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Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Timpanogos Cave National Monument

Natural Resource Report NPS/TICA/NRR—2020/2188

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ON THIS PAGE
American Fork Canyon in fall. (NPS).

ON THE COVER
The formation on the right side of this photo, called flowstone, was made over thousands of years by flowing water carrying dissolved mineral. The flow of the water caused this formation to look very much like a frozen waterfall. (NPS).

Natural Resource Condition Assessment

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Publisher's Note: See Prologue for information regarding the delayed publication of this report.

Executive Summary

A subset of natural resources at Timpanogos Cave National Monument was assessed for current condition. All available information, data, and expertise were utilized to determine resource condition and to evaluate whether the condition was stable, improving, or deteriorating (trend). A level of confidence was also provided for each assessment. Results of this assessment are presented in detail in Chapter 4, and discussed in Chapter 5.

The resources assessed are organized into three ecological zones within TICA: caves, upland, and riparian. Resources associated with the caves were found to be in the best condition overall. Cave water quality, cave formations, and the watershed that feeds the cave were found to be in generally good condition, while cave climate and microorganism communities were assessed as being in moderate condition. Confidence in the assessments for most cave resouces is high.

The relative isolation of the caves along with diligent management have likely resulted in a high level of protection of cave resources. The caves are at risk from continued human presence, though these risks are identified and mitigation measures in place in most cases. Global climate change may negatively affect cave climate and cave water supply in coming decades.

Upland resouces are generally in moderate condition, though data are lacking that would allow high confidence in these assessments. Vegetation communities are threatened by impacts of climate change including recurring and severe drought and invasive plant species. Very little information exists to determine the condition of resident small and medium-sized mammals or mammal communities overall. Bat species diversity appears to be high, and one bat species of concern—Townsends big-eared bat—seems to be present in expected numbers. Confidence in these assessments is low, however, due to the absence of sufficient data to evaluate the status of any species or group.

Riparian resources are in moderate to poor condition due to altered hydrologic function and human impacts to the riparian community along the American Fork River. Habitat integrity outside of the caves is moderate to poor given the presence of the highway that bisects the park, and high recreational and commercial use throughout the canyon. Impacts from artificial light at night and anthropogenic noise are unmeasured but are likely increasing. Confidence in assessments for riparian and habitat resources is generally moderate to low.

Prologue

Publisher's Note: Changes in publishing requirements, and in some cases scientific delays, resulted in several NRCA reports not being published in a timely manner. Since Natural Resource Condition Assessments provide a snapshot-in-time evaluation of park resource conditions, it is important to note that data discovery and analyses for this study was conducted a few years prior to publication. Park conditions reported in this document pertain to the approximate timeframe of 2006–2013.

Chapter 1. NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources in national park units. NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue—and threat-based resource assessments.

All NRCAs have several characteristics in common. First, they address only a subset of natural resource issues in each park. Resource topics are selected by a team of park staff and outside experts based on a variety of criteria including legal status, management need, and available data. For each resource assessed, NRCAs include a description and background information, definition of the reference condition(s), descriptions of data and analysis methods used, evaluations of level of confidence for each assessment, and identification of information gaps and research that would be needed to have high confidence in the assessment and determine condition trends (if such information does not presently exist).

Next, NRCAs assess current condition by comparing various measures of present-day status with ecological reference measures that describe past and/or desired conditions. The credibility of an NRCA results from the data, methods, and reference values used in the project work. There is generally strong dependence on information available from the NPS Inventory and Monitoring (I&M) program, and NRCAs utilize I&M data whenever possible. NRCAs can also potentially contribute to the I&M program by identifying resources that are not currently monitored but are of management interest or concern.

NRCAs do not establish management targets for study indicators; that process occurs within the realm of park planning and management activities. NRCA products can, however, help park managers define short-term workload priorities, frame data and study needs for important park resources, and communicate current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision-making, planning, and partnership activities.

Chapter 2. Park Resource Setting/Resource Stewardship Context

2.1. Introduction

Timpanogos Cave National Monument (TICA) comprises 250 ac (101 ha) in American Fork Canyon in north-central Utah (Figure 2.1-1). The primary feature of the park is a system of three caves—Hansen, Middle, and Timpanogos—which formed separately but are now connected by a series of short, man-made tunnels. The caves contain abundant and unique cave formations (speleothems) as well as several small lakes that support cave-specialized microorganisms and invertebrates.

The above-ground portion of the park is mostly forested, with communities dominated by Douglas and white fir (*Pseudotsuga menziesii* and *Abies concolor*). Deciduous forests and oak/shrub areas make up a smaller proportion of vegetated areas. The American Fork River runs through the northern portion of the park adjacent to a narrow riparian zone and state highway. The park also protects the Timpanogos Cave Historic District, a collection of buildings constructed during the 1920s–1940s that includes several made from local rock and stone.

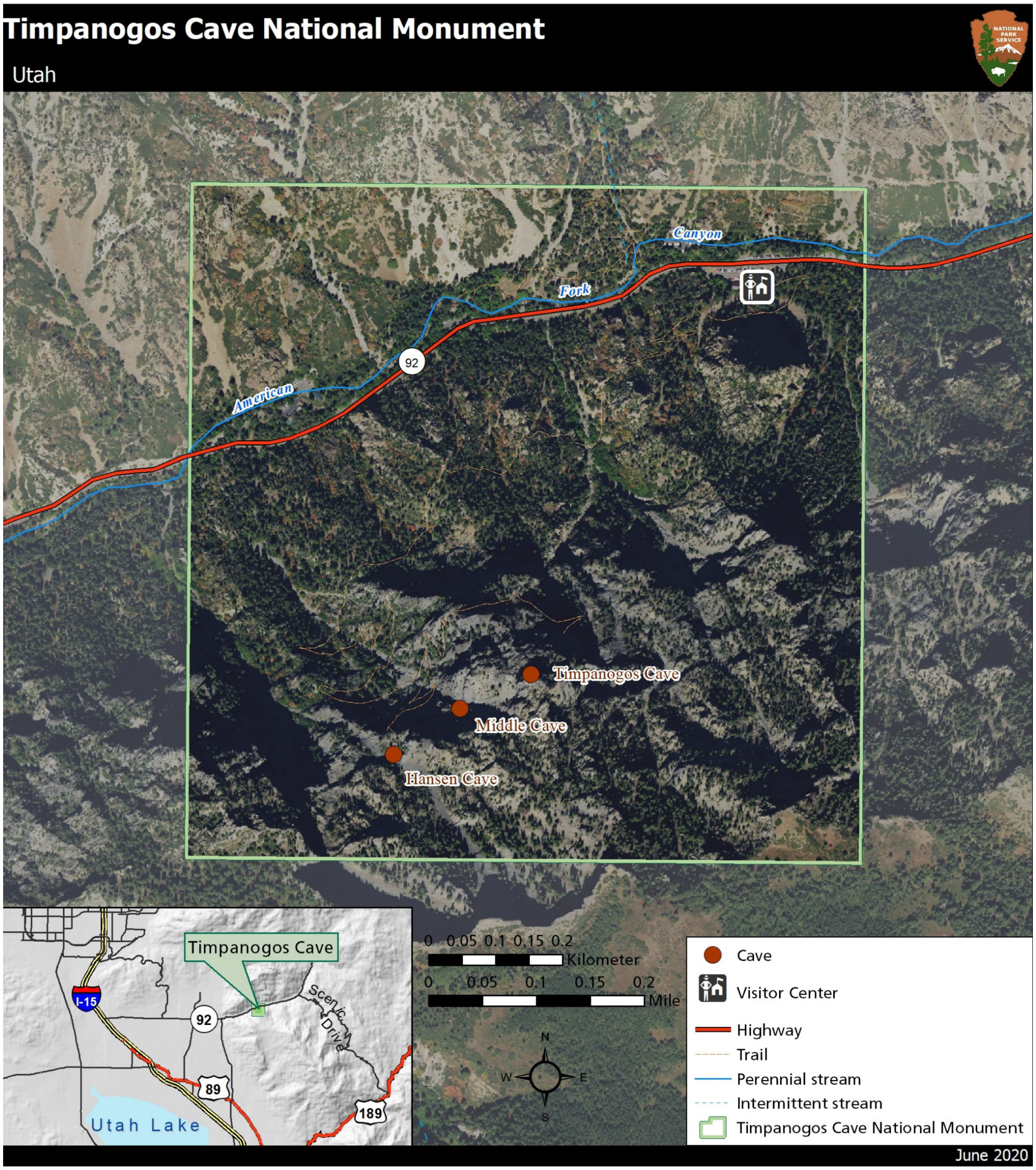


Figure 2.1-1. Location of Timpanogos Cave National Monument in Utah. NCPN – NPS.

2.1.1. Enabling Legislation/Administrative History

The purposes of TICA are to assure preservation of national resources of unusual scientific interest and importance, and to conserve the natural and cultural resources of the monument and provide for public use and enjoyment (NPS 1984). TICA is significant because of the unusually large variety of cave formations, because the caves were formed by relatively uncommon geologic processes, and because this portion of the canyon, and particularly the trail to the caves, exposes and preserves a geologic record dating to the Precambrian Era (Pulham 2009, NPS 2013).

The first cave, Hansen Cave, was discovered by local explorers in 1887. Unfortunately, once the location of the cave was known some formations were removed or damaged by looters and souvenir hunters. When Timpanogos Cave was discovered in 1913, followed by Middle Cave in 1921, proactive steps were taken to protect these caves from similar damage. In 1922 President Harding created Timpanogos Cave National Monument to preserve the "unusual scientific interest and importance" of the caves. Initially the caves were managed by the U.S. Forest Service (USFS), and USFS and private citizens raised money to install lighting, build trails, and construct the tunnels that now connect the three caves. In 1934 management of all national monuments was transferred to NPS, and for over 20 years TICA was managed remotely by the Superintendent of Zion National Park. An excellent, detailed summary of the administrative history of TICA is provided in Pulham (2009).

The constraints imposed by the physical location of the park present particular challenges for managers. Due to the steep terrain on both sides of the canyon, all visitor and administrative facilities, aside from the caves and the trail, are located in the floodplain of the American Fork River. As a result, the highway and many park buildings are periodically flooded and closed to visitors and employees. A fire in 1991 at the Visitor Center resulted in the placement of what was intended to be a temporary facility in the floodplain, however, the absence of an appropriate alternative site prevented the construction of a permanent structure elsewhere until 2019. Frequent rockfalls from the steep slopes threaten both visitor and employee safety (Mayo et al. 2000, Thornberry-Ehrlich 2006, Coe and Harp 2007, NPS 2012b).

Because TICA is surrounded by USFS land, NPS and USFS cooperate in managing travel through and around the monument. In 2001 Congress passed the 'Timpanogos Interagency Land Exchange Act' which authorized but did not obligate the acquisition of funds to acquire land and construct a joint NPS-USFS administrative facility. Increased visitation and travel through the canyon have led to an acknowledged need to improve transportation, parking, and visitor management throughout the park (NPS 2012b).

2.1.2. Geographic Location and Physical Setting

The Wasatch Mountains separate the Basin and Range geologic province to the west of TICA from the Rocky Mountain province to the east. Known as the Wasatch Front, these mountains are some of the steepest on earth, in some locations rising over 6,500 ft (1,981 m) from the valley floor. The Wasatch Range extends approximately 124 mi (200 km) from north to south, and is bisected by canyons created by faults that formed as the mountains were uplifted (Machette et al. 1991). The park is located in the American Fork Canyon (AFC) of the range at a relatively high elevation for North American caves (6,730 ft; 2,051 m). South of TICA, Mount Timpanogos rises to an elevation of 11,752 ft (3,582 m) while several other nearby peaks are over 11,000 ft (3,353 m).

2.1.3. Cultural History and Significance

Paleo-Indians lived in the greater Wasatch region as long ago as 12,000 years, though there are no specific records of their presence in AFC. The earliest known inhabitants of the area around TICA were members of the Desert Archaic Culture, nomads who inhabited the region between 10,000 BC and 400 AD. The Fremont people were the first farmers to live in the area and may have been the ancestors of the Ute tribes who arrived around 1400–1500 AD (Nelson 1997). Numerous Anglo explorers and trappers ventured through Utah beginning in the mid-1700s, eventually establishing trade with the Ute. When Mormon migration began in the mid-1800s there were more than 20,000 American Indians living in the area that is now Utah. Following statehood in 1848, greater numbers of settlers began exploring the AFC, eventually establishing substantial timber and mining operations in the area. Timpanogos Cave Historic District is listed on the National Register of Historic Places (NRHP) and includes period-constructed buildings such as the Rock House (built in 1941) and several other park structures (Pulham 2009).

2.1.4. Visitation

Annual visitation at TICA averaged approximately 110,000 visitors per year between 2000–2019 (https://irma.nps.gov/STATS, accessed 3/23/20). Visitation is highest during the summer months; the cave and the trail to it are both closed in the winter. To reach the caves, visitors must hike a steep trail that begins at the visitor center on the valley floor and climbs over 1,000 ft/305 m to the cave entrance. Because visitation to the caves is restricted, the majority of TICA visitors participate in guided cave tours. Cave tours are extremely popular, and on the busiest summer days tours of up to 16 people occur every 15 minutes. On summer weekends parking areas are nearly always full and traffic is congested, leading to concerns for pedestrian safety (NPS 2012b). The impacts of nearly 70,000 people entering the caves during the six months the caves are open are of concern to managers (NPS 2013, Section 4.2 and 4.5).

Visitors also participate in non-cave related activities such as picnicking and hiking. No camping is allowed in TICA, though adjacent USFS lands have both maintained campgrounds and backcountry camping opportunities.

2.2. Physical Resources and Processes

2.2.1. Climate

The weather at TICA is characteristic of the mid-latitude Rocky Mountains. Winters are fairly cold, with temperatures averaging below freezing with regular snowfall. Maximum summer temperatures reach 90°F (32°C). Precipitation is influenced primarily by the orographic effects of the mountains, especially during summer months (Gillies and Ramsay undated). Afternoon thundershowers are common during mid-to-late summer, and snowfall is usually moderate (NRCS 2014). The Visitor Center has an average of 90 in (229 cm) of snow and 25 in (64 cm) of rain annually (NPS 2012a).

Within the caves, relatively consistent climatic conditions over many centuries have allowed the development of numerous cave formations and the evolution of unique cave ecosystems. The cave climate has changed, however, as a result of human use and the physical joining of the three caves via tunnels; the tunnels now facilitate an increased passage of air through the cave system, reducing average humidity and likely increasing seasonal temperature variation (Armstrong 2010, NPS 2013). Cave climate is addressed in Section 4.2.

2.2.2. Geology

From the Precambrian through most of the Paleozoic (~300–600 mya), what is now the Wasatch area of Utah was subjected to alternating periods of deposition under shallow inland seas and erosion driven by tectonic uplift. The Deseret Limestone formation, in which the TICA caves would ultimately form, was laid down approximately 340 mya during a period of marine inundation. The creation of the caves themselves began about 17 mya as the Wasatch Range was uplifted (White and Van Gundy 1971). Faults were created during this process facilitating water flows that created future cave openings as well as the origins of American Fork Canyon (Mayo et al. 2000).

The structural orientations of Hansen and Middle Caves are similar to each other but are different from Timpanogos Cave, indicating that Timpanogos was formed along a different (though related) set of faults (Pulham 2009). Currently, a total of 5,600 ft, (1,707 meters) of passageways have been surveyed in the three cave systems. The Wasatch Fault zone that runs along the eastern side of the Great Basin is still extremely active, and the likelihood of a large earthquake in this area within the next several centuries is high. (Machette et al. 1991, Mayo et al. 2009, McCalpin and Nishenko 1996).

2.2.3. Soils

Soils at TICA are very shallow and overlay an extremely rocky subsurface (Coles et al. 2009). The steepness of the terrain does not allow the accumulation of a substantial soil layer except at the base of the slopes and in some forested areas on relatively flat slopes (Coles et al. 2009).

2.2.4. Hydrology and Water Quality

TICA is located in the Utah Lake Watershed (U.S. Geological Survey Hydrologic Unit Code 16020201 [USGS HUC]) which drains nearly 3,800 mi^2 (10,000 km^2) of mostly mountainous terrain on the west side of the Wasatch Range. The American Fork River (AFR) flows generally west through AFC and TICA. Periodic floods during the last century led to the construction of hard-surface, flood-control revetments along this reach of the river. These artificial riverbanks alter natural floodplain processes while often failing to prevent flooding during peak events that damage highway and park structures. Though proposals have been developed to move park facilities out of the canyon, economic and social challenges to such plans have prevented their implementation (C. McKinney, pers. comm. 2015). The hydrology and general ecology of the AFR as is passes through TICA are discussed in Section 4.7.

Efforts to assess the water quality of the AFR are conducted in the canyon though few data have been collected from the river reach adjacent to TICA. Water quality data are collected at the USGS Powerplant stream gage approximately a mile upstream from TICA. The Northern Colorado Plateau Network (NCPN) does not sample for water quality in the AFR (Hackbarth and Weissinger 2013).

2.2.5. Fire

The ecological role of fire varies among the vegetation communities present in the Wasatch Range (Heyerdahl et al. 2011). Given the relatively small area of TICA that supports fire-prone vegetation, fire will not generally be discussed further within this assessment. The greatest concerns for managers are the increased likelihood of catastrophic fires in reponse to climate change (Millar and Stephenson 2015), and the potential for diminished hydrologic function and increased soil erosion within the watershed (Rice et al. 2017).

2.3. Natural Resources

2.3.1. Vegetation Communities

Though TICA is relatively small, vegetation diversity within the park is high and includes forest, woodland, shrub, and riparian plant communities (described briefly belowl; Coles et al. 2009, Witwicki 2010; Figure 2.1-2). Upland vegetation resources (with associated binomial names for species) are assessed in Section 4.12.

Montane Chaparral/Shrub

Chaparral/shrub communities are found primarily on the south-facing slopes of the park (on the north side of the canyon) where soils are generally dry and of poor quality. Plant communities here are dominated by Gambel oak and bigtooth maple, with common occurrences of mountain mahogany, rabbitbrush, and cliff rose. Many areas on the south-facing slopes are unvegetated and rocky.

Mixed-Conifer/Aspen Forests

On the north-facing, cooler slopes, (south side of the canyon) forests are dominated by Douglas fir and white fir, with small areas of quaking aspen at the highest elevations. The rich, moist soils here also allow for the development of a diverse understory of shrubs, juniper, forbs and grasses. In the absence of fire, mixed-conifer forests have undergone major changes in structure and species composition, and insect infestations potentially exacerbated by drought are potential limiting factors related to forest health (Wager and Baker 2003).

Riparian Woodland

The AFR as it flows through TICA is bordered by a narrow band of riparian vegetation dominated by cottonwood, boxelder, and dogwood. Natural riparian function is impeded in this area by the presence of concrete streambank constraints. The general ecology of the riparian zone and effects of impaired flood processes are assessed in Section 4.7.

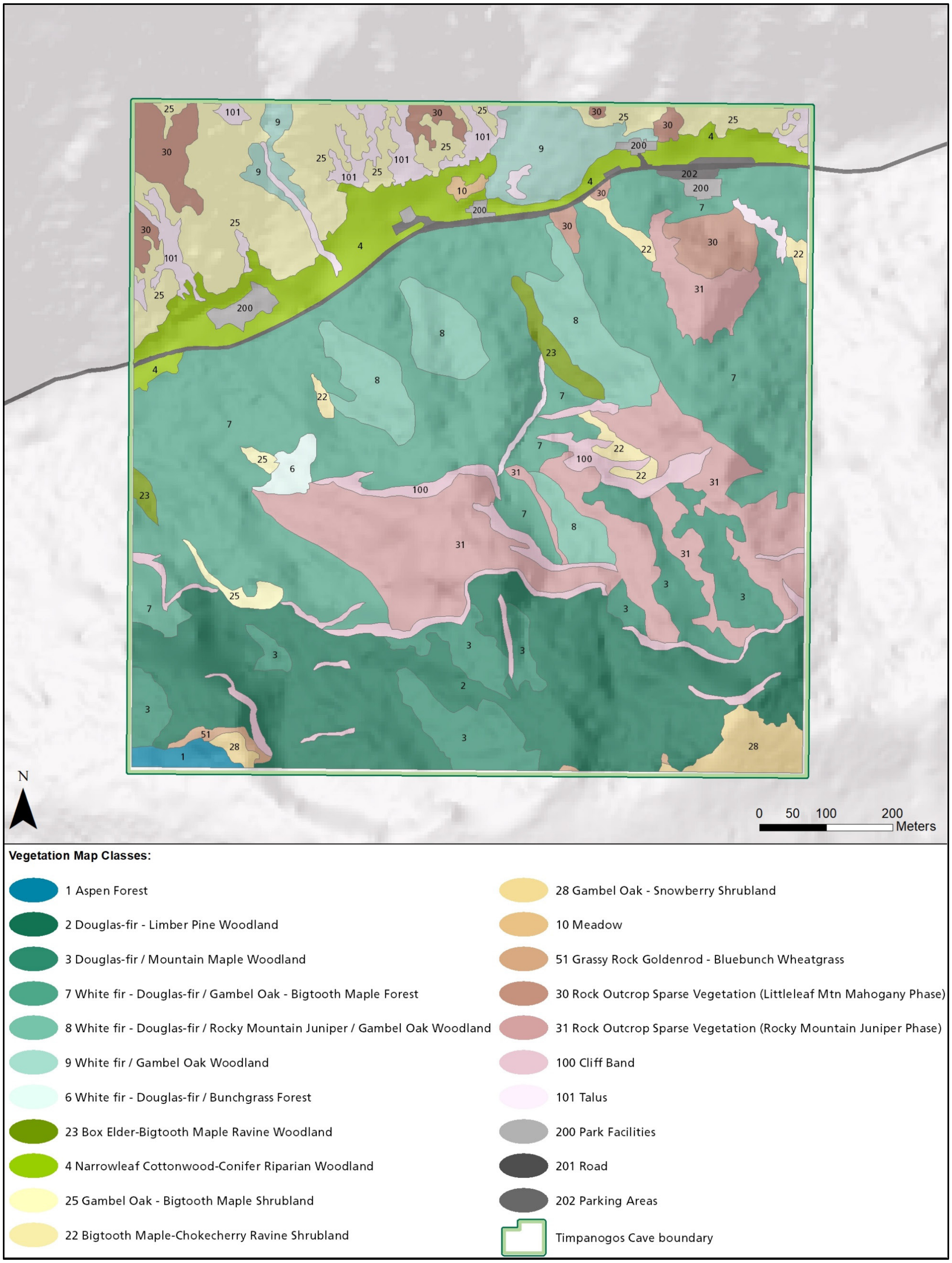


Figure 2.1-2. Vegetation distribution in Timpanogos Cave National Monument. From Coles et al. 2009, courtesy of NCPN-NPS.

2.3.2. Threatened/Endangered Species

There are no federally or state-listed endangered or threatened species resident in TICA.

2.3.3. Species and Communities of Concern

Townsend's Big-Eared Bats (*Corynorhinus townsendii*; Utah species of concern)

Townsend's big-eared bats ('Townsends') are in decline across the western U.S. due primarily to habitat loss (Gruver and Keinath 2006). Townsends, along with several other bat species, roost in the Timpanogos caves and forage throughout AFC. Big-eared bats are a hibernating species, making them susceptible to white-nose syndrome (WNS), though the disease has not yet been detected in Townsends populations. Only small numbers of Townsends likely hibernate in the area, and no Townsends maternity colonies have been found in the Timpanogos Cave system. Townsends bats are assessed in Section 4.10.

Peregrine Falcon (*Falco pereginus anatum*)

Peregrine falcons have a nearly world-wide distribution and breed across much of western North America (Green et al. 2006). Nests are located on cliffs and other protected sites situated adjacent to open areas for hunting preferred prey species such as small birds. During the early 1970s, impacts from DDT led to peregrines becoming one of the first wildlife species in the U.S. to be listed under the Endangered Species Act (USFWS 1984). Since that time peregrine populations have recovered extremely well, and the species was delisted in 1999 (Mesta 1999). However, FWS required continued monitoring through 2015 (USFWS 2003, Daw et al. 2006), and NPS still considers peregrines to be a species of concern. Peregrines are present in TICA and nesting has been documented but they are not currently monitored (C. Mckinney, pers. comm. 2020).

Small and medium-sized vertebrates

Mammal diversity at TICA is high, though for many of the larger species (mountain lion, elk), the monument itself does not provide breeding habitat and species are transient (Haymond et al. 2003). Medium-size mammals such as ringtail cats, longtail weasels, and raccoons likely breed in the monument, and small mammal diversity is also high. Of particular concern is the increasing number of encounters between humans and rattlesnakes, interactions that usually end in the death of the snake (C. McKinney, pers. comm. 2015). Overall, current threats to vertebrate populations are largely unknown; the presence of the highway, increased visitation, habitat loss, and climate change are all potential risks. Small and medium-sized mammals are assessed in Section 4.11.

Bats

The status of bat communities at TICA is of concern for several reasons. White-nose syndrome (WNS) has not yet been detected in Utah, but many observers fear the spread of the disease to the Rocky Mountains (Foley et al. 2011). White-nose syndrome affects hibernating species of bats, and information on hibernating species in many areas is lacking (Diamond et al. 2009, Sullivan et al. 2010). For example, little brown bats (*Myotis* spp.) are extremely common in many western habitats and demonstrate high rates of susceptibility to WNS, but very little is known about their habits in the TICA region (NPS and McKinney 2009). Habitat loss, including the closure of old mines that bats utilize, may increase the importance of cave and protected environments for bat populations (Adams 2003). Bat communities are assessed in Section 4.9.

Cave Microorganisms and Invertebrates

Nearly all primary production in cave ecosystems arises from bacteria that utilize inorganic chemicals obtained from rock substrates and the atmosphere (Barton 2006). Because of their isolation, most living caves have unique micro-organism communities that are sensitive to introductions of new taxa (Saiz-Jimenez 2012, Griffin et al. 2014). Higher on the trophic scale, invertebrate communities are often the only significant group of secondary consumers in caves (Gibert and Deharveng 2002).

Very little to nothing is known regarding the historical diversity of both of these groups in TICA during the first decades after the caves were open. There is concern that species will be extirpated and/or harmful species introduced in the absence of additional study and protection (Nelson et al. 2004, C. McKinney, pers. comm. 2015). The condition of microorganism and invertebrate communities are addressed in Sections 4.5 and 4.8, respectively.

Rare Plants

Populations of rare plants at TICA occur primarily in the vicinity of the cave trail and on limestone outcrops above the cave (C. McKinney, pers. comm. 2015). Six species of rare plants in TICA of regional concern are listed below:

- King's woody aster (*Herrickia* [Aster] *kingii var. kingii*): a former candidate species for Federal listing and identified as a rare plant in Utah; endemic to the Wasatch and Canyon mountains in Utah.

- Wasatch draba (*Draba brachystylis*): identified as a rare plant in Utah; located in five counties in Utah and possibly in Nevada.

- Wasatch jamesia (*Jamesia americana* var. *macrocalyx*): identified as a rare plant in Utah; found only in Utah.

- Wasatch daisy (*Erigeron arenarioides*): not federally- or state-listed, found only in northern Utah.

- Wasatch goldenbush (*Haplopappus watsonii* var. *rydbergii*): not federally- or state-listed; found only in Utah.

- Broadleaf penstemon (*Penstemon platyphyllus*): not federally or state listed; found primarily along the Wasatch front.

Because none of these species are endemic to TICA and are generally well-distributed in other areas, they will not be addressed separately in this assessment:

2.3.4. Non-biologic Resources of Concern

Air Quality

Air quality in TICA is threatened primarily by the expanding urban corridor to the west of AFC between Salt Lake City and Provo (UDAQ 2015). Risks to human health and vegetation from ground-level ozone, and nitrogen and sulfur deposition, are all concerns at TICA. Little is known about mercury deposition. Regional and local sources of air pollution include emissions from coal-fired power plants, industrial facilities, agricultural emissions, rapid adjacent urban development, and impacts from increased vehicular traffic in the canyon. In the monument's Foundation Document (2016), the need for air quality assessment and monitoring was identified but was ranked a lower priority than other data deficits (NPS 2016). Air quality is assessed in Section 4.1.

Cave Features

The collection of cave features (speleothems) in the Timpanogos Cave system is unique in several ways (Pulham 2009). For example, there is an abundance of helictites, relatively rare spiral formations that can 'grow' in directions counter to gravity when capillary action moves water through tiny (< 0.5 mm) canals. The colors of many of the Timpanogos formations are also uncommon, tinted in unusual ways by combinations of various minerals. Unfortunately, small numbers of beautiful and unique cave features were lost to looters, particularly from Hansen Cave, early in the century when the caves were unprotected (C. McKinney, pers. comm. 2015). The condition of TICA speleothems is addressed in Section 4.5.

Cave Climate

Maintaining natural climate conditions within the caves is critical for the protection of cave resources (Fernandez-Cortes et al. 2010). Increased airflow resulting from the construction of the tunnels in the 1930s has altered cave climate (Armstrong 2010), though long-term impacts are largely unknown. Doors between the man-made tunnels were first installed in the 1980s but were not airtight. Newer doors provide a more effective seal but airflow through the tunnels still occurs, and the doors are opened numerous times each day for tours during the summer season (NPS 2013). New airlock doors were installed in 2015, and observations indicate improved climate stabilization in the caves. The condition of cave climate is addressed in Section 4.2.

Subterranean Water Quality and Quantity

Water flow into and through caves is responsible for cave formation growth and supports cave biota (Bonacci et al. 2009). Water in the caves appears to be of good quality, but human activities within the watershed and visitor impacts may reduce water quality or alter water chemistry (Florea et al. 2013). Consequently, identification of surface activities that may affect water quality in the caves as well as the precise extent of the subsurface cave watershed (which is unknown) are high priorities (C. McKinney, pers. comm. 2015; Florea et al. 2013). Reductions in winter snowpack of the Wasatch Range that might result from climate change may also impact cave hydrology (Dragoni and Sukhija 2008). Cave water quality and hydrology are addressed in Sections 4.4 and 4.6.

Night Skies and Soundscape

Natural quiet and night skies are increasingly being recognized as desired elements in natural areas. Though both resources are generally addressed as visitor issues, (i.e. how the absence of quiet and natural night skies affect the human experience), recent studies have revealed that artificially bright night skies and higher noise levels can also have significant negative impacts on wildlife (Rich and Longcore 2005, Barber et al. 2009, Gaston and Bennie 2014). Natural night skies and natural sounds are assessed in Section 4.13.

2.4. Relevant Regional and Landscape-scale Information

The monument lies within Utah County and is completely surrounded by the Uinta-Wasatch-Cache National Forest. To the north the park abuts the USFS Lone Peak Wilderness, and to the southeast (but not adjacent) is the USFS Mount Timpanogos Wilderness, one of the most popular mountain recreation destinations in Utah. A two-lane state highway (State Route [SR] 92) runs through the northern third of the monument adjacent to the American Fork River. An entrance station west of TICA at the USFS boundary is managed by the USFS.

2.5. Primary Threats to Natural Resources

2.5.1. Climate Change

Climate change effects will likely impact numerous TICA resources, including hydrology of the American Fork River, hydrologic processes within the caves, and vegetation (UCCC 2007, NCA 2014, NRCS 2014). Climate change is addressed in Section 4.3.

2.5.2. Adjacent Land Use

Approximately one-third of the cave watershed includes lands managed for multiple use, (e.g. ORV sites, camping, hunting, and snowmobiling), activities that could have impacts on cave water quality (Florea et al. 2013). Wildfires, which may increase in frequency and intensity in response to drought and forest disease, will likely also have negative impacts on water quality (Dale et al. 2001). Habitat integrity in relation to adjacent land use is assessed in Section 4.13.

2.5.3. Visitor Use

The presence of high numbers of people in cave ecosystems generally has negative impacts on cave resources (Calaforra et al. 2003, Griffin et al. 2014). TICA managers are striving to balance visitor enjoyment of the caves with resource protection (NPS 2013). Specific impacts to cave resources indirectly caused by human presence is addressed in Sections 4.2, 4.4, 4.5, and 4.8.

2.5.4. Cave Lights

Lights were first installed in the caves nearly a century ago for visitor safety and to enhance viewing of cave features (Pulham 2009). Lights in caves have since been shown to cause unnatural levels of algal growth, (‘lampenflora’), which impacts cave formations, water quality, and invertebrate and microorganism communities (Mulec and Kosi 2009). TICA is currently replacing older lights with cooler LED bulbs, an effort that should reduce algal growth. The impacts of lampenflora are addressed in Section 4.5.

2.5.5. Non-native/Invasive Species

Approximately 20 exotic plant species are of concern to park managers and invasive plants occur on an estimated 25% of park lands (NPS 2005, Whiteside 2011, Armstrong 2012). Exotic brown trout (*Salmo trutta*) were introduced to the American Fork Canyon early in the last century and are highly competitive with native cutthroat trout (*Oncorhynchus clarki utah*; McHugh and Budy 2005). Mountain goats (*Oreamnos americanus*) were introduced into Utah during the 1960’s and are now resident in TICA and the Mount Timpanogos Wilderness. Introduced mountain goats can have negative effects on existing high-altitude ecosystems (Gross et al. 2000), and there is debate as to whether this species of goat is native to the Wasatch Mountains (see overview in Mead and Lawler

1994 for a discussion of mountain goat species distribution in the Colorado Plateau). The Utah Department of Wildlife Resources (UDWR) maintains and manages the goat population as a big-game species (UDWR 2013).

2.6. Resource Stewardship

2.6.1. Management Directives, Planning Guidance and Research

General/Resource Plans (listed in reverse chronological order)

Cave Management Plan, 2013 (NPS 2013)

This plan addresses all areas of cave management, including visitor use limits, trail maintenance, safety, ecosystem health, and watershed management.

Transportation Alternatives Plan, 2012 (NPS 2012b)

This effort evaluated parking capabilities at TICA and the possible feasibility of a shuttle system in American Fork Canyon.

Core Operations Review, 2008 (NPS unpublished)

The first priority in this document is to '…preserve cave and karst resources by developing a cave and natural resource management program.' Specifically, the document states that cave and karst resources will be protected by '…replacing the cave trail restroom sewage disposal system, and through appropriate policy, research, monitoring, and mitigation techniques.' This review also led to the addition of a full-time, permanent Chief of Resources position.

Vegetation Management Plan, 2005 (NPS 2005)

The Vegetation Management Plan outlines the long-term approach for controlling invasive plants and revegetation of disturbed areas, and Environmental Assessment (EA).

General Management Plan, 1993 (NPS 1993)

The GMP was completed in 1993 following a fire that destroyed the TICA Visitor Center. This document focuses on the replacement of this building and overall facility management at TICA.

Specific Resource/Restoration Efforts

Invasive plants and greenhouse

Since 2005 TICA staff and volunteers have been removing exotic plants and establishing populations of native species, with a goal of treating five acres of invasives and revegetating one acre with park-grown native plants each year. A small greenhouse constructed at the park yields approximately 500 plants each year grown from locally collected seeds.

Cave restoration

Park staff perform lint/debris removal from cave formation surfaces on a regular basis. In addition, a 3-day Restoration Camp is hosted by the park for volunteers each fall after the caves close to visitors for the season. Typically, 12 volunteers work on each of the three days. Algae is also removed from formations and other surfaces 1–2 times per season, and when necessary repairs are made to broken formations.

2.6.2. Supporting Science

<u>NPS Inventory and Monitoring Program</u>
Of the 18 high-priority vital signs identified by TICA and NCPN, six (integrated uplands, water quality, climate, land surface phenology, landscape dynamics, and air quality) are subject to long-term monitoring and study by NCPN. A challenge for TICA and NCPN staff is to include the unique monitoring needs of the TICA cave ecosystems within the full set of NCPN monitoring priorities (C. McKinney pers. comm. 2015).

2.7. Literature Cited

Adams, R.A. 2003. Bats of the Rocky Mountain West. University Press of Colorado, Boulder, CO.

Armstrong, A. 2010. Monitoring Cave Climate Changes, 2009–2010. Final Report. Unpublished, available at: http://store.wnpa.org/research/tica09-10.pdf.

Armstrong, B. 2012. Weed Report, TICA. Unpublished Report at TICA headquarters.

Barber, J.R., K.R. Crooks and K.M. Fristrup. 2009. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution 25:180–189.

Barton, H.A. 2006. Introduction to cave microbiology: A review for the non-specialist. J. Cave and Karst Studies 68:43–54.

Bonacci, O., T. Pipan and D.C. Culver. 2009. A framework for karst ecohydrology. Environmental Geology 56:891–900.

Calaforra, J.M., A. Fernandez-Cortés, F. Sanchez-Martos, J. Gisbert, and A. Pulido-Bosch. 2003. Environmental control for determining human impact and permanent visitor capacity in a potential show cave before tourist use. Envir. Cons. 30: 160–167.

Coe, J.A., and E.L. Harp. 2007. Influence of tectonic folding on rockfall susceptibility, American Fork Canyon, Utah, USA. Natural Hazards and Earth System Science 7:1–14.

Coles, J., J. Von Loh, A. Wight, K. Schulz, and A. Evenden. 2009. Vegetation classification and mapping project report, Timpanogos Cave National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2009/210. National Park Service, Fort Collins, Colorado.

Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks and B.M. Wotton. 2001. Climate change and forest disturbances: climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. BioScience 51:723–734.

Daw, S., S. Ambrose, M. Beer and M.A. Powell. 2006. American Peregrine Falcon Monitoring Protocol for the Park Units in the Northern Colorado Plateau Network, v1.01. Northern Colorado Plateau Network Inventory and Monitoring Program, National Park Service, U.S. Department of the Interior, Moab, UT.

Diamond, J.M., R.N. Knight, L.B. Wilson, K. Asmus-Hersey, and B. Sutter. 2009. Status of Utah Bats. U.S. Army Dugway Proving Grounds, UT.

Dragoni, W. and B.S. Sukhija. 2008. Climate change and groundwater: a short review. Geological Society, London, Special Publications 288:1–12.

Fernandez-Cortes, A., S. Sanchez-Moral, J.C. Cañaveras, J. Cuevas-Gonzalez, S. Cuezva, and J.M. Andreu. 2010. Variations in seepage water geochemistry induced by natural and anthropogenic microclimatic changes: Implications for speleothem growth conditions. Geodinamica Acta 23:1–13.

Florea, L.J., C.R. Dugan, and C. McKinney. 2013. Preliminary summary of water resource investigations during 2012 at TImpanogos Cave National Monument, Utah. In Proceedings of the 20th National Cave and Karst Management Symposium, pp. 61–67. 2013.

