National Park Service
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Natural Resource Stewardship and Science

Colorado National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/COLM/NRR—2016/1356

ON THE COVER
The view of Colorado National Monument, looking east toward Grand Junction, Colorado.
Photograph courtesy of the National Park Service

Colorado National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/COLM/NRR—2016/1356

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

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program aims to provide documentation about the current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. Findings from the NRCA will help Colorado National Monument (COLM) managers to develop near-term management priorities, engage in watershed- or landscape-scale partnership and education efforts, conduct park planning, and report program performance (e.g., Department of the Interior's Strategic Plan "land health" goals, Government Performance and Results Act).

The objectives of this assessment are to evaluate and report on current conditions of key park resources, to evaluate critical data and knowledge gaps, and to highlight selected existing stressors and emerging threats to resources or processes. For the purpose of this NRCA, staff from the National Park Service (NPS) and Saint Mary's University of Minnesota – GeoSpatial Services (SMUMN GSS) identified key resources, referred to as "components" in the project. The selected components include natural resources and processes that are currently of the greatest concern to park management at COLM. The final project framework contains 21 resource components, each featuring discussions of measures, stressors, and reference conditions.

This study involved reviewing existing literature and, where appropriate, analyzing data for each natural resource component in the framework to provide summaries of current condition and trends in selected resources. When possible, existing data for the established measures of each component were analyzed and compared to designated reference conditions. A weighted scoring system was applied to calculate the current condition of each component. *Weighted Condition Scores*, ranging from zero to one, were divided into three categories of condition: low concern, moderate concern, and significant concern. These scores help to determine the current overall condition of each resource. The discussions for each component, found in Chapter 4 of this report, represent a comprehensive summary of current available data and information for these resources, including unpublished park information and perspectives of park resource managers, and present a current condition designation when appropriate. Each component assessment was reviewed by COLM resource managers, NPS Northern Colorado Plateau Network staff, or outside experts.

Existing literature, short- and long-term datasets, and input from NPS and other outside agency scientists support condition designations for components in this assessment. However, in some cases, data were unavailable or insufficient for several of the measures of the featured components. In other instances, data establishing reference condition were limited or unavailable for components, making comparisons with current information inappropriate or invalid. In these cases, it was not possible to assign condition for the components. Current condition was not able to be determined for nine of the 21 components (43%) due to these data gaps.

For those components with sufficient available data, the overall condition varied. Only two components (riparian habitats/large dry washes and bighorn sheep) were determined to be in good condition. Five components (pinyon-juniper woodlands/savannas, seeps, springs and tinaja habitats, birds, air quality and paleontological resources) were of moderate concern. Birds were the only component where the available data were sufficient enough to assign a trend. At this time, the bird community exhibits a stable trend. Three components were determined to be of significant concern (kit fox, dark night skies, and viewscape). The high concern for kit fox was due to the species likely being extirpated from the region; as it is unlikely to return on its own, a stable trend was assigned. The remaining two components of significant concern (dark night skies and viewscape) are strongly influenced by urban land uses and other anthropogenic factors outside of NPS control. While they are currently exhibiting deteriorating trends, there is little that NPS managers can do to mitigate these trends. Detailed discussion of these designations is presented in Chapters 4 and 5 of this report.

Several park-wide threats and stressors influence the condition of priority resources in COLM. Those of primary concern include invasive exotic plant (IEP) species, regional climate change, and drought. Understanding these threats, and how they relate to the condition of park resources, can help the NPS prioritize management objectives and better focus their efforts to maintain the health and integrity of the park ecosystem.

Acknowledgments

We acknowledge Colorado National Monument staff for the technical expertise provided during scoping, through multiple stages of review, and via phone and email; specifically, Ken Mabery COLM Superintendent and Kim Hartwig COLM Chief of Resources Management. Northern Colorado Plateau Inventory and Monitoring Network staff, including Dusty Perkins (Program Manager) and Dana Witwicki (Vegetation Ecologist), offered logistical insight and critical review of interim documents. Additional program guidance and reviews were provided by Donna Shorrock, Intermountain Region NRCA Coordinator, and Jeff Albright, Natural Resource Condition Assessment Coordinator. Thank you to all others who assisted the development of this document.

