, feedlots, fires, and catalytic converters. In the atmosphere, these transform to sulfate, nitrate, and ammonium, and can be transported long distances across state and national borders, impacting resources (USEPA 2017b), including at Sunset Crater Volcano NM.

Mercury and other toxic pollutants (e.g., pesticides, dioxins, PCBs) accumulate in the food chain and can affect both wildlife and human health. Elevated levels of mercury and other airborne toxic pollutants like pesticides in aquatic and terrestrial food webs can act as neurotoxins in biota that accumulate fat and/or muscle-loving contaminants. Sources of atmospheric mercury include by-products of coal-fire combustion, municipal and medical incineration, mining operations, volcanoes, and geothermal vents. High mercury concentrations in birds, mammals, amphibians, and fish can result in reduced foraging efficiency, survival, and reproductive success (NPS-ARD 2017a).

Additional air contaminants of concern include pesticides (e.g., DDT), industrial by-products (PCBs), and emerging chemicals such as flame retardants for fabrics (PBDEs). These pollutants enter the atmosphere from historically contaminated soils, current day industrial practices, and air pollution (Selin 2009).

4.4.2. Data and Methods

The approach we used to assess the condition of air quality within Sunset Crater Volcano NM's airshed was developed by the NPS-ARD for use in Natural Resource Condition Assessments (NPS-ARD 2015a,b). NPS-ARD uses all available data from NPS, USEPA, state, and/or tribal monitoring stations to interpolate air quality values, with a specific value assigned to the maximum value within each park. Even though the data are derived from all available monitors, data from the closest stations "outweigh" the rest. Trends are computed from data collected over a 10-year period at on-site or nearby representative monitors. Trends are calculated for sites that have at least six years of annual data and an annual value for the end year of the reporting period.

<u>Haze Index</u>
Visibility is monitored by the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program (NPS-ARD 2010). Visibility data were collected at the IMPROVE monitoring station SYCA1, AZ, which is located 48 km (30 mi) southwest of the monument. NPS-ARD considers stations located within 150 km (93 mi) of NPS parks representative of Class II airsheds (NPS-ARD 2015a).

NPS-ARD assesses visibility condition status based on the deviation of the estimated current Group 50 visibility conditions from estimated Group 50 natural visibility conditions (i.e., those estimated for a given area in the absence of human-caused visibility impairment; EPA-454/B003-005). Group 50 is defined as the mean of the visibility observations falling within the range of the 40th through the 60th percentiles, as expressed in terms of a Haze Index in deciviews (dv; NPS-ARD 2015a). A factor of the haze index is light extinction, which is used as an indicator to assess the quality of scenic vista and is proportional to the amount of light lost due to scattering or absorption by particles in the air as light travels a distance of one million meters. The haze index for visibility condition is calculated as follows:

Visibility Condition/Haze Index (dv) =
estimated current Group 50 visibility – estimated Group 50 visibility
(under natural conditions)

The deciview scale scores pristine conditions as a zero and increases as visibility decreases (NPS-ARD 2015a).

For visibility condition assessments, annual average measurements for Group 50 visibility are averaged over a 5-year period at each visibility monitoring site with at least 3-years of complete annual data. Five-year averages are then interpolated across all monitoring locations to estimate 5-year average values for the contiguous U.S. The maximum value within national monument boundaries is reported as the visibility condition from this national analysis.

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

Level of Ozone

Ozone is monitored across the U.S. through air quality monitoring networks operated by the NPS, USEPA, states, and others. Aggregated ozone data are acquired from the USEPA Air Quality System (AQS) database. Note that prior to 2012, monitoring data were also obtained from the USEPA Clean Air Status and Trends Network (CASTNet) database. Ozone data were collected at a monitoring station located farther than 10 km (7 mi), which is beyond the distance at which NPS-ARD considers representative for calculating trends in Class II airsheds (NPS-ARD 2015a).

Human Health: Annual 4th-highest 8-hr Concentration

The primary NAAQS for ground-level ozone is set by the USEPA, and is based on human health effects. The 2008 NAAQS for ozone was a 4th-highest daily maximum 8-hour ozone concentration of 75 parts per billion (ppb). On October 1, 2015, the USEPA strengthened the national ozone standard by setting the new level at 70 ppb (USEPA 2017a). The NPS-ARD assesses the status for human health risk from ozone using the 4th-highest daily maximum 8-hour ozone concentration in ppb. Annual 4th-highest daily maximum 8-hour ozone concentrations are averaged over a 5-year period at all monitoring sites. Five-year averages are interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The ozone condition for human health risk at the park is the maximum estimated value within park boundaries derived from this national analysis.

Vegetation Health: 3-month Maximum 12-hr W126

Exposure indices are biologically relevant measures used to quantify plant response to ozone exposure. These measures are better predictors of vegetation response than the metric used for the human health standard. One annual index is the W126, which preferentially weighs the higher ozone concentrations most likely to affect plants and sums all of the weighted concentrations during daylight hours (8am-8pm). The highest 3-month period that occurs from March to September is reported in "parts per million-hours" (ppm-hrs), and is used for vegetation health risk from ozone condition assessments. Annual maximum 3-month 12-hour W126 values are averaged over a 5-year period at all monitoring sites with at least three years of complete annual data. Five-year averages are interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The estimated current ozone condition for vegetation health risk at the park is the maximum value within park boundaries derived from this national analysis.

Wet Deposition

Atmospheric wet deposition is monitored across the United States as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) for nitrogen and sulfur wet deposition, and at the Mercury Deposition Network (MDN) for mercury wet deposition.

Nitrogen and Sulphur

Wet deposition is used as a surrogate for total deposition (wet plus dry), because wet deposition is the only nationally available monitored source of nitrogen and sulfur deposition data. Values for nitrogen (N) from ammonium and nitrate and sulfur (S) from sulfate wet deposition are expressed as amount of N or S in kilograms deposited over a one-hectare area in one year (kg/ha/yr). For nitrogen and sulfur condition assessments, wet deposition was calculated by multiplying nitrogen (from ammonium and nitrate) or sulfur (from sulfate) concentrations in precipitation by a normalized precipitation. Annual wet deposition is averaged over a 5-year period at monitoring sites with at least three years of annual data. Five-year averages are then interpolated across all monitoring locations to estimate 5-year average values for the contiguous U.S. For individual parks, minimum and maximum values within park boundaries are reported from this national analysis. To maintain the highest level of protection in the park, the maximum value is assigned a condition status. Wet deposition trends are evaluated using pollutant concentrations in precipitation (micro equivalents/liter) so that yearly variations in precipitation amounts do not influence trend analyses. Nitrogen and sulfur data were interpolated from multiple monitoring stations located farther than 16 km (10 mi). NPS-ARD considers stations located farther than this distance outside the range that is representative for calculating trends in Class II airsheds (NPS-ARD 2015a).

Mercury

The condition of mercury was assessed using estimated 3-year average mercury wet deposition (ug/m^2/yr) and the predicted surface water methylmercury concentrations at NPS Inventory & Monitoring parks. It is important to consider both mercury deposition inputs and ecosystem susceptibility to mercury methylation when assessing mercury condition, because atmospheric inputs of elemental or inorganic mercury must be methylated before it is biologically available and able to accumulate in food webs (NPS-ARD 2015b). Thus, mercury condition cannot be assessed according to mercury wet deposition alone. Other factors like environmental conditions conducive to mercury methylation (e.g., dissolved organic carbon, wetlands, pH) must also be considered (NPS-ARD 2015a).

Annual mercury wet deposition measurements are averaged over a 3-year period at all NADP-MDN monitoring sites with at least three years of annual data. Three-year averages are then interpolated across all monitoring locations using an inverse distance weighting method to estimate 3-year average values for the contiguous U.S. For individual parks, minimum and maximum values within park boundaries are reported from this national analysis.

Conditions of predicted methylmercury concentration in surface water are obtained from a model that predicts surface water methylmercury concentrations for hydrologic units throughout the U.S. based on relevant water quality characteristics (i.e., pH, sulfate, and total organic carbon) and wetland abundance (U.S. Geological Survey [USGS] 2015). The predicted methylmercury concentration at a park is the highest value derived from the hydrologic units that intersect the park. Mercury data were interpolated from multiple monitoring stations located farther than 16 km (7 mi). NPS-ARD considers stations located farther than this distance outside the range that is representative for calculating trends in Class II airsheds (NPS-ARD 2015a).

4.4.3. Reference Conditions

The reference conditions against which current air quality parameters are assessed are identified by NPS-ARD (2015a,b) for NRCAs and listed in Table 4.4.3-1.

Visibility (Haze Index)

A visibility condition estimate of less than 2 dv above estimated natural conditions indicates a “good” condition, estimates ranging from 2-8 dv above natural conditions indicate a “moderate concern” condition, and estimates greater than 8 dv above natural conditions indicate “significant concern.” The NPS-ARD chose reference condition ranges to reflect the variation in visibility conditions across the monitoring network.

Level of Ozone

Human Health

The human health ozone condition thresholds are based on the 2015 ozone standard set by the USEPA (USEPA 2017a) at a level to protect human health: 4th-highest daily maximum 8-hour ozone concentration of 70 ppb. The NPS-ARD rates ozone

Table 4.4.3-1. Reference conditions for air quality parameters.

Indicator and Measure	Very Good	Good	Moderate Concern	Significant Concern
Visibility Haze Index	n/a	< 2	2-8	>8
Ozone Human Health (ppb)	n/a	≤ 54	55-70	≥ 71
Ozone Vegetation Health (ppm-hrs)	n/a	<7	7-13	>13
Nitrogen and Sulfur Wet Deposition (kg/ha/yr)	n/a	< 1	1-3	>3
Mercury Wet Deposition ((µg/m^2/yr)	< 3	≥ 3 and < 6	≥ 6 and < 9	≥ 9
Predicted Methylmercury Concentration (ng/L)	< 0.038	≥ 0.038 and .<0.053	≥ 0.053 and < 0.075	≥ 0.075 and < 0.12

Sources: NPS-ARD (2015a,b), USEPA (2017a).

Note: Human health ozone thresholds have been revised since NPS-ARD (2015a).

condition as: "good" if the ozone concentration is less than or equal to 54 ppb, which is in line with the updated Air Quality Index breakpoints; "moderate concern" if the ozone concentration is between 55 and 70 ppb; and of "significant concern" if the concentration is greater than or equal to 71 ppb.

Vegetation Health
The W126 condition thresholds are based on information in the USEPA's Policy Assessment for the Review of the Ozone NAAQS (USEPA 2014). Research has found that for a W126 value of:

- ≤ 7 ppm-hrs, tree seedling biomass loss is ≤ 2 % per year in sensitive species; and
- ≥13 ppm-hrs, tree seedling biomass loss is 4-10 % per year in sensitive species.

ARD recommends a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation; this level is considered good; 7-13 ppm-hrs is considered to be of "moderate" concern; and >13 ppm-hrs is considered to be of "significant concern" (NPS-ARD 2015a).

Wet Deposition
Nitrogen and Sulfur
The NPS-ARD selected a wet deposition threshold of 1.0 kg/ha/yr as the level below which natural ecosystems are likely protected from harm. This is based on studies linking early stages of aquatic health decline with 1.0 kg/ha/yr wet deposition of nitrogen both in the Rocky Mountains (Baron et al. 2011) and in the Pacific Northwest (Sheibley et al. 2014). Parks with less than 1 kg/ha/yr of atmospheric wet deposition of nitrogen or sulfur compounds are assigned "good" condition, those with 1-3 kg/ha/yr are assigned a "moderate concern" condition, and parks with depositions greater than 3 kg/ha/yr are considered to be of "significant concern."

Mercury
Ratings for mercury wet deposition and predicted methylmercury concentrations can be evaluated using the mercury condition assessment matrix shown in Table 4.4.3-2 to identify one of three condition categories. Condition adjustments may be made if the presence of park-specific data on mercury in food webs is available and/or data are lacking to determine the wet deposition rating (NPS-ARD 2015a).

4.4.4. Condition and Trend
The values used to determine conditions for all air quality indicators and measures are listed in Table 4.4.4-1.

Haze Index
The estimated 5-year (2011-2015) value (4.8 dv) for the monument's visibility condition fell within the moderate concern condition rating, which indicates visibility is degraded from the good reference condition of <2 dv above the natural condition (NPS-ARD 2015a,b). For 2005-2014, the trend in visibility at Sunset Crater Volcano NM was stable on the 20% clearest days and on the 20% haziest days (Figure 4.4.4-1) (IMPROVE Monitor ID: SYCA1, AZ). Data for 2015 were not available to determine the trend from 2006-2015. Confidence in this measure is high because there is an on-site or nearby visibility monitor. Visibility impairment primarily results from small particles in the atmosphere that include natural

Table 4.4.3-2. Mercury condition assessment matrix.

Predicted Methylmercury Concentration Rating	Mercury Wet Deposition Rating				
	Very Low	Low	Moderate	High	Very High
Very Low	Good	Good	Good	Moderate Concern	Moderate Concern
Low	Good	Good	Moderate Concern	Moderate Concern	Moderate Concern
Moderate	Good	Moderate Concern	Moderate Concern	Moderate Concern	Significant Concern
High	Moderate Concern	Moderate Concern	Moderate Concern	Significant Concern	Significant Concern
Very High	Moderate Concern	Moderate Concern	Significant Concern	Significant Concern	Significant Concern

Source: NPS-ARD (2015a).

Table 4.4.4-1. Condition and trend results for air quality indicators at Sunset Crater Volcano NM.

Data Span	Visibility (dv)	Ozone: Human Health (ppb)	Ozone: Vegetation Health (ppm-hrs)	N (kg/ha/yr)	S (kg/ha/yr)	Mercury (µg/m²/yr)	Predicted Mercury (ng/L)
Condition	Moderate Concern (4.8) (2011-2015)	Moderate Concern (70.8) (2011-2015)	Significant Concern (17.1) (2011-2015)	Moderate Concern (1.7) (2011-2015)	Good (0.7) (2011-2015)	Moderate Concern (8.1-8.3) (2012-2014)	Good (0.03) (2012-2014)
Trend (2006-2015)	The trend in visibility remained stable on the 20% clearest days and on the 20% haziest days (IMPROVE Monitor ID: IKBA1, AZ) (text excerpted from NPS 2017b).						

Sources: NPS-ARD (2017b,c,d).

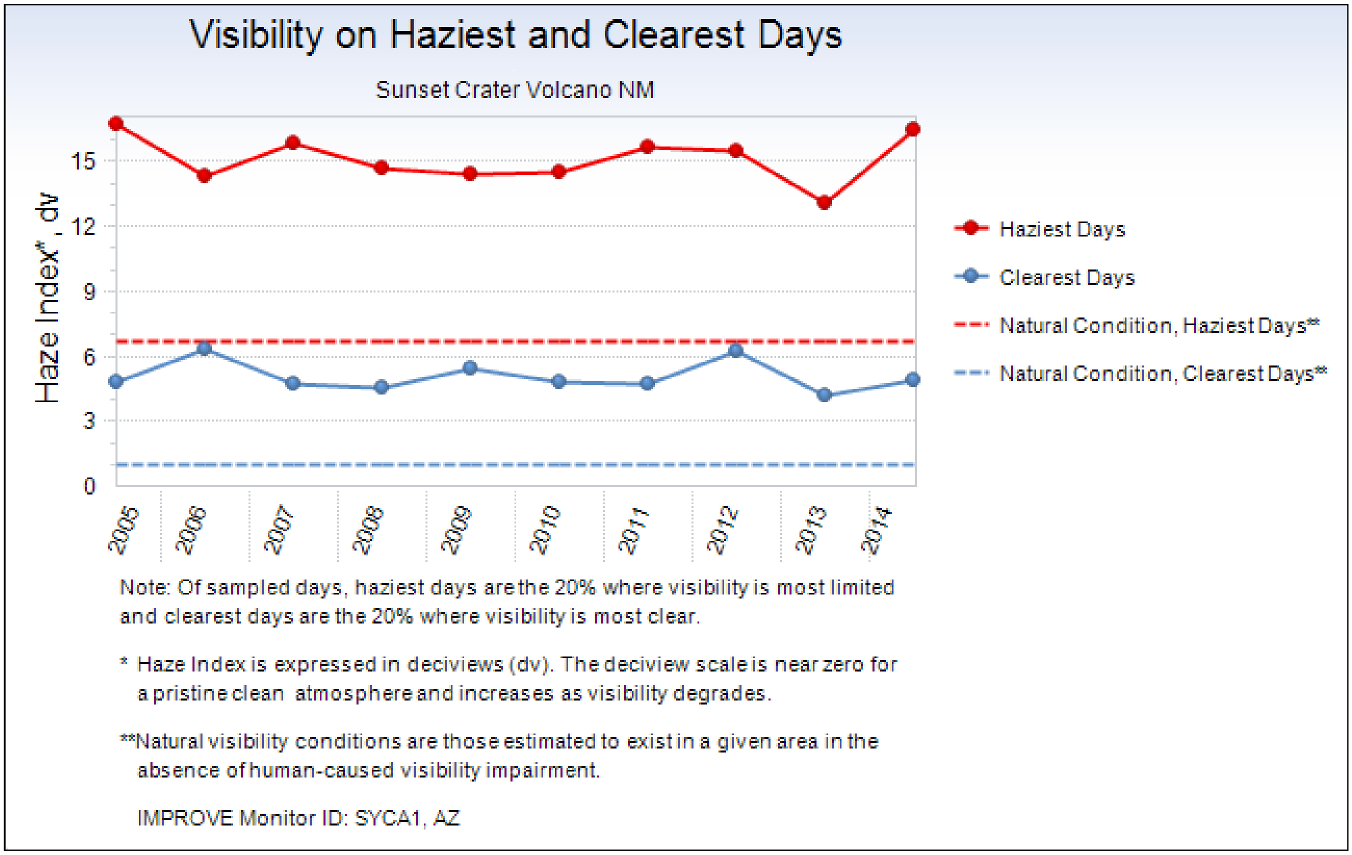


Figure 4.4.4-1. For 2005–2014, the trend in visibility at Sunset Crater Volcano NM. Figure Credit: NPS-ARD 2017b.

particles from dust and wildfires and anthropogenic sources from organic compounds, NOx and SO2. The contributions made by different classes of particles to haze on the clearest days and on the haziest days are shown in Figures 4.4.4-2 and 4.4.4-3, respectively, using data collected at the IMPROVE monitoring location, SYCA1, AZ.

The primary visibility-impairing pollutants on the clearest days from 2005-2014 were ammonium sulfate and organic carbon (data for 2015 were not available). On the haziest days, organic carbon and coarse mass were the primary visibility-impairing pollutants (NPS-ARD 2017b). Ammonium sulfate originates mainly from coal-fired power plants and smelters, and organic carbon originates primarily from combustion of fossil fuels and vegetation. Sources of coarse mass include road dust, agriculture dust, construction sites, mining operations, and other similar activities.

In 2014, the clearest days occurred during January (Figure 4.4.4-4), while the haziest days occurred during the months of May, June, and July (Figure 4.4.4-5). Data for 2015 were not available.

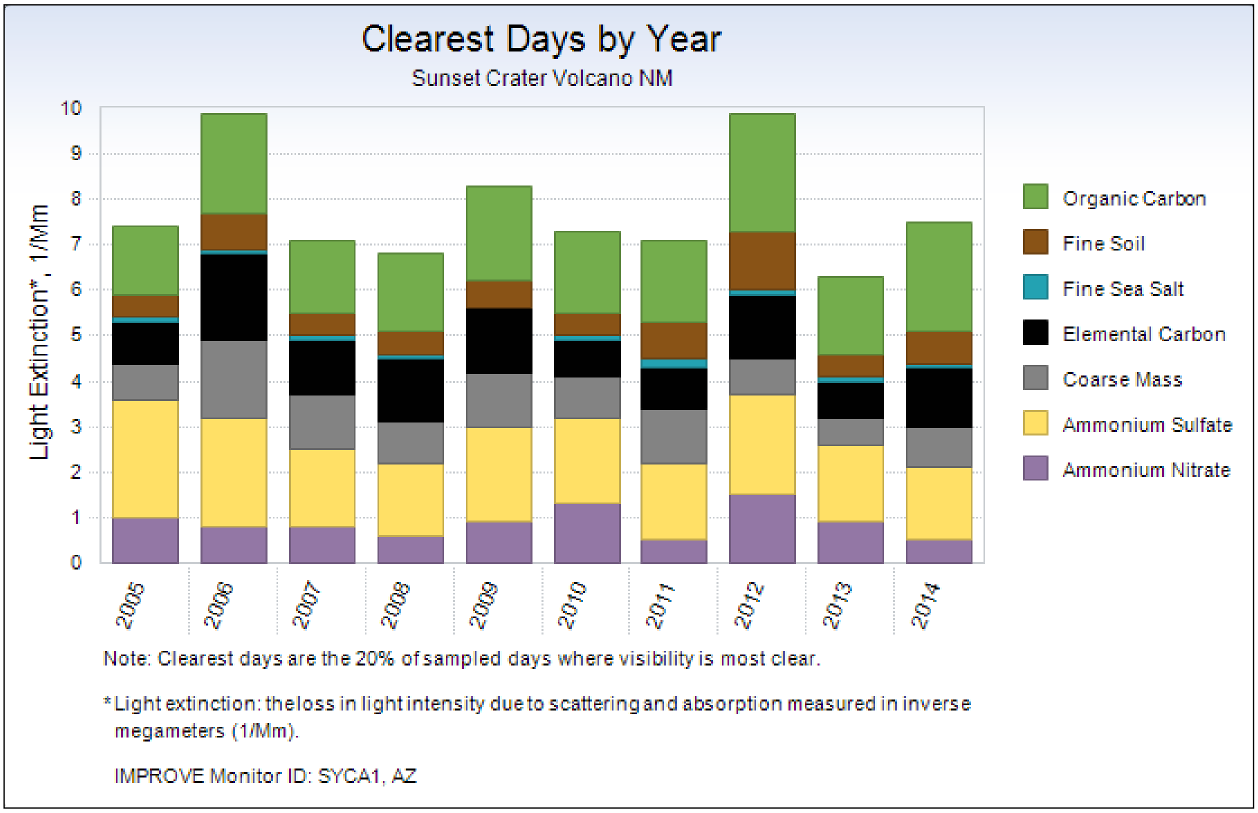


Figure 4.4.4-2. **Visibility data collected at SYCA1, AZ IMPROVE station showing the composition of particle sources contributing to haze during the clearest days by year (2005-2014). Figure Credit: NPS-ARD 2017b.**

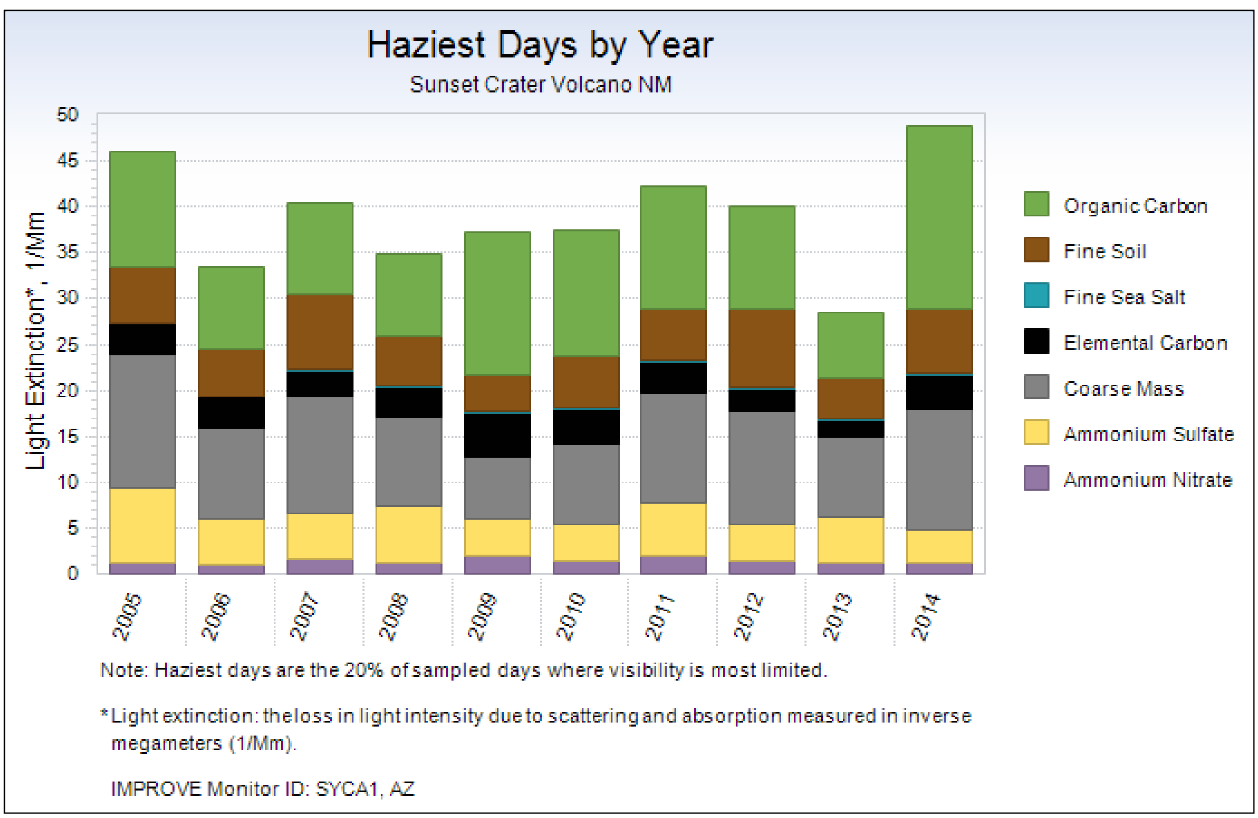


Figure 4.4.4-3. **Visibility data collected at SYCA1, AZ IMPROVE station showing the composition of particle sources contributing to haze during the haziest days by year (2005-2014). Figure Credit: NPS-ARD 2017b.**

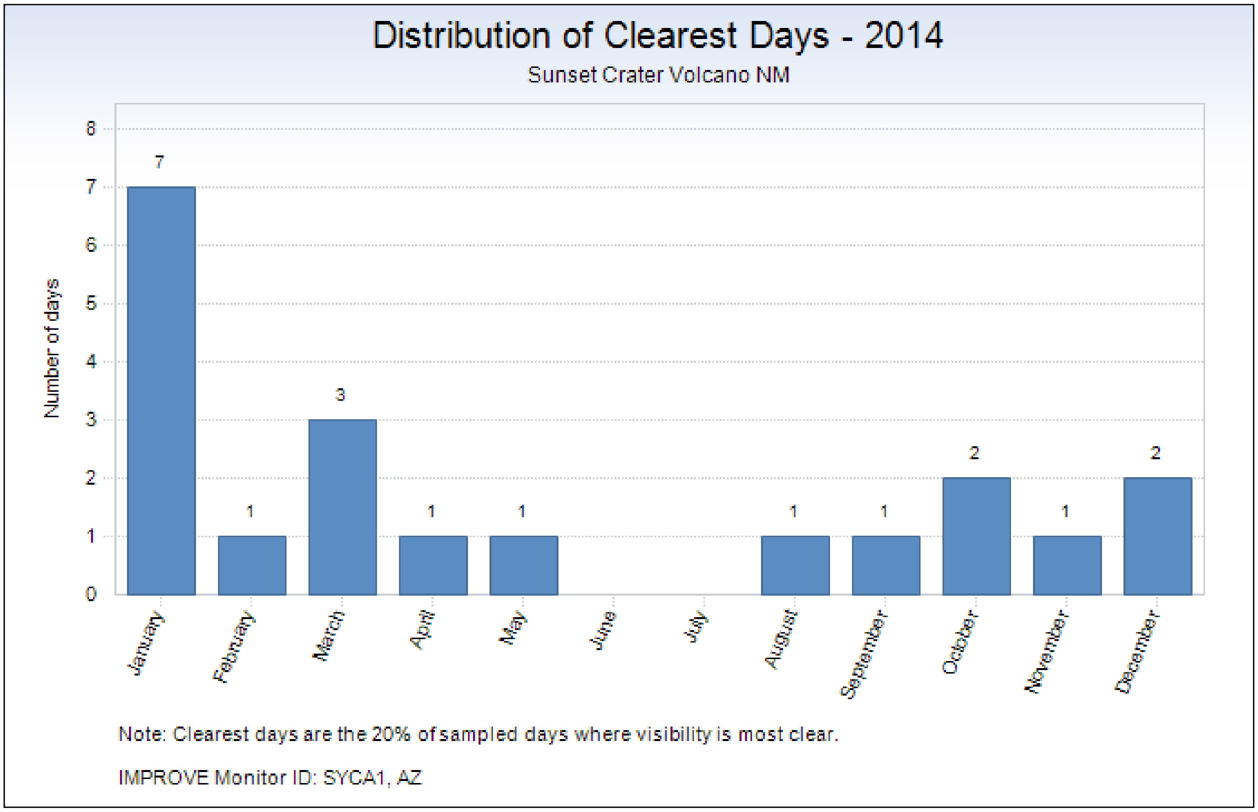


Figure 4.4.4-4. Visibility data collected at SYCA1, AZ IMPROVE station showing the distribution of clearest days by month for 2014. Figure Credit: NPS-ARD 2017b.

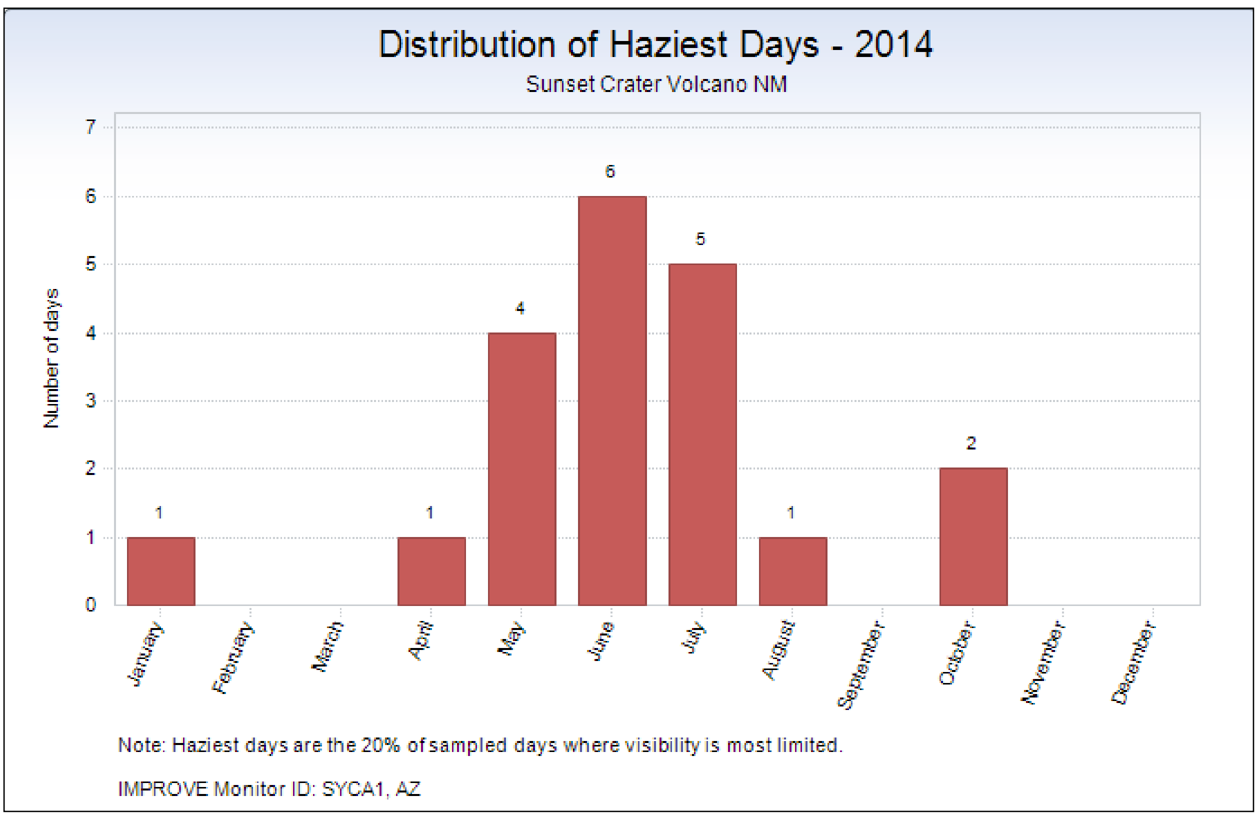


Figure 4.4.4-5. Visibility data collected at SYCA1, AZ IMPROVE station showing the distribution of haziest days by month for 2014. Figure Credit: NPS-ARD 2017b.

Human Health: Annual 4th-highest 8-hr Concentration

Ozone data used for this measure were derived from estimated five-year (2011-2015) values of 70.8 parts per billion for the 4th highest 8-hour concentration, which resulted in a condition rating warranting moderate concern for human health (NPS-ARD 2017b). Trend could not be determined because there are not sufficient on-site or nearby monitoring data. The level of confidence is medium because estimates are based on interpolated data from more distant ozone monitors.

Vegetation Health: 3-month Maximum 12-hr (W126)

Ozone data used for this measure of the condition assessment were derived from estimated five-year (2011-2015) values of 17.1 parts per million-hours (ppm-hrs) for the W126 Index. Using these numbers, vegetation health risk from ground-level ozone warrants significant concern at Sunset Crater Volcano NM (NPS-ARD 2017b). Trend could not be determined because there are not sufficient on-site or nearby monitoring data. Our level of confidence in this measure is medium because estimates are based on interpolated data from more distant ozone monitors.

A list of ozone sensitive plants is continually updated against species found in parks (Bell in review). Two of the three species found at the monument are listed in Table 4.4.4-2 and could be used as a bioindicator (noted in table). Bioindicators can reveal ozone stress in ecosystems by producing distinct visible and identifiable injuries to plant leaves. An ozone risk assessment conducted by Kohut (2004, 2007) for Southern Colorado Plateau Network parks concluded that plants in the national monument were at moderate risk of foliar ozone injury.

Nitrogen

Wet N deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 1.7 kg/ha/yr. This resulted in a condition rating of moderate concern (NPS-ARD 2017b). No trends could be determined given the lack of nearby monitoring stations. Confidence in the assessment is medium because estimates are based on interpolated data from more distant deposition monitors. For further discussion of N deposition, see the section entitled "Additional Information for Nitrogen and Sulfur" below.

Sulfur

Wet S deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 0.7 kg/ha/yr, which resulted in a good condition rating for Sunset Crater Volcano NM (NPS-ARD 2017b). No trends could be determined given the lack of nearby monitoring stations. Confidence in the assessment is medium because estimates are based on interpolated data from more distant deposition monitors. For further discussion of sulfur, see below.

Additional Information on Nitrogen and Sulfur

Sullivan et al. (2011a) studied the risk from acidification from acid pollutant exposure and ecosystem sensitivity for Southern Colorado Plateau Network (SCPN) parks, which included Sunset Crater Volcano NM. Pollutant exposure included the type of deposition (i.e., wet, dry, cloud, fog), the oxidized and reduced forms of the chemical, if applicable, and the total quantity deposited. The ecosystem sensitivity considered the type of terrestrial and aquatic ecosystems present at the parks and their inherent sensitivity to the atmospherically deposited chemicals.

These risk rankings were considered low for acid pollutant exposure and ecosystem sensitivity at the monument, and moderate for park protection from acidification, for an overall summary risk of low (Sullivan et al. 2011a). The effects of acidification can include changes in water and soil chemistry that impact ecosystem health.

Sullivan et al. (2011b) also developed risk rankings for nutrient N pollutant exposure and ecosystem sensitivity to nutrient N enrichment. These risk

Table 4.4.4-2. Ozone sensitive plants found at Sunset Crater Volcano NM.

Scientific Name	Common Name	Bell (in review)	Bioindicator?
Amelanchier utahensis	Utah serviceberry	Present	No
Populus tremuloides	Quaking aspen	Present	Yes
Salix scouleriana	Scouler's willow	Present	Yes

rankings were considered low for pollutant exposure and ecosystem sensitivity at the monument, and moderate for park protection, with an overall summary risk of very low for the monument. Potential effects of nitrogen deposition include the disruption of soil nutrient cycling and impacts to the biodiversity of some plant communities, including arid and semi-arid communities, grasslands, and wetlands. These nitrogen sensitive communities cover a relatively small portion of Sunset Crater Volcano NM, mostly as grassland and meadow plant communities (Figure 4.4.4-6), but again, the overall summary risk was very low for the park (Sullivan et al. 2011b).

In general, nitrate, sulfate, and ammonium deposition levels have changed over the past 20 years throughout the United States (Figure 4.4.4-7). Regulatory programs mandating a reduction in emissions have proven effective for decreasing both sulfate and nitrate ion deposition, primarily through reductions from electric utilities, vehicles, and industrial boilers, although a rise in ammonium ion deposition has occurred in large part due to the agricultural and livestock industries (NPS-ARD 2012d). A study conducted by Lehmann and Gay (2011) indicated a statistically significant decrease in sulfate concentrations from 1985-2009 in the area surrounding the monument, but a statistically significant increase in nitrate concentrations. According to the Lehmann and Gay (2011) study, for the areas that saw a change in nitrate concentrations across the county, most saw a decrease; increases were seen primarily in Arizona, New Mexico, and a portion of western Texas. It seems reasonable to expect a continued improvement in sulfate deposition levels because of CAA requirements. At this time, however, ammonium levels are not regulated by the USEPA, and may therefore continue to rise (NPS-ARD 2010).

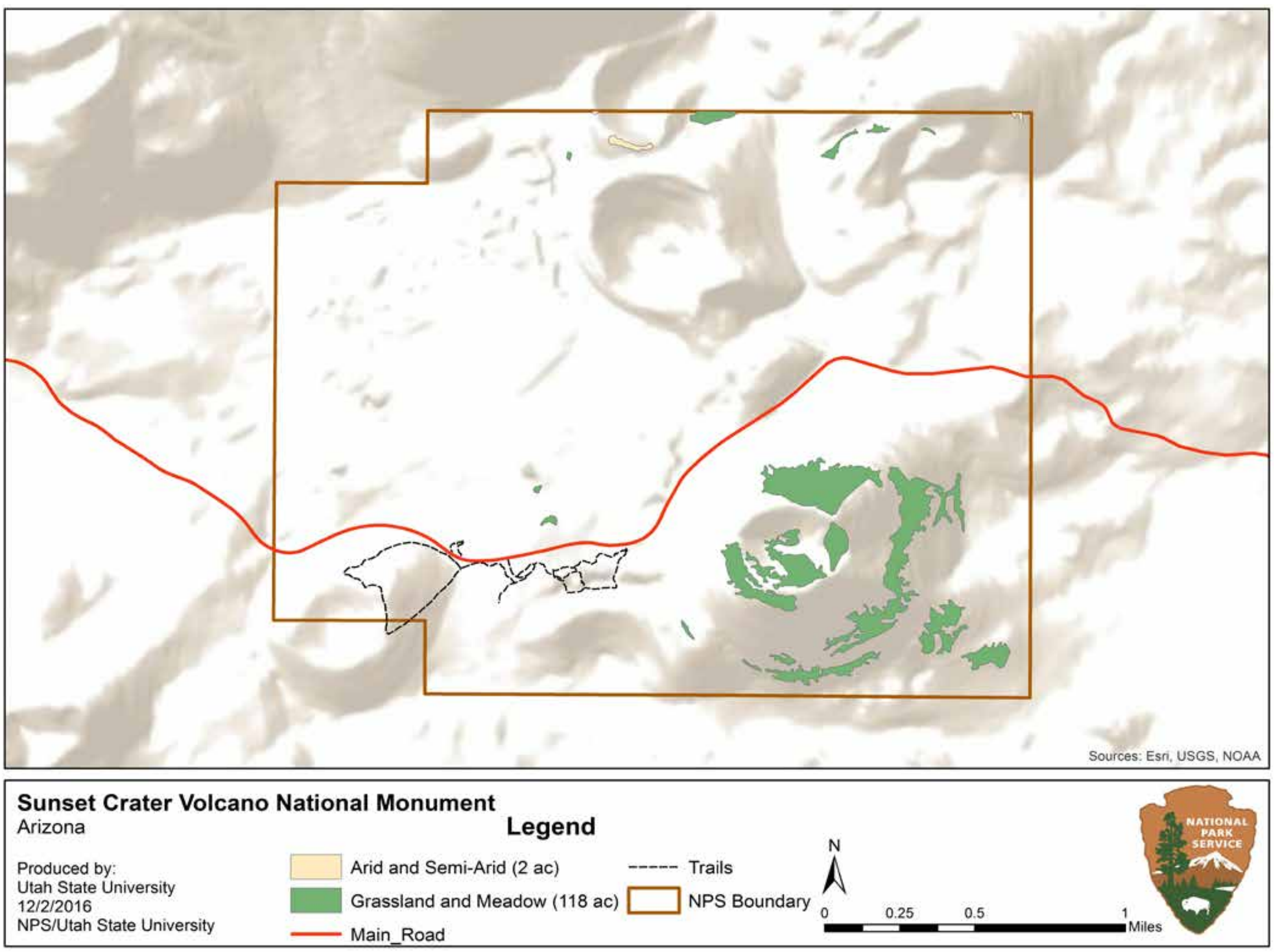


Figure 4.4.4-6. Locations of nitrogen sensitive communities at Sunset Crater Volcano NM using the NPS/USGS veg mapping dataset. Secondary Data Source: E&S Environmental Chemistry, Inc.. (2009).

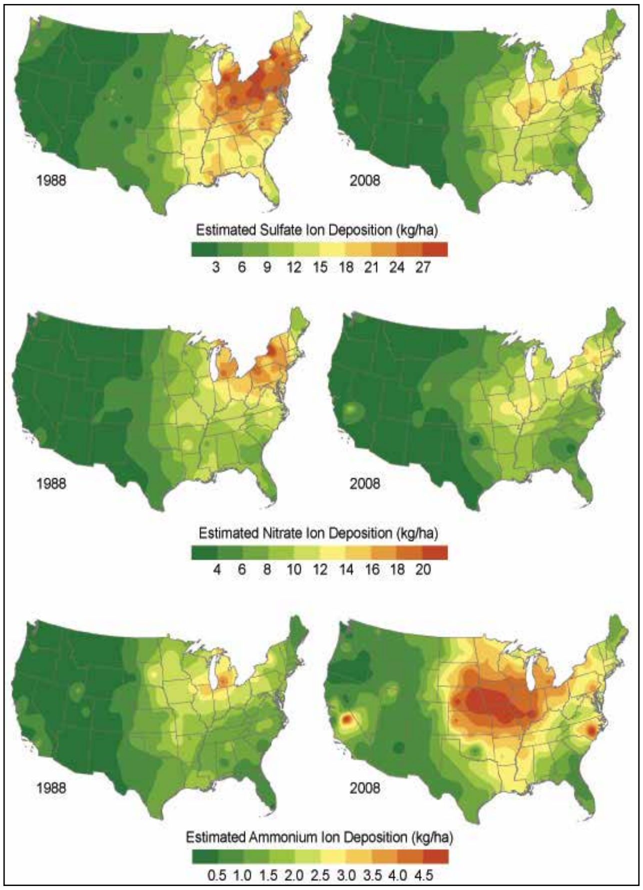


Figure 4.4.4-7. Change in wet deposition levels from 1988-2008 throughout the United States. Figure Source: http://www.nature.nps.gov/air/Monitoring/wetmon.cfm.

Mercury and Predicted Methylmercury

The 2012–2014 estimated wet mercury deposition is moderate at the monument, ranging from 8.1 to 8.3 micrograms per square meter per year (NPS-ARD 2016). The predicted methylmercury concentration in park surface waters is very low, estimated at 0.03 ng/L. Wet deposition and predicted methylmercury ratings were combined to determine a good condition status. The degree of confidence in the mercury/toxics deposition condition is low because there are no park-specific studies examining contaminant levels. Trend could not be determined.

Overall Condition and Trend, Confidence Level, and Key Uncertainties

For assessing the condition of air quality, we used three air quality indicators with a total of seven measures. Our indicators/measures for this resource were intended to capture different aspects of air quality, and a summary of how they contributed to the overall condition is summarized in Table 4.4.4-3.

Based on these indicators and measures, we consider the overall condition of air quality at Sunset Crater Volcano NM to be of moderate concern. Among the individual measures, two were considered good, four were considered to be of moderate concern, and one was considered to be of significant concern. The only measure that was considered to be of significant concern was vegetation health. We consider the confidence level as high for visibility based on the IMPROVE monitoring station, SYCA1, AZ. The confidence levels for ozone and wet deposition of N and S are medium because estimates are based on interpolated data from more distant monitors. Finally, the confidence levels for mercury/toxics deposition and predicted methylmercury concentration were low because wet deposition values were based on interpolated data. Based on these confidence levels, we assigned an overall medium confidence to the air quality condition rating.

Those measures for which confidence in the condition rating was high were weighted more heavily in the overall condition rating than measures with medium or low confidence. Factors that influence confidence level include age of the data (<5 years unless the data are part of a long-term monitoring effort), repeatability, field data versus modeled data, and whether data can be extrapolated to other areas in the monument.

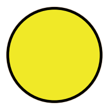
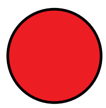
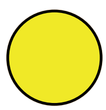
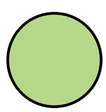
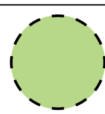
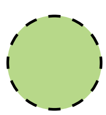
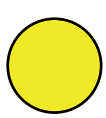
The trend in visibility at Sunset Crater Volcano NM did not change on the 20% clearest days nor on the 20% haziest days (IMPROVE Monitor ID: SYCA1, AZ). Trends for the remaining indicators could not be derived because there are no on-site monitoring stations or existing monitoring sites are located at a distance that would not be representative of conditions at the monument. Since we could derive trend for only one measure, we did not assign an overall trend for air quality.

A key uncertainty of the air quality assessment is knowing the effect(s) of air pollution, especially of nitrogen deposition, on ecosystems at the monument.

Threats, Issues, and Data Gaps

Clean air is fundamental to protecting human health, the health of wildlife and plants within parks, and for protecting the aesthetic value of lands managed by the NPS (NPS 2006). The majority of threats to air quality within Sunset Crater Volcano NM originate from outside the monument and include the effects

Table 4.4.4-3. Summary of air quality indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Visibility	Haze Index		Visibility warrants moderate concern at Sunset Crater Volcano NM. This is based on NPS ARD benchmarks and the 2011-2015 estimated visibility on mid-range days of 4.8 deciviews (dv) above estimated natural conditions. For 2005-2014, the trend in visibility at the monument remained stable on the 20% clearest days and on the 20% haziest days (IMPROVE Monitor ID: SYCA1, AZ). The Clean Air Act visibility goal requires visibility improvement on the 20% haziest days (not met), with no degradation on the 20% clearest days (not met). The level of confidence is high because there is an on-site or nearby visibility monitor.
Level of Ozone	Human Health: Annual 4th-Highest 8-hour Concentration		Human health risk from ground-level ozone warrants moderate concern. This status is based on NPS ARD benchmarks and the 2011-2015 estimated ozone of 70.8 parts per billion (ppb). Trend could not be determined because there are not sufficient on-site or nearby monitoring data. The level of confidence medium because estimates are based on interpolated data from more distant ozone monitors.
	Vegetation Health: 3-month maximum 12hr W126		Vegetation health risk from ground-level ozone warrants significant concern. This status is based on NPS ARD benchmarks and the 2011-2015 estimated W126 metric of 17.1 parts per million-hours (ppm-hrs). The W126 metric relates plant response to ozone exposure. A risk assessment concluded that plants in the park were at moderate risk for ozone damage (Kohut 2007, Kohut 2004). Trend could not be determined because there are not sufficient on-site or nearby monitoring data. The confidence level is medium because estimates are based on interpolated data from more distant ozone monitors.
Wet Deposition	N in kg/ha/yr		Wet nitrogen deposition warrants moderate concern. This status is based on NPS ARD benchmarks and the 2011-2015 estimated wet nitrogen deposition of 1.7 kilograms per hectare per year (kg/ha/yr). Ecosystems in the park were rated as having low sensitivity to nutrient-enrichment effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011a; Sullivan et al. 2011b). No trend information is available because there are not sufficient on-site or nearby deposition monitoring data. The confidence level is medium because estimates are based on interpolated data from more distant deposition monitors.
	S in kg/ha/yr		Wet sulfur deposition is in good condition. This status is based on NPS ARD benchmarks and the 2011-2015 estimated wet sulfur deposition of 0.7 kilograms per hectare per year (kg/ha/yr). Ecosystems in the park were rated as having low sensitivity to acidification effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011a; Sullivan et al. 2011b). No trend information is available because there are not sufficient on-site or nearby deposition monitoring data. The level of confidence is medium because estimates are based on interpolated data from more distant deposition monitors.
	Mercury		The 2012–2014 estimated wet mercury deposition was moderate ranging from 8.1 to 8.3 micrograms per square meter per year. This measure is used in conjunction with predicted methylmercury to determine the overall condition of mercury/toxics.
	Predicted Methylmercury Concentration		The predicted methylmercury concentration in park surface waters was 0.03 nanograms per liter, which was low. Together, these two measures indicate good condition. However, confidence is low since there are no park-specific studies examining contaminant levels in taxa from park ecosystems, which are useful in determining overall condition for mercury/toxics condition within the monument. Trend could not be determined.
Overall Condition			Overall, we consider air quality at the national monument to be of moderate concern. Vegetation health risk from ground-level ozone warrants significant concern while the haze index, human health risk from ozone, nitrogen, and mercury all warrant moderate concern. Sulfur deposition and predicted methylmercury indicate good condition. Overall confidence in the assessment is medium with an unknown trend, although the haze index indicates unchanging conditions for that measure.

Note: Condition summary text was primarily excerpted from NPS-ARD (2017b, 2016).

of climate change, forest fires (natural or prescribed), dust created from mineral and rock quarries, and carbon emissions.

The western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall (Prein et al. 2016). Since 1974 there has been a 25% decrease in precipitation, a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016). One effect of climate change is an increase in wildfire activity (Abatzoglou and Williams 2016). Fires contribute a significant amount of trace gases and particles into the atmosphere that affect local and regional visibility and air quality (Kinney 2008). In addition to prescribed burns by the U.S. Forest Service (USFS 2016a), natural wildfires have increased across the western U.S., and the potential for the number of wildfires to grow is high as climate in the Southwest becomes warmer and drier (Abatzoglou and Williams 2016). Warmer conditions can also increase the rate at which ozone and secondary particles form (Kinney 2008). Declines in precipitation may also lead to an increase in wind-blown dust (Kinney 2008). Weather patterns influence the dispersal of these atmospheric particulates. Because of their small particle size, airborne particulates from fires, motor vehicles, power plants, and wind-blown dust may remain in the atmosphere for days, traveling potentially hundreds of miles before settling out of the atmosphere (Kinney 2008). The Navajo Generating Station ~200 km (124 mi) north, the Cholla Power Plant 100 km (62 mi) east, and the Coronado Generating Station ~200 km (124 mi) east are potential sources for air quality impacts.

4.4.5. Sources of Expertise

The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. Information and text for the assessment was obtained from the NPS-ARD website and provided by Jim Cheatham, Park Planning and Technical Assistance, ARD. The assessment was written by Lisa Baril, science writer at Utah State University.

4.5. Recent Volcanic Cinder Terrain

4.5.1. Background and Importance

Sunset Crater Volcano National Monument (NM) is a very young (< 1000 years) landscape dominated by the 300-m (985-ft.) high Sunset Crater cinder cone (Figure 4.5.1-1). The geomorphically youthful terrain exhibits very little modification since the eruption. The cinder cone is steep-sided and the lava flows are rough and unweathered. The present sparse vegetation is surrounded by broad expanses of barren cinders, and soil development is incipient at best. Processes related to chemical and physical weathering of the basaltic bedrock, breakdown of organic matter, and ecological succession progress slowly in the relatively arid environment. The loose, deep, mobile cinders have few nutrients and low water-holding capacity, further limiting vegetative colonization of the landscape. Aside from these limiting factors, the Sunset Crater Volcano NM landscape is gradually undergoing modification by natural processes including eolian, alluvial, and freeze/thaw activity. Additionally, the deposition of "desert dust" or loess, is a widespread, but poorly documented, process which influences the geomorphic evolution transformation of the NM's landscape. Certain parts of the landscape may be particularly sensitive to various land-use activities such as logging, facility and infrastructure development, and recreation.

To understand the landscape evolution, it is important to provide a temporal context to sequentially describe morphology of the Sunset Crater cinder cone and Bonito lava flow in its present form. Based on what is known about the long-term landscape evolution of the San Francisco Volcanic Field (SFVF), we applied the concept of "space-for-time" substitution in which the present-day characteristics of older cinder cones and lava flows of known age are used to produce a time-series to describe the evolution of landscape changes at Sunset Crater Volcano NM. The condition assessment analysis begins with the original, post-eruptional shape and describes landscape evolution, soil development, and ecological succession at Sunset Crater Volcano NM.