Foley, J., D. Clifford, K. Castle, P. Cryan and R.S. Ostfeld. 2011. Investigating and managing the rapid emergence of white-nose syndrome, a novel, fatal, infectious disease of hibernating bats. Cons. Bio. 25:223–231.

Gaston, K.J., and J. Bennie. 2014. Demographic effects of artificial nighttime lighting on animal populations. Environmental Reviews 22:1–8.

Gibert, J. and L. Deharveng. 2002. Subterranean ecosystems: A truncated functional biodiversity. BioScience 52, no. 6 (2002): 473–481.

Gillies, R.R. and R.D. Ramsey. Undated. Climate of Utah. Available online: http://extension.usu.edu/utahrangelands/files/uploads/RRU_Section_Five.pdf.

Green, M.G., T. Swem, M. Morin, R. Mesta, M. Klee, K. Hollar, R. Hazlewood, P. Delphey, R. Currie, and M. Amaral. 2006. Monitoring results for breeding American Peregrine Falcon (*Falco pereginus anatum*). 2003. U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-R1005-2006, Washington DC.

Gross, J.E., M.C. Kneeland, D.M. Swift and B.A. Wunder. 2000. Scientific Assessment of the Potential Effects of Mountain Goats on the Ecosystems of Rocky Mountain National Park. Final Report to NPS, Rocky Mountain National Park, Estes Park, CO. Contract #1443PX15099062. Natural Resource Ecology Laboratory and Department of Biology, Colorado State University, Ft. Collins, CO.

Griffin, D.W., M.A. Gray, M.B. Lyles, and D.E. Northup. 2014. The transport of nonindigenous microorganisms into caves by human visitation: A case study at Carlsbad Caverns National Park. Geomicrobiology Journal 31:175–185.

Gruver, J.C. and D.A. Keinath. 2006. Townsend's Big-eared Bat (*Corynorhinus townsendii*): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region.

Available: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5181908.pdf [accessed January 30, 2020].

Hackbarth, C. and R. Weissinger. 2013. Water quality in the Northern Colorado Plateau Network, water years 2010–2012. Natural Resource Technical Report NPS/NCPN/NRTR—2013/831. National Park Service, Fort Collins, Colorado.

Haymond, S., M.A. Bogan and E.W. Valdez. 2003. 2001–2002 Mammalian Inventory Final Report for Selected Northern Colorado Plateau Network Parks, U.S. Geological Survey, Fort Collins Science Center, Ft. Collins, CO, and Arid Lands Field Station, Department of Biology, University of New Mexico, Albuquerque, NM.

Heyerdahl, E.K., P.M. Brown, S.G. Kitchen, and M.H. Weber. 2011. Multicentury fire and forest histories at 19 sites in Utah and eastern Nevada. Gen. Tech. Rep. RMRS-GTR-261WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 192 p.

Machette, M.N., S.F. Personius, A.R. Nelson, D.P. Schwartz, and W.R. Lund. 1991. The Wasatch fault zone, Utah—segmentation and history of Holocene earthquakes. Journal of Structural Geology 13:137–149.

Mayo, A.L., D. Herron, S.T. Nelson, D. Tingey, and M.J. Tranel. 2000. Geology and hydrology of Timpanogos Cave National Monument, Utah. Pp. 263–275 in: Geology of Utah's Parks and Monuments, 2000. Utah Geological Association Pub. 28, Salt Lake City, UT.

Mayo, A.L., J. Bruthans, D. Tingey, J. Kadlec, and S. Nelson. 2009. Insights into Wasatch fault vertical slip rates using the age of sediments in Timpanogos Cave, Utah. Quaternary Research 72:275–283.

McCalpin, J.P. and S.P. Nishenko. 1996. Holocene paleoseismicity, temporal clustering, and probabilities of future large (M> 7) earthquakes on the Wasatch fault zone, Utah. Journal of Geophysical Research: Solid Earth (1978–2012) 101:6233–6253.

McHugh, P. and P. Budy. 2005. An experimental evaluation of competitive and thermal effects on brown trout (*Salmo trutta*) and Bonneville cutthroat trout (*Oncorhynchus clarkii utah*) performance along an altitudinal gradient. Canadian Journal of Fisheries and Aquatic Sciences 62:2784–2795.

Mead, J.I., and M. C. Lawler. 1994. Skull, mandible, and metapodials of the extinct Harrington's mountain goat (*Oreamnos harringtoni*). Journal of Vertebrate Paleontology 14(4):562–576.

Mesta, R. 1999. Final Rule to Remove the American Peregrine Falcon from the Federal list of endangered and threatened wildlife, and to remove the similarity of appearance provision for free-flying peregrines in the conterminous United States. Federal Register 64, no. 164:46541–46558.

Millar, C.I. and N.L. Stephenson. 2015. Temperate forest health in an era of emerging megadisturbance. Science 349:823–826.

Mulec, J. and G. Kosi. 2009. Lampenflora algae and methods of growth control. J Cave Karst Stud 71:109–115.

National Climate Assessment (NCA). 2014. Selected Findings and Information from the Third U.S. National Climate Assessment Relevant to UTAH. (http://www.whitehouse.gov/sites/default/files/docs/state-reports/UTAH_NCA_2014.pdf).

National Park Service (NPS). 1984. Timpanogos Cave National Monument, Statement for Management.

NPS. 1993. Draft: Environmental Impact Statement, General Management Plan, Development Concept Plan. Timpanogos Cave National Monument, American Fork, UT. (https://www.nps.gov/tica/learn/management/upload/TICA_1993-Draft-GMP-and-DCP-EIS.pdf).

NPS. 2005. Timpanogos Cave National Monument Invasive Species Management Plan.

NPS and A. McKinney. 2009. Bat Species Baseline: Timpanogos Cave National Monument. Timpanogos Cave National Monument, Utah.

NPS. 2012a. Timpanogos Cave System Climate Records 2002–2012. Timpanogos Cave National Monument, Utah.

NPS. 2012b. Alternative Transportation Feasibility Study. Timpanogos Cave National Monument, PMIS #172474. Prepared by Cambridge Systematics, Inc. and David Evans and Associates, Inc.

NPS. 2013. Timpanogos Cave National Monument, Draft Cave Management Plan Environmental Assessment. Timpanogos Cave National Monument, American Fork, UT.

NPS. 2016. Foundation document: Timpanogos Cave National Monument. National Park Service, Denver, Colorado.

Natural Resources Conservation Service (NRCS). 2014. Utah Climate and Water Report. Available online: http://www.wcc.nrcs.usda.gov/scan/Utah/utah.html.

Nelson, S.R., ed. 1997. History of the Uinta National Forest: A History of Stewardship. Uinta National Forest, U.S. Forest Service.

Nelson, C.R., J. Guptill and R.W. Baumann. 2004. Macroinvertebrates of Timpanogos Cave, Timpanogos National Monument, Utah. Draft Final Field Report; Cooperative Agreement #CA1248-009 between NPS and Brigham Young University.

Pulham, C. 2009. Heart of the Mountain: The History of Timpanogos Cave National Monument. National Park Service, Washington, D.C.

Rice, J., T. Bardsley, P. Gomben, D. Bambrough, S. Weems, S. Leahy, C. Plunkett, C. Condrat, and L.A. Joyce. 2017. Assessment of watershed vulnerability to climate change for the Uinta-Wasatch-Cache and Ashley National Forests, Utah. RMRS-GTR-362. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 111 p., 362.

Rich, C. and T. Longcore, eds. 2005 Ecological Consequences of Artificial Night Lighting. Island Press, Washington, DC. 480 pp.

Saiz-Jimenez, C. 2012. Microbiological and environmental issues in show caves. World Journal of Microbiology and Biotechnology 28:2453–2464.

Sullivan, A.R., J.K. Bump, L.A. Kruger, and R.O. Peterson. 2012. Bat-cave catchment areas: using stable isotopes (δD) to determine the probable origins of hibernating bats. Ecological Applications 22:1428–1434.

Thornberry-Ehrlich, T. 2006. Timpanogos Cave National Monument Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2006/013. National Park Service, Denver, Colorado.

U.S. Fish and Wildlife Service (USFWS). 1984. American Peregrine Falcon Recovery Plan (Rocky Mountain/Southwest Population). Prepared in cooperation with the American Peregrine Falcon Recovery Team. US Dept. of Interior, Fish and Wildlife Service, Denver, CO.

USFWS. 2003. Monitoring plan for the American Peregrine Falcon, a species recovered under the Endangered Species Act. US Dept. of Interior, Fish and Wildlife Service, Divisions of Endangered Species, Migratory Birds, and State Programs. Pacific Region, Portland, OR.

Utah Blue Ribbon Commission on Climate Change (UCCC). 2007. http://www.inscc.utah.edu/~steenburgh/papers/utah_climate_report_2007.pdf.

Utah Division of Wildlife Resources, Department of Natural Resources (UDWR). 2013. Utah Mountain Goat Statewide Management Plan. https://wildlife.utah.gov/hunting/biggame/pdf/mtn_goat_plan.pdf.

Utah Division of Air Quality, Air Monitoring Section (UDAQ). 2015. Utah Air Quality Monitoring Network Five-year Network Assessment. State of Utah, Salt Lake City, UT.

Wager, D.J. and F.A. Baker. 2003. Potential effects of ozone, climate, and spruce budworm on Douglas-fir growth in the Wasatch Mountains. Canadian Journal of Forest Research 33:910–921.

White, W.B., J.J. Van Gundy. 1971. Geological reconnaissance of Timpanogos Cave, Utah. The NSS Bulletin 33:147–148.

Whiteside, R. 2011. Invasive Species Report. Unpublished Report at TICA headquarters.

Witwicki, D. 2010. Integrated upland monitoring in Timpanogos Cave National Monument: annual report 2009 (non-sensitive version). Natural Resource Technical Report NPS/NCPN/NRTR—2010/391.N. National Park Service, Fort Collins, Colorado.

Chapter 3. Study Approach

This NRCA is a collaborative project between TICA, NCPN, the NPS Intermountain Region, and cooperators from the Institute of Wildlife Studies in Arcata, California. The TICA park staff, in particular Cami Pulham McKinney, provided substantial input to the project including project definition and direction, data summaries and analysis, and review.

The purpose of this assessment is to provide a "snapshot-in-time" evaluation of a select set of natural resources within the park. Findings presented will aid NPS staff in developing near-term management priorities, engaging partners and stakeholders in watershed and landscape scale resource protection efforts, and conducting park planning.

3.1. Preliminary Scoping

The preliminary scoping process occurred during a workshop organized by NCPN at TICA headquarters in August 2010 (Summary notes from this meeting are provided in Appendix A). Workshop attendees developed a preliminary list of focal resource topics and prioritized the list in relation to both park management priority and how well each topic would fit within the NRCA guidelines. Also included in the scoping discussions were general determinations of available data and the amount of time it would take TICA staff or other personnel to collate or synthesize necessary information. At the conclusion of the workshop the team had completed a draft list of resource topics. The list was modified as the project proceeded; the final list of topics is presented in Table 3.1.

3.1.1. Targeted Investigation Topic – Cave Watershed

The Intermountain Region provided funding for an outside investigator to address one natural resource topic in greater depth than would otherwise have been possible within the allocated NRCA budget. This agreement was facilitated by NCPN. Park staff determined that funding an effort to more precisely delineate the extent of the cave watershed was the highest priority. The TICA cave ecosystem is directly dependent on the quality and quantity of water that enters the caves from the surface, but at the time of initial scoping for the NRCA a delineation of the watershed had not yet been completed. It was hypothesized that the watershed extended outside NPS boundaries to adjacent USFS lands, where permitted activities might introduce contaminants into the caves via water transport. NRCAs generally do not include data collection efforts, however, in this case the information needed was likely obtainable with relatively simple methods. The results of this study are presented briefly in Section 4.6, and in detail in Florea et al. (2013) and Dugan (2015).

Table 3.1-1. List of selected resource topics for the TICA NRCA organized within the Inventory and Monitoring Framework.

Monitoring Framework Level 1 Category	TICA Element/Resource	Management Priority	Project Priority	Ecological Zone
Air and Climate	Climate – Surface, Climate Change	High	High	Riparian, Upland
	Climate – Caves	High	High	Caves
	Air Quality	Low	Medium	Riparian, Upland
Geology and Soils	Subsurface – Cave Formations	High	High	Caves
Water	Water Quality – AFR	Low	Low	Riparian
	Water Quality and Quantity – Caves	High	High	Caves
	Hydrology – AFR	Medium	Medium	Riparian
	Hydrology – Caves (watershed)	High	High	Caves
Biological Integrity	Focal Species: Townsends Big-eared bats	High	High	Caves, Riparian, Upland
	Focal Communities: Bats	High	Medium	Caves, Riparian, Upland
	Focal Communities: Small and medium-sized mammals	Medium	Medium	Riparian, Upland
	Focal Communities: Cave microorganisms and invertebrates	Medium	High	Caves
	Upland vegetation	Medium	Low	Upland
	Riparian Vegetation	Low	Medium	Riparian
Landscapes (Ecosystem Pattern and Processes)	Ecosystem Connectivity	Medium	HIgh	Riparian, Upland
	Dark Night Sky/ Soundscape/ Viewshed	Medium	High	Riparian, Upland

3.2. Study Design

3.2.1. Indicator Framework, Study Resources and Indicators

The NPS Ecological Monitoring Framework (Fancy et al. 2009) was incorporated in the TICA NRCA to identify and synthesize the natural resource topics, indicators, and measures in the study. This framework was selected due to the tight integration of the framework with the NPS Inventory and Monitoring (I&M) program. For example, if large data gaps were identified for a particular resource or topic, this information could be evaluated for potential inclusion in the I&M program more easily if the NRCA were organized using this framework (Table 3.1).

Per NPS NRCA guidelines, resource assessments are often spatially organized into reporting areas. This approach is helpful for managers as it allows integration of the NRCA with planning documents such as GMPs. In small parks such as TICA, though, the use of reporting areas is generally unnecessary, and it was not done here. The resources did, however, fit clearly into three ecological zones within TICA: caves, riparian, and upland (Table 3.1).

Reference conditions were developed separately for each topic by first conducting a literature search to determine what types of measures had been or were being used to evaluate similar resources. Discussions were also held with local knowledge experts, and existing NRCA documents reviewed to compare references conditions applied to similar resources in other NPS units. For some topics determining reference conditions was straightforward; however, in many cases no relevant reference conditions were available. The process for determining reference conditions (or reasons why they are unavailable or unquantified) is included within each topic section in Chapter 4.

3.2.2. General Approach and Methods

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

3.2.3. Components Included in Each Analysis

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

<u>Background</u>

This section describes the resource and why it was selected for inclusion in the project. This section also may include a brief biological or physical description, the ecological context of the resource within TICA, and threats to the resource or process.

Reference Conditions
The measures used to evaluate the condition of the resource are defined here. If no clear science-based measures exist and alternate evaluation methods were utilized, those are also included. The absence of any valid reference conditions is noted if necessary.

Data and Methods
This section includes references to both existing data and methodologies as well as specific assessment methods incorporated for this NRCA.

Resource Condition and Trend
This section summarizes what is known about the resource in relation to described reference conditions. If the condition appears to be changing ('trend') that information is also presented here.

Level of Confidence
In some cases, very little is known about the status of the resource, the reference conditions that should be used to make the assessment, or both. This section evaluates the science-based level of confidence for each assessment.

Data Gaps and Research Needs
This section presents recommendations for further research or data that would be needed to have a high confidence in making an assessment of the current condition and/or condition trend for the resource.

Sources of Expertise
If applicable, subject matter experts who contributed to the assessment but are not identified elsewhere are listed here.

Literature Cited
Each section is followed by a complete reference list.

3.2.4. Project Challenges

In the fall of 2011, the project was suspended due to funding issues. In the summer of 2012 funding was restored through a cooperative agreement, but staff changes and funding uncertainty again suspended the work. Funding to complete the project became available in 2020, though this work did not include updates to resource topics. In lieu of that work, a brief list of relevant publications or general information that have been published or made available in the past few years but are not referenced within the text is presented in Appendix B.

3.2.4 Condition Reporting Symbols

Chapter 5 provides general-level condition or concern reporting for resources evaluated in Chapter 4. Tables 3.2-1 and 3.2-2 show the descriptions of the condition indicator symbols.

Table 3-.2-1. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

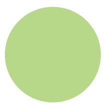
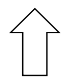
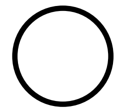
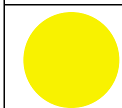
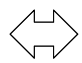
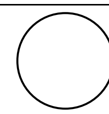
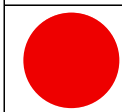
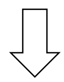
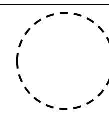
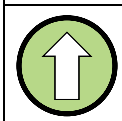
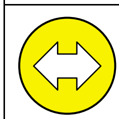
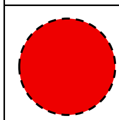
Condition Status		Trend in Condition		Confidence in Assessment	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low

Table 3.2-2. Example indicator symbols and descriptions of how to interpret them in WCS tables.

Symbol Example	Verbal Description
	Resource is in good condition; its condition is improving; high confidence in the assessment.
	Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.
	Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.

3.2.5. Project Challenges

In the fall of 2011, the project was suspended due to funding issues. In the summer of 2012 funding was restored through a cooperative agreement, but staff changes and funding uncertainty again suspended the work. Funding to complete the project became available in 2020, though this work did not include updates to resource topics. In lieu of that work, a brief list of relevant publications or general information that have been published or made available in the past few years but are not referenced within the text is presented in Appendix B.

3.3. References

Dugan, C.R. 2015. Investigating Vadose-zone Hydrology in Alpine Karst Aquifers Using Quantitative Groundwater Tracing Methods: Timpanogos Cave National Monument, Utah County, Utah. Master's Thesis, Ball State Univ., Muncie, IN.

Fancy, S.G., J.E. Gross, and S.L. Carter. 2009. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment 151:161–174.

Florea, L.J., C.R. Dugan, and C. McKinney. 2013. Preliminary summary of water resource investigations during 2012 at TImpanogos Cave National Monument, Utah. In Proceedings of the 20th National Cave and Karst Management Symposium, pp. 61–67. 2013.

Chapter 4. Natural Resource Conditions

4.1. Air Quality

4.1.1. Background

Under the direction of the National Park Service (NPS) Organic Act, Air Quality Management Policy 4.7.1 (NPS 2006), and the Clean Air Act (CAA) of 1970 (P.L. 94-567; 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 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-ARD 2006a).

Different categories of air quality areas are 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 regulatory agencies’ decisions that might affect air quality in the federally protected areas they administer (NPS-ARD 2005). Like most NPS areas, TICA is designated a Class II airshed.

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).

Air quality management requires extensive interaction with state and federal agencies, as identified in NPS management policies. Specific air quality threats for TICA include:

- Regional and local sources of air pollution such as power plants, industrial facilities, agriculture, vehicle exhaust, and Rapid adjacent urban development.
- Regional coal fired power plants, mobile sources (e.g., highway vehicles), and wildfires are believed to contribute to air quality impacts in the park. Sulfur dioxide emissions have been reduced at Utah power plants. Additional reductions in nitrogen oxides emissions from the coal-fired power plants may be required if the national standard for ozone pollution is reduced in October 2015 or under the Regional Haze program for the protection of Class I areas. Mobile source emissions are also being reduced. These reductions will also improve air quality conditions at TICA.
- Increasing visitation and associated vehicle traffic. In recent years, traffic in American Fork Canyon has steadily increased. Latest figures from the U.S. Forest approximate 1.3 million visitors, annually. Census data from 2010 show that the communities closest to the park/canyon have grown 200% in the last 10 years (McKinney pers. comm. 2015).

- The Wasatch Front inversion is a big air quality issue at Timpanogos Cave. Air inversions have been occurring for years and work has been done to reduce inversions. Geneva Steel, a contributor to the pollution locally, is no longer operating, resulting in some improvement to air quality, but other factors are impacting it (NPS 2015).

There are also opportunities to work cooperatively with federal, state, tribal, local agencies, industry, and public interest groups, to develop strategies to reduce air quality impacts in the park from sources of air pollution. There are ongoing opportunities through federal air quality programs (e.g., regional haze program) for the NPS to work cooperatively with these stakeholders (NPS-ARD 2015e).

<u>Air Quality Standards</u>
Air quality is deteriorated by many forms of pollutants that occur either 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 US Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS) (40 CFR part 50) to regulate air pollutants considered harmful to human health and the environment (EPA 2015). The two types of NAAQS are primary and secondary. The primary standards establish limits to protect human health, and the secondary standards establish limits to protect public welfare from air pollution effects, including decreased visibility, damage to animals, crops, vegetation, and buildings (EPA 2015). The NPS' Air Resources Division (NPS-ARD) air quality monitoring program uses EPA's NAAQS, natural visibility goals, and ecological thresholds as benchmarks to assess current conditions of visibility, ozone, and atmospheric deposition throughout parks.

<u>Visibility</u>
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. At night, air-borne particles reflect and scatter artificial light, increasing the effect of light pollution. The CAA established a national goal to return visibility to "natural conditions" in Class I areas and the NPS ARD recommends a visibility benchmark condition for all NPS units, regardless of Class designation, consistent with the Clean Air Act goal. Natural visibility conditions are those estimated to exist in a given area in the absence of human-caused visibility impairment (EPA-454/B-03-005).

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) 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).

<u>Ozone</u>
Ozone is a gaseous constituent of the atmosphere produced by reactions of nitrogen oxides (NOx) from vehicles, power plants, industry, and fire and volatile organic compounds from industry, solvents, and vegetation in the presence of sunlight (Porter and Biel 2011). It is one of the most widespread air pollutants and the major constituent in smog (NPS-ARD 2002).

Ozone can be harmful to human health, and is phytotoxic, causing foliar damage to plants (NPS-ARD 2006b). Ozone penetrates leaves through stomata (openings) and oxidizes plant tissue, which alters the physiological and biochemical processes (NPS-ARD 2013a). Once the ozone is inside the plant's cellular system, the chemical reactions can cause cell injury or even death (NPS-ARD 2013a), but more often will reduce the plant's resistance to insects, diseases, growth, and reproductive capability (NPS-ARD 2015a).

N and S Wet Deposition

Airborne pollutants can be atmospherically deposited to ecosystems through rain and snow (wet deposition) or dust and gases (dry deposition). Nitrogen, sulfur, and mercury air pollutants can have a variety of effects on ecosystem health, including acidification, fertilization or eutrophication, and accumulation of toxins (NPS-ARD 2010, Fowler et al. 2013). Although nitrogen is an essential plant nutrient, excess nitrogen from atmospheric deposition can stress ecosystems. Excess nitrogen acts as fertilizer, favoring some plants and leaving others at a competitive disadvantage. This creates an imbalance in natural ecosystems, and over time may lead to shifts in the types of plant and animal species present, increases in insect and disease outbreaks, disruption of ecosystem processes (such as nutrient cycling), and changes in wildfire frequency (Bobbink et al. 2010; De Schrijver et al. 2011; Greaver et al. 2012).

Natural resource managers are particularly concerned about the tendency for invasive exotic plant species to thrive in elevated nitrogen environments and the negative impacts of surplus nitrogen on native plants, particularly in arid ecosystems (Brooks 2003; Schwinning et al. 2005; Allen et al. 2009). Nitrogen may also decrease water use efficiency in arid land plant groups such as sagebrush (Inouye 2006). 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 pollutants than others, including high-elevation ecosystems in the western U.S., upland areas in the eastern part of the country, areas on granitic bedrock, coastal and estuarine waters, arid ecosystems, some grasslands, and many surface waters (NPS-ARD 2013b).

According to the EPA (2012), in the U.S., roughly two thirds of all sulfur dioxide (SO_2) and one-fourth of all NO_x depositions 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, with the potential to negatively impact resources far beyond point sources (EPA 2012).

Mercury Wet Deposition and Predicted Methylmercury Concentration

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 2015b).

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).

4.1.2. Data and Methods

The approach used for assessing the condition of air quality parameters at the park was developed by the NPS-ARD for use in Natural Resource Condition Assessments (NPS-ARD 2015b, d). NPS-ARD uses all available data from NPS, EPA, 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 will "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 6 years of annual data and an annual value for the end year of the reporting period.

Indicators/Measures: Visibility (Haze index)
Visibility is monitored through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program (NPS-ARD 2010).

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). 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 (NPS-ARD 2003). The haze index for visibility condition is calculated as follows:

$$\text{Visibility Condition/Haze Index (dv)} = \text{estimated current Group 50 visibility} - \text{estimated Group 50 visibility (under natural conditions)}$$

The deciview scale scores pristine conditions as a zero and increases as visibility decreases.

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 the TICA boundary 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 Clean Air Act 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.

An IMPROVE monitoring site considered being representative of a Class II park has to be between within +/− 100 feet or 10% of maximum and minimum elevation of the park and at a distance of no more than 150 kilometers. IMPROVE representative monitors are not assigned to parks with a land-use status of urban (NPS-ARD 2015b). There are no on-site or nearby representative monitors to assess visibility trends. The closest monitoring stations for visibility are at Capitol Reef NP, 143 mi (230 km) south of the monument; at Great Basin NP, 168 mi (270 km) southwest of the monument; and at Canyonlands NP 280 km (174 mi) southeast of the monument.

<u>Indicators/Measures: Level of Ozone (Human Health: Annual 4th-highest 8hr concentration and Vegetation Health: 3-month maximum 12hr W126)</u>

Ozone is monitored across the U.S. through air quality monitoring networks operated by the NPS, EPA, states, and others. Aggregated ozone data are acquired from the EPA Air Quality System (AQS) database. Note that prior to 2012, monitoring data were also obtained from the EPA Clean Air Status and Trends Network (CASTNet) database.

The primary National Ambient Air Quality Standard (NAAQS) for ground-level ozone is set by the EPA, and is based on human health effects. The current NAAQS for ozone is a 4th-highest daily maximum 8-hour ozone concentration of 75 ppb. 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 TICA is the maximum estimated value within the monument boundary derived from this national analysis.

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 during the growing season 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 3 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 TICA is the maximum value within the monument boundary derived from this national analysis.

Ozone trends are computed for parks with a representative ozone monitor that is within 10 km of park boundaries. Monitors operated by NPS take precedence over other nearby monitors. In cases where the park has more than one monitor operated by the NPS, the monitor with the longest monitoring history is selected to represent the park. There are a handful of representative monitors that are no longer the closest monitor within a 6 mi (10 km) radius but are retained as the representative monitor to maintain a consistent historic record of status and trends. There are no on-site or nearby representative monitors to assess trends in ozone levels. The closest monitoring station for ozone is at Provo, UT, 9 mi (15 km) south of the monument.

Indicators/Measures: Wet Deposition (Nitrogen, Sulfur, and Mercury)
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.

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 3 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. There are no on-site or nearby representative monitors to assess wet deposition trends. The closest monitoring stations for nitrogen and sulfur are located at Murphy Ridge, UT, 71 mi (115 km) northeast of the monument; at Logan, UT, 87 mi (140 km) north of the monument; and at Green River, UT, 134 mi (215 km) southeast of the monument (NPS ARD 2015a).

Total Mercury
The status of mercury is assessed using estimated 3-year average mercury wet deposition (µg/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 2015c).

Annual mercury wet deposition measurements are averaged over a 3-year period at all NADP-MDN monitoring sites with at least 3 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 (USGS 2015). The predicted methylmercury concentration at a park is the highest value derived from the hydrologic units that intersect the park.

There are no on-site or nearby representative monitors to assess mercury wet deposition trends (NPS-ARD 2015c).

4.1.3. Reference Conditions

The reference conditions against which current air quality indicators and measures were assessed are identified by NPS ARD (2015c) for condition assessments and are listed in Table 4.1-1.

Table 4.1-1. Reference conditions for air quality parameters (NPS-ARD 2015b).

Air Quality Indicator	Significant Concern	Moderate	Good	Very Good
Visibility (dv)	>8	2–8	< 2	n/a
Ozone: Human Health (ppb)	≥ 76	61–75	≤ 60	n/a
Ozone: Vegetation Health (ppm-hrs)	>13	7–13	<7	n/a
Total N and Total S Wet Deposition (kg/ha/yr)	>3	1–3	< 1	n/a
Mercury Wet Deposition (μg/m^2/yr)	≥ 9 and < 12	≥ 6 and < 9	≥ 3 and < 6	< 3
Predicted Methylmercury Concentration (ng/L)	≥ 0.075 and < 0.12	≥ 0.053 and < 0.075	≥ 0.038 and < 0.053	< 0.038

<u>Visibility</u>

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 "moderate" 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.

<u>Ozone</u>

The human health ozone condition thresholds are based on the ozone standard set by the EPA at a level to protect human health: 4th-highest daily maximum 8-hour ozone concentration of 75 ppb. The NPS-ARD rates ozone condition as "good" if the ozone concentration is less than or equal to 60 ppb, which is 80% of the human health-based NAAQS; "moderate" if the ozone concentration is between 61 and 75 ppb; and of "significant concern" if the concentration is greater than or equal to 76 ppb.

The W126 condition thresholds are based on information in EPA's Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards (EPA 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 and is considered good; 7–13 ppm-hrs to be in "moderate" condition; >13 ppm-hrs is considered to be of "significant concern" (NPS-ARD 2015b).

N and S Wet Deposition

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, based on studies linking early stages of aquatic health decline correlated 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 "moderate" condition, and parks with depositions greater than 3 kg/ha/yr to be of "significant concern."

Mercury Wet Deposition and Predicted Methylmercury Concentration

Ratings for mercury wet deposition and predicted methylmercury concentrations can be evaluated using the mercury condition assessment matrix shown in Table 4.1-2 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 2015b).

Table 4.1-2. Mercury condition assessment matrix (NPS-ARD 2015b).

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

4.1.4. Resource Condition and Trend

A summary of indicator measures and contributions to overall assessment is presented in Table 4.1-3.

Table 4.1-3. Summary of the air quality indicators/measures and their contributions to the overall air quality assessment.

Air Quality Indicator	Specific Measure	Condition Status/ Trend[1]	Rationale
Ozone	Human Health: Annual 4th-highest 8hr concentration	Moderate	Human health risk from ground-level ozone warrants moderate concern. No trend information is available because there are not sufficient on-site or nearby ozone monitoring data. The degree of confidence at TICA is moderate because estimates are based on interpolated data from more distant ozone monitors.
	Vegetation Health: 3-month maximum 12hr W126	Moderate	Vegetation health risk from ground-level ozone warrants moderate concern. A risk assessment concluded that plants at Timpanogos Cave NM were at moderate risk for ozone damage (Kohut 2007; Kohut 2004). No trend information is available because there are not sufficient on-site or nearby ozone monitoring data. The degree of confidence is moderate because estimates are based on interpolated data from more distant ozone monitors.
Visibility	Haze Index[3]	Moderate	Visibility warrants moderate concern. No trend information is available because there are not sufficient on-site or nearby visibility monitoring data. The degree of confidence is moderate because estimates are based on interpolated data from more distant visibility monitors.
Wet Deposition[2]	Nitrogen	Moderate	Wet nitrogen deposition warrants moderate concern. Ecosystems in the park were rated as having very low sensitivity to nutrient-enrichment effects relative to all I&M 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 degree of confidence is moderate because estimates are based on interpolated data from more distant deposition monitors.

[1] Condition assessments for contiguous U.S. parks use the Inverse Distance Weighted (IDW) interpolation method is used to estimate 5year average (2009–2013) values. Trend analyses use 10 years (2004–2013) of data from onsite or nearby monitors.

[2] Reporting units for wet deposition conditions and trends are different. Wet deposition trends are evaluated using pollutant concentrations in precipitation (micro equivalents/liter) so that yearly variations in precipitation amounts do not influence trends analyses. Wet deposition conditions are based on nitrogen and sulfur loading (kilograms per hectare per year) to ecosystems.

[3] Visibility trends and conditions are both expressed in terms of a Haze Index in deciviews (dv); however, the benchmark metrics are different. Condition assessments are based on estimated five-year average visibility on midrange days (40th to 60th percentile) minus the estimated natural visibility condition on midrange days. Visibility trends are computed from the haze index values on the 20% haziest days and the 20% clearest days. Natural visibility conditions are those estimated to exist in a given area in the absence of human caused visibility impairment. Estimated annual average natural condition on midrange days equals 3 deciviews (dv) at Timpanogos Cave NM.

Table 4.1-3 (continued). Summary of the air quality indicators/measures and their contributions to the overall air quality assessment.

Air Quality Indicator	Specific Measure	Condition Status/ Trend[1]	Rationale
Wet Deposition[2] (continued)	Sulfur	Moderate	Wet sulfur deposition warrants moderate concern. Ecosystems in the park were rated as having moderate sensitivity to acidification effects relative to all I&M parks (Sullivan et al. 2011c; Sullivan et al. 2011d). No trend information is available because there are not sufficient onsite or nearby deposition monitoring data. The degree of confidence is moderate because estimates are based on interpolated data from more distant deposition monitors.
	Mercury	Unknown	TICA has moderate levels of mercury deposition at the park, relative to other areas of the United States (NADP-MDN 2014). However, there are insufficient data to determine predicted concentrations of methylmercury in park surface waters (USGS 2015). Therefore, the condition is unknown.

[1] Condition assessments for contiguous U.S. parks use the Inverse Distance Weighted (IDW) interpolation method is used to estimate 5year average (2009–2013) values. Trend analyses use 10 years (2004–2013) of data from onsite or nearby monitors.

[2] Reporting units for wet deposition conditions and trends are different. Wet deposition trends are evaluated using pollutant concentrations in precipitation (micro equivalents/liter) so that yearly variations in precipitation amounts do not influence trends analyses. Wet deposition conditions are based on nitrogen and sulfur loading (kilograms per hectare per year) to ecosystems.

[3] Visibility trends and conditions are both expressed in terms of a Haze Index in deciviews (dv); however, the benchmark metrics are different. Condition assessments are based on estimated five-year average visibility on midrange days (40th to 60th percentile) minus the estimated natural visibility condition on midrange days. Visibility trends are computed from the haze index values on the 20% haziest days and the 20% clearest days. Natural visibility conditions are those estimated to exist in a given area in the absence of human caused visibility impairment. Estimated annual average natural condition on midrange days equals 3 deciviews (dv) at Timpanogos Cave NM.

Visibility

Vistas at Timpanogos Cave NM are sometimes obscured by pollution-caused haze. Based on 2009–2013 estimated visibility data, average visibility on mid-range days Timpanogos Cave NM does not meet the NPS ARD recommended benchmark for good condition as it was 2.6 dv above estimated natural conditions (3 dv). Therefore, the condition of visibility falls within the moderate concern category. The degree of confidence in the visibility condition at Timpanogos Cave NM is medium because estimates are based on interpolated data from more distant visibility monitors (NPS-ARD 2015c).

Ozone

The NAAQS for ozone is set by the EPA and is based on human health effects. Timpanogos Cave NM is located in Utah county that meets the NAAQS ozone standard of an 8-hour average concentration of 75 parts per billion (ppb). For this reason, the county is an EPA-designated "attainment" area for ozone.

Human health risk from ground-level ozone warrants moderate concern at Timpanogos Cave NM. This condition is based on NPS Air Resources Division benchmarks (NPS-ARD 2015b) and the 2009–2013 estimated ozone concentration (4th highest 8-hour average) of 67.7 parts per billion (ppb).

Vegetation health risk from ground-level ozone warrants moderate concern at Timpanogos Cave NM. This condition is based on NPS Air Resources Division benchmarks (NPS-ARD 2015b) and the 2009–2013 estimated W126 metric of 10.3 parts per million-hours (ppm-hrs). The W126 metric relates plant response to ozone exposure. A risk assessment that considered ozone exposure, soil moisture, and sensitive plant species concluded that plants at Timpanogos Cave NM were at moderate risk of foliar ozone damage (Kohut 2007; Kohut 2004 in NPS-ARD 2015c). The park has at least three ozone-sensitive plants including box elder (*Acer negundo*), Saskatoon serviceberry (*Amelanchier alnifolia*) and mallow-leaved ninebark (*Physocarpus malvaceus*) (NPSpecies 2015).

Two of the three ozone-sensitive plant species, box elder and mallow-leaved ninebark, are bioindicators, which can reveal ozone stress in ecosystems by producing distinct visible and identifiable injuries to plant leaves (Sullivan 2017).

The degree of confidence in the ozone condition is medium because estimates are based on interpolated data from more distant ozone monitors (NPS-ARD 2015c). A past trend from a nearby monitor that closed in 2010, indicated that from 2001–2010 ozone concentrations improved (AQS Monitor ID: 490495008, UT) (NPS-ARD 2015e).

Wet N Deposition

Wet nitrogen deposition data used for the condition assessment were derived from estimated five-year average values (2009–2013) of 2.76 kg/ha/yr, which resulted in a moderate concern status. The degree of confidence at Timpanogos Cave NM is medium because estimates are based on interpolated data from more distant deposition monitors (NPS-ARD 2015c).

Ecosystems in the park were rated as having very low sensitivity to nutrient-enrichment effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011a; Sullivan et al. 2011b in NPS-ARD 2015c), However, cheatgrass has been identified as a problematic non-native invasive species at the monument and previous studies indicate that nutrient enrichment can exacerbate the growth of cheatgrass, a nitrogen-loving grass ([Brooks 2003; Schwinning et al. 2005;Vasquez 2008; Allen et al. 2009] in NPS-ARD 2015e). Extensive areas of weedy grasses have also increased fire risk in the park. Fire risk increases exponentially when nitrogen deposition reaches 3–4 kilograms per hectare per year (Rao et al. 2010 as stated in (NPS-ARD 2015e). Fires alter park ecosystems by reducing the diversity and density of native shrubs. (NPS-ARD 2015e).

In addition to assessing wet deposition levels, critical loads can also be a useful tool in determining the extent of deposition impacts (i.e., nutrient enrichment) to monument resources. A critical load is defined as a level of deposition below which harmful effects to the ecosystem are not expected. For the Timpanogos Cave NM, Pardo et al. (2011) in NPS-ARD 2015d suggested following critical load ranges for total nitrogen deposition in the Northwestern Forested Mountains ecoregion:

- 2.5–7.1 kg/ha/yr to protect lichen
- 4.0–10.0 kg/ha/yr to protect herbaceous vegetation
- 4.0–17.0 kg/ha/yr to protect forest vegetation

To maintain the highest level of protection in the park, the minimum of the critical load ranges (2.5 kg/ha/yr) is an appropriate management goal.