Acronyms and Abbreviations

AET – Actual Evapotranspiration

AQI – Air Quality Index

ARD – Air Resources Division

BCSD – Bias Correction followed by Spatial Disaggregation

BLM – Bureau of Land Management

BPP – Bird Phenology Program

BPU – Biophysical Unit

BSC – Biological Soil Crust

CAA – Clean Air Act

CBC – Christmas Bird Count

CBS – Colorado Bat Society

CCD – Charge-coupled Device

CCRP – Climate Change Response Program

CCVA – Climate Change Vulnerability Assessment

CNM – Colorado National Monument

COLM – Colorado National Monument

CPW – Colorado Parks and Wildlife

CSU – Colorado State University

DAU – Data Analysis Unit

dB – Decibel

dBA – Weighted Decibels

DEM – Digital Elevation Model

DO – Dissolved Oxygen

dv – Deciviews

EC – Emerging Contaminant

Acronyms and Abbreviations (continued)

EDC – Endocrine-disrupting Chemicals

EPA – Environmental Protection Agency

ET – Evapotranspiration

FAA – Federal Aviation Administration

GCM – General Circulation Model

GIS – Geographic Information System

GMU – Game Management Unit

gpm – Gallons Per Minute

GPRA – Government Performance and Results Act

GPS – Global Positioning System

Hg – Mercury

Hz – Hertz

I&M – Natural Resources Inventory & Monitoring

IBA – Important Bird Area

IEP – Invasive Exotic Plant

IMPROVE – Interagency Monitoring of Protected Visual Environments Program

IPCC – Intergovernmental Panel on Climate Change

IRMA – Integrated Resource Management Application

KGJT – Grand Junction Regional Airport

L_{50} – Median Existing Sound Levels

LEC – Lower Echo Canyon

L_{nat} – Median Natural Ambient Sound Levels

lpm – Liters Per Minute

LPR – Light Pollution Ratio

MCL – Maximum Contaminant Level

Acronyms and Abbreviations (continued)

MDS – Mercury Deposition Network

MDTS – Minimum Detection Target Size

MMU – Minimum Mapping Unit

mya – Million Years Ago

N – Nitrogen

NAAQS – National Ambient Quality Standard

NADP – National Atmospheric Deposition Program

NAS – National Audubon Society

NCCSC – North Central Climate Science Center

NCDC – National Climatic Data Center

NCPN – Northern Colorado Plateau Network

NED – National Elevation Dataset

NO_3 – Nitrate

NOx – Nitrogen Oxides

NPS – National Park Service

NRCA – Natural Resource Condition Assessment

NSNSD – Natural Sounds and Night Skies Division

NTC – No Thoroughfare Canyon

NTN – National Trends Network

NVC – National Vegetation Classification

NWS – National Weather Service

O_3 – Ozone

PET – Potential Evapotranspiration

PI – Principle Investigator

PIT – Passive Integrated Tag

Acronyms and Abbreviations (continued)

P-J – Pinyon-Juniper

PM – Particulate Matter

POMS – Portable Ozone Monitoring Station

ppb – Parts Per Billion

ppm – Parts Per Million

RCP – Representative Concentration Pathway

RMBO – Rocky Mountain Bird Observatory

SC – Specific Conductance

SCPN – Southern Colorado Plateau Network

SL – Significance Level

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

SPL – Sound Pressure Level

SRES – Special Report on Emissions Scenarios

TNC – The Nature Conservancy

USFS – United States Forest Service

USGS – United States Geological Survey

UV-B – Ultraviolet B

VES – Visual Encounter Surveys

VOC – Volatile Organic Compound

WCS – Weighted Condition Score

WHO – World Health Organization

WNS – White-nose Syndrome

WRD – Water Resources Division

ZLM – Zenithal Limiting Magnitude

1. NRCA Background Information

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

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

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

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

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

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

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

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

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

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

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

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

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

Important NRCA Success Factors

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

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

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

NRCA Reporting Products…

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

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

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

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

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

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

2. Introduction and Resource Setting

2.1 Introduction

2.1.1 Enabling Legislation

Colorado National Monument (COLM) was officially established on 24 May 1911 by President William Taft. The presidential proclamation (1126) stated the following:

> *Whereas, in Mesa County, Colorado, the extraordinary examples of erosion are of great scientific interest, and it appears that the public interest would be promoted by reserving these natural formations as a National Monument, together with as much public land as may be necessary for the proper protection thereof (LOC 1913, p.1681).*

The area that eventually became COLM was originally included as part of the 1868 Colorado Ute Reservation Treaty (NPS 2005). The area was ceded in 1880 when the Utes were relocated to Utah, and settlers began to arrive and stake agricultural claims in the Grand Valley (NPS 2005). The area came under the management of the NPS with the initial designation of approximately 5,598 ha (13,883 ac) as a National Monument (LOC 1913). Over the years, COLM has undergone several boundary changes, with the most recent expansion in 1978 bringing the park to its current size of 8,310 ha (20,534 ac) (NPS 2005, NPS 2014a).

2.1.2 Geographic Setting

Geophysical Setting

COLM is located in northwestern Mesa County in western Colorado, near the border of Utah (Figure 1). It is situated on the northeastern portion of the Uncompahgre Plateau, near the northern tip of this formation (Tweet et al. 2012). The majority of the park is composed of a series of canyons and mesas formed by ephemeral streams draining into the Colorado River (Figure 2) (Tweet et al. 2012). Elevations within the park range from 1,408 m (4,620 ft) at the foot of the cliffs, to 2,166 m (7,107 ft) on the mesa tops (NPS 2004). Among the many canyons, Monument Canyon comprises much of the northern portion of COLM, and the entire southeastern portion includes much of No Thoroughfare Canyon (Figure 2). The area along the northeastern border of COLM is referred to as the Redlands, due to the color of the rocks (Tweet et al. 2012). The communities of Grand Junction and Fruita are located to the east and north of the park and are separated by the Colorado River, while Glade Park is located to the southwest (Figure 3). The latest census figures estimating the populations of Grand Junction, Fruita, and Mesa County are given in Table 1.

Figure 1. General location of COLM.