4.5.2. Data and Methods

Sunset Cinder Cone and Bonito Lava Flow Background

Sunset Crater erupted about 930 years ago (Ort et al. 2008). Initially, there was a 10 km (6.2 mi) long earth crack, or fissure, that opened up between the present location of Sunset Crater Volcano (SCV) and another volcanic vent to the southeast (Figure 4.5.2-1). A curtain of spewing lava and cinders was deposited along this fissure that can still be observed today. Eventually, when the fissure closed, the main locus of eruption settled on the present location of SCV where a ~ 300 m (985 ft) high edifice was produced by a series of mildly explosive, intermittent eruptions of

Figure 4.5.1-1. Sunset Crater Volcano. Photo Credit: NPS.

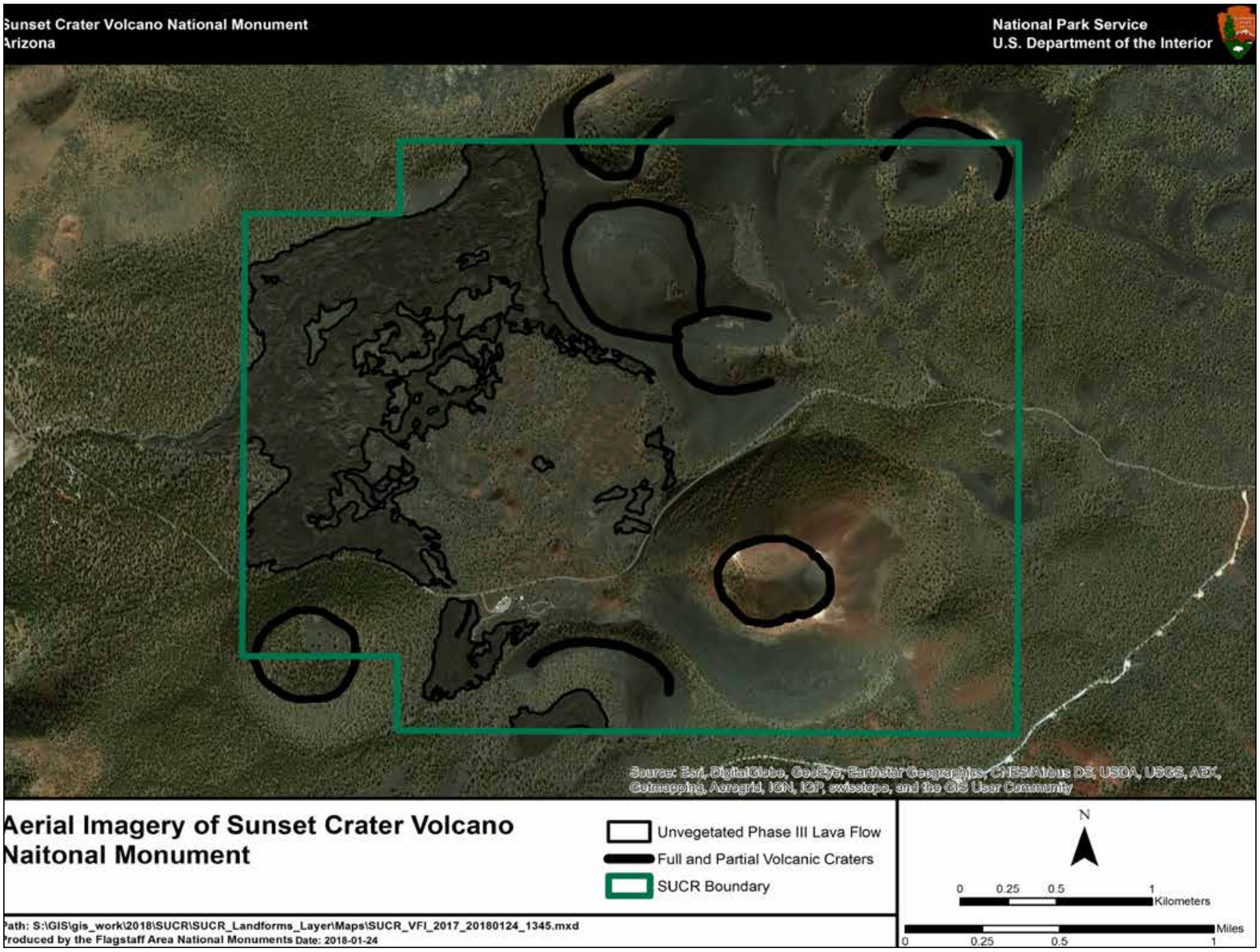


Figure 4.5.2-1. Image of Sunset Crater Volcano NM. Note black un-vegetated Phase III lava and barren cinder terrain in grey. Probable volcanic craters are outlined in black.

cinder and ash (Figure 4.5.2-2). At least six definable tephra layers are present in various locations both within and outside the monument ranging from 0 – 12 m (0-40 ft) deep (Amos 1986, Hooten and Ort 2007). The tephra layers cover the pre-eruption landforms, including the Lenox Crater cinder cone. Perhaps the final evidence of the eruption was uncovered during the construction of the amphitheater in 2017 near the Lava Flow trailhead (Wagner 2016, Anderson 2017).

Two lava flows associated with the eruption are the Bonito flow on the west side of the monument, and the Kana'a flow on the east (Figure 4.5.2-3). The lava from the Bonito flow ponded against the flanks of older cinder cones, filling a depression as it rolled towards Bonito Park to the west. The most recent parts of both flows have no cinders on top of them, indicating that they continued to be extruded both during and after cinder cone construction ceased. Most of the deposits associated with the initial fissure and the Kana'a lava flow are located outside of the monument (Elson et al. 2007).

Three separate phases of the Bonito flow, identified in Figure 4.5.2-4, are distinguished by their location, morphology, and the presence or absence of cinders (Thornberry-Ehrlich 2005). The Phase III deposits are the youngest and least vegetated. Phase III are also the furthest away from the volcano, having been extruded from beneath the older deposits. Evidence of a partially destroyed pre-SCV cinder cone is found in the numerous agglutinate mounds and rafted pieces of the older cone within the Phase I deposits. Phase I deposits are the most heavily vegetated, due at least in part to the layer of cinders overlying this phase of the Bonito flow. Phase II flow deposits consist of pieces of Phase I rafted on top (Holm 1987).

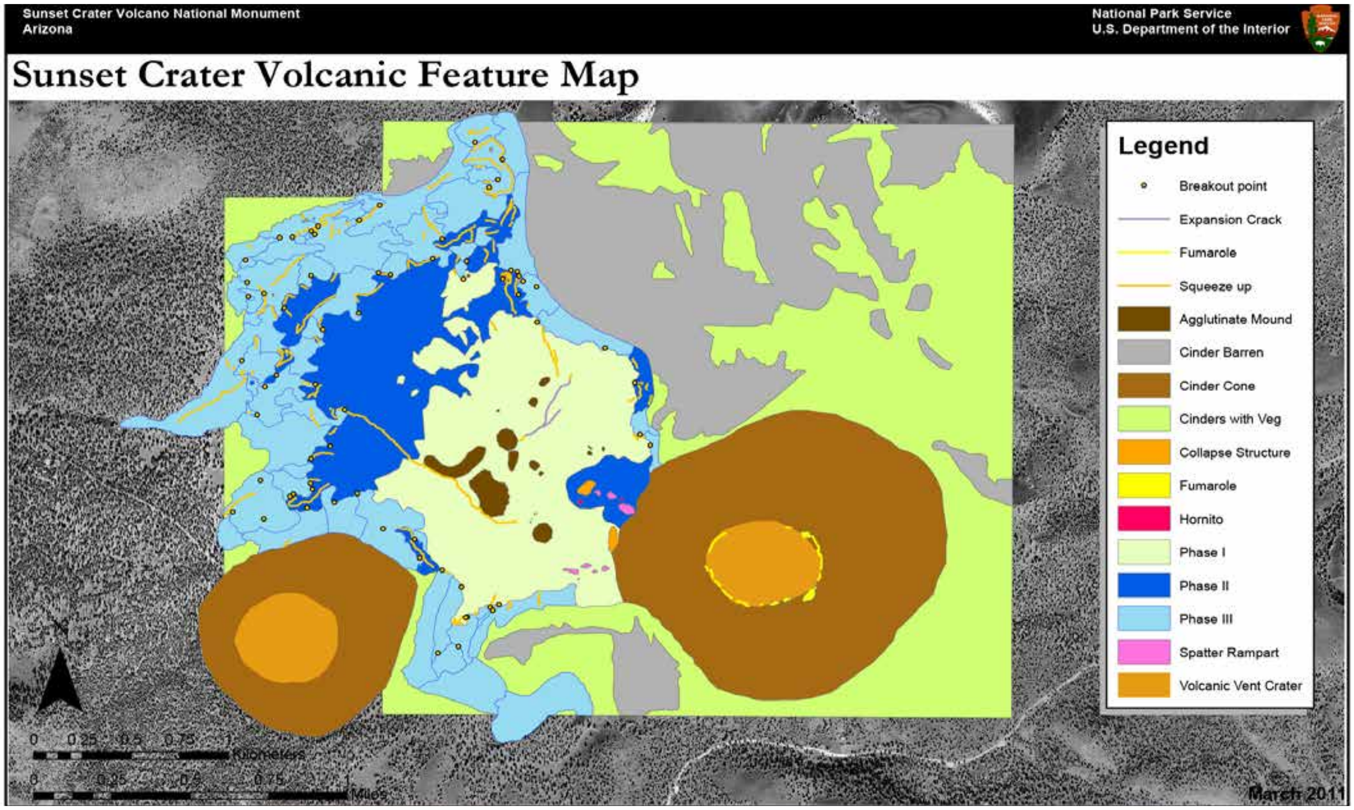


Figure 4.5.2-2. Sunset Crater volcanic features.

This assessment focuses on modifications of the original cinder cone and lava flow morphologies, processes of soil formation, and ecological succession. It should be taken into account that landform change in this arid landscape occurs on the order of thousands to millions of years. Nonetheless, the indicators and measures identified here can be applied to assess shorter-term impacts from land-use activities such as recreation and facility development and evaluate potential impacts from climate change scenarios.

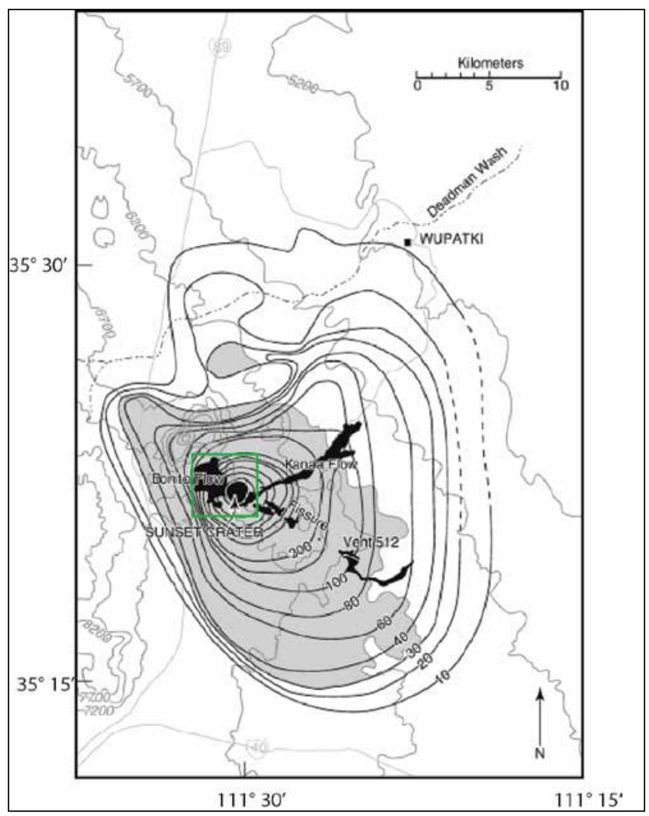


Figure 4.5.2-3. Isopach map of cinder thickness at Sunset Crater Volcano NM. Green square approximates location of the monument boundaries. Figure Credit: Modified from Hooten and Ort (2007).

Sunset Crater Cinder Cone Morphology

To assess transformations in cinder cone morphology, soil formation and ecological succession, it is important to provide a temporal context. The results of these analyses are several chronosequences illustrating changes over time. We rely on data and interpretations from previous studies about the long-term landscape evolution of the SFVF (Colton 1936, Hooper and Sheridan 1998, Duffield et al. 2006, Hanson 2008, Houts et al. 2013, Pearthree et al. 2014) and from other volcanic landforms in the southwestern United States (McFadden et al. 1987, Wells et al. 1985). Trends in soil development on lava flows came from McFadden et al. 1987, Reheis 1999, Anderson et al. 2002, Anderson 2006, Selmants and Hart 2008, Broadman and

Anderson, 2013, Homan et al. 2014, and United States Department of Agriculture (USDA) 2014. Concepts of plant colonization and succession at Sunset Crater Volcano NM came from Eggler 1966, Schlesinger et al. 1990, Hansen et al. 2004, Selmants and Hart 2008, and USDA 2014.

Sunset Crater today is a very youthful-looking cinder cone with steep sides and a narrow base. It is likely that virtually all of the more than 600 cinder cones in the SFVF were of similar morphology when they first appeared on the landscape, unless altered during the eruption. Due to erosion over time, the slope angle is reduced, the cone height decreases, and the base increases in diameter as colluvial material accumulates downslope. This progression in cone degradation is well studied for cinder cones in the SFVF (Hooper and Sheridan 1998). The initial slope angle for cinder cone volcanoes composed of unconsolidated scoria is approximately the angle of repose, ~ 33°. Slope angles for Holocene to Late Pleistocene cones decrease to a mean average of ~ 26°. For very old cinder cones, such as Pliocene, their slope angles may be as low as ~ 8°. The series of photographs shown in Figure 4.5.2-4 illustrate three examples in the progressive pattern of cinder cone erosion in the SFVF. The upper photograph is that of S P Crater, a 250-m (820-ft) high cone that dates to ~60,000 to 70,000 years old (Baksi 1974, Rittenour et al. 2015). As is typical for 'youthful' cones, it has steep slopes and a bowl-shaped crater. The center photograph, displays an unnamed cone belonging to the early Pleistocene – late Pliocene age group, demonstrating a more subdued slope than younger cones. The cone no longer has a crater, but does have an extensive debris apron. In the lowest photograph, an unnamed Pliocene cone has been degraded to a shield-like hill with very low slope angles.

Cone Slope Angle(s), Hc/Wc, Cd/Cw, Rill Length, Rill Density, and Trail Networks

Measures to assess trends in the changing cinder-covered landscapes, including cone slope, height to cone width (Hc/Wc), crater depth to crater width (Cd/Cw), rill length and density of rills along the slope, and location and extent of trail networks can be determined using GIS and LiDAR (Hansen 2014). The cone degradation illustrated in Figure 4.5.2-5 uses 237 cones for the analysis (Table 4.5.2-1). The same temporal trends are found when comparing the ratio of cone Hc/Wc and Cd/Cw (Figure 4.5.2-5).

Bonito Lava Flow Morphology

Surface Roughness and Trail Networks

Similarly, erosion and soil development over time affects the evolution of lava flows. Figure 4.5.2-6 illustrates the trends in lava flow degradation through time. Although these data are from the hotter and drier Cima Volcanic Field in California, the trends are the same as those from the different aged lava flows of the SFVF (Wells et al. 1985, McFadden et al. 1987, Anderson et al. 2002, Homan et al. 2014). Over time, the amount of exposed bedrock decreases as it breaks down and weathers. Additionally, the aerosolic additions of loess are a major factor in soil development and the gradual flattening of the originally rough lava flow surface. Very long-term trends in the lava flow and cone degradation are commonly accompanied by increases in soil development and

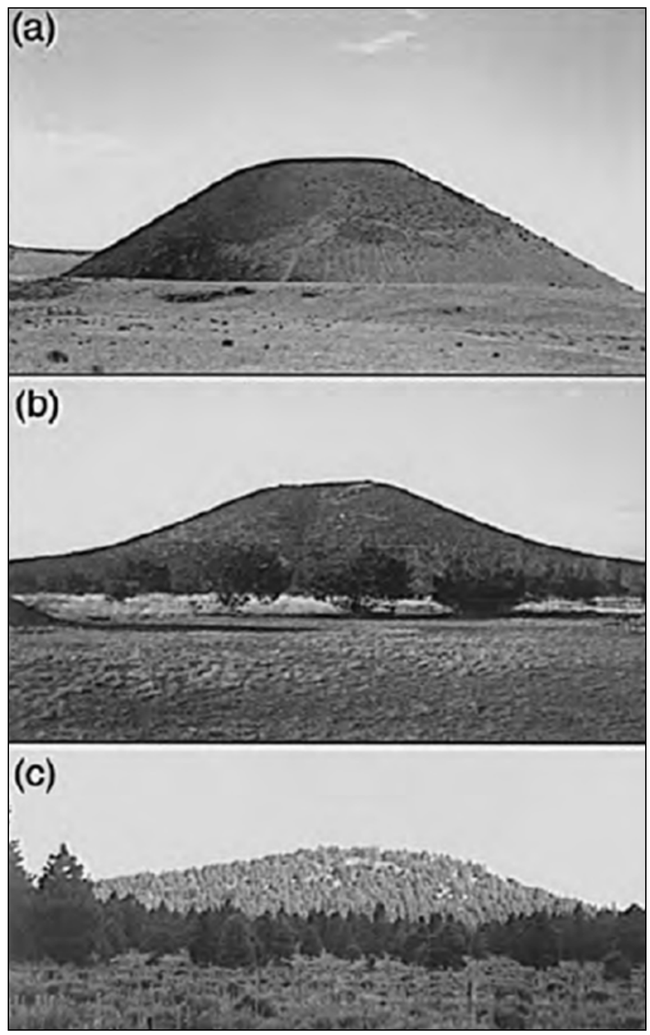


Figure 4.5.2-4. Time series photographs showing cone degradation with age. Youngest cone (a) eventually decreases in height (b) and increases in width through time (c). Photo Credits: © Hooper and Sheridan (1998).

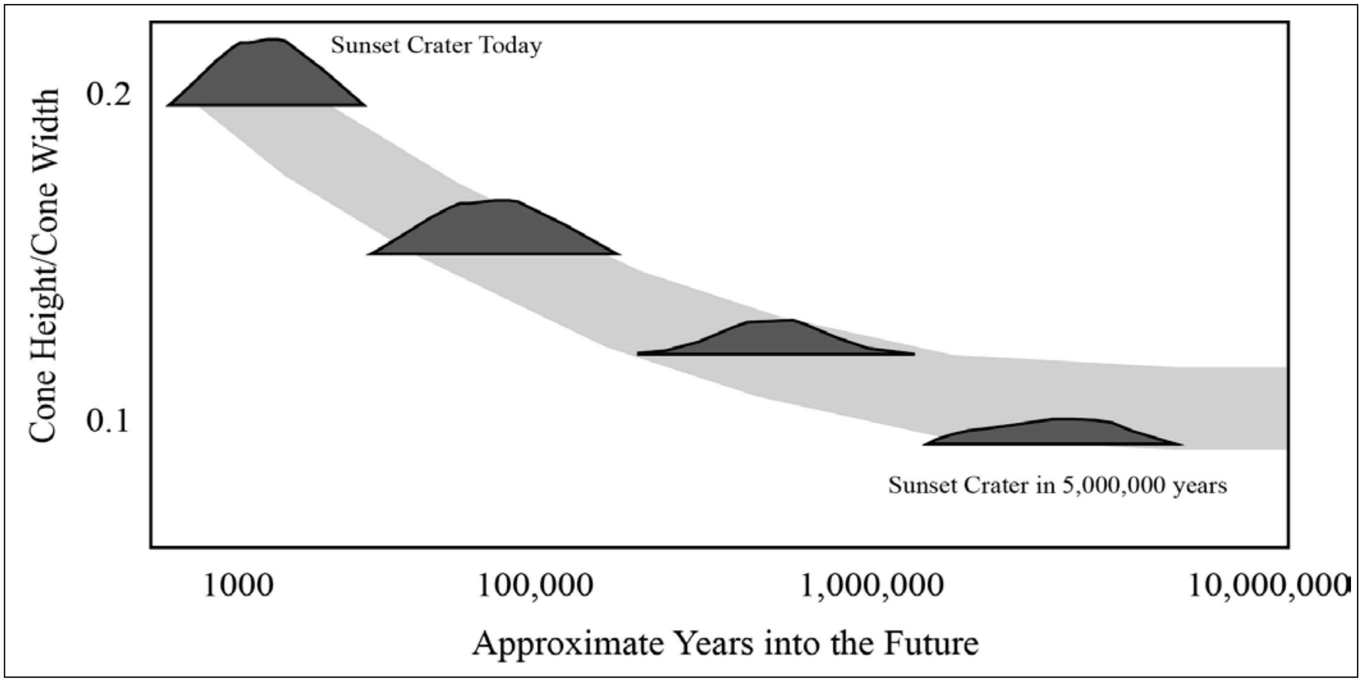


Figure 4.5.2-5. Conceptual diagram illustrating hypothetical morphologic evolution of the Sunset Crater cinder cone compared to the morphology of other cinder cones. Grey band represents uncertainties in rates and magnitudes of change. Trend line is based on Hooper and Sheridan (1998). Figure Credit: © K. Anderson.

Table 4.5.2-1. Major morphometric parameters for cone age groups in the San Francisco Volcanic Field, Arizona.

Cone Age Group	*n*	Mean Hc/Wc	Mean Average Slope
Sunset Crater (~ 950 years)	1	0.1965	30°
Holocene-Latest Pleistocene (1000-0.16 m.y.)	12	0.178 ± 0.041	26.4 ± 7.3°
Middle Pleistocene (0.16 – 0.73 m.y.)	91	0.135 ± 0.028	18.1 ± 4.9°
Early Pleistocene (0.73 – 2.0 m.y.)	20	0.113 ± 0.027	13.4 ± 3.2°
Early Pleistocene – Late Pliocene (0.73 – 2.48 m.y.)	87	0.091 ± 0.025	10.6 ± 3.6°
Pliocene (2.48 – 5.0 m.y.)	27	0.077 ± 0.024	8.7 ± 2.7°

Sources: Hooper and Sheridan (1998) and data measured by K. Anderson for this assessment.

ecological progression. These trends are determined by a diffusion model (not discussed here) where the main erosion agents are wind, running water, plant and animal activity, additions of loess, and time. A dramatic change in the frequency or activity of any one of these agents would alter the rate of change. Measures of the Bonito Lava Flow morphology can be determined using existing GIS and LiDAR at the monument. These measures can be repeated over a yet-undetermined period of time to properly monitor morphologic changes.

Soil Formation

% Organic Matter, O Horizon Thickness, Total Organic Carbon, Total Soil Nitrogen, % Silt and Clay ("Loess"), And Soil Aggregate Stability

Selmants and Hart (2008) undertook a study of changes in soil development over time for a chronosequence in the SFVF. They measured trends in soil development based on several properties, including soil organic carbon, total soil nitrogen, and clay concentration, to establish a 3 million year-old chronosequence across four basaltic cinder cone substrates (Figure 4.5.2-7). Essentially, the trends in soil development have about the same rate of change as that of the landform evolution studies previously discussed. The carbon and nitrogen concentrations in Sunset Crater soils are less than for the 55,000 year-old

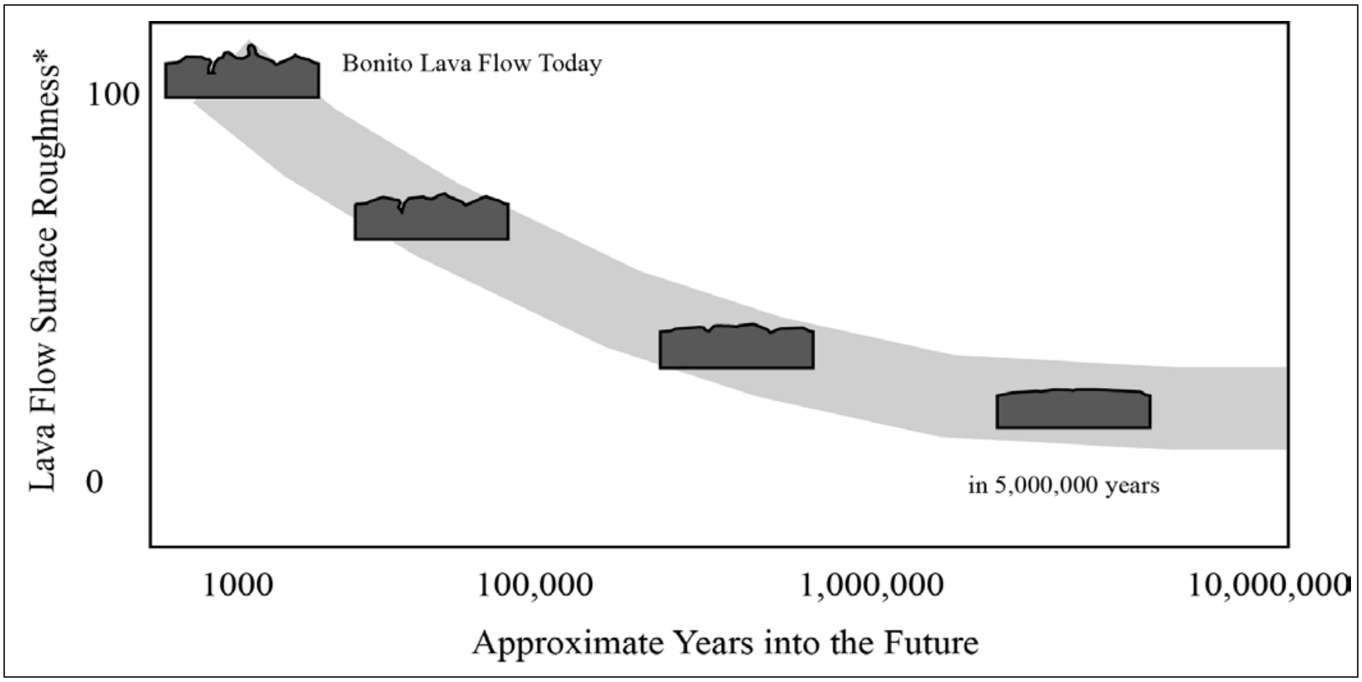


Figure 4.5.2-6. Conceptual diagram illustrating hypothetical morphologic evolution of the Bonito Lava Flow surface. Grey band represents uncertainties in rates and magnitudes of change (modified from Wells et al. 1985). Figure Credit: © K. Anderson.

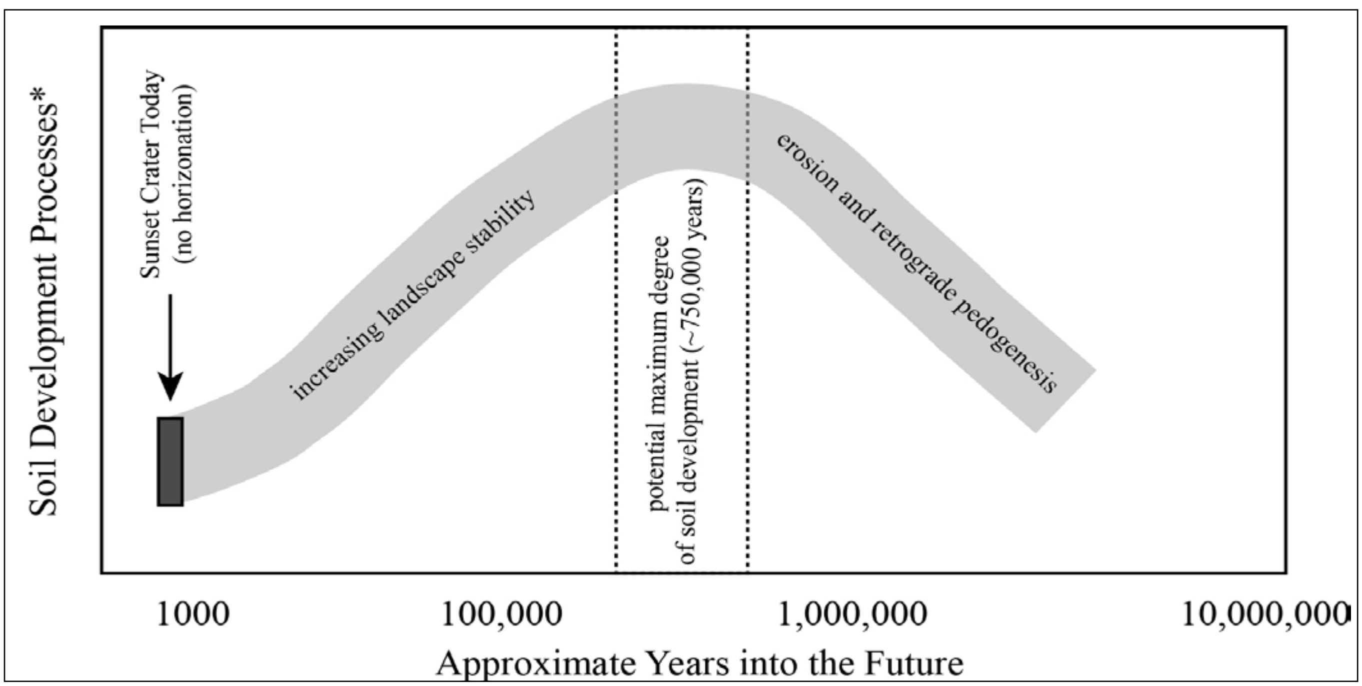


Figure 4.5.2-7. Trends in soil development over time illustrate the hypothetical soil evolution at Sunset Crater, based on analysis by Selmants and Hart (2008). Figure Credit: © K. Anderson.

substrate, which in turn are less than the 750,000 year-old substrate, at which time they reach their maximum concentrations in the soil. The values then decrease for the 3 million year-old substrate (Selmants and Hart 2008). Measurements of percent clay and water holding capacity exhibit a continued increase all the way through the 3 million year-old chronosequence, indicating that clay accumulation may be a good indicator of age in these substrates.

Specifically related to soil development, but important for ecological succession as well, Selmants and Hart

(2008) investigated the progression of "islands of fertility," which are characterized as isolated groves of ponderosa, pinyon, and/or juniper trees scattered throughout the Sunset Crater cinder fields. The "islands of fertility" are particularly important because of the associated soil development, which is dominated by organic matter accumulation and O horizon development. For Sunset Crater the "islands of fertility" are spatially and pedogenically heterogeneous, compared to the more widespread and homogeneous mature ponderosa pine forest observed on the older substrates. As with other geomorphic properties described earlier, these properties maximize to the 750,000-year time frame, after which, they become more fractured and heterogeneous with age. Selmants and Hart (2008) attributed this, in part, to the increased clay content. Very clay-rich soils tend to decrease infiltration, increase surface runoff and therefore result in retrograde pedogenesis, including the loss of organic matter and soil nutrients. An extreme result of this, not discussed in Selmants and Hart (2008), might be the 5-8 million year-old basalt flows where high clay contents result in reduced forest cover, increased parklands, and the formation of ephemeral ponds and lakes, such as on Anderson Mesa. For older soils on basalt flows, the clay derives from weathering of the basalt. However, for younger volcanic terrain, clay and silt are delivered to the ground surface as a result of regional deposition of loess.

Soil development is very slow in the arid environment, particularly the weathering of basaltic parent material on young landforms. Therefore, based on the USDA (2014) report, and Broadman and Anderson (2013), perhaps the two most significant processes in soil development and landform stability at Sunset Crater Volcano NM are: 1) build-up of organic matter in the O Horizon, particularly the accumulation of ponderosa pine needles, and 2) the aerosolic additions of loess to the ground surface, particularly silt and clay-sized particles comprised of gypsum, calcium carbonate, iron oxides, and various aluminosilicate minerals not related to the eruption (Reheis 1999). Valuable nutrients are also added to the soil via the deposition of loess (Reynolds et al. 2012). An excellent example of a soil that developed primarily from the additions of loess is the buried soil underlying the Sunset Crater cinders on Lenox Crater (Figure 4.5.2-8).

The rate of deposition and chemical components of loess accumulation are a major data gap related to soil formation at Sunset Crater Volcano NM. Loess measurements can be conducted by analyzing the soil constituents, and by the use of dust traps to collect aerosolic loess. Through time, and with the addition of organic matter, silt, and clay, soil particles tend to adhere to one another, increasing soil aggregate stability (Soil Survey Staff, 2014). Therefore, soil aggregate stability is a useful indicator of soil development.

Primary Ecological Succession

Colonization of flow edges and Islands of Fertility

The first study focusing specifically on primary ecological succession at Sunset Crater was undertaken by Eggler (1966). He concludes that there are no answers to the following questions: Is plant succession taking place? Are certain species being replaced? Are numbers of individuals within species changing

Figure 4.5.2-8. Buried soil at Lenox Crater. Scale is in centimeters. The upper 10 cm are light brown as they contain loess deposited since the eruption of Sunset Crater. At ~ 35 cm is the contact between the black Sunset Crater tephra and the brown buried pre-eruptive soil, a result of the accumulation of loess, aerosolic silt and clay deposited on the ground surface. Photo Credit: © USDA 2014.

over time? Is the plant population changing from a pioneering to climax community? Given these conclusions, and the lack of data on primary ecological succession since the Eggler study, it is difficult to come up with proper measures. Although the USDA (2014) study suggested that the spread of sand bluestem, and the establishment of pinyon pine and wax currant along the flow edges may be indicators of succession, such occurrences are very limited in spatial extent over the monument. Eggler does suggest that by observing the types, density, and distribution of plants on older cones, we can extrapolate what types of vegetative communities might be expected for SCV. However, as with previous analyses, Eggler indicates that ecological succession occurs over several millennia, due to the dry climate and slow weathering of the cinders.

The USDA (2014) defined four ecosite categories at Sunset Crater Volcano NM: Cindery-Ashy Uplands, Cinders-Lava Flow, Cinder Cone, and Loamy Bottoms. Because the Sunset Crater Volcano NM landscape and soils are so young, and ecological processes so slow, properties of the four ecosites are very similar and may be summarized together. The exception is the Loamy Bottoms, as that ecosite category is limited to alluvial parent materials in meadowlands, so is not used in this study. Characteristics of these ecosites are summarized in Table 4.5.2-2. In general, high daytime temperatures, high permeability and deep soils, low nutrients, low water-holding capacity, and sediment mobility by water, wind, and gravity, limit growth on most parts of the three cindery ecosites. These three ecosites occur in the same precipitation and temperature regime, have the same type of parent material, and are of the same age. The main differences are due to slope, aspect, and vegetation.

In essence, the USDA (2014) defines ecosites the "State and Transition" model, progressing from barren lava or cinder fields, to isolated "islands of fertility" to more expansive ponderosa pine-dominated forest.

To illustrate this idea, we apply the "islands of fertility" concept to observations made by the USDA (2014) where they infer that organic-rich soils occurring on lava flows represent the primary stage of ecological succession; essentially using the accumulation of organic matter as a proxy for ecological succession. Lithic Haplofibrists, a type of soil representative of this concept occurs in unique settings on the otherwise barren lava flow where aspen trees are growing in isolated niches. The aspen groves and the Fibrist soils are indicative of ecological succession on the Bonito lava flow. The accumulation of organic matter in these settings fundamentally benefits ecological succession because it is a major source of nutrients including nitrogen, phosphorus, and sulfur. Organic matter also increases cation exchange capacity, water availability, and aeration. The build-up of an O horizon on lava flows and volcanic cinder terrain is a fundamental indicator of ecological succession (Miller and Gardiner 1998). According to the USDA (2014), ecological succession progresses as a direct consequence of soil development that facilitates increasing density and diversity of plant and animal species. These extremely important organic soils on the lava flows are comparable to the "islands of fertility" on the cindered landscapes.

As discussed with the soils, Selmants and Hart (2008) further documented long-term trends in plant succession and landscape stability related to the "islands of fertility." Along with the soils spreading across the landscape, small groves of trees increase

Table 4.5.2-2. Ecosite characteristics.

Ecosite	Dominant Vegetation	Secondary Vegetation	Other	Significance
Cindery-Ashy Uplands	Ponderosa Pine	Apache plume, sand bluestem, blue grama	Increasing blue grama and decreasing sand bluestem	Indicates more stable surface and soil development; most developed ecosite
Cindery-Lava Flow Uplands	Ponderosa Pine and Apache plume	Pinyon, wax currant	Aspen pockets on barren lava flow	Cooler, moisture pockets of lava flow; high OM and Fibrist soils
Cinder Cones	Ponderosa Pine and Apache plume	Sparse twin pod, buckwheat, sand bluestem	–	–
Loamy Bottoms	Blue grama, Indian rice grass, perennial and annual forbs	Ponderosa pine	–	As soil development increases, blue grama increases

Source: USDA (2014).

in area, eventually merging together into expansive, stabilized, mature ponderosa pine forests (Figure 4.5.2-9). The trend from heterogeneous "islands of fertility" to homogeneous expanses reverses with clay buildup in the soils leading to erosion and loss of nutrients, and a shrinking forest.

Perhaps an optimum way to measure the ongoing stability of the Sunset Crater Volcano NM landscape is using LiDAR/GIS techniques to quantify the (changing) aerial extent of the "islands of fertility." Analysis of the data would illustrate where the islands are growing, where they are shrinking, and the relationship of the growing or shrinking areas to human activity and microclimates. Ground transects can document the types, density, and diversity of plant communities along the flow edges, in niches on the flow surface, as well as in the "islands of fertility."

4.5.3. Reference Conditions

Building on the previous discussion of "space for time" substitution and "islands of fertility", chronosequences of landscape evolution, soil formation, and ecological succession at Sunset Crater Volcano NM are presented in Table 4.5.3-1. Reference conditions allow for an assessment of the present landscape, and potential changes in the future.

4.5.4. Condition and Trend

Landform evolution, soil development, and ecological succession will continue to progress under natural conditions unless adversely impacted by National Park Service (NPS) facility development, recreation activities, climate change, or natural disasters such as fire. Activities of any kind should avoid 1) steep slopes, 2) disturbance of O horizons, and "islands of fertility."

<u>Overall Condition and Trend, Confidence Level, and Key Uncertainties</u>

For assessing the condition of volcanic cinder terrain, four indicators and 16 measures were used and are summarized in Table 4.5.4.-1. The overall trend of the resource is in good condition and stable, though significant data gaps indicate a moderate level of confidence in this conclusion.

The technical contents for this assessment were elicited from the author by park staff. The request was based on the author's level of research and expertise on the subject of Sunset Crater geomorphology. The conditions and trends were determined based on the author's best professional judgement and on an on-site rapid condition assessment, in addition to previous research projects conducted at the park. Additionally, the volcanic cinder terrain soil formation and ecological succession timescale is on the order of

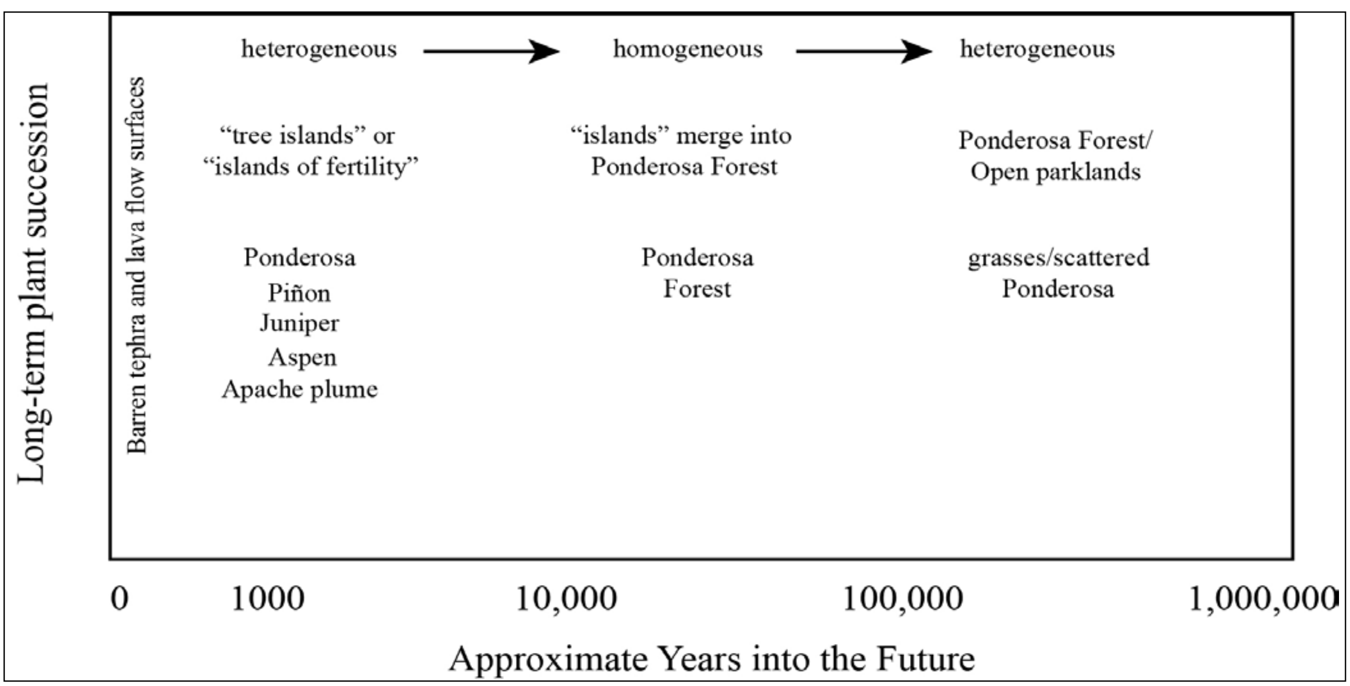


Figure 4.5.2-9. Conceptual diagram illustrating potential long-term trends in ecological succession at Sunset Crater NM. Figure Credit: © K. Anderson.

Table 4.5.3-1. Reference conditions used to assess the volcanic cinder terrain.

Indicators	Measures	Good	Moderate / Significant Concern
Cinder Cone Morphology	Cone Slope Angles	Remains unchanged	Measures change to indicate accelerated erosion such as decreasing slope angles, Hc/Wc, Cd/Cw; and increasing rill length, density, and trail networking. Significant data gaps can be addressed by GIS and LiDAR analysis.
	Hc/Wc	Remains unchanged	Same as above.
	Cd/Cw	Remains unchanged	Same as above.
	Rill Length	Remains unchanged	Same as above.
	Rill Density	Remains unchanged	Same as above.
	Trail Networks	Remains unchanged	Same as above.
Lava Flow Morphology	Surface Roughness	Remains unchanged	Measures change to indicate accelerated erosion such as decreasing surface roughness and increasing trail networking. Significant data gaps can be addressed by GIS and LiDAR analysis.
	Trail Networks	Remains unchanged	Same as above.
Soil Formation	% Organic Matter	Remains unchanged or increases in value and/or concentration	Measures decrease in value or concentration indicating retrograde soil formation with loss of organic matter and nutrients. In-field soil descriptions and laboratory analysis can address the major data gaps for soil formation indicators, and can be used to compare to the existing data from the USDA (2014).
	O Horizon Thickness	Remains unchanged or increases in value and/or concentration	Same as above.
	Total Organic Carbon	Remains unchanged or increases in value and/or concentration	Same as above.
	Total Soil Nitrogen	Remains unchanged or increases in value and/or concentration	Same as above.
	% Silt + Clay (“Loess”)	Remains unchanged or increases in value and/or concentration	Same as above.
	Soil Aggregate Stability	Remains unchanged or increases in value and/or concentration	Same as above.
Primary Ecological Succession	Colonization Of Flow Edges And Niches On Flow	Remains unchanged or increases in in size, diversity, density	Measures decrease in size, diversity, and/or density indicating reverse of ecological succession. Significant data gaps can be addressed by GIS and LiDAR analysis and in-field analysis of plant communities.
	Islands of Fertility	Remains unchanged or increases in in size, diversity, density	Same as above.

Table 4.5.4-1. Summary of volcanic cinder terrain indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Cinder Cone Morphology	Cone Slope Angles		The morphology of the Sunset Crater cinder cone is changing very slowly under seemingly natural processes such as from wind, rain, and ungulate trampling. The condition is good, with a stable trend and high confidence.
	Hc/Wc		The morphology of the Sunset Crater cinder cone is changing very slowly under seemingly natural processes such as from wind, rain, and ungulate trampling. The condition is good, with a stable trend and high confidence.
	Cd/Cw		The morphology of the Sunset Crater cinder cone is changing very slowly under seemingly natural processes such as from wind, rain, and ungulate trampling. The condition is good, with a stable trend and high confidence.
	Rill Length		Not enough systematic information about rill length with respect to the rate of rill erosion exists to determine why the southern half seems to have more rill erosion. As a result, we assign a low confidence in the good condition and stable trend rating.
	Rill Density		Not enough systematic information about rill length with respect to the rate of rill erosion exists to determine why the southern half seems to have more rill erosion. As a result, we assign a low confidence in the good condition and stable trend rating.
	Trail Networks		After NPS closed the trail to the summit, the trail is still visible after several decades, but it is no longer increasing the threat of erosion. The condition is good, with a stable trend and high confidence.
Lava Flow Morphology	Surface Roughness		While most surfaces of the lava flow are quite resistant to erosion, some of the more delicate features and the presence of social trails causes some concern. The condition is good, with a stable trend and high confidence.
	Trail Networks		Trail networks have not been specifically targeted to evaluate the changes in lava flow morphology. The condition is of moderate concern, with a deteriorating trend and medium confidence.
Soil Formation	% Organic Matter		Although low, nutrients and other indicators are in good condition for the age of the deposits. Changes in the identified measures may take a very long time to be detectible. The condition is good, with a stable trend and medium confidence.
	O Horizon Thickness		Although low, nutrients and other indicators are in good condition for the age of the deposits. Changes in the identified measures may take a very long time to be detectible. The condition is good, with a stable trend and medium confidence.
	Total Organic Carbon		Although low, nutrients and other indicators are in good condition for the age of the deposits. Changes in the identified measures may take a very long time to be detectible. The condition is good, with a stable trend and medium confidence.
	Total Soil Nitrogen		Although low, nutrients and other indicators are in good condition for the age of the deposits. Changes in the identified measures may take a very long time to be detectible. The condition is good, with a stable trend and medium confidence.
	% Silt + Clay ("Loess")		Although low, nutrients and other indicators are in good condition for the age of the deposits. Changes in the identified measures may take a very long time to be detectible. The condition is good, with a stable trend and medium confidence.

Table 4.5.4-1 continued. Summary of volcanic cinder terrain indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Soil Formation *continued*	Soil Aggregate Stability	Good, stable trend, medium confidence	Soil formation proceeds very slowly in this environment. Soils properties are likely to remain at normal levels for the young landscape. The condition is good, with a stable trend and medium confidence.
Primary Ecological Succession	Colonization Of Flow Edges And Niches On Flow	Good, stable trend, medium confidence	Since Eggler (1966) there has been no study specifically targeting primary ecological succession, though the Hansen (et al., 2004) and the USDA (2014) provide valuable data from which to move forward. The condition is good, with a stable trend and medium confidence.
	Islands of Fertility	Good, stable trend, medium confidence	Key measures are the growth or decline of the Islands of Fertility, but a low level of confidence is applied because of the lack of detailed analysis. The data may be there to quantify, but as yet it has not been done. The condition is good, with a stable trend and medium confidence.
Overall Condition		Good, stable trend, medium confidence	Spatial heterogeneity and limited studies creates a moderate confidence in any generalized determination, but we consider the overall condition of the volcanic cinder terrain to be good with a stable trend.

hundreds if not thousands of years, representing very long-term conditions and trends.

Threats, Issues, and Data Gaps

Impacts of Land-use on Recent Volcanic Cinder Terrain

The USDA (2014) Soil Survey provides a number of valuable parameters from which to evaluate the impact of human-land-use on soil formation, landscape stability, and vegetation establishment. Some of the potential land-use impacts include timber extraction, facility and infrastructure development, and recreation.

Timber extraction

Lenox Crater was partially logged just outside the southwest corner of the monument in 1916 and 1917 (see DeYoung, no date, NPS report on file). Other areas a bit further from Sunset Crater Volcano NM were logged on and off since the late 1800s. Logging of Lenox Crater and other cinder cones in the area, but outside the monument, as well as regional fire suppression, have changed the ponderosa pine (*Pinus ponderosa*) forest characteristics, so care needs to be applied when attempting to use the space-for-time concept in determining the predicted ecological succession for Sunset Crater. Additionally, logging on Lenox Crater, outside of the monument, may have influenced erosional rates along the logged slopes, which could affect erosional rilling, for example, along areas of the Lenox cinder cone within the monument.

NPS Facility Development

Because of the fragile characteristics of young soil development in arid climates, the construction of facilities can have a negative impact on ecological succession and soil development if steps are not taken to avoid sensitive areas. Sensitive areas would include "islands of fertility", comprised of ponderosa, pinyon, juniper, and aspen groves, and the associated O horizons. The recent construction of the amphitheater at the Lava Trail trailhead serves as an example. The excavation exposed the youngest tephra erupted from the volcano (Figure 4.5.4-1), thus supplying valuable scientific information for management and education purposes. Placement of the amphitheater avoided sensitive terrain. Facility development should avoid construction on steep terrain and the "islands of fertility." Areas of thick pine needle accumulation should be avoided for facility and infrastructure development, as they form an interlocking mat of organic matter that helps stabilize the soil. Although pine needles decay slowly, pine needles are a major source of O horizon development (Figure 4.5.4-2).

Recreation

Recreation within the monument is currently limited to hiking on existing trails, though occasionally social trails may become a resource issue. Use of Off Road Vehicles (ORV) is prohibited in the monument, although occasional trespass vehicles have entered, leaving tell-tale tire tracks. A large ORV area to the south of the monument (Coconino National Forest, adjacent to Sunset Crater Volcano NM) has

Figure 4.5.4-1. Tephra deposits from the last eruptive phase of Sunset Crater. The height of the section is 1.0 m (3.3 ft). Photo Credit: © K. Anderson.

Figure 4.5.4-2. Organic-rich soil horizon associated with a small "island of fertility" exposed at the amphitheater excavations. The height of this section is 0.5 m (1.6 ft). Photo Credit: © K. Anderson.

been studied to determine potential impacts on the ecological succession in the sensitive volcanic cinder terrain. Conclusions from these studies can be used to infer potential impacts to the monuments landscape if such activities are allowed to occur there in the future.

Kennedy (2005) investigated the potential impacts of ORVs on cinder-covered terrain comprised of ponderosa pine trees. They identified four patterns: 1) tree regeneration and recruitment was greater in control sites, 2) litter cover and depth was greater in control sites, 3) soil bulk density was lower while soil moisture, water infiltration, and root biomass were greater in control sites, and 4) mycorrhizal colonization, abundance, inoculum potential and community were all greater in the control sites. Mycorrhizae are necessary for healthy soils and plant growth. Kennedy (2005) concludes that ORV activities have the potential to restrict ponderosa pine establishment, thus altering (or reversing) ecological succession of the forest.

Swan, in her 2002 study, concluded that ORV activity in the Coconino National Forest reduced ponderosa pine density, interlocking canopy, and recruitment, and reduced shrub cover. Additionally, ORV areas had less activity by Abert's squirrel (*Sciurus aberti*) and ungulates, further indicators of negative impacts on the ecosystem.

Trail Systems

Trail systems were mapped using GIS and LiDAR information in order to obtain baseline data on the potential impacts to the landscape (Hansen 2014). Social trails can be detrimental to sensitive landforms, soils, and ecological succession if left unregulated. Increased rates of localized change occurred when, for example, hiking to the summit of Sunset Crater was permitted. Persistent foot traffic along any of the numerous steep cinder-covered slopes in the monument, or across lava flow surfaces, can exacerbate erosion rates, particularly in the more susceptible landforms (Hansen 2014). Re-routing of the steep trail that previously was situated somewhat perpendicular to the slope of Lenox Crater (Figure 4.5.4-3), and replacing it with a trail that more closely follows contours (Figure 4.5.4-4), helped reduce the rate of erosion and rilling. See the Unique Volcanic Resources assessment in this report for more information on social trails and their impact on the Sunset Crater NM landscape.

The "land capability class," used by the USDA (2014) to identify land suitable for crop production, concludes that all areas of Sunset Crater Volcano NM have limitations preventing commercial plant production. Sunset Crater Volcano NM is classified as best suited for wildlife, watershed protection, recreation, and aesthetic purposes. The USDA further concludes that due to the loose, sandy, and gravelly substrate, and

Figure 4.5.4-3. Trail ascending Lenox Crater was washed out by heavy rains in 2016. Photo Credit: NPS/P. Whitefield.