The estimated maximum 2010–2012 average for total nitrogen deposition was 8.3 kg/ha/yr in the Northwestern Forested Mountains ecoregion (NADP-TDEP 2014) of Timpanogos Cave NM. Therefore, the total nitrogen deposition level in the park is above the minimum ecosystem critical loads for some park vegetation communities, suggesting that lichen, herbaceous, and forest vegetation is at risk for harmful effects. (NPS-ARD 2015e).

No trend could be determined given the lack of nearby monitoring stations (NPS-ARD 2015c).

<u>Wet S Deposition</u>
Wet sulfur deposition data used for the condition assessment were derived from estimated five-year average values (2009–2013) of 1.0 kg/ha/yr, which resulted in a moderate concern status. No trend could be determined given the lack of nearby monitoring stations (NPS-ARD 2015c).

Ecosystems in the park were rated as having moderate sensitivity to acidification effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011c; Sullivan et al. 2011d in NPS-ARD 2015e). Acidification effects can include changes in water and soil chemistry that impact ecosystem health.

In general, nitrate, sulfate, and ammonium deposition levels have changed over the past 20 years throughout the United States. Regulatory programs that mandated 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 2009). It seems reasonable to expect a continued improvement in sulfate deposition levels because of Clean Air Act requirements, however, at this time, ammonium levels are not regulated by the EPA and may continue to rise as a result (NPS-ARD 2010).

Wet Deposition: Mercury and Predicted Methylmercury Concentration
Timpanogos Cave NM has moderate levels of mercury deposition at the park, relative to other areas of the United States (NADP-MDN 2014). However, there are insufficient data to determine predicted concentrations of methylmercury in park surface waters (USGS 2015). There are currently no consumption guidelines due to mercury or toxics for fish caught in the American Fork River running through Timpanogos Cave NM (EPA NLFA 2014 in NPS-ARD 2015e).

Overall Condition and Trend
For assessing the condition of air quality, we used three air quality indicators, which are summarized in Table 4.1.4-2. We consider the overall condition of air quality at Timpanogos Cave National Monument to be of moderate concern. No trends could be determined since no monitoring sites are located within the requisite distances to be representative.

4.1.5. Level of Confidence

The degree of confidence in visibility, ozone, and atmospheric deposition measurements at Timpanogos Cave NM is medium because all estimates are based on interpolated data from more distant monitors. There are insufficient data to rate the mercury and toxics deposition condition at Timpanogos Cave NM.

4.1.6. Data gaps/Research needs/Management recommendations

In the monument's Foundation document, staff identified air quality assessment and monitoring as a need but ranked it a lower priority than other data deficits (NPS 2015). When considering future actions, the park should consider partnerships with state, federal or academia partners for additional monitoring studies as funding sources allow.

Data and planning priorities for improving air quality at TICA include:

- Continued support for existing in-park air quality monitoring.
- Increased monitoring of atmospheric deposition (sulfur, nitrogen, and mercury).
- Additional support for monitoring air quality and mitigating impacts during wildfire and prescribed fire events.
- Management direction and planning efforts that emphasize efforts to protect air quality, scenic views, and resources sensitive to air pollution.
- Incorporate air quality and scenic views as appropriate into fundamental resources and values, park significance statements, interpretive themes, and messaging (NPS 2015).

- Identify resources sensitive to air quality and assess future needs in air quality and effects research and monitoring (in consultation with NPS Air Resources Division and the Regional Air Resources Coordinator).

- Monitor mercury and other toxic contaminants in park biota.

- Special studies to examine pollution dose-response relationships in sensitive park ecosystems.

- Monitoring of air quality parameters (e.g., visibility, ozone, and deposition) to better understand potential threats from nearby development.

- Consultation with the Utah Division of Air Quality is required prior to prescribed fire implementation to meet smoke management and air quality requirements.

- Encouragement for park staff to take the "Air Resources in National Parks" free 2-hour training course available for online at DOI Learn.

4.1.7. 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. They also provide condition assessment guidance, data, and trend analysis, routinely updating the 5-year averages from which air quality conditions are evaluated.

Kimberly Struthers of Utah State University has written numerous Air Quality assessments for NRCAs in the Intermountain Region and graciously provided the introductory and background materials for this section.

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.For current air quality data and information for this park, please visit the NPS Air Resources Division website at www.nps.gov/subjects/air/index.htm.

4.1.8. Literature Cited

Allen, E.B., L.E. Rao, R.J. Steers, A. Bytnerowicz, and M.E. Fenn. 2009. Impacts of atmospheric nitrogen deposition on vegetation and soils in Joshua Tree National Park. Pages 78–100 in R. H. Webb, L. F. Fenstermaker, J.S. Heaton, D. L. Hughson, E. V. McDonald, and D. M. Miller, editors. The Mojave Desert: ecosystem processes and sustainability. University of Nevada Press, Las Vegas, Nevada, USA.

Baron, J.S., C.T. Driscoll, J.L. Stoddard, and E.E. Richer. 2011. Empirical critical loads of atmospheric nitrogen deposition for nutrient enrichment and acidification of sensitive U.S. lakes. BIOSCIENCE. American Institute of Biological Sciences, 61(8):602–613.

Bobbink, R., K. Hicks, J. Galloway, T. Spranger, R. Alkemade, M. Ashmore, M. Bustamante, S. Cinderby, E. Davidson, F. Dentener, B. Emmett, J-W. Erisman, M. Fenn, F. Gilliam, A. Nordin, L. Pardo, and W. De Vries. 2010. Global assessment of nitrogen deposition effects on terrestrial plant diversity: a synthesis. Ecological Applications 20:30–59.

Brooks, M.L. 2003. Effects of increased soil nitrogen on the dominance of alien annual plants in the Mojave Desert. Journal of Applied Ecology. 40:344–353.

De Schrijver, A., P. De Frenne, E. Ampoorter, L. Van Nevel, A. Demey, K. Wuyts, and K. Verheyen. 2011. Cumulative nitrogen input drives species loss in terrestrial ecosystems. Global Ecology and Biogeography 20:803–816.

Environmental Protection Agency (EPA). 2012. Acid rain. Available at http://www3.epa.gov/acidrain/what/ (accessed December 15, 2015).

EPA. 2014. Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards. EPA-452/R-14-006. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Available at: http://www3.epa.gov/ttn/naaqs/standards/ozone/s_o3_2008_pa.html (accessed December 15, 2015).

EPA. 2015. National ambient air quality standards (NAAQS). Available at http://www3.epa.gov/ttn/naaqs/criteria.html (accessed December 15, 2015).

Fowler, D., J.A. Pyle, J.A. Raven, and M.A. Sutton. 2013. The global nitrogen cycle in the twenty-first century: introduction. Philosophical Transactions of the Royal Society B: Biological Sciences, 368(1621), 20130165. http://doi.org/10.1098/rstb.2013.0165

Greaver, T.L., T.J. Sullivan, J.D. Herrick, M.C. Barber, J.S. Baron, B.J. Cosby, M.E. Deerhake, R.L. Dennis, J.B. Dubois, C.L. Goodale, A.T. Herlihy, G.B. Lawrence, L. Liu, J.A. Lynch and K.J. Novak. 2012. Ecological effects of nitrogen and sulfur air pollution in the US: what do we know?. Frontiers in Ecology and the Environment 10:365–372.

Inouye, R.S. 2006. Effects of shrub removal and nitrogen addition on soil moisture in sagebrush steppe. Journal of Arid Environments. 65: 604–618.

Kohut, R.J., 2004. Assessing the risk of foliar injury from ozone on vegetation in parks in the Sonoran Desert Network. 47 pages.

Kohut, R.J., 2007. Ozone risk assessment for Vital Signs Monitoring Networks, Appalachian National Scenic Trail, and Natchez Trace National Scenic Trail. NPS/ NRPC/ARD/NRTR—2007/001. National Park Service, Fort Collins, Colorado.

Malm, W.C. 1999. Introduction to visibility. Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO 80523.

NPSpecies. 2015. The National Park Service biodiversity database. Available at IRMA Portal version. https://irma.nps.gov/npspecies (accessed December 4, 2015).

National Park Service (NPS). 2006. Management Policies 2006-The guide to managing the National Park System. Washington D.C. 180pp.

NPS. 2015. Foundation Document, Timpanogos Cave National Monument, Utah. 48 Pages.

National Park Service Air Resources Division (NPS-ARD). 2002. Air quality in the national parks, second edition. Lakewood, Colorado. 70pp.

NPS-ARD. 2003. Air atlas summary tables for I&M parks. Available at http://www.nature.nps.gov/air/Maps/AirAtlas/IM_materials.cfm (accessed December 15, 2015).

NPS-ARD. 2005. Redesignation of clean air areas. Available at http://www.nature.nps.gov/air/Regs/redesig.cfm (accessed December 15, 2015).

NPS-ARD. 2006a. Clean Air Act and regulations. Available at http://www.nature.nps.gov/air/Regs/cleanAir.cfm (accessed December 15, 2015).

NPS-ARD. 2006b. Ozone sensitive plant species, by park, November 2006. Available at https://irma.nps.gov/NPSpecies/Reports/Systemwide/Ozone-Sensitive%20Species%20in%20a%20Park (accessed December 16, 2015).

NPS-ARD. 2009. Wet deposition monitoring. Available at http://www.nature.nps.gov/air/Monitoring/wetmon.cfm (accessed December 16, 2015).

NPS-ARD. 2010. Air quality in national parks: 2009 annual performance and progress report. Natural Resource Report NPS/NRPC/ARD/NRR—2010/266. National Park Service, Denver, Colorado.

NPS-ARD. 2013a. Ozone effects on vegetation. Available at http://www.nature.nps.gov/air/AQBasics/ozoneEffects.cfm (accessed December 15, 2015).

NPS-ARD. 2013b. Methods for Determining Air Quality Conditions and Trends for Park Planning and Assessments. Available at http://www.nature.nps.gov/air/data/products/methods.cfm (accessed December 15, 2015).

NPS-ARD. 2015a. Ozone effects on tree growth. Available at http://www.nature.nps.gov/air/AQBasics/TreeGrowth/index.cfm (accessed December 15, 2015).

NPS-ARD. 2015b. National Park Service Air Quality Analysis Methods: September 2015. Natural Resource Report NPS/NRSS/ARD/NRR–2015/XXX. National Park Service, Denver, Colorado. Available at http://www.nature.nps.gov/air/data/products/docs/DRAFT_NPS-AirQualityAnalysis_Methods_09-11-2015.pdf (accessed December 15, 2015).

NPS-ARD. 2015c. Air quality in parks. Available at http://nature.nps.gov/air/data/products/parks/index.cfm (accessed December 15, 2015).

NPS-ARD. 2015d. Guidance for evaluating air quality in Natural Resource Conditions Assessments. Available at http://www.nature.nps.gov/air/planning/docs/20150916_Guidance-For-Evaluating-AQ-In-NRCA.pdf (accessed December 15, 2015).

NPS-ARD. 2015e. June 2015 TICA Resource Brief provided for SotP reports (Why do we care about air?)

Porter, E., and A. Wondrak Biel. 2011. Air quality monitoring protocol and standard operating procedures for the Sonoran Desert, Southern Plains, and Chihuahuan Desert networks. Version 2.00. Natural Resource Report NPS/SODN/NRTR— 2011/390. National Park Service, Fort Collins, Colorado.

Schwinning, S. B.I. Starr, N.J. Wojcik, M. E. Miller, J.E. Ehleringer, and R. L. Sanford. 2005. Effects of nitrogen deposition on an arid grassland in the Colorado Plateau cold desert. Rangeland Ecology and Management. 58: 565–574.

Selin, N.E. 2009. Global biogeochemical cycling of mercury: a review. Annual Review of Environment and Resources 34:43.

Sheibley, R.W., M. Enache, P.W. Swarzenski, P. W. Moran, and J.R. Foreman. 2014. Nitrogen Deposition Effects on Diatom Communities in Lakes from Three National Parks in Washington State. Water, Air, & Soil Pollution 225.

Sullivan, T. J., T. C. McDonnell, G. T. McPherson, S. D. Mackey, and D. Moore. 2011a. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: main report. Natural Resource Report NPS/ NRPC/ARD/NRR—2011/313. National Park Service, Denver, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2168692 (accessed December 17, 2015).

Sullivan, T. J., T. C. McDonnell, G. T. McPherson, S. D. Mackey, and D. Moore. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: Northern Colorado Plateau Network (NCPN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/321. National Park Service, Denver, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2168722 (accessed December 17, 2015).

Sullivan, T. J., McPherson, G. T., McDonnell, T. C., Mackey, S. D., Moore, D. 2011c. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: main report. Natural Resource Report NPS/ NRPC/ARD/NRR—2011/349. National Park Service, Denver, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2170555 (accessed December 17, 2015).

Sullivan, T. J., G. T. McPherson, T. C. McDonnell, S. D. Mackey, and D. Moore. 2011d. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: Northern Colorado Plateau Network (NCPN). Natural Resource Report NPS/ NRPC/ARD/NRR—2011/366. National Park Service, Denver, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2170594 (accessed December 17, 2015).

Sullivan, T.J. 2017. Air Pollution and Its Impacts on US National Parks. CRC Press, Boca Raton, FL.

United States Federal Register. 1970. Clean Air Act. Public Law 95-124. Pages 5673–5965.

4.2. Cave Climate

4.2.1. Background

The climates of subterranean caves are largely unaffected by short-term variability in surface weather conditions (Smithson 1991). Cave biota and speleothem formation processes have thus adapted to conditions characterized by the relatively small ranges of temperature and humidity unique to a particular cave system (Loaiciga et al. 2000, Fernandez-Cortes et al. 2010; Section 4.5). Maintaining natural cave climate regimes (those that existed prior to human presence) is often identified as the most important means by which to conserve cave resources (Thornberry-Ehrlich 2006, Toomey 2009, Fernandez-Cortes 2010).

Tunnel Construction

The caves that make up the TICA system formed independently as three physically separate caverns (Pulham 2009). In the 1930s tunnels were constructed to facilitate access for visitors, modifications that resulted in one interconnected system. Eliminating the natural isolation of the three caves altered the climate in all of them by facilitating novel airflow patterns and reducing humidity (Armstrong 2010, NPS 2013). Connecting the caves also likely compromised what may have been important differences in microclimates between the three caves (Šebela and Turk 2011, Mammola et al. 2015). Redwood doors were later installed at each end of the three tunnels in an attempt to mitigate these impacts. However, over time, the redwood doors deteriorated and were replaced. New doors, made of a composite material, were then installed but did not adjust well to humidity and airflow actually increased (Armstrong 2010, NPS 2013). The tunnel doors were again replaced in June 2015 with doors that include more efficient airlocks (C. McKinney, pers. comm. 2015).

Human Impacts

The large number of people who enter the TICA caves during the visitation season—mostly visitors but NPS staff as well—have measurable impacts on the natural climate of the caves. The topic of visitor impacts on cave climate is addressed in detail in the park's Cave Management Plan (NPS 2013), which concludes that the primary impacts of high visitation are: 1) seasonal increases in average ambient cave temperatures that occur as a result of body heat and artificial lighting, and 2) increased airflow and reduced humidity resulting from hundreds of door openings each day (Calaforra et al. 2003, Armstrong 2010, NPS 2013).

Climate Change

Global climate change effects that alter surface conditions will likely have impacts on cave climate (Section 4.3). For example, reduced precipitation and higher temperatures, as are predicted for this region, will affect the hydrology of the cave watershed, potentially further reducing humidity (Loáiciga et al. 2010). Temperature changes on the surface may translate to increased cave temperatures, but early research suggests many decades may ensue before correlated changes will be noticed (Domínguez-Villar et al. 2014).

4.2.2. Reference Conditions

Given the absence of information on climate conditions of the caves prior to human entrance, determining the natural ranges of temperature and humidity within the caves is not possible. Even if historic conditions were known, the existence of the tunnels precludes the possibility of completely restoring a natural climate. Ideally, airflow between the caves should be near zero and future changes in temperature, humidity and airflow should not impact formation processes or alter biotic communities (NPS 2013).

4.2.3. Data and Methods

An NPS monitoring effort that began in 2000 measures temperature and humidity throughout the cave system (NPS 2012). Permanent dataloggers (currently six) are installed near caves entrances to detect seasonal fluctuations while data collected from interior regions record the stable, 'dark zone' climate conditions. The methods and data from this effort are described in Armstrong (2010) and subsequent reports and are summarized below. In an effort to understand cave climate fluctuations associated with the tunnels, 12 additional dataloggers were installed in 2009–2010 to record interior ceiling and floor conditions (Armstrong 2010). A summary of cave climate data was compiled in 2015 (NPS unpublished data).

4.2.4. Resource Condition and Trend

Temperature

In areas away from entrances and primary tour routes, temperatures were mostly unchanged throughout the 2009–2010 study. The average temperature of Hansen Cave, the lowest/coldest cave and the one least affected by tour impacts, was nearly consistent at 43.0°F/6.0°C. The average temperature of Middle Cave was 47.5°F/8.6°C, and in the tunnel between those two caves (during the tour season) maximum temperatures were about 48.0°F/8.9°C. The average temperature for Timpanogos Cave was 46.5°F/8.1°C and the daily variation in temperature in that cave was smaller during the tour season than it was in the other caves.

Near entrances, in the tunnels between the caves, and at lighted portions of the tour (where people congregate), maximum temperatures were higher and more variable than in other areas. For example at Middle Cave Entrance, the most variable sampling point, average daily temperatures throughout the year varied within a range of 11.4°F/6.3°C. Temperature variability also increased in relation to visitation levels, for example when visitation was greatest—on the weekends during the summer—daily temperatures increased 0.5°F/0.3°C more than on weekdays. Temperature changes that occurred during the high visitation periods of summer were persistent and some cave areas did not return to pre-summer levels until the following spring (Armstrong 2010).

Humidity

In all areas except Hansen Cave humidity was 100% throughout the year. In the area of Hansen Cave, which is closest to the main entrance, the movement of cold, dry air into the cave caused humidities to drop as low as 82%. Also, the absence of complete seals on the doors allowed cold air to move from the lower parts of the caverns, where it would otherwise remain stationary, to higher parts of the caves (Armstrong 2010).

A non-statistical observation of temperature data obtained since 2002 suggests that average temperatures in the caves have declined (NPS unpublished data). Though further analysis of these data is needed, a true declining trend in temperature may indicate the effectiveness of better cave management policies such as fewer visitors and the installations of LED lighting (C. McKinney, pers. comm. 2015).

Overall Condition

The condition of the cave climate cannot be determined. Although the climate has been changed by human presence and physical modifications, it is not known to what degree these changes have affected biologic organisms and physical processes.

4.2.5. Level of Confidence

High for conditions during the 2008–2009 study, Moderate to Low at present.

4.2.6. Data Gaps and Research Needs

Climate monitoring within the caves should continue. Higher level of statistical analysis of past temperature and humidity data could reveal important trends or stability in these measures and accompany observations of changes in surface climate related to global climate change. Further research on speleothem development and studies on microorganisms should be encouraged and could also benefit from additional analysis of cave climate data.

Monitoring the impacts of high visitation levels on cave climate should continue.

The 2009–2010 airflow study should be repeated with the existing doors in place.

4.2.7. Sources of Expertise

Cami McKinney, Andy Armstrong

4.2.8. Literature Cited

Armstrong, A. 2010. Monitoring Cave Climate Changes, 2009–2010. Final Report. Unpublished, available at: http://store.wnpa.org/research/tica09-10.pdf.

Calaforra, J.M., A. Fernandez-Cortés, F. Sanchez-Martos, J. Gisbert, and A. Pulido-Bosch. 2003. Environmental control for determining human impact and permanent visitor capacity in a potential show cave before tourist use. Envir. Cons. 30: 160–167.

Domínguez-Villar, D., S. Lojen, K. Krklec, A. Baker, and I.J. Fairchild. 2014. Is global warming affecting cave temperatures? Experimental and model data from a paradigmatic case study. Climate Dynamics:1–13.

Fernandez-Cortes, A., S. Sanchez-Moral, J.C. Cañaveras, J. Cuevas-Gonzalez, S. Cuezva, and J.M. Andreu. 2010. Variations in seepage water geochemistry induced by natural and anthropogenic microclimatic changes: Implications for speleothem growth conditions. Geodinamica Acta 23:1–13.

Loáiciga, H.A., D.R. Maidment, and J.B. Valdes. 2000. Climate-change impacts in a regional karst aquifer, Texas, USA. Journal of Hydrology 227:173–194.

Mammola, S., E. Piano, P.M. Giachino, and M. Isaia. 2015. Seasonal dynamics and micro-climatic preference of two Alpine endemic hypogean beetles. International Journal of Speleology 44:239–249.

National Park Service (NPS). 2012. Timpanogos Cave System Climate Records 2002–2012. Timpanogos Cave National Monument, Utah.

NPS. 2013. Timpanogos Cave National Monument, Draft Cave Management Plan Environmental Assessment.

Pulham, C. 2009. Heart of the Mountain: The History of Timpanogos Cave National Monument. National Park Service, Washington, D.C.

Šebela, S. and J. Turk. 2011. Local characteristics of Postojna Cave climate, air temperature, and pressure monitoring. Theoretical and applied climatology 105:371–386.

Smithson, P.A. 1991. Inter-relationships between cave and outside air temperatures. Theoretical and Applied Climatology 44:65–73.

Thornberry-Ehrlich, T. 2006. Timpanogos Cave National Monument Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2006/013. National Park Service, Denver, Colorado.

Toomey III, R. S. 2009. Geological monitoring of caves and associated landscapes. Pp. 27–46 in: Geological Monitoring. Edited by R. Young and L. Noby. Geological Society of America, Boulder, CO.

4.3. Surface Climate

4.3.1. Background

Climate change is affecting resources in national parks across the country (Gonzalez 2011, Hansen et al. 2014). Data show that changes in temperature and precipitation are accelerating (Monahan and Fisichelli 2014), and all models predict future increases in the rates of change if CO_2 emissions are not significantly and rapidly reduced (Weaver et al. 2007, Ashfaq et al. 2013, IPCC 2014).

Climate change is a strong force that will require species to respond rapidly to environmental conditions to which they are largely unadapted (Burns et al. 2003, Saunders et al. 2007, NPS 2010, Corlett and Westcott 2013, Quintero and Wiens 2013). To protect and preserve resources in this scenario will require immense effort, and the National Park Service (NPS) recognizes this challenge (Whittington et al. 2013, van Riper et al. 2014), though NPS faces many challenges in responding to climate change, including budget constraints, uncertainty regarding agency priorities, and the vagaries of public perception and awareness (Archie et al. 2012, Cross et al. 2013).

Environmental properties that will be particularly affected by climate change and that have strong influence on natural resources and ecological processes at TICA are average annual and seasonal temperatures, and total precipitation and form (rain vs. snow). This report identifies observed and predicted impacts to resource groups from climate change at TICA in general terms only; specific impacts to resources, if known, will be included in relevant sections below.

<u>Regional Climate – Temperature</u>

Temperatures recorded at TICA headquarters (approx. 5,600 ft/1,700 m elev) range from lows of near 0°F/−18°C to over 100°F/38°C (Gillies and Ramsey undated). Nearly all climate models predict that average temperatures in the western U.S. and specifically across the Colorado Plateau and in Utah will continue to increase over the next several decades by approximately 4°F (2°C) by 2050 (Utah 2007, Bonfils et al. 2008, Gutzler and Robbins 2011, dos Santos et al. 2013, Hansen et al. 2014, IPCC 2014, Scherer and Diffenbaugh 2014). Moreover, some models suggest that temperature change in Utah will be greater than almost anywhere else in the world, resulting in fewer frost days, longer growing periods, and possibly prolonged drought (Utah 2007).

<u>Regional Climate – Precipitation</u>

Summers in the Wasatch Mountains of Utah are warm and characterized by orographic storms, while winters can be severe with heavy snowfall (Gillies and Ramsay undated). Precipitation can range from lows of 10 in/year (~25 cm) to over 50 in (127 cm) in areas of high snowfall. Climate change is predicated to have significant impacts on precipitation in Utah, for example, the projected decline in average annual precipitation for the west under a high emission scenario is approximately 3% by 2100 (Gutzler and Robbins 2011, NCA 2014).

Models predict that climate change will result in persistent drought and declining precipitation amounts across most of the western U.S. and specifically in Utah for at least the next half-century (Utah 2007, Gutzler and Robbins 2011, IPCC 2014, NCA 2014). Increasing temperatures, and particularly increasing average minimum temperatures, will also result in reductions in annual snowpack and runoff (Hamlet et al. 2005, Ashfaq et al. 2013, US Assess, 2014).

Impacts on Resources

Caves

The potential impacts of climate change on cave resources are addressed in Sections 4.5 (Speleothems and Microorganisms), 4.6 (Water Quality and Chemistry) and 4.8 (Cave Watershed and Hydrology).

Vegetation Communities

Overall, vegetation cover and native species richness are expected to decline in the western U.S. (and specifically in national parks) as a result of climate change (Notaro et al. 2012, King et al. 2013, Whittington et al. 2013). Entire vegetation communities may experience spatial shifts or increases or decreases in extent (Harsch and Ris Lambers 2014, Kopp and Cleland 2014). The direction and degree of change will be extremely variable across community types but is expected to be particularly dramatic in western forests (Dale et al. 2001, Allen et al. 2010, Martinez-Vilalta et al. 2012, Vose et al. 2012, Williams et al. 2012, Rice et al. 2017).

Plant Populations

In mountainous areas such as the Rockies, earlier snowmelt and higher spring temperatures are triggering flowering plants to bloom when migrating pollinators (such as hummingbirds) have not yet arrived from their wintering locations (Inouye 2008, Anderson et al. 2012), or before insects have developed to an appropriate life stage (Hegland et al. 2009, McKinney et al. 2012, Caradonna et al. 2014). The absence of pollinators may have particularly serious consequences in high-altitude plant species and consumers (Post et al. 2008, Mysterud 2013). In the higher altitudes of TICA and the Wasatch range, herbaceous species with short growing seasons will likely be less productive under reduced precipitation scenarios (Walker et al. 2006).

Landbirds

As temperatures warm, landbird species are likely to experience relatively rapid elevational range shifts (Sekercioglu et al. 2008, Maggini et al. 2011). Species already living at higher elevations have a greater risk of extinction given the limitation of additional habitat at higher (cooler) elevations (Sekercioglu et al. 2008, Grundel et al. 2014). Phenological responses to climate change impacts have already been widely observed (Crick 2004, Swanson and Palmer 2009, Kellermann and Van Riper 2015) and it is expected that migratory species, including many temperate landbird species, will be particularly affected by phenological disruptions that alter landbird-resource connections (Auer and Martin 2013, Small-Lorenz et al. 2013).

Wildlife

Increasing temperatures will drive species with lower thermal tolerances (e.g. pikas, *Ochotona princeps uinta*) to shift their distributions to higher elevations, though clearly there are altitudinal limits (Inouye et al. 2000, Moritz et al. 2008, Chen et al. 2011). Generalist species—those that can adapt to greater variability in habitat and resources—may increase in abundance while more specialist species will likely decrease (Rowe et al. 2011, Kelt et al. 2013; Section 4.11).

4.3.2. Reference Conditions

Given the realities of climate change it is not possible to determine a reference condition for climate at TICA. An assessment could be made of the extent of change compared to historic climate conditions or to predicted change, but such efforts are beyond the scope of this report. This assessment will present general observations of predicted and current climate conditions as reported by other sources.

4.3.3. Data and Methods

Within the NPS, the Northern Colorado Plateau Network (NCPN) summarizes precipitation, temperature, and wind data monitored via RAWS (Remote Access Weather Station), SNOTEL (Garman et al. 2004), and stations within the National Weather Service Cooperative Network. TICA has three monitored weather stations: one NWS Co-Op station is located on the canyon floor and one is on the canyon rim, while the third station is a staff-monitored HOBO station located near the Timpanogos Cave Entrance. Data synthesis and analysis methods as well as station identifiers and locations are provided in Witwicki (2013).

The National Climate Data Center (www.ncdc.noaa.gov) provides copious data for the Wasatch Range, though there is no station in close proximity to TICA. Data presented in Figures 1 and 2 for total precipitation and snowfall are from three stations: Alta, Deer Creek, and Silver Lake (Table 4.3-1). Snowfall accumulation data are presented in Figure 4.3-1 from the SNOTEL site on Mt. Timpanogos. The data from these stations are provided in addition to data included in Witwicki 2013.

Long-term climate analyses using multiple temperature and precipitation variables for many national park units were compiled by Monahan and Fisichelli (2014) with methods described therein. A summary of data from two stations (at the canyon bottom and near the cave entrance) was compiled in 2015 (NPS unpublished data).

Future climate change predictions for Utah and the western U.S. have been developed by numerous researchers utilizing various methods. An evaluation of climate models and how they are applied is beyond the scope of this assessment; details of global (GCM) and regional (RCM) climate models used are available in referenced materials.

Table 4.3-1. Station locations included in assessment (TICA ranges in elevation from approximately 5,400–8,000 ft/1,650–2,450 m).

Station Name	Station ID	Elevation	Location
Alta	USC00420072	8,730 ft/2,661 m	Alta ski resort; approx. 12 (direct) miles from TICA
Deer Creek Dam	USC00422057	5,270 ft/1,606 m	Deer Creek State Park; approx. 10 miles from TICA
Silver Lake	USC00427846	8,740 ft/2,664 m	Brighton; approx. 13 miles from TICA

4.3.4. Resource Condition and Trend (Climate Change)

<u>Temperature</u>

The average temperatures in Utah for the past decade were higher than ever previously recorded (Utah 2007, NRCS 2014). Average winter temperatures have shown the greatest increase, and minimum temperatures are increasing faster than maximum temperatures (Dos Santos et al. 2013). For TICA, Monahan and Fisichelli (2014) found that five temperature variables were "extreme warm" (annual mean temperature, maximum temperature of the warmest month, minimum temperature of the coldest month, mean temperature of the driest quarter, mean temperature of the warmest quarter), and that no temperature variables were "extreme cold." Witwicki (2013) found no significant trends in means of annual maximum and minimum temperatures in over 50 years of records since 1948.

<u>Precipitation</u>

Available data do not yet indicate changing trends in annual (or water year) precipitation or snowfall on the Colorado Plateau (Mote et al. 2005, Utah 2007, Day 2009, Ashfaq et al. 2013, Dos Santos et al. 2013, Witwicki (2013), Pederson et al. 2013; Figure 4.3-1). Snowfall data, however, suggest declining trends in northern Utah (Figure 4.3-2, 4.3-3). For TICA, Monahan and Fisichelli (2014) found no extreme variability in precipitation variables. Witwicki (2013) found no significant trends in means of total snowfall or total precipitation since 1948.

In general, though it is somewhat redundant, the condition of the climate must be considered poor.

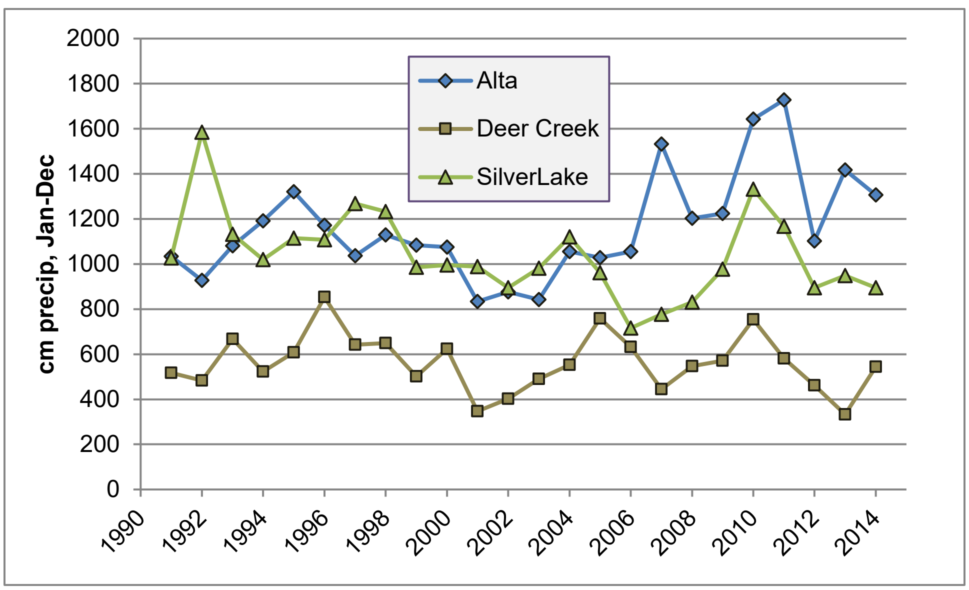


Figure 4.3-1. Total precipitation, three Uinta Range stations, 1990–2014, from National Climate Data Center data (https://gis.ncdc.noaa.gov/maps/).

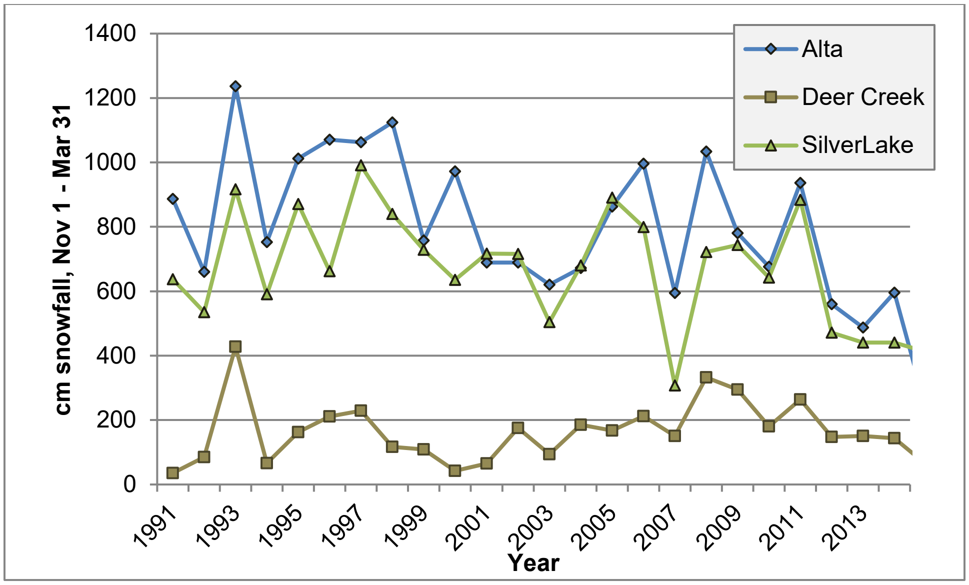


Figure 4.3-2. Snowfall accumulations Nov–Mar, three Uinta Range stations, 1990–2014, from National Climate Data Center data (https://gis.ncdc.noaa.gov/maps/).

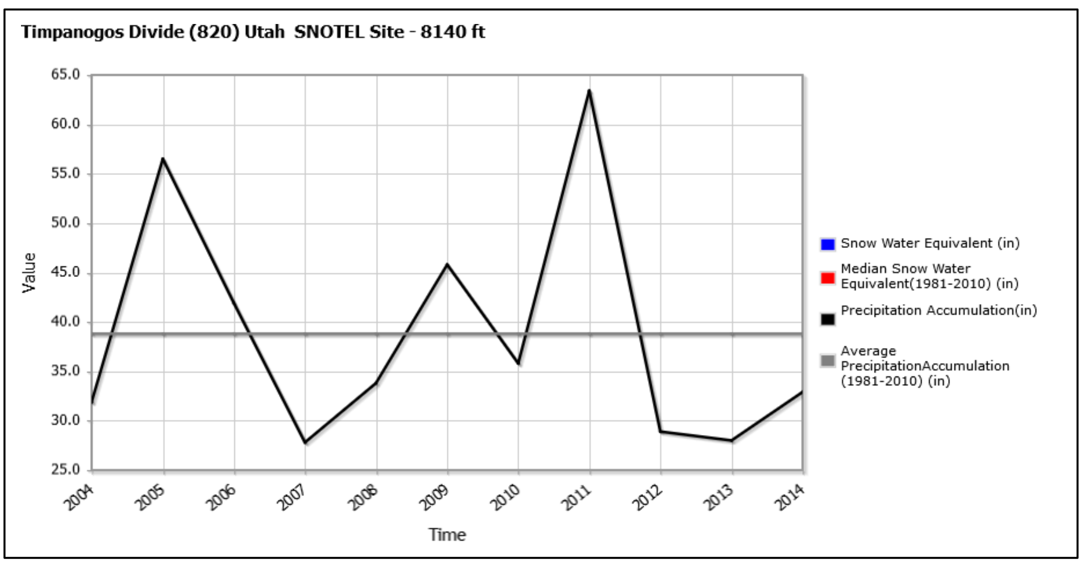


Figure 4.3-3. Snowfall accumulations, 2004–2014, SNOTEL station on Mount Timpanogos (https://www.wcc.nrcs.usda.gov/index.html).

4.3.5. Level of Confidence

For past and current conditions – high. For future trends – moderate to high.

4.3.6. Data gaps/Research needs/Management recommendations

There is an acknowledged need by climate scientists for downscaled ecologic information regarding short and long-term responses to climate change for most if not all species and systems of interest (Parmesan 2006, van Riper et al. 2014).

4.3.7. Literature Cited

Allen, C.D., A.K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kizberger, more, 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For. Ecol. Manage. 259:660–684.

Anderson, J.T., D.W. Inouye, A.M. McKinney, R.I. Colautti, and T. Mitchell-Olds. 2012. Phenotypic plasticity and adaptive evolution contribute to advancing flowering phenology in response to climate change. Proceedings of the Royal Society: Biological Sciences 279:3843–3852.

Archie, K.M., L. Dilling, J.B. Milford, and F.C. Pampel. 2012. Climate change and western public lands: a survey of U. S. federal land managers on the status of adaptation efforts. Ecology and Society 17:20.

Ashfaq, M., S. Ghosh, S. Kao, L.C. Bowling, P. Mote, D. Touma, S. Rauscher, and N.S. Diffenbaugh. 2013. Near-term acceleration of hydroclimatic change in the western US. Journal of Geophysical Research: Atmospheres 118:10–676.

Auer, S.K. and T.E. Martin. 2013. Climate change has indirect effects on resource use and overlap among coexisting bird species with negative consequences for their reproductive success. Global Change Biology 19:411–419.