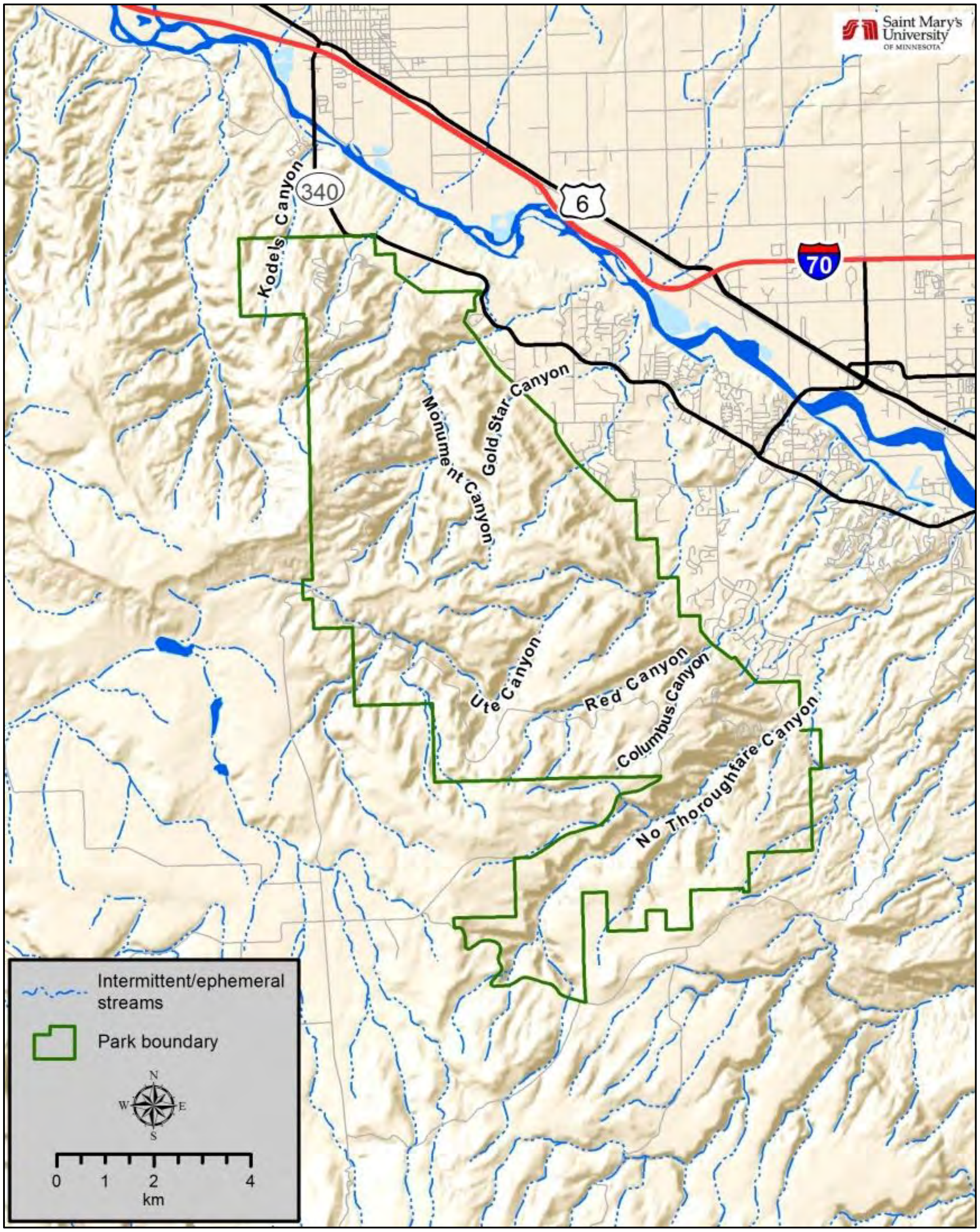

Figure 2. Canyons and ephemeral stream network at COLM.