Figure 4.5.4-4. New trail ascending Lenox Crater follows contours and is therefore less susceptible to erosion. Photo Credit: NPS/P. Whitefield.

steep slopes, activities related to camping, picnicking, foot traffic, equestrian trails, mountain bike trails, and ORV activity is classified as somewhat-to-severely limited. Finally, because of the sandy and gravelly substrate, and steep terrain, building construction is classified as somewhat-to-severely limited (USDA 2014).

In addition, high daytime temperatures, high permeability in the deep cinders, low nutrient concentrations, low water-holding capacity, and sediment mobility by water, wind, and gravity limit plant growth and ecological succession in the volcanic cinder terrain of Sunset Crater Volcano NM. The related slow rates of soil development further limit the rate of ecological succession. For the region in which Sunset Crater Volcano NM is located, climate change scenarios predict warming temperatures, accompanied by more intense monsoon activity (Garfin et al. 2013).

Data Gaps

There are numerous data gaps for each of the indicators in this assessment. For example, while recent studies discussing Sunset Crater Volcano NM ecology provide valuable information, Eggler (1966) appears to be the most recent study specifically targeting ecological succession at the monument.

Measures to assess trends in the changing cinder-covered landscapes, including cone slope, Hc/Wc, Cd/Cw, rill length and density of rills along the slope, and location and extent of trail networks can be determined using GIS and LiDAR (Hansen 2014). This data gap on cone morphology should be readily addressed using existing GIS and LiDAR data at the monument. Such monitoring activities can be repeated over a yet-undetermined period of time to properly monitor morphologic changes.

4.5.5. Sources of Expertise

Dr. Kirk Anderson, author of this assessment, is a geomorphologist at the Museum of Northern Arizona in Flagstaff, AZ. He has conducted research and co-authored numerous publications and reports on the eruption of Sunset Crater.

4.6. Volcanic Resources

4.6.1. Background and Importance

Sunset Crater Volcano National Monument (NM) was authorized under the Antiquities Act to protect the Sunset Crater Volcano (Figure 4.6.1-1) and Bonito Lava Flow. The feature for which the monument is named, Sunset Crater Volcano, formed approximately 900 years ago during the Sunset Eruption event, and in western literature, it was first referred to as Sunset Mountain by John Wesley Powell (Colton 1945).

The preservation of the monument's volcanic resources is its primary purpose and significance under its General Management Plan (GMP) (NPS 2002, as amended NPS 2013b). These volcanic features are identified as fundamental resources and values in the Foundation Document for Sunset Crater Volcano NM (NPS 2015a). Since the 1930s, Sunset Crater Volcano remains the subject of geological, archeological, anthropological, and ecological investigations, as the volcanic landforms and features preserve scientific evidence of the origin, sequence, duration, and environmental impacts of the eruption. The largely barren and unweathered volcanic landscape continues to fascinate the human imagination, and is integral to the visitor experience. A number of eruption features are the focus of interpretive exhibits and greatly contribute to visitor enjoyment. They are also integral to geologic science education, included in geology field guides (for example, Hanson 2003), and frequently visited by public school and university groups. Additionally, both the eruption event and the volcanic landscape have remained important to Native Americans for centuries, and the Sunset Crater Volcano and eruption features within the monument are identified as traditional cultural properties by affiliated tribes (NPS 2002). Native American oral histories and archeological studies report the occupation and farming of the area by ancestral Puebloans preceding the time of eruption, who then moved from their settlements as the eruption began (Elson et al. 2011a). The Sunset Eruption may also have been one of the more powerful cinder cone eruption events in southwestern North America (Wagner 2016).

The Sunset Crater Volcano and Bonito Lava Flow were formed during a single volcanic eruption (Holm and Moore 1987, Elson et al. 2011b). During the eruption, very coarse volcanic scoria accumulated to nearly 330 m (1,000 ft) deep, forming the Sunset Crater Volcano, which is a textbook example of a cinder cone volcano.

While the cinder cone was forming, the Bonito Lava Flow originated at the western base of the cone. The lava flow extruded in three stages, eventually

Figure 4.6.1-1. Colorful fumarole mineral deposits on inner rim ridgeline of Sunset Crater Volcano, with the San Francisco Peaks in the background. Photo Credit: NPS.

inundating a total area of 430 ha (1,060 ac), and accumulating up to 45 m (150 ft) thick at the center. Also scattered across the surface of the Bonito Flow are remnants of an earlier stage of the Sunset Cinder Cone, which was torn away as lava extruded from the west side of the cone, and rafted westward up to 2 km (1.25 mi) away. The cinder cone remnants now rest as jumbled mounds and hills of very coarse, loose cinder, with some layers of fully welded spatter ("agglutinate," Holm 1987). At the same time this was occurring, a column of finer cinder and ash-fall (volcanic tephra) was ejected high over the Sunset Crater vent, falling and accumulating around the cinder cone and on the Bonito Flow (Amos 1986, Hooten et al. 2001, Wagner 2016). This volcanic tephra layer ranges from 1 m (3 ft) deep to more than 120 m (400 ft) deep, and covers most of the land surface within Sunset Crater Volcano NM, including a number of older cinder cones readily visible around the horizon (Moore and Wolfe 1987).

A variety of small-scale features formed by the Sunset Eruption are also recognized for their scientific and educational value, and for their contribution to visitor enjoyment. These features provide objective evidence of the sequence of events during the eruption, and retain the appearance of still-flowing lava or an accumulating deposit of molten fluid, and are essential to the dramatic character of the young volcanic landscape. With recurrent recreational and administrative activity, they are vulnerable to accelerated, erosive modification. Similar to parks containing foundational resources that are influenced by visitor and administrative activities, such as cave formations, fossils, or archeological structures and artifacts, the volcanic resources within Sunset Crater Volcano NM may be steadily degraded, damaged, or removed over time.

The 900 year-old volcanic terrain is in the very early stages of ecological recovery. Soils and vegetation will eventually develop and stabilize the Sunset eruption deposits. In the meantime, the volcanic terrain is primarily comprised of very deep, coarse, and loose material. The material is highly porous and brittle, and susceptible to rapid displacement and pulverization. The barren cinder slopes are particularly prone to erosion of deep rills and slope failure. In the recently completed soil survey, the U.S. Department of Agriculture Natural Resource Conservation Service (NRCS) and U.S. Department of Interior National Park Service (NPS) (2014) rated the slopes as unsuitable for any conventional land use, unsuitable for trails, and unsuitable for intensive recreation. In addition, many small-scale eruption features are comprised of very loosely welded lava spatter, or very soft minerals (Hanson et al. 2008).

The NPS Public Use Statistics Office (2018) indicates that between 1934 and 2015 more than 15 million visitors have experienced the volcanic resources within Sunset Crater Volcano NM. Sustained visitor activity gradually alters surface topography in some locations, wearing down some of the more popular eruption features (Hansen 2015). In 1973, all visitor access on Sunset Crater Volcano was restricted, and the trail to the crest was permanently closed and rehabilitated due to unacceptable erosion impacts that were highly visible across the steep slopes of its western face. Sections of the rehabilitated Sunset Crater Crest Trail remain visible more than 50 years later (NPS 2002).

In 1998, much of the remaining area within Sunset Crater Volcano NM was closed to general visitor access to protect the fragile volcanic resources (NPS 2002, as amended NPS 2013b). Under the monument's current GMP (NPS 2002, as amended NPS 2013b), visitor access is provided within 114 ha (282 ac), or less than 10% of the total area within the monument. Sustained surface disturbance to the barren cinder terrain, particularly on open slopes, can accelerate loss of surface deposits and may expose underlying pristine volcanic layers. The highest degree of large-scale alterations to landforms occurred with the construction of the access roads and trails (Whitefield et al., *in prep*). The most persistent impacts remain visible at great distance, degrade viewsheds from interpretive areas and trails, and detract the most from the desired visitor experience. In other areas, persistent erosional rilling, undermined slopes, social trail development on hillslopes, and compaction/pulverization of cinder to fines, can be observed with subsequent deflation of surfaces through wind and winnowing processes. Attempts to restore surfaces and contours by raking or filling with material often result in sustained trampling and impact during rehabilitation work. For many efforts, the landform surface can rarely be fully restored to the original contour, and the lost material cannot be replaced.

4.6.2. Data and Methods

This assessment of volcanic resources is based upon review of the published pertinent geologic literature, along with a series of volcanic resource inventory, mapping, and baseline condition data on file with the Resource Management Division, Flagstaff Area National Monuments (NMs) (see Whitefield et al., *in prep* for details).

From 2007-2017, the Flagstaff Area NMs Resources Management Division, along with students and faculty at Northern Arizona University, undertook a series of projects and cooperative studies to inventory and map volcanic resources and develop a monitoring framework for Sunset Crater Volcano NM. This assessment provides a condensed synthesis of these projects and studies. Whitefield et al., *in prep,* includes more details of the Sunset Eruption, field survey procedures, mapping methods, condition assessment methods, resulting GIS data and maps, photo-documentation, and baseline condition summary statistics for the volcanic resources within Sunset Crater Volcano NM. The report also provides photographic records and narratives to document observed impacts to volcanic landforms and small-scale eruption features, as well as to provide a rationale for the types of impacts considered persistent or permanent.

Based on the information detailed in Whitefield et al., *in prep*, two indicators are used to evaluate the condition of volcanic resources in this condensed assessment: volcanic landforms and unique volcanic features. Each indicator has one associated measure: the degree to which their surfaces are physically altered from their original topography, shape, or volume, and the related integrity of volcanic eruption material. Measurable impacts are alterations caused by recreation and/or agency operations. Although there is evidence of human activity in the area for several thousands of years, including several centuries of Puebloan agriculture occurring from 1,200 to 900 years ago, any pre-historic impacts within Sunset Crater Volcano NM are buried under the Sunset eruption deposits.

To describe and assess the impacts from visitor activities and/or agency operations, the following elements are considered here:

- Impacts from visitor activities are typically very gradual. The condition assessment documentation completed by Flagstaff Area NMs staff since 2007 remains accurate for condition within the last five years. Most of these features were revisited by Whitefield between 2015 and 2017, and little change was observed that would warrant a lowered condition rating if the data were collected in the past five years;
- Geologic formations and deposits are relatively static over timescales spanning centuries to millennia. Maps produced more than 50 years ago remain accurate for describing geologic resources within Sunset Crater Volcano NM;
- Many documented impacts to volcanic resources occurred more than five years ago. Some impacts have persisted for decades and remain readily observable at present. The impacts of greatest concern occur cumulatively over periods of time spanning 40+ years.

<u>Estimated Percentage of Persistent Surface Alteration of Volcanic Landforms</u>

The primary volcanic landforms within Sunset Crater Volcano NM include the Sunset Crater Volcano and the Bonito Lava Flow. For the purposes of this assessment, Sunset Crater Volcano will be referred to hereafter as the Sunset Cinder Cone. Other volcanic landforms that are distinguishable from their topography include the older Lenox Crater cinder cone volcano, one unnamed older cinder cone, and portions of at least three other unnamed older partial cones (Moore and Wolfe 1987; see Figure 4.6.2-1).

Based on compiled NPS observations and records since 2002 documenting chronic erosion impacts, trail maintenance practices, and insight gained from the outcomes of the abandoned Sunset Crater Trail and former alignment of the Lenox Crater Trail, only recreational and operational impacts on cinder slopes greater than a 15° slope angle are measured under the volcanic landform indicator. In some areas, documented impacts to the topographic shapes and/or the integrity of the upper deposits of volcanic landforms are permanent (Hansen 2013, Whitefield et al., *in prep*).

Under the condition assessment measure, impacts are caused by cumulative human activities over time, including agency operations, infrastructure and facilities development, as well as visitor activity. In addition, a series of unauthorized off-road driving incidents have occurred over the last 25 years.

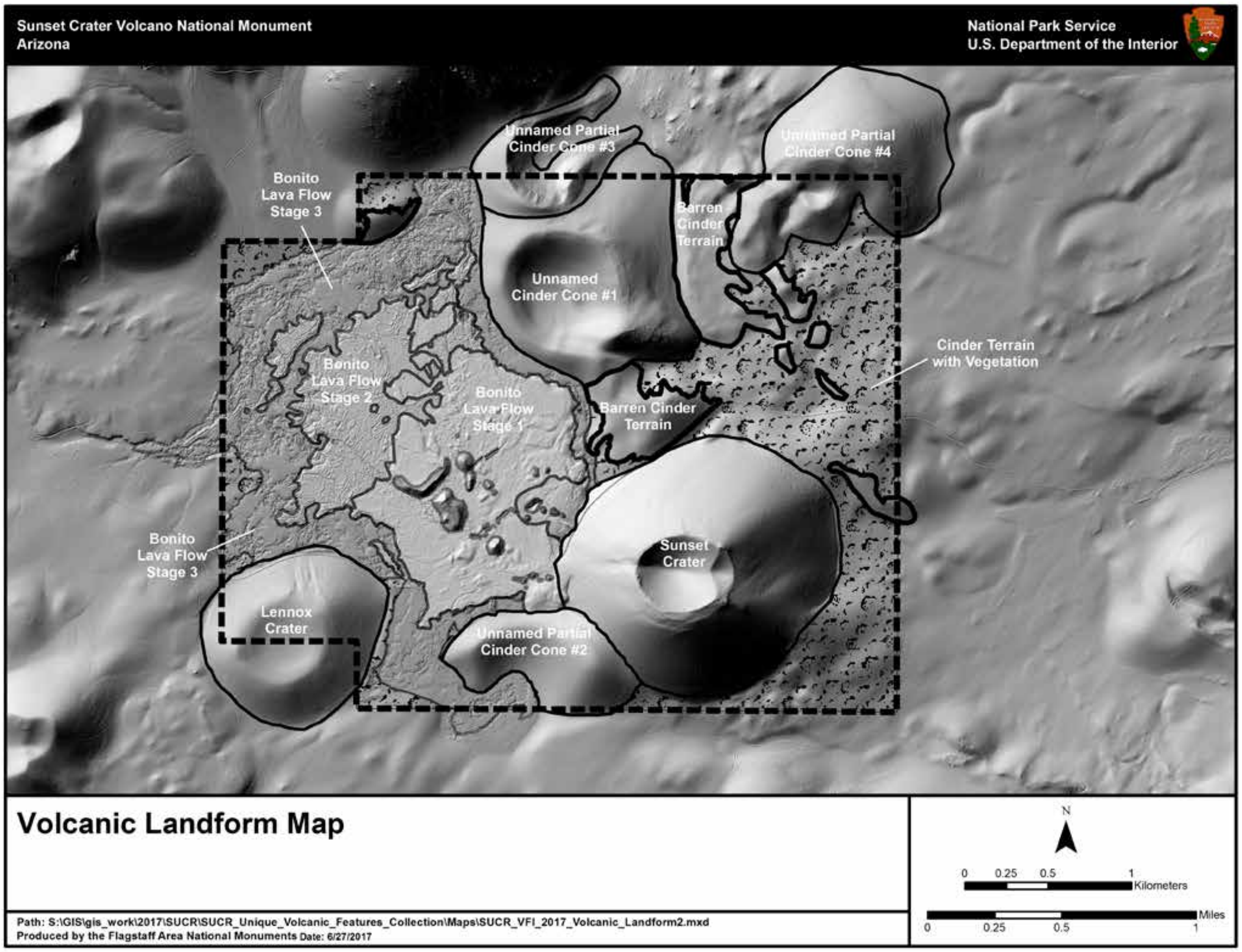


Figure 4.6.2-1. Map of 11 volcanic landforms within Sunset Crater Volcano NM. All of the landforms, except for Stage 3 of the Bonito Lava Flow, are covered by a layer of Sunset eruption tephra/ash-fall. Figure Credit: NPS.

The geospatial data and baseline conditions framework developed since 2007 (see Whitefield et al., *in prep*) supports a largely quantitative approach to assigning condition for volcanic landforms. To develop a landform cover map, monument staff mapped and classified all of the area within Sunset Crater Volcano NM, identifying each readily distinguishable cinder cone volcano and three stages of the Bonito Flow.

To quantify persistent impacts to the dominant volcanic landforms, the Resources Management Division, Flagstaff Area NMs, completed a multi-step GIS analysis in 2017. The analysis was conducted in ArcGIS and utilized four primary source datasets: (1) GIS layer of eleven total classified volcanic landforms within the monument (Figure 4.6.2-1); (2) archived GIS data files provided by Hansen (2014); (3) rapid landform condition assessment conducted by Flagstaff Area NM staff during 2017 to supplement Hansen's data; and (4) a Light Detection and Ranging (LiDAR) based "bare earth model" procured by the Flagstaff Area NMs in 2012 (Watershed Sciences, Inc. 2013). These GIS layers and supplemental data were taken through a sequence of steps to calculate the total area of each volcanic landform with persistent surface impact and/or permanent topographic modification.

Hansen's (2014) recreational impact survey data were reanalyzed in 2017 to merge layers of the most persistent off-trail and off-road travel impacts. Hansen completed ground-based GPS-mapping of 207 ha (511 ac), or 17% of the total monument area, including most visitor access areas, trail corridors, and access road corridor. Primary observed impacts included in the analysis were areas of high-intensity off-trail trampling in cinder barrens, permanent social trail terraces on slopes, volcanic eruption feature damage, illegal off-road travel, chronic erosion along trail alignments, and major excavation for the monument access road. For the remaining area not included in Hansen's survey, monument staff completed a rapid assessment of volcanic landforms in 2017. Next, the 2013 LiDAR bare earth model was also utilized to create polygons around a few remaining areas of chronic erosion associated with trail alignments, and around roadcuts excavated into two prominent cinder cones. Each of the derived impact layers were then overlaid onto the landform classification layer, and the sub-total area of impact was calculated and tabulated for each of the eleven landforms (labeled in Figure 4.6.2-1). Last, the tabulated recreational impact area and modified landform area were summed to provide the total impact area for each mapped landform. Summary map layers and area calculation tables for the intermediate steps described here are presented in Whitefield et al., *in prep*. Only final summary data of total impacted area for all combined landforms is presented in this assessment.

In addition to quantifying the total area impacted by concentrated surface pedestrian activity, a LiDAR-derived bare earth model was used to identify and map polygons around all permanent topographic alteration of the cinder cones from operational and access trails and roads. Further details on the technical approach and methods, GIS data acquisition and analysis, results maps, and calculated area statistics are provided in Whitefield et al., *in prep*.

<u>Relative Percentage of Altered Inventoried Unique Volcanic Features</u>

Existing geologic literature describes a variety of features formed during basaltic cinder cone and lava flow eruptions, with specific examples for the Sunset eruption in Colton and Parks (1930), Colton (1945), Amos (1986), Holm (1987), and Holm and Moore (1987), and Hanson et al. (2008). Although Sunset Crater Volcano NM was established to protect 900 year-old volcanic features, as of 2006 the Hornito spatter cone and the Ice Cave along the Lava Flow Trail, along with very few other eruption features, were well known to NPS managers. To address this deficiency, a volcanic feature inventory project was initiated in 2007 by the Resources Management Division, Flagstaff Area NMs and geology students with Northern Arizona University. Data were developed directly into GIS, using both digital aerial imagery analysis and field-based GPS-mapping of most of the accessible volcanic terrain within the monument. As part of the project, original criteria were developed to define "unique volcanic features", based primarily upon geologic significance, relative scarcity within the Sunset eruption deposits, and/or physical fragility. Additional features that contribute greatly to visitor enjoyment and education were also included.

All features identified as unique were extracted to a separate GIS layer, assigned identification numbers, and corresponding attribute data were also recorded. All features inspected or mapped in the field were digitally photographed. A condition assessment field form was completed, assigning a rating based upon the degree of observed surface damage from recreational activity. From 2015 to 2017, additional GIS data and field mapping was completed by Flagstaff Area NMs staff to add numerous other features to the original dataset. A field condition assessment form was not completed for these features. Instead, rapid condition ratings were assigned in summary results tables, included in Whitefield et al., *in prep*. Ratings were based upon observed estimates of surface alteration or damage, consistent with the original field assessment form.

To date, the total GIS unique feature inventory for Sunset Crater Volcanic NM includes 79 features, including: spatter mounds, spatter cones (hornitos), spatter ramparts, rafted lava flow segments, rafted cinder cone remnants, rafted dike segments, agglutinate deposits, lava "squeeze-ups", fissure openings, lava collapse zones, lava "breakouts", lava bombs, lava "rivulets", xenoliths, fumarole mineral deposits (sulfide, gypsum, and iron oxide minerals), cave openings, ice deposits, and lightning "splashes". Refer to the Whitefield et al., *in prep* manuscript, which includes three separate maps composed at appropriate classification and scale to properly display all 79 unique features.

4.6.3. Reference Conditions

For assigning an overall condition to volcanic resources, the reference condition is their near-pristine condition after the Sunset eruption ceased, accounting for initial natural weathering and displacement of surface cinder over the last 900 years. Determining condition entails distinguishing between natural rates of erosion and ecological recovery, and accelerated rates of landform alteration and loss of fragile eruption features due to recreational and operational activities. Table 4.6.3-1 presents the reference condition thresholds

Table 4.6.3-1. Reference conditions used to assess the volcanic resources in Sunset Crater Volcano NM.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Volcanic Landforms	Estimated Percentage of Persistent Surface Alteration	0 – 20 %	21 – 40%	> 40%
Unique Volcanic Features	Relative Percentage of Altered Inventoried Eruption Features	≥ 80% are good or pristine	≥ 60 to < 80% are good or pristine	< 60% are good or pristine

for volcanic landforms and the unique volcanic features. The reference thresholds are expressed as simple, aggregated relative percentages of observed permanent alteration or damage to volcanic resources. They are analogous to qualitative thresholds given for minor, moderate, and major impacts for geologic resources under the General Management Plan for Sunset Crater Volcano NM (NPS 2002, as amended by NPS 2013). The reference conditions for both indicators are intended to provide a semi-quantitative framework for understanding cumulative impact within primary visitor access zones, and whether impacts are expanding into areas where access is restricted to protect fragile volcanic resources. There are no published regulatory standards or accepted scientific thresholds for assigning conditions to volcanic resources. These were developed ad-hoc by Whitefield et al., *in prep* over the last decade. A primary consideration was ensuring repeatability and minimizing variation in field spatial mapping and ocular impact estimates. Thresholds between the condition classes were established based upon quintile percentage brackets, which my be more reliably estimated by personnel with sufficient field experience. They reflect resource damage levels which are believed to be tolerable to both NPS managers and the general public. If the percentages are approaching moderate concern, it is likely management intervention is warranted. The thresholds for good, moderate concern, and significant concern may need to be adjusted as the condition assessment is repeated over time to understand trend.

4.6.4. Condition and Trend

<u>Estimated Percentage of Persistent Surface Alteration of Volcanic Landforms</u>

Based upon the aggregated condition statistics, 88% of all volcanic landforms are in good condition (Table 4.6.4-1). In general, larger proportions of the Lenox Cinder Cone and the Stage 1 Bonito Flow landforms are more affected by visitor activity than other landforms. Readily observable impacts are occurring around the most heavily visited areas, including limited vegetation trampling, soil compaction, and unplanned (“social”) trails. The rugged terrain of the Stage 3 Bonito Flow, the Sunset Cinder Cone, and most of the remote interior areas with older cinder cones, remain in good condition.

The results demonstrate that various landforms comprised of deep, unconsolidated cinder deposits have experienced some degradation since the 1950s. However, with few exceptions, impacts at the landform scale are of minor concern except for a few specific areas. Some of the largest permanent alterations of landforms are related to poorly sited access trails or road alignments. For example, segments of the abandoned trail to the crest of the Sunset Cinder Cone have persisted for more than 40 years. Switchbacks remain visible as broad diagonal bands of discolored surface cinder across the western face of the cinder cone, and are distinguishable on the 2012 high-resolution digital terrain model (see Whitefield et al., *in prep*). Likewise, permanent roadbed alignments were graded with heavy equipment into the flanks of both the Sunset Cinder Cone and the Lenox Cinder Cone. The road-cut is relatively shallow and remains stable on Lenox, while the road-cut on Sunset is very deep and remains unstable 50 years after construction, with the erosive impacts gradually migrating upslope into the side of the cinder cone.

A slope angle of greater than 15° for all open cinder terrain is a first priority threshold to protect from heavy visitor activity, due to its soil characteristics and susceptibility to accelerated erosion (NRCS and NPS 2014; see guidance for trail design in USFS 2017a). In the recently completed soil survey for Sunset Crater Volcano NM, the NRCS also recognizes distinct soil development in steeper cinder terrain, and divided most soils into separate types where they occur on slopes lesser than or greater than 15° (NRCS and NPS 2014). The LiDAR-derived slope data shown in Figure 4.6.4-1, are utilized in planning new trail alignments, and in establishing resource protection measures for recently implemented guided hikes (NPS 2013b).

Table 4.6.4-1. Volcanic landforms condition results summary.

Total # Landform Types	Total Landform Area (ha)	Total Area Surveyed (ha) Hanson (2014)	Total Area with Rapid Condition Assessment (ha) (2017)	Total Landform Area Impacted (ha)	# and % of Landforms in Good Condition	# and % of Landforms in Fair Condition	# and % of Landforms in Poor Condition
11	1,238 (100%)	206.845 (17%)	1,023.155 (83%)	30.802 (2.5%)	9 (88%)	2 (2%)	0 (0%)

An effort to mitigate persistent trail erosion impacts on the Lenox Cinder Cone occurred with the re-routing of the trail onto a gentler alignment. Follow-up assessments to measure and monitor erosional impacts may need to occur to determine if the desired effect is achieved.

Casual field observations of trampling activity within the Resource Preservation Zone are that infrequent, low-level activity on relatively flat cinder terrain is not detectable within three to five years of occurrence. Presumably, visitor footprint patterns on level to gently sloping terrain naturally weather out over this timeframe, due to exposure to strong winds, sheet-flow runoff from rainstorm bursts, compression under deep snowpack, and regular winter freeze-thaw processes. Light, off-trail activity on slopes may remain visible temporarily, and are of minor concern. However, an undetermined threshold is evident where social trails are established through recurrent and frequent pedestrian activity, resulting in compaction pavements and permanent alteration of the landform.

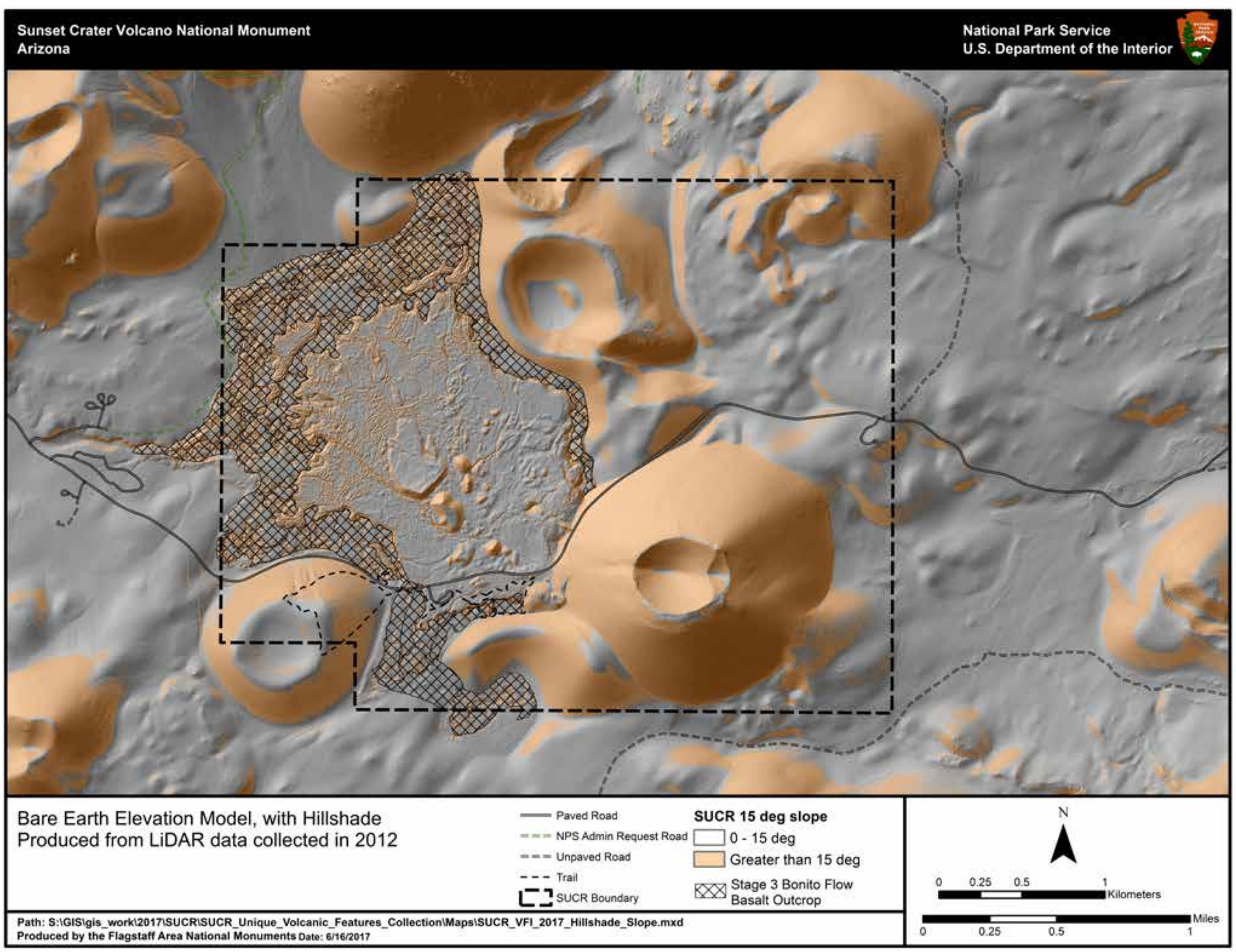


Figure 4.6.4-1. Bare earth image for Sunset Crater Volcano NM, with hillshade, developed from 2012 LiDAR data. Slopes greater than 15% slope angle are shown in orange. Figure Credit: NPS.

This activity is also subject to a threshold where slopes begin to collapse to lower angles. However, activities impeding vegetation recovery on mounds, hills, cones, and other slopes are of greater consideration, as vegetation and litter cover provide structural cover and enhance slope integrity in more complex cinder terrain.

Relative Percentage of Altered Inventoried Unique Volcanic Features

Ninety-five percent of the inventoried unique volcanic features are in pristine or good condition (Table 4.6.4-2). Furthermore, most of the unique volcanic features that are in fair or poor condition occur in proximity to popular visitor access areas, trail corridors, and road corridors.

As the documented examples of impacts to unique volcanic features illustrate (Whitefield et al., *in prep*), many of those that are mapped and identified are rare and/or fragile within the context of the monument. Examples of the more uncommon feature types occur along interpretive trails and within the newly established guided hike zone, where visitors may enjoy and learn about them but are also the most impacted.

Interpretive information and communication with visitors on the fragility of the resources has improved and has increasingly become more sophisticated. In general, this may slow volcanic resource impacts as visitors are more aware and act accordingly, even though total visitation has risen from 127,000 to as many as 597,000 visitors per year (1979-2016) (NPS Public Use Statistics Office 2018).

Overall Condition and Trend, Confidence Level, and Key Uncertainties

For assessing the condition of volcanic resources at Sunset Crater Volcano NM, two indicators and two measures were used, which are summarized in Table 4.6.4-3. The volcanic resource conditions remain within the environmental impact thresholds defined for various management zones under the GMP (NPS 2002). Conditions of both measures are good, which results in an overall good condition rating.

Table 4.6.4-2. Unique volcanic features condition results summary.

Volcanic Features	Pristine	Good	Fair	Poor
Total Number	49	26	2	2
Condition Class Percent	62%	33%	2.5%	2.5%

The Unique Volcanic Feature Inventory (see Whitefield et al., *in prep*) and Recreational Impact Assessment (RIA) (Hansen 2014) were both designed to be repeatable in order to monitor trends and landscape changes over time. The LiDAR bare earth model provides a high-accuracy baseline for detecting trends for changes in topography, such as rounding and reduction of mounds, hills, and cinder cones; undermining and slumping of open slopes; formation of large erosion rills on slopes; incision of social trails; loss of rock outcrop volume; and deflation of surface lag and exposure of underlying volcanic deposits.

In Hansen's (2014) RIA, he assigned trend values of stable, decreasing, or increasing impact for the 44 RIA impact types analyzed. Hansen's (2014) classification, however, are more descriptive of the degree of natural weathering on observed impacts, rather than an understanding of how long a given impact may persist. Recovery may be episodic, driven by highly variable weather cycles, and steady-state recovery of shallow surface lag deposits to natural surface at a constant rate. In general, the effects of casual and infrequent visitor trampling and off-road travel activity are known to diminish in many settings, given wind, gravity, as well as wet years of storm-burst sheet-wash, deep snowpack, frost-heave, and snow melt. Thus, there is an imprecise understanding of the thresholds that drive enduring impacts to the underlying pristine Sunset Eruption Ash-fall units. At the current resolution and accuracy, repeat LiDAR imagery will be needed periodically to compare and identify topographic alterations exceeding 10 cm (6 in) or more in depth. The unique volcanic feature inventory provides a baseline for further monitoring, via ocular and repeat photographic estimates to assess change in overall shape, alteration of surface texture, removal or loss of surface material that comprises these localized lava spatter, injection, or flow features. However, at this time there are no repeat data to determine trend.

Under the assessment framework applied to the volcanic resources, there is confidence that their degradation is unidirectional, meaning unique volcanic features do not recover to good condition from fair or poor condition.

For other reasons described in Whitefield et al., *in press*, the potential subjective nature of the baseline RIA (Hansen 2014), and short-term record of condition evaluations on anecdotal-based examples

Table 4.6.4-3. Summary of volcanic resources indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Volcanic Landforms	Estimated Percentage of Persistent Surface Alteration		Nine out of 11 volcanic landforms are rated in pristine or good condition, therefore, the condition rating for this measure is good. Confidence level is low and trend is currently unknown.
Unique Volcanic Features	Relative Percentage of Altered Inventoried Eruption Features		More than 95% of unique volcanic features are rated in pristine or good condition, therefore, the condition rating for this measure is good. Confidence level is medium and trend is currently unknown.
Overall Condition			Most of the volcanic resources within the Resource Management Preservation Zone remain in pristine to good condition. The impacts that are occurring are located within visitor use and transportation zones, but monument staff consider minor to moderate impacts to volcanic resources in these areas as acceptable, especially since they are relatively rare and isolated. Some areas are also locally impacted by cross-boundary recreational use from adjacent lands, but this activity is occurring within more resilient, vegetated cinder terrain and not in proximity to rare or sensitive volcanic resources. Overall, the volcanic resources are in good condition, although confidence is low and trend is unknown.

of a large amount of observations, a confidence level of low is assigned for the volcanic landforms condition, medium for the unique volcanic features condition, and low for the overall confidence level rating for volcanic resources within Sunset Crater Volcano NM.

The conclusions for this assessment are based on a combination of data from several sources, acquired at various scales, and ranging from site-specific observations to landforms mapped using remote imagery, and using methods ranging from thorough and repeatable to rapid observations.

The conditions assigned for small-scale, unique volcanic features is based upon one-time field observations by resource managers, science technicians, and university students. Estimates were made rapidly in the field or from viewing photographs. Human ocular estimates of the amount of physical surface alteration or damage to unique volcanic features may be difficult to make on a repeatable basis. To maintain as much consistency in repeat data as possible, the selected condition classes were intentionally kept to a minimum (three), which should be repeatable with some measure of confidence. Error in ocular estimates is most probable where impacts are subtle or the measured impact level is near the break between given sets of classes. Each unique volcanic feature was also photographed, to provide information that is more objective for monitoring. However, a range of issues is also identified with repeat photography, including focus, depth of field, time-of-day, season-of-year, etc.

Fully objective methods are unavailable for quantifying impacts – ground-based LiDAR scanning of features or latest digital photogrammetric techniques have not been pilot tested on volcanic spatter or agglutinate deposits, or lava flow outcrop. These would support more robust condition assessment, but are time and cost prohibitive. Hansen acknowledges in his RIA report that the determination of the intensity level for impacts is somewhat subjective, particularly for lower intensity impact classes, and may lack a level of precision required for repetition and comparison.

The original Sunset Crater Trail route was not thoroughly documented by the NPS, nor were the conditions of trail and the purported erosion impacts to western slope of the Sunset Cinder Cone at the time it was closed and rehabilitated. The 15° slope threshold for identifying slopes more vulnerable to recreational impacts and erosion was established subjectively following technical guidance provided by NRCS and NPS (2014), and is based upon observations of chronic erosion and maintenance problems observed from 2002 through 2016 on the Lenox Trail.

<u>Threats, Issues, and Data Gaps</u>

For these physical resources, few threats are identified beyond those given and described in this assessment. A trend of increasing visitation, if coupled with insufficient communications to visitors about the appropriate levels of recreational activity in areas of rare and fragile resources, is likely the greatest stressor. Monument staff is aware that unmanaged cross-country hiking is occurring in some areas where access to park lands is being gained by crossing the boundary fences from the surrounding Coconino National Forest. Evidence of unauthorized off-road vehicle travel, presumably from adjacent lands and across the Sunset Crater Volcano NM boundary, was evident and mapped on aerial imagery acquired during the late 1990s. While this activity appears to have declined over the last 15 years (Whitefield, pers. obs.), isolated off-road travel incidents continue to occur occasionally along the main Sunset Crater Volcano NM access road.

The monument's understanding of permanence versus resilience of trampling impacts on volcanic cinder substrates is particularly problematic. There is some scientific understanding of impacts on vegetation recovery in heavy visitor use areas, but an improved understanding of the effects of continuous human activity on soils development and preserving the integrity of the underlying volcanic cinder and ash-fall units is warranted

The Geological Monitoring manual (GSA 2009) should be reviewed for additional methods and datasets that may applicable to monitoring condition and trend within Sunset Crater Volcano NM. The chapters on monitoring aeolian features (Chapter 1), cave features (Chapter 2), and slope movements (Chapter 11) may be relevant.

4.6.5. Sources of Expertise

This volcanic resources condition assessment was excerpted from an unpublished manuscript submitted in June 2017 by Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs and edited by Phyllis Pineda Bovin, NPS IMR NRCA Coordinator and P. Whitefield. Michael M. Jones, GIS Specialist Flagstaff Area NMs, prepared GIS maps used in the figures, and completed the GIS analysis to derive landform area statistics. Whitefield relied heavily on the background information, data, and results summarized in Whitefield et al., *in prep*, and upon the GIS data developed by Hansen (2014).

4.7. Ponderosa Pine (*Pinus ponderosa*) and Pinyon-Juniper (*P. edulis-Juniperus* spp.)

4.7.1. Background and Importance

Sunset Crater Volcano National Monument (NM), located 29 kilometers (km; 18 mi) northeast of Flagstaff, encompasses 1,230 hectares (ha; 3,040 ac) of land dominated by a volcanic landscape. Lands surrounding the national monument consist largely of the Coconino National Forest (NF), managed by the U.S. Forest Service (USFS). The landscape and vegetation in the vicinity of the monument are diverse and include largely unvegetated beds of cinder or lava and rock outcrops, grassy meadows, open tree stands, and dense forests (Hansen et al. 2004). The 2,447 m (8,029 ft) high Sunset Crater cinder cone is one of the main features within the national monument (Figure 4.7.1-1). It is the youngest, least-eroded cinder cone in the San Francisco Volcanic Field (Hansen et al. 2004), and its eruption around 1080 A.D. (Elson et al. 2007) left much of the national monument's ground surface covered by lava flows or deep volcanic cinder deposits. The Bonito Lava Flow covers more than one-quarter of the surface area within the monument (NPS 2009). Overall, the vegetation has been described as relatively sparse, except for the north- and east-facing slopes of the cinder cones (Eggler 1966, NPS 2009).

Woodlands (with relatively open forest canopies) are the predominate vegetation type in the national monument and surrounding area (Hansen et al. 2004), with ponderosa pine *(Pinus ponderosa*) being the most common tree species, followed by pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*; Hansen et al. 2004). Ponderosa pine woodlands are usually found on cinder soils within the monument, and can be found on most landforms, except at the highest elevations and on the driest, south-facing slopes (Hansen et al. 2004). Canopy cover in the ponderosa pine woodlands within Sunset Crater NM is relatively sparse compared to other ponderosa pine associations throughout their range due to limits on tree establishment and growth rates in the volcanic environment (Hansen et al. 2004). The ponderosa pine communities within the monument tend to have little to no understory cover. Pinyon pine and juniper trees are more common (mixed with ponderosa pine) in the eastern and northern portions of the national monument (NPS 2009). Because areas dominated by pinyon pine and juniper compose such a small proportion of the national monument (< 1 percent of woodland types), this assessment focuses primarily on ponderosa pine communities.

The vegetation of Sunset Crater Volcano NM has been the focus of some inventory and research efforts. These efforts include a floristic inventory and other sampling

Figure 4.7.1-1. The north slope of Sunset Crater cinder cone, with woodlands dominated by Ponderosa pine. Photo Credit: NPS.

studies in the late 1970s (Bateman et al. 1976, 1978, 1980), a study of plant succession after eruption of the volcano (Eggler 1966), and a project to inventory, classify, and map the monument's vegetation alliances and associations (Hansen et al. 2004). At least 166 plant species have been documented within the national monument (NPS 2009).

In general, ponderosa pine habitats are of considerable value to wildlife. At least 250 species of vertebrates inhabit ponderosa pine forests in the Southwest (Allen et al. 2002). Patton et al. (2014) reported 48 mammals, 111 birds, and 47 amphibians and reptiles, as well as 422 arthropods in their database of species found in Arizona ponderosa pine forests. Wildlife species using these habitats include the Abert's squirrel (*Sciurus aberti*; Hansen et al. 2004), a conspicuous inhabitant of ponderosa pine forests on the Southern Colorado Plateau (Figure 4.7.1-2). This species, which is known to occur in the monument, feeds on ponderosa pine seeds and the tree's cambium layer, and uses the tree for shelter and nesting. Other species use these forests, such as deer, elk, bears, raccoons, skunks, rabbits and hares, rats, mice, voles, and bats (Patton et al. 2014). Many different bird species also use ponderosa pine habitats, such as Steller's Jay (*Cyanocitta stelleri*), brown creeper (*Certhia americana*), white-breasted nuthatch (*Sitta carolinensis*), dark-eyed junco (*Junco hyemalis*), and western tanager (*Piranga ludoviciana*). Each of these birds is known to occur at Sunset Crater Volcano NM (NPS 2016b). Lists of mammals, birds, and reptiles that have been recorded in the national monument (not just in the ponderosa pine woodlands) are presented in Appendix A of the NRCA report.

Figure 4.7.1-2. Abert's squirrel (*Sciurus aberti*), one of the wildlife species known to use ponderosa pine forests. Photo Credit: © Robert Shantz.

4.7.2. Data and Methods
To assess condition of ponderosa pine and pinyon-juniper woodlands at Sunset Crater Volcano NM, we used three indicators with a total of three measures. We based the assessment on several studies and reports for the national monument, especially the mapping project of Hansen et al. (2004), the 2009 Fire Management Plan (FMP; i.e., NPS 2009), and information from the USFS's Forest Health Monitoring Program on insect pests (Potter and Conkling 2016). Studies by Bateman et al. (1980) and Eggler (1964) were also used. It is important to note that there is a lack of basic data on ponderosa pine age/size classes and the presettlement fire regime in these woodlands (NPS 2009).

<u>Total Area Covered</u>
Of 16 map classes used during the vegetation mapping project at the national monument, seven were dominated by ponderosa pine, pinyon pine, and/or Utah juniper vegetation (Hansen et al. 2004). For example, the three of the seven with the greatest coverages within the monument are Ponderosa Pine / Apache Plume Woodland, Ponderosa Pine / Apache Plume Woodland (Sparse), and Ponderosa Pine / Cinder Woodland. The total areas of each of the seven map classes and their distributions within the national monument are discussed in the Condition section.

Total area covered is more of a descriptive measure on the occurrence of ponderosa pine and pinyon-juniper vegetation in the national monument. We have no data on the overall coverage other than that provided by Hansen et al. (2004), more than a decade ago. However, there have been few specific concerns expressed for this vegetation, other than the more general threats discussed in the Threats and Issues section of the assessment (e.g., from drought conditions, high temperatures [due to climate change], severe/uncharacteristic wildfire, and forest pests/disease).

Departure from Natural Historical Fire Regime:
Ponderosa pine forests have existed in northern Arizona for at least 4,000 years (Cole 1990 as cited by Menzel 1996). Over this time, the ponderosa pine has adapted to conditions in its environment, including frequent wildfires. Fire is an important natural process within much of the landscape surrounding all three Flagstaff Area NMs (NPS 2009). Surface fires of low severity occurred in ponderosa pine forests on the order of every 2-26 years (Reynolds et al. 2013). For the period from about 1700-1880, Knox (2004) calculated an average fire return interval of 8.2 years (with a range of 1 to 11 years) for ponderosa pine forests at Walnut Canyon NM (excluding fires recorded only on single trees). These fires served to maintain forest composition, structure, and spatial patterns (Reynolds et al. 2013). They seldom killed large trees but maintained an open forest structure by thinning out regenerating vegetation.

European settlement in the middle to late 1800s, however, brought changes to the ponderosa pine forests due to fire suppression, logging activities, and the introduction of exotic species (Allen et al. 2002). In general, old-growth trees have decreased, thick stands of young trees are common, in some places species composition has shifted, grasses and forbs in the understory have declined in diversity and abundance, and in some cases, wildlife species are thought to have declined in abundance due to habitat changes (Allen et al. 2002). These forests are now more vulnerable to large, stand-replacing crown fires that represent a threat to both ecological communities and human communities (Allen et al. 2002). However, efforts have been underway to restore the ecology of Southwestern ponderosa pine forests (e.g., Moore et al. 1999, Allen et al. 2002, Ecological Restoration Institute 2005, Reynolds et al. 2013).

The natural fire return interval for the ponderosa pine and pinyon-juniper woodlands on the young

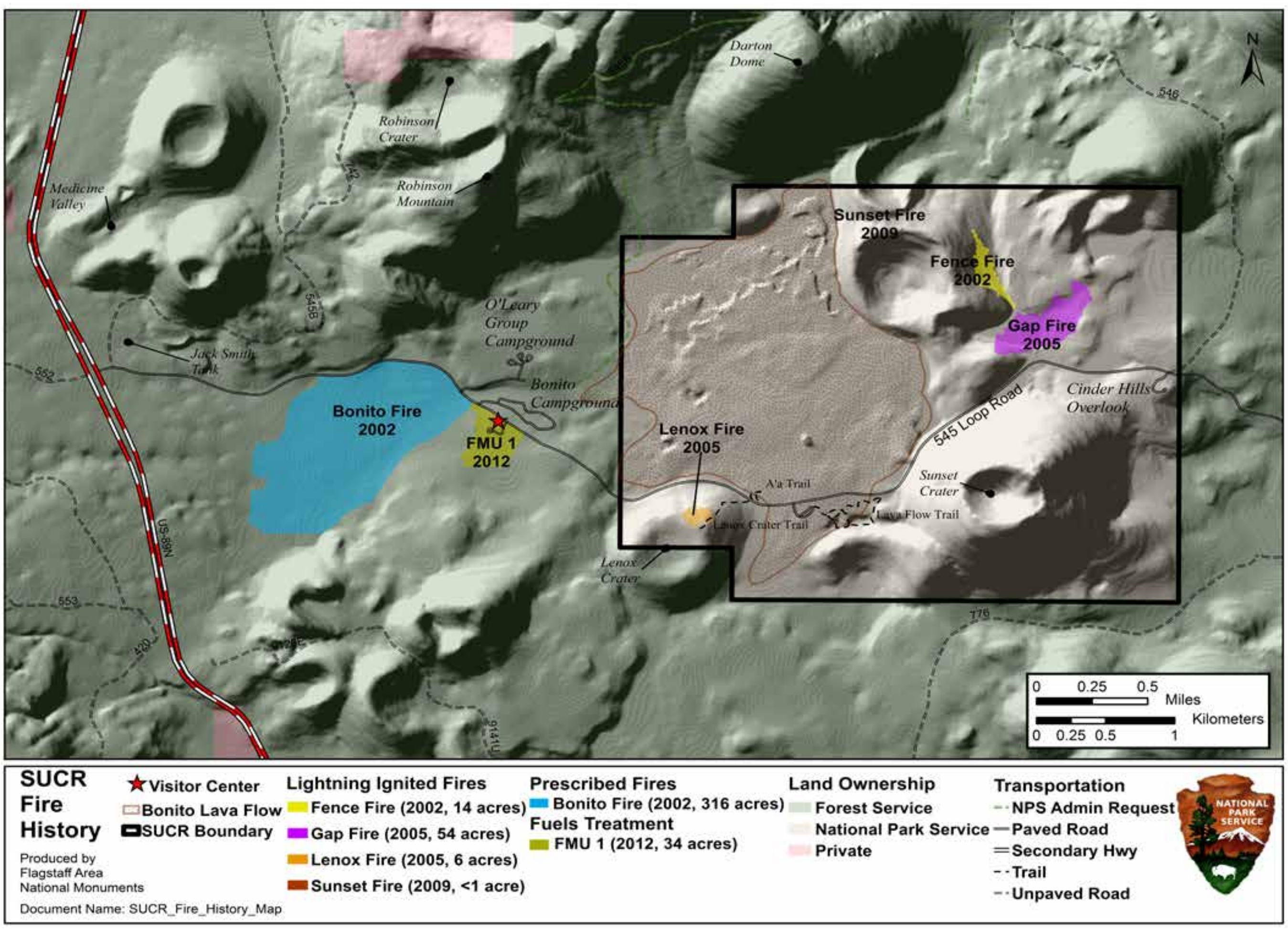


Figure 4.7.2-1. Fire occurrence at Sunset Crater Volcano NM from 2002-2012. Figure Credit: Flagstaff Area NMs.

volcanic terrain within Sunset Crater Volcano NM is probably longer than for the more typical ponderosa pine vegetation described above (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.). This is because of the naturally barren cinder understory, patchy distribution of trees, and natural firebreaks on the recent lava flows. However, lightning-ignited fires have occurred within the national monument in recent years (Figure 4.7.2-1). The Foundation Document for the monument (NPS 2015a) expresses concern for an unnaturally severe fire impacting the stands of ponderosa pine trees growing on the cinder barrens and volcanic slopes. Figure 4.7.2-1 shows fires that have occurred within the monument since 2002, including both lightning-ignited and prescribed fires. In addition to what is shown on the figure, there were four additional fires during 2015-2016, but they were all single tree lightning strikes (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.). Also, going a bit further back in time, the FMP for the monument reported that 55 fires occurred within and next to the monument boundary from 1957 to 2009, with 43 of them being lightning ignitions (NPS 2009). A few of the more recent fires (Fence Fire (2002) and Gap Fire (2005)) showed that even in the relatively barren volcanic terrain, fire can travel when wind and other conditions are conducive (NPS 2009).

Fire Regime Condition Class

We based this measure on the results of a Fire Regime Condition Class (FRCC) analysis conducted by the NPS (2009). The NPS conducted the FRCC analysis as part of its fire management planning process. The analysis "characterizes the degree of historic change in vegetation as a result of the disruption from its natural fire regime. The results can help identify appropriate management strategies and can help prioritize areas for restoring vegetation and natural ecological process" (NPS 2009). The NPS conducted the initial assessment in 2003 using the vegetation maps from Hansen et al. (2004).

It is important to note that although we included this measure based on the FRCC analysis in our assessment, more recent monument documents (i.e., NPS 2015a) report that fire history data for ponderosa pine stands within the national monument are needed to update the FMP, "including completing an accurate fire regime condition-class assessment and predicting potential wildland or prescribed fire severity." Because of this needed update, we have only low confidence in the measure. We included the measure in the overall assessment because of its importance, even if it needs to be re-evaluated. NPS (2009) separated the national monument's fire-prone vegetation types into one of five natural historical fire regime categories with related fire return intervals and burn severity descriptions. The ponderosa pine vegetation in the national monument fell into fire regime I, with a fire return interval of 0-35 years and a burn severity of low.

Ponderosa pine (including pinyon-juniper) vegetation at the national monument was also separated into two vegetation-wildland fuel types. These two types are 1) ponderosa pine with patchy shrub-herbaceous understory and needlecast, and 2) ponderosa pine with contiguous shrub-herbaceous understory and needlecast. Each type consists of two to three different map classes from Hansen et al. (2004; Table 4.7.2-1).