Bonfils, C., D.W. Pierce, B.D. Santer, H. Hidalgo, G. Bala, T. Das, T. Barnett, C. Doutriaux, A.W. Wood, A, Mirin, and T. Nazawa. 2008. Detection and attribution of temperature changes in the mountainous Western United States. J. Climate 21:6404–6424, doi:10.1175/ 2008JCLI2397.1.

Burns, C. E., K.M. Johnston, and O. J. Schmitz. 2003. Global climate change and mammalian species diversity in US national parks. Proceedings of the National Academy of Sciences 100:11474–11477.

Caradonna, P.J., A.M. Iler, and D.W. Inouye. 2014. Shifts in flowering phenology reshape a subalpine plant community. PNAS, DOI: 10.1073/pnas.1323073111.

Chen, I-Ching, J.K. Hill, R. Ohlemüller, D.B. Roy, and C.D. Thomas. 2011. Rapid range shifts of species associated with high levels of climate warming. Science 333:1024–1026.

Corlett, R.T. and D.A. Westcott. 2013. Will plant movements keep up with climate change? Trends in Ecology and Evolution 28:482–488.

Crick, H.Q.P. 2004. The impact of climate change on birds. Ibis 146:48–56.

Cross, M.S., P.D. McCarthy, G. Garfin, D. Gori and C.A.F. Enquist. 2013. Accelerating adaptation of natural resource management to address climate change. Conservation Biology 27:4–13.

Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks and B.M. Wotton. 2001. Climate change and forest disturbances: climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. BioScience 51:723–734.

Day, C. A. 2009. Modelling impacts of climate change on snowmelt runoff generation and streamflow across western US mountain basins: a review of techniques and applications for water resource management. Progress in Physical Geography 33:614–633.

dos Santos, C. A.C., J. I. B. de Brito, E. G. dos Santos, T. V.R. Rao, and V. R. da Silva. 2013. Temporal variability of extreme temperature indices in Utah during the past few decades. Revista Brasileira de Meteorologia 28:364–372.

Garman, S.L., M. Beer, M.A. Powell and R. DenBleyker. 2004. Climate Monitoring Protocol for the Park Units in the Northern Colorado Plateau Network. National Park Service, Northern Colorado Plateau Network Inventory and Monitoring Program, Moab, Utah.

Gillies, R.R. and R.D. Ramsey. Undated. Climate of Utah. Available online: http://extension.usu.edu/utahrangelands/files/uploads/RRU_Section_Five.pdf.

Gonzalez, P. 2011. Climate change impacts and carbon in U.S. national parks. 2011. Park Science 28:10–15.

Grundel, R., K.J. Frohnapple, D.N. Zaya, G.A. Glowacki, C.J. Weiskerger, T.A. Patterson, and N.B. Pavlovic. 2014. Geographic coincidence of richness, mass, conservation value, and response to climate of US land birds. Ecological Applications 24:791–811.

Gutzler, D.S. and T.O. Robbins. 2011. Climate variability and projected change in the western United States: regional downscaling and drought statistics. Climate Dynamics 37:835–849.

Hamlet, A.F., P.W. Mote, M.P. Clark, and D.P. Lettenmaier. 2005. Effects of temperature and precipitation variability on snowpack trends in the Western United States. Journal of Climate 18:4545–4561.

Hansen, A.J., N. Piekielek, C. Davis, J. Haas, D.M. Throbald, J.E. Gross, W.B. Monahan, T. Olliff and S.W. Running. 2014. Exposure of U.S. National Parks to land use and climate change 1900–2100. Ecol. Appl. 24:484–502.

Harsch, M.A., and J.H. Ris Lambers. 2014. Species distributions shift downward across western North America. Global Change Biology. Article first published online: 18 Aug 2014; DOI: 10.1111/gcb.12697.

Hegland, S.J., A. Nielsen, A. Lázaro, A. Bjerknes, and Ø. Totland. 2009. How does climate warming affect plant-pollinator interactions?. Ecology Letters 12:184–195.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II, Fifth Assessment Report, Cambridge University Press, Cambridge, UK.

Inouye, D.W., B. Barr, K.B. Armitage, and B.D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences 97:1630–1633.

Inouye, D.W. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology 89:353–362.

Kellermann, J.L. and C. Van Riper III. 2015. Detecting mismatches of bird migration stopover and tree phenology in response to changing climate. Oecologia 2015:1–12.

Kelt, D.A., D.H. VanVuren, M.L. Johnson, J.A. Wilson, R.J. Innes, B.R. Jesmer, K.P. Ingram, J. Smith, S.W. Bigelow, R.D. Burnett and P.A. Stine. 2013. Small mammals exhibit limited spatiotemporal structure in Sierra Nevada forests. Journal of Mammalogy 94:1197–1213.

King, D. A., D. M. Bachelet, and A. J. Symstad. 2013. Vegetation projections for Wind Cave National Park with three future climate scenarios: Final report in completion of Task Agreement J8W07100052. Natural Resource Technical Report NPS/WICA/NRTR—2013/681. National Park Service, Fort Collins, Colorado.

Kopp, C.W. and E.E. Cleland. 2014. Shifts in plant species elevational range limits and abundances observed over nearly five decades in a western North America mountain range. Journal of Vegetation Science 25:135–146.

Maggini, R., A. Lehmann, M. Kéry, H. Schmid, M. Beniston, L. Jenni, and N. Zbinden. 2011. Are Swiss birds tracking climate change?: detecting elevational shifts using response curve shapes. Ecological Modelling 222:21–32.

Martinez-Vilalta, J., F. Lloret and D.D. Breshears. 2012. Drought-induced forest decline: Causes, scope and implications. Biol.Lett. 8:689–691.

McKinney, A.M., P.J. CaraDonna, D.W. Inouye, B. Barr, C.D. Bertelsen and N.M. Waser. 2012. Asynchronous changes in phenology of migrating Broad-tailed Hummingbirds and their early-season nectar resources. Ecology 93:1987–1993.

Monahan, W.B. and N.A. Fisichelli. 2014. Climate exposure of US national parks in a new era of change. PLoS ONE 9(7): e101302. doi:10.1371/journal.pone.0101302. Available from http://dx.plos.org/10.1371/journal.pone.0101302.

Moritz, C., J.L. Patton, C.J. Conroy, J.L. Parra, G.C. White, and S.R. Beissinger. 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science 322:261–264.

Mote, P.W., A.F. Hamlet, M.P. Clark, and D.P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American meteorological Society 86, no. 1.

Mysterud, A. 2013. Ungulate migration, plant phenology, and large carnivores: the times they are a-changin'. Ecology 94:1257–1261.

National Climate Assessment (NCA). 2014. Selected Findings and Information from the Third U.S. National Climate Assessment Relevant to UTAH. (http://www.whitehouse.gov/sites/default/files/docs/state-reports/UTAH_NCA_2014.pdf)

National Park Service (NPS). 2010. National Park Service Climate Change Response Strategy. National Park Service Climate Change Response Program, Fort Collins, Colorado.

Natural Resources Conservation Service (NRCS). 2014. Utah Climate and Water Report. Available online: http://www.wcc.nrcs.usda.gov/scan/Utah/utah.html.

For Mt. Timpanogos precip rpt: http://www.wcc.nrcs.usda.gov/reportGenerator/view/customChartReport/annual_water_year/820:UT:SNTL|id=%22%22|name/2010-01-01,2015-01-01/WTEQ::value,WTEQ::median_1981,PREC::value,PREC::average_1981?fitToScreen=false

Notaro, M., A.Mauss, and J.W. Williams. 2012. Projected vegetation changes for the American Southwest: combined dynamic modeling and bioclimatic-envelope approach. Ecological Applications 22:1365–1388.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annu. Rev. Ecol. Evol. Syst. 37:637–669.

Pederson, G. T., J. L. Betancourt, and G. J. McCabe. 2013. Regional patterns and proximal causes of the recent snowpack decline in the Rocky Mountains. U.S., Geophys. Res. Lett. 40:1811–1816. doi:10.1002/grl.50424.

Post, E., C. Pedersen, C.C. Wilmers, and M.C. Forchhammer. 2008. Warming, plant phenology and the spatial dimension of trophic mismatch for large herbivores. Proceedings of the Royal Society of London B: Biological Sciences 275:2005–2013.

Quintero, I. and J.J. Wiens. 2013. Rates of projected climate change dramatically exceed past rates of climatic niche evolution among vertebrate species. Ecology Letters 16:1095–1103.

Rice, J., T. Bardsley, P. Gomben, D. Bambrough, S. Weems, S. Leahy, C. Plunkett, C. Condrat, and L.A. Joyce. 2017. Assessment of watershed vulnerability to climate change for the Uinta-Wasatch-Cache and Ashley National Forests, Utah. RMRS-GTR-362. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 111 p., 362.

Rowe, R.J., R.C. Terry, and E.A. Rickart. 2011. Environmental change and declining resource availability for small-mammal communities in the Great Basin. Ecology 92:1366–1375.

Saunders, S., T. Easley, J.A. Logan, T. Spencer, and J.B. Jarvis. 2007. The Challenges of Climate Change. George Wright Forum 24:41–81.

Scherer, M. and N.S. Diffenbaugh. 2014. Transient twenty-first century changes in daily-scale temperature extremes in the United States. Climate Dynamics 42:1383–1404.

Sekercioglu, C.H., S.H. Schneider, J.P. Fay, and S.R. Loarie. 2008. Climate change, elevational range shifts, and bird extinctions. Conservation Biology 22:140–150.

Small-Lorenz, S.L., L.A. Culp, T.B. Ryder, T.C. Will, and P.P. Marra. 2013. A blind spot in climate change vulnerability assessments. Nature Climate Change 3:91–93.

Swanson, D.L., and J.S. Palmer. 2009. Spring migration phenology of birds in the Northern Prairie region is correlated with local climate change. Journal of Field Ornithology 80:351–363.

U.S. Third Climate Assessment (US Assess). 2014. http://www.whitehouse.gov/sites/default/files/docs/state-reports/UTAH_NCA_2014.pdf

Utah Blue Ribbon Commission on Climate Change. 2007. (Utah 2007). http://www.inscc.utah.edu/~steenburgh/papers/utah_climate_report_2007.pdf

van Riper III, C ., J.R. Hatten, J.T. Giermakowski, D. Mattson, J.A. Holmes, M.J. Johnson, E.M. Nowak, K. Ironside, M. Peters, P. Heinrich, K.L. Coles, C. Truettner and C.R. Schwalbe. 2014. Projecting climate effects on birds and reptiles of the Southwestern United States. U .S. Geological Survey Open-File Report 2014–1050; http://dx.doi.org/1 0.3133/ofr2 0141050.

Vose, J.M., D.L. Peterson, T. Patel-Weynand, eds. 2012. Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector. Gen. Tech. Rep. PNW-GTR-870. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Walker, M.D., C.H. Wahren, R.D. Hollister, G.H.R. Henry, L.E. Ahlquist, J.M. Alatalo, M.S. Bret-Harte, M.P. Calefh, T.V. Callaghani, A.B. Carrolla, H.E. Epsteini, I.S. Jonsdottirk, J.A. Kleinl, B. Magnussonm, U. Molaug, S.F. Oberbauerf, S.P Rewan, C.H. Robinsono, G.R. Shaverp, K.N. Sudingq, C.C. Thompson, A. Tolvanenws, O Totlandt, P.L. Turneru, C.E. Tweediev, P.J. Webberw and P.A. Wookeyx. 2006. Plant community responses to experimental warming across the tundra biome. Proceedings of the National Academy of Sciences of the United States of America 103:1342–1346.

Weaver, A.J., K. Zickfeld, A. Montenegro and M. Eby. 2007. Long term climate implications of 2050 emission reduction targets. Geophys. Res. Lett. 34:L19703.

Whittington, T., S.T. Olliff and P. Benjamin, eds. 2013. Climate Change Action Plan Report: Intermountain Region. National Park Service, Fort Collins, Colorado.

Williams, A.P., C.D. Allen, A.K. Macalady, D. Griffin, C.A. Woodhouse, D.M. Meko, T.W. Swetnam, S.A. Rauscher, R. Seager, H.D. Grissino-Mayer, J.S. Dean, E.R. Cook, C. Gangodagamage, M. Cai and N.G. McDowell. 2012. Temperature as a potent driver of regional forest drought stress and tree mortality. Nature Climate Change DOI:10.1038/nclimate1693.

Witwicki, D. 2013. Climate Monitoring in the Northern Colorado Plateau Network: Annual Report 2011. Natural Resource Technical Report NPS/NCPN/NRTR—2013/664. National Park Service, Fort Collins, Colorado.

4.4. Cave Water Quality

4.4.1. Background

The presence of fresh water is fundamental to living cave ecosystems (Bonacci et al. 2009, Angel and Peterson 2012, Baker and Fairchild 2012). Water can enter caves rapidly from the surface or it can seep slowly from groundwater aquifers (Bonacci et al. 2009).

Environmental conditions within the watershed surrounding a cave strongly influence the quality of water within the cave (Fairchild et al. 2006; Section 4.5), and water that is negatively impacted by surface landuse can impact cave formations and biological organisms (Lerch et al. 2001, Neill et al. 2004, Knierim et al. 2015). For example, human and animal waste can deposit pathogens which are then transported through the epikarst (roughly the zone between the soil and the cavern; Northup and Lavoie 2001, Campbell et al. 2011, Kniemen et al. 2015), and chemicals from human activities, such as hydrocarbons from oil and gas production, can enter caves and degrade cave water quality, particularly during storm events (Mahler et al. 2000, Kniemen et al. 2015). In general, studies have found that cave water quality declines as the relative amount of non-vegetated landcover increases within a cave watershed; the loss of vegetation removes the natural filtering properties of vegetation and human inputs are correspondingly increased (Breecker et al. 2012, Lan et al. 2015).

4.4.2. Reference Conditions

Water quality and chemistry in caves are generally assessed as factors that impact cave processes and biological organisms (Smith et al. 2003, Lan et al. 2015), though such studies are rare. Efforts that have evaluated water quality in relation to invertebrate communities in caves have utilized temperature (T), dissolved oxygen (DO), electric conductivity (EC), pH, velocity of water flow (V) and percentage of organic matter (OM) in the sediment (Taylor and Ferreira 2012). Only for organic matter have measurable reference conditions been discussed in the literature; for *E. coli* levels should be within 100–200 colonies/mL especially during storm events (Campbell et al. 2011, Taylor and Ferreira 2012, Kniemen et al. 2015). Nitrate should be less than 1 mg NO_3/L (Angel and Peterson 2012). Other than these parameters, established criteria for acceptable water quality standards for caves or emerging contaminants have not generally been identified (C. McKinney and D. Perkins, pers. comm. 2011).

4.4.3. Data and Methods

A recent study (reported in Florea et al. 2013 and Dugan 2015) looked closely at the chemical composition of TICA cave waters in relation to water sources (Detailed methods are available in those reports). Briefly, Florea et al. (2013) collected water samples weekly from May through August and in October of 2012 in five cave pool locations and analyzed them for constituent chemicals and the presence of dye tracers.

Prior to the work cited above, in 2003 and 2004 the park sampled cave waters for multiple contaminants at two sites, Hansen Cave Spring and Hidden Lake (Van Grinsven et al. 2010). In 2010 NCPN began sampling for emerging contaminants (pesticides, pesticide degradation products, and wastewater indicators) and added sampling for pharmaceuticals and personal care products (PPCPs) in 2012 (Weissinger 2014). All known sampling of cave waters is presented in Table 4.4-1.

Table 4.4-1. Locations and dates of known water sampling in TICA caves.

Location	Type of Sampling	Date (s)	Reference
Middle Cave Lake (MC)*	Electric Conductivity	2010–2013	Weissinger 2014
	Ion Chemistry	2012	Florea et al. 2013
Hansen Cave Lake (HC) (STORET #4994970)	Standard WQ Parameters	2008–2009	VanGrinsven et al. 2010
	Standard WQ Parameters	2010–2012	Hackbarth and Weissinger 2013
	Electric Conductivity	2013	Weissinger 2014
	Ion Chemistry	2012	Florea et al. 2013
Hidden Lake (TC)	Standard WQ Parameters	2008–2009	VanGrinsven et al. 2010
	Standard WQ Parameters	2010–2012	Hackbarth and Weissinger 2013
	Electric Conductivity	2010–2013	Weissinger 2014
	Ion Chemistry	2012	Florea et al. 2013
Cavern of Sleep (TC)	Ion Chemistry	2012	Florea et al. 2013
Soda Pop Pit (TC)	Ion Chemistry	2012	Florea et al. 2013
Unknown	Standard WQ Parameters	1990–1991	USGS and NPS 2003

* MC – Middle Cave; HC – Hansen Cave; TC – Timpanogos Cave.

4.4.4. Resource Condition and Trend

<u>Water Quality</u>
Water quality in the caves is generally very good, and none of the samples collected in 2008–2009 exceeded water quality standards (Van Grinsven et al. 2010). Hackbarth and Weissinger (2013) found increased phosphorous levels from 2010–2012. Contaminants of emerging concern (CEC) that were detected in Middle Cave Lake from 2010–2013 include caffeine and DEET (>30% of samples), and three new Personal Care Products (PPCPs) occurred in 2013: methylparaben, theobromine, and theophylline (Weissinger 2014).

<u>Water Chemistry</u>
Water chemistry results indicate that water flows primarily over limestone bedrock before reaching the caves, with dominant chemical constituents in cave pools of calcium and magnesium ions (Ca_2+, Mg_2+) and bicarbonate (HCO_3-; Florea et al. 2013). There may also be geothermal sources of water, indicated by elevated concentrations of sulfate and fluorine in the pools (Florea et al. 2013). Though water flows through multiple pathways from the surface and/or aquifers, there are at present no indications that water is transporting toxic or hazardous materials to the TICA caves (Florea et al. 2013).

4.4.5. Level of Confidence
Moderate.

4.4.6. Data Gaps and Research Needs
Further research should be encouraged that builds upon Florea et al. (2013) to definitively determine the extent of the cave watershed.

Partnerships with landowners of surface areas known to be within the cave watershed should be developed or expanded upon to cooperatively prevent introduction of hazardous materials that may flow into the TICA cave system (Florea et al. 2013).

Water monitoring should continue within the caves, and the potential impacts of climate change on karst groundwaters should be investigated (Veni 2013).

4.4.7. Literature Cited
Angel, J.C. and E.W. Peterson. 2012. Nitrates in karst systems: comparing impacted systems to a relatively unimpacted system. Journal of Geography and Geology 7:65–76.

Baker, A., and I.J. Fairchild. 2012. Drip water hydrology and speleothems. Nature Education Knowledge 3:16.

Bonacci, O., T. Pipan and D.C. Culver. 2009. A framework for karst ecohydrology. Environmental Geology 56:891–900.

Breecker, D.O., A.E. Payne, J. Quade, J.L. Banner, C.E. Ball, K.W. Meyer, and B.D. Cowan. 2012. The sources and sinks of CO_2 in caves under mixed woodland and grassland vegetation. Geochimica et Cosmochimica Acta 96:230–246.

Campbell, J., A. Watson, C. Watson, H. Ball, and R. Pirkle. 2011. *Escherichia coli*, other coliform, and environmental chemoheterotrophic bacteria in isolated water pools from six caves in northern Alabama and northwestern Georgia. Journal of Cave and Karst Studies 73:75–82.

Dugan, C.R. 2015. Investigating Vadose-zone Hydrology in Alpine Karst Aquifers Using Quantitative Groundwater Tracing Methods: Timpanogos Cave National Monument, Utah County, Utah. Master's Thesis, Ball State Univ., Muncie, IN.

Fairchild, I.J., S. Frisia, A. Borsato, and A.F. Tooth. 2006. Speleothems. In: *Geochemical Sediments and Landscapes* (ed. Nash, D.J. and McLaren, S.J.), Blackwells, Oxford

Florea, L.J., C.R. Dugan, and C. McKinney. 2013. Preliminary summary of water resource investigations during 2012 at TImpanogos Cave National Monument, Utah. In *Proceedings of the 20th National Cave and Karst Management Symposium*, pp. 61–67. 2013.

Hackbarth, C. and R. Weissinger. 2013. Water quality in the Northern Colorado Plateau Network, water years 2010–2012. Natural Resource Technical Report NPS/NCPN/NRTR—2013/831. National Park Service, Fort Collins, Colorado.

Knierim, K.J., P.D. Hays and D. Bowman. 2015. Quantifying the variability in *Escherichia coli* (*E. coli*) throughout storm events at a karst spring in northwestern Arkansas, United States. Environmental Earth Sciences. DOI 10.1007/s12665-015-4416-5.

Lan, F., X. Qin, Z. Jiang, R. Meng, R. Mo, S. Yang, W. Wang, and S. An. 2015. Influences of Land Use/Land Cover on Hydrogeochemical Indexes of Karst Groundwater in the Dagouhe Basin, Southwest China. CLEAN–Soil, Air, Water 43:683–689.

Lerch, R.N., J.M. Erickson, and C.M. Wicks. 2001. Intensive water quality monitoring in two karst watersheds of Boone County, Missouri. In: Proceedings of the 15th National Cave and Karst Management Symposium (October 16–19, 2001), National Cave and Karst Management Symposium Steering Committee, Tuscon, AZ. 2001.

Mahler, B.J., J-C. Personné, G.F. Lods, and C. Drogue. 2000. Transport of free and particulate-associated bacteria in karst. Journal of Hydrology 238:179–193.

Neill, H., M. Gutierrez and T. Aley. 2004. Influences of agricultural practices on water quality of Tumbling Creek cave stream in Taney County, Missouri. Environmental Geology 45:550–559.

Northup, D.E., and K.H. Lavoie. 2001. Geomicrobiology of caves: A review. Geomicrobiology Journal 18:199–222; doi:10.1080/01490450152467750.

Smith, H., P.J. Wood, and J. Gunn. 2003. The influence of habitat structure and flow permanence on invertebrate communities in karst spring systems. Hydrobiologia 510:53–66.

Taylor, E.L.S. and R.L. Ferreira. 2012. Determinants on the structure of an aquatic invertebrate community in a neotropical limestone cave. Revista Brasileira de Espeleologia 1:1–12.

US Geological Survey (USGS) and National Park Service (NPS). 2003. National Park Service, Northern Colorado Plateau Network, Inventory and Monitoring Program. Water Quality Vital Signs. Summary document prepared for the Vital Signs Workshop, April 10–11, 2003, Moab, UT.

Van Grinsven, M., D. Thoma, M. Malick, and M. Moran. 2010. Water quality in the Northern Colorado Plateau Network, 2006–2009. Natural Resource Technical Report NPS/NCPN/NRTR—2010/358. National Park Service, Fort Collins, Colorado.

Veni, G. 2013. Impact of climate change on human and ecological use of karst groundwater resources: A case study from the Southwestern USA. 2013. In: Land, L. and M. Joop, eds. Proceedings of the 20th National Cave and Karst Management Symposium, November 4–8, 2013, Carlsbad, NM. National Cave and Karst Institute, Carlsbad, NM.

Weissinger, R. 2014. Screening for contaminants of emerging concern in the Northern Colorado Plateau Network, 2013. Natural Resource Technical Report NPS/NCPN/NRTR—2014/923. National Park Service, Fort Collins, Colorado.

4.5. Cave Formations and Microorganisms

4.5.1. Background

Formations

Cave formations (speleothems) are residual deposits in karst environments created when water flows or drips through cave systems (Baker and Fairchild 2012). As water flows from the surface through rocks and soil it reacts with CO_2, increasing the acidity of the water. If carbonate and sulfate rocks such as limestone are present beneath the surface, water moving through these layers dissolves the rocks and $CaCO_3$ (calcium carbonate) is carried in solution ('solution caves'; Baker and Fairchild 2012). When water reaches the ceiling of an underground space and reacts with the air, CO_2 is released and calcite is deposited.

Depending on conditions, the accumulations of calcite and other minerals over long periods of time can create the enormous variety of cave formations collectively known as speleothems (Fairchild and Baker 2012). Speleothems are non-renewable resources, increasing in size and complexity (i.e. accumulating deposits, or 'growing') at very slow rates (~0.25 in/0.64 cm per year). The rate and form of speleothem growth depend on the chemical and biological composition of cave waters, atmospheric conditions (particularly levels of CO_2), and surface vegetation (Genty et al. 2001, Banner et al. 2007, Lachniet 2009, Stein et al. 2010, Breecker et al. 2012, Veni 2013). Because speleothems accumulate different compositions of minerals as water chemistry changes over time, similar to glacial ice cores, cave formations preserve a very long-term record of past environmental and atmospheric conditions (McDermott 2004, Fairchild and Treble 2009, Brennan and White 2013).

TICA caves contain a high diversity of formations, including stalactites (formations that grow from the ceiling), helictites (formations where new growth can occur sideways or even vertically), and flowstones (formations created when water flows over cave walls and floors rather than drips from the ceiling; White and Van Gundy 1971). The diversity and colors of the TICA speleothems are in many ways unique for caves of this size (Figure 4.5-1). Descriptions of the cave formations of the TICA caves can be found in Thornberry-Ehrlich (2006), Pulham (2009), Florea et al. (2013), and on the park website, nps.gov/tica.

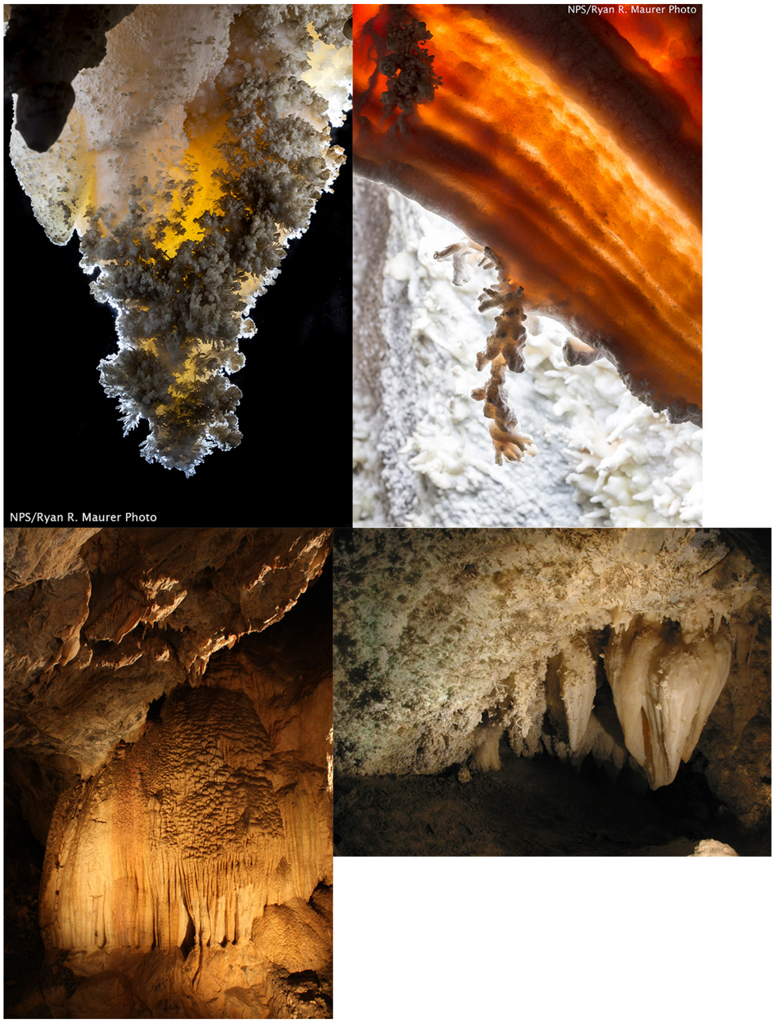


Figure 4.5-1. Examples of speloethems from TICA caves. Photos by C. Schwemm.

<u>Microorganisms</u>

Energy pathways in cave ecosystems differ from those in terrestrial systems in that very little primary production results from photosynthesis (Cunningham et al. 1995, Barton 2006). In un-altered cave systems, most energy is produced by chemoautotrophs (usually bacteria) that utilize inorganic chemical sources obtained from rock substrates and the atmosphere (Barton et al. 2004, Barton 2006, Engel 2007, Falasco et al. 2014). Consequently, most cave systems are nutrient (carbon) limited and energy pathways are short (Gibert and Deharveng 2002, Campbell et al. 2011, Venarsky et al. 2014). van Beynen and Townsend (2005) suggest that changes in the microbiology and invertebrate fauna of caves may be the greatest indicator of human impacts in cave ecosystems. Because microorganisms have important impacts on cave formations (Jones 2010, Gray and Engel 2012, Tomczyk-Żak and Zielenkiewicz 2015), the condition of both resources will be addressed together.

Threats

Physical Impacts

Humans can physically damage speleothems both accidentally and by intent (Horrocks 2013). Loss of TICA cave features began as soon as the caves were discovered, when early visitors removed pieces and entire features as souvenirs (Pulham 2009). As visitation increased, ladders and doors were constructed to make the caves more accessible, and cave features were damaged during those efforts (Pulham 2009). Current visitation levels necessitate the crowding of many people into small spaces, conditions that increase the risk of damage to cave formations (NPS 2013). And though visitors are required to be with ranger tour guides at all times, there are still rare instances of vandalism (C. McKinney, pers. comm. 2015). In addition to physical damage, speleothem integrity can be degraded by biological organisms and chemical processes; for example, the significantly increased levels of CO_2 in show caves resulting from human respiration have been shown to affect formation growth processes (Baker and Genty 1998, Fernandez-Cortes et al. 2010, Saiz-Jimenez 2012).

Introduced Species

When novel microorganisms are introduced into a cave system the diversity and function of these unique communities are degraded (Chelius et al. 2009, Gray and Engel 2012). Though animals traveling in and out of caves historically introduced occasional novel species, microorganisms transported into caves by humans have rapidly altered communities that have evolved largely in isolation (Barton 2006, Chelius et al. 2009, Adetutu et al. 2012, Griffin et al. 2014). A particular problem in show caves (caves with high visitation) is lint, a generic term for small particles of hair and fiber. This material naturally exudes from clothing and bodies then adheres to the moist surfaces of cave walls and formations, leading to further changes in the existing microorganism communities (Ikner et al. 2007, Chelius et al. 2009, NPS 2013).

Artificial Lighting

The presence of artificial lighting in caves has had substantial impacts on cave microbiology (Mulec and Kosi 2009, Alt and Moura 2013). Prior to human visitation, the only light available in cave systems came from sunlight at entrances or other surface openings, making those the only locations where photoautotrophs could survive (Barton 2006). Artificial lighting was installed in the TICA caves beginning in 1938 and since then species that can convert light to energy ('lampenflora') have colonized all parts of the caves where lights are present. The presence of lampenflora facilitates further disruption of microbial communities by providing resources for novel heterotrophic species (primarily bacteria; Smith and Olson 2007, Chelius et al. 2009, Falasco et al. 2014). The bacteria then produce a layer of 'biofilm' which discolors features and further alters the chemistry and ecology of these sites (Cañveras et al. 2001, Falasco et al. 2014).

Changes in Surface Hydrology

Altered surface hydrology expected to result from climate change may further contribute to changes in existing communities of cave microorganisms. Reductions in water flow and/or changes in water chemistry have the potential to alter speleothem formation and growth (Baker and Genty 1998). Potential reductions in snowpack driven by climate change could reduce water flow and affect drip rates and water chemistry of cave waters (Baker and Genty 1998, Chelius et al. 2009). Finally, agricultural and other land uses can introduce livestock-generated and human-related organisms (*E. coli*) via water flow from the surface (Campbell et al. 2011; Section 4.4).

4.5.2. Reference Conditions

Formations

The reference conditions for cave formations would be that they continue to grow and develop naturally and that there be no further damage to speleothems in the future (NPS 2013). Any future damage or alteration to TICA speleothems would be considered a degraded condition. Because physical structure affects flow processes, natural function includes no change (reduction) in drip rate measures.

Microorganisms

Though extant mircroorganisms can be identified, the composition of these communities prior to human presence is unknown. There should be no further introductions of taxa that have obvious human sources (e.g. *E. coli*, lampenflora), or reductions in known diversity of existing native taxa (NPS 2013).

4.5.3. Data and Methods

Formations

Cave feature inventories were conducted at TICA in 2004 and 2007 by NPS (data available at TICA headquarters). One result of those inventories was the development of a geospatial (GIS) database with the locations of all features (NPS 2004). Geologic features are also monitored using 80 established photo-points on a three-year cycle (C. McKinney, pers. comm. 2015). CO_2 data collection in the caves began in May 2014; data are collected once per month during the tour season from 30 locations within the caves.

Microorganisms

St. Clair and Rushforth (1976) surveyed the diatoms (one group of microorganisms) in the TICA caves. They found 26 species from 7 sites, 22 of which were found in the big room of Middle Cave. They suggested that the amount of moisture available at a microclimate scale was the primary factor influencing diatom diversity, for example species diversity was much lower at drier sites away from natural openings.

A survey of microbial diversity was initiated in 2003 using DNA identification techniques. Samples from pristine (minimal human disturbance or presence) and disturbed (near tourist trails) sites throughout the caves were compared (Porter et al. 2004 with methods described therein). Those surveys found nine major taxonomic groups in disturbed sediments (Acidobacteria [39%], Gammaproteobacteria [24%], and Planctomycetes [18%]), but the only group retrieved from the pristine sites in TC were related to Crenarcheota. Twelve taxonomic groups were retrieved from HD sediments, with the majority belonging to Betaproteobacteria (20%), Acidobacteria (17%), Alphaproteobacteria (16%), and Deltaproteobacteria (15%).

4.5.4. Resource Condition and Trend

Formations

Photopoint data indicate that there have been no observable structural changes in formation condition since monitoring began. Due to the relatively short period of CO_2 data collection, no trend information is available. Data from the most recently available summer periods (2014–2015) indicate that Timpanogos Cave has the highest levels of CO_2 and Middle Cave the lowest (NPS unpublished data). Variability in CO_2 amounts throughout the cave system may be related to distance from entrances, microclimate differences, hydrologic processes and human presence (Baker and Genty 1998, Breecker et al. 2012, NPS unpublished data).

Microorganisms

The presence of lampenflora shows that new species have been introduced to the caves. The park regularly conducts 'lint removal' volunteer efforts, indicating the persistent introduction of human-transported particles into the caves. Nothing else is known regarding changes in microbial communities in the caves since the previously-mentioned studies (C. McKinney, pers. comm. 2015).

4.5.5. Level of Confidence

For speleothems moderate to high. For microorganisms low.

4.5.6. Data Gaps and Research Needs

The Cave Management Plan (NPS 2013) addressed future management options for protection of cave features and microbes given the realities of visitor impacts. In particular for TICA the largest data gaps include annual monitoring of microorganism communities. The Park Service acknowledges that more effort is needed to monitor and understand current conditions of unique cave resources that have not had the level of funding support that other natural resources groups have had (Pate 2013, Baker et al. 2015).

4.5.7. Sources of Expertise

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4.5.8. Literature Cited

Alt, L. and V. Moura. 2013. Use of impact mapping for planning the infrastructure in tourist caves – case study: Maquine Cave, Brazil. In: Land, L. and M. Joop, eds. Proceedings of the 20th National Cave and Karst Management Symposium, November 4–8, 2013, Carlsbad, NM. National Cave and Karst Institute, Carlsbad, NM.

Adetutu, E. M., K. Thorpe, E. Shahsavari, S. Bourne, X. Cao, R.M.N. Fard, G. Kirby and A.S. Ball. 2012. Bacterial community survey of sediments at Naracoorte Caves, Australia. Int. J. Speleo. 41:137–147.

Baker, A. and D. Genty. 1998. Environmental pressures on conserving cave speleothems: effects of changing surface land use and increased cave tourism. J. Envir. Manag. 53:165–175.

Baker, A., and I.J. Fairchild. 2012. Drip water hydrology and speleothems. Nature Education Knowledge 3:16.

Baker, G.M., S.J. Taylor, S. Thomas, K. Lavoie, R. Olson, H. Barton, M. Denn, S.C. Thomas, R. Ohms. K. L. Helf, J. Despain, J. Kennedy, and D. Larson. 2015. Cave ecology inventory and monitoring framework. Natural Resource Report NPS/NRPC/NRR—2015/XXX. National Park Service, Fort Collins, Colorado.

Banner, J.L., A. Guilfoyle, E.W. James, L.A. Stern, and M. Musgrove. 2007. Seasonal variations in modern speleothem calcite growth in central Texas, USA. Journal of Sedimentary Research 77:615–622.

Barton, H.A., M.R. Taylor, and N.R. Pace. 2004. Molecular phylogenetic analysis of a bacterial community in an oligotrophic cave environment. Geomicrobiology Journal 21:11–20.

Barton, H.A. 2006. Introduction to cave microbiology: A review for the non-specialist. J. Cave and Karst Studies 68:43–54.

Breecker, D.O., A.E. Payne, J. Quade, J.L. Banner, C.E. Ball, K.W. Meyer, and B.D. Cowan. 2012. The sources and sinks of CO_2 in caves under mixed woodland and grassland vegetation. Geochimica et Cosmochimica Acta 96:230–246.

Brennan, E.S. and W.B. White. 2013. Luminescence of speleothems: a comparison of sources and environments. Journal of Cave and Karst Studies 75:210–217.

Campbell, J.W., A.Watson, C. Watson, H. Ball, and R. Pirkle. 2011. *Escherichia coli*, other coliform, and environmental chemoheterotrophic bacteria in isolated water pools from six caves in northern Alabama and northwestern Georgia. Journal of Cave and Karst Studies 73:75–82.

Cañveras, J.C., S. Sanchez-Moral, V. Sloer, and C. Saiz-Jimenez. 2001. Microorganisms and microbially induced fabrics in cave walls. Geomicrobiology Journal 18:223–240.

Chelius, M.K., G. Beresford, H. Horton, M. Quirk, G. Selby, R.T. Simpson, R. Horrocks and J.C. Moore. 2009. Impacts of alterations of organic Inputs on the bacterial community within the sediments of Wind Cave, South Dakota, USA. International Journal of Speleology, 38: 1–10.

Cunningham, K. I., D. E. Northup, R. M. Pollastro, W. G. Wright, and E. J. LaRock. 1995. Bacteria, fungi and biokarst in Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico. Environmental Geology 25:2–8.

Engel, A.S. 2007. Observations on the biodiversity of sulfidic karst habitats. Journal of Cave and Karst Studies 69:187–206.

Fairchild, I.J. and P.C. Treble. 2009. Trace elements in speleothems as recorders of environmental change. Quaternary Science Reviews 28:449–468.