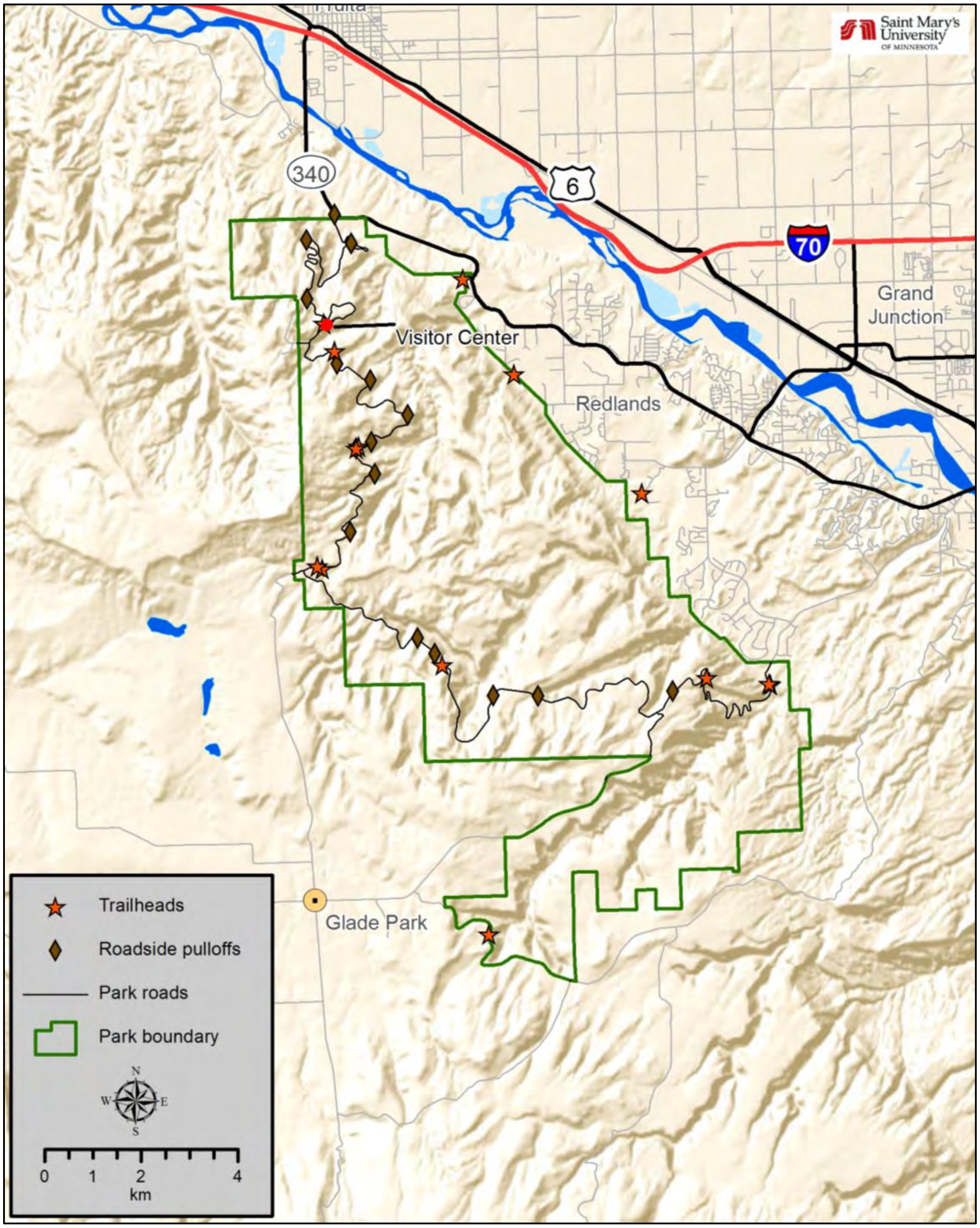

Figure 3. Communities located in proximity to COLM.

Table 1. Population estimates for Mesa County and municipalities. Population estimates are as of July 2013 (DOLA 2015).

Area	Population Estimate
Mesa County	147,811
Fruita	12,615
Grand Junction	61,212

COLM has a semi-desert upland climate characterized by very hot and dry summers and cold, dry winters (NPS 2005). Precipitation is evenly distributed throughout the year with small peaks in the spring, late summer and early fall (Figure 4). Average monthly precipitation is 2.47 cm (0.95 in) with approximately 28.9 cm (11.4 in) precipitation annually (1981-2010 period; WRCC 2015). The average snow depth during the winter is 2.5 cm (1 in) with a total annual snowfall of 84.6 cm (33.3 in), with the heaviest accumulations usually occurring in January (NPS 2005).

Daily temperatures vary from season to season with highs above 35 °C (90 °F) in the summer to winter lows that can drop below freezing (WRCC 2015). Annual average daily maximum temperature is 18.2 °C (64.7 °F) and the average minimum temperature is 6.2 °C (43.2 °F) (Figure 5) (WRCC 2015).