Extent of Conifer Mortality

Within nearby Walnut Canyon NM, a substantial, but unmeasured, proportion of conifers died in the early to mid 2000s, starting around 2002 (NPS 2009). This mortality included older ponderosa and pinyon pine trees in the ponderosa-pinyon-juniper ecotone of the monument, older trees in the pinyon-juniper woodlands, and patches of mature Douglas-fir (*Pseudotsuga menziesii*) on north-facing slopes of the canyon. During these same years, fewer younger/small diameter trees died in Sunset Crater Volcano NM compared to in Walnut Canyon NM and other areas (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.). The purpose of this measure is to examine the extent of recent conifer

Table 4.7.2-1. Fire management planning cover classes for Sunset Crater Volcano NM.

Vegetation-Wildland Fuel Type	Corresponding Hansen et al. Vegetation Map Classes *
Ponderosa Pine with Patchy Shrub-Herbaceous Understory and Needlecast	Ponderosa Pine/Apache Plume Woodland (including Pinyon, and Sparse); Pinyon Pine-Utah Juniper/Blue Grama Woodland (Sparse)
Ponderosa Pine with Contiguous Shrub-Herbaceous Understory and Needlecast	Ponderosa Pine/Cinder Woodland; Ponderosa Pine/Sand Bluestem Woodland; Sand Bluestem Herbaceous Vegetation

* Some map classes adjacent to but outside of the monument may be included.

Source: NPS (2009).

mortality within the monument based on information from the USFS's Forest Health Monitoring Program.

Tree mortality has increased across the western U.S. (van Mantgem et al. 2009). For example, in northern Arizona, mortality was monitored in ponderosa pine and mixed-conifer forests from 1997-2007 (Ganey and Vojta 2011). These researchers found that mortality occurred on nearly all of their 1-ha (2.5-ac) ponderosa pine and mixed-conifer plots (98 and 100%, respectively). In most cases the mortality was due to forest insects attacking drought-stressed trees. The number of ponderosa pine trees that died from 2002 to 2007 was 74% greater than the number that died in the earlier years of the study; the proportions were even greater in the mixed-conifer forest. For both forest types, the magnitude of mortality varied spatially, and the largest size classes were affected the most, especially in the mixed-conifer forest.

To assess condition under this measure, we used data from the USFS Forest Health Monitoring Program (USFS 2004, 2005, 2007, 2013, 2014a, 2014b, 2016). The FHM Program conducts annual aerial detection surveys across the United States to document tree mortality as a result of bark beetle infestation and other insects and diseases (Potter and Conkling 2016). Surveyors document visible damage to tree crowns and identify, when possible, the damage agent, usually by identifying the host-tree species (Potter and Conkling 2016). The information used in the assessment was from 2001-2006 (encompassing a period of documented mortality in nearby Walnut Canyon NM) and 2012-2015, the most recent several years. Supporting information was also used for 2008-2011 from a USFS dataset provided by Flagstaff Area NMs.

Bark beetles (Coleoptera: Curculionidae, Scolytinae) are a group of native insects composed of many species that live between the bark and wood of host trees and feed on the tree's phloem tissues (Bentz et al. 2010). Their feeding habits interrupt the flow of nutrients and water in the tree, eventually leading to tree death. Bark beetles preferentially attack weakened trees. Although bark beetle outbreaks are a natural ecosystem process, climate change has increased drought stress on western coniferous forests, making many millions of hectares of trees available to bark beetle infestation (Bentz et al. 2010). Widespread bark beetle infestation may have undesirable effects on vegetation structure and composition, fire behavior and occurrence, and carbon storage (Jenkins et al. 2012, Ghimire et al. 2015, and Potter and Conkling 2016).

Table 4.7.3-1. Reference conditions used to assess ponderosa pine-pinyon-juniper vegetation in Sunset Crater Volcano NM.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Ponderosa Pine-Pinyon-Juniper Vegetation Occurrence	Total Area Covered within National Monument	No reference conditions were developed.	No reference conditions were developed.	No reference conditions were developed.
Fire Regime	Departure from Natural Historical Fire Regime: FRCC	Fire regimes are within an historical range, and the risk of losing key ecosystem components is low. Vegetation attributes (species composition and structure) are intact and functioning within an historical range.	Fire regimes have been moderately altered from their historical range. The risk of losing key ecosystem components is moderate. Fire frequencies have departed from historical frequencies by one or more return intervals (either increased or decreased). This results in moderate changes to one or more of the following: fire size, intensity and severity, and landscape patterns. Vegetation attributes have been moderately altered from their historical range.	Fire regimes have been significantly altered from their historical range. The risk of losing key ecosystem components is high. Fire frequencies have departed from historical frequencies by multiple return intervals. This results in dramatic changes to one or more of the following: fire size, intensity, severity, and landscape patterns. Vegetation attributes have been significantly altered from their historical range.
Status / Health of Trees	Extent of Conifer Mortality	Current extent of conifer mortality in the national monument is small or nonexistent.	Current extent of conifer mortality in the national monument is relatively small to moderate.	Current extent of conifer mortality in the national monument is moderate to substantial and/or is increasing.

4.7.3. Reference Conditions

Table 4.7.3-1 summarizes the condition thresholds for measures in good condition, those warranting moderate concern, and those warranting significant concern. No specific reference conditions were developed for the first indicator/measure, that of ponderosa pine-pinyon-juniper vegetation occurrence (total area covered) within the national monument. For the second indicator/measure, the reference conditions correspond to those used by NPS (2009) for the fire regime condition class analysis. Reference conditions for the third indicator/measure are general (and qualitative) in nature.

In this section of the assessment we also present information on two topics (logging and plant succession), which may be useful in understanding the ponderosa pine-pinyon-juniper vegetation within the national monument. We present information on logging that occurred in the general and immediate area in the 1900s, as well as information on plant succession after the eruption of Sunset Crater Volcano.

Logging Activities, late 1800s - 1970s

Intensive logging in northern Arizona started in the 1880s, which was when the transcontinental railway was developing (Stein 1993 as cited in DeYoung no date). Local and national markets, which lasted into the 1930s, were created due to the railway. The industry, however, began to decline in the 1940s because most of the "good" timber had been removed from the Coconino and Kaibab National Forests. Although several logging companies carried out operations in the area, the Arizona Lumber and Timber Company (AL&T) was the main company logging around Sunset Crater Volcano and Walnut Canyon NMs. From 1889-1937, the AL&T ran the Central Arizona Railway (CAR), which enabled relatively quick access to stands of timber. Lenox Crater and adjoining areas of Sunset Crater were logged using the railway in 1916 and 1917. Areas around Walnut Canyon NM were logged using the railway around 1922-1923.

DeYoung (no date) reported no apparent logging around the monuments in the 1930s and 1940s. In the 1950s and 1960s, timber activities on the Coconino NF near the national monuments were mainly related to the sale of dead or dying trees. After a fire in 1974, timber was salvaged in areas north, northwest, west, and south of Sunset Crater Volcano NM.

Plant Succession on Sunset Crater

Sunset Crater erupted around 1080 A.D. (Elson et al. 2007). According to Eggler (1966), the processes of soil production and plant invasion to the summit of the cinder cone and on the lava flows "have not progressed very far" since the eruption. Vegetation was thought to have been entirely destroyed within at least a 3.2-km (2-mile) radius from the base of the cone, and much of the area is still largely unvegetated. Within the national monument, plants are distributed irregularly on the cone and flows, with the main location of continuous soil and vegetation cover being the lower half of the north slope of the Sunset Crater cinder cone.

The weathering rate of the ash and cinders produced by the eruption is slow, and that for the lava is "insignificant" (Eggler 1966). Climates with long winters, short summers, and low levels of precipitation are not particularly favorable for the weathering of volcanic material. Eggler (1966) noted that more vascular plants will establish once weathering of the ash and cinders on the cone occurs, and once aeolian material is carried to the flows. On the cone, weathering occurs more rapidly after vegetation has established. According to Eggler (1966) soil is most developed in the densest pine woodlands, where pine litter helps to retain moisture, which in turn facilitates breakdown of the ash and cinders.

This researcher conducted a study in 1964, which included vegetation transects on the north and south sides of Sunset Crater volcano, and two transects on the lava flows west of the cinder cone (the Bonito Flow). He identified plant species and their densities along the transects. Eggler (1966) reported that vascular plants on the lava flows occur primarily where deposits of ash and cinders occur, as the aeolian material provides both a reservoir for water and anchorage for the plants. Based on his field sampling, he found that the most plants occurred on flows where ash coverage was 50%; where ash coverage was 1-2%, the fewest plants occurred.

Some specific results of Eggler's sampling of the two transects on the Sunset Crater cinder cone are presented in the Condition section (also reported in Eggler 1964). On the cinder cone, the most trees grow on the lower portion of the north slope. At the time of Eggler's work, some of the ponderosa pine trees in this area were as old as 430 years. Assuming at least some of these trees are still alive today, they are about

480 years old. His study in this area also indicated that from the base of the slope to the timberline, trees became less dense, smaller, and younger. Near the timberline, the maximum age of the trees in 1964 was about 50 years. Eggler (1966) suggested that the trees towards the timberline have a shorter life span, as he observed dead and dying trees in this area. On the rest of the cinder cone, trees grow more sparsely, if at all. The south side has almost no trees.

Eggler (1966) compared the vegetation occurring on the Sunset Crater cinder cone and lava flows to the vegetation on a nearby, older cinder cone (Cone 48). This cone is completely forested and dominated by ponderosa pine on the north slope, and by pinyon pine and ponderosa pine on the south slope. Eggler suggested that the Sunset Crater cone will most likely develop a similar forest with time, and that the lava flows will also support a ponderosa pine forest.

4.7.4. Condition and Trend

<u>Total Area Covered</u>

Seven map classes used by Hansen et al. (2004) to map the vegetation in the national monument were dominated by ponderosa pine, pinyon pine, and/or Utah juniper. These map classes and the areas they cover within Sunset Crater Volcano NM are shown in Table 4.7.4-1. As noted in the Background and Importance section, the woodland area dominated by pinyon-juniper is very small within the monument (i.e., 2 ha [4.9 acres], or <1 percent of the woodland types). The three map classes with the greatest coverages within the monument are Ponderosa Pine / Apache Plume Woodland, Ponderosa Pine / Apache Plume Woodland (Sparse), and Ponderosa Pine / Cinder Woodland, respectively. The distribution of all seven of these vegetation map classes is shown in Figure 4.7.4-1. Ponderosa pine trees may also occur in some of the other map classes used by Hansen et al. (2004).

Ponderosa Pine / Apache Plume Woodland (including its modifiers, Sparse and Pinyon) is one of the most common vegetation associations within the national monument and environs (Hansen et al. 2004). It is found on level cinder areas and cinder slopes in the eastern portion of the monument. The most abundant plant species in the association are ponderosa pine and Apache plume (*Fallugia paradoxa*), although a number of additional species may also occur. These may include, among others, Utah juniper, pinyon pine, Douglas-fir, sand bluestem (*Andropogon hallii*), blue grama (*Bouteloua gracilis*), rabbitbrush (*Ericameria nauseosa*), and wax currant (*Ribes nauseosa*) (Hansen et al. 2004). Based on Hansen et al.'s sampling plots within and outside of the monument, total vegetation cover for the association ranged from 9-55% cover (and averaged 24%). Absolute cover of the tree layer ranged from 9-55% (and averaged 24%); that of the shrub layer ranged from 1-43% (averaged 6%); and that of the herbaceous layer ranged from 1-20% (averaged 4%). Ponderosa pine trees measured had a diameter at breast height (DBH) ranging from 11-85 cm (4.3-33.5 in; average 34 cm [13.4 in]).

Ponderosa Pine / Cinder Woodland is also one of the most common associations in the monument and vicinity (Hansen et al. 2004). It is found on level and steeply-sloped cinder areas, including in lower elevations on the north side of Sunset Crater cinder cone. A number of species may be found with ponderosa pine in this association, including (but

Table 4.7.4-1. Ponderosa pine and pinyon-juniper map class occurrence in Sunset Crater NM.

Map Class Common Names	Map Class National Vegetation Classification Standard Name	Total area within NM: ha (acres)
Pinyon Pine - Utah Juniper / Blue Grama Woodland	*Pinus edulis* - (*Juniperus osteosperma*) / *Bouteloua gracilis* Woodland	2 (4.9)
Ponderosa Pine / Cinder Woodland	*Pinus ponderosa* / Cinder Woodland	93 (229.8)
Ponderosa Pine / Montane Grass Mosaic	*Pinus ponderosa* / *Muhlenbergia montana* Woodland, *Pinus ponderosa* / *Bouteloua gracilis* Woodland	3 (7.4)
Ponderosa Pine / Apache Plume Woodland (Sparse)	*Pinus ponderosa* / *Fallugia paradoxa* Woodland	115 (284.2)
Ponderosa Pine / Apache Plume Woodland	*Pinus ponderosa* / *Fallugia paradoxa* Woodland	238 (588.1)
Ponderosa Pine / Apache Plume Woodland (Pinyon)	*Pinus ponderosa* / *Fallugia paradoxa* Woodland	1 (2.5)
Ponderosa Pine / Sand Bluestem Woodland	*Pinus ponderosa* / *Andropogon hallii* Woodland	15 (37.1)
Total area for these woodland types	N/A	467 (1,154)

Source: Hansen et al. (2004).

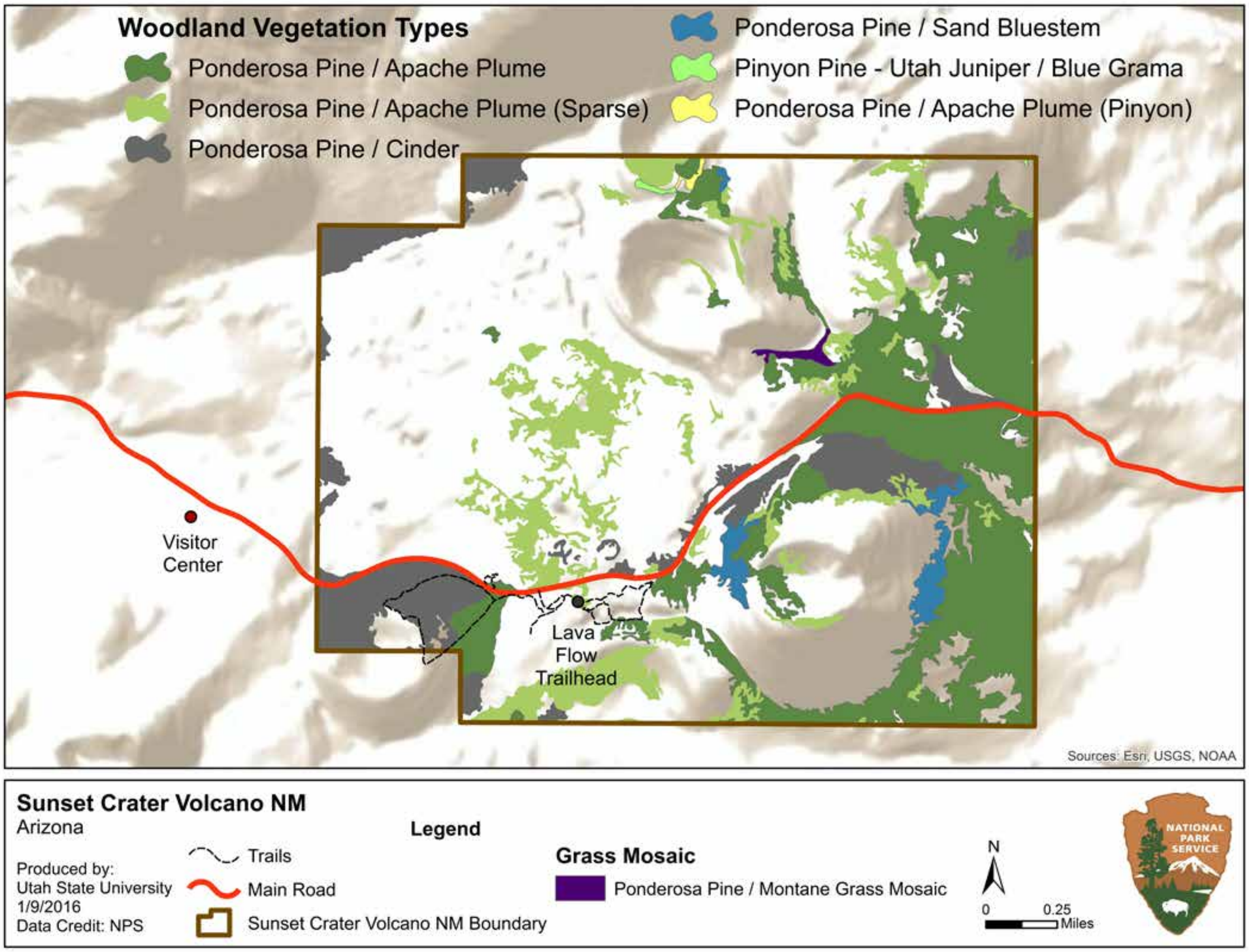


Figure 4.7.4-1. Ponderosa pine and pinyon-juniper woodland types at Sunset Crater Volcano NM according to the vegetation mapping project for the monument.

not limited to) pinyon pine, sand bluestem, blue grama, brickellbush (*Brickellia californica*), squirrel tail (*Elymus elymoides*), rabbitbrush, Apache plume, mountain muhly (*Muhlenbergia montana*), and wax currant (Hansen et al. 2004). Total vegetation cover for the association ranged from 21-70% cover (average 36%). Absolute cover of the tree layer ranged from 19-55% (and averaged 32%); that of the shrub layer ranged from 0.5-10% (averaged 3%); and that of the herbaceous layer ranged from 0.5-20% (averaged 3%). Ponderosa pine trees measured had a DBH ranging from 11-99 cm (4.3-38.9 in; average 31 cm [12.2 in]) and heights from 5-30 m (16.4-98.4 ft; Hansen et al. 2004).

As noted in the Data and Methods section, this measure is more of a descriptive measure on the total area covered by ponderosa pine and pinyon-juniper woodlands in the national monument. We have no current (or older) data on areal coverage to compare for changes over time. However, no specific concerns have been reported in monument reports or by monument personnel for these woodlands, other than the more general threats from drought conditions, high temperatures [due to climate change], severe/uncharacteristic wildfire, and pests/disease. Therefore, we consider current condition to be good. However, we have low confidence in the measure. We do not consider confidence low because we have little confidence in the estimated area covered; instead, it is because this is not a typical measure of condition. Based on Hansen et al. (2004), a total of about 467 ha (1,154 ac) of ponderosa pine and pinyon-juniper woodlands occur in the monument. Trends are unknown.

Additional Information

We also present additional information on these ponderosa pine woodlands from Eggler (1964) and Bateman et al. (1978 and 1980), which may be of interest. Both Eggler (1964) and Bateman et al. (1980) sampled the vegetation in ponderosa pine woodland transects running up/down the north and south slopes of the Sunset Crater cinder cone. The same transects were sampled in these two efforts on the north slope, but Bateman et al. (1980) was unable to locate the exact transect used by Eggler on the south slope. The two studies were 14 years apart and used similar methods. On the north slope, the researchers used a 10 m (33 ft) wide transect that was 900 m (2,953 ft) long (Bateman et al. 1980). The transect was divided into 90, 10 m (33 ft) by 10 m plots. The transect ran from the summit of the crater to 200 m (656 ft) north of the crater base. Trees and shrubs were counted in the 10 m wide transect, and herbaceous plants were counted within a 2 m (6.6 ft) wide transect (within the larger transect).

In both studies, the dominant tree was ponderosa pine. Both studies also recorded pinyon pine and limber pine (*Pinus flexilis*), but as is discussed in detail in the next assessment on Sensitive and Vulnerable Tree Species, it now appears that the species reported as limber pine may actually be southwestern white pine (*Pinus strobiformis*; but this is currently uncertain). A fourth species, Douglas-fir, was reported by Bateman et al. (1980; just one tree), but not by Eggler (1964). Each study presented data by individual plot, but somewhat different measurements were reported in some cases (e.g., diameter size classes and total basal area by Eggler [1964], and percent cover for all tree species by Bateman et al. [1980]). In both studies, the first tree recorded (from the crater summit down) was located 380 m (1,247 ft) up from the base of the cone (at about 2,286 m [7,500 ft]; Bateman et al. 1980). For tree species, there were few differences in the data from the two years (Bateman et al. 1980). Figure 4.7.4-2 shows the tree line on the north slope in 2016. Bateman et al. (1980) indicated that the timberline position did not change from 1964 to 1978, and Eggler (1964) suggested that it might be fixed in its position.

Figure 4.7.4-2. Vegetation on the north slope of Sunset Crater Volcano with the tree line obvious. Photo Credit: © Patty Valentine-Darby.

The researchers also presented information on the dominant shrub and herbaceous species in the plots. The two dominant shrub species in both years were crispleaf buckwheat (*Eriogonum corymbosum* var. *aureum*) and Apache plume. The other shrub species recorded in the two studies were thorn skeletonweed (*Pleiacanthus spinosus* [= *Lygodesmia spinosa*]), wax currant, and rabbitbrush (1978 study only). Seventeen herbaceous species were recorded in both of the studies, with those species occurring in relatively high densities or in a relatively high number of plots including sand bluestem, *Artemisia* spp., blue grama, Fendler's sandmat (*Chamaesyce* [=*Euphorbia*] *fendleri*), Wright's bedstraw (*Galium wrightii [= rothrockii*]*)*, mountain monardella (*Monardella odoratissima)*, and Newberry's twinpod (*Physaria newberryi*). Five new species were reported in the 1978 study.

Bateman et al. (1980) also presented and compared the results of both studies on the south slope of the Sunset Crater cinder cone. Overall, Bateman et al. (1980) concluded that no rapid plant invasion was occurring on the north or south slopes based on the two studies. Although some differences had been observed, they could "easily be the result of environmental variability."

Bateman et al. (1978) also reported on the results of three "community map" transects sampled in ponderosa pine at the monument, but no map showing the location of these transects was presented in any of the three Bateman et al. (1976, 1978, 1980) reports. For this reason, we do not present any of their results here, but note that they presented information on all plant species that were recorded on the transects (combined), including absolute and relative cover, densities, frequencies, and importance values for each species.

Table 4.7.4-2. Fire regime condition class assessment results for ponderosa pine vegetation (including pinyon-juniper) at Sunset Crater Volcano NM.

Vegetation-Wildland Fuel Type	Total ha (acres) *	Fire Regime	Condition Class
Ponderosa Pine with Patchy Shrub-Herbaceous Understory and Needlecast	384 (948)	I	1
Ponderosa Pine with Contiguous Shrub-Herbaceous Understory and Needlecast	294 (726)	I	2

Source: NPS 2009.

* Note that the analysis by NPS (2009) included areas immediately adjacent to but outside of the national monument.

Departure from Natural Historical Fire Regime: Fire Regime Condition Class

There are two vegetation-wildland fuel types within the national monument that include ponderosa pine vegetation. Table 4.7.4-2 shows the FRCC results for the ponderosa pine-dominated areas within (and immediately adjacent to) the national monument (NPS 2009).

As seen in the table, a slight majority (57%) of the ponderosa pine vegetation at Sunset Crater Volcano NM was placed into condition class 1 in the 2003 assessment. This condition class corresponds to our reference condition of good. The remaining areas dominated by ponderosa pine vegetation were placed into condition class 2, which corresponds to a reference condition of moderate concern. As mentioned in the Data and Methods section, NPS (2015) reported that the FMP needs to have an updated FRCC assessment. Therefore, we have low confidence in this measure at the current time. The condition is good to of moderate concern and trends are unknown.

Additional Information

Another important aspect of the fire management program at the Flagstaff Area NMs is the Fire Management Unit (FMU). FMUs are geographic planning units for actual implementation of fire program activities (NPS 2009). Four FMUs have been designated within and immediately adjacent to the national monument, with ponderosa pine and pinyon-juniper vegetation falling into three FMUs (FMU-1, FMU-3, and FMU-4; Figure 4.7.4-3).

FMU-1 consists of "developed areas and areas of heavy visitor use within fire-prone vegetation where human safety and protection of public or private property are paramount values" (NPS 2009). FMU-3 includes areas that are believed to have experienced a frequent fire regime during the reference period based on the available information (but more information would be desirable). Prescribed fire may be considered within this FMU, pending additional information on reference period conditions. FMU-4 includes "areas with a variety of vegetation, fuels, fire regimes, resources at risk, and topographic features." This FMU includes areas that NPS "will either be required to or be able to manage with more passive strategies than the other FMUs" (NPS 2009). Management objectives, appropriate fire management strategies, and resource concerns and considerations are described for all of the FMUs at Sunset Crater Volcano NM.

Extent of Conifer Mortality

The USFS, as part of their Forest Health Monitoring Program, conducts annual forest insect and disease aerial detection surveys in the state. Data available from this program for Sunset Crater Volcano and Walnut Canyon NMs indicate that bark beetles affecting ponderosa pine, and to a much lesser extent Douglas-fir, were reported in a substantial area of the monuments combined in 2002-2003 (USFS 2004). According to USFS (2004), a total of 560 ha [1,383 acres] were affected in 2002, and a total of 749 ha [1,850 ac] were affected in 2003; tabular data provided by USFS (2004) listed all of this area occurring within Walnut Canyon NM, but it is uncertain whether data for the two monuments were reported in a combined fashion. An examination of USFS data sets provided by Flagstaff Area NMs (i.e., IDS_year_clipped data sets) indicated that ponderosa pine in both monuments experienced effects from bark beetles and drought in both years. This dataset indicated that forests/woodlands in Walnut Canyon NM experienced more insect/drought damage in 2002 compared to 2003, and that the reverse was true for Sunset Crater Volcano NM.

In 2004, a total of 206 ha (510 ac) of woody vegetation were reported as drought stressed in both monuments combined, with 78 ha [192 ac]) being reported within Sunset Crater Volcano NM (USFS 2004). Bark beetle activity in 2004 was reported at Walnut Canyon NM, but not at Sunset Crater Volcano NM (USFS 2004; IDS_year_clipped data sets). The GIS data set was

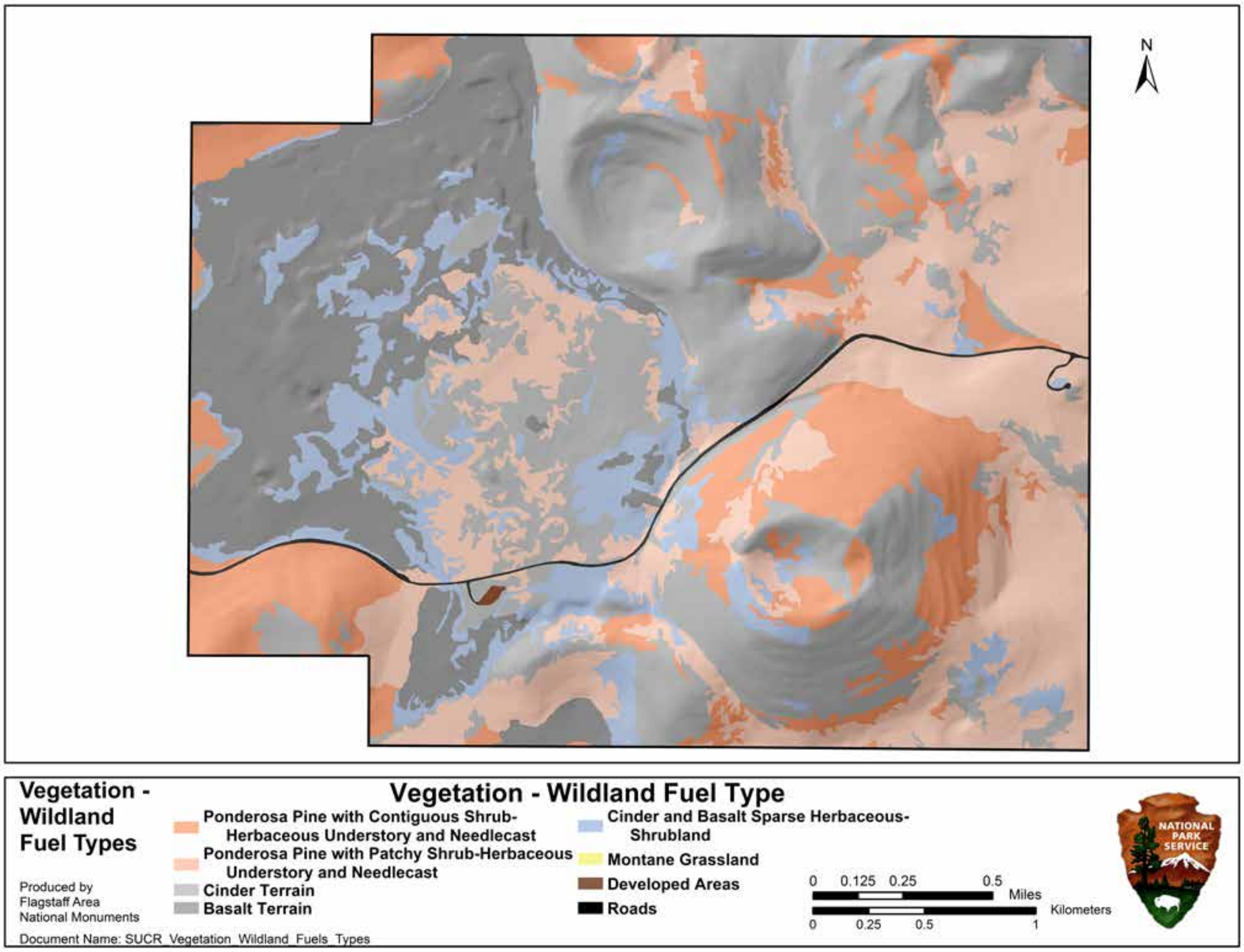


Figure 4.7.4-3. Wildland fuel types within Sunset Crater Volcano NM. Figure Credit: Flagstaff Area NMs.

provided to Paul Whitefield from Amanda Grady, USDA Forest Service, Forest Health Protection Program, Southwestern Region, Flagstaff, Arizona.

The area of ponderosa pine impacted by bark beetles had dropped to 0.4 or 0.8 ha (1 or 2 ac) for the monuments in 2005 and 2006 (USFS 2005, 2007). A regional drought occurred in the Southwest in the early 2000s, with particularly dry conditions occurring in 2002-2003 (Owen 2008).

The USFS dataset provided by the Flagstaff Area NMs (i.e., IDS_year_clipped data sets) showed that there were no insect or drought-affected woodland areas within Sunset Crater Volcano NM for 2008-2011. The most recent data available for the national monument, for 2012 to 2015, indicated low levels of bark beetle activity or drought stress. In 2012, no activity was reported for the monument (USFS 2013). In 2013, 14 ha (35 ac) of western pine beetle activity were mapped in ponderosa pine, with the occurrence reportedly associated with fire activity (USFS 2014a). In 2014, bark beetle activity was in <0.4 ha (<1 ac; USFS 2014b), and in 2015, activity in ponderosa pine was reported in < 2.0 ha (<5 ac; USFS 2016b).

Using our reference conditions, we consider this level of bark beetle activity and conifer mortality in the last several years to be good. The trend appears relatively unchanging over the last approximately eight years based on the information available, except for the area reported in 2013. However, this is a relatively short period of time, and some uncertainty exists concerning the exact area impacted in the early 2000s. We have moderate confidence in the assessment. The continuing threat of drought and climate change could lead to more drought stress and bark beetle attacks in the future.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Overall and based on the information available, we consider the condition of ponderosa pine and pinyon-juniper woodlands in Sunset Crater Volcano NM to be in good condition, but the confidence level is low. This condition rating was based on three indicators and measures, which are summarized in Table 4.7.4-3. Two measures were judged to be in good condition (total area covered by ponderosa pine and pinyon-juniper woodlands, and extent of conifer mortality), and one measure (fire regime condition class) was judged to be in good to moderate concern condition. Overall trends in condition are unknown.

There are several factors that influence confidence in the condition rating. The first is that recent data on these woodlands within the national monument is lacking. The most recent data and information available on areal coverage (and related information, such as percent cover) is from the vegetation mapping project (i.e., Hansen et al. 2004). No data are available on age/size classes for the stands. Also, as mentioned in the Foundation Document for the monument (NPS 2015a), an updated FRCC assessment is needed. Information on historic fire return intervals for the national monument's woodlands is considered a data gap. Also, although specific information for the monument on the area affected by bark beetles and/or drought stress was available for some years, including

Table 4.7.4-3. Summary of ponderosa pine and pinyon-juniper woodlands indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Ponderosa Pine-Pinyon-Juniper Vegetation Occurrence	Total Area Covered within National Monument		This measure was more of a descriptive measure on the occurrence (total area covered) of ponderosa pine and pinyon-juniper vegetation in the national monument (so we assigned it a confidence rating of "low"). Based on the 2004 vegetation map for the monument, there are a total of about 467 ha (1,154 ac) of ponderosa pine and pinyon-juniper woodlands in the monument. Although we have no more recent (or older) comparable data to compare areal coverage over time, we consider current condition to be good. No specific concerns have been expressed by monument reports or Flagstaff Area NMs personnel for these woodlands, other than the more general threats discussed in the Threats and Issues section. Trends are unknown.
Fire Regime	Departure from Natural Historical Fire Regime: Fire Regime Condition Class		There are two vegetation-wildland fuel types within the monument that include ponderosa pine and pinyon-juniper vegetation. According to the 2003 FRCC assessment, a slight majority of the vegetation was placed into condition class 1 (corresponding to a good condition), and the remaining areas were placed into condition class 2 (corresponding to a condition of moderate concern). Therefore, the condition under this measure is good to of moderate concern. However, because an updated FRCC assessment is needed (NPS 2015a), we have low confidence in the measure. Trends are unknown.
Status / Health of Trees	Extent of Conifer Mortality		It is unclear how large an area was affected by bark beetles and drought stress in the monument during regional, severe drought conditions in 2002-2003. However, in 2004, there were a total of 78 ha (192 ac) of woody vegetation reported as drought stressed. By 2005 and 2006, the area potentially affected by bark beetles was 0.8 ha (2 ac) or less. Recent data (2008-2015) for the monument indicated no or low levels of bark beetle activity or drought stress. The greatest area affected for these years was reported for 2013, believed to be associated with fire activity (USFS 2014a). Using our reference conditions, we consider conifer mortality in the last several years to be good. Trends are unknown but appear relatively unchanging from 2008-2015. Confidence is medium.
Overall Condition			This assessment was based on three indicators/measures. Overall, we consider the condition of ponderosa pine and pinyon-juniper woodlands in Sunset Crater Volcano NM to be good, but our confidence in the assessment is low. For two measures, the condition was good, and for one measure the condition was good to of moderate concern. Confidence in two of the measures was low, while that for one measure was medium. Trends are unknown.

the most recent several years, there was some uncertainty about the acreage affected in 2002-2003.

Threats, Issues, and Data Gaps

Some of the main threats to ponderosa pine and pinyon-juniper woodlands and forests within Sunset Crater Volcano NM and the region include drought, bark beetle infestations, and uncontrolled or severe wildfire. An overarching threat is from climate change (high temperatures and drought conditions). These are threats to all trees and ecosystem components within the forest, but they may be of particular concern for older, larger conifer trees. For example, during drought conditions in the early 2000s, large ponderosa pine trees suffered higher mortality than smaller ponderosa pines in Walnut Canyon NM (Monumenter et al. 2003). Greater mortality in larger size classes due to drought and bark beetles during this period was also reported by Ganey and Vojta (2011).

The western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall (Prein et al. 2016). NPS (2015) reports that the projected increase in mean annual temperature is 4-5 °F by 2050. Decreasing precipitation may be partially counteracted by increasing precipitation intensity (Prein et al. 2016). However, it may be more difficult for native plants to take advantage of short duration, intense precipitation events followed by long intervals of drought, and intense rainfall events may lead to increased soil erosion. Droughts are projected to be more intense and last longer in the coming century (Kent 2015).

Within Sunset Crater Volcano NM, "recent climatic conditions are already shifting beyond the historical range of variability" (Monahan and Fisichelli 2014). In their analysis for the monument vicinity, three temperature variables were found to be "extreme warm," (annual mean temperature, maximum temperature of the warmest month, and mean temperature of the warmest quarter), and three precipitation variables were found to be "extreme dry" (annual precipitation, precipitation of the driest month, and precipitation of the driest quarter) for the most recent period (2003-2012).

The Sunset Crater Volcano NM Foundation Document (NPS 2015a) acknowledged an increase in severity of wildfires in the region after more than a century of fire suppression and logging. It was further suggested that an unnaturally severe fire could result in substantial impacts to the stands of ponderosa pine trees on the volcanic slopes and cinder barrens (NPS 2015a). Information on the fire history in these woodlands (e.g., fire frequency and severity) is lacking (NPS 2015a), but it has been suggested that due to the very sparse to patchy understory, fire may have occurred less frequently in these stands than in ponderosa pine stands covering much of the region (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.). There is no land use history of livestock grazing in the monument and the much larger surrounding Cinder Hills area of the Coconino NF. There is no grass to graze, and the lands have long been classified as "unproductive" in the Coconino NF Plan (USFS 1987).

Fire activity might be influenced by climate change due to changes in fuel loading, changes in fuel condition (fuel moisture), and changes in fuel ignition (Hessl 2011 as cited by Kent 2015). Changes in fuel loading, for example, could occur due to mortality of trees and loss of vegetation cover, changes in regeneration patterns, range shifts, and disturbances such as severe fire and insect outbreaks (Kent 2015).

Some data gaps identified by Paul Whitefield, Natural Resource Specialist, include a need for basic and repeatable stand data to determine trend, either from a set of fixed reference plots, or from a statistically robust random sampling method. Basic metrics include tree size/age classes, densities, basal area, fire/lightning strike evidence, tree health (or perhaps growth form - a disproportionate amount of trees in the landscape appear to have abnormal growth forms but this has not been documented). Also improved documentation of any widespread mortality events that occur in the future.

4.7.5. Sources of Expertise

The assessment author is Patty Valentine-Darby, science writer, Utah State University. Lisa Baril, science writer, Utah State University, contributed text on bark beetles.

4.8. Sensitive and Vulnerable Tree Species

4.8.1. Background and Importance

Sunset Crater Volcano National Monument (NM) is located among hundreds of volcanic features (National Park Service [NPS] 2015). The 1,230-hectare (ha; 3,040-ac) park includes the approximately 2,447 m (8,029 ft) high Sunset Crater cinder cone (Figure 4.8.1-1), which is the youngest, least-eroded cinder cone in the San Francisco Volcanic Field (Hansen et al. 2004). The eruption of Sunset Crater Volcano was dated to around 1080 A.D. (Elson et al. 2007). Much of the national monument's ground surface is covered by lava flows or deep volcanic cinder deposits. The national monument may be most well-known for its sparsely vegetated cinder cones, lava beds, and lava rock outcrops (Hansen et al. 2004).

There is a diversity of vegetation within the monument and the surrounding environment (consisting of the Coconino National Forest immediately around the monument), including largely unvegetated beds of cinder or lava and rock outcrops, grassy meadows, open tree stands, and dense forests (Hansen et al. 2004). The vegetation in the national monument and surrounding area is dominated by woodlands (having open forest canopies; Hansen et al. 2004). Ponderosa pine (*Pinus ponderosa*) is the most common tree species in the area, with pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) also common (Hansen et al. 2004). The previous assessment in this document focused on the ponderosa pine and pinyon-juniper woodlands within the monument. Also within that assessment is a brief description of plant succession on Sunset Crater volcano (from Eggler 1966) and results of vegetational surveys conducted in 1964 (Eggler 1964) and 1978 (Bateman et al. 1980).

Some tree species within Sunset Crater Volcano NM are of particular interest because of their limited occurrence within the national monument, and because they generally depend upon cooler and more mesic (wet) conditions in order to establish and survive than the other tree species within the monument, making them more sensitive or vulnerable to disturbances and threats. These species are Douglas-fir (*Pseudotsuga menziesii;* Figure 4.8.1-2), quaking aspen (*Populus tremuloides;* Figure 4.8.1-3), and southwestern white pine (*Pinus strobiformis*). Note that in our assessment of southwestern white pine, we also discuss limber pine (*Pinus flexilis*). As described in greater detail below, there has been some confusion and uncertainty as to which species, or whether both species, occur within the national monument (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.). Threats to these trees, which occur in low

Figure 4.8.1-1. View of Sunset Crater and its vegetation from the Lava Flow Trail. Photo Credit: © Patty Valentine-Darby.

numbers within the national monument, are related to drought stress, increasing air temperatures, severe or uncharacteristic wildfire, and pests/disease.

This assessment of sensitive/vulnerable tree species is limited because there is a lack of information on the individual species to assess condition. However, the assessment presents the information that is available on the species regarding their occurrence within the national monument, as well as threats and issues related to their continued existence.

4.8.2. Data and Methods

To assess the condition of these sensitive and vulnerable tree species at Sunset Crater Volcano NM, we used one indicator, species occurrence. The one indicator had a total of three measures (on presence/absence), one for each of the tree species of interest; southwestern white pine and limber pine are discussed together under one measure. The purpose of the indicator was to assess the occurrence (presence/absence) of each species within the monument; specifically, where possible, we addressed where each species occurs (location and/or vegetation community), and abundance (for one of the species).

We based the assessment on the information available, which was scant for each of the species. Our general sources of information for the assessment included reports for or by the monument, especially the vegetation mapping report (i.e., Hansen et al. 2004), as well as the 2009 Fire Management Plan (FMP; i.e., NPS 2009), Eggler (1964), and Bateman et al. (1980). Specific data sources and general species descriptions for each species are mentioned as appropriate under each of the measures. We also incorporated information on threats and stressors from a variety of sources.

<u>Presence/Absence of Douglas-fir</u>

Unlike for quaking aspen (see next measure), no information on Douglas-fir within the national monument exists except for the general resources already mentioned, as well as some information provided by monument personnel. A general description of the species is provided based on information from Anderson (2008) and Hermann and Lavender (no date).

<u>Presence/Absence of Quaking Aspen</u>

Of the species addressed in this condition assessment, the most information on occurrence and distribution

Figure 4.8.1-2. Douglas-fir. Photo Credit: NPS.

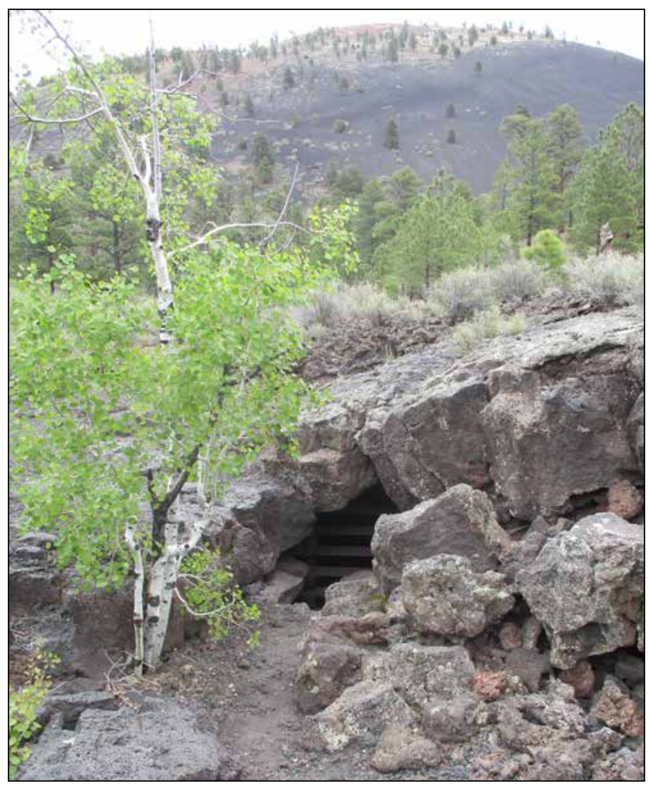


Figure 4.8.1-3. Quaking aspen at Sunset Crater Volcano NM. Photo Credit: © Patty Valentine-Darby.

may exist for quaking aspen. In addition to being addressed to some extent in the vegetation mapping report for the monument (i.e., Hansen et al. 2004), the mapping effort produced a separate map showing the occurrence of small patches of quaking aspen within the national monument. This is the main source of information for this measure, as well as the general description of the species from Nesom (2008).

Presence/Absence of Southwestern White Pine

The same resources used for the other two tree species were used for this measure, although a few additional resources were used. As mentioned previously, there is some uncertainty surrounding the occurrence of limber pine within the national monument, and there have been misidentifications of southwestern white pine (as limber pine) in the past. The following studies/reports include limber pine, but not southwestern white pine: Eggler (1964, 1966), Bateman et al. (1980), and Hansen et al. (2004, although from this source it is unclear whether they reported limber pine within the monument itself). Some additional information on the issue was provided by Megan Swan, Botanist, with the Southern Colorado Plateau Network (SCPN). She indicated that there are two collections of "limber pine" from the monument from the 1950s, but that both were later re-identified by different, local botanists as southwestern white pine. Another collection exists from the 1970s that was identified as southwestern white pine and later confirmed as such by another botanist. Therefore, it appears that southwestern white pine occurs within the monument. The occurrence of limber pine has not yet been verified, and no voucher specimens exist. Based on the information available, it appears that both Eggler (1964, 1966) and Bateman et al. (1980) may have misidentified southwestern white pine as limber pine (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, and Megan Swan, Botanist, SCPN, pers. comm.). It may also be worth noting that some believe that southwestern white pine is a variety of limber pine (*P. flexilis* var. *reflexa;* Utah State University 2017). Because voucher specimens exist for southwestern white pine, we focus on this species in the assessment, but we also include discussion of limber pine in the Condition section.

4.8.3. Reference Conditions

This assessment of sensitive/vulnerable tree species is a limited assessment due to the paucity of information available on the topic. For this reason, we did not develop reference conditions to assess condition. Although no reference conditions were developed, the assessment presents the most current information available for these three (to four) tree species in the national monument. Although not needed for this assessment, the Ponderosa Pine and Pinyon-Juniper Vegetation assessment in this report contains information on the logging of ponderosa pine stands in the early 1900s within the national monument and Flagstaff area (NPS 2009), as well as information on plant successional studies on Sunset Crater Volcano (Eggler 1964, Eggler 1966, and Bateman et al. 1980).

4.8.4. Condition and Trend

Presence/Absence of Douglas-fir

Description of the Species

Douglas-fir is a member of the pine family (Pinaceae). Across its range, this native tree grows up to 67 m (220 ft) tall and 4.4 m (14.4 ft) wide. When mature, its bark is dark brown, thick, and furrowed deeply. The seed cones mature the first season and reach 5-9 cm (2-3.5 in) in length. Douglas-fir is common in northern and central Arizona. It extends southward to northern Mexico, and eastward to western Texas. The species also occurs in areas of California, north to British Columbia. Where Douglas-fir occurs with other species, the proportion in which it grows may vary substantially, depending on aspect, elevation, soil type, and past fire history of an area (Hermann and Lavender, no date). Within the Douglas-fir's range, various species of wildlife consume its winged seeds (e.g., white-footed deer mice, chipmunks, shrews, and birds), foliage and twigs, and needles (Anderson 2008, Hermann and Lavender, no date).

Occurrence and Distribution within the Monument

As mentioned elsewhere, woodlands (with open forest canopies) are the predominant vegetation type in the monument and surrounding environment (Hansen et al. 2004). Ponderosa pine woodlands are most common, and they usually occur on cinder soils with little or no understory cover. Ponderosa pine may occur in almost pure stands, but it may also occur with other coniferous trees, such as Douglas-fir. Within the area mapped by Hansen et al. (2004), which included a substantial area surrounding the national monument, Douglas-fir occurred to the greatest extent on O'Leary Peak and Darton Dome (both outside of and north of the monument). These areas (outside of the monument) were mapped by Hansen et al. (2004) as Douglas-fir forest. Within the national monument, there are no areas mapped where Douglas-fir is dominant. Figure 4.8.4-1 shows the areas within the national monument that are dominated by ponderosa pine vegetation (in orange); Douglas-fir occurs in some of these areas. Bateman et al. (1980) reported one Douglas-fir tree on the north slope of Sunset Crater, and Eggler (1964) reported a small number on the Sunset Crater cone and on the Sunset lava flows.

The 2005 Gap Fire within the monument (Figure 4.8.4-2, 54 ac) adversely impacted an area of Douglas-fir trees. According to personnel with the Flagstaff Area NMs natural resource program, the Gap Fire torched and killed a patch of trees that was among the largest and oldest known Douglas-fir trees in the national monument (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.). Figure 4.8.4-2 also shows the other fires that have occurred within the monument since 2002, including both lightning-ignited and prescribed fires. In addition to what is shown on the figure, there were four additional fires during 2015-2016, but they were all single tree lightning strikes (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.).

No other data are available on this species, such as specific distribution within the monument, or density or age/size class statistics. Because data on this species are scant, we consider current condition of the species to be unknown at this time. We have low confidence in the measure.

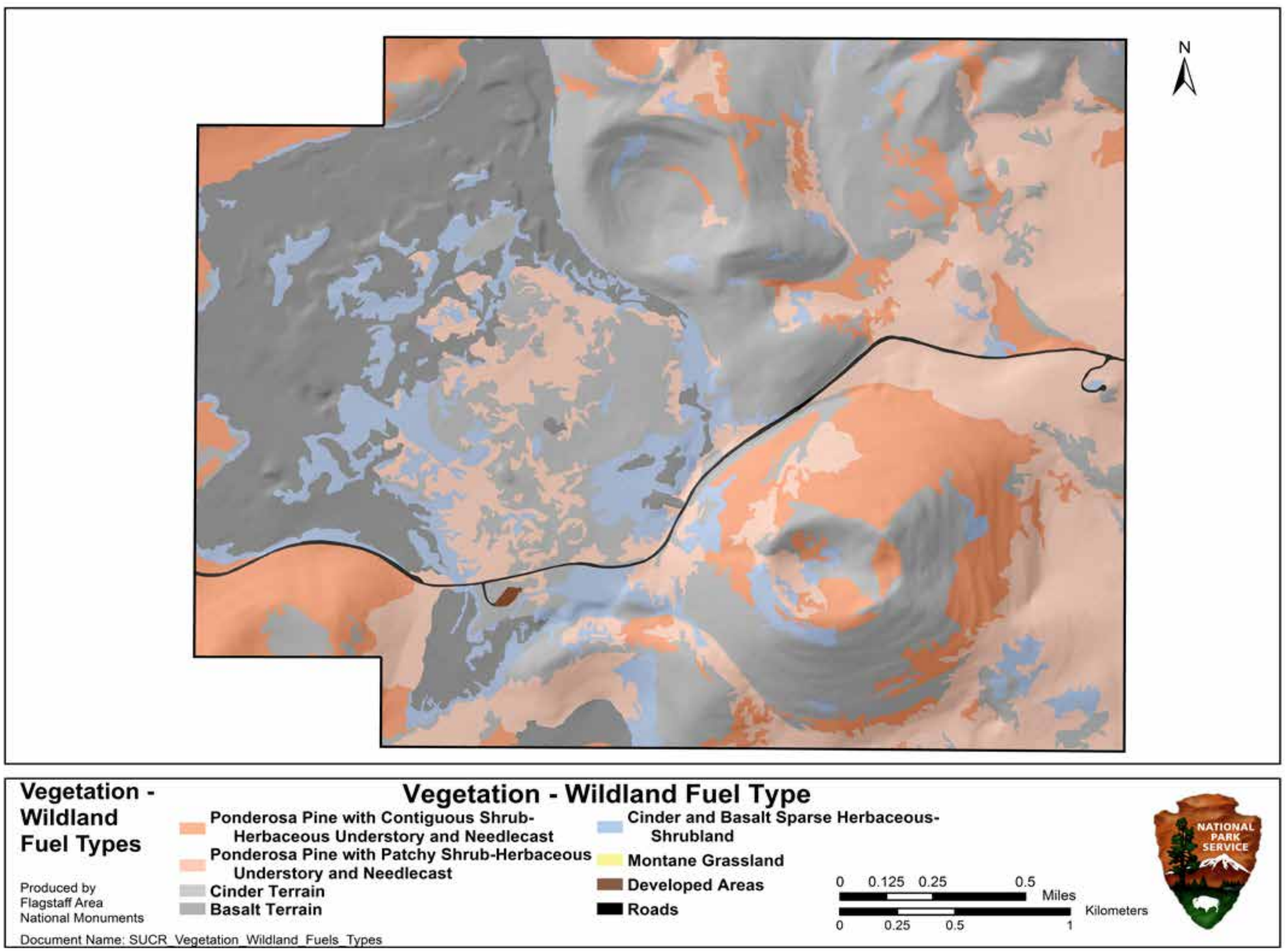


Figure 4.8.4-1. Vegetation and wildland fuel types at Sunset Crater Volcano NM, showing ponderosa pine vegetation in orange. Figure Credit: Flagstaff Area NMs.