Fairchild, I.J. and A. Baker. 2012. Carbonate and Karst Cave Geology, in Speleothem Science: From Process to Past Environments, John Wiley & Sons, Ltd, Chichester, UK. doi: 10.1002/9781444361094.ch2

Falasco, E., L. Ector, M. Isaia, C.E. Wetzel, L. Hoffmann, and F. Bona. 2014. Diatom flora in subterranean ecosystems: a review. International Journal of Speleology 43:1.

Fernandez-Cortes, A., S. Sanchez-Moral, J.C. Cañaveras, J. Cuevas-Gonzalez, S. Cuezva, and J.M. Andreu. 2010. Variations in seepage water geochemistry induced by natural and anthropogenic microclimatic changes: Implications for speleothem growth conditions. Geodinamica Acta 23:1–13.

Florea, L.J., C.R. Dugan, and C. McKinney. 2013. Preliminary summary of water resource investigations during 2012 at TImpanogos Cave National Monument, Utah. In *Proceedings of the 20th National Cave and Karst Management Symposium*, pp. 61–67. 2013.

Genty, D., A. Baker and B. Vokal. 2001. Intra-and inter-annual growth rate of modern stalagmites. Chem. Geol. 176: 191–212.

Gibert, J. and L. Deharveng. 2002. Subterranean ecosystems: A truncated functional biodiversity. *BioScience* 52, no. 6 (2002): 473–481.

Gray, C.J. and A.S. Engel. 2012. Microbial diversity and impact on carbonate geochemistry across a changing geochemical gradient in a karst aquifer. The ISME Journal 7:325–337.

Griffin, D.W., M.A. Gray, M.B. Lyles, and D.E. Northup. 2014. The transport of nonindigenous microorganisms into caves by human visitation: A case study at Carlsbad Caverns National Park. Geomicrobiology Journal 31:175–185.

Horrocks, R.D. 2013. The NPS cave visitor impact vital signs monitoring protocol. In: Land, L. and M. Joop, eds. Proceedings of the 20th National Cave and Karst Management Symposium, Carlsbad, New Mexico, November 2013. National Cave and Karst Research Institute, Carlsbad, NM.

Ikner, L.A., R.S. Toomey, G. Nolan, J.W. Neilson, B.M. Pryor, and R.M. Maier. 2007. Culturable microbial diversity and the impact of tourism in Kartchner Caverns, Arizona. Microbial ecology 5330–42.

Jones, B. 2010. Microbes in caves: agents of calcite corrosion and precipitation. Geological Society, London, Special Publications 336:7–30.

Lachniet, M.S. 2009. Climatic and environmental controls on speleothem oxygen-isotope values. Quaternary Science Reviews 28:412–432.

McDermott, F. 2004. Palaeo-climate reconstruction from stable isotope variations in speleothems: a review. Quaternary Science Reviews 23:901–918.

Mulec, J. and G. Kosi. 2009. Lampenflora algae and methods of growth control. J Cave Karst Stud 71:109–115.

National Park Service (NPS) 2004. Timpanogos Cave National Monument. 2004. Major Cave Features, 2004 Timpanogos Cave National Monument, Utah. Timpanogos Cave National Monument GIS Program. Geospatial Dataset-1043701

NPS. 2013. Timpanogos Cave National Monument, Draft Cave Management Plan Environmental Assessment.

Pate, D. 2013. Moving the National Park Service cave and karst program forward: Identifying and understanding park resources. In: Land, L. and M. Joop, eds. Proceedings of the 20th National Cave and Karst Management Symposium, November 4–8, 2013, Carlsbad, NM. National Cave and Karst Institute, Carlsbad, NM.

Porter, M., A. Bennin, H. Marrujo, and J. Jasper. 2004. Microbial Communities in Timpanogos Cave. Unpublished findings. Brigham Young University. Provo, Utah.

Pulham, C. 2009. Heart of the Mountain: The History of Timpanogos Cave National Monument. National Park Service, Washington, D.C.

Saiz-Jimenez, C. 2012. Microbiological and environmental issues in show caves. World Journal of Microbiology and Biotechnology 28:2453–2464.

Smith, T. and R. Olson. 2007. A taxonomic survey of lamp flora (algae and cyanobacteria) in electrically lit passages within Mammoth Cave National Park, Kentucky. Int. J. Speleology 36:105–114.

St. Clair, L.L. and S.R. Rushforth. 1976. The diatoms of Timpanogos Cave National Monument, Utah. American Journal of Botany 63:49–59.

Stein, H. C. Kellermann, S.I. Schmidt, H. Brielmann, C. Steube, S. Berkhoff, A. Fuchs, H. Jürgen Hahn, B. Thulin, and C. Griebler. 2010. The potential use of fauna and bacteria as ecological indicators for the assessment of groundwater quality. Journal of Environmental Monitoring 12:242–254.

Thornberry-Ehrlich, T. 2006. Timpanogos Cave National Monument Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2006/013. National Park Service, Denver, Colorado.

Tomczyk-Żak, K. and U. Zielenkiewicz. 2015. Microbial diversity in caves. Geomicrobiology Journal just-accepted: 00-00. (http://www.tandfonline.com/doi/abs/10.1080/01490451.2014.1003341)

Van Beynen, P. and K. Townsend. 2005. A disturbance index for karst environments. Environmental Management 36:101–116.

Venarsky, M.P., B.M. Huntsman, A.D. Huryn, J.P. Benstead, and B.R. Kuhajda. 2014. Quantitative food web analysis supports the energy-limitation hypothesis in cave stream ecosystems. Oecologia 176:859–869.

Veni, G. 2013. Impact of climate change on human and ecological use of karst groundwater resources: A case study from the Southwestern USA. 2013. In: Land, L. and M. Joop, eds. Proceedings of the 20th National Cave and Karst Management Symposium, November 4–8, 2013, Carlsbad, NM. National Cave and Karst Institute, Carlsbad, NM.

White, W.B., J.J. Van Gundy. 1971. Geological reconnaissance of Timpanogos Cave, Utah. The NSS Bulletin 33:147–148.

4.6. Cave/Subsurface Watershed

4.6.1. Background

Cave ecosystems are dependent on the quality (Section 4.4) and quantity of water that enters the caves (Thornberry-Ehrlich 2006, Bonacci et al. 2009). Water from the surface flows through the epikarst matrix—micropores and small fissures in the overlying rock and soil layers—or larger conduits, before dripping or seeping into the caverns and collecting in cave pools (Bonacci et al. 2009). Source waters for caves can come from multiple locations (Childre 2013), and the amount of water entering a cave can vary greatly depending on season, surface weather conditions and land use (Doctor et al. 2000). Understanding not only the spatial extent of all waters that flow into a cave system (subsurface watershed) but also the amount of water necessary to maintain speleothem processes and biologic communities is necessary for the protection of cave systems (Bonacci et al. 2009, Engel 2010).

The surface watershed from which TICA cave waters originate is located above and generally south of the caves and can be delineated based on elevation, but the precise extent and location of the subsurface waters that enter the caves is undefined (Florea et al. 2013, K. Bahr pers. comm, 2020). Studies have indicated that there are multiple flow paths from the surface; for example while drip rates at some cave sites (Hansen and Middle caves) increase within minutes to hours after a storm, the rates at other sites (Timpanogos Cave) remain relatively constant regardless of surface conditions (Tranel et al. 1992, Thornberry-Ehrlich 2006, Florea et al. 2013, Dugan 2015).

<u>Threats</u>

Any factor that decreases the average yearly flow of water to the caves could indirectly impact cave resources and processes. For example, if recharge rate—the rate at which groundwater is replenished—is measurably reduced due to climate change as nearly all models predict (Dragoni and Sukhija 2008, Green et al. 2011), water quantity in the caves could likewise decline (Hartmann et al. 2014). Type conversion of forest vegetation, such as a significant reduction in tree cover due to drought or disease, could also alter hydrologic processes that affect groundwater (Vose et al. 2012; Section 4.12). Reduced water availability for cave ecosystems is anticipated as precipitation amounts in the western U.S. decline in response to climate change (Dragoni and Sukhija 2008, Hamlet et al. 2005).

The possibility that NPS operations are affecting subsurface hydrology should be considered. Middle Cave Lake is pumped at the beginning of the visitor season because during the winter months (when the cave is closed to visitors) the level of the water in the pool rises to a point where it inundates the trail. The effects, if any, of removing that volume of water from the system are unknown (NPS 2013, C. McKinney, pers. comm. 2015).

4.6.2. Reference Conditions

<u>Subsurface Watershed</u>

Though much of the surface watershed is outside park boundaries, land-use activities that affect (decrease) the water quantity of the watershed should be discouraged. The subsurface watershed, if found to include any additional areas, should likewise be free of factors that impede water flow into the caves.

Quantity

Though hydrologic patterns vary over time, a decreasing trend of water entering the TICA caves would be cause for concern (Hartmann et al. 2014). However, the total amount of water that flows through caves is not generally measured (as compared to surface flows, e.g. cfs on rivers and streams). Instead, drip rates at monitored locations and water levels of cave pools are often used as proxys for total flow (Hartman et al. 2014). Thus, drip rates at TICA should not decline from recent averages, though it has been suggested that the available data may have been collected during a period of drought and reduced flows (Hamlet et al. 2005). Pool elevations should vary as they have historically and likewise should show no indication of declining trends in annual or seasonal levels.

4.6.3. Data and Methods

Subsurface Watershed

A very thorough investigation of the hydrology of the TICA cave system was conducted in 2011–2012 by Florea et al. (2013) and Dugan (2015), with detailed methods described in those references. Along with other goals, their research attempted to identify the water flow paths for cave waters and identify the chemical composition of cave pools as well as chemical changes that occur throughout the year.

Quantity

Drip rates are generally measured using containers and rain gauges located below actively dripping speleothems. Pool levels are measured using standard water depth techniques. For TICA, geospatial information exists on the location of all drip rate monitoring sites (NPS 2004). Lake levels in Hansen Lake were monitored from June–Dec. 2010, and from Nov. 2012–Sept. 2015, and in Middle Cave Lake from Aug. 2011–July 2015. Gauge measurements have been collected monthly in Hansen and Hidden Lakes since 2008.

4.6.4. Resource Condition and Trend

Subsurface Watershed

Middle Cave Lake (MCL) and Hansen Cave Lake (HCL) have greater ranges of water level variability than do Hidden Lake (HL) and Cavern of Sleep Lake (CSL) which are more consistent. Florea et al. (2013) and Dugan (2015) suggest that the water sources of the pools with less depth variability (HL and CSL) are likely near the elevation of the cave (i.e. cave waters come mostly from groundwater), while the pools with large water-level changes (MCL and HCL) have a greater proportion of water that originates from the surface (where water availability correlates primarily to daily rainfall and snowmelt amounts). Given the absence of a clear connection between sources and pools, actual flow routes into the caves remain elusive and the extent of the subsurface watershed is still not definitively known.

Quantity

The level of Hidden Lake was relatively constant from 2009–2012 (approx. 2.8 ft/0.8 m) but has declined since that time to a depth of approx. 2.0 ft/0.6 m (NPS unpublished data).

4.6.5. Level of Confidence

Moderate

4.6.6. Data Gaps and Research Needs

Many advanced modeling techniques are available that could be applied to the TICA cave system in the future (Bonacci et al. 2009). However, the absence of definitive results by Dugan (2015) and Florea et al. (2013), despite the application of established techniques and several attempts, illustrates the challenges of determining the true sources of TICA cave waters.

Lake-level monitoring should continue.

4.6.7. Sources of Expertise

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4.6.8. Literature Cited

Bonacci, O., T. Pipan, and D.C. Culver. 2009. A framework for karst ecohydrology. Environmental Geology 56:891–900.

Childre, M. 2013. Hydrologic controls on the occurrence and movement of groundwater discharged at Magic Spring in the Spring Branch Creek drainage basin, Spring Branch Texas. 2013. In: Land, L. and M. Joop, eds. Proceedings of the 20th National Cave and Karst Management Symposium, November 4–8, 2013, Carlsbad, NM. National Cave and Karst Institute, Carlsbad, NM.

Doctor, D.H., S. Lojen and M. Horvat. 2000. A stable isotope investigation of the classical karst aquifer: evaluating karst groundwater components for water quality preservation. Acta Carsolog 29:79–92.

Dragoni, W. and B.S. Sukhija. 2008. Climate change and groundwater: a short review. Geological Society, London, Special Publications 288:1–12.

Dugan, C.R. 2015. Investigating Vadose-zone Hydrology in Alpine Karst Aquifers Using Quantitative Groundwater Tracing Methods: Timpanogos Cave National Monument, Utah County, Utah. Master's Thesis, Ball State Univ., Muncie, IN.

Engel, A.S. 2010. Microbial Diversity of Cave Ecosystems. Chap. 10 in: Loy, A., M. Mandl, and L. Barton, eds. Geomicrobiology: Molecular and Environmental Perspective. Springer, Netherlands.

Florea, L.J., C.R. Dugan, and C. McKinney. 2013. Preliminary summary of water resource investigations during 2012 at TImpanogos Cave National Monument, Utah. In Proceedings of the 20th National Cave and Karst Management Symposium, pp. 61–67. 2013.

Green, T.R., M.Taniguchi, H.Kooi, J.J. Gurdak, D.M. Allen, K.M. Hiscock, H.Treidel, and A.Aureli. 2011. Beneath the surface of global change: Impacts of climate change on groundwater. Journal of Hydrology 405:532–560.

Hamlet, A.F., P.W. Mote, M.P. Clark, and D.P. Lettenmaier. 2005. Effects of temperature and precipitation variability on snowpack trends in the Western United States. Journal of Climate 18:4545–4561.

Hartmann, A. N. Goldscheider, T. Wagener, J. Lange, and M. Weiler. 2014. Karst water resources in a changing world: Review of hydrological modeling approaches. Reviews of Geophysics 52:218–242.

National Park Service (NPS). 2004. Drip Rates, 2004, Timpanogos Cave National Monument, Utah. Timpanogos Cave National Monument GIS Program. Geospatial Dataset-1043684.

NPS. 2013. Timpanogos Cave National Monument, Cave Management Plan, Environmental Assessment. Timpanogos Cave National Monument, American Fork, UT.

Thornberry-Ehrlich, T. 2006. Timpanogos Cave National Monument Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2006/013. National Park Service, Denver, Colorado.

Tranel, M., Mayo, A.L., and Jensen, T.M., 1992. Preliminary investigation of the hydrology and hydrogeochemistry at Timpanogos Cave National Monument, Utah, and its implications for management. In: Foster, D.L. (ed.). Proceedings of the 1991 National Cave Management Symposium, Bowling Green, KY. American Cave Conservation Association, Horse Cave, KY.

Vose, J.M., D.L. Peterson, T. Patel-Weynand, eds. 2012. Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector. Gen. Tech. Rep. PNW-GTR-870. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

4.7. American Fork River (Hydrology and Riparian Ecology)

4.7.1. Background

Hydrology – American Fork Canyon

With headwaters high in the Wasatch Mountains, the American Fork River (AFR) drains the Utah Lake watershed upstream and to the north/northeast of TICA. A relatively small reach (0.7 mi/1 km) of the AFR flows through TICA before exiting the canyon and entering Utah Lake to the west. The American Fork Canyon (AFC), through which the AFR flows, is one of many east-west trending canyons along the Wasatch Front that were created by tectonic processes (Machette et al. 1991, Mayo et al. 2009). The Wasatch Front is still rising relative to the western basin, and the entire area is considered geologically active (Thornberry-Ehrlich 2006, Personius et al. 2012).

Erosional processes on the steep slopes of AFC result in periodic rockfall events that often cause structural damage and even human fatalities (Thornberry-Ehrlich 2006, Coe and Harp 2007, Harp et al. 2011; Figure 4.7-1). The incised geology of the canyon also means that flood waters are channeled into a narrow zone which increases the energy of the flow, resulting in potentially significant economic consequences (Wieczorek et al. 1989, Shun and Duffy 1999, Thornberry-Ehrlich 2006). The steep topography has necessitated the location of both NPS and USFS facilities within the 500-year and in some cases 100-year floodplains, leading to several instances of road and facility closures, evacuations, and structural damage during intense storm events (Kunkle 2001, Thornberry-Ehrlich 2006, Pulham 2009, NPS 2012, NPS 2014). For an overview of the geology of this portion of the AFC see Coe et al. (2005) and Coe and Harp (2007).

Figure 4.7-1. American Fork Canyon, looking generally west. TICA caves are on the south canyon side (left in the photo and higher in elevation), and the American Fork River runs through the canyon bottom where park facilities are also located. Photo by C. Schwemm.

In addition, the reach of the AFR that runs through TICA has been altered by the addition of cement streambank amendments constructed to protect the highway and facilities from flooding. The effectiveness of streambank stabilization and other flood-control mechanisms to prevent damage to buildings and infrastructure has been strongly debated (Gerlak et al. 2009), but nearly all research demonstrates that hard-surfaces (e.g. revetments, rip-rap) along stream and river courses have significant detrimental impacts on ecological processes (Tockner and Stanford 2002, Groffman et al. 2003).

Water flow rates of the AFR vary throughout the year in a pattern characteristic of mountain landscapes in temperate regions (Fig. 4.7-2). The highest flows are between May–July with dynamics dependent on winter snowfall amounts and snowmelt periods (Shun and Duffy 1999). Average June flows display the greatest variability when snowmelt and late spring weather patterns interact to drive flood dynamics, and flows taper off on average throughout the fall and winter with periods punctuated by floods and high flow events. Flows are likely affected by the presence of the Tibble Fok Dam, 5 mi (8 km) above TICA, though data describing flows through TICA coincident with water management activities in relation to holding or reseasing wate are lacking (T. McKinney pers. comm. 2020). Reductions in flow over time are anticipated as climate change drives altered precipitation patterns and higher temperatures (discussed in Section 4.3).

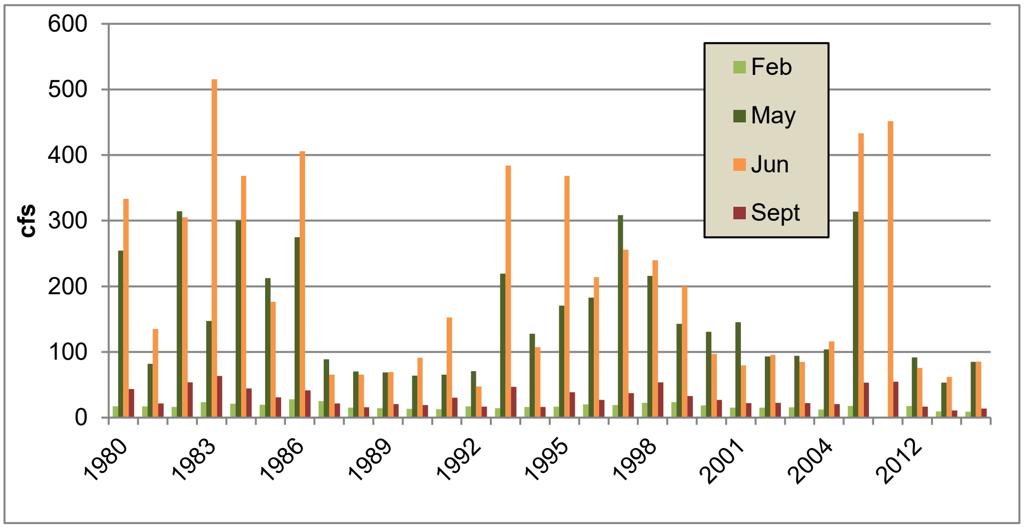

Figure 4.7-2. USGS data from gage #10164500, 1980–2012 (https://waterdata.usgs.gov/ut/nwis/uv?site_no=10164500).

Ecology

Because of the steep geology of the canyon, the riparian zone associated with the AFR is narrow. Still, there exists an area adjacent to the river course that in an unaltered state would support flood-adapted vegetation communities and associated wildlife and natural ecohydrological processes (Merritt and Wohl 2002, Hamilton et al. 2015). Periodic flooding in riparian forests results in younger (more frequently disturbed) stands of woody species near the stream course and increasingly mature stands further from the water on higher ground (Lytle and Merritt 2004). Cottonwood (*Populus* sp.) in particular requires periodic flooding to trigger seed germination and establishment and remove competitor species that are not flood-adapted (Braatne et al. 1996, Rood et al. 2003, Lytle and Merritt 2004).

Two riparian woodland plant associations have been identified in TICA: Box-elder/Narrowleaf Cottonwood/White Fir (*Acer negundo*/*Populus angustifolia*/*Abies concolor*), and Box-elder/Bigtooth Maple (*Acer negundo*/*A. grandidentatum*; Coles et al. 2009). Cumulatively these two woodland types comprise about 15 ac (6 ha), approximately 9% of the vegetated area of the park (Coles et al. 2009). Additional common species include Douglas-fir (*Pseudotsuga menziesii*), Rocky Mountain juniper *Juniperus scopulorum*), water birch (*Betula occidentalis*), willows (*Salix* spp.), various shrub species, and exotic grasses (Coles et al. 2009, NPS 2014).

Functioning riparian systems in the western U.S. also support high diversities of invertebrates, amphibians, fish, landbird, bats, and aquatic-adapted mammals such as beaver (Knopf et al. 1988, Lytle and Poff 2004, Scott et al. 2010). In Utah, riparian woodlands have been identified as the most important bird habitat type in the state (Gardner et al. 1999). In the last several decades the greatest impacts to the quality of AFR water as wildlife habitat have come from toxic materials, particularly arsenic, leached from upstream silver and copper mines that are now mostly abandoned (Kunkle 2001, Kimball et al. 2009). Levels of arsenic reached such high levels during the early 2000s that fish consumption advisories were issued by the EPA and the State of Utah (Lachmar et al. 2006).

The main AFR river stem also supports populations of native Bonneville cutthroat trout (BCT, *Oncorhynchus clarki utah*, the State Fish of Utah) a species that has been proposed for federal listing and that is identified by USFS as a species of concern (Budy et al. 2007). However, because there is such a small stretch of river that runs through TICA that BCT might use and because the factors that endanger the species are almost wholly outside the management of NPS and TICA, fish will not be considered further in this assessment.

4.7.2. Reference Conditions

Hydrologic Function
There should not be a declining trend in average streamflows. An improving condition would be that periodic floodwaters be allowed to reach shoreline vegetation and man-made alterations that prevent natural flood processes be removed.

Ecology
The absence of periodic floodplain inundation results in a reduction in woody species reproduction, a decline in understory diversity, and an increase in exotic species (Rocchio et al. 2004, Williams and Cooper 2005, Braatne et al. 2007, Merritt and Poff 2010). Consequently, good riparian condition would support the recruitment of woody species over time, and wildlife and bird communities should reflect structurally diverse riparian vegetation (Rich 2002).

4.7.3. Data and Methods

Hydrologic Function
Approximately a mile upstream from the park is USGS stream gage # 10164500 ('Upper Powerplant'), data which are available online (https://waterdata.usgs.gov/nwis/inventory/?site_no=10164500&agency_cd=USGS; confirmed 2/19/20).

Ecosystems
There is currently no monitoring of vegetation, landbirds or invertebrates in the riparian area at TICA. As far as is known the riparian zone at TICA in general has been little studied from an ecological perspective. Judson and Nelson (2010) investigated the ecology and distribution of aquatic invertebrates (Ephemeroptera, Plecoptera, and Trichoptera – EPT) in the area. There have been several surveys that include reviews of the resources of the developed area along the river in relation to affected areas of construction and restoration projects (NPS 2012, NPS 2014).

4.7.4. Resource Condition and Trend

Hydrologic Function
Free-flowing streams and rivers in temperate zones generally experience multi-year flood patterns often measured by the distance to which water extends outside or above the normal channel (Bayley

1995). Thus flood measures are relative and defined by how often they are statistically expected to occur (for example every 25, 100, or 500 years; http://water.usgs.gov/edu/100yearflood.html). Rainfall and flood processes along the Wasatch Front are highly variable and large floods relatively common (Bekker et al. 2014). While the presence of revetments prevents small flood events that would function naturally to nourish the riparian zone (Opperman et al. 2010), they do not prevent flooding during significant events. As far as is known no specific studies have been conducted on this portion of the AFR to quantify ecologic changes resulting from floodplain alterations.

Nearly all observers anticipate that water availability in the western U.S. will decline as a result of climate change (Harding et al. 2012), and that reductions in annual precipitation will impact river flows and riparian systems, particularly in Utah (Bardsley et al. 2013, Reynolds et al. 2015). Streamflow patterns are also changing in response to climate change, with temperate, snow-dependent systems experiencing earlier peak flows on average (Stewart et al. 2005), and possibly greater variability over longer time scales (Jain and Lall 2000, Carson 2007). A cursory examination of available data (Figure 4.7-3) indicate that AFR flows have been below average for the past several years, though these data have not been statistically evaluated. An historic water diversion facility of upstream of TICA historically reduced flows through the TICA reach (Martin and Jackson 1999) but has since been decommissioned.

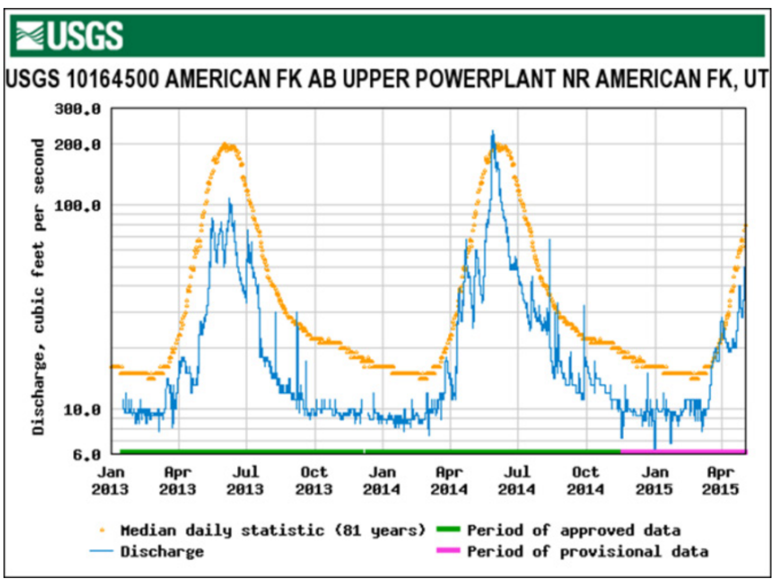

Figure 4.7-3. Recent flow hydrograph of American Fork River, from USGS gage # 101645000 (http://nwis.waterdata.usgs.gov/ut/nwis/uv/?dd_cd=01_00060&format=img_stats&site_no=10164500&begin_date=20130101&end_date=20150502).

Ecosystems

Coles et al. (2009) found white fir seedlings in one riparian sample plot, indicating some reproduction for that species (though not necessarily recruitment because seedlings often die before becoming established; Fenner and Thompson 2005). Judson and Nelson (2010) found relatively high diversity of aquatic invertebrates but long-term data are unavailable. All data suggest very good water quality in the portion of the AFR that runs through TICA, though the river is recovering from very high toxic loads present as a result of past mining activities upstream. Clean-up efforts have been ongoing since the mid-2000s and appear to have been largely successful (Lachmar et al. 2006). This area of the river experiences high visitor use in the summer by picnickers and hikers. Foot traffic likely impacts potential seedling recruitment, particularly of woody species (Poff et al. 2011), and riparian bird communities (Miller et al. 1998).

4.7.5. Level of Confidence
Hydrologic Function – High

Ecosystems – Low to Moderate.

4.7.6. Data Gaps and Research Needs
Stream flow data collected by USGS upstream of TICA may be interrupted if funding to maintain the gauge is unavailable. If this occurs, efforts should be made to collected stream flow data by alternate methods.

Additional information on streamside ecosystems should be collected.

4.7.7. Literature Cited

Bardsley, T., A. Wood, M. Hobbins, T. Kirkham, L. Briefer, J. Niermeyer, and S. Burian. 2013. Planning for an Uncertain Future: Climate Change Sensitivity Assessment toward Adaptation Planning for Public Water Supply. Earth Interactions 17:1–26.

Bayley, P.B. 1995. Understanding large river: floodplain ecosystems. BioScience 45:153–158.

Bekker, M.F., R.J. DeRose, B.M. Buckley, R.K. Kjelgren, and N.S. Gill. 2014. A 576-year Weber River streamflow reconstruction from tree rings for water resource risk assessment in the Wasatch Front, Utah. Journal of the American Water Resources Association (JAWRA) 1-11. DOI: 10.1111/jawr.12191.

Braatne, J.H., S.B. Rood, and P.E. Heilman. 1996. Life history, ecology, and conservation of riparian cottonwoods in North America. in: Biology of *Populus* and its implications for management and conservation. Part I, Chapter 3. Edited by R.F. Stettler, H.D. Bradshaw, Jr., P.E. Heilman, and T.M. Hinckley. NRC Research Press, National Research Council of Canada, Ottawa, ON, Canada. 539 pp.

Braatne, J.H., R. Jamieson, K.M. Gill, and S.B. Rood. 2007. Instream flows and the decline of riparian cottonwoods along the Yakima River, Washington, USA. River Research and Applications 23:247–267.

Budy, P., G.P. Thiede, and P. McHugh. 2007. Quantification of the vital rates, abundance, and status of a critical, endemic population of Bonneville cutthroat trout. North American Journal of Fisheries Management 27:593–604.

Carson, E.C. 2007. Temporal and seasonal trends in streamflow in the Uinta Mountains, northeastern Utah, and relation to climatic fluctuations. Arctic, Antarctic, and Alpine Research 39:521–528.

Coe, J.A., E.L. Harp, A.C. Tarr, and J.A. Michael. 2005. Rock-fall hazard assessment of Little Mill Campground, American Fork Canyon, Uinta National Forest, Utah. USFS Open-File Report No. 2005–1229.

Coe, J.A., and E.L. Harp. 2007. Influence of tectonic folding on rockfall susceptibility, American Fork Canyon, Utah, USA. Natural Hazards and Earth System Science 7:1–14.

Coles, J., J. Von Loh, A. Wight, K. Schulz, and A. Evenden. 2009. Vegetation classification and mapping project report, Timpanogos Cave National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2009/210. National Park Service, Fort Collins, Colorado.

Fenner, M. and K. Thompson. 2005. The ecology of seeds. Cambridge University Press, Cambridge, UK.

Gardner, P.A., R.S. Stevens, and F P. Howe. 1999. A handbook of riparian restoration and revegetation for the conservation of land birds in Utah with emphasis on habitat types in middle and lower elevations. Utah Division of Wildlife Resources Publication Number 99-38.

Gerlak, A.K., S. Eden, S. Megdal, K.M. Lacroix, and A. Schwarz. 2009. Restoration and river management in the arid southwestern USA: exploring project design trends and features. Water Policy 11:461–480.

Groffman, P.M., D.J. Bain, L.E. Band, K.T. Belt, G.S. Brush, J.M. Grove, R.V. Pouyat, I.C. Yesilonis, and W.C. Zipperer. 2003. Down by the riverside: urban riparian ecology. Frontiers in Ecology and the Environment 1:315–321.

Hamilton, B.T., B.L. Roeder, K.A. Hatch, D.L. Eggett and D. Tingey. 2015. Why is small mammal diversity higher in riparian areas than in uplands? Journal of Arid Environments 119:41–50.

Harding, B.L., A.W. Wood, and J.R. Prairie. 2012. The implications of climate change scenario selection for future streamflow projection in the Upper Colorado River Basin. Hydrology and Earth System Sciences 16:3989–4007.

Harp, E.L., R.L. Dart, and P. Reichenbach. 2011. Rock fall simulation at Timpanogos Cave National Monument, American Fork Canyon, Utah, USA. Landslides 8:373–379.

Jain, S. and U. Lall. 2000. Magnitude and timing of annual maximum floods: Trends and large-scale climatic associations for the Blacksmith Fork River, Utah. Water Resources Research 36:3641–3651.

Judson, S.W. and C. R. Nelson. 2010. Diversity, phenology, and elevational distribution of Ephemeroptera, Plecoptera, and Trichoptera in American Fork Canyon, Utah. Western North American Naturalist 70:526–540.

Kimball, B.A., R.L. Runkel and L.J. Gerner. 2009. Methods and basic data from mass-loading studies in American Fork, October 1999, and Mary Ellen Gulch, Utah, September 2000: U.S. Geological Survey Data Series 443, 33p.;Available at http://pubs.usgs.gov/ds/443.

Knopf, F. L., R.R. Johnson, T. Rich, F.B. Samson and R.C. Szaro. 1988. Conservation of riparian ecosystems in the United States. The Wilson Bulletin 100:272–284.

Kunkle, S. 2001. Water Quality Monitoring Trip Notes, 31 pp. Unpublished.

Lachmar, T.E., N.I. Burk, and P.T. Kolesar. 2006. Groundwater contribution of metals from an abandoned mine to the North Fork of the American Fork River, Utah. Water, Air, and Soil Pollution 173:103–120.

Lytle, D.A. and D.M. Merritt. 2004. Hydrologic regimes and riparian forests: a structured population model for cottonwood. Ecology 85:2493–2503.

Lytle, D.A. and N.L. Poff. 2004. Adaptation to natural flow regimes. Trends in Ecology and Evolution 19:94–100.

Machette, M.N., S.F. Personius, A.R. Nelson, D.P. Schwartz, and W.R. Lund. 1991. The Wasatch fault zone, Utah—segmentation and history of Holocene earthquakes. Journal of Structural Geology 13:137–149.

Martin, M.W. and W.L. Jackson. 1999. Hydraulic modeling of low flows, American Fork Creek, Timpanogos Cave National Monument, Utah. Water Resources Division, NPS, Ft. Collins. http://archive.org/stream/hydraulicmodelin00mart/hydraulicmodelin00mart_djvu.txt

Mayo, A.L., J. Bruthans, D. Tingey, J. Kadlec, and S. Nelson. 2009. Insights into Wasatch fault vertical slip rates using the age of sediments in Timpanogos Cave, Utah. Quaternary Research 72:275–283.

Merritt, D.M. and Poff, N.L.R. 2010. Shifting dominance of riparian Populus and Tamarix along gradients of flow alteration in western North American rivers. Ecological Applications 20:135–152.

Merritt, D.M. and E.E. Wohl. 2002. Processes governing hydrochory along rivers: hydraulics, hydrology, and dispersal phenology. Ecological Applications 12:1071–1087.

Miller, S.G., R.L. Knight, and C.K. Miller. 1998. Influence of recreational trails on breeding bird communities. Ecological Applications 8:162–169.

National Park Service (NPS). 2012. Alternative Transportation Feasibility Study. Timpanogos Cave National Monument, PMIS #172474. Prepared by Cambridge Systematics, Inc. and David Evans and Associates, Inc.

NPS. 2014. Cave Camp Springs Rehabilitation, Environmental Assessment. Timpanogos Cave National Monument, American Fork, UT.

Opperman, J.J., R. Luster, B.A. McKenney, M. Roberts, and A.W. Meadows. 2010. Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale. Journal of the American Water Resources Association 46: 211–226.

Personius, S.F., C.B. DuRoss and A.J. Crone. 2012. Holocene Behavior of the Brigham City Segment: Implications for Forecasting the Next Large-Magnitude Earthquake on the Wasatch Fault Zone, Utah. Bulletin of the Seismological Society of America 102:2265–2281.

Poff, B., K.A. Koestner, D.g. Neary, and V. Henderson. 2011. Threats to Riparian Ecosystems in Western North America: An Analysis of Existing Literature 1. JAWRA Journal of the American Water Resources Association, 47:1241–1254.

Pulham, C. 2009. Heart of the Mountain: The History of Timpanogos Cave National Monument. National Park Service, Washington, D.C.

Reynolds, L.V., P.B. Shafroth, and N.L. Poff. 2015. Modeled intermittency risk for small streams in the Upper Colorado River Basin under climate change. Journal of Hydrology 523:768–780.

Rich, T. D. 2002. Using breeding land birds in the assessment of western riparian systems. Wildlife Society Bulletin 30:1128–1139.

Rocchio, J., G. Doyle and R. Rondeau. 2004. Survey of critical wetlands and riparian areas in Gunnison Colorado. Colorado Natural Heritage Program.

Rood, S. B., J.H. Braatne and F.M. Hughes. 2003. Ecophysiology of riparian cottonwoods: stream flow dependency, water relations and restoration. Tree Physiology 23:1113–1124.

Scott, S.J., G. McLaren, G. Jones, and S. Harris. 2010. The impact of riparian habitat quality on the foraging and activity of pipistrelle bats (*Pipistrellus* spp.). Journal of Zoology 280:371–378.

Shun, T. and C.J. Duffy. 1999. Low-frequency oscillations in precipitation, temperature, and runoff on a west facing mountain front: A hydrogeologic interpretation. Water Resources Research 35:191–201.

Stewart, I.T., D.R. Cayan, and M.D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate 18:1136–1155.

Thornberry-Ehrlich, T. 2006. Timpanogos Cave National Monument Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2006/013. National Park Service, Denver, Colorado.

Tockner, K. and J.A. Stanford. 2002. Riverine flood plains: present state and future trends. Environmental conservation 29:308–330.

Wieczorek, G.F., E.W. Lips and S.D. Ellen. 1989. Debris flows and hyperconcentrated floods along the Wasatch Front, Utah, 1983 and 1984. Bulletin of the Association of Engineering Geologists 26:191–208.

Williams, C.A., and D.J. Cooper. 2005. Mechanisms of riparian cottonwood decline along regulated rivers. Ecosystems 8:382–395.

4.8. Cave Invertebrates

4.8.1. Background

Invertebrate species found in caves can be either cave-obligates (troglobites) or species that utilize caves but also spend time above-ground (troglophiles; Howarth 1983). The absence of photosynthetic organisms in caves leads to a situation where energy comes largely from outside the system (allochthonous), such as from leaves and other vegetative material that wash into the cave (Smith et al. 2003, Schneider et al. 2011, Venarsky et al. 2012). Consequently, invertebrate community diversity in caves often varies in relation to the number and location of connections between the cave and the surface (Tobin et al. 2013). Because caves are highly insular systems (Culver 1970, Barr and Holsinger 1985) they often support relatively high levels of troglobite endemism (Culver et al. 2000, Panek and Despain 2013, Wynne 2013).

<u>Threats</u>

Because nothing is known about invertebrate diversity in the TICA caves prior to human entry, it is impossible to know the extent to which human presence has altered this community. It is likely that in the century following the discovery of the caves some native troglophilic invertebrate species, as well as microorganisms (Section 4.5), were lost and new species introduced (Panek and Despain 2013). The construction of the tunnel systems at TICA eliminated the natural habitat insularity of the three caves, potentially allowing movement of invertebrate species across communities that were historically separate (Nelson et al. 2004, Mammola et al. 2015). Current concerns for managers are that invertebrate diversity will be further altered into the future, additional new species will be introduced, and/or as-yet undiscovered species will be extirpated before they are identified (Culver 1970, Pate 2013, C. McKinney pers. comm. 2015).