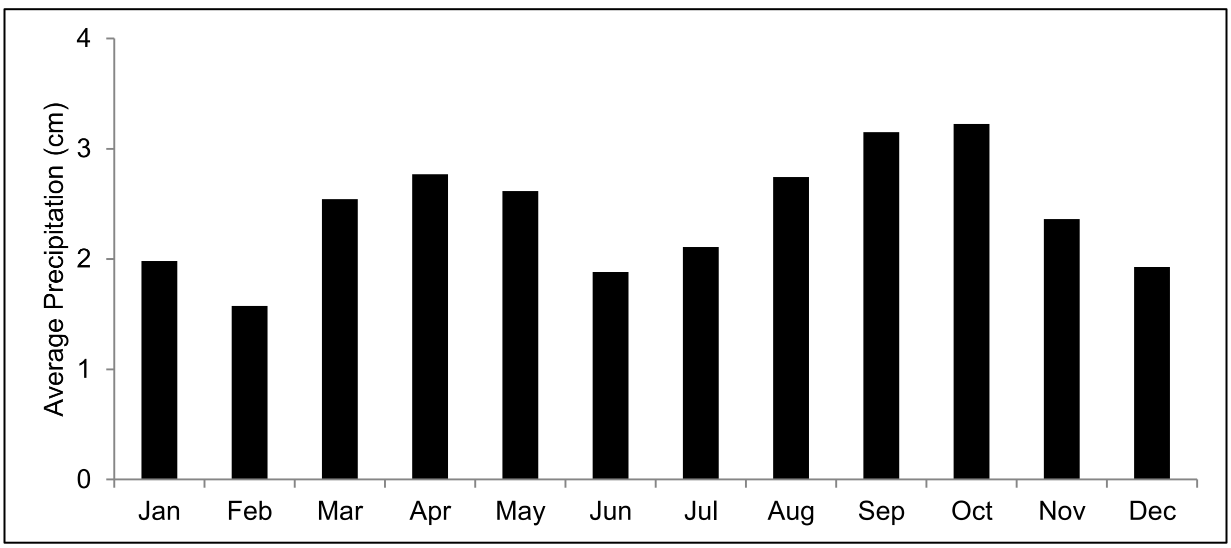

Figure 4. Average monthly precipitation for the period 1981-2010 for the COLM weather station (Station ID 051772) (WRCC 2015).

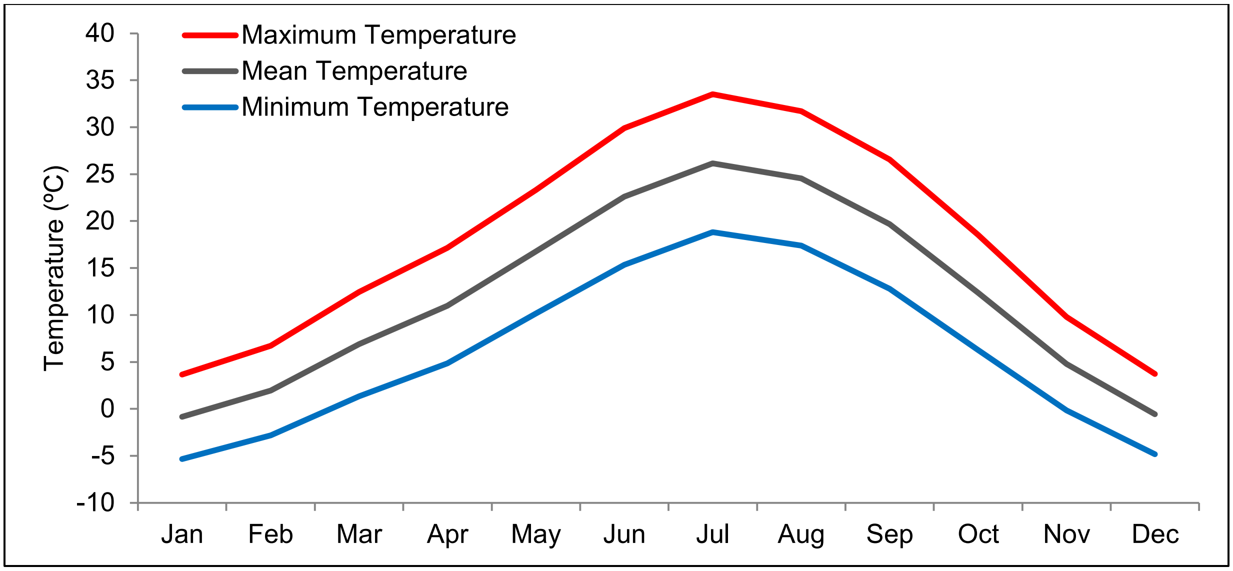

Figure 5. Monthly temperature for the period 1981-2010 for the COLM weather station (Station ID 051772) (WRCC 2015).