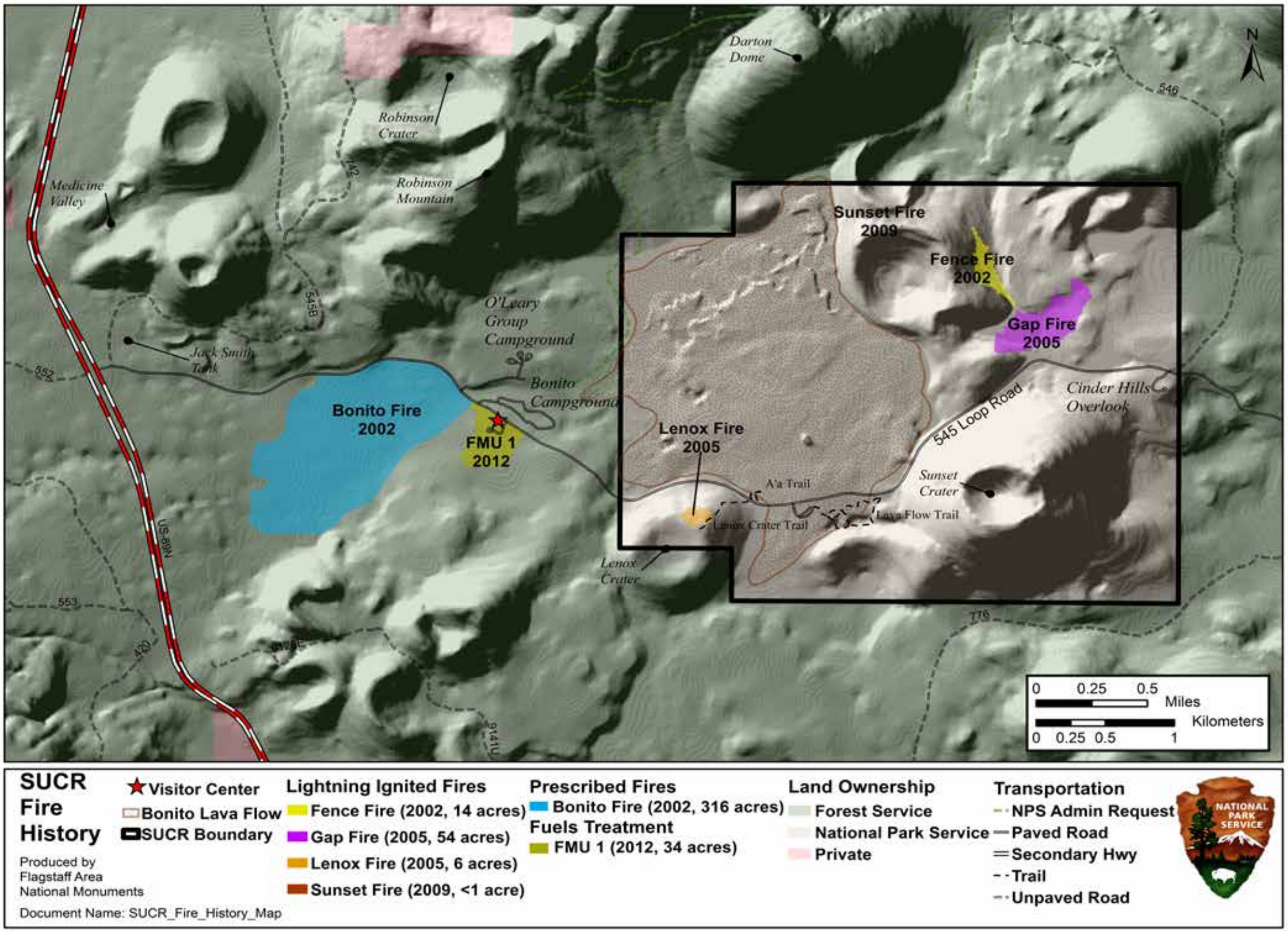


Figure 4.8.4-2. Fire occurrence at Sunset Crater Volcano NM from 2002-2012. Figure Credit: Flagstaff Area NMs.

Presence/Absence of Quaking Aspen

Description of the Species

Quaking aspen is easily identified from other trees, with its whitish bark and colorful fall leaves. The bark is usually smooth, and often thin and peeling, although it becomes thicker and less smooth with age. The simple, roundish, deciduous leaves are dark green and shiny on the upper surfaces, but turn bright yellow, gold, yellow-orange, or reddish in the fall. The tree's common name originates from the shaking of its leaves in the wind. Typically, less than 15 m (49.2 ft) in height, quaking aspen ranges from about 5-30 m (16.4-98.4 ft) tall across its range. Its lateral roots may reach 30 m (98.4 ft) out, and vertical roots from the laterals may reach almost 3 m (9.8 ft) downward. Root sprouting is the primary means of reproduction. A characteristic of the species is its extensive clones of trees connected by roots. A stand of quaking aspen may be comprised of one clone or a group of different clones. Individual quaking aspen trees are relatively short-lived (e.g., 150 years in the western U.S.), but the clones persist for a very long time (e.g., 8,000 years in the Rocky Mountain and Great Basin regions; Nesom 2008).

This tree is the most widely distributed tree species on the continent, growing in the U.S., Canada, and Mexico. It grows in the U.S. in all but 13 states, and in all of the western U.S. except for Oklahoma and Kansas. In addition to its expansive geographic range, it grows at a range of elevations and in a variety of habitats. Quaking aspen is not tolerant of shade conditions, and it grows on disturbed sites. In Eggler's study (1964), he described individual stems living for only a few years, then dying back to the roots, to be followed by new stems growing from the live, horizontal roots. He suggested the die-back was from a lack of water. The tree provides food and habitat for various wildlife, including large (e.g., deer), medium (e.g., porcupine), and small (e.g., mice, rabbits) mammals and birds (Nesom 2008).

Quaking aspen trees are vulnerable to diseases and insect damage, as well as fire damage, due to their thin, soft bark (Nesom 2008). Overgrazing by livestock or native wildlife can also affect sucker formation (Nesom 2008). Aspen trees are also susceptible to effects from drought (e.g., Ganey and Vojta 2011) and have died back to their roots within the national monument following drought conditions (Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs, pers. comm.).

Occurrence and Distribution within the Monument

Small stands of quaking aspen occur within the national monument and surrounding area (Hansen et al. 2004). Aspen trees grow along the edges of lava beds, within the lava beds, and in small stands on peaks (e.g., on O'Leary Peak and Darton Dome, both outside of the monument). NPS (2009) also mentions a small number of small aspen stands on the north slopes of the cinder cones.

In the vegetation mapping effort for the national monument, a separate aspen map was produced showing small, photointerpreted quaking aspen patches (Hansen et al. 2004; Figure 4.8.4-3). As seen from the figure, the greatest number of trees was reported near the road passing through the monument (545 Loop Rd.). The largest dots shown indicate the occurrence of more than 15 to 30 trees. The next-largest dots (outside of the boundary and near the road) represent >7-15 trees. There has not been a repeat of this coverage, so we cannot compare the pre-2004 occurrence to that of the present time.

In addition to the separate map that was produced for quaking aspen, the tree species was included in the Lava Bed Sparse Vegetation map class by Hansen et al. (2004). This map class generally occurs on the lava flows in the western half of the monument and includes small areas of different vegetation types (including aspen woodlands, as well as ponderosa

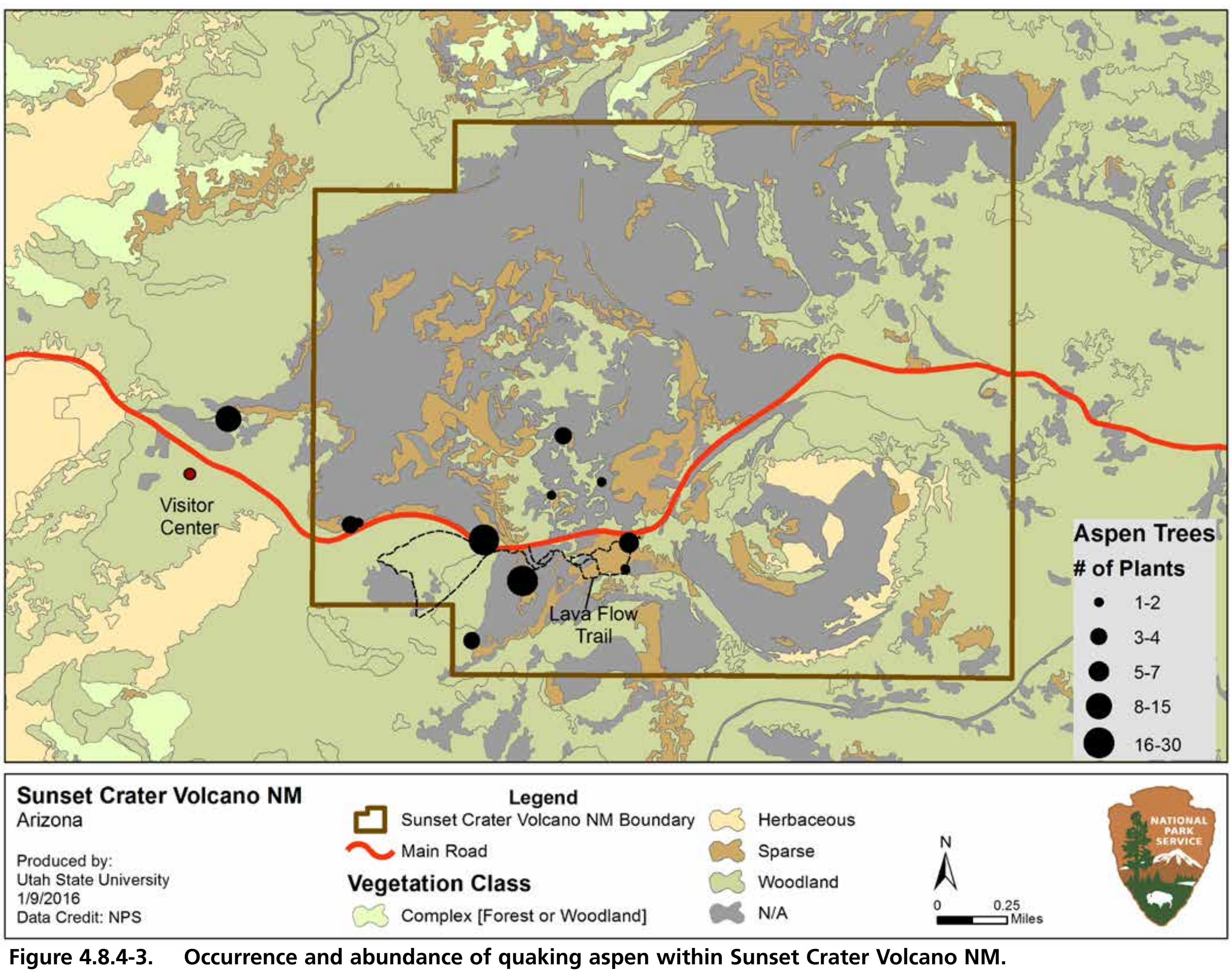


Figure 4.8.4-3. Occurrence and abundance of quaking aspen within Sunset Crater Volcano NM.

pine woodlands, apache plume shrublands, and mixed shrublands; Hansen et al. 2004). Also, a Quaking Aspen/Cinder Woodland association was described by Hansen et al. (2004), but either areas were combined with adjacent vegetation communities on the overall vegetation map (because of their small size), or they were shown on the separate coverage shown in Figure 4.8.4-3. No other baseline data are available on this species, such as age/size class statistics. Because data on this species within the monument are incomplete, and the information that exists is more than 12 years old (from the Hansen et al. 2004 report), we consider current condition of this species to be unknown at this time. Confidence is low.

<u>Presence/Absence of Southwestern White Pine</u>

Description of the Species

Southwestern white pine is a five-needled pine that has an open, irregular crown (Pavek 1993). It may reach a height of 27 m (90 ft) and a diameter of 1 m (3.2 ft; Pavek 1993). It occurs in southwestern pine, mixed-conifer, and spruce-fir forests (Pavek 1993, Depinte 2016). It is rare to find this species in a pure stand; more often, individual trees or groups of southwestern white pine co-occur with other species. The species is described as widespread in mesic sites on slopes, ridges, and canyons of montane zones, with its best growth on moist, cool sites that have deep soil (Pavek 1993). Southwestern white pine is described as a persistent, long-lived seral or climax species (Pavek 1993).

Southwestern white pine has a limited distribution in the United States; it grows in the mountains of western Texas, New Mexico, Arizona, and southwestern Colorado, and extends south into Mexico (Pavek 1993). In the U.S., it usually grows at elevations of about 1,829 m to 3,048 m (6,000 to 10,000 ft; Pavek 1993, Depinte 2016). Although the tree has been reported on all aspects, it often occurs on north- to east-facing slopes (Pavek 1993).

Young age classes of southwestern white pine are sensitive to fire, and older trees, with thicker bark, are somewhat more resistent (Pavek 1993). The species' thin bark and drooping branches increase its fire sensitivity. Seeds of the species, relatively large and nutrient rich, provide food to small mammals and birds (Pavek 1993, Depinte 2016).

Occurrence and Distribution within the Monument

Little information exists on the presence and distribution of southwestern white pine in the monument. There are three collections of the tree from the monument, from the 1950s and 1970s (the first two of which were originally identified as limber pine; Megan Swan, Botanist, SCPN, pers. comm.).

Although it now appears that the trees may have been misidentified, both Eggler (1964) and Bateman (1980) reported limber pine in transects they sampled (i.e., the same transect) on the north slope of Sunset Crater. In both studies (which sampled the same transect), this species may have actually been southwestern white pine. Although the tree was reported in low numbers (seven total individuals reported by Bateman 1980), it was reported in six plots along the slope of the cone.

Hansen et al. (2004) also included mention of limber pine, but it is unclear whether the species occurred within the national monument. Hansen et al. (2004) reported that "limber pines and Douglas-fir are confined to a mixed conifer zone on O'Leary Peak and Darton Dome" (outside of the monument), but as has been discussed in the assessment, individual Douglas-fir are known to occur within the monument. Hansen et al. (2004) also wrote that "ponderosa pine most often occurs in pure stands; however, it can intermix in areas of high elevation with Douglas-fir or limber pine." The Limber Pine Woodland map class of Hansen et al. (2004) occurs only on the "exposed, south-facing upper slopes of O'Leary Peak." It may be that Hansen et al. (2004) identified this area of limber pine outside of the monument accurately (Megan Swan, Botanist, SCPN, pers. comm.), but this is unknown.

Acknowledging that there is uncertainty concerning whether both southwestern white pine and limber pine occur within the national monument, we consider information on their occurrence to be a data gap. There is a paucity of current information available on either species to assess current condition. Therefore, we consider condition of the species to be unknown at this time. Confidence is low.

In recent years, an invasive pathogen has been spreading throughout the southwestern white pine's native range in the U.S. and Canada (Depinte 2016, U.S. Forest Service [USFS] 2017). White pine blister rust (*Cronartium ribicola*) is a fungus that alternates between currants and gooseberries (*Ribes* spp.) and white pine species as its host. Southwestern white pine is the only species in the Southwest that is currently affected by the disease, but limber pine is also susceptible (USFS 2017b). The disease is one of the most damaging across the continent, affecting trees of all sizes (USFS 2017b). Although it is thought to have existed earlier, the disease was discovered in New Mexico in 1990, and has since spread throughout most of the state and into the White Mountains of eastern Arizona (Depinte 2016). The NPS has received recent requests from scientists at Northern Arizona University (NAU) to collect southwestern white pine tissue samples from trees that can readily be seen from the monument access road on the north slope of the Sunset Crater cinder cone. The NAU scientists are studying genetic differentiation of southwestern white pine and resistance to blister rust fungus (Dr. Kristen Waring, Associate Professor, School of Forestry, Northern Arizona University, pers. comm. to Paul Whitefield, Natural Resource Specialist, Flagstaff Area NMs). This disease and others are also addressed in the Threats and Issues section.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Overall, we consider the current condition of sensitive/vulnerable tree species at Sunset Crater Volcano NM to be unknown with an unknown trend. The associated confidence level is low. This condition rating was based on one indicator with a total of three measures, which are summarized in Table 4.8.4-1.

Each measure was considered to have an unknown condition, although somewhat more information existed for quaking aspen due to the map of occurrence produced by Hansen et al. (2004). Overall, there is a paucity of information on the three tree species addressed in the assessment, with little information on their distribution within the national monument, densities, and age/size classes. Uncertainty also remains regarding the existence of limber pine within the monument, although a review of the information by Megan Swan (Botanist, SCPN) and Paul Whitefield (Natural Resource Specialist, Flagstaff Area NMs), suggests that it is unlikely that limber pine occurs within the national monument boundaries. Additional surveys are needed to document the distribution of

Table 4.8.4-1. Summary of sensitive and vulnerable tree species indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Presence/Absence of Douglas-fir	(unknown condition, dashed circle)	Condition is considered unknown due to the lack of current information available on the presence and distribution of the species within the monument. The species is known to be present and has been reported in various monument reports (as well as by monument staff). The 2005 Gap Fire killed a patch of trees that were among the largest and oldest known Douglas-fir to occur within the monument. Trends are unknown and confidence is low.
	Presence/Absence of Quaking Aspen	(unknown condition, dashed circle)	Condition is considered unknown due to the lack of current information available on the presence and distribution of the species within the monument. Some information on its occurrence is available from a map produced by Hansen et al. (2004). Other data are lacking. Trends are unknown and confidence is low.
	Presence/Absence of Southwestern White Pine	(unknown condition, dashed circle)	Condition is considered unknown due to a lack of current information on the presence and distribution of the species within the monument. This species has been confirmed within the monument based on collections that have been verified (although two of the three collections were originally identified as limber pine). It is unclear, although unlikely, that limber pine occurs within the monument; this remains to be determined. Trends are unknown and confidence is low.
Overall Condition		(unknown condition, dashed circle)	Overall condition and trend are unknown, and confidence is low. These three species are known to occur within Sunset Crater Volcano NM, but detailed and current information on their presence is lacking. These trees are considered sensitive and vulnerable to possible conditions (drought, high temperatures, severe wildfire, pests/disease) due to their apparent relatively low levels of occurrence within the monument.

southwestern white pine and to confirm it is the only one of the two species present within the monument.

Threats, Issues, and Data Gaps

Because the distribution/occurrence of the tree species discussed in this assessment is relatively lower than species such as ponderosa pine, they may be considered more susceptible to threats than the more common species. Threats to these sensitive and vulnerable trees species are related to drought conditions, climate change (high temperatures and/or drought conditions), severe wildfire, and pests/disease.

An overarching threat is from climate change. The western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall (Prein et al. 2016). NPS (2015) reports that the projected increase in mean annual temperature is -16 to -15 °C (4 to 5 °F) by 2050. Since 1974 there has been a 25% decrease in precipitation, a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016). However, it may be more difficult for native plants to take advantage of short duration, intense precipitation events followed by long intervals of drought, and intense rainfall events may lead to increased soil erosion. Droughts are projected to be more intense and last longer in the coming century (Kent 2015). Within Sunset Crater Volcano NM, "recent climatic conditions are already shifting beyond the historical range of variability" (Monahan and Fisichelli 2014). In their analysis for the monument, three temperature variables were found to be "extreme warm" (annual mean temperature, maximum temperature of the warmest month, and mean temperature of the warmest quarter), and three precipitation variables were found to be "extreme dry" (annual precipitation, precipitation of the driest month, and precipitation of the driest quarter) for the most recent period (2003-2012).

Mortality of trees has increased across the western U.S. (van Mantgem et al. 2009). For example, in northern Arizona, mortality was monitored in ponderosa pine and mixed-conifer forests from 1997-2007 (a period of severe drought; Ganey and Vojta 2011). These researchers found that mortality occurred on nearly all of the 1 ha (2.5 ac) mixed-conifer and ponderosa pine plots (100 and 98%, respectively). In most cases the mortality was due to forest insects attacking drought-stressed trees. The number of Douglas-fir trees that died in mixed-conifer forest from 2002 to 2007 was more than 200% greater than the number that died in the earlier years of the study period. For both forest types, the magnitude of mortality varied spatially, and the largest size classes were affected the most. In the same study, mortality of quaking aspen relative to other tree species was high in both mixed-conifer and ponderosa pine forests.

Climate change might influence fire activity in three different ways: changes in fuel loading; changes in fuel condition (fuel moisture); and changes in fuel ignition (Hessl 2011, as cited by Kent 2015). The Sunset Crater Volcano NM Foundation Document (NPS 2015a) acknowledged an increase in severity of wildfires in the region after more than a century of fire suppression and logging. It was further suggested that an unnaturally severe fire could result in substantial impacts to the stands of ponderosa pine trees on the volcanic slopes and cinder barrens (NPS 2015a), amongst which the species addressed in this assessment grow. As discussed earlier, the Gap Fire that burned in 2005 impacted an area of some of the largest and oldest known Douglas-fir trees in the monument.

The FMP for the monument (NPS 2009) reported that 55 fires occurred within and next to the monument boundary from 1957 to 2009, with 43 of them being lightning ignitions. The number of fires was the highest for all three of the Flagstaff Area NMs for these years. The behavior of fire and its spread is moderated within the national monument by the discontinuous fuels, especially in the lava flow features (NPS 2009). However, a few of the more recent fires (Fence Fire and Gap Fire) showed that even in the relatively barren volcanic terrain, fire can travel when wind and other conditions are conducive.

Trees within Sunset Crater Volcano NM may also be impacted by pests and disease. Under the measure for southwestern white pine, we discussed white pine blister rust, an invasive fungus that is affecting southwestern white pine in the Southwest. There is no information on the disease occurring within the national monument to date. Another potential source of damage and mortality to pine trees is bark beetles. Bark beetles (Coleoptera: Curculionidae, Scolytinae) are a group of native insects composed of many species that live between the bark and wood of host trees and feed on the tree's phloem tissues (Bentz et al. 2010).

Their feeding habits interrupt the flow of nutrients and water in the tree, eventually leading to tree death. Bark beetles preferentially attack weakened trees. Although bark beetle outbreaks are a natural ecosystem process, climate change has increased drought stress on western coniferous forests, making many millions of hectares of trees available to bark beetle infestation (Bentz et al. 2010). Widespread bark beetle infestation may have undesirable effects on vegetation structure and composition, fire behavior and occurrence, and carbon storage (Jenkins et al. 2012, Ghimire et al. 2015, and Potter and Conkling 2016).

The USFS, as part of their Forest Health Monitoring Program, conducts annual forest insect and disease aerial detection surveys in the state. Data available from this program for Sunset Crater Volcano and Walnut Canyon NMs indicate that bark beetles affecting ponderosa pine, and to a much lesser extent Douglas-fir, were reported in a substantial area of the two national monuments combined in 2002-2004 (USFS 2004). More recent data from 2012 to 2015 indicated no beetle mortality of Douglas-fir, and a small amount of activity for ponderosa pine in the two monuments (USFS 2013, 2014a, 2014b, and 2016b).

4.8.5. Sources of Expertise

No outside experts were consulted for this assessment, except that Megan Swan, Botanist with SCPN, provided input on the occurrence of southwestern white pine and limber pine within the national monument. The assessment author is Patty Valentine-Darby, science writer, Utah State University. Lisa Baril, science writer, Utah State University, contributed text on bark beetles.

4.9. Sunset Crater Beardtongue (*Penstemon clutei*)

4.9.1. Background and Importance

Sunset Crater beardtongue (*Penstemon clutei*) is a perennial herb endemic to the volcanic soils of the northeastern San Francisco Volcanic Field. The range of Sunset Crater beardtongue (hereafter referred to as beardtongue) is approximately 350 km^2 (135 mi^2), but the population is disjunct (Springer et al. 2010) (Figure 4.9.1-1). The larger of the two subpopulations is centered on the Cinder Hills OHV (off-road vehicle) area south of the Sunset Crater Volcano National Monument (NM). Plants growing in this region occur on relatively young tephra deposits, while the smaller subpopulation, located approximately 20 km (12 mi) to the northwest, occurs on older cinder cones (Springer et al. 2010). Although the two subpopulations are separate, microsatellite data suggest there is no significant difference in genetic composition between them (Springer et al. 2010). This may suggest gene flow is occurring between the subpopulations or that there are yet undiscovered subpopulations between the two that are currently known (J. Springer, 13 Jun 2017, pers. comm.).

Throughout its range beardtongue typically grows in ponderosa pine (*Pinus ponderosa*), and pinyon pine (*Pinus edulis*)-Utah juniper forests (*Juniperus osteosperma*) with a sparse understory that may include blue grama (*Bouteloua gracilis*) and Apache plume (*Fallugia paradoxa*) among other herbaceous species (Huisinga and Hogan 2000, NPS 2012b). Beardtongue often grows at the base of large trees, particularly snags, or in previously disturbed areas (Huisinga and Hogan 2000), but in a study of habitat relationships, these factors were not significant, although the sample size was small (Springer et al. 2010). Disturbance may be an important factor for recruitment (Crisp 1996, Fulé et al. 2001, Springer et al. 2012).

A variety of insects and hummingbirds pollinate beardtongue's bright pink flowers (Figure 4.9.1-2),

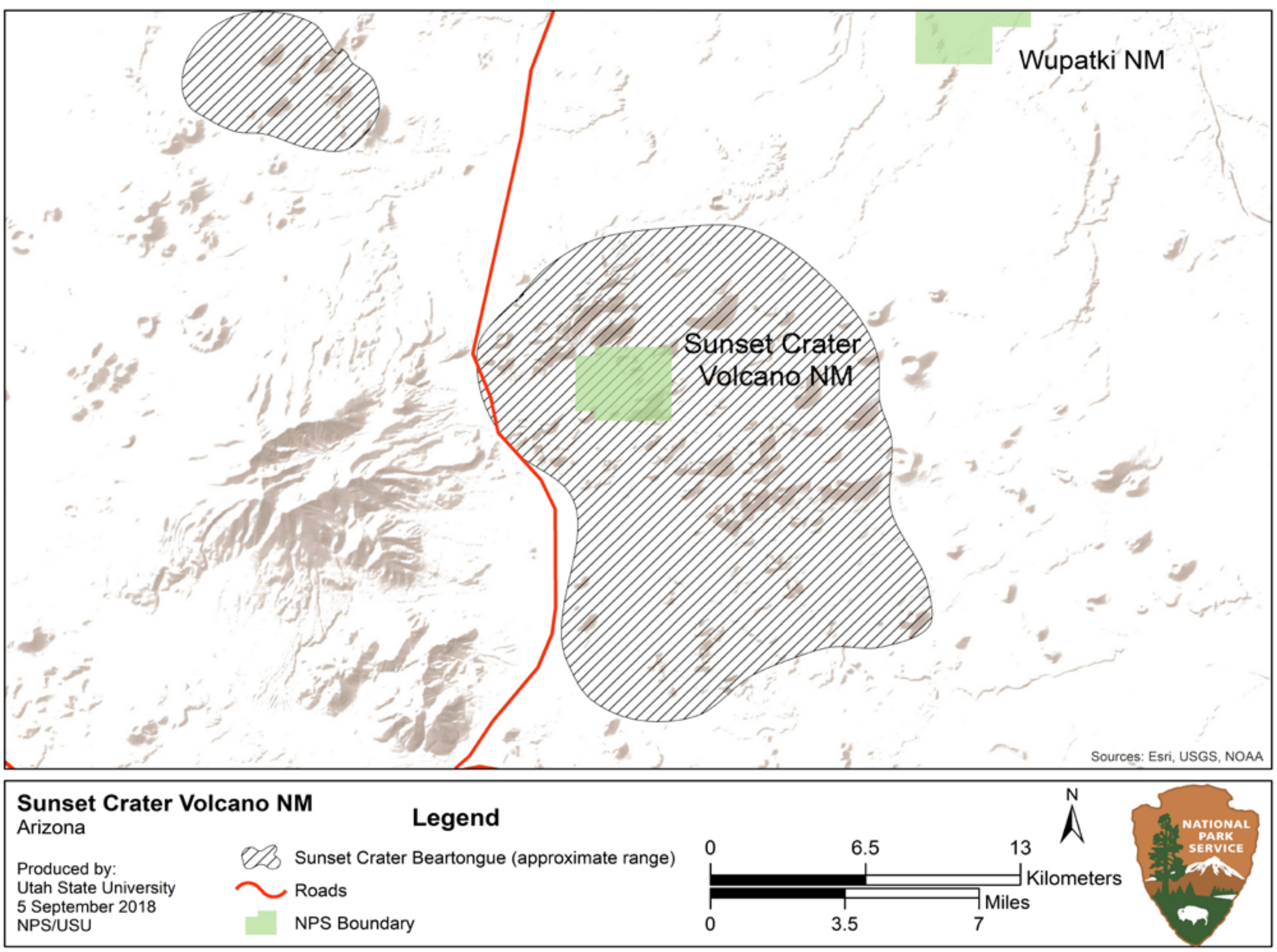


Figure 4.9.1-1. Map showing the approximate range of Sunset Crater beardtongue in northern Arizona.

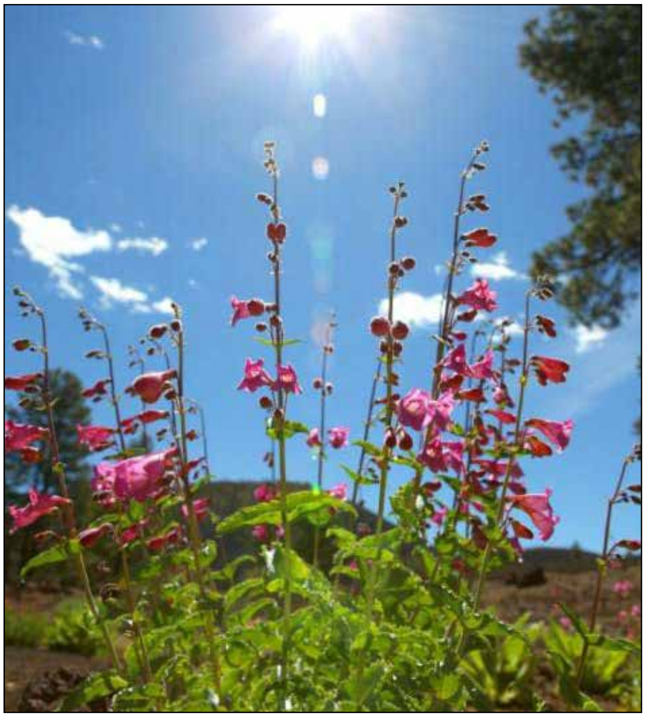


Figure 4.9.1-2. Sunset Crater beardtongue in bloom. Photo Credit: Springer et al. (2010).

which bloom from June through September and even into October in favorable years (Bateman 1980, Wolfe et al. 2006, J. Springer, Northern Arizona University, Research Specialist, Sr., personal observations). Beardtongue flowers have been used in katsina ceremonies by the Hopi at Shungopavi and the plant is also used by the Navajo for Lifeway and other healing ceremonies (Huisinga and Hogan 2000). Although basic life history characteristics of beardtongue have been documented, much about the biology of this narrow endemic species is unknown (Springer et al. 2012). There is some debate regarding beardtongue's lineage, but the species may have diverged from desert penstemon (*P. pseudospectabilis*) sometime after the Sunset Crater eruption, or the species may be an intermediate between desert penstemon and Palmer's penstemon (*P. palmeri*) (Springer et al. 2012). A study on the phylogeny of the *Penstemon* genus produced inconclusive results for Sunset Crater beardtongue (Wolfe et al. 2006). The conflicting results may be the result of rapid speciation within the genus or a result of hybridization among various *Penstemon* species (Wolfe et al. 2006). Beardtongue is ranked as an imperiled species by NatureServe and is considered a Region 3 (Southwestern Region) sensitive species by the U.S. Forest Service (Springer et al. 2012).

4.9.2. Data and Methods

Several studies have reported on beardtongue, but only two of them specifically documented plant presence in the park (Huisinga and Hogan 2000, Springer et al. 2010, but see NPS 2012b). Given the scarcity of data on Sunset Crater beardtongue in the monument and the plant's narrow range within and around Sunset Crater Volcano NM, we also included three studies that were conducted on the Coconino National Forest (CNF) that surrounds the monument (Crisp 1996, Fulé et al. 2001, Springer et al. 2012). These studies focus on beardtongue's response to disturbance but are relevant to understanding how beardtongue may respond to National Park Service (NPS) activities within the monument. Furthermore, activities outside the monument may influence population dynamics within the monument, which is important given the plant's narrow range. We used a total of three indicators with a total of five measures.

<u>Presence/Absence</u>

In 1999 and 2001, the NPS Vegetation Mapping Inventory Program classified, described, and mapped vegetation in and around Sunset Crater Volcano NM (Hansen et al. 2004). The total area mapped and classified included the monument, a 1.6 km (1.0 mi) buffer surrounding the monument, and areas of special interest such as Bonito Park for a total of 7,588 ha (18,750 ac) (Hansen et al. 2004). The inventory uses the National Vegetation Classification Standard (Hansen et al. 2004). The NVCS has seven hierarchical levels, with the finest level represented by the association. An association is defined as "a vegetation classification unit consistent with a defined range of species composition, diagnostic species, habitat conditions, and physiognomy" (Jennings et al. 2003 as cited in Hansen et al. 2004). Associations are named for the species characteristic of the association. If more than one species characterizes the association, the species in the dominant strata is listed first and is separated by a forward slash from dominant species occurring in the lower strata. If species occur in the same strata, they are separated by a dash. Parentheses indicate a common species considered important to the community but may not be present all the time (Hansen et al. 2004).

Vegetation was mapped using 1:12,000 scale color infrared (CIR) photographs. Map classes were derived from 114 relevé plots located in the field and interpretation of CIR photosignatures. The plots were allocated based on the percent contribution of each environmental type. Field data were collected in 1999 with some follow-up work in 2000. Relevé plots were generally 1,000 m^2 (10,764 ft^2), but were occasionally reduced to 400 m^2 (4,306 ft^2) in densely vegetated areas. Plots were either circular or square depending how the plot best fit in the landscape (Hansen et al. 2004). Using field data from the relevé plots, we identified the plant associations where beardtongue was present and the number of plots containing beardtongue within each association. Percent cover data is also provided.

# of Plants/Life Stage

In 2009 and 2010, 28 long-term vegetation plots were established in the CNF (*n* = 22) and within the monument (*n* = 6) in order to monitor the population structure of beardtongue (Springer et al. 2010). Plots were randomly chosen after initial surveys for the plant. A requirement was that each plot contained at least five individual plants. Plots were 10 m x 10 m (33 ft x 33 ft) and were categorized by soil type according to the Terrestrial Ecosystems Survey of the CNF (Springer et al. 2010). Individual beardtongue plants were mapped in each plot in addition to all trees, shrubs, and coarse woody debris. Individual beardtongue plants were classified by size and height into six life stages: seedling, juvenile, young reproductive, mature, senescing, and dead (Table 4.9.2-1). We report the number of plants per life stage for the six plots located within the monument.

Prescribed Fire, Root Trenching, or Tornado Salvage

Three studies detail the effects of various disturbances on growth rates and the soil seedbank of beardtongue (Crisp 1996, Fulé et al. 2001, Springer et al. 2012). Because these studies were experimental in nature, they were conducted in the adjacent CNF rather than within the monument. Although these studies were not conducted in the monument, the results may be useful for better understanding how natural (e.g., fire) and anthropogenic (e.g., trail building) disturbances within the monument may affect beardtongue growth, survival, and recruitment. Furthermore, because beardtongue is a narrow endemic, activities occurring on lands outside of the monument may impact the population of beardtongue within the monument (e.g., through dispersal). There were three types of disturbances examined: prescribed fire, root trenching, and salvage logging.

Table 4.9.2-1. Six life stages of Sunset Crater beardtongue.

Life Stage	Description
Seedling	First season growth as indicated by cotyledons.
Juvenile	One year or more of growth and pre-reproductive. Without cotyledons or flowering stems.
Young reproductive	One to five flowering stems. No evidence of flowering stems from previous years.
Mature	Six or more flowering stems. Plants often have woody characteristics at base of plant and evidence of old leaves and flowering stems from previous years.
Senescing	Plants are discolored with brown, gray or off-colored green leaves. Obviously suffering from severe stress, with no evidence of healthy vegetation.
Dead	No evidence of living vegetation.

Source: Springer et al. (2010).

Prescribed Fire

In 1994, 40 plant-centered plots were established on the CNF in the vicinity of O'Leary Peak located north of the monument (Fulé et al. 2001). Plots were 2.5 m (8.2 ft) radius circular plots centered 0.3 m (1.0 ft) northwest of an existing plant. Plots were randomly selected for burn or control treatments. Burning occurred in September 1994 (Fulé et al. 2001). Twenty additional plots located north of the main experimental site were burned in April 1995 to test the effects of burn season (Fulé et al. 2001). Plots burned in September were re-measured in July 1995; and all 80 plots were re-measured in August/September 1996, August 1997, August 1998; and August/September 2008 (Springer et al. 2012). Plant densities were compared between years (see Fulé et al. 2001 and Springer et al. 2012 for more details). In 2008, two soil seedbank samples were collected from each of the 80 prescribed burn plots (*n* = 160). Samples were collected in late August and early September after germination but before new seeds were dispersed (Springer et al. 2012). Seed bank soil samples were placed on sterile soil, situated in a greenhouse, and watered daily for five months.

Root Trenching

In October 1997, 10 plots were established for root trenching within the prescribed burn study area as described above (Fulé et al. 2001). Root trenching plots were paired with a control plot from the original burn experiment. Two root trenching plots were removed as a result of off-road vehicle damage and other factors. Trenches were 1 m (3 ft) deep around each plot and located 50 cm outside the plot boundary. Trenches were lined with heavy plastic sheeting to minimize tree root re-growth. Trenches were then backfilled and were re-measured in August 1998, September 1999, August 2000 and August/September 2008 (Fulé et al. 2001, Springer et al. 2012). Root trenching mimics the effects of tree death and removal of root competition following a severe forest fire or other disturbance such as wind throw. In 2008, soil seedbank samples were collected from the eight root trenching plots (n = 16) (Springer et al. 2012). Samples were collected and grown as described above.

Salvage Logging

Tornadoes are a rare occurrence in northern Arizona, but on October 26, 1992 a tornado passed through the Flagstaff area (Crisp 1996). The event uprooted many large ponderosa pine trees on the CNF and within the monument. The Forest Service developed a salvage plan to remove and sell downed trees in two stands damaged by the tornado. Although several mitigation measures were followed to limit the damage to live beardtongue plants and the soil seedbank, the removal of large trees still required heavy equipment (e.g., tractors). A basic monitoring plan was established to determine the effects of salvage logging on the population of beardtongue (Crisp 1996). The two units included in the salvage area were searched for beardtongue plants in November 1992 (Crisp 1996). One unit was located to the west of the monument while the other unit was located southeast of the monument. Individual plants were categorized as either adults or seedlings based on plant size or presence/absence of a seed stalk, but age classes were only described for the southeast unit (Crisp 1996). In August 1994, following completion of the timber harvest, a second area search was conducted in both units; however, only a partial search was conducted in the southeast unit since the earlier survey revealed that this was marginal beardtongue habitat (Crisp 1996). We report the number of individual plants for each site and time period as well as age class data.

4.9.3. Reference Conditions

The reference conditions listed in Table 4.9.3-1 identify the potential range of conditions for good and moderate/significant concern for beardtongue. Although basic life history characteristics have been described, there have been few long-term studies and much about the species remains unknown. Furthermore, the three studies used to assess beardtongue's response to disturbance occurred outside of the monument. While these studies mimic the types of disturbances that may occur within the monument, they may not reflect actual response to disturbances within the monument. For these reasons, we did not assign a condition for the measures of population structure or response to disturbance.

4.9.4. Condition and Trend

Presence/Absence

Beardtongue occurred in eight of the 22 vegetation associations mapped by Hansen et al. (2004). The vegetation associations in which beardtongue were found are listed in Table 4.9.4-1. Beardtongue most frequently occurred in the ponderosa pine/cinder woodland association but was also found in the pinyon pine - (Utah juniper)/blue grama woodland (not mapped in the monument) and ponderosa pine/Apache plume woodland associations. These plant associations comprise 442 ha (1,092 ac), or 36% of the

Table 4.9.3-1. Reference conditions used to assess Sunset Crater beardtongue in Sunset Crater Volcano NM.

Indicator	Measure	Good	Moderate/Significant Concern
Prevalence	Presence/Absence	Beardtongue occurs in a wide variety of plant associations, reflecting broad distribution.	Beardtongue occurs within a narrow range of habitat types.
Population Structure	# Plants/Life Stage	Demographics suggest a stable or growing population.	Demographics suggest a declining population.
Response to Disturbance	Prescribed Fire	Beardtongue tolerates or benefits from disturbance.	Beardtongue does not tolerate disturbances and possibly declines with disturbance.
	Root Trenching	Beardtongue tolerates or benefits from disturbance.	Beardtongue does not tolerate disturbances and possibly declines with disturbance.
	Salvage Logging	Beardtongue tolerates or benefits from disturbance.	Beardtongue does not tolerate disturbances and possibly declines with disturbance.

Table 4.9.4-1. Plant associations containing beardtongue, mean beardtongue cover, and mean total ground cover.

Association	# Total Plots with Beardtongue (# NPS Plots with Beardtongue) of Total Sample Plots in Plant Association	Mean Beardtongue Cover (%)	Mean Total Ground Cover (%)
Sand bluestem (*Andropogon hallii*) Colorado Plateau Herbaceous Vegetation	2 (2) of 2	0.25	8.5
Apache plume - tasselflower brickellbush (*Brickellia grandiflora*) - (rock spirea [*Holodiscus dumosus*]) Scree Shrubland	1 (0) of 3	0.17	7.6
Mountain muhly (*Muhlenbergia montana*) herbaceous vegetation	1 (0) of 1	0.50	25.0
Pinyon pine - (Utah juniper)/blue grama woodland	4 (0) of 7	0.07	6.0
Ponderosa pine/cinder woodland	9 (1) of 22	0.02	3.0
Ponderosa pine/Apache plume woodland	4 (1) of 26	0.02	4.0
Ponderosa pine - (quaking aspen [*Populus tremuloides*])/Apache plume (rock spirea) lava bed sparse vegetation	1 (0) of 5	0.10	2.4
Quaking aspen/cinder woodland	1 (1) of 1	0.50	4.0
Douglas fir/mountain muhly forest	1 (0) of 1	0.50	13.0

Source: NPS 2016d.

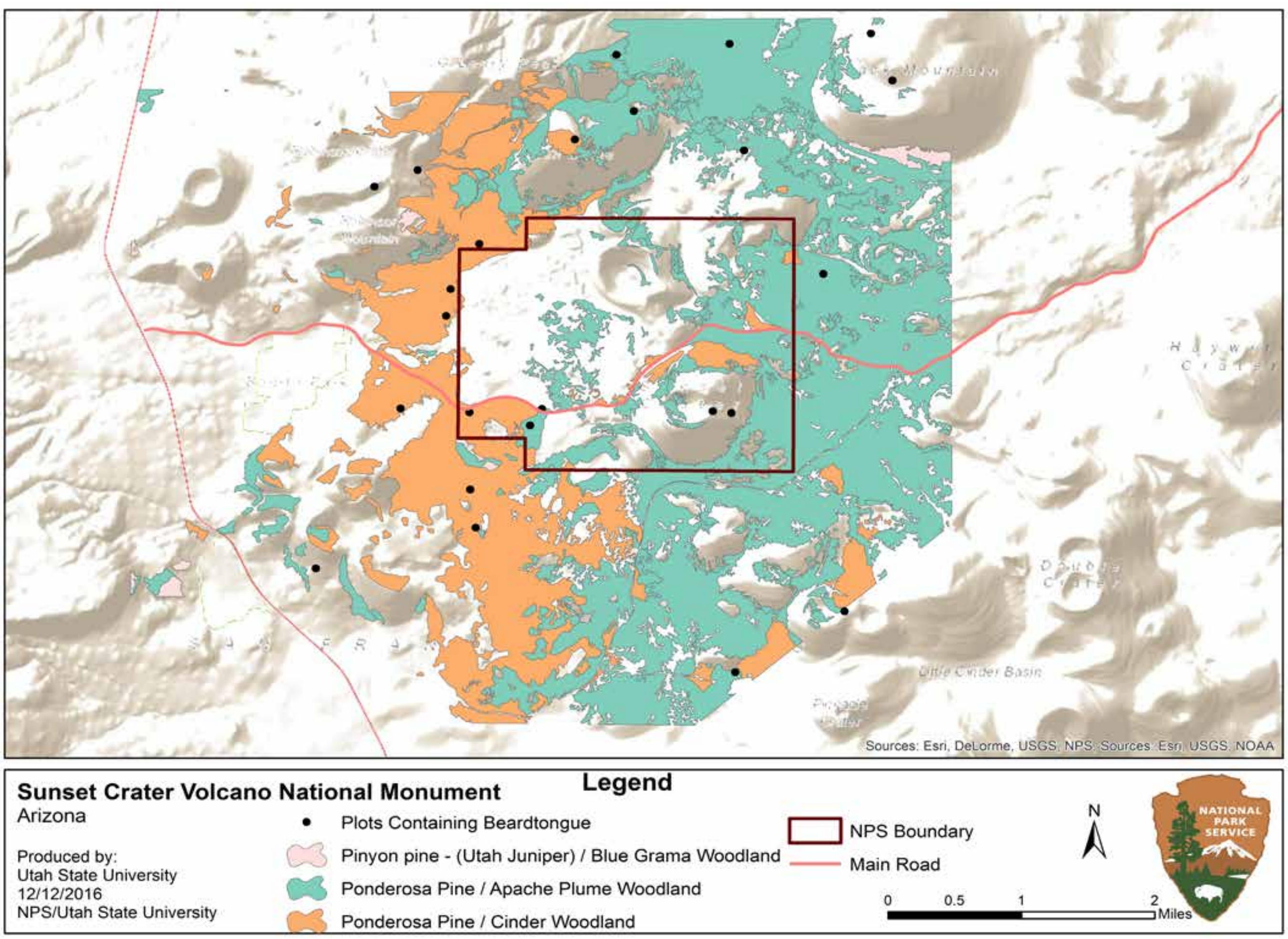


Figure 4.9.4-1. Map showing the three most common habitat associations for Sunset Crater beardtongue in and around Sunset Crater Volcano NM.

monument's total area and indicate that the available habitat for beardtongue is widespread in Sunset Crater Volcano NM (Figure 4.9.4-1).

Although beardtongue was found in a variety of vegetation associations, the species was still relatively uncommon. Only 24 of the 114 relevé plots contained beardtongue (includes inside and outside the monument), and only five of those plots occurred within the monument. Percent cover in the eight plant associations containing beardtongue ranged from 0.02% to 0.5% cover (Table 4.9.4-1). Although beardtongue cover was low, total cover for the ground layer was also low. Average percent cover of all ground vegetation in the eight associations ranged from 3% to 25%. Low vegetation cover is characteristic of the monument's flora in general and beardtongue habitat in particular. Although these data indicate good condition for presence/absence, the mapping effort was not designed to address a species that is patchily distributed. Therefore, we consider the condition good, but assigned low confidence. Furthermore, these data are nearly 20 years old. Trend could not be determined since this was a one-time field and mapping effort.

# of Plants/Life Stage

Across the 28 plots surveyed in both the CNF and the monument there were more mature plants than juveniles and seedlings (Springer et al. 2010). Of the 60 individual plants mapped in the six monument plots about half (31) were classed as seedlings, juveniles, or young reproductive plants (Figure 4.9.4-2). The remaining plants were categorized as mature, senescing, or dead. Juveniles and mature plants represented the largest age classes. The relatively low abundance of seedlings was attributed to high seedling mortality, probably as a result of harsh growing conditions or a lack of disturbance (Springer et al. 2010). The authors note that the six age classes used in this study are not true age classes and that the age at which plants remain reproductively mature is unknown (Springer et al. 2010). Although individuals are thought to live 5-10 years, this is also unknown because individual plants have not been monitored throughout their life cycle (Springer et al. 2010). Since the life history strategy for beardtongue is unknown, and population life stages may fluctuate dynamically within relatively short periods of time, we did not assign a condition for this measure. We could not determine trend since there is only one year of data; however, a repeat study is planned for summer 2017 contingent upon funding. Confidence is low

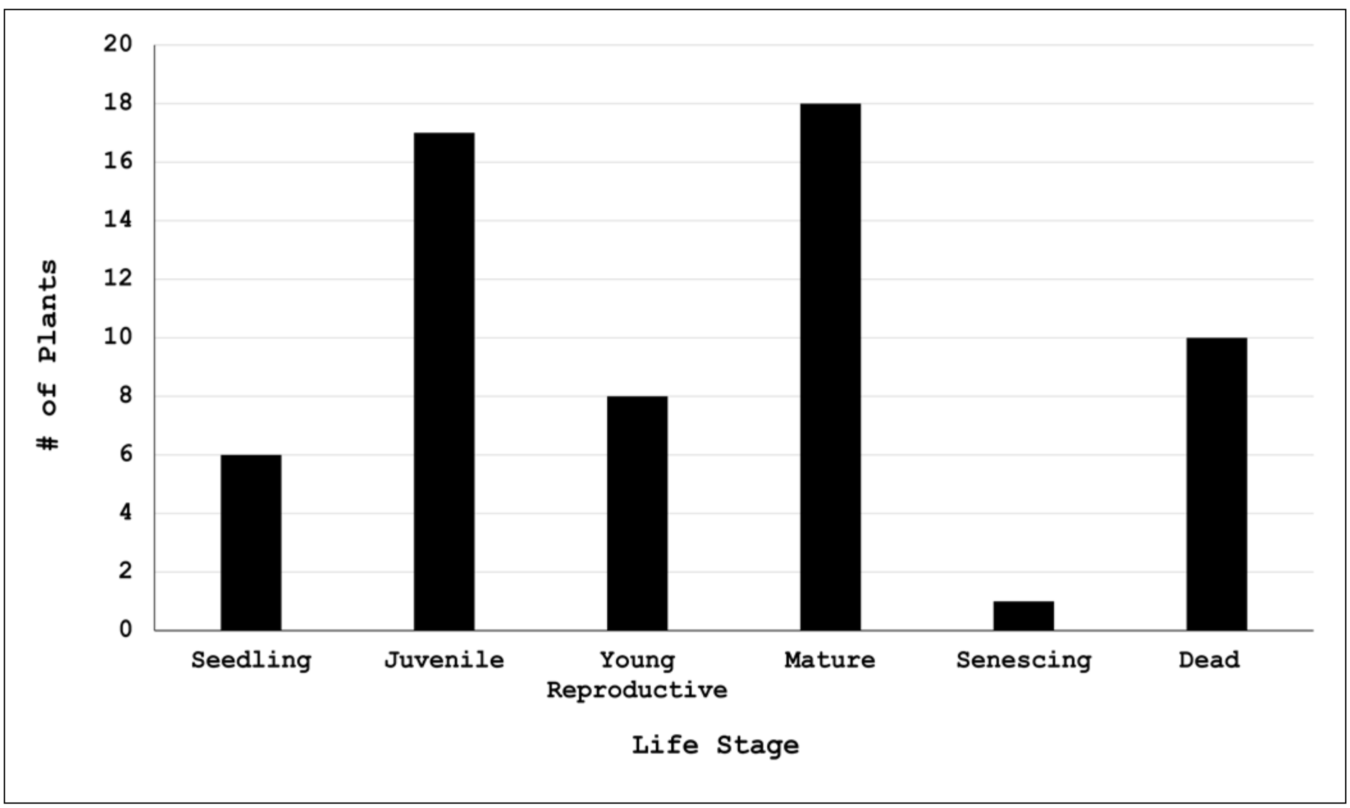


Figure 4.9.4-2. Number of Sunset Crater beardtongue plants in each of six life stages in Sunset Crater Volcano NM.