4.8.2. Reference Conditions

Given the absence of known, natural diversity, Panek and Despain (2013) suggest the best measure of the condition of cave invertebrate communities is the presence/absence of species in their host caves for a period of observation of 5–10 years. Specifically, for TICA, the continued presence of extant troglophiles will demonstrate habitat connectivity between the caves and surface environments (NPS 2013, Pape and O'Connor 2014). Conversely, the presence of new troglophiles indicates that species are being introduced from the outside environment, likely by human transport. It is extremely unlikely if not impossible that any troglobite species (cave obligate) would now naturally colonize the TICA caves from another cave, so any 'new' cave obligates observed in the future should be considered native but previously undetected species. As far as possible, differences in diversity that may be related to variable microclimates between the three cave communities, (i.e. that existed prior to tunnel construction) should be maintained.

4.8.3. Data and Methods

In 2002–2003 Nelson et al. (2004) attempted to quantify invertebrate diversity within the TICA system using a variety of trapping and observational approaches (methods are described therein). This effort resulted in the collection of 31 species (30 arthropods and one annelid; Table 4.8-1). The report does not mention whether any species had been recently introduced by human activities (or whether it is even possible to know). There have been no subsequent studies on invertebrates or microorganisms in the caves (C. McKinney, pers. comm. 2015).

Table 4.8-1. Macroinvertebrates found by Nelson et al. 2004.

Group	Species	Comments
Annelids: Oligochaeta	Earthworms	One species probably came from outside.
Arthropods: Myriapoda	Chilopoda (centipedes)	Single unidentified species in the order Lithobiomorpha; common in this survey
	Diplopoda (millipedes)	Several unidentified species
Arthropods: Chelicerata	Arachnids (spiders)	Six species: one mite, one pseudoscorpion, three spiders, one harvestman (daddy long-legs); they suggested there may be additional spider species; the pseudoscorpion may be a cave-adapted species;
Arthropods: Insecta	Colembola (springtails)	Four families; one species (*Tomocerus* spp.) possibly of conservation concern;
	Orthoptera (crickets)	One species (*Ceuthophilus*?)
	Coleoptera (beetles)	Five species, none appeared to be cave specialists
	Diptera (flies)	Nine species, several common outside the caves; one gnat species may be undescribed and endemic;
	Lepidoptera (moths and butterflies)	Two species, at least one common outside of caves;
	Hymenoptera (bees, wasps, ants)	One species, likely not a cave obligate

4.8.4. Resource Condition and Trend

There have been no further surveys of macroinvertebrates in TICA since Nelson et al. (2004), and the current distribution and diversity of invertebrates is unknown (NPS 2013, C. McKinney, pers. comm. 2015). There have been no efforts to determine whether species have expanded from one of the three original cave systems to other areas of the larger complex with the creation of the tunnels, nor has there been identification of any species known to be introduced since the caves were discovered. Consequently, very little can be said regarding the current condition of invertebrate communities in the TICA caves in relation to the natural condition or to the surveys by Nelson et al. (2004) over a decade ago.

4.8.5. Level of Confidence

Low

4.8.6. Data Gaps and Research Needs

Ideally regular cave-wide surveys should be conducted for invertebrates to quickly detect new and undesired introductions. However, because new introductions will occur from the outside and cave-wide surveys have additional impacts, regular presence-absence trapping only near entrances would likely detect new introductions (Cunningham et al. 1995, Tobin et al. 2013, Pape and O'Connor 2014). Also, limited surveys could be conducted at the end of each visitor season to determine whether new species have been introduced (Baker et al. 2015).

4.8.7. Sources of Expertise

Cami McKinney, National Park Service, TICA

4.8.8. Literature Cited

Baker, G.M., S.J. Taylor, S. Thomas, K. Lavoie, R. Olson, H. Barton, M. Denn, S.C. Thomas, R. Ohms. K. L. Helf, J. Despain, J. Kennedy, and D. Larson. 2015. Cave ecology inventory and monitoring framework. Natural Resource Report NPS/NRPC/NRR—2015/XXX. National Park Service, Fort Collins, Colorado.

Barr, T.C. and J.R. Holsinger. 1985. Speciation in cave faunas. Annual Review of Ecology and Systematics 1985:313–337.

Culver, D.C. 1970. Analysis of simple cave communities I. Caves as islands. Evolution: 463–474.

Culver, D.C., L.L. Master, M.C. Christman, and H.H. Hobbs. 2000. Obligate cave fauna of the 48 contiguous United States. Conservation Biology 14:386–401.

Cunningham, K. I., D. E. Northup, R. M. Pollastro, W. G. Wright, and E. J. LaRock. 1995. Bacteria, fungi and biokarst in Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico. Environmental Geology 25:2–8.

Howarth, F.G. 1983. Ecology of cave arthropods. Annual Review of Entomology 28:365–389.

Mammola, S., E. Piano, P.M. Giachino, and M. Isaia. 2015. Seasonal dynamics and micro-climatic preference of two Alpine endemic hypogean beetles. International Journal of Speleology 44:239–249.

Nelson, C.R., J. Guptill and R.W. Baumann. 2004. Macroinvertebrates of Timpanogos Cave, Timpanogos National Monument, Utah. Draft Final Field Report; Cooperative Agreement #CA1248-009 between NPS and Brigham Young University.

National Park Service (NPS). 2013. Timpanogos Cave National Monument, Draft Cave Management Plan Environmental Assessment.

Panek, J. and J. Despain. 2013. A natural resource condition assessment for Sequoia and Kings Canyon National Parks: Appendix 18 – cave invertebrates. Natural Resource Report NPS/SEKI/NRR—2013/665.18. National Park Service, Fort Collins, Colorado.

Pape, R.B., and B.M. O'Connor. 2014. Diversity and ecology of the macro-invertebrate fauna (Nemata and Arthropoda) of Kartchner Caverns, Cochise County, Arizona, United States of America. Check List 10:761–794.

Pate, D. 2013. Moving the National Park Service cave and karst program forward: Identifying and understanding park resources. In: Land, L. and M. Joop, eds. Proceedings of the 20th National Cave and Karst Management Symposium, November 4–8, 2013, Carlsbad, NM. National Cave and Karst Institute, Carlsbad, NM.

Schneider, K., M.C. Christman, and W.F. Fagan. 2011. The influence of resource subsidies on cave invertebrates: results from an ecosystem-level manipulation experiment. Ecology 92:765–776.

Smith, H., P.J. Wood, and J. Gunn. 2003. The influence of habitat structure and flow permanence on invertebrate communities in karst spring systems. Hydrobiologia 510:53–66.

Tobin, B.W., B.T. Hutchins, and B.F. Schwartz. 2013. Spatial and temporal changes in invertebrate assemblage structure from the entrance to deep-cave zone of a temperate marble cave. International Journal of Speleology 42:203–214.

Venarsky, M.P., J.P. Benstead, and A.D. Huryn. 2012. Effects of organic matter and season on leaf litter colonisation and breakdown in cave streams. Freshwater Biology 57:773–786.

Wynne, J. J. 2013. Inventory, conservation, and management of lava tube caves at El Malpais National Monument, New Mexico. Park Science 30(1):45–55. Available at http://www.nature.nps.gov/ParkScience/archive/PDF/Article_PDFs/ParkScience30(1)Summer2013_45-55_Wynne_3651.pdf.

4.9. Bat Community

4.9.1. Background

Bats are a diverse group of flying mammals found throughout the world, with approximately 47 species in North America (Adams 2003). Bats are extremely important insect predators and pollinators in ecosystems worldwide and the economic and ecologic value of maintaining healthy bat communities is substantial (Agosta 2002, Boyles et al. 2011, Kunz et al. 2011).

Common to all bat species is a nocturnal life history that includes the physiological adaptations of echolocation and flight, but other aspects of bat ecology vary across species. In particular species can differ greatly in their habitat requirements and social behaviors, for example in whether they are colonial or solitary, hibernate or migrate, or require the establishment of maternity colonies for reproduction (Adams 2003). Bats are adapted to specialized habitats for roosting, hibernating, and breeding that almost without exception must be dark, within certain temperature and humidity parameters, and relatively free of human disturbance (Adams 2003). Caves, rock crevices, buildings and abandoned mines (especially in the West) are all utilized, sometimes by more than one species concurrently (Ellison et al. 2003).

The status of bat populations throughout the world is of concern. Habitat loss, climate change, and especially White-nose syndrome have all been identified as significant threats to bat populations and bat species diversity (Kunz et al. 2011, Adams and Hayes 2008, Duchamp and Swihart 2008, Foley et al. 2011).

While few data exist on specific habitat use by bats in TICA, general descriptions of the habitat requirements for species found here suggest that all habitat types within the park, including the caves, are likely utilized. Of the bat species known to occur in the TICA area four are Utah species of concern: Townsend's big-eared bats (*Plecotus townsendii*; Section 4.10), spotted bats (*Euderma maculatum*), fringed myotis (*Myotis thysanodes*), and big free-tailed bats (*Nyctinomops macrotis*); none are federally protected (Table 4.9-1).

Table 4.9-1. Bat species identified from TICA. NOTE: Improved identification techniques suggest that some *Myotis* species may have been misidentified in surveys prior to 2015 (Armstrong 2015).

Species	**Common Name**	**2001–2002 TICA Survey**	**Habits (Adams 2003, Oliver et al. 2008 avg. mass/wingspan)**	**Range-wide status and conservation priority (Adams 2003, Ellison et al. 2003, Oliver et al. 2008)**
Antrozous pallidus #[1]	Pallid	Unconfirmed	roosts and hibernates in structures, caves, mines; forages in relatively open arid scrublands, PJ woodlands and riparian; 19 g/38 cm;	generally declining trend but minimal data; low to medium; range in UT unclear but no records from Wasatch; elevs 2,700–8,700 ft.; possible acoustic detection in 2015;
Corynorhinus townsendii[2] *#*[1]	Townsend's big-eared	Present	forages widely in mixed-con, semi-desert scrub, PJ, PP; roosts and establishes hibernacula in caves, mines and buildings; easily disturbed; 11 g/28 cm;	insufficient data to determine trends but this species is considered at-risk throughout its range; high; UT wildlife species of concern; detected rarely in acoustic surveys 2015;
Eptesicus fuscus[2]	Big brown	Present	wide-ranging in multiple habitats; forages in meadows, PP, grasslands; hibernates in mines and caves; 17 g/36 cm	very common, no detectable overall trends; low to medium concern outside of WNS.
Euderma maculatum #[1]	Spotted	Present	a desert specialist that forages in desert scrub and PJ, often in canyonlands; roosts in rock crevices, buildings, and caves; one of the more difficult species to survey for, often injured or killed in mist nets; 14 g/35 cm;	former C2 species, but may be more widespread than previously thought, no detectable trends; medium to high; rare in UT; UT wildlife species of concern; elevs 2,500–9,670 ft.; recorded often during the 2015 acoustic surveys;
Lasionycteris noctivagans[2] *M*[3]	Silver-haired	Present	forages near woodland ponds and streams; roosts in trees and snags; thought to be migratory with unknown winter range; 12 g/29 cm;	insufficient data to determine trends; low to medium; common in UT.

[1] **#** indicates hibernating species that may be affected by WNS in the future (from http://www.fort.usgs.gov/wns/; last updated 6/8/12)

[2] identified in the CMP as found in TICA

[3] ***M*** indicates migratory species (Adams 2003)

[4] ***S***pecies that have been affected by WNS outside UT (also in bold)

Table 4.9-1 (continued). Bat species identified from TICA. NOTE: Improved identification techniques suggest that some Myotis species may have been misidentified in surveys prior to 2015 (Armstrong 2015).

Species	Common Name	2001–2002 TICA Survey	Habits (Adams 2003, Oliver et al. 2008 avg. mass/wingspan)	Range-wide status and conservation priority (Adams 2003, Ellison et al. 2003, Oliver et al. 2008)
Lasiurus cinerus[2] *M*[3]	Hoary	Present	forages in many habitats including forests and riparian; roosts mostly in trees but also buildings and caves; likely migrates out of UT for the winter; 28 g/36 cm.	insufficient data to determine trends; medium; uncommon in UT; elevs 2,500–9,200 ft.
L. blossevillii	Desert/western red bat	–	–	Possible acoustic detection in 2015;
Myotis californicus[2,4] *#*[1]	California	Unconfirmed but likely present	forages in arid habitats, edges of mixed-conifer woodlands, desert scrub; roosts in multiple sites; 4 g/24 cm.	former C2 species, insufficient data to determine trends; low to medium; common in other parts of UT but no records from central mts. elevs 2,600–9,000 ft.
M. ciliolabrum[2] *#*[1]	Western small-footed	Present	forages in many habitats; roosts and hibernates primarily in mines and caves; 4 g/22 cm;	former C2 species, no trends detected; medium; uncommon in UT
M. evotis[2] *#*[1]	Western long-eared	Present	forages primarily in Doug-fir and spruce-fir forests; many roosting sites including structures, caves and mines; wintering habits in UT unknown;7 g/28 cm;	insufficient data to determine trends; low to medium; common in UT
M. lucifugus[2]	Little brown	Present	generalist forager, often around water; numerous roost types; widely distributed; not known if it hibernates in UT; 12 g/25 cm;	no detectable trends; medium; commonly recorded in 2015 acoustic surveys;

[1] **#** indicates hibernating species that may be affected by WNS in the future (from http://www.fort.usgs.gov/wns/; last updated 6/8/12)

[2] identified in the CMP as found in TICA

[3] ***M*** indicates migratory species (Adams 2003)

[4] ***S***pecies that have been affected by WNS outside UT (also in bold)

Table 4.9-1 (continued). Bat species identified from TICA. NOTE: Improved identification techniques suggest that some Myotis species may have been misidentified in surveys prior to 2015 (Armstrong 2015).

Species	Common Name	2001–2002 TICA Survey	Habits (Adams 2003, Oliver et al. 2008 avg. mass/wingspan)	Range-wide status and conservation priority (Adams 2003, Ellison et al. 2003, Oliver et al. 2008)
M. thysanodes #[1]	Fringed	Present in American Fork Canyon (AFC) but not confirmed in park;	multiple foraging habitats including woodlands and forests; roosts in caves, mine and buildings; wintering habits in UT unknown; 6 g/30 cm; habitat model does not predict preferred habitat in area of TICA;	former C2 species, no detectable trends at summer roosts but declines at hibernacula; UT wildlife species of concern; distribution in UT unclear, most records from southern and southeastern portion of the state; elevs 2,400–8,900 ft.; likely rare in the park;
M. volans[2] #[1]	Long-legged	Present in AFC but not confirmed in park;	forages in many forests and woodlands; roosts in caves, mines and buildings; wintering habits in UT unknown; 8 g/28 cm;	former C2 species, no detectable trends; low to medium; common in UT; elevs 3,150–10,000 ft.
M. yumanensis[2] #[1]	Yuma	Present (acoustic detection)	many foraging and roosting habitats including mines and buildings; wintering habits in UT unknown; 5 g/24 cm;	former C2 species, no detectable trends; low to medium; uncommon in UT.
Nyctinomops macrotis	Big free-tailed	Present (acoustic detection)	forages in rocky, open areas and forests; roosts in crevices, high rocky areas, buildings and trees; may be migratory and breeding locations generally unknown; TICA may be at the northern range limit; 28 g/44 cm; model does not predict TICA habitat;	former C2 species, insufficient data to determine trends; medium; UT wildlife species of concern; range in UT unclear.
Parastrellus Hesperus[2]	Canyon	Present in AFC but not confirmed in park;	–	–

[1] **#** indicates hibernating species that may be affected by WNS in the future (from http://www.fort.usgs.gov/wns/; last updated 6/8/12)

[2] identified in the CMP as found in TICA

[3] ***M*** indicates migratory species (Adams 2003)

[4] ***S***pecies that have been affected by WNS outside UT (also in bold)

Table 4.9-1 (continued). Bat species identified from TICA. NOTE: Improved identification techniques suggest that some Myotis species may have been misidentified in surveys prior to 2015 (Armstrong 2015).

Species	Common Name	2001–2002 TICA Survey	Habits (Adams 2003, Oliver et al. 2008 avg. mass/wingspan)	Range-wide status and conservation priority (Adams 2003, Ellison et al. 2003, Oliver et al. 2008)
Tadarida brasiliensis M[3]	Brazilian free-tailed	Present (acoustic detection)	multiple foraging and roosting sites; both winters in UT and migrates;13 g/33 cm;	no detectable trends; medium; common in UT but uncommon at high elevations; captured and identified during 2015 mistnet surveys, most common species detected during acoustic surveys in 2015;

[1] **#** indicates hibernating species that may be affected by WNS in the future (from http://www.fort.usgs.gov/wns/; last updated 6/8/12)

[2] identified in the CMP as found in TICA

[3] ***M*** indicates migratory species (Adams 2003)

[4] ***S***pecies that have been affected by WNS outside UT (also in bold)

Threats

White-nose Syndrome

White-nose syndrome (WNS) is a fungus-caused disease that affects hibernating bat colonies and is nearly 100% fatal to all individuals in affected colonies (Foley et al. 2011, USFWS 2011). WNS was first discovered in 2006 in New York State and has since spread across the Northeast and eastern Canada and as far west as Arkansas. The disease has not yet reached Utah, but the means of contamination and a cure are not yet identified and many researchers anticipate further spread in coming years (Knudsen et al. 2013, Vanderwolf et al. 2013, www.whitenosesyndrome.org; nature.nps.gov/biology/wns/index.cfm; accessed 3/23/20).

Global Climate Change

Multiple environmental disruptions attributable to climate change are altering bat behavior and survival (Sherwin et al. 2013). For example higher temperatures are affecting hibernation patterns requiring bats to utilize stored energy at greater rates (Humphries et al. 2002), fruit-eating bat species are becoming phenologically disconnected from their resources (Lučan et al. 2013), higher temperatures are disrupting echolocation processes (Luo et al. 2014), and changes in timing and levels of precipitation appear to be affecting reproductive success in some species (Adams and Hayes 2008).

Abandoned Mines

An additional conservation concern is the threat to bat populations of closing, or conversely, re-opening abandoned mines (Tuttle and Taylor 1998, Hayes et al. 2011). With the loss of forest and riparian habitats and increased human presence in caves, bats have frequently re-located their roosts, hibernacula and maternity colonies to abandoned but accessible mines (Hayes et al. 2011). The mineral-rich states of the western U.S. have tens of thousands of such sites; for example, it is estimated that there are 8,000–17,000 abandoned mine openings in Utah alone (http://blm.gov/ut/st/en/prog/more/Abandoned_Mine_Lands.html).

Because abandoned mines pose a substantial hazard to humans, for decades there have been efforts decades to close abandoned mines. However, physically closing a mine without attention to potential bat impacts can result not only in the loss of habitat but more seriously the entombing of entire bat colonies (Altenbach et al. 2000, www.batgating.com). At the same time new mineral extraction technologies are leading to the re-opening of previously abandoned mines. Such activities, again without coincident bat surveys, can permanently displace or destroy entire colonies (Hayes and Wiles 2013).

4.9.2. Reference Conditions

Given the diversity of terrain and vegetation, the presence of the caves, and the American Fork River (as insect habitat; Haymond et al. 2003, Scott et al. 2010), bat species diversity at TICA should be relatively high. If there are critical habitat areas for some species, such as hibernacula, the use of those sites should persist. (The existence of such sites is currently undocumented though specific surveys for them have not been conducted).

Diamond et al. (2009a) calculated occupancy estimates for 12 common bat species in various ecoregion strata across the U.S. For the Wasatch and Uinta montane forests they found the most common species to be big-brown bats, long-eared myotis, little brown bats, hoary bats, silver-haired bats, and long-legged myotis; all six species have been documented in TICA (Table 4.9-1, including binomial names). The presence of all six species at TICA would indicate good bat habitat, while the absence of any of the documented species for several years would suggest degraded habitat and a declining trend in bat diversity (Jones et al. 2009, Bader et al. 2015).

There is no indication of WNS for any species that hibernates in Utah, and bats should continue to use the TICA caves in patterns observed historically.

4.9.3. Data and Methods

In 2001 and 2002 mammal inventories were conducted by USGS (for NCPN) that included bat surveys (Haymond et al. 2003). Those efforts, which included both physical capture and acoustic detection, documented a cumulative inventory of 20 species (Table 4.9-1). No efforts were made to estimate populations sizes.

Extensive surveys have been conducted in Utah by the Department of Defense Legacy Program (DOD 2007, Diamond et al. 2009b, 2010). Though no sites have been surveyed in or directly adjacent to TICA, many of areas of similar habitat have been investigated.

TICA has been conducting annual summer bat surveys using mistnets along the American Fork River since approximately 2008 (NPS and McKinney 2009, NPS unpublished data). Acoustic monitoring of bats was added to the survey protocol in 2015; methods are described in Armstrong (2015). Roost loggers were also placed near several cave entrances beginning in 2015 (Armstrong 2015).

4.9.4. Resource Condition and Trend

It appears that bat species diversity is high at TICA and near what would be expected given available habitat and climate conditions. Between 2008–2015, 11 species represented by 507 individual bats were detected via mistnetting. In 2015 an average of 26 bats were caught on each of three nights, by far the highest number of individuals caught in mistnets during park surveys. (Improved techniques and observer experience likely contributed to the relatively higher success; Armstrong 2015).

Very little is known regarding habitat use by any species in the park and surrounding areas. Evidence suggests that the number of individual bats specifically utilizing the caves has declined (C. McKinney, pers. comm. 2015). Roost loggers deployed in 2015 indicated that bats use the caves though not in large numbers, and that bats were present in the caves primarily during late evening hours. Very little can be said regarding the status or trend of any bat species. WNS has not been detected.

4.9.5. Level of Confidence

Moderate for species diversity; Low for any other measure other than the absence of disease.

4.9.6. Data Gaps and Research Needs

The need for standardization of bat survey methods has been widely acknowledged (O'Shea et al. 2003, Stahlschmidt and Brühl 2012, Loeb et al. 2015), and TICA is currently following the protocols recommended by the Utah Department of Natural Resources to standardize bat surveys within Utah.

The TICA WNS Response Plan (NPS 2011) provides detailed protocols for monitoring for WNS, and these protocols should be continued.

Additional research on habitat use by bats in the park, and population information for rare species should be encouraged and supported if possible. Ongoing surveys should continue, and techniques modified as needed.

4.9.7. Sources of Expertise

Andy Armstrong, National Park Service, TICA

Cami McKinney, National Park Service, TICA

4.9.8. Literature Cited

Adams, R.A. 2003. Bats of the Rocky Mountain West. University Press of Colorado, Boulder, CO.

Adams, R.A. and M.A. Hayes. 2008. Water availability and successful lactation by bats as related to climate change in arid regions of western North America. J. Anim. Ecol. 77:1115–1121.

Agosta, S.J. 2002. Habitat use, diet and roost selection by the big brown bat (*Eptesicus fuscus*) in North America: a case for conserving an abundant species. Mammal Review 32:179–198.

Altenbach, J.S., R.E. Sherwin, and P.E. Brown. 2000. Pre-mine closure bat survey and inventory techniques. In: Bat Conservation and Mining: A Technical Interactive Forum. US Department of the Interior, Office of Surface Mining, Bat Conservation International, Coal Research Center, Southern Illinois University at Carbondale, St. Louis, MO, USA.

Armstrong, A. 2015. Timpanogos Cave National Monument Bat Study Report for 2015. Unpublished report, Timpanogos Cave NM, American Fork, UT.

Bader, E., K. Jung, E.K.V. Kalko, R.A. Page, R. Rodriguez, and T. Sattler. 2015. Mobility explains the response of aerial insectivorous bats to anthropogenic habitat change in the Neotropics. Biological Conservation 186:97–106.

Boyles, J.G., P.M. Cryan, G.F. McCracken and T.H. Kunz. 2011. Economic importance of bats in agriculture. Science 332: 41–42.

Department of Defense (DoD). 2007. Maps and GIS Information for Bat Occurrence Data on Department of Defense Land and in the State of Utah: Before and After Legacy Funded Efforts. #07-346

Diamond, J.M., T. Langley, R.N. Knight, L.B. Wilson, K. Asmus-Hersey and B. Sutter. 2009a. Species Specific Bat Habitat Models: Random Forest Analysis. Dept. of Defense Legacy Resource Management Program #09-346.

Diamond, J.M., R.N. Knight, L.B. Wilson, K. Asmus-Hersey, and B. Sutter. 2009b. Status of Utah Bats. U.S. Army Dugway Proving Grounds, UT.

Diamond, J.M., R.N. Knight, L.B. Wilson, K. Asmus Hersey, and B. Sutter. 2010. Year 1 Field Work Report: Utah Bat Monitoring Protocol. U.S. Army Dugway Proving Ground, Natural Resources Program, Dugway Proving Ground,UT.

Duchamp, J.E. and R.K. Swihart. 2008. Shifts in bat community structure related to evolved traits and features of human-altered landscapes. Landscape Ecol. 23:849–860.

Ellison, L.E., T.J. O'Shea, M.A. Bogan, A.L. Everette, and D.M. Schneider. 2003. Existing data on colonies of bats in the United States: summary and analysis of the U.S. Geological Survey's Bat Population Database. In: O'Shea, T.J., and M.A. Bogan (eds.). Monitoring trends in bat populations of the United States and territories: problems and prospects. USGS Information and Technology Report 2003-0003.

Foley, J., D. Clifford, K. Castle, P. Cryan and R.S. Ostfeld. 2011. Investigating and managing the rapid emergence of white-nose syndrome, a novel, fatal, infectious disease of hibernating bats. Cons. Bio. 25:223–231.

Hayes, M.A., R.A. Schorr, and K.W. Navo. 2011. Hibernacula selection by Townsend's big-Eared bat in southwestern Colorado. The Journal of Wildlife Management 75:137–143.

Hayes, G. and G. J. Wiles. 2013. Washington Bat Conservation Plan. Washington Department of Fish and Wildlife, Olympia, WA.

Haymond, S., M.A. Bogan and E.W. Valdez. 2003. 2001–2002 Mammalian Inventory Final Report for Selected Northern Colorado Plateau Network Parks. USGS – Ft. Collins Science Center, and Dept. of Biology, University of New Mexico, Albuquerque, NM. Submitted to NPS, NCPN, Moab UT.

Humphries, M.M., D.W. Thomas, and J.R. Speakman. 2002. Climate-mediated energetic constraints on the distribution of hibernating mammals. Nature 418:313–316.

Jones, G., D.S. Jacobs, T.H. Kunz, M.R. Willig, and P.A. Racey. 2009. Carpe noctem: the importance of bats as bioindicators. Endangered Species Research 8:93–115.

Knudsen, G.R., R.D. Dixon, and S.K. Amelon. 2013. Potential spread of White-Nose Syndrome of bats to the Northwest: epidemiological considerations. Northwest Science 87:292–306.

Kunz, T.H., E.B. de Torrez, D.Bauer, T.Lobova, and T.H. Fleming. 2011. Ecosystem services provided by bats. Annals of the New York Academy of Sciences 1223:1–38.

Loeb, S.C., T.J. Rodhouse, L.E. Ellison, C.L. Lausen, J.D. Reichard, K.M. Irvine, T.E. Ingersoll, J.T.H. Coleman, W.E. Thogmartin, J.R. Sauer, C.M. Francis, M.L. Bayless, T.R. Stanley, and D.H. Johnson. 2015. A plan for the North American Bat Monitoring Program (NABat). General Technical Report SRS-208. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 112 p.

Luo, J., K.Koselj, S. Zsebők, B.M. Siemers, and H.R. Goerlitz. 2014. Global warming alters sound transmission: differential impact on the prey detection ability of echolocating bats. Journal of the Royal Society Interface 11:20130961; http://dx.doi.org/10.1098/rsif.2013.0961.

Lučan, R. K., M. Weiser, and V. Hanák. 2013. Contrasting effects of climate change on the timing of reproduction and reproductive success of a temperate insectivorous bat. Journal of Zoology 290:151–159.

National Park Service (NPS) and McKinney, A. 2009. Bat Species Baseline: Timpanogos Cave National Monument. Timpanogos Cave National Monument, Utah.

NPS. 2011. Timpanogos Cave National Monument: White-nose Syndrome Response Plan. Timpanogos Cave National Monument, Utah.

Oliver, G.V., A. Kozlowski, K. Day and K.D. Bunnell. 2008. Utah Bat Conservation Plan. Utah Division of Wildlife Resources, Salt Lake City, UT.

O'Shea, T.J., M.A. Bogan and L.E. Ellison. 2003. Monitoring trends in bat populations of the United States and territories: status of the science and recommendations for the future. Wild. Soc. Bull. 31:16–29.

Scott, S.J., G. McLaren, G. Jones, and S. Harris. 2010. The impact of riparian habitat quality on the foraging and activity of pipistrelle bats (*Pipistrellus* spp.). Journal of Zoology 280:371–378.

Sherwin, H.A., W. I. Montgomery, and M.G. Lundy. 2013. The impact and implications of climate change for bats. Mammal Review 43:171–182.

Stahlschmidt, P. and C.A. Brühl. 2012. Bats as bioindicators–the need of a standardized method for acoustic bat activity surveys. Methods in Ecology and Evolution 3:503–508.

Tuttle, M. D. and D. A. R. Taylor. 1998. Bats and mines. Resource Publication Number 3, Bat Conservation International, Austin, Texas.

U.S. Fish and Wildlife Service (USFWS). 2011. A National Plan for Assisting States, Federal Agencies, and Tribes in Managing White-Nose Syndrome in Bats. Hadley, MA.

Vanderwolf, K.J., D. Malloch, D.F. McAlpine, and G.J. Forbes. 2013. A world review of fungi, yeasts, and slime molds in caves. International Journal of Speleology 42:9.

4.10. Townsends Big-eared Bats (*Corynorhinus townsendii*)

4.10.1. Background

Townsend's big-eared bats (*Corynorhinus townsendii*; 'Townsends'), are medium-sized (0.3–0.5 oz/10–12 g) bats found in portions of the eastern U.S. and western Canada and broadly across the western U.S. (Gruver and Keinath 2006). Several subspecies have been identified, including *C.t. townsendii* which occurs in western states. In Utah Townsends occur throughout the state in appropriate habitats below approx. 9,000 ft/2,700 m (dwrcdc.nr.utah.gov/rsgis2/search/Display.asp?FlNm=corytown).

Townsends have been listed as vulnerable to extinction by the World Conservation Union and are on the IUCN Red List of threatened species (www.redlist.org). Townsends are identified by the Utah Division of Wildlife Resources (UDWR) as a Utah Species of Concern (UDWR 2010) and by the Western Bat Working Group as of high conservation concern (WBWG). Though a recommendation to do so has been made, there is at present no comprehensive Utah state plan for Townsends conservation (UDWR 2010).

Ecology

The natural roosting habitat for Townsends is caves and rock cavities. With the loss and disturbance of many natural sites these bats now often utilize old buildings and abandoned mines (Sherwin et al. 2000, Fellers and Pierson 2002, Sherwin et al. 2003, Betts 2010), and UDWR suggests that their distribution in Utah is correlated with the availability of such sites (UDWR 2010). Like other insectivorous bats Townsends forage primarily near water sources (Fellers and Pierson 2002), and will travel great distances (up to 15 mi/25 km) from roosts to optimal feeding areas sites (Brown et al. 1994, Fellers and Pierson 2002, Wynne 2013).

A facet of life history that makes Townsends particularly vulnerable to extirpation is the establishment of maternity colonies where a few to several hundred pregnant females congregate at one site (Pierson and Rainey 1998, Pierson et al. 1999). The environmental requirements for maternity colonies are fairly specific, and include large, open spaces protected from predators with acceptable ranges of temperature and humidity (Ingersoll et al. 2010, Betts 2010). Once the young are born, nursing females will transfer the young to 'babysitter bats' (non-reproductive females and juvenile males) to hold and keep warm while the mother bats forage at night throughout the summer (P. Brown pers. comm. 2010). Maternity colonies are normally occupied from spring until early fall when all the bats leave for winter roost and hibernation locations. Townsends exhibit high site fidelity and in the absence of disturbance will utilize the same maternity colony for many years (Fellers and Pierson 2002).

Threats

The loss of critical roosting, hibernating, and maternity sites has caused the decline of Townsend's throughout the western U.S. and in Utah (Pierson et al. 1999, Gruver and Keinath 2006, UDWR 2010). As mentioned in Section 4.9, with the loss of historic habitat sites Townsends (and other bat species) now often occupy human structures, particularly abandoned mines. Because of safety issues, land managers prefer to have such sites closed permanently, a process that if conducted without sufficient attention to possible bat impacts can result in the direct mortality of bats as well as the loss of entire colonies (Pierson et al. 1999).

Disturbance at Townsends maternity colonies is a substantial threat and has been a primary contributor to population declines seen in this species (Gruver and Keinath 2006). If a maternity colony is disturbed before the young are volant (flying independently), the mother or babysitter bats often drop the young when they are disturbed because they cannot fly with the additional weight (P. Brown pers. comm. 2010). The young bats then fall to the ground, nearly always a fatal event. Because maternity colonies can support over 100 nursing females, disturbances at these sites can have devastating population consequences (Pierson et al. 1999). At least 13 maternity colonies have been lost in Utah (UDWR 2010), though none are known to have existed in the TICA area.

Townsends are a hibernating species and hibernacula include both sexes. Disturbance of hibernating roosts will arouse the bats from torpor requiring them to use scarce energy resources otherwise needed to survive the winter (Hayes et al. 2011). Such disturbance has been identified as a precursor to infection of colonies by the fungus (*Pseudogymnoascus destructans*) that causes WNS, though no Townsend's population have yet been identified as having WNS (whitenosesyndrome.org).

4.10.2. Reference Conditions

As far as is known there are no data regarding distribution, abundance, or habitat use patterns of Townsends in TICA or American Fork Canyon. For northern Utah, Sherwin et al. (2000) found Townsends in sagebrush–grass, juniper woodland, and mountain shrubland vegetation types. Townsends have been observed roosting in the TICA caves, though historic numbers are unknown (Pulham 2009). Townsends were observed during the 2001–2002 surveys in small numbers (Haymond et al. 2003), so the absence of Townsend's from TICA caves for several seasons would be a situation of concern.

4.10.3. Data and Methods

In 2001 and 2002 mammal inventories were conducted by USGS (for NCPN) that included bat surveys (Haymond et al. 2003). Those efforts documented a cumulative inventory of 20 species, both by capture and acoustic documentation (Table 4.9-1), though no efforts were made to estimate population sizes. Extensive surveys have been conducted in Utah by the Department of Defense Legacy Program (DOD 2007, Diamond 2010). Though no sites have been surveyed in or directly adjacent to TICA, many of areas of similar habitat have been investigated.

TICA has been conducting annual summer bat surveys using mistnets along the American Fork River since approximately 2008 (NPS 2009, NPS unpublished data). Acoustic monitoring of bats was added to the survey protocol in 2015; methods are described in Armstrong (2015). Roost loggers were also placed near several cave entrances beginning in 2015 (Armstrong 2015). As far as is known no targeted surveys for Townsends have been conducted in AFC or this portion of the Wasatch Range.

4.10.4. Resource Condition and Trend

Observations suggest that management activities may have reduced the number of Townsends that utilize the TICA caves (Pulham 2009). There are no indications that maternity colonies or significant hibernation roosts exist in the park though single hibernating individuals are often observed (C. McKinney, pers. comm. 2015). In 2015 Townsends were detected occasionally during acoustic surveys (Armstrong 2015). Data collected in 2015 from roost detectors indicated that Townsends are utilizing the caves, again in low numbers (Armstrong 2015). No information is available on trends for Townsends populations that include park lands as habitat.

4.10.5. Level of Confidence

Low

4.10.6. Data Gaps and Research Needs

Sherwin et al. (2003) suggested that the specific and seasonal habitat requirements of Townsend's be given particular attention when developing management protocols. However, the need to determine presence and abundance of species that are sensitive to disturbance, such as Townsends, must be weighed against the potential harm of investigation. That said, Weller et al. (2014) found that annual counts of Townsends did not reduce the number of observed bats over time.

4.10.7. Sources of Expertise

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Cami McKiney, National Park Service, TICA

4.10.8. Literature Cited

Armstrong, A. 2015. Timpanogos Cave National Monument Bat Study Report for 2015. Unpublished report, Timpanogos Cave NM, American Fork, UT.

Betts, B.J. 2010. Thermoregulatory mechanisms used in a maternity colony of Townsend's big-eared bats in Northeastern Oregon. Northwestern Naturalist 91:288–298.

Brown, P., PhD. Bat biologist, Brown-Berry Biological Consulting, Bishop, CA.

Brown, P.E., R.D. Berry, and C. Brown. 1994. Foraging behavior of Townsend's big-eared bats (*Plecotus townsendii*) on Santa Cruz Island. In: Fourth California Islands Symposium, Santa Barbara Museum of Natural History, Santa Barbara, CA.

Diamond, J.M., R.N. Knight, L.B. Wilson, K. Asmus Hersey, and B. Sutter. 2010. Year 1 Field Work Report: Utah Bat Monitoring Protocol. U.S. Army Dugway Proving Ground, Natural Resources Program, Dugway Proving Ground,UT.

Fellers, G.M., and E.D. Pierson. 2002. Habitat use and foraging behavior of Townsend's big-eared bat (*Corynorhinus townsendii*) in coastal California. Journal of Mammalogy 83:167–177.

Gruver, J.C. and D.A. Keinath. 2006. Townsend's Big-eared Bat (*Corynorhinus townsendii*): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/townsendsbigearedbat.pdf.

Hayes, M.A., R.A. Schorr, and K.W. Navo. 2011. Hibernacula selection by Townsend's big-Eared bat in southwestern Colorado. The Journal of Wildlife Management 75:137–143.

Haymond, S., M.A. Bogan and E.W. Valdez. 2003. 2001–2002 Mammalian Inventory Final Report for Selected Northern Colorado Plateau Network Parks. USGS – Ft. Collins Science Center, and Dept. of Biology, University of New Mexico, Albuquerque, NM. Submitted to NPS, NCPN, Moab UT.

Ingersoll, T.E., K.W. Navo, and P. de Valpine. 2010. Microclimate preferences during swarming and hibernation in the Townsend's big-eared bat, *Corynorhinus townsendii*. Journal of Mammalogy 91:1242–1250.