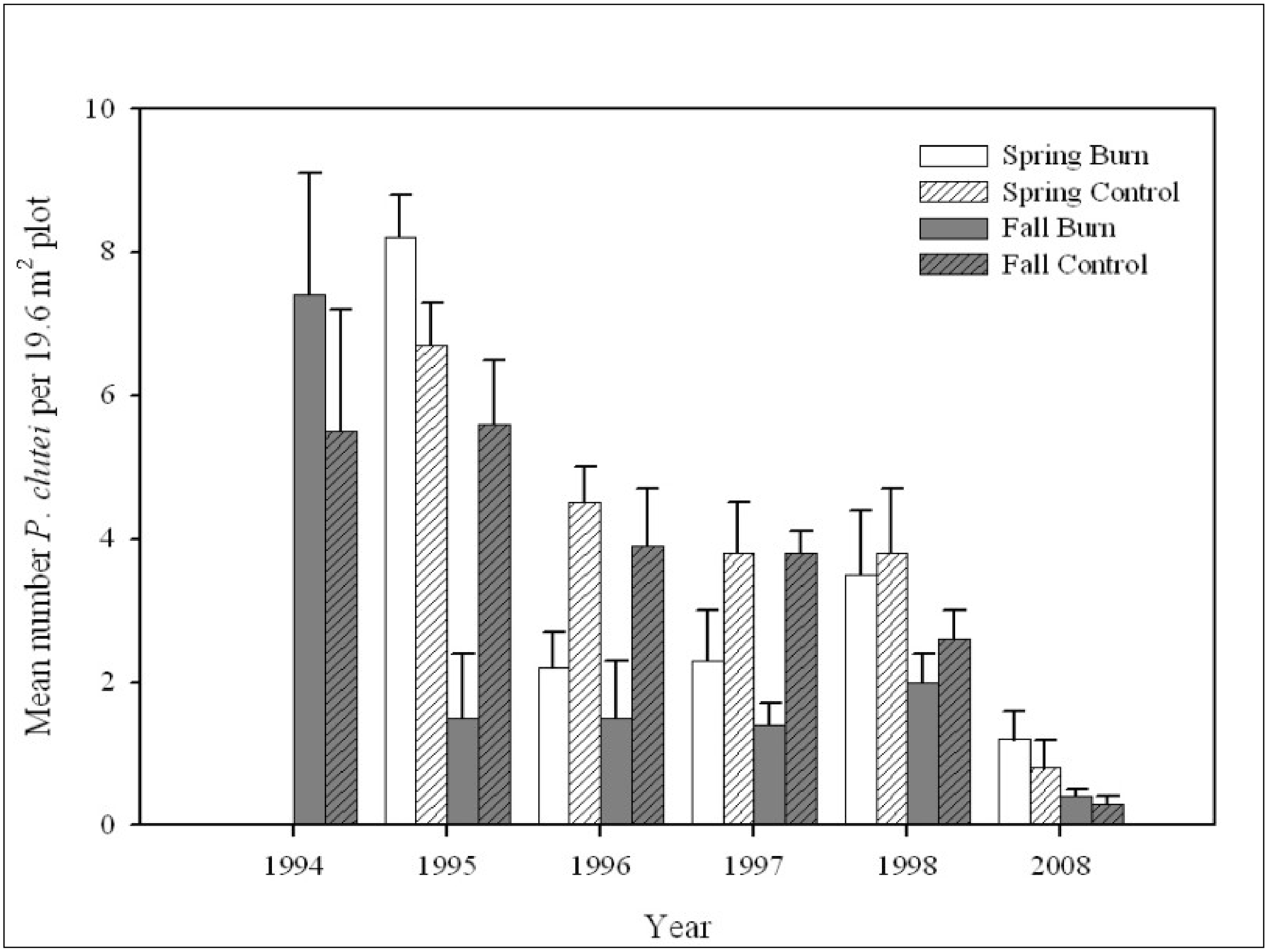


Figure 4.9.4-3. Number of Sunset Crater beardtongue plants in root trenched and control plots from 1997-2008 in the Coconino National Forest.

since the condition rating is unknown, only six plots were monitored within the monument, and data were collected seven years ago.

Prescribed Fire

Over the total period of measurements, burning caused a significant decline in the number of plants per plot, regardless of burn season or elevation (Figure 4.9.4-3). However, beardtongue also declined in control plots. By the end of the experiment in 2008, there was no difference in plant density between burn and control plots. Density in all burned plots averaged 0.9 live plants, while density in control plots averaged 0.6 live plants. Burning killed reproductively mature plants, which may have decreased the soil seedbank for future recruitment. These results conflict with anecdotal observations from two fires in the region. Beardtongue was considered a "pioneering species" following the Burnt Fire in 1973, which occurred west of the monument, and vigorous growth was observed after the Hochderffer Fire in 1996 (Goodwin 1984, Fulé et al. 2001). These apparent differences may be due to fire severity. Of the 18 seedlings that grew from seeds collected from the soil seedbank of burned and unburned plots nearly all (94%) emerged from unburned plots. These data suggest that prescribed fire may inhibit beardtongue survival and lower the soil seedbank. We did not assign a condition for this measure since the study did not occur within the monument. Confidence is low because the condition could not be determined for the monument. Since the condition is unknown, we did not assign a trend.

Root Trenching

Overall, plant density was lower in control plots vs. root trenched plots, even pre-treatment; however, differences were not significant for pre-treatment and control plots (Figure 4.9.4-4). One year after root

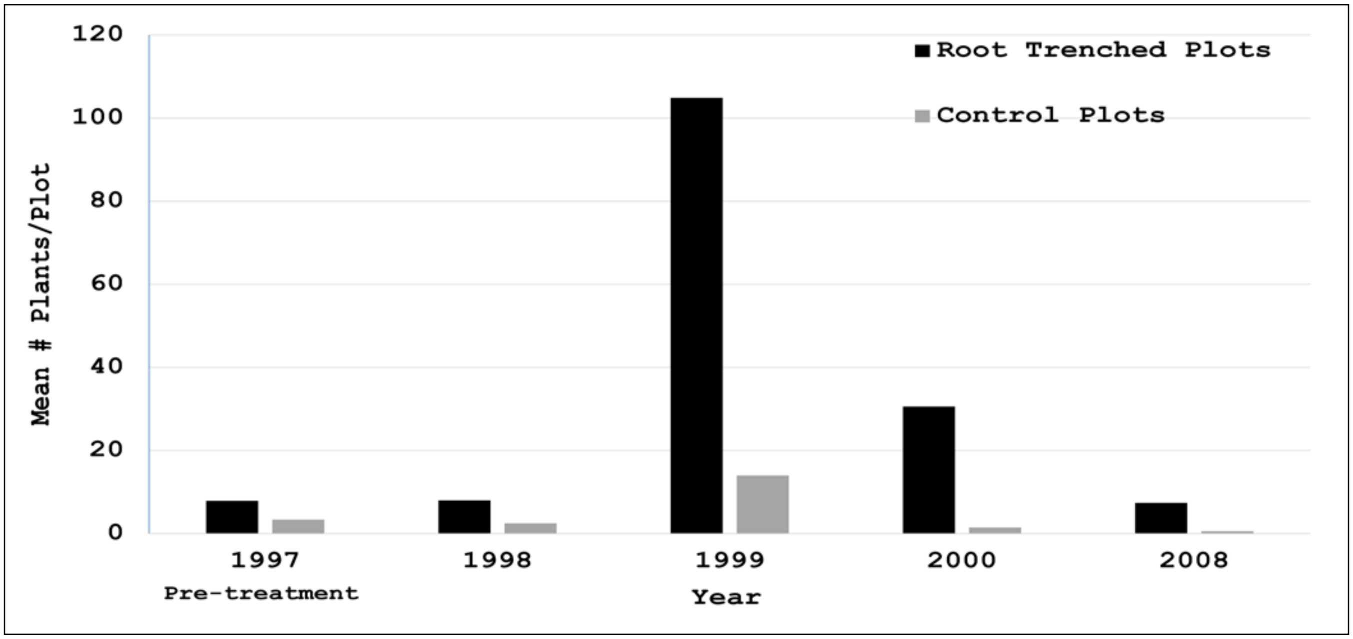


Figure 4.9.4-4. Number of Sunset Crater beardtongue plants in prescribed burn and control plots in the Coconino National Forest. Figure Credit: © Springer et al. (2012).

trenching there was a significant difference in density between trenched plots (104.9 plants/plot) and control plots (14.0 plants/plot). This suggests that removal of below-ground root competition has an immediate positive effect on reproduction. Both treatment and control plots declined in subsequent years, but root trenched plots always contained significantly more plants than control plots. Root trenched plots also contained more living individuals than control plots. The positive effects of root trenching may be attributed to increased soil moisture and/or reduced competition for nutrients (Springer et al. 2012). Only four seedlings emerged from samples collected from the root trenched and control plots; three of them emerged from the trenched plots and one emerged from control plots. Overall, root trenching had a positive effect on beardtongue and this positive effect was evident 10 years later. We did not assign a condition for this measure since the study did not occur within the monument. Confidence is low because the condition is unknown. Since the condition is unknown, we did not assign a trend.

Salvage Logging

From 1992 to 1994 the population of beardtongue increased in the two salvaged forest stands. The western unit contained 831 plants in 1992 (pre-harvest) and 2,099 plants in 1994 (post-harvest). The southeastern unit contained 110 plants in 1992 and 285 plants in 1994. Of the 285 plants documented in the southeastern unit during 1994, 200 were classified as seedlings and 85 were classified as adults. Age class data were not provided for the western unit nor for the pre-harvest southeastern unit, although the author indicates that most of the 110 plants counted in the southeastern unit during 1992 were seedlings. These data indicate an increase in population size following disturbance created by the tornado itself and/or subsequent salvage logging; however, the mechanism behind the population increase is unknown. The author attributes at least some of the population increase to the salvage logging via seed dispersal from log skidding (Crisp 1996). Salvage logging occurred during the winter when the soil was mostly frozen, which limited the potential for destroying the soil structure that is important for beardtongue. Beardtongue grows in cinder soils that are about 5-13 cm (2-5 in) deep, usually with a silty layer beneath the cinders that helps retain water during periods of drought (Huisinga and Hogan 2000).

Although some individual plants were destroyed by heavy machinery, the overall population increased, which indicates beardtongue can tolerate, and may even require, a high level of disturbance. We did not assign a condition for this measure since the study did not occur within the monument. Confidence is low because the condition is unknown. Trend could not be determined.

Overall Condition, Trend, Confidence Level, and Key Uncertainties

Overall, we consider the condition for beardtongue in the monument to be unknown (Table 4.9.4-2). Confidence is low and the trend could not be determined. The condition is unknown since only one study specifically investigated beardtongue within the monument. While this study provided useful information, data were collected in only six plots seven years ago (Springer et al. 2010). Although beardtongue was found in a few of the plots surveyed by Hansen et al. (2004), this may be a reflection of the study design, which was not intended to specifically map beardtongue. The remaining studies related to disturbance were all conducted outside of the monument and do not inform the current condition of beardtongue within the monument (Crisp 1996, Fulé et al. 2001, Springer et al. 2012). Personal observations of NPS staff indicate available habitat for beardtongue is widespread within the monument, and although the species is patchily distributed, NPS staff describe the species as being "relatively abundant" (Flagstaff NM, P. Whitefield, Natural Resource Specialist, written comments, 6 December 2016). This observation is supported by a survey for beardtongue and other sensitive plants with respect to the development of a trail in the southeastern corner of the monument (NPS 2012b). During the study, nearly 4,000 individual beardtongue plants were documented both within and outside the monument's boundary (NPS 2012b). In general, robust sampling to detect population trends for species with sparse and/or patchy distribution patterns requires careful design and considerably more sampling effort than the studies summarized here.

The data used in this assessment suggest that the beardtongue population will gradually decline in the absence of disturbance, even though individual plants will likely persist for a decade or longer (Springer et al. 2012). Dr. Springer has revisited a few areas that experienced large-scale disturbance and had thriving populations of the plant following disturbance. She observed that with time, the plants really did decrease in number (could be due to herbivory or competition or other factors) but they didn't entirely disappear. So in a sense, they act somewhat as ruderal species – very abundant following disturbance and then fading away, but not completely. In 2017, Dr. Springer will be collecting additional data on the 28 plots in the CNF and the monument, so hopefully will have more information to inform its life history.

Although the previous studies point to the positive effects of disturbance, the threshold of impact remains unclear. The prescribed fire treatment described in Fulé et al. (2001) and Springer et al. (2012) did not appear sufficient to maintain beardtongue, but the population did increase following root trenching and vigorous growth was observed following wildfires on the CNF in 1973 and 1996 (Goodwin 1984, Fulé et al. 2001). This may suggest that fire has a positive effect on beardtongue depending on severity. The fire regime is within the historical range for ponderosa pine forests in the monument (NPS 2009). The historical fire regime is characterized by low-intensity fires every 0-35 years (NPS 2009). Wildland fire use for resource benefit was determined infeasible for the monument because of the fragile volcanic cinder terrain (NPS 2009). However, lightning-caused natural fires may be allowed to burn for resource benefit provided certain conditions are met (NPS 2009). Salvage logging also appeared to benefit beardtongue, and Fulé et al. (2001) noted high plant densities along the Transwestern pipeline and in roadcuts. However, repeated disturbances may eventually negatively affect the species (Fulé et al. 2001).

Lastly of note, three of the four disturbance studies were initiated and continued through an extended drought period beginning in 1996; a period which may still be ongoing. The salvage logging study was conducted during a period of normal to above average precipitation, and also had the only documented increase in sample numbers. Observed declines in the prescribed fire, trenching, and salvage-logging experiments may be due to prolonged soil moisture deficits and lack of reproduction by this short-lived herbaceous species. Similar declines over the same period have been widely documented in many prevalent species across the Arizona-New Mexico Mountains Ecoregion (see other assessments in this report).

Threats, Issues, and Data Gaps

The Cinder Hills OHV area lies at the center of beardtongue habitat (Springer et al. 2012). Unregulated off-road vehicle activity may negatively affect the species, especially with repeated use, but there are no studies that address this potential threat (Figure 4.9.4-5). Other potential threats include herbivory,

Table 4.9.4-2. Summary of Sunset Crater beardtongue indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Prevalence	Presence/ Absence		Beardtongue occurred in eight of the 22 vegetation associations mapped by Hansen et al. (2004). Beardtongue most frequently occurred in the ponderosa pine/cinder woodland association but was also found in the pinyon pine - (Utah juniper)/blue grama woodland and ponderosa pine/Apache plume woodland associations. Although these data indicate good condition for presence/absence, the study does not adequately address a species that is patchily distributed. Therefore we consider the condition good, but assigned low confidence. Furthermore, these data are nearly 20 years old. Trend could not be determined because this was a one-time field and mapping effort.
Population Structure	# Plants/Life Stage		Of the 60 individual plants mapped in the six plots located within the monument about half (31) were classed as seedlings, juveniles, or young reproductive plants. The remaining plants were categorized as mature, senescing, or dead. Juveniles and mature plants represented the largest age classes. Since the life history strategy for beardtongue is unknown, we did not assign a condition for this measure. We could not determine trend since there is only one year of data. Confidence is low because the condition rating is unknown, only six plots were monitored within the monument, and data were collected seven years ago.
Response to Disturbance	Prescribed Fire		Burning caused a significant decline in the number of plants per plot, regardless of burn season or elevation. However, beardtongue also declined in control plots. By the end of the experiment in 2008, there was no difference in plant density between burn and control plots. We did not assign a condition for this measure because the study did not occur within the monument. Since the condition is unknown, confidence is low. We did not assign a trend.
	Root Trenching		One year after root trenching there was a significant difference in density between trenched plots (104.9 plants/plot) and control plots (14.0 plants/plot). This suggests that removal of below-ground root competition has immediate beneficial effects on reproduction. Both treatment and control plots declined in subsequent years, but root trenched plots always contained significantly more plants than control plots. We did not assign a condition for this measure because the study occurred outside the monument. Since the condition is unknown, confidence is low. We did not assign a trend.
	Salvage Logging		From 1992 to 1994 the population of beardtongue increased in the two units. The western unit contained 831 plants in 1992 (pre-harvest) and 2,099 plants in 1994 (post-harvest). The southeastern unit contained 110 plants in 1992 and 285 plants in 1994. This suggests that beardtongue can tolerate, and may even require, a high level of disturbance. We did not assign a condition for this measure since the study did not occur within the monument. Confidence is low because the condition is unknown. Trend could not be determined.
Overall Condition			Overall, we consider the condition for beardtongue in the monument unknown. Confidence is low and trend could not be determined. Most studies have been conducted outside the monument with only one study conducted within the monument. Personal observations of NPS staff indicate beardtongue is widespread and relatively common. This is supported by vegetation mapping data; however, anecdotal observations are insufficient to determine current condition, and the vegetation mapping effort was not designed to survey a widely distributed but patchy species. Therefore, condition cannot be determined without a focused monitoring effort.

Figure 4.9.4-5. Sunset Crater beardtongue in Cinder Hills OHV area. Photo Credit: Springer et al. (2010).

and hybridization with cultivated *Penstemon* species (Glenne 2003 as cited in Springer et al. 2010). But of all the stressors on beardtongue, climate change has the most potential to influence this species (Krause et al. 2015, Krause no date). Monahan and Fischelli (2014) evaluated which of 240 NPS units have experienced extreme climate changes during the last 10-30 years. Extreme climate changes were defined as temperature and precipitation conditions exceeding 95% of the historical range of variability. The results of this study indicate a trend toward extreme warm and extreme dry conditions within the monument (Monahan and Fisichelli 2014), and are indicative of trends occurring throughout the southwestern U.S. (Prein et al. 2016). Although beardtongue is adapted to harsh conditions, a trend toward even harsher conditions could adversely affect the species. A climate model envelope developed by Krause et al. (2015) and Krause (no date) suggests that Sunset Crater beardtongue is at very high climate change risk.

The period of data collection for any of the studies included in this assessment would need to continue into a normal/wet cycle to understand if population declines since 1996 may also be attributed to long-term drought in the region.

4.9.5. Sources of Expertise

Judith Springer (Senior Research Specialist, Northern Arizona University, Flagstaff, Arizona) reviewed a draft of the assessment. Assessment author was Lisa Baril, science writer, Utah State University.

Surface water is rare at Sunset Crater Volcano NM and the volcanic terrain is in the very early stages of ecological recovery. Photo Credit: NPS / C. Schelz.

Chapter 5. Discussion

5.1. Overall Condition Summary

The Colorado Plateau Ecoregion has the highest density of national parks, monuments (including the Flagstaff Area National Monuments (NMs)), and recreational areas than any other location in the United States (AZGFD 2006). However, despite the high number, land managers are increasingly recognizing resource impacts from activities occurring outside their jurisdictions, underscoring the fact that no single agency (or group of agencies) can conserve species survival needs alone. Instead, these protected lands need to be linked with their surrounding landscapes, working together as a whole, especially given the very real threats of climate change and increasing habitat fragmentation.

Sunset Crater Volcano NM's Foundation Document (NPS 2015a) acknowledges that the Flagstaff Area NMs "stand as separate monuments, yet are interconnected through the violent geologic past that shaped and transformed the environment. Each monument contains important physical traces of the cultures, communities, and families that made their homes for thousands of years in the landscape surrounding the San Francisco Peaks. Those physical traces on the landscape, and the landscape itself, tell the story of the human experience through time." The present day landscape continues to tell the story of human habitation and the associated effects of habitat connectivity and fragmentation. Flagstaff Area NM Resource Management staff has worked in partnership with several agencies and stakeholders to proactively manage Sunset Crater Volcano, Walnut Canyon, and Wupatki NMs' resources in such a way that maintains and/or improves resource conditions. These overall condition ratings for Sunset Crater Volcano NM's natural resources are summarized in Table 5.1-1.

5.2. Habitat Connectivity Importance

Some of the greatest threats to wildlife species and biodiversity around the globe are from habitat loss and fragmentation associated with land use changes (Turner 1989, U.S. General Accounting Office 1994, Trzcinski et al. 1999, Fahrig 2003 as cited in Monhan et al. 2012). Habitat loss increases the risk of species extirpation or extinction; thus, maintaining connectivity of habitat is an integral part of protecting species (Crooks and Sanjayan 2006). In general, a connected landscape increases population viability for numerous species (Beier and Noss 1998) but also

Table 5.1-1. Overall condition summary of Sunset Crater Volcano NM's natural resources.

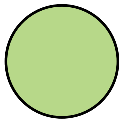
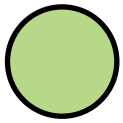
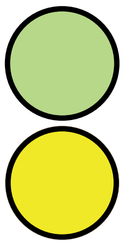
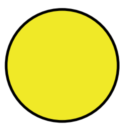
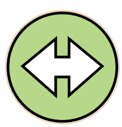
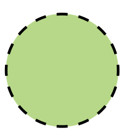
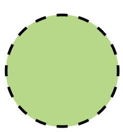
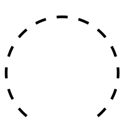
Priority Resource or Value	Condition Status/Trend	Summary of Overall Condition Rating
Viewshed		Viewsheds are an important part of the visitor experience at national parks, and features on the landscape influence the enjoyment, appreciation, and understanding of a particular region. At Sunset Crater Volcano NM, few human-made features are visible within the monument's assessed viewshed. Both housing and road densities are low, resulting in a good condition rating. There are no data available to determine overall trend. Instead, these data may serve as a baseline to make future comparisons. Confidence in this condition rating is medium since the majority of data used were based on models.
Night Sky		Sunset Crater Volcano NM's night sky is in good condition. Two of the three measures for which thresholds have been developed met the threshold for good condition. Although field data were collected over a 12-year period (2001-2012), there were only six data points. Therefore, trend could not be determined. Confidence in this rating is high.
Soundscape		Natural sounds and the absence of human-caused noise are important resources to national park visitors and wildlife. In Sunset Crater Volcano NM, while sound levels rarely exceeded 35 dBA, which is the maximum recommended noise level for bedrooms, the data showed that noise was audible about 49% of the time, warranting an overall condition of good to moderate concern. Confidence in the data is high but trend is unknown at this time.
Air Quality		Overall, we consider air quality at the national monument to be of moderate concern. Vegetation health risk from ground-level ozone warrants significant concern while the haze index, human health risk from ozone, nitrogen, and mercury all warrant moderate concern. Sulfur deposition and predicted methylmercury indicate good condition. Overall confidence in the assessment is medium with an unknown trend, although the haze index indicates unchanging conditions for that measure only.
Volcanic Cinder Terrain		The morphology of the Sunset Crater cinder cone and soil formation are changing very slowly, and while most surfaces of the lava flow are quite resistant to erosion, some of the more delicate features and the presence of social trails causes some concern. Since 1966, there has been no study specifically targeting primary ecological succession on the cinder terrain. Overall, the condition of the resource is good and the trend is stable, though significant data gaps indicate a moderate level of confidence in this conclusion.
Volcanic Resources		Most of the volcanic resources within the Resource Management Preservation Zone remain in pristine to good condition. The impacts that are occurring are located within visitor use and transportation zones, but monument staff consider minor to moderate impacts to volcanic resources in these areas as acceptable, especially since they are relatively rare and isolated. Some areas are also locally impacted by cross-boundary recreational use from adjacent lands, but this activity is occurring within more resilient, vegetated cinder terrain and not in proximity to rare or sensitive volcanic resources. Overall, the volcanic resources are in good condition, although confidence is low and trend is unknown.
Ponderosa Pine and Pinyon Juniper		Overall, we consider the condition of ponderosa pine and pinyon-juniper woodlands in Sunset Crater Volcano NM to be good, but our confidence in the assessment is low. For two measures, the condition was good, and for one measure the condition was good to of moderate concern. Confidence in two of the measures was low, while that for one measure was medium. Trends are unknown.
Sensitive Trees		Douglas-fir, quaking aspen, and southwestern white pine are known to occur within Sunset Crater Volcano NM, but detailed and current information on their presence is lacking. These trees are considered sensitive and vulnerable to possible conditions (drought, high temperatures, severe wildfire, pests/disease) due to their apparent relatively low levels of occurrence within the monument. Overall condition and trend are unknown, and confidence is low

Table 5.1-1 continued. Overall condition summary of Sunset Crater Volcano NM's natural resources.

Priority Resource or Value	Condition Status/Trend	Summary of Overall Condition Rating
Sunset Crater Beardtongue	(dashed circle)	Overall, we consider the condition for beardtongue in the monument as unknown. Confidence is low and trend could not be determined. Most studies have been conducted outside the monument with only one study conducted within the monument. NPS staff observations indicate beardtongue is widespread and relatively common. This is supported by vegetation mapping data; however, anecdotal observations are insufficient to determine current condition, and the vegetation mapping effort was not designed to survey a widely distributed but patchy species. Therefore, condition cannot be determined without a focused monitoring effort.

maintains or improves conditions of abiotic resources such as scenic views, natural quiet, and dark night skies— resources that most park visitors value and appreciate and that certain wildlife species require for their survival.

In 1980, the National Park Service (NPS) reported that over 50% of threats to park resources were from activities occurring outside park boundaries. Surrounding development, such as roads and railroads, housing/business developments, and air pollution were the most frequently cited concerns (NPS 1980). To further exacerbate these threats, specifically to national park resources, Davis and Hansen's (2011) study of land use change trajectories noted that lands surrounding national parks were altered at a more rapid rate than national averages.

Unfortunately, after almost 40 years, the concerns cited in NPS (1980) and Davis and Hansen (2011) are even more relevant and threatening to park resources today. The reality is that very few national parks are large enough to encompass a self-contained ecosystem to adequately conserve species' life cycle needs (Monahan et al. 2012). Thus, partnerships that focus on landscape-scale conservation goals are critical for achieving resource sustainability.

5.2.1. Arizona and Coconino County Population

Throughout the state of Arizona, the population is expected to increase from almost 6.5 million in 2010 to more than 14 million by 2050 (Arizona Department of Transportation [ADOT] 2010, U.S. Census Bureau 2011, both as cited by AGFD 2011). This same source notes that the population of Coconino County, where the Flagstaff Area National NMs are located, may increase by more than 50% by the year 2050. Based on 2010-2015 data, the populations of both Coconino County and Flagstaff, AZ have increased over the five-year period since April 2010, increasing 3.5% and 6.4%, respectively (U.S. Census Bureau 2016a).

5.2.2. Preserving State-wide and Coconino County Habitat Connectivity

In 2004, a group of concerned land managers and biologists from federal, state, and regional agencies, along with researchers from Northern Arizona University (NAU) formed the Arizona Wildlife Linkages Workgroup (AWLW). The workgroup identified critical areas that would help preserve Arizona's diverse natural resources in the midst of the state's rapid population growth. They identified and mapped large areas of protected habitat (i.e., habitat blocks) and the potential linkages (i.e., matrix) between these blocks. This effort became known as the *Arizona Missing Linkage*s project, identifying 152 statewide coarse-level linkage zones (AWLW 2006). The Deadman Mesa – Gray Mountain linkage was the only one associated with any of the Flagstaff Area NMs, with Wupatki NM's western boundary accounting for 3% of the linkage area along Highway 89 (AWLW 2006).

Following AWLW's statewide effort, in 2009 and 2010 the Arizona Game and Fish Department (AGFD), in partnership with Coconino County and the AWLW, developed a *Wildlife Connectivity Assessment Report* for Coconino County (AGFD 2011). The goal of this effort was to facilitate the maintenance and enhancement of wildlife connectivity throughout the county. The linkages identified were intended to be used as a starting point to assist future finer-scale evaluations of habitat connectivity throughout the county. Several of the linkages identified in Coconino County are associated with the three Flagstaff Area NMs.

Coconino County encompasses an area of 48,332 km^2 (18,661 mi^2), with Wupatki, Walnut Canyon, and Sunset Crater Volcano NMs protecting a little over 170 km^2 (~65.6 mi^2) of public land combined. And while the national monuments are managed as one administrative unit, they are separated by approximately 17.7 km (11 mi) between Walnut Canyon NM and Sunset Crater Volcano NM and about 17.1 km (10.6 mi) between Sunset Crater Volcano NM and Wupatki NM (as a straight line distance from the northern boundary of the first stated monument to the southern boundary of the second monument). The physical separation of the monuments, some of which support the same wildlife species, presents unique management challenges and opportunities, which is why monument staff were interested in evaluating the habitat connectivity between the three national monuments as part of their NRCA effort.

According to Monahan et al. (2012), "the importance of habitat area and pattern is readily apparent for parks, but it is nonetheless difficult to identify a small suite of metrics that adequately describe area and pattern characteristics in ways that generally inform decisions on how to manage park resources. Many people want to know, for example, whether large intact patches of habitat still exist, without reference to any particular species or other resource. [However,] the most important habitat features vary according to question, species, or issue. For example, structural connectivity measures physical attributes without any consideration to species or ecological function. [Conversely], functional connectivity measures landscape attributes, such as land cover type, elevation, distance from roads, etc., that are relevant to an identified species or process." As a result, habitat connectivity "is shaped by both pattern and the attributes of what is moving" (Monahan et al. 2012). It is within this functional connectivity context that NAU scientists developed tools to assist others in evaluating habitat connectivity on a landscape-scale. While NRCAs are not designed to report on conditions outside a park's boundary, an evaluation such as this can serve as an initial step to identify areas that may be of high conservation value, thereby, working "for connectivity than against fragmentation" (Beier et al. 2008).

5.3. Habitat Connectivity Methods

5.3.1. Arizona CorridorDesigner and Area of Analysis Characteristics

Identifying functional habitat connectivity between the three national monuments required several steps throughout the analysis process. These steps or decision points are listed in Appendix F, Table F-1, using a framework developed during NAU's *Arizona's Missing Linkages* (AWLW 2006) and *South Coast Wildlands 2003-2006* (Penrod et al. 2006) wildlife linkages projects. NAU conservation biologists and GIS analysts developed this decision framework along with two GIS toolboxes, CorridorDesigner and Arizona CorridorDesigner (2007-2013) (Beier et al. 2008, Majka et al. 2007), to guide end-users in creating "a transparent, rigorous rationale for a linkage design."

To begin the Flagstaff Area NMs' connectivity evaluation process, an area of analysis (AOA) needed to be determined. Through an extensive literature review of ecologically-relevant AOAs, Monahan et al. (2012) identified a 30 km (18.6 mi) radius from a park's boundary as sufficient for meeting most park's natural resource survival needs (NPS 2011b). Following this guidance, a dissolved 30 km buffer surrounding each of the three Flagstaff Area NMs' boundaries served as the entire AOA, totaling 7,489 km^2 (2,891.5 mi^2) (Figure 5.3.1-1, Table 5.3.1-1). The land within each monument's legislated boundary served as the habitat blocks from which the matrix or connectivity between the monuments was evaluated. Each individual monument and its surrounding 30 km (AOA) is discussed in more detail within its respective NRCA report, although a certain degree of overlap exists between the three monuments' habitat connectivity discussions given the nature of the topic.

Sunset Crater Volcano NM encompassed the smallest 30 km AOA (shown as a thicker black polygon in subsequent figures), totaling 3,254 km^2 (1,256 mi^2) or 43.4% of the entire Flagstaff Area AOA. Sunset Crater Volcano NM's 30 km AOA extends just north of Wupatki's northernmost boundary. It then extends to the east about 8 km (5 mi) into the Navajo Reservation then south, encompassing all of Walnut Canyon NM and extending approximately 8 km (5 mi) south of Flagstaff, AZ. Sunset Crater Volcano NM's western AOA boundary includes San Francisco Mountain and almost 48 km (30 mi) of Highway 180. The entire 30 km AOA is bisected by Highway 89 and Interstate 40. Information specific to Wupatki and Walnut Canyon

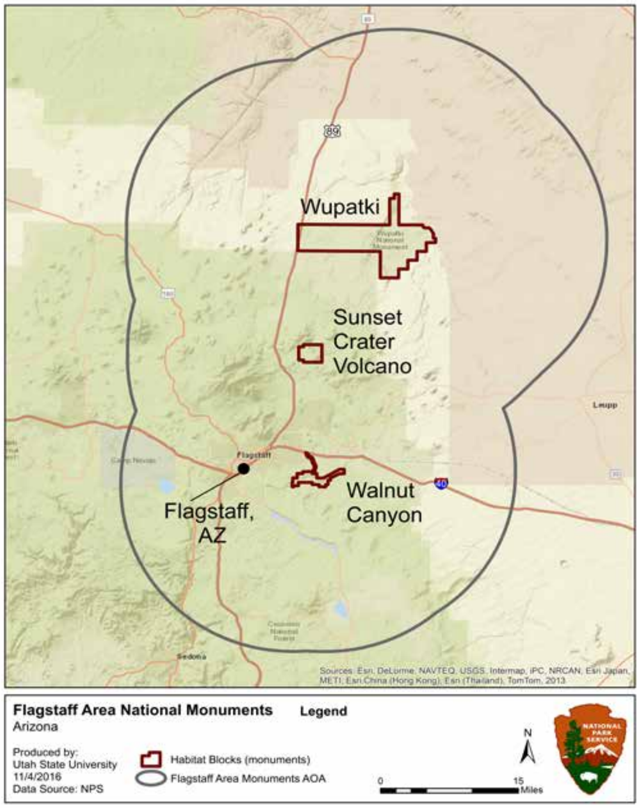


Figure 5.3.1-1. The entire area of analysis for Flagstaff Area NMs' habitat connectivity evaluation is 7,489 km².

NMs is also presented in Table 5.3.1-1 but is further discussed within each of their respective NRCA reports.

Conservation Status

The U.S. Geological Survey (USGS) (2016b) Gap Analysis Program (GAP) Protected Areas Database (PAD)-US version 1.4 conservation status metric was used to calculate the percentage of Flagstaff Area NMs' 30 km AOA that is classified as GAP status 1-4 categories (1 = highest protection, 4 = lowest protection) (refer to Appendix F for category definitions) and the percentage of broad ownership categories (e.g., federal, state, tribal, etc.). According to Monahan et al. (2012), "the percentage of land area protected provides an indication of conservation status and offers insight into potential threats (e.g., how much land is available for conversion and where it is located in relation to a park's boundary), as well as offers insights into potential opportunities (e.g., connectivity and networking of protected areas)."

Within the entire Flagstaff Area AOA, 42,606 hectares (ha) (105,282 ac) (5.7%) of land is designated as permanently protected and managed for biodiversity (dark and light green areas shown in Figure 5.3.1-2). Disturbance events on 39.5% of the permanently protected lands are allowed, whereas events are suppressed on the remaining 60.5% of those permanently protected lands. Another 331,835 ha (819,983 ac) (44.3%) of land within the entire AOA is managed for multiple uses, such as logging, mining, etc. (yellow areas shown in Figure 5.3.1-2). The U.S. Forest Service (USFS) and Bureau of Indian Affairs are the primary agencies managing 363,302 ha (897,739 ac) (48.5%) and 242,425 ha (599,046 ac) (32.4%) of the land throughout Flagstaff Area NMs 30 km AOA.

Table 5.3.1-1. Area of analysis summary.

Area	Sq. km	Sq. Miles	% Total
Entire AOA	7,489	2,891.5	100
Wupatki NM	4,917	1,898	65.7
Sunset Crater Volcano NM	3,254	1,256	43.4
Sunset Crater Volcano NM	3,607	1,393	48.1
Area of Overlap	1,096	423	14.6

The conservation status of lands specifically within Sunset Crater Volcano NM's 30 km AOA is largely comprised of lands that are managed for multiple uses (yellow areas on Figure 5.3.1-2), such as extraction or off-road vehicle use, accounting for 65% of land within its AOA with a designated conservation status. An additional 12% of the land within Sunset Crater Volcano NM's AOA is permanently protected, including the areas within Walnut Canyon and Wupatki NMs. The white areas shown in Figure 5.3.1-2 represent potentially unprotected or privately held land and include the city of Flagstaff, AZ.

5.3.2. *Arizona CorridorDesigner Models*

The Arizona CorridorDesigner toolbox was developed to assess habitat suitability and size of breeding areas for 16 mammal and 12 herpetofauna Arizona wildlife species. In turn, these models are used to develop wildlife corridor models. For Sunset Crater Volcano NM, five native wildlife species (American badger (*Taxidea taxus*), American black bear (*Ursus americanus*), American pronghorn (*Antilocapra americana*), mountain lion (*Puma concolor*), and mule deer (*Odocoileus hemionus*), are listed on its species

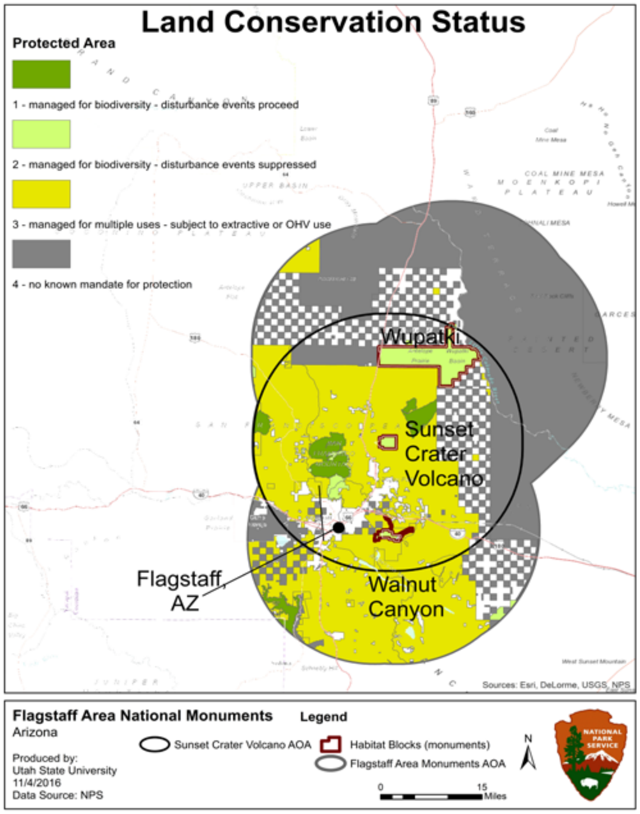


Figure 5.3.1-2. Conservation status of lands within the entire area of analysis surrounding Flagstaff Area NMs.

list (NPS 2016b) and were selected to evaluate habitat connectivity between its boundary and Walnut Canyon and Wupatki NMs. These species and their associated selection criteria are presented in Table 5.3.2-1.

The Arizona CorridorDesigner toolbox outputs for each species included three models that were mapped at a 30 m x 30 m (98 ft x 98 ft) resolution: 1) habitat suitability models (HSM), 2) patch models (PM), and 3) corridor models (CM). Four datasets were used to create a HSM for each species: 1) Southwest Regional Gap Analysis Project (SWReGAP) land cover (USGS 2004), 2) U.S. Geological Survey's (USGS 2016a) National Elevation Dataset (NED) digital elevation model (DEM), 3) topography, and 4) distance from roads.

Subject matter experts identified attributes within each dataset to serve as proxies for each of the species' survival needs, including cover, food, hazard avoidance, reproductive habitat needs, etc. If an expert was unavailable, three biologists independently reviewed the scientific literature and assigned scores then compared their results to calculate an average score (Majka et al. 2007).

Land Cover

The SWReGAP land cover dataset was categorized into 46 vegetation classes creating 10 broad categories, such as evergreen forest or grassland-herbaceous vegetation. By grouping the closely related vegetation types, the accuracy of the models improved (Beier et al. 2008). Using the entire Flagstaff Area NM 30 km AOA, the SWReGAP's land cover dataset was clipped, and resulted in all 10 land cover types occurring within the AOA (Figure 5.3.2-1). Shrub-scrub (tan), grassland-herbaceous (light green), and evergreen forest (dark green) are the dominant land cover types throughout the AOA and are situated along a northwest to southeast gradient from north to south. The primary land cover types within Sunset Crater Volcano NM's

Table 5.3.2-1. Arizona CorridorDesigner wildlife species selected for Sunset Crater Volcano NM's habitat connectivity assessment and their associated weighted habitat factors.

Common Name	Scientific Name	Species Selection Criteria	Land Cover	Elevation	Topography	Distance From Roads
American badger	*Taxidea taxus*	Large home range; many protected lands are not large enough to ensure species' life cycle.	65	7	15	13
American black bear	*Ursus americanus*	Requires habitat variety; low population densities makes them vulnerable to habitat fragmentation.	75	10	10	5
American pronghorn	*Antilocapra americana*	Susceptible to habitat fragmentation and human development; sensitive to barriers.	45	0	37	18
Mountain lion	*Puma concolor*	Requires a large area of connected landscapes to support even minimum self sustaining populations.	70	0	10	20
Mule deer	*Odocoileus hemionus*	Important prey species; road systems may affect the distribution and welfare of species.	80	0	15	5

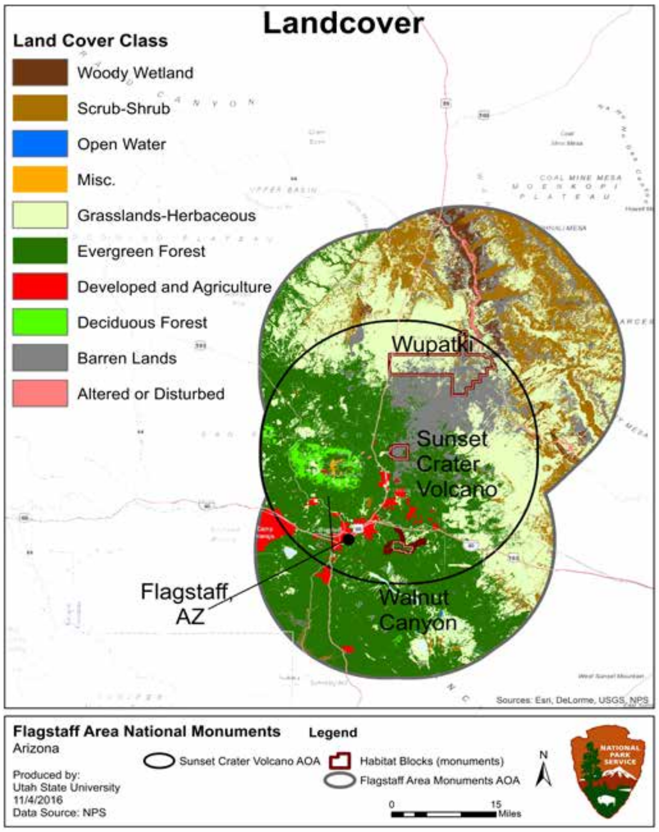


Figure 5.3.2-1. Land cover classes within the Flagstaff Area NM 30 km area of analysis.

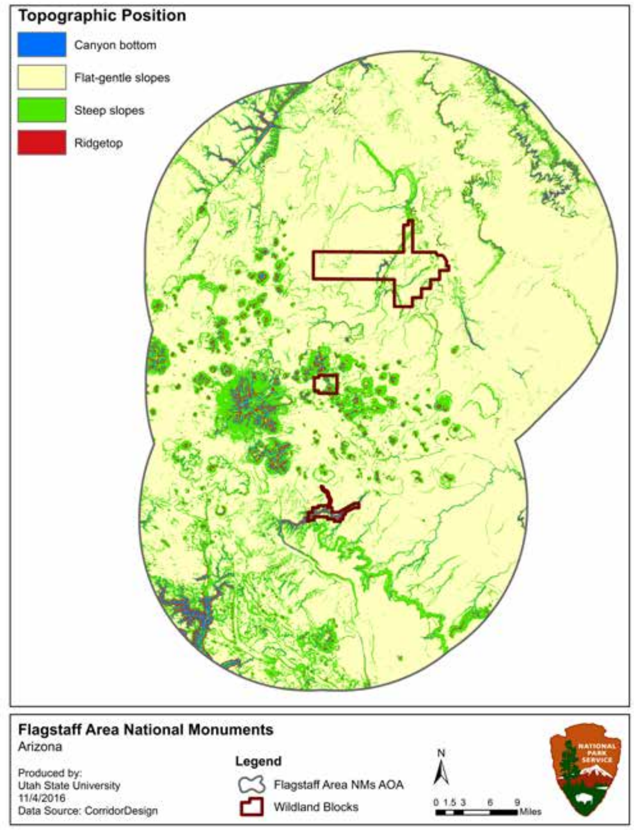


Figure 5.3.2-2. Topographic position within the Flagstaff Area NM 30 km area of analysis.

30 km AOA were evergreen forest and grassland-herbaceous, followed by barren land, (representing the volcanic-derived landscape between Sunset Crater Volcano and Wupatki), and developed land, including the city of Flagstaff, AZ and developments, such as subdivisions north of Walnut Canyon NM.

Topography

Using the USGS (2016a) NED DEM, topographic features such as aspect and slope were analyzed to create topographic position categories (i.e., canyon bottom, flat-gentle slopes, steep slopes, and ridgetop; Figure 5.3.2-2). These features were ranked for each species based on their survival needs. For example, Ockenfels et al. (1996) noted that pronghorn avoid canyon walls due to the increased likelihood of mountain lion predation and instead prefer flat to gently rolling terrain where they are able to easily detect predators. This topographic preference is shown in Table 5.3.2-1, with the highest topography rank of 37% assigned to pronghorn, reflecting its sensitivity to this feature.

Elevation and Distance from Roads

Elevations were identified for each species also using the USGS (2016a) NED DEM. And finally, distance to nearest roads was used as a proxy for disturbance avoidance. Beier et al. (2008) suggested not including crossing structures in the habitat connectivity evaluation process since it "forces the position of a modeled corridor, which may in fact be a suboptimal location."

Scoring System

Four scores, based on a scale of 1 (best habitat) to ten (worst habitat), were assigned to each grouping or class of attributes within each of the four datasets for a given species. Each 30 m x 30 m pixel was assigned a score between 1 and 10 then each factor was weighted by a factor between 0 - 100%, summing to 100%. The four weighted scores were combined using a weighted geometric mean to "better reflect situations in which one factor limits wildlife movement in a way that cannot be compensated for by a lower resistance for another factor" (UWFWS 1981 as cited in Beier et al. 2008). This scoring process created the HSMs for each species, which were then used to create the PMs and

CMs (refer to Beier et al. 2008 for a detailed account of the methodology involved in developing these models).

The HSMs identified five classes of habitat suitability for each species based on the weighted habitat factors. The five classes ranged from absolute non-habitat to optimal. Areas of habitat large enough to support breeding populations were identified using neighborhood analysis, creating PMs. The PMs were grouped by size into three classes: less than (<) breeding patch, breeding patch, and population patch. The population patch was the largest area of the three classes and represented the ability to support the breeding requirements of a given species for 10 or more years, even if isolated from interaction with other populations of the species (Majka et al. 2007). The breeding patch represented a "core" area for each species and was smaller than a population patch but large enough to occasionally support a single breeding event and serve as a potential "stepping stone" within a corridor linkage (Beier et al. 2008).

Finally, the third model type, CM, was created by identifying well-connected pixels in the HSMs and PMs that represented the easiest area for a particular species to move through. This is based on the assumption that the habitat requirements for each species survival are the same ones needed for their movement patterns (Beier et al. 2008). The habitat patches within the wildland blocks (i.e., monuments) were used as the corridor terminuses, and the travel cost was mapped as increasingly wide polygons sliced into 11 different widths (i.e., 0.1%, 1-10%). The smallest slice (i.e., 0.1%) represented the least amount of effort or resistance for a species to move through. As the corridor widths increased, so did practical constraints that would affect realistic conservation efforts by land managers. As a result, each species largest corridor width was selected based on its home range size, using information provided in Majka et al. (2007). Finally, all selected CM slices were unioned (and minimally trimmed only when an area represented one species but suitable habitat was available nearby within the remaining corridor), showing potential areas of connectivity to facilitate movements of the selected species. The output of this phase of the evaluation process is referred to as the preliminary linkage design (PLD).

5.4. Preliminary Linkage Design Results

The PLD for Sunset Crater Volcano NM, shown in Figure 5.4.1-1, resulted in two primary areas linking Sunset Crater Volcano to Walnut Canyon and to Wupatki NMs. Sunset Crater Volcano NM had the lowest number of species modeled for its PLD compared to Wupatki and Walnut Canyon NMs. The PLD is based on the unioned CMs for badger, pronghorn, mountain lion, bear, and mule deer, all of which have been observed within the other two monuments.

Two primary linkage routes were modeled, with one located south of Sunset Crater Volcano NM linking it to the northeastern boundary of Walnut Canyon NM. The southern PLD is comprised primarily of evergreen forest, which is the predominant land cover type that exists between Sunset Crater Volcano and Walnut Canyon. Development is also a predominant land cover type in this linkage.

The southern PLD connects Walnut Canyon NM's northeastern boundary to two locations along Sunset Crater Volcano's southern boundary, with the primary linkage located at Sunset Crater Volcano NM's southwestern corner. Pronghorn, badger, mountain lion, mule deer, and bear are included in the wider area of the southern PLD linkage, shown in Figure 5.4.1-1. Extending from Walnut Canyon NM, the southern PLD crosses I-40/U.S. 180 then extends north to its widest area north of Turkey Hills. The largest (and southernmost) hole in the linkage design is located around Doney Park. Townsend-Winona Road bisects the widest area of the PLD into northern and southern portions and Highway 89 bisects a western portion of the PLD.

Sunset Crater Volcano NM's southern PLD is becoming increasingly developed as the city of Flagstaff expands north and east and numerous subdivisions, either built or planned, are located north of Townsend-Winona Road in the widest portion of the northern PLD. In addition, Slayton Ranch Estates development is located in the middle strand that was modeled for bear only as shown on Figure 5.4.1-1. The easternmost strand of the southern PLD was modeled for mountain lion only and extends north crossing I-40/U.S. 80 east of O'Neil Crater and west of Little Cinder Basin where it joins the middle strand for bear. These two narrow strands finally join and connect to Sunset Crater Volcano NM's southeastern boundary

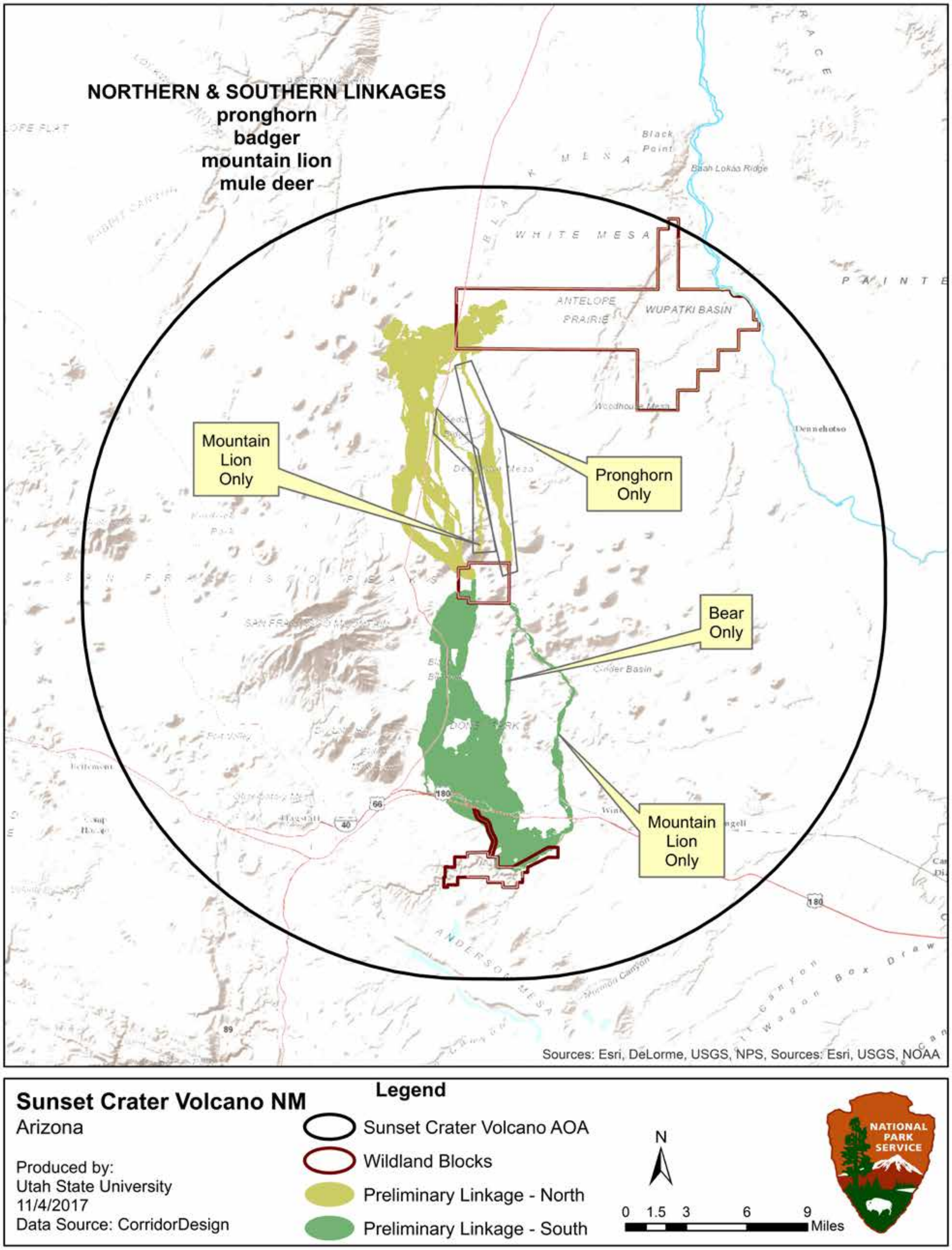


Figure 5.4.1-1. Preliminary linkage design for Sunset Crater Volcano NM only.

at a very narrow point. The majority of the 21.7 km (13.5 mi) southern PLD is privately owned, with the exception of the easternmost strand for mountain lion, which is located in the Coconino National Forest.

The northern PLD is comprised of evergreen forest, which is the predominant land cover type between Sunset Crater Volcano and Wupatki NMs. The western portion of the linkage connects Wupatki NM's western boundary to three locations along Sunset Crater Volcano's northern boundary, with the primary linkage located at Sunset Crater Volcano NM's northwestern corner. Pronghorn, badger, mountain lion, and mule deer are included in the wider linkage area west of Highway 89, shown in Figure 5.4.1-1, but black bear was not represented in the results due to absolute non-habitat. This strand crosses Highway 89, approximately 3.2 km (2 mi) north of the entrance road to Sunset Crater Volcano NM and approximately 3.6 km (2.25 mi) south of Sacred Peak subdivision. The middle linkage strand is for mountain lion only and the easternmost strand, traversing through the volcanic landscape with interspersed grasslands, is for pronghorn only. The majority of the 17.7 km (11 mi) northern PLD is located in the Coconino National Forest, although none of the PLD is located in the Strawberry Crater Wilderness Area.

Ockenfels et al. (1996) evaluated a landscape-level habitat model for pronghorn within Arizona Game and Fish Department's Game Management Units (GMU). GMU 7E, which encompasses Sunset Crater Volcano and Wupatki NMs (refer to the American pronghorn assessment in Wupatki's NRCA report (Baril et al. 2018) for GMU maps), was included in the 1996 study. Vegetation types and terrain were the primary criteria used to develop the model. Ockenfels et al. (1996) also included locations of water, fences, and human developments as model modifiers. They identified six classes of habitat suitability based on the aforementioned data in this assessment and validated the model by locating 84 adult pronghorns over a 2-4 year period in four GMUs. They used both experienced and inexperienced observers as a comparison to determine whether the quality of pronghorn habitat could be consistently identified. Ockenfels et al. (1996) found that determining high quality habitat was the most difficult. Two maps were produced for GMU 7E, showing the locations of pronghorn relative to the habitat quality rank. When comparing the Ockenfels et al. (1996) maps to the PLD results, they are both consistent in showing that the volcanic terrain between Sunset Crater Volcano and Wupatki NMs is mostly avoided. The highest number of observed pronghorn during the Ockenfels et al. (1996) study was in the northwestern - north central portion of Wupatki NM and north of its northern boundary. Ockenfels et al. (1996) map also showed pronghorn paralleling U.S. Highway 89. An interesting observation is that the PLD was not trained with actual highway crossing structures as recommended by Beier et al. (2008), but shows what appears to be a higher concentration of pronghorn gathering along Highway 89 just northwest of Sunset Crater Volcano NM, perhaps suggesting a natural crossing but currently existing as a barrier.

Coconino County Wildlife Linkages

Sunset Crater Volcano NM's 30 km AOA encompassed 29 of the coarse-level linkages identified in the *Wildlife Connectivity Assessment Report* for Coconino County (AGFD 2011) (Figure 5.4.1-2; refer to Appendix F for a summary of these linkages). County linkages 17 and 32 overlapped with the PLD's northern strands, and six of the county's linkages, 34, 38, 39, 46, and small areas of 22, and 32, overlapped with Sunset Crater Volcano's southern PLD.

Coconino County linkage 17 is the largest and includes the grassland north and east of San Francisco Peaks, east of Anderson Mesa. This linkage identified habitat for pronghorn, Gunnison's prairie dog (*Cynomys gunnisoni*), black-tailed jackrabbit (*Lepus californicus*), golden eagle (*Aquila chrysaetos*), milk snakes, birds, and bats. Linkage 32 included San Francisco Peaks – Sunset Crater and O'Leary Peak, and identified habitat for elk (*Cervus canadensis*), northern goshawk (*Accipiter gentilis*) and mountain lion. The threats identified within these three Coconino County linkages as they relate to Sunset Crater Volcano NM's PLD are discussed in the Threats section.

Coconino County linkages 34, 38, 39, 46, which include Elden Spring Road and Elden Pueblo, Rio de Flag, and Walnut Canyon NM were identified as important for mule deer, mountain lion, striped skunk (*Mephitis mephitis*), raccoon (*Procyon lotor*), gray fox (*Urocyon cinereoargenteus*), coyote (*Canis latrans*), elk, porcupine (*Erethizon dorsatum*), bats, Gunnison's prairie dog, and several bird species (i.e., waterfowl, bald eagle (*Haliaeetus leucocephalus*), turkey (*Meleagris gallopavo*), peregrine falcon, (*Falco peregrinus*), and neotropical migratory birds). The threats associated within the primary Coconino County linkages as they relate to Sunset Crater Volcano NM's PLDs are discussed in the Threats section as well.

<u>Uncertainties</u>

As with any model, there are several inherent assumptions and uncertainties. A model is intended to serve as a proxy, and in this assessment, each model is based on the premise that the landscape factors and weights selected for each species' habitat preferences remain the same for their movement needs. To the extent that this assumption is true, the models are more likely to provide accurate results. To further compound uncertainty, the error inherent in any dataset also affects the accuracy of results. And finally, the size and configuration of suitable habitat patches were not further analyzed for each species nor were any of the potential corridor routes ground-truthed, such as checking areas for new developments and/or barriers such as freeways, canals, or major fences that are only a pixel or two in width in the model and most likely not captured in the analyses.

Instead, the PLD should be viewed as a starting point for a more in-depth investigation where specific conservation targets and goals, such as habitat restoration or barrier removal, can be identified and included in the overall linkage design. In addition, information such as wildlife passage locations, water sources, and telemetry data could be added to create a comprehensive linkage evaluation. According to Beier et al. (2008), the results obtained from the Arizona CorridorDesigner tools "should only be relied upon with corroboration of the methods, assumptions, and results by a qualified independent source," suggesting areas for field surveys and more detailed analysis to guide decisions about conservation goals.

Beier et al. (2008) included the following steps for creating a comprehensive linkage design from preliminary results:

- determine if you need to include focal species for which you could not build a corridor model
- remove redundant strands
- determine other conservation goals that should be included
- mitigate barriers (such as locating highway wildlife crossings)
- evaluate the land management in and adjacent to the mapped area.

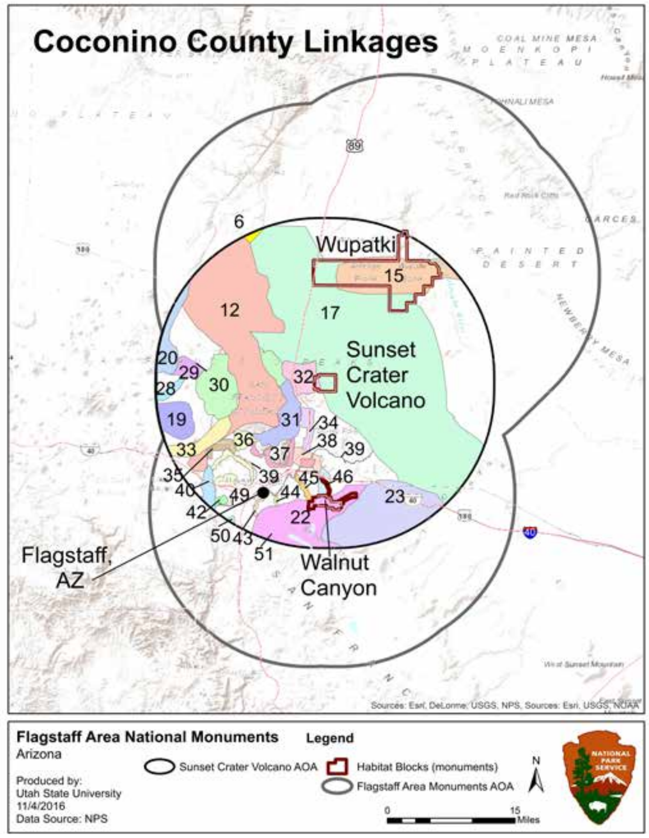


Figure 5.4.1-2. Twenty-nine Coconino County wildlife linkages (shown in different colors) were located within Sunset Crater Volcano NM's 30 km AOA.

In addition, an increasing number of studies are finding that habitat density has a great effect on wildlife populations (Monahan et al. 2012). "Among terrestrial species, Lande (1987) suggests that species with a large dispersal range, high fecundity, and high survivorship, may be able to persist when suitable habitat covers only 25-50% of the landscape, while species with low demographic potential may be lost when as much as 80% of the landscape remains suitable habitat" (as cited in Monahan et al. 2012). Grassland or forest density metrics could be added to a more-detailed, ground-truthed linkage design for further refinement and evaluation. Based on Stegner et al. (2017) findings of mammalian diversity in protected areas within the Colorado Plateau, certain wildlife such as pronghorn, mountain lion, and several water-dependent species are less common than what they expected when compared to species historic range maps. In addition, all of the Flagstaff Area NMs showed lower present-day mammal diversity when compared to historic records and their current NPSpecies lists (Stegner et al. 2017).

Threats, Issues, and Data Gaps

As the population within the city of Flagstaff continues to increase and sprawl toward the Flagstaff Area NMs, especially between Sunset Crater Volcano and Walnut Canyon, increased habitat fragmentation will also likely continue (NPS 1996). The effects of habitat fragmentation as a result of development are varied and range from the direct mortality of animals on roads to the genetic isolation of wildlife populations that have become fragmented (AGFD 2011). Roadways are a well-known cause of fragmentation (e.g., Corlatti et al. 2009), especially fenced highways.

The wildlife barriers identified within the primary Coconino County linkages (i.e., 17, 32, 34, 38, 39, and 46) that overlap with Sunset Crater Volcano's NM's PLD include off-road vehicle use, mining, Timberline development, urban development, Sunset Crater Volcano NM entrance road, highways I-40, U.S. 89, and U.S. 180, BNSF Railroad, and Leupp and Elden Springs Roads (AGFD 2011). Among the mammals evaluated for Sunset Crater Volcano NM's connectivity assessment, mountain lion and pronghorn were ranked highest for being particularly sensitive to roads. This has contributed to the isolation of pronghorn populations and interference with their seasonal migrations (Dodd et al. 2011, AGFD 2011).

In a two-year telemetry study of 37 pronghorn (about one-half captured on each side of U.S. Highway 89, researchers found that only one of the collared pronghorn crossed the road during the tracking period (Dodd et al. 2011); thirty animals, however, approached the highway to within 0.24 km (0.15 mi). Recent genetic work found that the pronghorn herd on each side of the highway differed from the other genetically, indicating restricted gene flow (Sprague 2010). Building upon these findings, a partnership of state and federal agencies, including Flagstaff Area NM Resource Management staff, private ranches, and nonprofit organizations began working together in 2013 to increase pronghorn habitat connectivity at the landscape level (NPS & AGFD 2014). Efforts to make fences more permeable to pronghorn included activities taken on NPS lands and on adjacent Coconino National Forest, Arizona State Trust lands, and Babbitt Ranches lands.

However, in 2004, ADOT began long-range planning to expand U.S. 89 to four lanes from around Wupatki NM's southern boundary northward to Cameron, Arizona (ADOT 2006). While the proposed expansion is located beyond Sunset Crater Volcano NM's 30 km AOA, it will likely impact pronghorn movements occurring within portions of its and Wupatki's AOAs. The effect(s) on the ability of pronghorn and other mammals to cross a four-lane highway is currently being assessed (NPS and AGFD 2014), and if a wider highway exacerbates habitat fragmentation effects, and long-term fence modification efforts are not sufficient to mitigate the effects, an overpass may be the only effective means of maintaining connectivity.

In addition to pronghorn, mountain lion is another mammal that is very sensitive to roads, and while it's known to use diverse habitats, its range has been restricted due to hunting and development (Currier 1983 as cited in Majika et al. 2007). Mountain lions require large areas of connected landscapes and riparian communities for their survival needs (Majika et al. 2007). As the human population continues to increase surrounding the greater-Flagstaff area, associated development, including more roads and housing, especially within the Coconino County linkage for Turkey Hills - Picture Canyon - Elden Pueblo, which cites rural development as a primary threat (AGFD 2011), will likely degrade and/or permanently convert natural habitat if the needs of wildlife are not considered as part of the area's regional planning process.

Spatially Explicit Regional Growth Model (SERGoM)

To examine the population increase within the Flagstaff Area NM and Sunset Crater Volcano NM AOAs, four projected housing density rasters (100 m [328.1 ft] resolution) for 1970, 2010, 2050, and 2100, (Figure 5.4.1-3) were evaluated using Theobald's (2005) Spatially Explicit Regional Growth Model (SERGoM) (NPS 2014a). SERGoM forecasts changes on a decadal basis using county specific population estimates and variable growth rates that are location-specific. Distribution of projected growth was based on accessibility to the nearest urban core, defined as development >100 ha (247 ac). The model assumed that housing density would not decline, which is consistent with Arizona's population projections.

ArcGIS Spatial Analyst's 'extract by mask' tool was used to clip the raster to the AOAs and a summary of the results is listed in Table 5.4.1-1. Most of the area within the Flagstaff Area AOA has been classified as rural and is expected to remain as such through the year 2100, however, a greater (i.e., more concentrated) amount of development is located within Sunset Crater Volcano NM's AOA due to its proximity to the city of Flagstaff and the development that is occurring north of Walnut Canyon (between Walnut Canyon and Sunset Crater Volcano NMs). The highest amount of exurban growth within Sunset Crater Volcano's AOA occurred between 1970 and 2010, and the growth model predicts increasing suburban growth surrounding the monument, more than doubling between 2010 to 2050 and again almost doubling in growth between 2050 to 2100.

Concluding Remarks

This preliminary linkage design for Sunset Crater Volcano NM is intended to assist resource managers and stakeholders to manage along ecological rather than political boundaries, promoting stewardship by comprehensively addressing resource needs in ways that lead to sustainability and cost-effectiveness. As such, this information should be used in conjunction with the more detailed information of individual monitoring and research programs at the monument.

The National Park System Advisory Board (NPSAB) identified "conservation at the landscape scale" as an important model to help guide NPS planning and management activities. According to NPSAB, transitioning from a model of standalone national parks into one of innovative partnering to protect landscapes that transcend administrative boundaries will help parks achieve shared conservation goals (NPSAB 2012a,b). This is not a new concept or management approach for the Flagstaff Area NM Resource Management staff even though this habitat connectivity evaluation is an initial attempt to identify and describe the finer-scale linkages between the Flagstaff Area NMs.

Even though the slow soil development and related ecological succession on Sunset Crater Volcano's volcanic terrain limit its capacity to support wildlife, its proximity between Wupatki and Walnut Canyon NMs serves as a significant linkage, especially as development continues to expand surrounding Flagstaff, AZ. The continued efforts of the Flagstaff Area NM Resource Management staff to facilitate wildlife movements across the landscape is crucial to the NPS mandate of conservation management. The staff's ability to apply scientific information to their management actions will continue to improve resource conditions at the landscape-level surrounding the Flagstaff Area NMs.

This chapter was authored by Kim Struthers, NRCA Coordinator for Utah State University projects.

Table 5.4.1-1. Housing density classes.

Grouped Housing Density Class	% Area in Sunset Crater Volcano NM's 30 km AOA				% Area in Flagstaff Area NMs' 30 km AOA			
	1970	2010	2050	2100	1970	2010	2050	2100
Rural	92.6	78.5	77.3	77.1	97.7	93.6	93.2	93.1
Exurban	4.2	16.3	14.6	10.4	1.5	4.8	4.3	3.3
Suburban	0.33	2.3	5.1	9.6	0.09	0.85	1.8	2.8
Urban	0.02	0.11	0.12	0.12	0.004	0.04	0.05	0.06
Commercial / Industrial	2.8	2.8	2.8	2.8	0.67	0.67	0.67	0.67

Sources: Theobold (2005) and NPS (2014a).

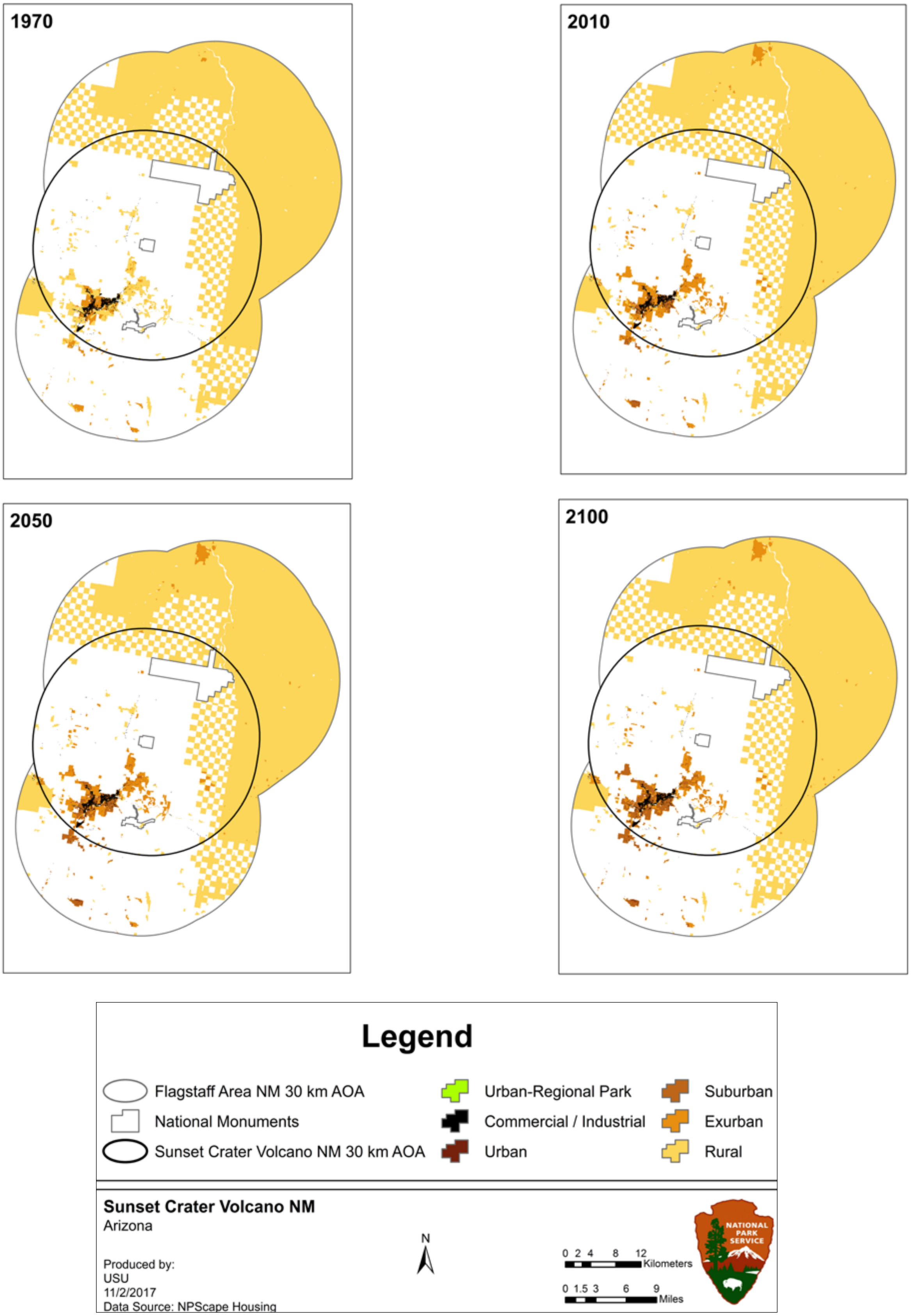


Figure 5.4.1-3. Spatially Explicit Regional Growth Model (SERGoM v3) housing density for four decades surrounding Flagstaff Area NMs, including Sunset Crater Volcano NM. Data Sources: Theobold (2005) and NPS (2014a).

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Appendix A. Sunset Crater Volcano NM Mammal, Bird, and Herpetofauna Species Lists

Listed below are the mammal species that have been recorded at Sunset Crater Volcano National Monument (NM). Sources used for the list were the Certified NPSpecies list for the national monument (dated 30 November 2016, NPS 2016b) and Drost (2009). Species listed by Drost (2009) were those recorded by him: 1) during bat surveys conducted from 2000-2003; and 2) based on his review of museum data and other sources. Species in the list are separated by mammal group (i.e., order). A total of 34 species have been documented in the monument, including two non-native species. The list also includes 14 species that were considered either historical, unconfirmed, or probably present by Drost (2009). The NPSpecies occurrence is also indicated. When occurrence information conflicts between the two sources, defer to Drost (2009) since the author provided supporting data that was not available in NPSpecies (2016b). All federally threatened and endangered species and those of Greatest Conservation Need (SGCN) in the state (Arizona Game and Fish Department [AGFD] 2012) were noted.

Table A.1. Mammals list for Sunset Crater Volcano NM.

Group	Common Name	Scientific Name	Occurrence (Drost 2009, NPSpecies 2016) 1
Ungulates	Bighorn sheep	Ovis canadensis	Historical
	Domestic sheep (non-native)	*Ovis aries*	Historical
	Elk[2] (non-native)	*Cervus canadensis* (or *elaphus*)	Present
	Mule deer	*Odocoileus hemionus*	Present
	Pronghorn	*Antilocapra americana*	Probably Present, Unconfirmed
Carnivores	American badger	*Taxidea taxus*	Present
	American black Bear	*Ursus americanus*	Present
	Bobcat	*Lynx rufus*	Present, Probably Present
	Coyote	*Canis latrans*	Present
	Gray fox	*Urocyon cinereoargenteus*	Present
	Long-tailed weasel	*Mustela frenata*	Present
	Mountain lion	*Puma concolor*	Present
	Northern raccoon	*Procyon lotor*	Present
	Ringtail	*Bassariscus astutus*	Present
	Striped skunk	*Mephitis mephitis*	Present, Unconfirmed
	Western spotted skunk	*Spilogale gracilis*	Probably Present, Unconfirmed
Lagomorphs	Black-tailed jackrabbit	*Lepus californicus*	Present
	Desert cottontail	*Sylvilagus audubonii*	Present
Bats	Big brown bat	*Eptesicus fuscus*	Present
	Brazilian (or Mexican) free-tailed bat[3]	*Tadarida brasiliensis*	Present
	California Myotis	*Myotis californicus*	Present
	Fringed myotis	*Myotis thysanodes*	Present
	Hoary bat	*Lasiurus cinereus*	Present

[1] Listed by Drost (2009) then NPSpecies (2016b). When only one occurrence category is listed, both sources agree or one reference did not list the species.

[2] NPSpecies lists the elk as Cervus elaphus, while Drost (2009) lists it as C. canadensis.

[3] Listed as a Species of Greatest Conservation Need (SGCN, Tier 1A or 1B [out of 1A-1C]) with the State (AGFD 2012). None of the species are federally-listed as endangered or threatened.

[4] Not listed by NPSpecies (NPS 2016b).

Note: When common names of Drost (2009) and NPSpecies (NPS 2016b) did not match, we used those from Drost.

Table A-1 continued. Mammals list for Sunset Crater Volcano NM.

Group	Common Name	Scientific Name	Occurrence (Drost 2009, NPSpecies 2016)[1]
Bats *continued*	Long-eared myotis	*Myotis evotis*	Present
	Long-legged myotis	*Myotis volans*	Present
	Pallid bat	*Antrozous pallidus*	Present
	Western pipistrelle	*Pipistrellus hesperus*	Present
	Western small-footed bat	*Myotis ciliolabrum*	Present
Rodents	Abert's squirrel	*Sciurus aberti*	Present
	Botta's pocket gopher	*Thomomys bottae*	Present
	Brush mouse	*Peromyscus boylii*	Probably Present
	Cliff chipmunk	*Tamias dorsalis*	Present
	Deer mouse	*Peromyscus maniculatus*	Present
	Golden-mantled ground squirrel	*Spermophilus variegatus*	Probably Present, Unconfirmed
	Gray-collared chipmunk[3,4]	*Neotamias cinereicollis*	Probably Present
	Merriam's shrew	*Sorex merriami*	Probably Present, Unconfirmed
	Mexican woodrat	*Neotoma mexicana*	Present
	North American porcupine	*Erethizon dorsatum*	Present
	Northern grasshopper mouse	*Onychomys leucogaster*	Probably Present, Unconfirmed
	Ord's kangaroo rat[4]	*Dipodomys ordii*	Unconfirmed
	Pinyon mouse	*Peromyscus truei*	Present
	Rock squirrel	*Spermophilus variegatus*	Present
	Silky pocket mouse	*Perognathus flavus*	Probably Present, Present
	Stephens's woodrat[3]	*Neotoma stephensi*	Probably Present
	Western harvest mouse	*Reithrodontomys megalotis*	Probably Present
	Western white-throated woodrat	*Neotoma albigula*	Unconfirmed
	White-tailed antelope squirrel	*Ammospermophilus leucurus*	Present
Insectivores	Crawford's desert shrew	*Notiosorex crawfordi*	Present

[1] Listed by Drost (2009) then NPSpecies (2016b). When only one occurrence category is listed, both sources agree or one reference did not list the species.

[2] NPSpecies lists the elk as Cervus elaphus, while Drost (2009) lists it as C. canadensis.

[3] Listed as a Species of Greatest Conservation Need (SGCN, Tier 1A or 1B [out of 1A-1C]) with the State (AGFD 2012). None of the species are federally-listed as endangered or threatened.

[4] Not listed by NPSpecies (NPS 2016b).

Note: When common names of Drost (2009) and NPSpecies (NPS 2016b) did not match, we used those from Drost.

Listed below are the reptile and amphibian species that have been recorded at Sunset Crater Volcano NM. Sources used for the list were the Certified NPSpecies list for the national monument (dated 30 November 2016, NPS 2016b) and Persons and Nowak (2006). Species listed by Persons and Nowak (2006) were those recorded during their field sampling efforts (2001-2003) and others' past, reliable observations or specimens. Five species have been documented in the monument (noted as present), with an additional eight species that may occur (probably occur or unconfirmed). No non-native species have been observed. The list of species was compared with lists of federally threatened and endangered species and those of Greatest Conservation Need in the State (Arizona Game and Fish Department 2012, species designated as Tier 1A or 1B), but no such species were identified. Scientific names follow Brennan (2015); a number of changes have been made to scientific names since the Persons and Nowak report.

Table A.2. Herpetofauna list for Sunset Crater Volcano NM.

Group	Common Name	Scientific Name	Occurrence (Persons and Nowak 2006, NPSPecies 2016b)
Reptiles	Desert night snake	*Hypsiglena chlorophaea*	Unconfirmed
	Eastern fence lizard	*Sceloporus undulatus*	Present
	Gopher snake (or Bullsnake)	*Pituophis catenifer*	Present
	Greater short-horned Lizard	*Phrynosoma hernandesi*	Present
	Many-lined skink	*Plestiodon multivirgats*	Probably Present, Unconfirmed
	Ornate tree lizard	*Urosaurus ornatus*	Present
	Plateau striped whiptail	*Aspidoscelis velox*	Present
	Prairie rattlesnake*	*Crotalus viridis*	Probably Present, Unconfirmed
	Sonoran mountain kingsnake	*Lampropeltis pyromelana*	Probably Present, Unconfirmed
	Striped whipsnake	*Coluber taeniatus*	Probably Present, Unconfirmed
	Western terrestrial garter snake	*Thamnophis elegans*	Unconfirmed
Amphibians	Mexican spadefoot	*Spea multiplicata*	Unconfirmed
	Tiger salamander	*Ambystoma tigrinum*	Unconfirmed

Note: Listed by Persons and Nowak (2006) then NPSpecies (2016b). When only one occurrence category is listed, both sources agree.

* Common name is listed as western rattlesnake in Persons and Nowak (2006), but the species has been reclassified as the prairie rattlesnake (*C. viridus*) vs. the western rattlesnake (*C. oreganus*) (SSAR 2016).

Listed below are the bird species that have been recorded at Sunset Crater Volcano NM. The species list was derived from the Certified NPSpecies list (dated 30 November 2016, NPS 2016b). NPSpecies included 103 confirmed species for the monument. An additional 12 species were considered probably present and 10 species were unconfirmed. Only two non-native species have been recorded. All federally threatened and endangered species and those of Greatest Conservation Need (SGCN) in the state (Arizona Game and Fish Department [AGFD] 2012) were noted.

Table A-3. Birds list for Sunset Crater Volcano NM.

Common Name	Scientific Name	Occurrence
Acorn woodpecker	*Melanerpes formicivorus*	Unconfirmed
Bushtit	*Psaltriparus minimus*	Present
American coot	*Fulica americana*	Present
American crow	*Corvus brachyrhynchos*	Present
American goldfinch	*Spinus tristis*	Probably Present
American kestrel	*Falco sparverius*	Present
American robin	*Turdus migratorius*	Present
American three-toed woodpecker	*Picoides dorsalis*	Unconfirmed
Ash-throated flycatcher	*Myiarchus cinerascens*	Present
Bald eagle*	*Haliaeetus leucocephalus*	Present
Band-tailed pigeon	*Patagioenas fasciata*	Present
Belted kingfisher	*Megaceryle alcyon*	Present
Black phoebe	*Sayornis nigricans*	Present
Black rosy-finch	*Leucosticte atrata*	Present
Black-chinned hummingbird	*Archilochus alexandri*	Present
Black-chinned sparrow	*Spizella atrogularis*	Present
Black-headed grosbeak	*Pheucticus melanocephalus*	Present
Black-throated gray warbler	*Setophaga nigrescens*	Present
Black-throated sparrow	*Amphispiza bilineata*	Present
Blue grosbeak	*Passerina caerulea*	Present
Bohemian waxwing	*Bombycilla garrulus*	Present
Brewer's blackbird	*Euphagus cyanocephalus*	Present
Brewer's sparrow	*Spizella breweri*	Present
Broad-tailed hummingbird	*Selasphorus platycercus*	Present
Bronzed cowbird	*Molothrus aeneus*	Unconfirmed
Brown creeper	*Certhia americana*	Present
Brown-headed cowbird	*Molothrus ater*	Present
Calliope hummingbird	*Selasphorus calliope*	Probably Present
Cassin's finch	*Haemorhous cassinii*	Present
Cassin's kingbird	*Tyrannus vociferans*	Present
Cedar waxwing	*Bombycilla cedrorum*	Present
Chipping sparrow	*Spizella passerina*	Present
Clark's nutcracker	*Nucifraga columbiana*	Present
Common nighthawk*	*Chordeiles minor*	Present
Common poorwill	*Phalaenoptilus nuttallii*	Present
Common raven	*Corvus corax*	Present
Cooper's hawk	*Accipiter cooperii*	Present
Cordilleran flycatcher	*Empidonax occidentalis*	Unconfirmed
Dark-eyed junco	*Junco hyemalis*	Present
Downy woodpecker	*Picoides pubescens*	Unconfirmed

*Listed as a Species of Greatest Conservation Need (SGCN, Tier 1A or 1B [out of 1A-1C]) with the State (AGFD 2012). None of the species are federally-listed as endangered or threatened.

Table A-3 continued. Birds at Sunset Crater Volcano NM.

Common Name	Scientific Name	Occurrence
Eastern meadowlark	*Sturnella magna*	Present
European starling (non-native)	*Sturnus vulgaris*	Present
Evening grosbeak*	*Coccothraustes vespertinus*	Present
Ferruginous hawk*	*Buteo regalis*	Probably Present
Flammulated owl	*Psiloscops flammeolus*	Unconfirmed
Gambel's quail	*Callipepla gambelii*	Probably Present
Golden eagle*	*Aquila chrysaetos*	Present
Grace's warbler	*Setophaga graciae*	Present
Gray vireo	*Vireo vicinior*	Probably Present
Gray-crowned rosy-finch	*Leucosticte tephrocotis*	Present
Great horned owl	*Bubo virginianus*	Present
Green-tailed towhee	*Pipilo chlorurus*	Present
Hairy woodpecker	*Picoides villosus*	Present
Hepatic tanager	*Piranga flava*	Present
Hermit warbler	*Setophaga occidentalis*	Probably Present
Horned lark	*Eremophila alpestris*	Present
House finch	*Haemorhous mexicanus*	Present
House sparrow (non-native)	*Passer domesticus*	Present
House wren	*Troglodytes aedon*	Present
Juniper titmouse	*Baeolophus ridgwayi*	Present
Killdeer	*Charadrius vociferus*	Probably Present
Lark sparrow	*Chondestes grammacus*	Present
Lazuli bunting	*Passerina amoena*	Present
Lesser goldfinch	*Spinus psaltria*	Present
Lesser yellowlegs	*Tringa flavipes*	Present
Lewis's woodpecker	*Melanerpes lewis*	Present
Loggerhead shrike	*Lanius ludovicianus*	Present
Long-eared owl	*Asio otus*	Probably Present
MacGillivray's warbler*	*Geothlypis tolmiei*	Present
Mallard	*Anas platyrhynchos*	Present
Merlin	*Falco columbarius*	Present
Montezuma quail	*Cyrtonyx montezumae*	Unconfirmed
Mountain bluebird	*Sialia currucoides*	Present
Mountain chickadee	*Poecile gambeli*	Present
Mourning dove	*Zenaida macroura*	Present
Northern flicker	*Colaptes auratus*	Present
Northern harrier	*Circus cyaneus*	Present
Northern pygmy-owl	*Glaucidium gnoma*	Present
Northern saw-whet owl	*Aegolius acadicus*	Present
Olive-sided flycatcher	*Contopus cooperi*	Probably Present
Orange-crowned warbler	*Oreothlypis celata*	Present
Peregrine falcon*	*Falco peregrinus*	Present
Pine grosbeak*	*Pinicola enucleator*	Unconfirmed
Pine siskin	*Spinus pinus*	Present
Pinyon jay*	*Gymnorhinus cyanocephalus*	Present
Plumbeous vireo	*Vireo plumbeus*	Present

*Listed as a Species of Greatest Conservation Need (SGCN, Tier 1A or 1B [out of 1A-1C]) with the State (AGFD 2012). None of the species are federally-listed as endangered or threatened.

Table A-3 continued. Birds at Sunset Crater Volcano NM.

Common Name	Scientific Name	Occurrence
Prairie falcon	*Falco mexicanus*	Present
Pygmy nuthatch	*Sitta pygmaea*	Present
Red crossbill	*Loxia curvirostra*	Present
Red-breasted nuthatch	*Sitta canadensis*	Present
Red-naped sapsucker	*Sphyrapicus nuchalis*	Present
Red-tailed hawk	*Buteo jamaicensis*	Present
Rock wren	*Salpinctes obsoletus*	Present
Rough-legged hawk	*Buteo lagopus*	Present
Ruby-crowned kinglet	*Regulus calendula*	Present
Rufous hummingbird	*Selasphorus rufus*	Present
Rufous-crowned sparrow	*Aimophila ruficeps*	Unconfirmed
Sabine's gull	*Xema sabini*	Present
Sage thrasher	*Oreoscoptes montanus*	Present
Savannah sparrow*	*Passerculus sandwichensis*	Present
Say's phoebe	*Sayornis saya*	Present
Sharp-shinned hawk	*Accipiter striatus*	Present
Spotted sandpiper	*Actitis macularius*	Present
Spotted towhee	*Pipilo maculatus*	Present
Steller's jay	*Cyanocitta stelleri*	Present
Swainson's hawk	*Buteo swainsoni*	Present
Western screech-owl	*Megascops kennicottii*	Probably Present
Townsend's solitaire	*Myadestes townsendi*	Present
Townsend's warbler	*Setophaga townsendi*	Present
Tree swallow	*Tachycineta bicolor*	Probably Present
Turkey vulture	*Cathartes aura*	Present
Violet-green swallow	*Tachycineta thalassina*	Present
Western bluebird	*Sialia mexicana*	Present
Western kingbird	*Tyrannus verticalis*	Present
Western meadowlark	*Sturnella neglecta*	Present
Western tanager	*Piranga ludoviciana*	Present
Western wood-pewee	*Contopus sordidulus*	Present
White-breasted nuthatch	*Sitta carolinensis*	Present
White-crowned sparrow	*Zonotrichia leucophrys*	Present
White-throated swift	*Aeronautes saxatalis*	Present
Wild turkey	*Meleagris gallopavo*	Present
Williamson's sapsucker	*Sphyrapicus thyroideus*	Present
Woodhouse's scrub-jay	*Aphelocoma woodhouseii*	Probably Present
Yellow-bellied sapsucker	*Sphyrapicus varius*	Unconfirmed
Yellow-rumped warbler	*Setophaga coronata*	Present

*Listed as a Species of Greatest Conservation Need (SGCN, Tier 1A or 1B [out of 1A-1C]) with the State (AGFD 2012). None of the species are federally-listed as endangered or threatened.

Appendix B. Scoping Meeting Participants and Report Reviewers

Table B.1. Scoping meeting participants.

Name	Affiliation and Position Title
Dr. Kirk Anderson	Museum of Northern Arizona, Geoarchaeologist (presented assessment approach for Recent Volcanic Cinder Terrain)
Lisa Baril	Utah State University, Wildlife Biologist and Writer/Editor
Mark Brunson	Utah State University, Professor and Principal Investigator
Kayci Cook-Collins	Flagstaff Area National Monuments, Superintendent
Michael M. Jones	Flagstaff Area National Monuments, GIS Specialist
Lisa Leap	Flagstaff Area National Monuments, Chief of Resources
Karla Mingus	Flagstaff Area National Monuments, Compliance Specialist
Kim Struthers	Utah State University, NRCA Project Coordinator and Writer/Editor
Mark Szydlo	Flagstaff Area National Monuments, Biologist
Lisa Thomas	NPS Southern Colorado Plateau Inventory and Monitoring Network, Program Manager
Patty Valentine-Darby	Utah State University, Biologist and Writer/Editor
Paul Whitefield	Flagstaff Area National Monuments, Natural Resource Specialist

Table B.2. Report reviewers.

Name	Affiliation and Position Title	Sections Reviewed or Other Role
Jeff Albright	National Park Service Water Resources Division, Natural Resource Condition Assessment Series Coordinator	Washington-level Program Manager
Phyllis Pineda Bovin	National Park Service Intermountain Region Office, Natural Resource Condition Assessment Coordinator	Regional Program Level Coordinator and Peer Review Manager
Donna Shorrock	National Park Service Intermountain Region Office, Natural Resource Condition Assessment Coordinator (former)	Regional Program Level Coordinator and Peer Review Manager
Kelly Adams and Todd Wilson	National Park Service, Grants and Contracting Officers	Executed agreements
Fagan Johnson	National Park Service Inventory & Monitoring Division, Web and Report Specialist	Washington-level Publishing and 508 Compliance Review
Lisa Leap	National Park Service Flagstaff Area National Monuments, Chief of Resources	Park Expert Reviewer
Paul Whitefield	National Park Service Flagstaff Area National Monuments, Natural Resource Specialist	Park Expert Reviewer and author of Volcanic Resources Assessment
Mark Szydlo	National Park Service Flagstaff Area National Monuments, Biologist	Park Expert Reviewer
Gwenn M. Gallenstein	Flagstaff Area National Monuments / Museum of Northern Arizona, Museum Curator (Acting Chief)	Soundscape, Ponderosa Pine, Sensitive Trees, and Sunset Crater Beardtongue Assessments
Lisa Thomas	National Park Service Southern Colorado Plateau I&M Network, Program Manager	Received Condition Assessments
Megan Swan	National Park Service Southern Colorado Plateau I&M Network, Botanist and Acting Program Manager	Sunset Crater Beardtongue Assessment
Li-Wei Hung	National Park Service Natural Sounds and Night Skies Division, Research Scientist	Night Sky Assessment and Data
Emma Brown	National Park Service Natural Sounds and Night Skies Division, Acoustical Resource Specialist	Soundscape Assessment and Data

Table B.2 continued. Report reviewers.

Name	Affiliation and Position Title	Sections Reviewed or Other Role
Ksienya Taylor	National Park Service Air Resources Division, Natural Resource Specialist	Air Quality Assessment
Tim Conners	National Park Service Geologic Resources Division, Geologist	Volcanic Cinder Terrain and Volcanic Resources Assessments
Todd Chaudhry	National Park Service Intermountain Region Office, Colorado Plateau Cooperative Ecosystem Studies Unit, Research Coordinator	Ponderosa Pine and Sensitive Trees Assessments
Judith Springer	Northern Arizona University Ecological Restoration Institute, Research Specialist, Senior	Sunset Crater Beardtongue Assessment
Dr. Kirk Anderson	Museum of Northern Arizona, Geoarchaeologist	Presented preliminary indicators/ measures at NRCA scoping meeting, May 19, 2016 and served as subject matter expert for resource topic via Cooperative Agreement Number P14AC00921

Appendix C. Viewshed Locations Excluded from Analysis

The following eight images are composite panoramic photos for two locations in Sunset Crater Volcano NM that were chosen by NPS staff but were not analyzed for the viewshed assessment because they did not offer additional information regarding the monument's viewshed condition. The two locations were Bonito Trail Overlook and Lenox Trail. The Bonito Overlook site was located at UTM E 452726, N 3913227 (NAD 83, 12N) and the Lenox Trail site was located at UTM E 452089, N 3913252 (NAD 83).

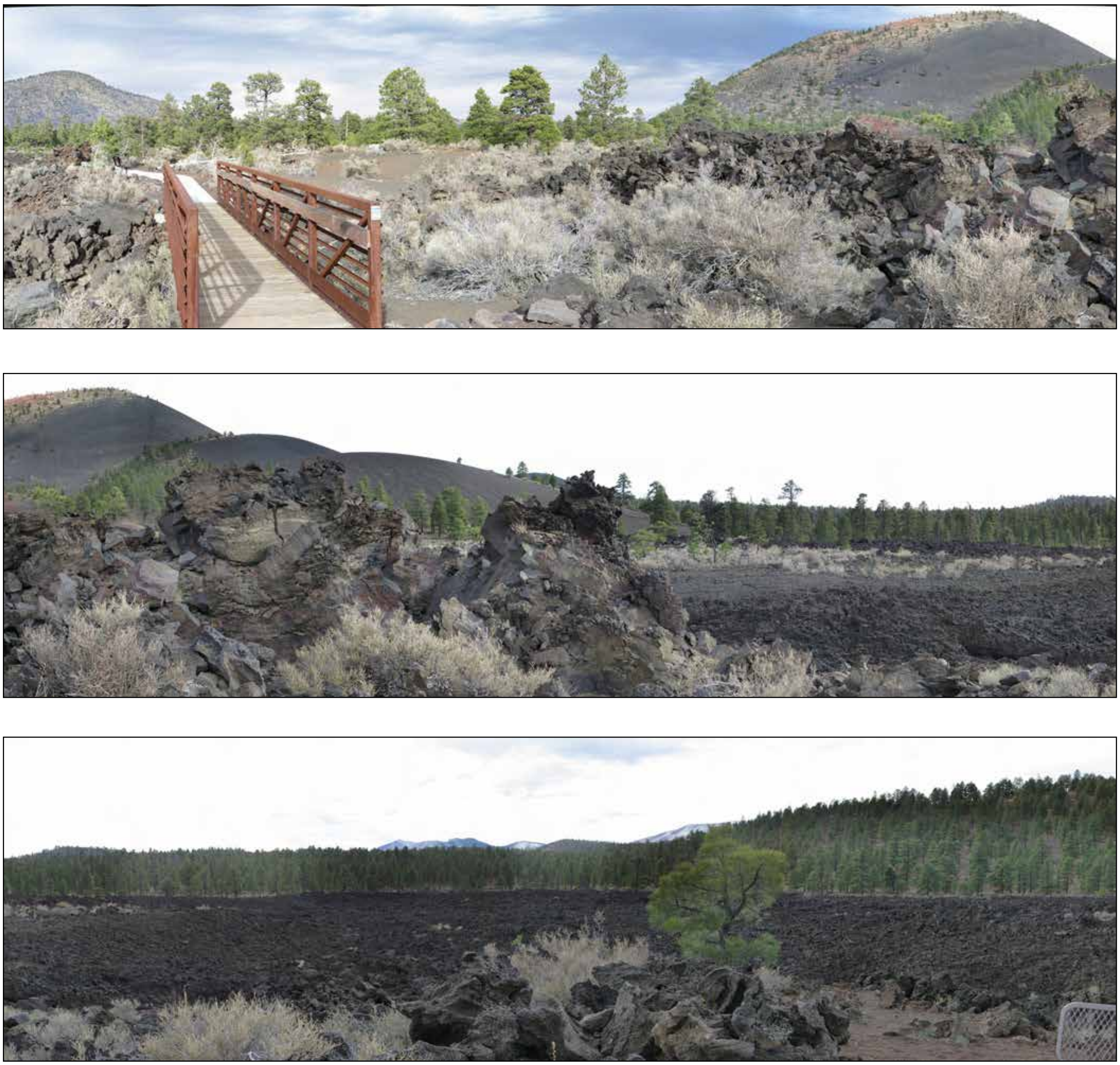

Figure C-1. Panoramic views in each direction from the Bonito Trail Overlook in Sunset Crater Volcano NM (from top: north to east, east to south, and south to west).

Figure C-1 *continued*. Panoramic view from west to north at the Bonito Trail Overlook in Sunset Crater Volcano NM.

Figure C-2. Panoramic views in each direction from the Lenox Crater site in Sunset Crater Volcano NM (from top: north to east, east to south, and south to west).

Figure C-2 *continued*. **Panoramic view from west to north at the Lenox Crater site in Sunset Crater Volcano NM.**

Appendix D. Viewshed Analysis Steps

The process used to complete Flagstaff Area National Monuments' viewshed analyses is listed below.

Downloaded 12 of the 1/3 arc second national elevation dataset (NED) grid (roughly equivalent to a 30 m digital elevation model [DEM]) from The National Map Seamless Server (http://seamless.usgs.gov/) (USGS 2016a) and created a mosaic dataset. The x and y values for the NED are in arc seconds while the z data are in meters. The DEMs were reprojected into NAD83 Albers Meter to get all data in meters and into a geographic extent that covered the entire area.

Prepared observation point layers for viewshed analyses by importing GPSd points for all vantage point locations selected for viewshed analysis. Exported data to a shapefile. Added field named "OFFSETA" (type = double) to shapefile and set value to an observer height of 1.68 m (~5'6").

Ran Viewshed Analysis using the Viewshed Tool in ESRI's ArcGIS 10.2, Spatial Analyst Toolbox, ran viewsheds using the following inputs.

- Input raster = 1/3 arc second NED
- Input point observer feature = obs_point.shp.

The rasters were reclassified into visible areas only to create the maps. The Observer Point Tool in Spatial Analyst was used, creating a composite viewshed, which showed all combined visible areas. A 97 km (60 mi) buffer was created surrounding the monument, reprojected into the Albers Equal Area Conic USGS projection, then used as the area of analysis (AOA) for the NPS NPScape's housing and road density rasters using NPScape tools (NPS 2011b). A text attribute field was added to the dataset for the AOA identifier (NPS 2015b).

Housing (CONUS, Density, SERGoM, 1970 - 2100, Metric Data (ESRI 9.3 File Geodatabase) (Theobald 2005) and road (United States and Canada, Density - All Roads, ESRI, Metric Data (ESRI 9.3 File Geodatabase) (ESRI 2014) GIS datasets were downloaded from NPScape's website at http://science.nature.nps.gov/im/monitor/npscape/gis_data.cfm?tab=1.

Standard Operating Procedures for both density tools (NPS 2014a,b) were followed based on NPScape instructions: https://irma.nps.gov/DataStore/Reference/Profile/2193329 and https://irma.nps.gov/DataStore/Reference/Profile/2193334.

Appendix E. Geospatial Sound Model Maps

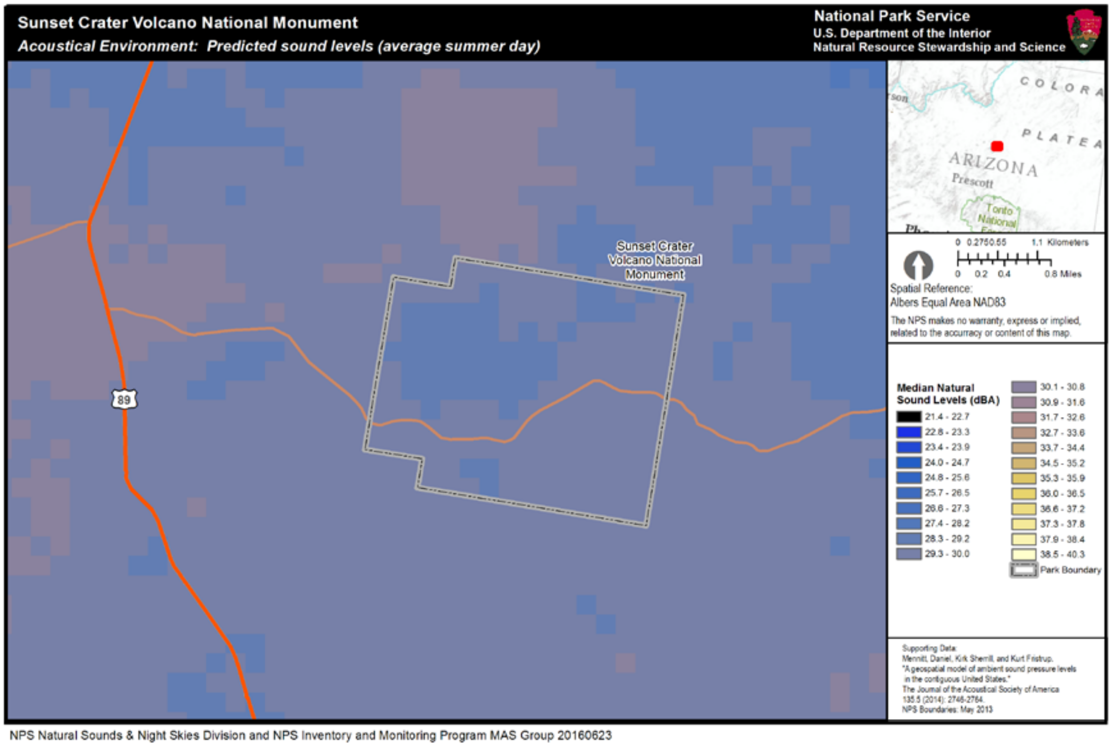

Figure E-1. Natural CONUS soundscape model zoomed to Sunset Crater Volcano NM. Figure Credit: NPS Natural Sounds and Night Skies Division.

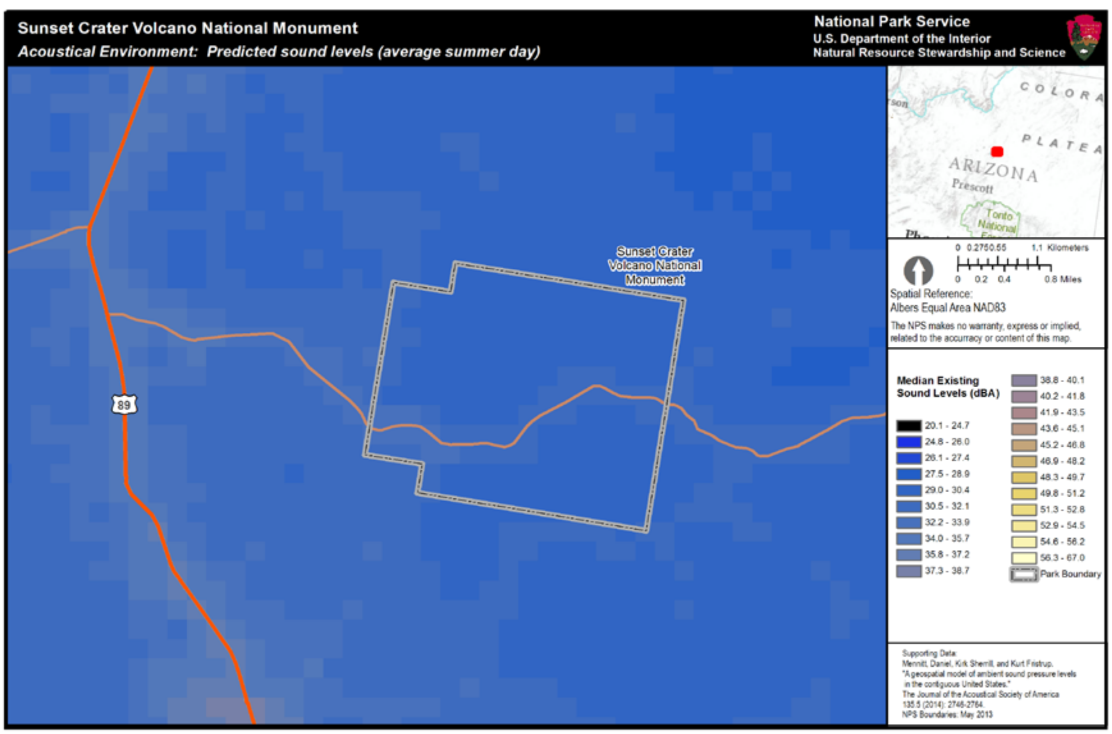

Figure E-2. Existing CONUS soundscape model zoomed to Sunset Crater Volcano NM. Figure Credit: NPS Natural Sounds and Night Skies Division.