Pierson, E.D. and W.E. Rainey. 1998. Distribution, status, and management of Townsend's big-eared bat (*Corynorhinus townsendii*) in California. State of California, Resources Agency, Department of Fish and Game, Sacramento, CA.

Pierson, E.D., M.C. Wackenhut, J.S. Altenbach, P. Bradley, P. Call, D.L. Genter, C.E. Harris, B.L. Keller, B. Lengus, L. Lewis, B. Luce, K. W. Navo, J.M. Perkins, S. Smith, and L. Welch. 1999. Species conservation assessment and strategy for Townsend's big-eared bat (*Corynorhinus townsendii townsendii* and *Corynorhinus townsendii pallescens*). Idaho Department of Fish and Game, Boise, ID.

Pulham, C. 2009. Heart of the Mountain: The History of Timpanogos Cave National Monument. National Park Service, Washington, D.C.

Sherwin, R.E., D. Stricklan, and D.S. Rogers. 2000. Roosting affinities of Townsend's big-eared bat (*Corynorhinus townsendii*) in northern Utah. Journal of Mammalogy 81:939–947.

Sherwin, R.E., W.L. Gannon, and J. S. Altenbach. 2003. Managing complex systems simply: understanding inherent variation in the use of roosts by Townsend's big-eared bat. Wildlife Society Bulletin 31:62–72.

Utah Division of Wildlife Resources (UDWR). 2010. Utah Sensitive Species List with appendices. Available online, http://dwrcdc.nr.utah.gov/ucdc/ViewReports/SSLAppendices20101011.pdf.

Wynne, J. J. 2013. Inventory, conservation, and management of lava tube caves at El Malpais National Monument, New Mexico. Park Science 30(1):45–55. Available at http://www.nature.nps.gov/ParkScience/archive/PDF/Article_PDFs/ParkScience30(1)Summer2013_45-55_Wynne_3651.pdf.

Weller, T.J., S.C. Thomas, and J.A. Baldwin. 2014. Use of long-term opportunistic surveys to estimate trends in abundance of hibernating Townsend's big-eared bats.2014. Journal of Fish and Wildlife Management 5:59–69.

Western Bat Working Group (WBWG). Online: http://wbwg.org/western-bat-species/. Accessed March 9, 2020.

4.11. Small and Medium-sized Mammals

4.11.1. Background

For this assessment, the term ‘small and medium sized mammals’ referes to rodents, insectivores, rabbits and small carnivores. Large mammals are not addressed due to the relatively small amount of time they spend in the park, and bats were previously addressed in Section 4.9. Binomials for all mammal species mentioned below are included in Table 4.11-1.

Functioning at mostly mid-trophic levels, small and medium-sized mammals have extremely important functional roles in upland and riparian communities as both prey and consumers (Prevedello et al. 2013). A discussion of all small and medium-sized vertebrate species in TICA is beyond the scope of this report, however a general understanding of changing diversity and dynamics in these four groups will greatly aid in efforts to maintain functioning terrestrial ecosystems (Prevedello et al. 2013).

<u>Small Mammals</u>

The term ‘small mammals’ generally refers to insectivores and small rodents (e.g. mice, rats, and squirrels but not beavers or marmots). In North America native insectivores include only moles and shrews, species that consume invertebrates such as insects and earthworms but that can also utilize plant material such as nuts. Moles live almost exclusively underground while shrews, which are the smallest mammals, do not burrow but live under leaf litter and vegetation. No moles have been documented from TICA. While shrews are present it is difficult to trap them in standard small mammal traps and when they are caught often perish before release. Consequently, shrews are often underrepresented in standard mammal surveys (Innes and Bendell 1988, Haymond et al. 2003).

Rodents are a highly diverse group of mammals; one family (Muridae, old world rats and mice) includes over 700 species. This diversity reflects the ability of rodents to adapt to a wide range of environmental and ecological conditions (Feldhamer 2007). In many ecosystems, rodents are the largest group of primary consumers, and as seed eaters, Howe and Brown (2001) have suggested that, ‘…plant communities…reflect what small vertebrates fail to eat…’. In addition to their role as consumers, rodents are also important seed distributors (Chambers and MacMahon 1994, Levin et al. 2003). Many studies have demonstrated strong interactions between rodents and both prey and predator populations (Drost and Fellers 1991, Hulme 1998). Approximately 17 rodent species have been documented from TICA, with five or more additional species expected or possibly present (Table 4.11-1).

<u>Lagomorphs</u>

This group includes rabbits, hares, and pikas (in the western U.S.). Lagomorphs are strictly vegetarian and are also important prey for larger carnivores such as golden eagles (*Aguila chrysaetos*). Only two species—snowshoe hares and Nuttall’s cottontails—are known from TICA.

<u>Carnivores</u>

Carnivores include most mammals that consume live prey but can also include omnivores such as raccoons. Because of their high energy requirements, carnivores are generally the largest mammals in a system, are the most-wide ranging, and often have strong limiting effects on prey populations

(Carbone and Gittleman 2002, Korpimäki and Krebs 1996). Many species of mammalian carnivores likely travel through TICA; small and mid-size species are the most common with larger species such as bobcats and foxes being less common.

Threats

Numerous ecological and physical changes in ecosystems affect diversity and population viability of mammal species. Habitat loss to human development and climate change likely have the greatest impacts (Moritz et al. 2008), and the degree to which a particular species will respond to changing resource and environmental conditions depends on that organisms' ability to adapt (Inouye et al. 2000, Rowe et al. 2015). Recent studies have suggested that resource generalists will fare better in rapidly changing environments than resource specialists (Morelli et al. 2012, Rowe et al. 2011, Schloss et al. 2012, Kelt et al. 2013, Elmhagen et al. 2015).

Predicting which species will be most affected by impacts of climate change is beyond the scope of this assessment. Many studies suggest that changes in forest vegetation resulting from drought, increased fire frequency and insect outbreaks will affect numerous species (Hansen et al. 2001, Tierney et al. 2009, Morelli et al. 2012, Armitage 2013, Kelt et al. 2013). Rodents and insectivores can be particularly affected by wildfire (Clayton 2003, Zwolak 2009). Mammals with large home ranges are most affected by habitat fragmentation and loss of migration and dispersal routes (Saunders et al. 1991, Krauss et al. 2010, Webb et al. 2011). Conversely, species with greater dispersal abilities are more likely to survive habitat loss resulting from climate change (Schloss et al. 2012).

4.11.2. Reference Conditions

A decline in small and medium-sized mammal abundance, or fundamental changes in species diversity of these groups, will affect food webs and trophic interactions and could indicate large-sclae alterations to the system (e.g. the elimination of native predators; Rowe et al. 2011). Small mammal diversity naturally varies over time in response to resource availability, but measureable reductions in diversity would be cause for concern, as would be the extirpation of any native species (Moritz et al. 2008). The establishment of non-native mammals such as black rats or cats would indicate fundamental system alteration and would be cause for high concern.

4.11.3. Data and Methods

George (1999) excavated holocene packrat middens from the TICA caves that included the bones of many species collected by the packrats (wood rats). Haymond et al. (2003) conducted mammal surveys in 2001–2002 with methods described therein. TICA personnel have conducted periodic small mammal trapping (C. McKinney, pers. comm. 2015, Figures 4.11-1 and 4.11-2). These efforts provide presence information, i.e. whether a species utilizes park resources during any period of its life cycle; surveys do not provide population information, nor can they reasonably confirm the absence of a species (Fielding and Bell 1997).

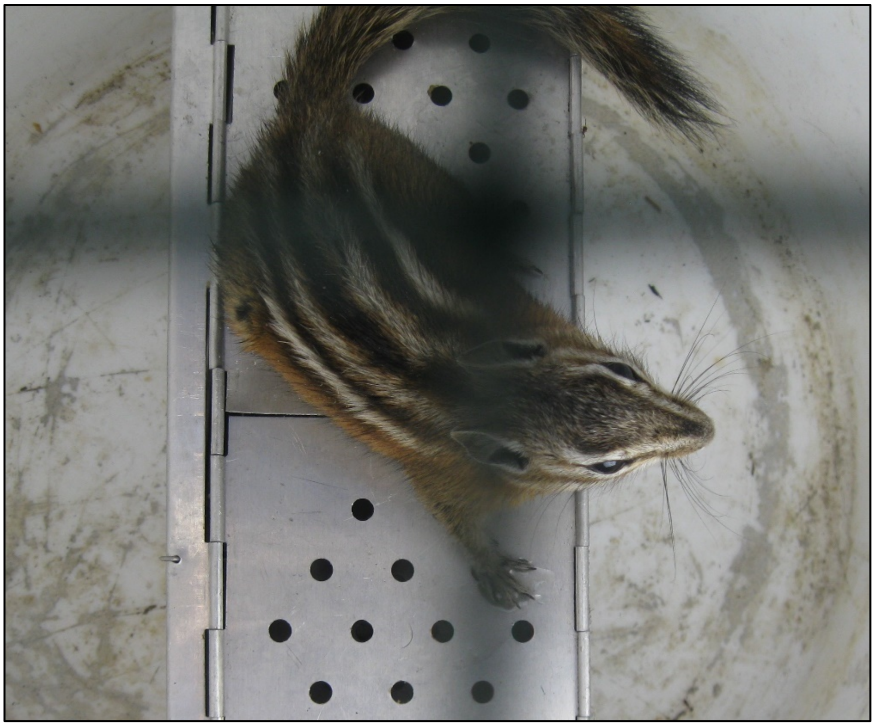


Figure 4.11-1. Unidentified species of chipmunk (*Neotamias* sp.) trapped during small mammal surveys at TICA, August 2010. Photo by C. Schwemm.

Figure 4.11-2. Technique employed for small mammal surveys, TICA, August 2010. Photo by C. Schwemm.

4.11.4. Resource Condition and Trend

Approximately 30–40 small and medium-sized mammals are documented from TICA (Table 4.11-1), reflecting a high diversity of vegetation types and functional niches. Table 4.11-1 identifies species that are known from TICA as well as those species that would be expected given habitat availability but have not been documented. As far as is known none of the small or medium-sized mammal species that George (1999) found in the packrat middens have been extirprated. Nothing is currently known regarding true species diversity, population sizes or trends for small and medium-sized mammals at TICA. The presence of non-native mammals has not been documented.

Table 4.11-1. Terrestrial mammals documented or potentially present in TICA.

Category	Species	2001–2002 surveys	2010 surveys	NPSpecies	Comments
Insectivores	Montane shrew *(Sorex monticolus)*	Present (from park collection)	–	x	Six other shrew species are listed as 'probably present', five others are identified as such in NPSpecies; vagrant shrew (*S. vagrans*) reported by George (1999) and trapped in 2012 (NPS data). Shrews are usually common in most systems but are difficult to survey and monitor, are likely under-sampled at TICA (Haymond et al. 2003), and are a group identified as potentially less likely to adapt to climate shifts than other mammals (Schloss et al. 2012);
Rodents	Yellow-bellied marmot (*Marmota flaviventris*)	present	–	x	George (1999); in rocky talus and open slopes; phonological changes due to climate change may be altering marmot behavior in the western US (Inouye et al. 2000), and may lead to local extirpations (Armitage 2013);
	Beaver (*Castor canadensis*)	present	–	x	George (1999); riparian, rare in the park?
	Rock squirrel (*Spermophilus variegatus*)	present	observed	x	George (1999)
	Red squirrel (*Tamiasciurus hudsonicus*)	present	–	x	George (1999)
	Golden-mantled ground squirrel (*Callospermophilus lateralis*)	present	observed	x	George (1999)
	Northern flying squirrel (*Glaucomys sabrinus*)	present	observed-dead	x	George (1999)

Table 4.11-1 (continued). Terrestrial mammals documented or potentially present in TICA.

Category	Species	2001–2002 surveys	2010 surveys	NPSpecies	Comments
Rodents (continued)	Uinta chipmunk (*Neotamias umbrinus*)	present	trapped	x	–
	Cliff chipmunk (*N. dorsalis*)	present	observed	x	George (1999)
	Least chipmunk (*N. minimus*)	present	–	x	–
	Western harvest mouse (*Reithrodontomys megalotis*)	present	trapped	x	–
	Western jumping mouse (*Zapus princeps*)	present	–	x	–
	Bushy-tailed woodrat (*Neotoma cinerea*)	present	trapped	x	George (1999)
	Deer mouse (*P. maniculatus*)	present	trapped	x	This was the most common species caught in the 2001–2002 trapping efforts;
	Brush mouse (*P. boylii*)	present	–	x	–
	Canyon mouse (*P. crinitus*)	present	trapped	–	–
	Long-tailed vole (*Microtus longicaudus*)	present	–	x	George (1999) though voles identified to genus only;
	Montane vole (*Mynomes montanus*)	present	–	x	–
	Meadow vole (*M. pennsulvanicus*)	present	–	x	–
	North American porcupine (*Erethizon dorsatum*)	probably present	–	*	George (1999); rare in the park
	Northern pocket gopher (*Thomomys talpoides*)	probably present	observed but not verified	*	–
	Pinon mouse (*Peromyscus truei*)	unconfirmed	–	–	–
	Muskrat (*Ondatra zibethicus*)	unconfirmed	–	–	George (1999); riparian, rare in the park?
	Southern red-backed vole (*Myodes gapperi*)	unconfirmed	–	–	–

* Documented occurrences of the species in the park or in the adjoining region of the park give reason to suspect that it probably occurs within the park; however, current, verifiable evidence is needed.

Table 4.11-1 (continued). Terrestrial mammals documented or potentially present in TICA.

Category	Species	2001–2002 surveys	2010 surveys	NPSpecies	Comments
Rodents (continued)	Great basin pocket mouse (*Perognathus parvus*)	unconfirmed	–	–	–
	House mouse (*Mus musculus*)	unconfirmed	–	–	–
Lagomorphs	Snowshoe hare (*L. americanus*)	present	–	x	George (1999)
	Nuttall's (mountain) cottontail (*Sylvilagus nuttallii*)	present	–	x	George (1999)
	White-tailed jackrabbit (*Lepus townsendii*)	probably present	–	*	George (1999)
	Black-tailed jackrabbit (*L. californicus*)	unconfirmed	–	–	–
	Pygmy rabbit (*Brachylagus idahoensis*)	unconfirmed	–	–	–
	American pika (*Ochotona princeps*)	unconfirmed	–	–	George (1999)
Chiropterans (covered in section 4.11)	–	–	–	–	–
Carnivores	Western spotted skunk (*Spilogale gracilis*)	present	–	x	George (1999)
	Striped skunk (*Mephitis mephitis)*	present	camera trap	x	George (1999)
	Ringtail (*Bassariscus astutus*)	present	observed	x	George (1999)
	Northern raccoon (*Procyon lotor*)	present	track	x	George (1999)
	Coyote (*Canis latrans*)	present	–	x	George (1999)
	Red fox (*Vulpes vulpes*)	present	track	x	George (1999)
	Long-tailed weasel (*Mustela frenata*)	present	observed	x	George (1999)
	American mink (*Neovison vison*)	present	observed just outside park boundary	x	George (1999)

* Documented occurrences of the species in the park or in the adjoining region of the park give reason to suspect that it probably occurs within the park; however, current, verifiable evidence is needed.

Table 4.11-1 (continued). Terrestrial mammals documented or potentially present in TICA.

Category	Species	2001–2002 surveys	2010 surveys	NPSpecies	Comments
Carnivores (continued)	Gray fox (*Urocyon cinereoargenteus*)	probably present	–	*	George (1999)
	Short-tailed weasel/mink (*Mustela erminea*)	probably present	–	*	George (1999)
	American badger (*Taxidea taxus*)	unconfirmed	–	–	George (1999)
	American marten (*Martes americana*)	unconfirmed	–	–	George (1999)
	Bobcat (*Lynx rufus*)	–	–	x	George (1999)

* Documented occurrences of the species in the park or in the adjoining region of the park give reason to suspect that it probably occurs within the park; however, current, verifiable evidence is needed.

4.11.5. Level of Confidence

Low to Moderate

4.11.6. Data Gaps and Research Needs

Because they are time-consuming and expensive, surveys and monitoring programs for mammals are less common than those for other groups such as landbirds or invertebrates. Consequently, the diversity and abundance of small and medium-sized mammals, and most importantly trends in these measures, are undocumented in most ecosystems (Burton et al. 2015). Incorporating mammal monitoring programs is challenging, and surveys for information other than presence is commonly lacking, though such programs can provide valuable information regarding ecosystem condition and change.

Haymond et al. (2003) reported 74% documentation for mammal species at TICA, though information for rodents and carnivores was higher (than when insectivores were included). Remote sensing methods like camera trapping are less expensive and less invasive, and can yield important information in the absence of in-hand methods (Silveira et al. 2003, Burton et al. 2015), even for small species (De Bondi et al. 2010).

4.11.7. Sources of Expertise

Andy Armstrong, National Park Service, TICA

Cami McKiney, National Park Service, TICA

4.11.8. Literature Cited

Armitage, K.B. 2013. Climate change and the conservation of marmots. Natural Science 5:36–43.

Burton, A.C., E. Neilson, D. Moreira, A. Ladle, R. Steenweg, J.T. Fisher, E. Bayne, and S. Boutin. 2015. Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. Journal of Applied Ecology 52:675–685.

Carbone, C. and J.L. Gittleman. 2002. A common rule for the scaling of carnivore density. Science 295:2273–2276.

Chambers, J.C., and J.A. MacMahon. 1994. A day in the life of a seed: movements and fates of seeds and their implications for natural and managed systems. Annual Review of Ecology and Systematics 25:263–292.

Clayton, J. C. 2003. Effects of clearcutting and wildfire on shrews (Soricidae: *Sorex*) in a Utah coniferous forest. Western North American Naturalist 63:264–267.

De Bondi, N., J.G. White, M. Stevens, and R. Cooke. 2010. A comparison of the effectiveness of camera trapping and live trapping for sampling terrestrial small-mammal communities. Wildlife Research:456–465.

Drost, C.A. and G.M. Fellers. 1991. Density cycles in an island population of deer mice, *Peromyscus maniculatus*. Oikos 60: 351–364.

Elmhagen, B., J. Kindberg, P. Hellström, and A. Angerbjörn. 2015. A boreal invasion in response to climate change? Range shifts and community effects in the borderland between forest and tundra. Ambio 44:39–50.

Feldhamer, G.A. 2007. Mammalogy: Adaptation, Diversity, Ecology. Johns Hopkins University Press, Baltimore MD.

Fielding, A.H., and J.F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24:38–49.

George, C. O. 1999. A systematic study and taphonomic analysis of the mammal remains from the packrat middens of Timpanogos Cave National Monument, Utah. Pp 109–117 in: Santucci, V.L. and L. McClelland, eds. National Park Service Paleontological Research, Vol. 4. Geological Resources Division Technical Report, NPS/NRGRD/GRDTR-99/03.

Hansen, A.J., R.P. Neilson, V.H. Dale, C.H. Flather, L.R. Iverson, D.J. Currie, S. Shafer, R. Cook, and P.J. Bartlein. 2001. Global change in forests: responses of species, communities, and biomes interactions between climate change and land use are projected to cause large shifts in biodiversity. BioScience 51:765–779.

Haymond, S., M.A. Bogan and E.W. Valdez. 2003. 2001–2002 Mammalian Inventory Final Report for Selected Northern Colorado Plateau Network Parks, U.S. Geological Survey, Fort Collins Science Center, Ft. Collins, CO, and Arid Lands Field Station, Department of Biology, University of New Mexico, Albuquerque, NM.

Howe, H.F. and J.S. Brown. 2001. The ghost of granivory past. Ecol. Lett. 4:371–378.

Hulme, P.E. 1998. Post-dispersal seed predation: consequences for plant demography and evolution. Perspectives in Plant Ecology, Evolution and Systematics 1:32–46.

Innes, D.G.L. and J.F. Bendell. 1988. Sampling of small mammals by different types of traps in northern Ontario, Canada. Acta Theriologica 33:443–450.

Inouye, D.W., B. Barr, K.B. Armitage, and B.D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences 97:1630–1633.

Kelt, D.A., D.H. VanVuren, M.L. Johnson, J.A. Wilson, R.J. Innes, B.R. Jesmer, K.P. Ingram, J. Smith, S.W. Bigelow, R.D. Burnett and P.A. Stine. 2013. Small mammals exhibit limited spatiotemporal structure in Sierra Nevada forests. Journal of Mammalogy 94:1197–1213.

Korpimäki, E. and C.J. Krebs. 1996. Predation and population cycles of small mammals. BioScience 1996:754–764.

Krauss, J., R. Bommarco, M. Guardiola, R.K. Heikkinen, A.Helm, M.Kuussaari, R.Lindborg, E. Ockinger, M. Partel, J. Pino, J. Poyry, K.M. Raatikainen, A. Sang, C. Stefanescu, T. Teder, M.

Zobel and I. Steffen-Dewenter. 2010. Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. Ecology Letters 13:597–605.

Levin, S.A., H.C. Muller-Landau, R. Nathan, and J. Chave. 2003. The ecology and evolution of seed dispersal: a theoretical perspective. Annual Review of Ecology, Evolution, and Systematics 34:575–604.

Morelli, T.L., A.B. Smith, C.R. Kastely, I. Mastroserio, C. Moritz, and S.R. Beissinger. 2012. Anthropogenic refugia ameliorate the severe climate-related decline of a montane mammal along its trailing edge. Proceedings of the Royal Society B: Biological Sciences (2012): rspb20121301.

Moritz, C., J.L. Patton, C.J. Conroy, J.L. Parra, G.C. White, and S.R. Beissinger. 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science 322:261–264.

Prevedello, J.A., C.R. Dickman, M.V. Vieira, and E.M. Vieira. 2013. Population responses of small mammals to food supply and predators: a global meta-analysis. Journal of Animal Ecology 82:927–936.

Rowe, R.J., R.C. Terry, and E.A. Rickart. 2011. Environmental change and declining resource availability for small-mammal communities in the Great Basin. Ecology 92:1366–1375.

Rowe, K.C., K.M.C. Rowe, M.W. Tingley, M.S. Koo, J.L. Patton, C.J. Conroy, J.D. Perrine, S.R. Beissinger, and C. Moritz. 2015. Spatially heterogeneous impact of climate change on small mammals of montane California. Proceedings of the Royal Society of London B: Biological Sciences 282:20141857.

Saunders, D. A., R.J. Hobbs, and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Cons. Bio. 5:18–32.

Schloss, C.A., T.A. Nuñez, and J.J. Lawler. 2012. Dispersal will limit ability of mammals to track climate change in the Western Hemisphere. Proceedings of the National Academy of Sciences 109:8606–8611.

Silveira, L., A.T. Jacomo, and J.A.F. Diniz-Filho. 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114:351–355.

Tierney, G.L., D. Faber-Langendoen, B.R. Mitchell, W.G. Shriver, and J.P. Gibbs. 2009. Monitoring and evaluating the ecological integrity of forest ecosystems. Frontiers in Ecology and the Environment 7:308–316.

Webb, S.L., M. R. Dzialak, S. M. Harju, L. D. Hayden-Wing, and J. B. Winstead. 2011. Influence of land development on home range use. J. Wildlife Research 38:163–167.

Zwolak, R. 2009. A meta-analysis of the effects of wildfire, clearcutting, and partial harvest on the abundance of North American small mammals. Forest Ecology and Management 258:539–545.

4.12. Upland Vegetation Communities

4.12.1. Background

TICA is located in the Wasatch and Uinta Montane Forests ecoregion, an area dominated by mixed coniferous forests with smaller areas of mountain grasslands, gambel oak and riparian forests (Woods et al. 2001). A brief summary of vegetation types in TICA is presented below and summarized in Table 4.12-1; common and scientific names for dominant plants in TICA are provided in Table 4.12-2. Detailed descriptions of vegetation and species lists are provided in Coles et al. (2009), and riparian vegetation is discussed separately in Section 4.4.

Upland forests comprise the majority of vegetated areas of the park (180 ac/73 ha; Coles et al. 2009). Higher elevation locations in and around TICA are largely dominated by coniferous species such as Douglas and white fir with deciduous species of aspen, bigtooth maple and box elder. At lower elevations coniferous trees are less common and Gambel oak, sagebrush, and shrub species become dominant (Woods et al. 2001, Coles et al. 2009). Gambel oak occurs primarily between 4,500–7,000 ft (1,500–2,330 m), and oak-dominated communities comprise approximately 23 ac (9 ha) within the park, almost solely on the south-facing slopes on the north side of AFC (Coles et al. 2009). Meadows and native grasslands account for less than one acre of vegetation in the southern and high elevation area of the park (Coles et al. 2009). Meadow sites support native grass and other herbaceous species, but also include the greatest relative abundance of exotic species (Coles et al. 2009).

Threats

The greatest threats to forest ecosystems in the arid west are drought, fire, and insect infestations, all of which are being intensified by climate change (Dale et al. 2001). Though all three of these processes are natural disturbances in forest ecosystems, they are having more substantial and often long-lasting impacts as temperatures increase (Allen et al. 2010, Martinez-Vilalta et al. 2012, Vose et al. 2012, Dodson and Root 2015). Forest pests such as fir engraver beetles (*Scolytus ventralis*) are a significant threat to fir forests in Utah, an example of a natural pest that has greater negative impacts on drought-stressed trees (Bentz et al. 2010, White 2014). Extreme wildfires that can cause soil sterilization and lead to stand conversion are likewise becoming a greater threat in forests impacted by climate change, drought and disease (Dennison et al. 2014, Jenkins et al. 2014, Enright et al. 2015). Higher elevation species may also be displaced by lower ranging species as temperatures increase, a process that will change alpine communities in ways that are difficult to predict (Vose et al. 2012, Hulme and Barrett 2013, Kopp and Cleland 2014).

For many flowering species, phenological changes driven by climate change are detaching pollination processes from host plants thereby reducing fertilization and productivity (Inouye 2008, Anderson et al. 2012, Caradonna et al. 2014, Rykken et al. 2014). Though not true in all cases, invasive plant species are often a threat to native vegetation communities (Richardson et al. 2000, Pyšek et al. 2012). In TICA invasive plant species appear to be more common and potentially threatening in meadows and grasslands than in forest communities (Witwicki 2013; Table 4.12-3) and may have increasing impacts as climates continue to change (Dodson and Root 2015).

Table 4.12-1. Plant associations and common species at TICA (Coles et al. 2009; no association was assigned to the meadow).

Association	Designation (s)	Dominant Species	Approx. Area ac (ha)
Southern Rocky Mountain Mesic and Dry-Mesic Montane Mixed Conifer Forest and Woodlands	CES 306.823; 306.825;	white fir/ bigtooth maple/ mallow-leaf ninebark/ douglas fir/ rocky mountain maple/ gambel oak/ mixed grasses	~138 (56)
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	306.819	Douglas fir/ limber pine	~41 (17)
Rocky Mountain Lower Montane-Riparian Woodland and Shrubland; Bigtooth Maple Ravine Woodland	306.821; 306.814	bigtooth maple/ chokecherry/ gambel oak/ box-elder	~17 (7)
Rocky Mountain Gambel Oak-Mixed Montane Shrubland	306.818	gambel oak/ mountain snowberry	~23 (9)
Inter-Mountain Basins Cliff and Canyon	304.779	mountain mahogany	~8 (3)

Table 4.12-2. Species names for dominant TICA plant species.

Common Name	Scientific Name
White fir	*Abies concolor*
Douglas fir	*Pseudotsuga menziesii*
Limber pine	*Pinus flexilis*
Bigtooth maple	*Acer grandidentatum*
Rocky Mountain maple	*A. glabrum*
Boxelder maple	*A. negundo*
Mallow-leaf ninebark	*Physocarpus malvaceus*
Gambel oak	*Quercus gambelii*
Chokecherry	*Prunus virginiana*
Mountain snowberry	*Symphoricarpos oreophilus*
Mountain mahogany	*Cercocarpus ledifolius*

Table 4.12-3. Primary non-native plant species known from TICA.

Species	Common Name	Ecological Traits[1]	Locations	Comments
Arctium minus	Lesser burdock	Barbed seeds and flowers attach to animals, facilitating wide dispersal; grows well in disturbed soils;	In disturbed areas and along road[1]	–
Capsella bursa-pastoris	Shepherd's purse	Copious seed producer; seeds are sticky when wet and highly persistent; grows well in disturbed and xeric soils;	Lower cave trail[2]	initiate control in 2012[2]
Cardaria draba	Hoary cress/ whitetop	Highly competitive, spreading root system with aerial shoots;	–	large patch in maintenance area in front of dumpsters; initiate control in 2012[2]
Centuarea maculosa	Spotted knapweed	Persistent rosette life stage forms from deep taproot;	On road sites[2]	significant ecological threat[3]
Cirsium arvense and *C. vulgare*	Canada and bull thistle	Highly adapted to disturbed sites; very successful asexual production; unpalatable to herbivores;	Generally in disturbed areas only[4]	good control[2]/Canada thistle (sp.) significant in the park[4]
Convolvulus arvensis	Bindweed	Extensive and competitive root system; long-term seed viability, viney species that can grow on natives[2]	–	annually abundant in the meadow and difficult to control[2]/significant in the park and difficult to control, though does not appear to be out-competing most native plants[4]
Cynoglossum officinale	Houndstongue	Drought tolerant and adapted to multiple soil conditions;	–	reduced, except for a few sites, good control[2]
Leonurus cardiac, Nepeta cataria	Motherwort and Catnip	(*L. cardiac* not listed at extension.usu.edu); dense, fibrous root systems;	Along roadsides, lower cave trail[2]	often found growing together, initiate control in 2012[2]

[1] extension.usu.edu

[2] Armstrong 2012

[3] Coles et al. 2009

[4] Whiteside 2011

[5] www.na.fs.fed.us/fhp/invasive_plants;

Table 4.12-3 (continued). Primary non-native plant species known from TICA.

Species	Common Name	Ecological Traits[1]	Locations	Comments
Lepidium latifolium	Pepperweed/ tall whitetop	Spreading root systems;	Adapted to wet areas, can become dominant competitor in riparian systems	significant ecological threat[3]
Linaria dalmatica	Dalmation toadflax	Colonial, adapted to disturbed soils;[5]	–	consistent but small patches, some difficult to access[2]/significant in the park[4]/significant ecological threat[3]
Melilotus officinalis	Yellow sweetclover	(not listed at extension.usu.edu); adapted to disturbance, particularly fire;[5]	–	significant in the park[4]
Ranunculus testiculatus	Burr buttercup	Small, but widespread and matting; toxic to some wildlife;	Lower cave trail[2]	initiate control in 2012[2]
Tragopogon dubius	Goatsbeard	Tall, adapted to wind seed dispersal; tolerant of disturbed soils;	–	common but generally not invasive; occasional in TICA[2]
Verbascum thapsus	Common mullein	Large, taller than many sympatric species; disturbance follower;	–	common but generally not invasive; annually common at several sites in TICA and difficult to control[2]/significant in the park[4]

[1] extension.usu.edu

[2] Armstrong 2012

[3] Coles et al. 2009

[4] Whiteside 2011

[5] www.na.fs.fed.us/fhp/invasive_plants;

4.12.2. Reference Conditions

For all plant communities, the reference conditions would include proper function, in particular regeneration and successional processes reflective of resilient communities, and the absence of invasive species and disease. In all communities, reproduction of dominant species should be ongoing with periodic recruitment dependent on species life history (Millar and Stephenson 2015). These measures are difficult to ascertain and vary spatially even within similar community types (Jiang et al. 2013). Given the relatively small size of the vegetated areas at TICA, forests with obvious disease or drought-killed individuals would be of great concern.

4.12.3. Data and Methods

Because of the steep terrain of the park, NCPN has established only three sampling plots, one each in subalpine meadow, mixed conifer forest, and Gambel oak, a sampling scheme that has no iterative power (Witwicki 2013). As far as is known there are no other monitoring or research efforts involving vegetation community ecology occurring in TICA.

4.12.4. Resource Condition and Trend

Vegetation monitoring in TICA began only recently, so data are insufficient for trend analyses. Moreover, there is only one sampling plot in each vegetation type so no inferences can be made regarding park-wide vegetation condition. There are many exotic species in the park, but TICA has a strong exotic plant management program and the highly invasive species are generally kept controlled (NPS 2005, Whiteside 2011, Armstrong 2012). In the absence of obvious loss of woody species to drought or disease, very little can be said regarding the current condition of TICA any vegetation community.

4.12.5. Level of Confidence

Moderate

4.12.6. Data Gaps and Research Needs

Vegetation monitoring should continue.

4.12.7. Sources of Expertise

Cami McKinney, National Park Service, TICA

4.12.8. Literature Cited

Allen, C.D., A.K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kizberger, more, 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For. Ecol. Manage. 259:660–684.

Anderson, J.T., D.W. Inouye, A.M. McKinney, R.I. Colautti, and T. Mitchell-Olds. 2012. Phenotypic plasticity and adaptive evolution contribute to advancing flowering phenology in response to climate change. Proceedings of the Royal Society: Biological Sciences 279:3843–3852.

Armstrong, B. 2012. Weed Report, TICA. Unpublished Report at park HQ.

Bentz, B.J., J. Régnière, C.J. Fettig, E. M. Hansen, J.L. Hayes, J.A. Hicke, R.G. Kelsey, J.F. Negrón, and S.J. Seybold. 2010. Climate change and bark beetles of the western United States and Canada: direct and indirect effects. BioScience 60:602–613.

Caradonna, P.J., A.M. Iler, and D.W. Inouye. 2014. Shifts in flowering phenology reshape a subalpine plant community. PNAS, DOI: 10.1073/pnas.1323073111.

Coles, J., J. Von Loh, A. Wight, K. Schulz, and A. Evenden. 2009. Vegetation classification and mapping project report, Timpanogos Cave National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2009/210. National Park Service, Fort Collins, Colorado.

Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks and B.M. Wotton. 2001. Climate change and forest disturbances: climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. BioScience 51:723–734.

Dennison, P.E., S.C. Brewer, J.D. Arnold, and M.A. Moritz. 2014. Large wildfire trends in the western United States, 1984–2011. Geophysical Research Letters 41:2928–2933.

Dodson, E.K. and H.T. Root. 2015. Native and exotic plant cover vary inversely along a climate gradient 11 years following stand-replacing wildfire in a dry coniferous forest, Oregon, USA. Global Change Biology 21:666–675.

Enright, N.J., J.B. Fontaine, D.M.J.S. Bowman, R.A. Bradstock, and R.J. Williams. 2015. Interval squeeze: altered fire regimes and demographic responses interact to threaten woody species persistence as climate changes. Frontiers in Ecology and the Environment 13:265–272.

Hulme, P.E. and S.C.H. Barrett. 2013. Integrating trait-and niche-based approaches to assess contemporary evolution in alien plant species. Journal of Ecology 101:68–77.

Inouye, D.W. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology 89:353–362.

Jenkins, M.J., J.B. Runyon, C.J. Fettig, W.G. Page, and B.J. Bentz. 2014. Interactions among the mountain pine beetle, fires, and fuels. Forest Science 60:489–501.

Jiang, X., S.A. Rauscher, T.D. Ringler, D.M. Lawrence, A.P. Williams, C.D. Allen, A.L. Steiner, D.M. Cai, and N.G. McDowell. 2013. Projected future changes in vegetation in western North America in the twenty-first century. Journal of Climate 26:3671–3687.

Kopp, C.W. and E.E. Cleland. 2014. Shifts in plant species elevational range limits and abundances observed over nearly five decades in a western North America mountain range. Journal of Vegetation Science 25:135–146.

Martinez-Vilalta, J., F. Lloret and D.D. Breshears. 2012. Drought-induced forest decline: Causes, scope and implications. Biol.Lett. 8:689–691.

Millar, C.I. and N.L. Stephenson. 2015. Temperate forest health in an era of emerging megadisturbance. Science 349:823–826.

National Park Service (NPS). 2005. Invasive Plant Management Plan, Timpanogos Cave National Monument. Unpublished Report, available at TICA Headquarters, American Fork, UT.

Pyšek, P., V. Jarošík, P.E. Hulme, J. Pergl, M. Hejda, U. Schaffner, and M. Vilà. 2012. A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. Global Change Biology 18:1725–1737.

Richardson, D.M., P. Pyšek, M. Rejmánek, M. G. Barbour, F. D. Panetta and C. J. West. 2000. Naturalization and invasion of alien plants: concepts and definitions. Diversity and Distributions 6:93–107.

Rykken, J., A. Rodman, S. Droege and R. Grundel. 2014. Pollinators in peril? A multipark approach to evaluating bee communities in habitats vulnerable to effects from climate change. ParkScience 31:84–90.

Vose, J.M., D.L. Peterson, T. Patel-Weynand, eds. 2012. Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector. Gen. Tech. Rep. PNW-GTR-870. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

White, T.C.R. 2014. Are outbreaks of cambium-feeding beetles generated by nutritionally enhanced phloem of drought-stressed trees? Journal of Applied Entomology 139: 567–578.

Whiteside, R. 2011. Invasive Species Report. Unpublished Report at park HQ.

Witwicki, D. 2013. Integrated upland monitoring in Timpanogos Cave National Monument: annual report 2011 (non-sensitive version). Natural Resource Technical Report NPS/NCPN/ NRTR—2013/714.N. National Park Service, Fort Collins, Colorado.

Woods, A.J., Lammers, D.A., Bryce, S.A., Omernik, J.M., Denton, R.L., Domeier, M., and Comstock, J.A. 2001. Ecoregions of Utah (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,175,000).

4.13. Ecosystem Integrity (Habitat Connectivity, Night Skies, and Natural Sounds)

4.13.1. Background

Habitat Connectivity

The ways in which lands surrounding national parks are utilized can have substantial impacts on natural resources and ecological processes (Fahrig and Merriam 1994, Hansen and DeFries 2007, Wade and Theobald 2010, Rudnick et al. 2012, Hansen et al. 2014). Though NPS generally has relatively little control over land use activities outside park boundaries, identifying potential impacts can assist with resource management goals and support NPS positions and interactions with adjacent communities and partners (Rudnick et al. 2012).

TICA lies within Utah County on the western edge of the Wasatch Range and is completely surrounded by the Uinta-Wasatch-Cache National Forest. To the north the park borders the Lone Peak Wilderness (USFS). At a landscape scale, the Rocky Mountain area of central Utah is within one of the largest, in-tact areas of habitat within North America (Jones et al. 2004).