Mennitt et al. (2013) developed a geospatial sound model by mapping sound pressure levels on a continental U.S. scale. The model included biological, climatic, geophysical, and anthropogenic factors to assess expected sound pressure levels for natural and existing conditions. The model suggested that the area within and surrounding Sunset Crater Volcano NM had a natural L_{50} dBA average of 29.48 (Figure E-1) and an existing L_{50} dBA average of 30.11(Figure E-2) (Emma Brown, Acoustical Resource Specialist, NPS Natural Sounds and Night Skies Division, provided Excel spreadsheet with values). The L_{50} represents the sound level reported that is exceeded 50 percent of the stated time period.

The impact of anthropogenic sound sources to the national monument's soundscape, which is the existing L_{50} dBA minus natural L_{50} dBA, was estimated to be an average of 0.7 dBA (map is included in the assessment). For further details refer to the soundscape assessment in the monument's report.

As NSNSD's predictive soundscape model continues to be developed and refined, it is intended to help monument staff anticipate impacts by projecting future developments that have the potential to degrade soundscape condition.

Appendix F. Habitat Connectivity Analysis

The workflow used to complete Flagstaff Area National Monuments' habitat connectivity analysis is listed in Table F-1. Outputs included habitat suitability models (HSM), patch models (PMs), and corridor models (CMs) for each species. Models were based on habitat preferences from four datasets: (1) land cover, (2) elevation, (3) topography, and (4) distance from roads. Depending on a species' particular needs, these preferences were weighted accordingly using the opinions of subject matter experts.

Table F-1. GIS-based habitat connectivity assessment workflow adapted from Beier et al. (2008).

Process / Step	Description	Selection
Define Area of Analysis	The area identified to address wildlife movement needs.	30 km (18.6 mi) ecological buffer (Monahan et al. 2012)
Select Wildland Blocks	Areas of publicly owned or other land expected to remain in a relatively natural condition for at least 50 years.	Flagstaff Area National Monuments: Wupatki NM, Sunset Crater Volcano NM, and Walnut Canyon NM
Select Focal Species	Species that collectively serve as an 'umbrella' for all native species and ecological processes.	Nine native species either found in one or all three monuments with Arizona CorridorDesigner habitat models
Identify Landscape Factors	Landscape factors are based on species' life needs such as food, cover, safety from hazards (e.g. roads), etc.	Land cover, elevation, topography, and distance from roads were selected as the landscape factors for each model.
Identify Landscape Metrics	Categories of landscape factor attributes.	47 land cover classes grouped into 10 categories; topography grouped into 4 topographic positions; elevation ranged from -1 - 3,846 m (3.3 - 12,625 ft); and roads were mapped as a land cover type and calculated as distance to nearest road.
Identify Resistance Values of Each Pixel Class	Establishes the "link between the non-ecological GIS information and the ecological-behavioral aspects of the mobility of the organism or process" (Adriaensen et al. 2003 as cited in Beier et al. (2008)).	Resistance values were based on literature review and expert opinion for each species (refer to Majka et al. (2007) Excel spreadsheet); landscape factor classes were weighted for all 10 species.
Identify Combining Factor Resistances	Method of combining inability to move through an area (i.e., resistance) due to landscape factors.	Weighted geometric mean
Identify Corridor Terminus	The area within a wildland block that ends the modeled corridor.	Habitat patches within monuments
Delineate Habitat Patches	Areas of habitat that can support reproduction by the focal species.	Thresholds for habitat quality, minimum area suitable for breeding, and how edge effects affects each species are identified as patches.
Decide How to Model Corridor Dwellers	A species that requires more than one generation for gene flow to occur between wildland blocks.	Assigned the lowest resistance value to habitat patches.
Decide How Continuous Swaths of Low-Resistance Pixels Are Identified (Travel cost map)	Areas that are easy for a given species to travel within may be disconnected (either by natural or unnatural features) and not form a continuous area or swath. So a method for connecting low resistance pixels (i.e., areas easy to travel) needs to be selected.	Each pixel's cost is calculated as the lowest possible cumulative resistance or travel cost from that pixel to habitat block terminuses.
Identify Corridor Width	For corridor dwellers, width should be substantially more than a home range width and use iterative mapping to identify acceptable number and severity of bottlenecks.	Increasingly wide corridors were displayed as nested polygons in a graded cost map, with each polygon defined by the largest cumulative travel costs allowed. The larger the polygon, the higher the cost.

F.1. Area of Analysis and Habitat Blocks

The NPScape landscape dynamics monitoring project recommended evaluating landscape attributes within a 30 km (18.6 mi) area of analysis (AOA). This scale captured ecological processes, such as wildland fires and some animal movements as well as dispersal patterns (Monahan et al. 2012) of park resources. The habitat blocks or protected areas of interest for maintaining habitat connectivity included the three national monuments: Wupatki, Walnut Canyon, and Sunset Crater Volcano. In total, these monuments protect a little over 17,000 ha (~42,000 ac) of public land and are expected to remain in a natural condition in perpetuity. Each of the three buffers were dissolved, creating one area totaling 7,489 km^2 (2,891.5 mi^2). The monuments comprised 2.3% of the entire AOA.

F.2. Focal Wildlife Species

Animals move within or among habitats to obtain the resources they need for survival (i.e., water, food, cover, and mates), and different species move at different scales (such as mountain lions compared to the Wupatki pocket mice). As a result, some species may be more affected (or affected sooner) by habitat fragmentation. Beier et al. (2008) suggested selecting focal species to serve as an 'umbrella' for the remaining species and natural processes not evaluated when developing habitat linkages/connectivity. Beier et al. (2008) further suggested that species selection include some that are: (1) area-sensitive, (2) habitat specialists, (3) dispersal limited, (4) sensitive to barriers, or (5) otherwise ecologically important. Beier et al. (2008) emphasized that the goal of identifying linkages should be "to conserve or restore a functioning wildland network that maintains ecological processes and provides for the movement of all native species between wildland [habitat] blocks." Table F-2 lists the species selected for habitat connectivity analysis for each national monument and Table F-3 summarizes each species' habitat preferences. Of the 16 mammals and 12 reptile and amphibian parameterized models included as raw data in the Arizona CorridorDesigner toolbox, a total of nine native species were known to occur at either all monuments (5 species) or

Table F-2. Arizona CorridorDesigner wildlife species known to occur at one or all Flagstaff Area National Monuments.

Common Name	Scientific Name	Species Selection Criteria	Wupatki	Walnut Canyon	Sunset Crater Volcano
American badger	*Taxidea taxus*	Large home range; many protected lands are not large enough to ensure species' life cycle.	X	X	X
American black bear	*Ursus americanus*	Requires habitat variety; low population densities makes them vulnerable to habitat fragmentation.	X	X	X
American pronghorn	*Antilocapra americana*	Susceptible to habitat fragmentation and human development; sensitive to barriers.	X	X	X
Black-tailed jack rabbit	*Lepus californicus*	Important seed dispersers and prey for other species; frequently killed by vehicles.	X	–	–
Kit fox*	*Vulpes macrotis*	Susceptible to habitat conversion and fragmentation.	X	–	–
Lyre snake	*Trimorphodon biscutatus*	Susceptible to habitat fragmentation.	–	X	–
Mountain lion	*Puma concolor*	Requires a large area of connected landscapes to support even minimum self sustaining populations.	X	X	X
Mule deer	*Odocoileus hemionus*	Important prey species; road systems may affect the distribution and welfare of species.	X	X	X
White-nosed coati	*Nasua narica*	Appears to be dispersal limited.	–	X	–

* Listed as a Species of Greatest Conservation Need in Arizona (AGFD 2012).

Note: X = species present.

Table F-3. Wildlife species habitat preferences.

Common Name	Land Cover	Elevation	Topography	Distance From Roads
American badger	Prefer grasslands and other open habitats	Lower	Flat terrain	No aversion; high mortality
American black bear	Require habitat variety	Often mountainous	Prefer to bed in locations with 20-60% slopes	Movements dependent on food supply; males have greater dispersal
American pronghorn	Areas of grasses and scattered shrubs with rolling hills or mesas	Gentle terrain	Prefer slopes < 30%	Right-of-way fences are major factor limiting movement
Black-tailed jack rabbit	Prefers open country	—	—	Frequently killed by vehicles
Kit fox*	Prefer desert grasslands and desert scrub with sandy soils for digging dens	Variable spatial patterns depending on prey, habitat quality, and precipitation	Variable spatial patterns depending on prey, habitat quality, and precipitation	Variable spatial patterns depending on prey, habitat quality, and precipitation
Lyre snake	All vegetation types and strongly associated with rocks and outcrops	up to 2,255.5 m (7,400 ft)	Mountain slopes	—
Mountain lion	Found throughout Arizona in rocky or mountainous areas; diverse habitat	304.8 - 914.4 m (1,000-3,000 ft)	Varied	Sensitive to vehicles
Mule deer	In northern Arizona inhabit yellow pine, spruce-fir, buckbrush, snowberry, and aspen habitats	—	Home ranges of mule deer vary depending upon the availability of food and cover	Home ranges of mule deer vary depending upon the availability of food and cover
White-nosed coati	Primarily a forest species	No constraints	No preference	Males tend to be hit by vehicles

Source: Majka et al. (2007)

Table F-4. Landscape factor percentage weights used in species habitat models.

Species Common Name	Land Cover	Elevation	Topography	Distance From Roads
American badger	65	7	15	13
American black bear	75	10	10	5
American pronghorn	45	—	37	18
Black-tailed jack rabbit	70	10	10	10
Kit fox	75	—	15	10
Lyre snake	—	10	80	10
Mountain lion	70	—	10	20
Mule deer	80	—	15	5
White-nosed coati	95	—	—	5

Source: CorridorDesigner Species Scores Excel Spreadsheet (Majka et al. 2007)

at one monument only (4 species). These nine species serve as the "umbrella" for the remaining species known to occur at each of the monuments.

F.3. Habitat Suitability and Patch Models

The Habitat Suitability Models (HSMs) were developed using the weighted geometric mean of the parameters selected for each species' life cycle and survival needs from four raster datasets: land cover, elevation, topography, and distance from roads. The factor weights assigned within each data set for each species analyzed are listed in Table F-4. The 30 m x 30 m pixels within each of the four rasters were combined using the geometric mean method to identify resistance through an area. Resistance factors for the parameterized habitat models were linearly stretched to a 0 (worst) – 100 (best) scale. The patch models (PMs) were developed using the results from each species' HSM. The HSMs and PMs for each species analyzed are shown in Figures F-1 through F-18.

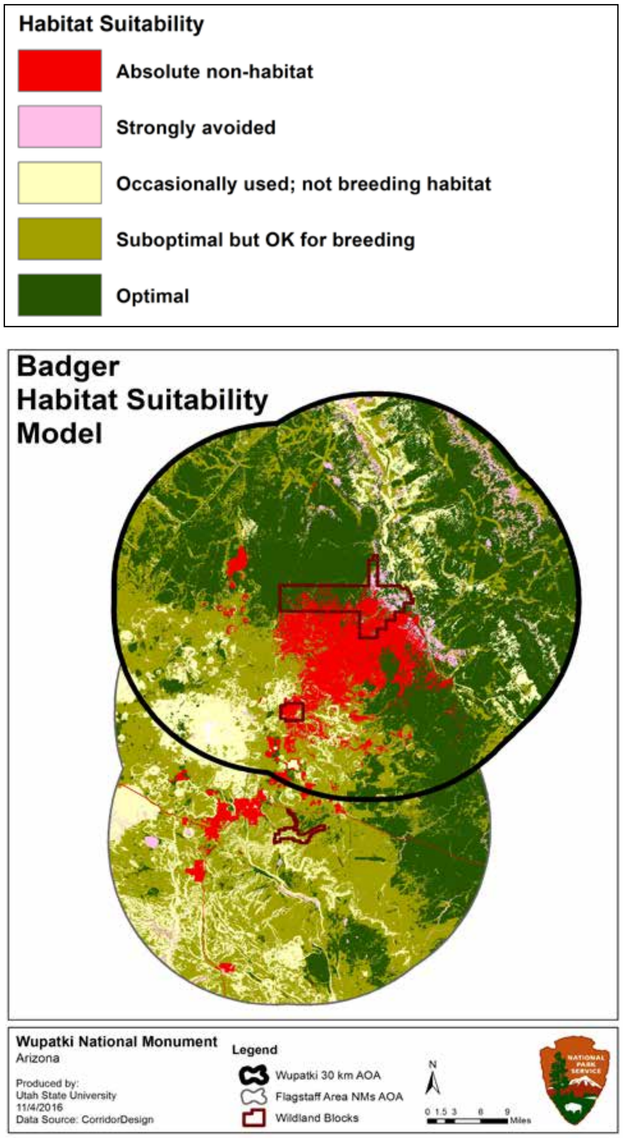

Figure F-1. **American badger habitat suitability model.**

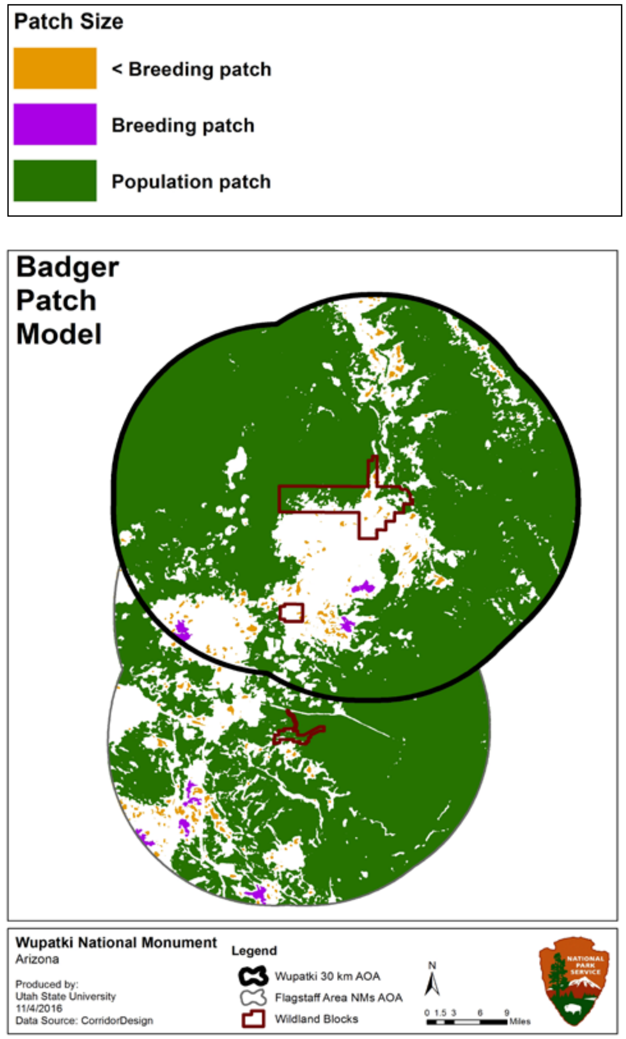

Figure F-2. **American badger patch size model.**

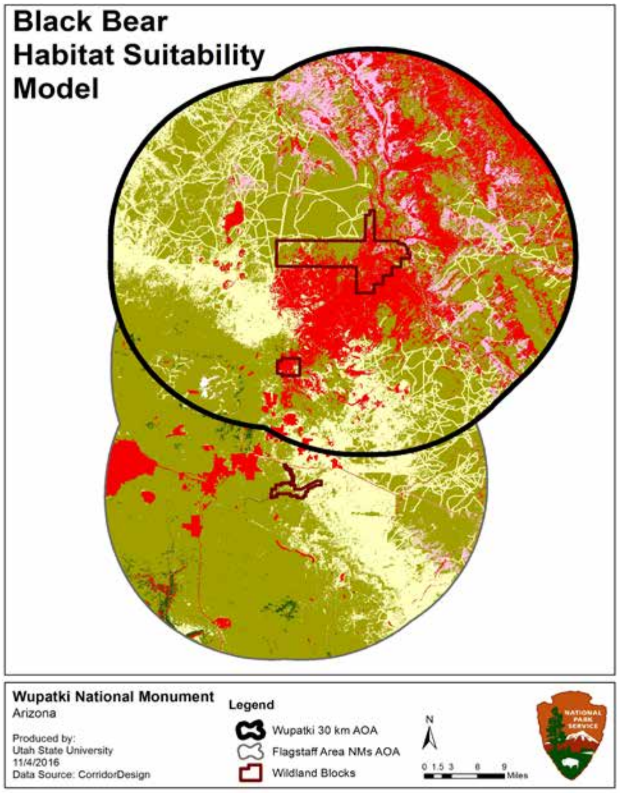

Figure F-3. Black bear habitat suitability model.

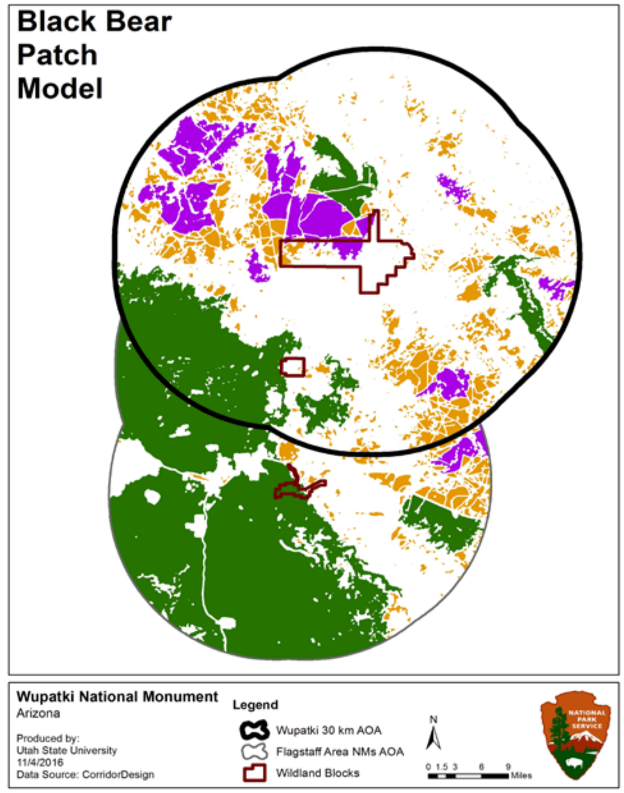

Figure F-4. Black bear patch size model.

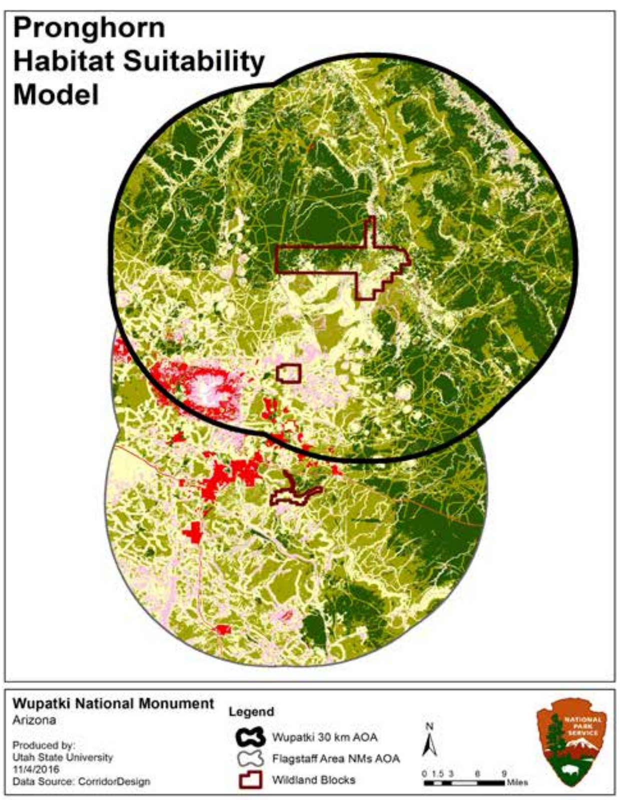

Figure F-5. American pronghorn habitat suitability model.

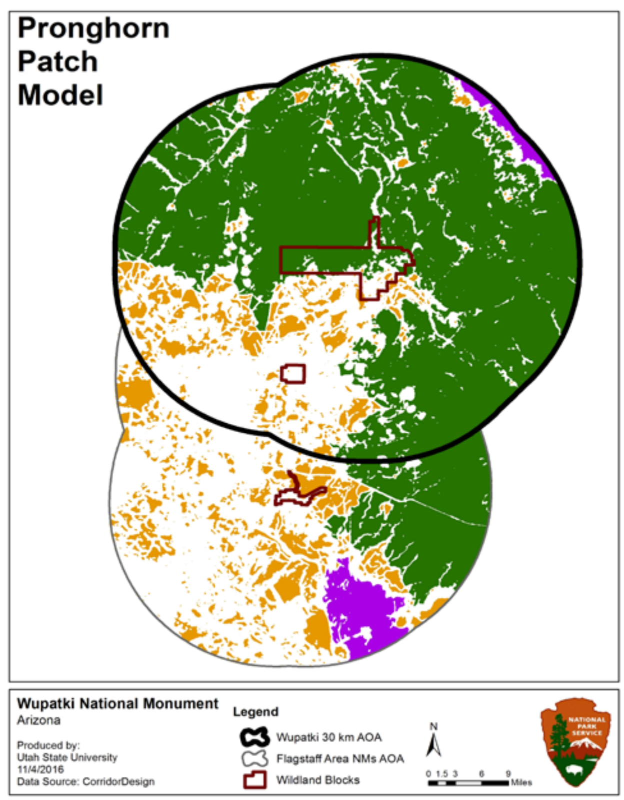

Figure F-6. American pronghorn patch size model.

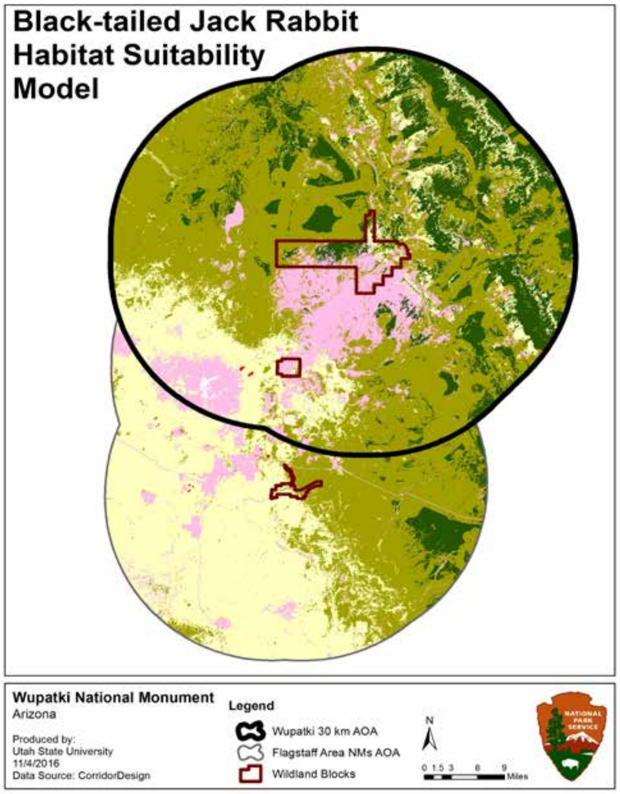

Figure F-7. **Black-tailed jack rabbit habitat suitability model.**

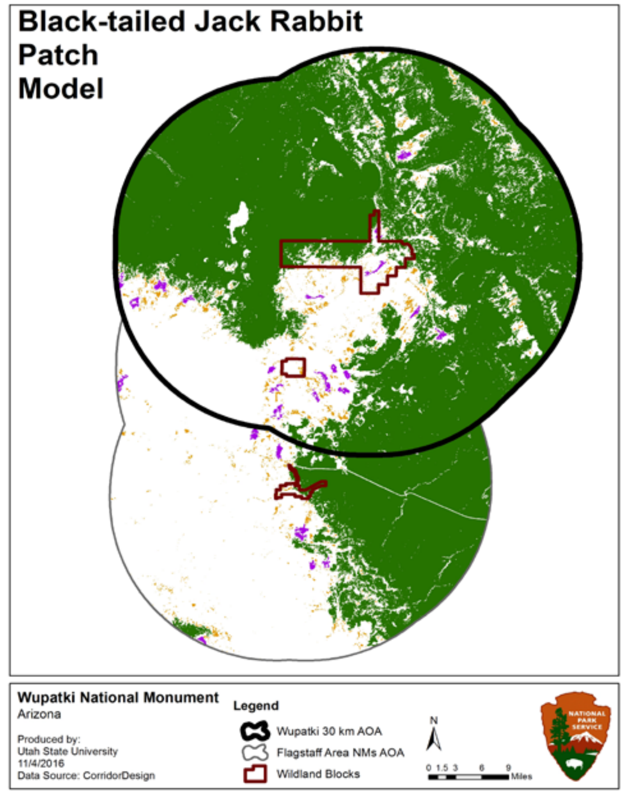

Figure F-8. **Black-tailed jack rabbit patch size model.**

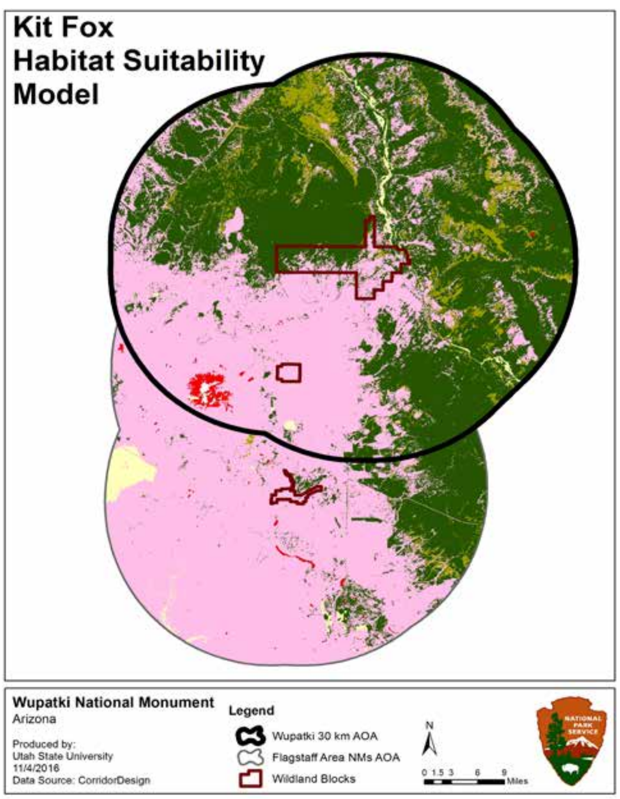

Figure F-9. **Kit fox habitat suitability model.**

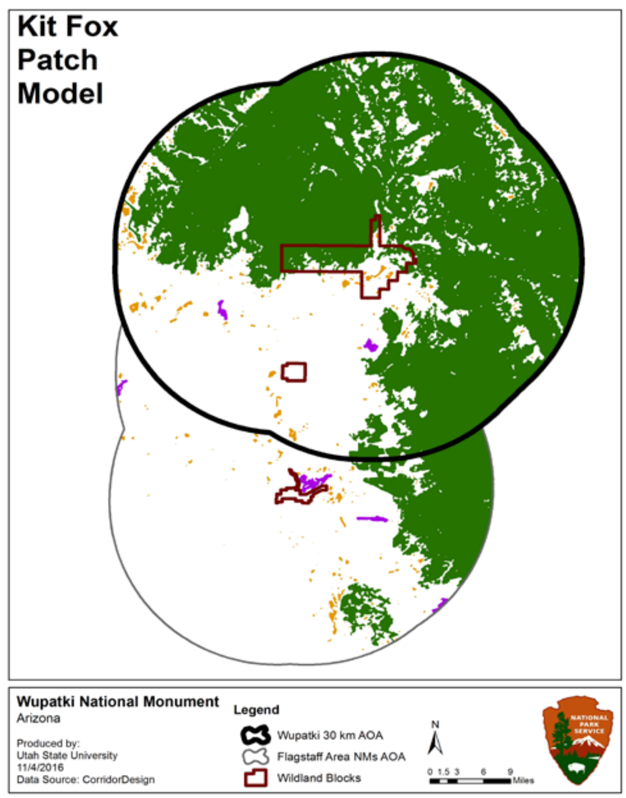

Figure F-10. **Kit fox patch size model.**

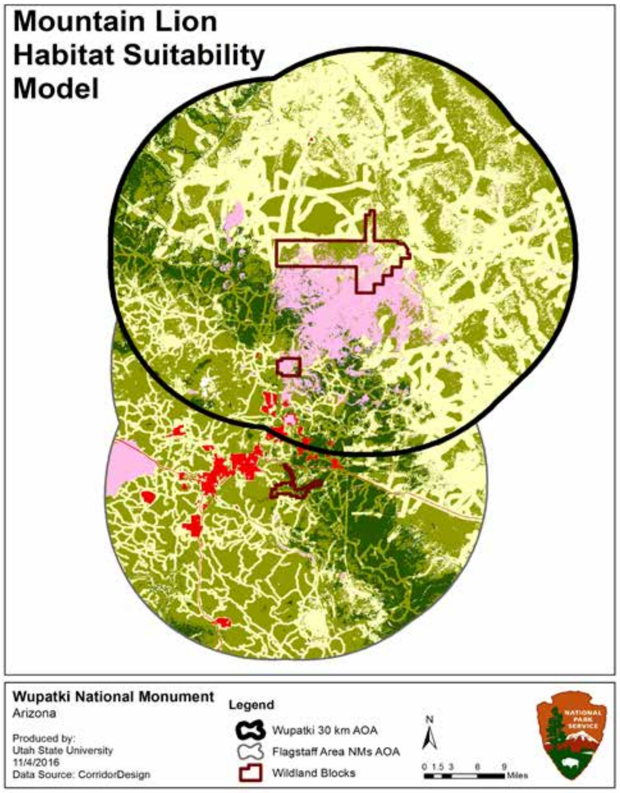

Figure F-11. **Mountain lion habitat suitability model.**

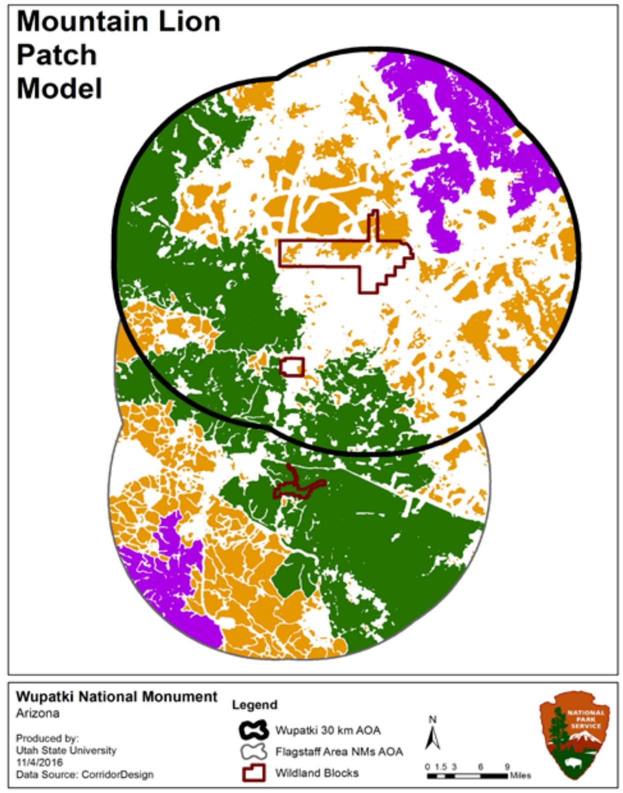

Figure F-12. **Mountain lion patch size model.**

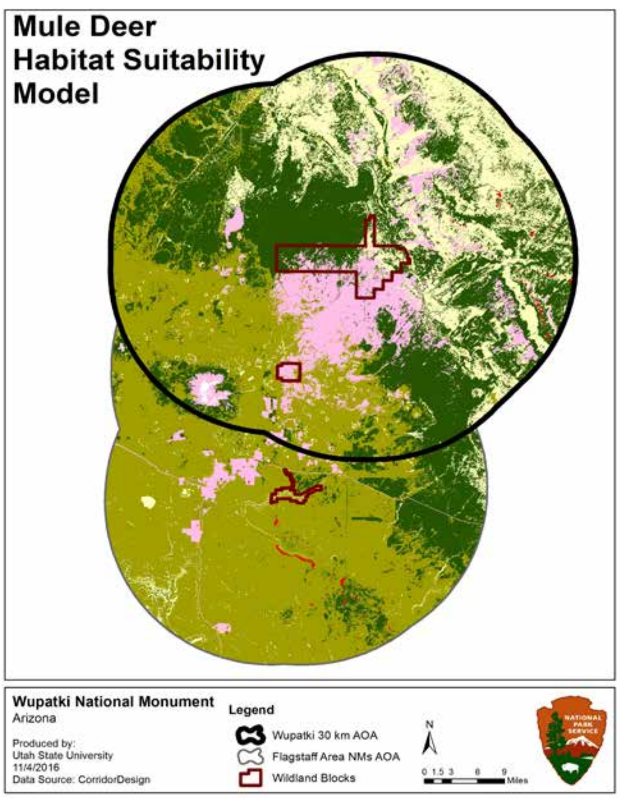

Figure F-13. **Mule deer habitat suitability model.**

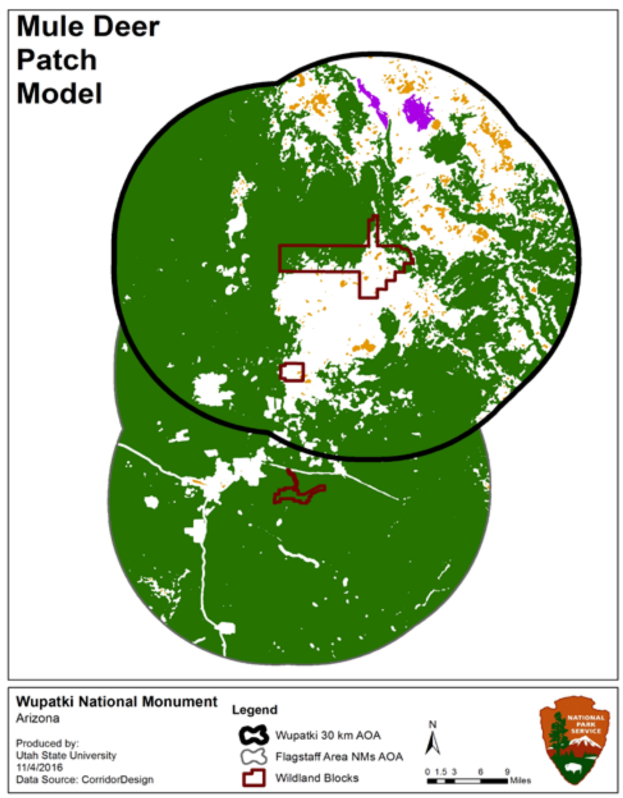

Figure F-14. **Mule deer patch size model.**

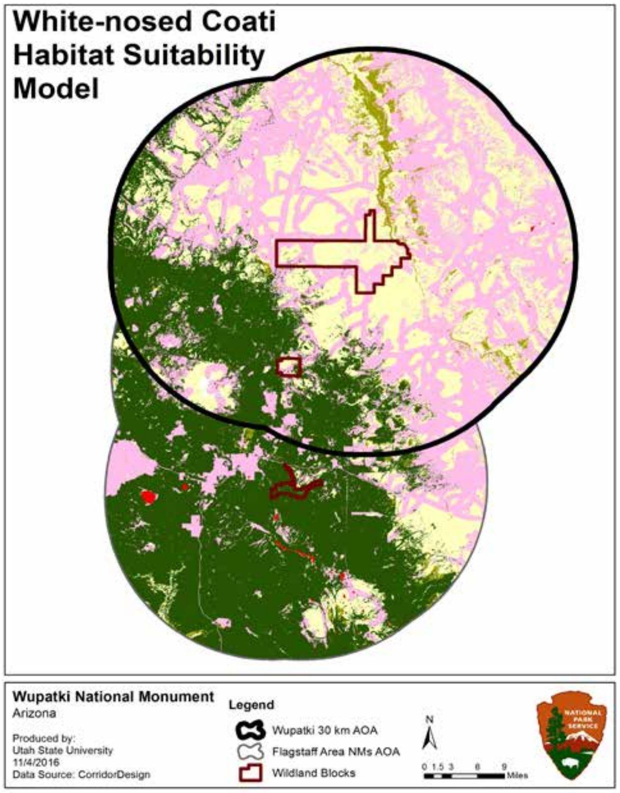

Figure F-15. White-nosed coati habitat suitability model.

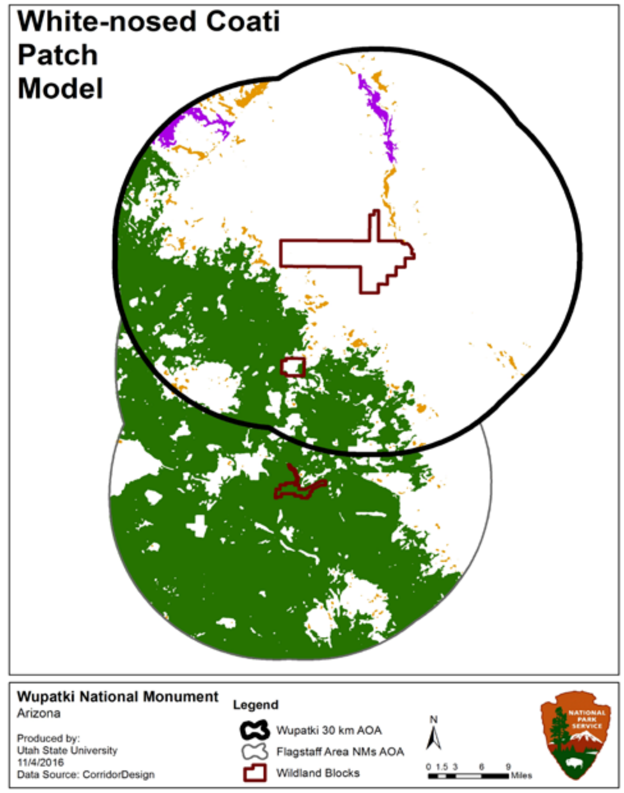

Figure F-16. White-nosed coati patch size model.

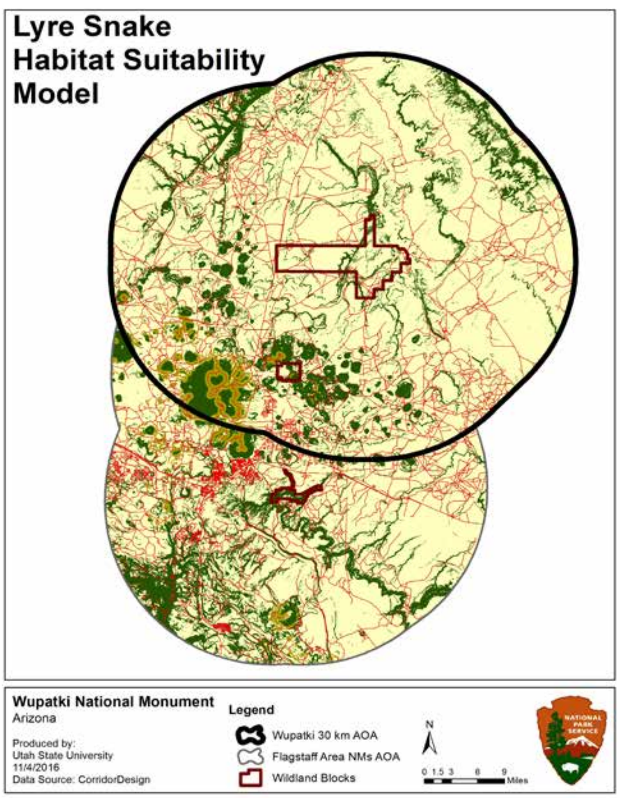

Figure F-17. Lyre snake habitat suitability model.

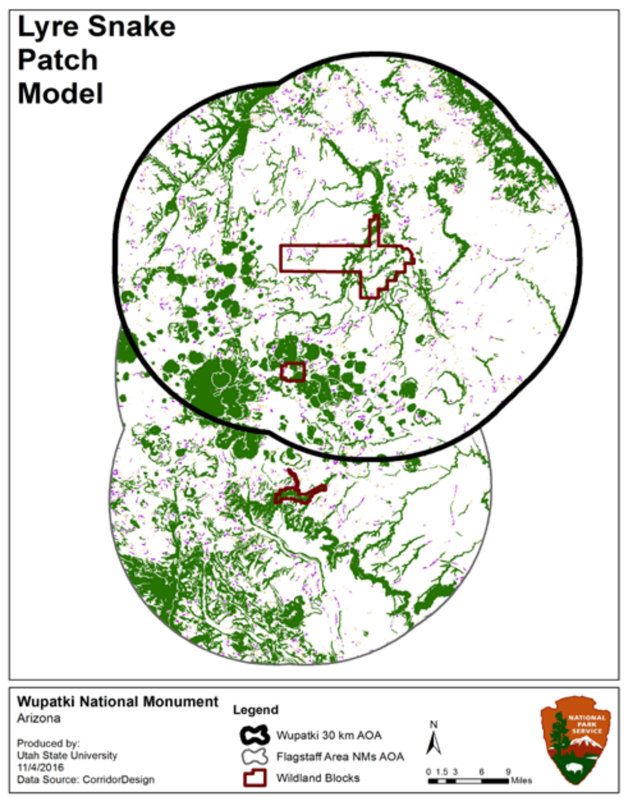

Figure F-18. Lyre snake patch size model.

F.4. Corridor Models

Corridor models (CMs) were created using the HSMs and PMs for each species to calculate the cumulative movement (travel cost) resistance within a given area. The process included five steps as follows: 1) calculated species patch sizes 2) found starting patches within the first habitat block. If no cores were within the block then patches were selected instead. 3) found starting patches within the second habitat block. If no cores were within the block then patches were selected instead.

4) Converted HSM to cost model and calculated cost distance in first and second rasters then combined cost distance rasters into one total accumulative cost grid/corridor model. 5) sliced corridor model into 11 different widths (i.e., 0.1%, 1-10%). The least-cost corridors selected for each species were unioned, producing one preliminary linkage design that showed potential areas of connectivity to facilitate movements of selected species between monuments.

F.5. Degree of Conservation

The linkage design model was used to clip the USGS GAP Protected Areas Database (2016c) conservation status dataset. There are four GAP categories that vary based on degree of protection and management mandates. Flagstaff Area NMs are GAP Status 1 lands. All GAP categories are described below.

GAP Status 1: Lands that have permanent protection from conversion of natural land cover and are managed for biodiversity and disturbance events.

GAP Status 2: Lands that have permanent protection from conversion of natural land cover and are managed for biodiversity but disturbance events are suppressed.

GAP Status 3: Lands that have permanent protection from conversion of natural land cover and are managed for multiple uses, ranging from low intensity (e.g., logging) to high intensity (e.g., mining).

GAP Status 4: No known mandate for protection and include legally mandated easements (USGS 2016c).

F.6. Coconino County Wildlife Linkages

A total of 40 wildlife linkages, identified in the *Wildlife Connectivity Assessment Report* for Coconino County (AGFD 2011a), were located within the entire Flagstaff Area NM AOA (Table F-6). Fifteen were within Wupatki's AOA, 35 were within Walnut Canyon's AOA, and 29 were within Sunset Crater Volcano's AOA.

Table F-6. Coconino County wildlife linkages that are within the Flagstaff Area NMs' 30 km AOA.

Area	#	Name	Species	Threats	WUPA	WACA	SUCR
Northern Coconino County	6	Utah - San Francisco Peaks	Raptors, bats	Powerlines, increasing off-highway vehicle use, proposed wind and solar developments, exotic species (cheatgrass, Russian thistle, snakeweed)	X	–	X
	12	South Rim - San Francisco Peaks Woody Ridge / Bellemont Area	mule deer, elk, Gunnison's prairie dog	Hwy 64, development in foothills on north side of the Peaks along FR 418, I-40	X	X	X
	13	Coconino Plateau	Elk, mule deer, pronghorn	Hwy 64	X	–	–
	15	Wupatki National Monument – Navajo Reservation	Pronghorn, small mammals, herpetofauna	Little Colorado River (for some species)	X	–	X

Note: X = species present.

Table F-6 continued. ***Coconino County wildlife linkages that are within the Flagstaff Area NMs' 30 km AOA.***

Area	#	Name	Species	Threats	WUPA	WACA	SUCR
Central Coconino County	17	Grassland north and east of San Francisco Peaks - east of Anderson Mesa	Pronghorn, Gunnison's prairie dog, jackrabbit, golden eagle, milk snakes, birds, bats	Hwy 89A, Leupp Rd, Meteor Crater Rd, FR 69, grazing and shrub encroachment, planned Red Gap pipeline, Grapevine wind development, BSNF Railroad, State Lands	X	X	X
	19	Dog Knobs - Ebert Mtn.-Govt. Prairie	Pronghorn, mule deer, black bear, mountain lion	Highway 180, fencing	–	X	X
	20	Mesa Butte - Kendrick	Mountain lion, elk, pronghorn	Highway 180	X	–	X
	21	Garland Prairie - Govt. Prairie	Pronghorn, mule deer, black bear, turkey, elk	Roads, railroad, urban development, I-40	–	X	–
	22	Walnut Canyon - Anderson Mesa - Antelope Park/ Mormon Mtn.	Mountain lion, elk, mule deer, black bear, northern goshawk, Mexican spotted owl, neotropical migratory birds, turkey, northern leopard frog, bats, bald eagle, peregrine falcon, tarantula, gray fox, raccoon, coyote, small mammals, bull snakes	Lake Mary Rd, recreation, crayfish invasion	–	X	X
	23	Youngs and Mormon/Padre Canyons Area	Pronghorn, elk, mule deer, white-tailed deer	Recreation	–	X	X
	25	Mormon Mtn. - Hutch Mtn.	Mexican spotted owl, forest bats, wintering bald eagle, northern leopard frog, other amphibians	High-severity landscape-level fire, forest restoration treatments, Lake Mary Rd	–	X	–
	26	Ashurst/ Kinnikinik - Mormon Lake	Tiger salamander, northern leopard frog, other amphibians	OHV use, Lake Mary Rd	–	X	–
	28	East of Kendrick - Government Hills	Pronghorn	Roads, development, recreation	X	–	X
	29	Kendrick - Hochderfer Hills	Black bear, elk, Mexican spotted owl	Highway 180	X	X	X
	30	San Francisco Peaks - North of Peaks	Mountain lion, pronghorn, elk, mule deer, black bear, badger, northern goshawk, Mexican spotted owl, Gunnison's prairie dog, turkey, northern leopard frog, Mexican vole, bats, neotropical migratory birds	FR 418, OHV use of illegal trails, traffic on FR 151, recreation	X	X	X
	31	San Francisco Peaks - Mt. Elden/Timberline	Mountain lion, deer, bear, northern goshawk, Mexican spotted owl, Gunnison's prairie dog, turkey, bats, neotropical migratory birds	Illegal OHV trails, traffic on Schultz Pass Rd, recreation	X	X	X
	32	San Francisco Peaks – Sunset Crater and O'Leary Peak	Elk, northern goshawk, mountain lion	Mining, off-highway vehicle use, urban development, Sunset National Monument entrance road, Hwy 89	X	X	X
	33	San Francisco Peaks - Observatory Mesa - Bellemont	Elk, mountain lion, mule deer, badger, Gunnison's prairie dog	I-40, urban and suburban development	X	X	X

Note: X = species present.

Table F-6 continued. ***Coconino County wildlife linkages that are within the Flagstaff Area NMs' 30 km AOA.***

Area	#	Name	Species	Threats	WUPA	WACA	SUCR
Flagstaff Area	34	Elden Spring Road - Landfill	Mule deer, mountain lion, striped skunk, raccoon, gray fox, coyote	Hwy 89 current use and future widening, OHV use, Timberline development, Timberline Trail development and trailhead at Elden Springs Rd	X	X	X
	35	Hwy 180 Meadows	Gunnison's prairie dog, ferruginous hawks, burrowing owls, other meadow species	Highway 180, development	–	X	X
	36	Peaks - Woody Ridge	Pronghorn, mountain lion, elk, mule deer, black bear, badger, northern goshawk, Gunnison's prairie dog, Mexican spotted owl, neotropical migratory birds, turkey, leopard frog, Mexican vole, bats, raptors	Highway 180, urban and suburban development, recreation	–	X	X
	37	Elden Foothills	Mountain lion, mule deer, bats	Urban and suburban development, recreation, illegal mountain bike trail use	X	X	X
	38	Turkey Hills - Picture Canyon - Elden Pueblo	Elk, mule deer, turkey, bald eagle, peregrine falcon, neotropical migratory birds, porcupine, bats, Gunnison's prairie dog, bats	Rural development, OHV recreation	–	X	X
	39	Rio de Flag	Neotropical migratory birds, waterfowl, bald eagle, bats	Hwy 89 current use and future widening, OHV use, Timberline development, Timberline Trail development and trailhead at Elden Springs Rd	X	X	X
	40	Woody Ridge	Pronghorn, mountain lion, black bear, elk, mule deer, badger, northern goshawk, Gunnison's prairie dog, Mexican spotted owl, neotropical migratory birds, turkey, leopard frog, Mexican voles, bats	Highway I-40, traffic and recreation along Woody Mountain Rd (FR 231), some fuels reduction treatments Notes: I-40 telemetry data should	–	X	X
	41	Rogers Lake - Volunteer Canyon	Elk, pronghorn, deer, turkey, black bear, mountain lion, northern leopard frog, bald eagle, bats, Gunnison's prairie dog	Recreation, military training	–	X	–
	42	Dry Lake - Rogers Lake	Pronghorn, elk, mule deer, black bear, turkey, Mexican spotted owl, bald eagle, Gunnison's prairie dog, northern goshawk, northern leopard frog, Mexican vole, neotropical migratory birds, bats	Suburban development, recreation, traffic on Woody Mountain Road	–	X	X
	43	Bow and Arrow	Neotropical migratory birds, bats, striped skunk	Urban and suburban development, Lake Mary Rd, Lone Tree Rd, invasive plants	–	X	X
	44	Hoffman Tank Area	Neotropical migratory birds, Gunnison's prairie dog, bats, elk	Suburban and rural development, invasive plants	–	X	X
	45	Peaceful Valley - Campbell Mesa	Bald eagle, neotropical migratory birds, Gunnison's prairie dog, elk, mule deer, porcupine, bats	Suburban development, recreation	–	X	X

Note: X = species present.

Table F-6 continued. Coconino County wildlife linkages that are within the Flagstaff Area NMs' 30 km AOA.

Area	#	Name	Species	Threats	WUPA	WACA	SUCR
Flagstaff Area *continued*	46	Rio de Flag - Walnut Canyon	Mountain lion, bald eagle, northern goshawk, neotropical migratory birds	I-40 expansion	–	X	X
	48	Black Pass	Pronghorn, mountain lion, elk, mule deer, black bear, badger, northern goshawk, Gunnison's prairie dog, Mexican spotted owl, neotropical migratory birds, turkey, leopard frog, Mexican vole, bats	State Route 89A, recreation, some fuels reduction treatments	–	X	–
	49	Sinclair Wash	Neotropical migratory birds, bats	Urban/suburban/commercial development, Milton Avenue, Beulah Road, Interstate 40, invasive plants, trash, stormwater	–	X	X
	50	Oak Cr. Canyon	White-tailed deer, black bear, javelina, elk	Highway 89A, recreation	–	X	X
	51	Schoolhouse Draw - Pumphouse Wash and Fry Canyon	Mountain lion, elk, deer, black bear, hawks, Gunnison's prairie dog, Mexican spotted owl, waterfowl, bald eagle, neotropical migratory birds, turkey, leopard frog, bats	I-17 and Hwy 89, suburban/rural development, OHV use on illegal trails, recreation and traffic along FR 237	–	X	X
	52	Mexican Pocket/ Pumphouse Wash/Village of Oak Creek	Turkey, black bear, elk, mule deer, mountain lion, Abert's squirrel, Mexican spotted owl	Summer dispersed camping, off-highway vehicle use, State Route 89A, forest thinning	–	X	–
	53	Newman Park - Willard Springs	Arizona black rattlesnake, elk, reptiles	I-17, shooting range	–	X	–
	54	Pumphouse Wash - Munds Canyon	Elk, mule deer, turkey	Off-highway vehicle use	–	X	–
South-central Coconino County	55	Anderson Mesa Summer - Winter Range	Pronghorn, elk	Fencing, proposed wind development, conifer encroachment	–	X	–
	56	Robber's Roost / Dutch Tank Area Morman Lk Area	Turkey, elk, javelina	I-17	–	X	–
TOTAL NUMBER OF LINKAGES IN EACH 30 km AOA					15	35	29

Note: X = species present.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 039/149831, December 2018

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