Given the relatively small area of TICA, few large animals spend significant time here so habitat fragmentation is probably of less concern to park managers than are adjacent land-uses that may impact water quality, hydrologic processes, and the movements of small- and medium sized animals (Forman and Alexander 1998, Yahner 1998, Benítez-López et al. 2010; Section 4.12). Though viewsheds are of interest as a visitor experience topic, they are not addressed here because they have at present no known ecological association.

Recreation and Roads

The presence of roads and associated vehicle traffic affect ecosystem integrity through direct impacts (animal mortality, Kassar 2005) and indirectly through increased noise, the introduction of toxic materials and seeds of non-native plants, and impacts from human disturbance on animal behavior (Mader 1984, Tyser and Worley 1992, Benitez-Lopez et al. 2010, Dietz et al. 2013, Kitzes and Merenlender 2014).

The Mt. Timpanogos Wilderness just to the southeast of TICA is extremely popular and may be the most-visited USFS wilderness area in the state of Utah (http://www.fs.usda.gov/uwcnf). State Route 92 bisects TICA into a smaller northern section (consisting of mostly south-facing slopes with gambel oak-dominated vegetation), and the larger southern portion that includes the cave system, the trail to the caves, and the park visitor center. SR 92 is one of the primary roads used to access the wilderness areas in the summer, and frequently the parking and picnic areas adjacent to TICA become so crowded with day-use visitors and cars that people park directly on the road (NPS 2012).

Natural Night Skies

The importance of maintaining dark night skies has become a priority issue in national parks, and increasing attention is being paid by NPS and others to measuring as well as minimizing the impacts of anthropomorphic sources of light (Henderson et al. 1985, Schelz and Richman 2003, NPS 2006, Duriscoe et al. 2007). Anthropogenically-derived light comes directly from all sources powered by electricity and batteries (e.g. vehicles) as well as indirectly from human-sourced light which is reflected back from the atmosphere (polarized light; Horvath et al. 2009). 'Light pollution' is fundamentally a cultural concept and refers to the over-abundance of artificial light in human landscapes ('lightscape'; Rogers and Sovick 2001, Sovick 2001, Moore et al. 2013). Specifically, the term 'astronomical light pollution' describes the degree to which light affects humans' ability to see stars and other objects in the night sky (Longcore and Rich 2004) and is often measured and discussed within the NPS as part of the visitor experience (Moore 2001, Smith and Hallo 2013).

Less often addressed are the ecological impacts of artificial light during diurnal dark periods (ecological light pollution – ELP). Artificial light at night has very different impacts on wildlife and ecological processes than it does on humans (Longcore and Rich 2004, Horvath et al. 2009). Evolutionarily the moon provided the only source of light at night, and organisms adapted their biology and behaviors to the patterns of lunar cycles (Duriscoe et al. 2007). Consequently, the dark night sky with lunar light only is considered the natural condition to which biotic components of ecosystems have evolved (Rich and Longcore 2005).

Research has examined the impacts of artificial night light on many groups of organisms, including plant populations (Lewanzik and Voight 2014), insects (Geffen et al. 2014, Perkin et al. 2014), birds (songbirds, owls, shorebirds, seabirds; Kempenaers et al. 2010, Rodriguez et al. 2012), amphibians (Perry et al. 2008), rodents, bats (Stone et al. 2009), snakes, marine organisms, and primates (Le Tallec et al. 2013; see Gaston et al. 2013 and Davies et al. 2013 for reviews). For example, the presence of artificial light at night can result in increased predation, reduced productivity, direct mortality, and reduced foraging opportunities (Longcore and Rich 2004, Duriscoe et al. 2007). Cumulatively these impacts can affect population dynamics, successional processes and biodiversity (Kyba and Hölker 2013, Gaston and Bennie 2014, Lewanzik and Voigt 2014).

<u>Natural Quiet</u>

Soundscapes are commonly defined as the total amount of ambient noise in an area measured in terms of frequency and amplitude (decibels; Ambrose and Burson 2004). Because national parks are often (perhaps wistfully) considered 'islands' of quiet (Lynch et al. 2011, Miller 2008), NPS has been working for several decades to establish baseline conditions and develop measuring and monitoring methods for soundscapes in national parks (Miller et al. 2008). Similar to the topic of light pollution soundscapes have primarily been addressed as a cultural resource in relation to visitor experiences (Rogers and Sovick 2001, Sovick 2001, Miller 2008, Lynch et al. 2011), however, increasing attention is being given to ecological and landscape-scale impacts, both terrestrial and aquatic (Barber et al. 2011, Buxton et al. 2017).

Soundscape ecology is an emerging field that attempts to connect ecological processes with human and natural sounds at landscape scales (Dumyahn and Pijanowski 2011, Pijanowski et al. 2011, Farina 2014). When evaluated ecologically, the impacts of anthropogenic sounds are most commonly considered in terms of effects on wildlife (Francis and Barber 2013, Luther and Gentry 2013, Shannon et al 2016). For example, studies have demonstrated the negative impacts of noise on songbirds (Slabbekoorn and Ripmeester 2008, Francis et al. 2009, Francis et al. 2011), bats (Schaub et al. 2008), rodents (Shier et al. 2012), frogs (Barber et al. 2010, Bee and Swanson 2007), and invertebrates (Morley et al. 2014). Prey species are particularly sensitive to human noise because it both mimics predator sounds and masks it (Landon et al. 2003, Chan et al. 2010, Brown et al. 2012).

A growing body of evidence shows that noise also affects plants by enhancing pollination and disrupting seed dispersal (Francis et al. 2012).

Road noise appears to have measurable negative impacts on wildlife, altering animal and bird behavior (McClure et al. 2013), movement patterns, ability to find prey (Siemers and Schaub 2011) and breeding processes (Reijnen and Foppen 2006, Bee and Swanson 2007, Barber et al. 2011). Some species are able to adapt to long-term additions of noise in their environment, but others are not (Barber et al. 2010), and impacts at individual and population scales can further translate up to ecosystem and process levels (Slabbekoorn and Halfwerk 2009).

4.13.2. Reference Conditions

Habitat Connectivity

Because the measures of ecosystem and habitat integrity are species and process specific, there are no common reference conditions for all resources of interest in TICA (Piekielek and Hansen 2012, Rudnick et al. 2012). Ideally there would be no negative impacts (direct or indirect) on natural resources from outside land uses. The diversity of all small and medium-sized mammals would persist, indicating the absence of habitat fragmentation impacts at this scale. Population dynamics of species that move in and out of the park would be maintained, indicating the absence of barriers to travel and genetic exchange.

Natural Night Skies

Levels of artificial light would have no measurable impacts on animal behavior or physiology. NPS directives have recommended a ratio of average anthropogenic sky luminance to natural conditions (ALR) be the primary measure for evaluating night sky conditions, though they stress that other metrics such as vertical and horizontal illuminance and impacts to species of concern should be considered for specific purposes (Moore et al. 2013).

Natural Quiet

Similarly, anthropogenic noise is addressed herein as an impact to wildlife populations and not as it may degrade the visitor experience. That said, at this point NPS generally measures noise conditions only in relation to human health (Lynch et al. 2011), for example 35 decibels (dB, $L_{Aeq, 1s}$) or less is recommended for sleeping, while 60 dB $L_{Aeq, 1s}$ would interrupt normal conversation (Lynch et al. 2011). Clearly these values may or may not have relevance to wildlife behavior and biology (Barber et al. 2011), but wildlife responses to noise in terrestrial environments has been shown to occur at noise levels as low as 40dB (Shannon et al. 2016).

4.13.3. Data and Methods

NPScape has identified land ownership and uses adjacent to TICA (http://science.nature.nps.gov/im/monitor/npscape/). A transportation study (NPS 2012) closely examined the impacts of SR92 on park resources and operations and provided mitigation alternatives. As far as is known, no other studies or data relating to impacts from adjacent land uses on TICA natural resources have been conducted nor have data been collected on nighttime light levels or anthropogenic sound in TICA or AFC.

4.13.4. Resource Condition and Trend

There is very little known regarding the condition of TICA natural resources in regards to adjacent land use. The number of automobiles using SR92 may stay the same or may increase in the future but it almost certainly will not decrease (Kassar 2005). The population of the region along the Wasatch Front to the west of TICA has been increasing over the last decade at rates higher than almost anywhere else in the country, with associated impacts to dark night skies (http://catalystmagazine.net/blogs/item/1978-the-brightness-blight). The lands immediately adjacent to the park are all within USFS jurisdiction but are heavily used for many types of recreation including hunting, off-road vehicles, and skiing.

Several efforts to increase use of mountain areas upstream of TICA in AFC are being opposed by groups hoping to prevent or minimize future development. The largest project currently being discussed is known as the 'Mountain Accord' and would require a permit from USFS to allow expansion of the Snowbird ski area into the upper areas of the AFR.

Nothing is known regarding the condition of natural night skies or the soundscape within TICA.

4.13.5. Level of Confidence

Low

4.13.6. Data Gaps and Research Needs

Measuring night sky brightness and the acoustic environment at TICA would provide important information regarding levels of these anthropogenic impacts and allow further assessment of the effects on sensitive wildlife (e.g. bats). NPS programs to assess light and sound levels are well-established and could be applied here. Levels of noise in particular are likely extremely variable between seasons, and during busy summer months highway noise is probably constant during daytime hours.

4.13.7. Literature Cited

Ambrose, S. and S. Burson. 2004. Soundscape studies in national parks. George Wright Forum 21:29–38.

Barber, J.R., C.L. Burdett, S.E. Reed, K.A. Warner, C. Formichella, K.R. Crooks, D.M. Theobald and K.M. Fristrup. 2011. Anthropogenic noise exposure in protected natural areas: estimating the scale of ecological consequences. Landscape Ecology 26:1281–1295.

Bee, M. A., and E. M. Swanson. 2007. Auditory masking of anuran advertisement calls by road traffic noise. Animal Behav. 74:1765–1776.

Benítez-López, A., R. Alkemade and P.A. Verweij. 2010. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Bio. Cons.143:1307–1316.

Buxton, R. T., M.F. McKenna, D. Mennitt, K. Fristrup, K. Crooks, L. Angeloni and G. Wittemyer. 2017. Noise pollution is pervasive in US protected areas. Science 356:531–533.

Davies, T.W., J. Bennie, R. Inger, and K.J. Gaston. 2013. Artificial light alters natural regimes of night-time sky brightness. Scientific Reports 3 (doi:10.1038/srep01722).

Dietz, M.S., C.C. Murdock, L. M. Romero, A. Ozgul, and J. Foufopoulos. 2013. Distance to a road is associated with reproductive success and physiological stress response in a migratory landbird. The Wilson Journal of Ornithology. 2013:50–61.

Dumyahn, S.L. and B.C Pijanowski. 2011. Beyond noise mitigation: managing soundscapes as common-pool resources. Landscape Ecol. 26:1311–1326.

Duriscoe, D.M., C.B. Luginbuhl and C. Moore. 2007. Measuring night-sky brightness with a wide-field CCD camera. PASP, 119:192–213

Fahrig, L. and G. Merriam. 1994. Conservation of fragmented populations. Cons. Bio. 8:50–59.

Farina, A. 2014. Soundscape ecology. Netherlands: Springer.

Forman, R.T.T., and Alexander, L.E. 1998. Roads and their major ecological effects: Annual Review of Ecology and Systematics. 29:207–231.

Francis, C.D., C.P. Ortega and A. Cruz. 2009. Noise pollution changes avian communities and species interactions. Current biology 19:1415–1419.

Francis, C.D., J. Paritsis, C.P. Ortega and A. Cruz. 2011. Landscape patterns of avian habitat use and nest success are affected by chronic gas well compressor noise. Landscape Ecol. 26:1269–1280.

Francis, C.D, N.J. Kleist, C.P. Ortega, and A. Cruz. 2012. Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. Proceedings of the Royal Society B: Biological Sciences 279, 2727–2735.

Francis, C.D. and J.R. Barber. 2013. A framework for understanding noise impacts on wildlife: an urgent conservation priority. Frontiers in Ecology and the Environment 11:305–313.

Gaston, K.J., J. Bennie, T. W. Davies, and J. Hopkins. 2013. The ecological impacts of nighttime light pollution: a mechanistic appraisal. Biological Reviews 88:912–927.

Gaston, K.J., and J. Bennie. 2014. Demographic effects of artificial nighttime lighting on animal populations. Environmental Reviews 22:1–8.

Geffen, K.G., R.H.A. Grunsven, J. Ruijven, F. Berendse, and E. M. Veenendaal. 2014. Artificial light at night causes diapause inhibition and sex-specific life history changes in a moth. Ecology and Evolution 4:2082–2089.

Hansen, A.J. and R. DeFries. 2007. Ecological mechanisms linking protected areas to surrounding lands. Ecol. Appl. 17:974–988.

Hansen, A.J., N. Piekielek, C. Davis, J. Haas, D. Theobald, J.E. Gross, W.B. Monahan, T. Olliff and S.W. Running. 2014. Exposure of US National Parks to Land Use and Climate Change 1900–2100. Ecol. Appl. 24:484–502.

Henderson, D., M.A. Yocke and H. Hogo. 1985. Night sky – a valuable resource in the nation's National Parks.

Horvath, G., G. Kriska, P. Malik and B. Robertson. 2009. Polarized light pollution: a new kind of ecological photopollution. Front. Ecol. Environ. 7:317–325.

Jones, A., J. Catlin, T. Lind, J. Freilich, K. Robinson, L. Flaherty, E. Molvar, J. Kessler, and K. Daly. 2004. Heart of the West Conservation Plan. Wild Utah Project, Salt Lake City, UT.

Kassar, C.A. 2005. Wildlife vehicle collisions in Utah: an analysis of wildlife road mortality hotspots, economic impacts, and implications for mitigation and management. PhD diss., Utah State University, Department of Forest, Range, and Wildlife Sciences, Logan, UT.

Kempenaers, B., P. Borgström, P. Loës, E. Schlicht, and M. Valcu. 2010. Artificial night lighting affects dawn song, extra-pair siring success, and lay date in songbirds. Current Biology 20:1735–1739.

Kitzes, J. and A. Merenlender. 2014. Large roads reduce bat activity across multiple species. PloS one 9:e96341.

Kyba, C.C.M. and F. Hölker. 2013. Do artificially illuminated skies affect biodiversity in nocturnal landscapes. Landsc. Ecol 10 (2013).

Le Tallec, T., M. Perret, and M. Théry. 2013. Light pollution modifies the expression of daily rhythms and behavior patterns in a nocturnal primate. PloS one 8:e79250.

Lewanzik, D. and C.C. Voigt. 2014. Artificial light puts ecosystem services of frugivorous bats at risk. Journal of Applied Ecology 51:388–394.

Longcore, T. and C. Rich. 2004. Ecological light pollution. Front. Ecol. Environ. 2:191–198.

Lynch, E., D. Joyce and K. Fristrup. 2011. An assessment of noise audibility and sound levels in U.S. National Parks. Landscape Ecol. 26:1297–1309.

Mader, H.J. 1984. Animal habitat isolation by roads and agricultural fields. Bio. Cons. 29:81–96.

McClure, C.J., H.E. Ware, J. Carlisle, G. Kaltenecker and J.R. Barber. 2013. An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road. Proceedings of the Royal Society B: Biological Sciences 280.1773: 20132290.

Moore, C.A. 2001. Visual estimation of night sky brightness. The George Wright Forum 18: 46–55.

Moore, C.A., F. Turina and J. White. 2013. Recommended Indicators and Thresholds of Night Sky Quality for NPS State of the Park Reports Interim Guidance; May 7, 2013. Natural Sounds and Night Skies Division WASO, Natural Resource Stewardship and Science, Ft. Collins, CO.

National Park Service (NPS). 2006. Management Policies 2006-The guide to managing the National Park System. Washington D.C. 180pp.

NPS. 2012. Alternative Transportation Feasibility Study. Timpanogos Cave National Monument, PMIS #172474. Prepared by Cambridge Systematics, Inc. and David Evans and Associates, Inc.

Perkin, E.K., F. Hölker and K. Tockner. 2014. The effects of artificial lighting on adult aquatic and terrestrial insects. Freshwater Biology 59:368–377.

Perry, G. B.W. Buchanan, R.N. Fisher, M.Salmon, and S.E. Wise. 2008. Effects of artificial night lighting on amphibians and reptiles in urban environments. Urban Herpetology:239–256.

Piekielek, N.B. and A.J. Hansen. 2012. Extent of fragmentation of coarse-scale habitats in and around US National Parks. Biological Conservation 155:13–22.

Pijanowski, B.C., L.J. Vllanueva-Rivera, S.L. Dumyahn, A. Farina, B.L. Krause, B.M. Napoletano, S.H. Gage and N. Pieretti. 2011. Soundscape ecology: the science of sound in the landscape. Bioscience 61:203–216.

Reijnen, R. and R. Foppen. 2006. Impact of road traffic on breeding bird populations. Chapter 12 in: Davenport, J. and J.L. Davenport, eds. The ecology of transportation: managing mobility for the environment. Springer Netherlands.

Rich, C. and T. Longcore, eds. 2005 Ecological Consequences of Artificial Night Lighting. Island Press, Washington, DC. 480 pp.

Rodríguez, A. B. Rodríguez, Á. J. Curbelo, A. Pérez, S. Marrero, and J.J. Negro. 2012. Factors affecting mortality of shearwaters stranded by light pollution. Animal Conservation 15:519–526.

Rogers, J. and J. Sovick. 2001. The Ultimate Cultural Resource? In: The George Wright Forum 18:25–29.

Rudnick, D.A., S.J. Ryan, P.Beier, S.A. Cushman, F. Dieffenbach, C.W. Epps, L.R. Gerber, J. Hartter, J.S. Jenness, J. Kintsch, A.M. Merenlander, R.M. Perkl, D.V. Preziosi and S.C. Trombulak. 2012. The role of landscape connectivity in planning and implementing conservation and restoration priorities. Issues in Ecology 16.

Schelz, C. and A. Richman. 2003. Night Sky Monitoring Program, Southeast Utah Group, Moab, UT. National Park Service, GTR SEUG-001-2003.

Shannon, G., M.F. McKenna, L.M. Angeloni, K.R. Crooks, K.M. Fristrup, E. Brown, K.A. Warner, M.D. Nelson, C. White, J. Briggs, S. McFarland and G. Wittemyer. 2016. A synthesis of two decades of research documenting the effects of noise on wildlife. Biological Reviews, 91(4), 982–1005.

Siemers, B.M. and A. Schaub. 2011. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. Proceedings of the Royal Society B: Biological Sciences 278:1646–1652.

Slabbekoorn, H. and W. Halfwerk. 2009. Behavioural ecology: noise annoys at community level. Current Biology 19:R693-R695.

Smith, B. L. and J.C. Hallo. 2013. A system-wide assessment of night resources and night recreation in the U.S. national parks: A case for expanded definitions. Park Science 29:54–59.

Sovick, J. 2001. Toward and appreciation of the dark night sky. George Wright Forum 18:15–19.

Stone, E.L., G. Jones and S. Harris. 2009. Street lighting disturbs commuting bats. Current Biology 19:1123–1127.

Tyser, R.W., and C.A. Worley. 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (U.S.A.): Cons. Bio. 6:253–262.

Wade, A.A. and D.M. Theobald. 2010. Residential Development Encroachment on U.S. Protected Areas. Cons. Bio. 24:151–161.

Yahner, R.H. 1988. Changes in wildlife communities near edges: Cons. Bio. 2:333–339.

Chapter 5. Discussion and Summary

5.1. Terrestrial Upland

5.1.1. Condition

Very little can be said regarding the condition of park vegetation communities, though they appear healthy and there are no obvious immediate threats (e.g. tree pests and diseases are absent). Non-native plant species are present but are managed well. Air quality is good but of increasing concern. Mammal diversity, including bats, appears to be high, and no non-native mammals have been documented. No diseases have been identified in mammal populations. The only mammal species of concern—Townsends' big-eared bats—are present in the park but nothing is known regarding population size or local habitat use by this species.

5.1.2. Trend

Climate change is expected to result in drier conditions over the next century, which may lead to a conversion to communities dominated by more xeric species and increasing invasion by non-native plant species. Increased fire frequencies and/or intensities and forest disease infestations are a concern. The loss of some high-altitude mammal species may occur as temperatures increase.

5.1.3. Level of Confidence

Given the small size of the upland area within the park, vegetation monitoring methods do not allow trend information for any vegetation type. Information regarding vegetation structure and composition other than data collected at three static monitoring sites is lacking and there are no data available for these indicators to evaluate possible trends.

Presence/absence information on small and medium-sized mammals and bats is collected, but overall diversity and/or population trend information for any species are not available. Consequently, it is not possible to document changes in population size or community diversity for any mammal species.

There is little information available regarding habitat connectivity, though the boundaries of the park (aside from the canyon bottom) are continuous with large areas of relatively protected open space. The presence of the highway is a clear barrier to movement for many animals and vehicle traffic and high levels of visitation along the road degrade canyon-bottom communities. There are no data quantifying the level of ecological impacts from artificial light or anthropogenic noise.

5.2. Riparian – American Fork River

5.2.1. Condition

Streamflow and hydrologic conditions have been greatly altered by the presence of flood control measures and the adjacent highway. Average (annual) water flows appear to be normal, though natural floodplain processes have been functionally eliminated. Riparian biological communities are altered by the presence of the road, the parking lots, other infrastructure, and human presence.

5.2.2. Trend
Only a very small stretch of the AFR flows through the park, and factors that control geomorphologic and biologic properties are largely outside NPS control. Natural floods will not return until (unless) hard surfaces and flood control revetments are removed. In the absence of floods, riparian vegetation communities will never return to natural conditions (e.g. recruitment of native woody species is generally absent, non-native species become established). Climate change effects are expected to result in altered seasonal flow patterns and perhaps reduced flows.

5.2.3. Level of Confidence
Flow information is available from a USGS gage upstream. No information is available regarding riparian biological resources, in particular vegetation and bird communities.

5.3. Caves

5.3.1. Condition
The climate of the caves has been affected by human presence to a degree that will never be completely mitigated given the importance of the caves as a visitor experience. Much effort has been expended to maintain the natural cave climate as much as possible, and humidity and temperature levels do not at present appear to be outside normal ranges. Water conditions in the caves are good; water quality appears to be relatively unimpacted by toxics or pollutants and water chemistry seems to reflect natural conditions. Cave formations are well-protected and physical damage is minimal, though the presence of lint and algae is an ongoing impact.

5.3.2. Trend
The caves are as protected as they can be given the high level of human presence. The primary risks to cave resources have all been identified and are managed well within the directives of the cave management plan. Climate change effects will most likely be reflected in reductions in water quantity (flow).

5.3.3. Level of Confidence
A relatively high level of information exists for physical cave resources. The extent of the cave watershed is now fairly well established, and recent efforts to delineate watershed boundaries and water flow paths also provided important information describing water chemistry. There is less information on extant microorganism and invertebrate communities, and data required to determine relationships between formation growth dynamics and water quantity are likewise unavailable.

5.4. Ecological Framework
Natural resources and processes were selected for this assessment with reference to the ecological framework described by Fancy et al. (2009; Table 5.1). One of the purposes of utilizing a framework is to determine the breadth of ecosystem elements across which focal resources occur. For example, if all of the focal resources are associated with the Biological Integrity element, such an assessment would fail to consider much of the target ecosystem (Noss 1990).

Table 5.1. TICA topics addressed in the NRCA organized within the ecological monitoring framework for each ecological zone.

Element	Upland	Riparian	Caves
Climate	Air and Climate	Air and Climate	Air and Climate
Geology and Soils	–	Riverine Geomorphology	Formations
Water	–	Water Quality	Water Quality and Chemistry Hydrology
Biological Integrity	Bats Medium and Small Mammals Upland Vegetation	–	Micro-organisms Invertebrates Bats
Ecosystem Pattern and Process	Habitat Connectivity Natural Night Sky Natural Sounds	Habitat Connectivity Natural Night Sky Natural Sounds	Cave Watershed

Table 5.1 indicates that the resources assessed within the cave ecological zone in TICA provided representation of all ecosystem elements. The subset of resources assessed for the upland ecological zone did not include resources associated with geology, soils, or water, and resources within the riparian zone did not include a biological resource. Ways that future work might address these deficits is discussed briefly below.

5.4.1. Possible Future Work

Terrestrial Upland

A monitoring program for mammals utilizing remote sensing would provide important information on changes in small and medium-size mammal diversity in coming decades. The geology of the upland zone is of great concern from a human safety perspective, however, no water, soil, or geological resources in the upland have been identified as natural resource priorities by TICA managers.

Riparian

Biological communities of the riparian zone are not monitored or surveyed, and the area where this could occur in TICA is quite small. In other riparian systems recruitment of woody species and bird diversity are often indicators of riparian condition. However, unless associated with specific management actions, monitoring of vegetation or bird communities in the small TICA riparian zone would likely provide little ecological information. Bat use of the riparian zone is likely high, and continued surveys here will provide important information on bat community ecology and habitat use.

Caves

Acquiring additional information on cave biological communities would allow managers to document future changes that may occur. Changes in water quantity, reductions in water quality, and introductions of novel species would be negative inputs to biological resources within the caves. Repeated surveys of microorganisms and invertebrates would be particularly valuable.

5.5 Condition Reporting

Based on the resource condition findings reported in Chapter 4, condition ratings were assigned to focal resources using condition reporting symbols defined in Chapter 3. Focal resource conditions are shown in Table 5.5-1.

Table 5.5-1. Summary of condition assessments for TICA focal resources.

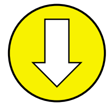
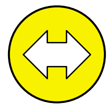
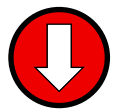
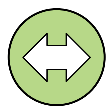
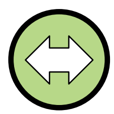
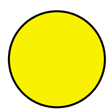
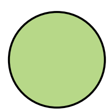
TICA Resource	Condition, Trend, and Level of Confidence	Assessment
Air Quality (Section 4.1)		Air quality in American Fork Canyon in the vicinity of TICA appears to be in moderate condition, though air quality along the Wasatch Front is often poor and impacts to TICA from that region are of concern. Impacts from increased vehicle traffic in the canyon in coming years is also of concern. Thus, air quality is likely not improving and may deteriorate further in coming decades. Confidence is moderate.
Cave Climate (4.2)		The climate of the caves is altered from natural conditions, though it is not known whether these changes affect biological or physical processes within the caves. Available data suggest the climate condition is stable, and confidence is moderate.
Climate (4.3)		Global climate change is affecting Utah and all western US forests, and negative impacts to TICA upland resources from climate change are predicted to increase in coming decades. Impacts to cave resources may occur. Confidence is high that the climate is changing and will negatively affect upland resources.
Cave Water Quality (4.4)		Water quality in the caves appears to be good. Available data indicate this condition is likely stable, and confidence is moderate.
Cave Formations and Microorganisms (4.5)	 	Natural cave formation processes do not at present appear to be impaired. Though physical damage occurs periodically, cave formations are generally well-monitored. This condition appears to be stable and confidence is high. Microorganism communities are little studied but appear to be diverse and what would be expected in caves of this size and origin. Data are insufficient to indicate trends and confidence is moderate.
Cave Watershed (4.6)		Watershed conditions appear to be unimpaired, and no introductions of chemicals or other contaminants into cave waters have been detected. Data are insufficient to detect trends and confidence is moderate.

Table 5.5-1 (continued). Summary of condition assessments for TICA focal resources.

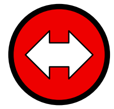
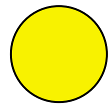
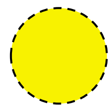
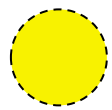
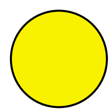
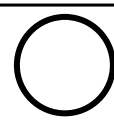
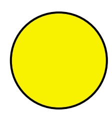
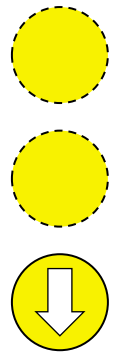
TICA Resource	Condition, Trend, and Level of Confidence	Assessment
American Fork River Hydrology and Riparian Ecology (4.7)	 	Hydrologic processes of the river reach adjacent to TICA are impaired and will remain so until articial barriers to natural flow are removed. Confidence in this assessment is high. Ecological function of the adjacent riparian zone is likewise impaired, though available data are insufficient to determine whether conditions are changing. Confidence is moderate.
Cave Invertebrates (4.8)		Little is known regarding the current condition of cave invertebrate communities. The most recent study (2004) revealed expected diversity and no introduced species. The trend is unknown and confidence is low.
Bat Communities (4.9)		Bat species diversity is likely high in TICA but little is known regarding current condition. The trend is uknown and confidence is low.
Townsends Big-eared Bats (4.10)		Townsends are present but demographic data are lacking. Trends are unknown and confidence is moderate.
Small and Medium-sized Mammals (4.11)		Aside from bats almost nothing is known regarding resident mammals at TICA.Trends are unknown and confidence in this assessment is high.
Upland Vegetation (4.12)		Vegetation in TICA is representative of the region. Disease presence in forests has not been detected and trends are unknown. Invasive plants and impacts from climate change are concerns. Confidence is moderate.

Table 5.5-1 (continued). Summary of condition assessments for TICA focal resources.

TICA Resource	Condition, Trend, and Level of Confidence	Assessment
Ecosystem Integrity (Natural Night Skies, Natural Sounds and Habitat Connectivity) (4.13)		Natural night skies and soundscapes have not been assessed at TICA. There are few artificial sources of light at night in the canyon, but impacts of light from the dense population corridor to the west are unknown.Traffic and other sources of human noise are likewise unmeasured. Habitat connectivity is highly impacted by the highway and high levels of human recreational and commercial activities in the canyon. Trends in any of these resources are unknown, though it is almost certain that human impacts to habitat quality will not decrease in coming years and may well increase. Confidence is moderate.

5.6. Literature Cited

Fancy, S.G., J.E. Gross, and S.L. Carter. 2009. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment 151:161–174.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355–364.

Appendix A. National Resource Condition Assessment (NRCA) Initial Planning Meeting

Timpanogos Cave National Monument, August 11th–12th, 2010

Attendees

TICA: Cami Pulham, Andy Armstrong; NCPN: Melanie Myers, Cathy Schwemm.

Meeting Summary

This was the first scoping meeting for the Timpanogos Cave Natural Resource Condition Assessment (NRCA). On the morning of the first day we had introductions, and Cathy and Melanie gave presentations on the NRCA program and the proposed approach to spatial data management (agenda attached). The presentations were followed by an informal conversation with the TICA staff on the project, who suggested that they felt that the NRCA could be useful, especially in relation to the cave management plan (CMP) which is currently in development. The CMP is nearly in draft form, but staff suggested that it would be beneficial for planning and future efforts if cave resource issues were addressed in both the CMP and the NRCA. The park is also working on an interpretive plan and a facilities plan, which could also benefit from information provided in the NRCA.

After this discussion we began listing the priority natural resource issues for the park, and by lunchtime we had what the staff considered a fairly complete list of resource concerns and topics. After lunch NCPN staff were taken on a tour of the caves, which gave us a much better idea of the unique challenges facing this park. On the second morning we revisited the issues list from the previous day, and populated the spreadsheet that included data availability, priority rankings, and level of work that would be required by TICA staff for each resource element. The priority issues are described below:

Potential Cooperator Issues

<u>Cave Watershed</u>

The amount and chemical composition of water that enters the three caves are the most important influences on the physical and biotic resources of the monument. As water flows from the surface through the ground it picks up nutrients and chemicals along its course, eventually depositing much of these elements in the caves. To properly manage cave resources it is therefore critical that managers understand the source(s) of the water that enters the caves. The watershed, including both surface and groundwater sources, has never been fully defined for TICA; it is known that water sources and recharge routes for Hansen and Middle caves are different than for Timpanogos Cave, but previous studies have been inconclusive regarding the precise hydrogeology of the region. Managers state that acquiring this information is at present their highest resource priority. This need was emphasized in the 2006 NPS Geologic Resources Evaluation Report which stated that the first priority for inventory, monitoring and research needs for water issues was to 'Determine the nature of the cave complex watershed by compiling baseline watershed and cave hydrogeologic data.'

Geological expertise would be needed to determine/suggest the hydrogeology affecting the cave. Dye marker studies would need to be conducted; however, park staff could do much of the ground work under direction from a cooperator, reducing costs. Expertise is available to summarize water quality data, climate data, and information on cave ecology, but further discussions between TICA and NCPN staff will be held in September to determine how best to proceed with potential cooperator issues.

Priority Issues to be addressed by NPS

Cave Climate

The three caves that are generally now known as Timpanogos Cave were not naturally connected. Tunnels were constructed in the 1930s to connect the three caves, which allowed greater visitor access but also substantially altered the natural atmospheric conditions of the previously separate areas. The presence of the tunnels now allows air to flow into or out of the caves (depending on the season) at rates higher than before the tunnels were constructed, changing the natural temperature and humidity regimes. In an attempt to reduce airflow between the caves, in the 1990s several doors were constructed in the tunnels that are opened then closed as visitors pass through. The presence of doors has had mixed results, but recent studies have shown that there is still considerable airflow around the doors because they are not airtight. Studies of temperature in the caves have shown a significant increase in temperature in the summer when the caves are open to visitation, due to both the outflow of colder cave air as well as the heat generated by the many (up to 1000) people who enter the cave during busy periods. At this point managers would like to summarize all of the existing historic temperature and humidity data, which come from several sources, to assess the scale of seasonal and longer term environmental changes within the caves.

Cave Physical Features

Thousands of beautiful and unique speleothems adorn the Timpanogos Cave system, but are at risk from multiple human-generated impacts. Artificial lights combined with humid conditions allow algae to grow on the formations, and dust, composed largely of fabric material and hair, accumulates on the features and is usually difficult or impossible to remove. Features are also broken, usually accidentally but occasionally by intent. Monitoring of the caves physical features is done primarily by photo monitoring; over 100 permanent camera stations have been installed and photo sets are acquired approximately every three years. The existence of historic photos and feature inventories are also used to assess both natural and human-caused changes in the physical structure of the caves and formations. Managers would like to summarize all these data sets to acquire a more comprehensive assessment of the extent of change to physical features, and to document the level of human impacts, for example by comparing changes in tour areas with those in more pristine locations where visitors do not go.

Cave Water Quality

Water quality assessment methods for caves are different than they are for stream and surface sites. Water quality monitoring in the Timpanogos caves is currently done in three subsurface lakes, one in each of the three caves. However, the protocols vary; one site is monitored by EPA, one by the State of Utah, and one by NPS. A summary and professional examination of the data, potentially in concert with a watershed assessment, would provide managers with important information on overall water quality in the cave ecosystem for planning and management, and for prioritizing future research priorities.

Cave Ecology

The biotic resources of the caves include bats, invertebrates, and microbial communities, and each group has different threats. Bats communities include species that use the caves as well as terrestrial habitats, so bats as a group will be discussed separately below. Invertebrates are primarily affected by changes in water quality and impacts from visitors (trash in lakes, etc.), and microbial communities are at risk primarily from the introduction of species from outside the caves. A fairly thorough inventory for invertebrates was completed in 2003 that provided a good species list but little to no information on population abundance or ecology, A microbial study was initiated around the same time but was never completed, though these data may be accessible. Data on invertebrates and microbes could be summarized and compared with other sites and historic information to potentially assess current changes in and threats to these communities.

Bats

Some bat species in the monument use both cave and surface resources, while others don’t use the caves at all. Previous studies and current sampling have provided good species lists for both groups but very little information on population abundance or ecology. Some bats do hibernate in the caves, but how many is not known, and impacts of visitors on bat populations in the caves is also not known. The substantial impacts of white-nose syndrome (WNS) on bat populations in the eastern part of the country, and the threat that the introduction of WNS would have on western populations makes an assessment of bats in TICA a high management priority.

Appendix B. Relevant Recent Literature

Call, R.S., J.C. Whiting, B. Doering, J. Lowe, d. Englestead, J. Frye, T. Stefanic, and G. Wright. 2018. Maternity roosts of Townsend's big-eared bats in lava tube caves of southern Idaho. Northwest Science 92:158–165.

Candiroglu, B. and N.D. Gungor. 2017. Cave Ecosystems: Microbiological View. European Journal of Biology 76:36–42.

Culver, D.C. and T. Pipan. 2019. The Biology of Caves and other Subterranean Habitats. Oxford University Press, Oxford, UK.

Gonzalez, P., F. Wang, M. Notaro, D.J. Vimont, and J.W. Williams. 2018. Disproportionate magnitude of climate change in United States national parks. Environmental Research Letters, 13(10), p.104001.

Hackbarth, C., and R. Weissinger. 2016. Water quality in the Northern Colorado Plateau Network: Water years 2013–2015. Natural Resource Report NPS/NCPN/NRR—2016/1332. National Park Service, Fort Collins, Colorado.

Helf, K.L. and R.A. Olson. 2017. Subsurface Aquatic Ecology of Mammoth Cave. In *Mammoth Cave* (pp. 209–226). Springer, Cham.

Lambert, C.T., L.K. Hall, R.T. Larsen, R.N. Knight, and B.R. McMillan. 2018. Temporal partitioning and the effects of climate change on two ecologically similar desert bats. Journal of Mammalogy 99:1486–1494.

Šebela, S., G. Baker, and B. Luke. 2019. Cave Temperature and Management Implications in Lehman Caves, Great Basin National Park, USA. Geoheritage 11:1163–1175.

U.S. National Forest Service, Uinta National Forest. Forest Plan Biennial Monitoring Report, 2016–2017. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd573359.pdf.

U.S. National Park Service, Timpanogos Cave National Monument. Undated. Proposed vegetation management plan https://parkplanning.nps.gov/projectHome.cfm?projectID=75838.

Voigt, C.C. and T. Kingston, editors. 2016. Bats in the Anthropocene: Conservation of Bats in a Changing World. Springer Open.

Weissinger, R.H., B.R. Blackwell, K. Keteles, W.A. Battaglin, and P.M. Bradley. 2018. Bioactive contaminants of emerging concern in National Park waters of the northern Colorado Plateau, USA. Science of the Total Environment 636:910–918.

Wynne, J.J., F.G. Howarth, S. Sommer, and B.G. Dickson. 2019. Fifty years of cave arthropod sampling: techniques and best practices. International Journal of Speleology 48:33–48.

Weller, T.J., T.J. Rodhouse, D.J., Neubaum, P.C. Ormsbee, R.D. Dixon, D.L. Popp, J.A. Williams, S.D. Osborn, B.W. Rogers, L.O. Beard, and A.M. McIntire. 2018. A review of bat hibernacula across the western United States: Implications for white-nose syndrome surveillance and management. PloS one, 13(10).

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.

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