Historical Climate Trends (1895-2012)

COLM is located in the semi-arid Southwest, one of the driest and hottest regions in the United States (Garfin et al. 2014). Water is typically scarce and its availability has defined the landscape (Garfin et al. 2014). This scarcity of water also limits plant growth (Running et al. 2004). Because water is such a key driver of natural and production systems, descriptions of climate variability that are associated with drought or aridity are of particular interest. The growth and vigor of vegetation influences physical processes such as erosion and the dynamics of native and domestic animals. These are key processes to management, and to the evaluation of climate change vulnerability.

Large areas of the central and western United States experienced severe droughts in the 1930s, 1950s, and late 1990s to about 2004 (Woodhouse and Overpeck 1998, Cook et al. 2004). While these recent droughts persisted for multiple years and had profound effects on natural ecosystems and on agricultural production, over recent millennia, records reveal sustained droughts that persisted for decades (Woodhouse and Overpeck 1998, Cook et al. 2004, Meko et al. 2007, Cook et al. 2010, Routson et al. 2011). These decades-long droughts affected ecological processes such as broad patterns of fire (Brown et al. 2004), and they emphasize the vulnerability of the region to precipitation deficits. Projections of future climates including higher temperatures and increased evapotranspiration rates or changes in precipitation that change soil water availability are particularly important in climate analyses in this NRCA.

The climate at any location is determined by factors that operate at multiple spatial scales. At a global scale, the Earth has experienced a general warming trend over the past century, closely correlated with increases in the greenhouse gas CO_2 (Figure 6) (Walsh et al. 2014). Global patterns of warming are modified by very broad-scale teleconnections, regional and local conditions, and the degree of warming or cooling varies geographically. Mote and Redmond (2012) provide a clear and comprehensive review and evaluation of climate drivers at local to global scales with a focus on the western United States.

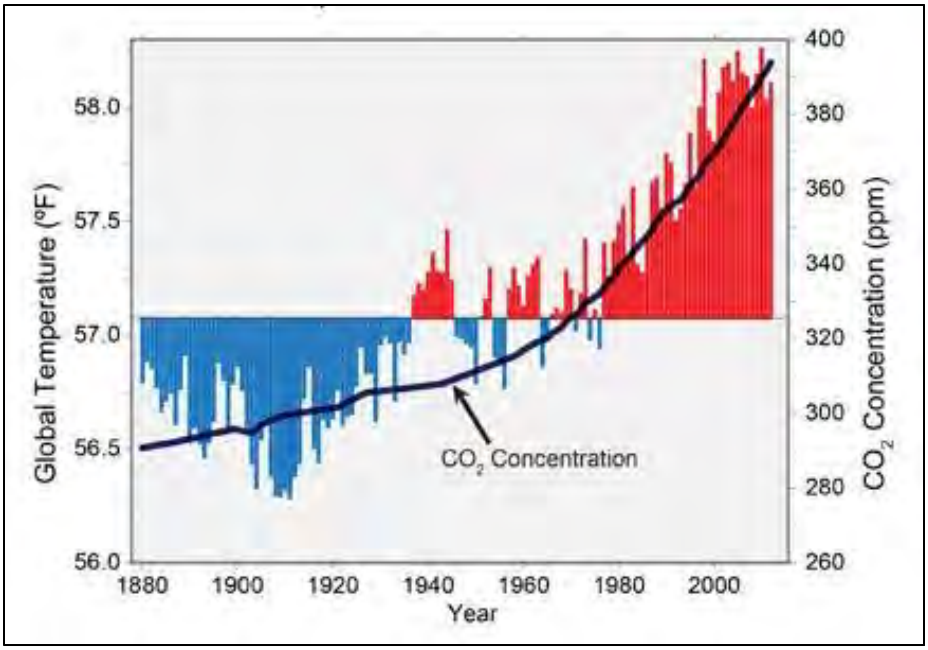

Figure 6. Annual average temperature measured over all the Earth's land and ocean surfaces. Red and blue bars indicate years with temperatures above and below the 1901-2000 average, and the black line is the trend in atmospheric CO_2 concentration. Figure from Walsh et al. (2014).

Recent historical climate patterns for COLM were evaluated using PRISM gridded climate data. These data are produced by the PRISM climate group at Oregon State University (Daly et al. 2002, PRISM 2015), and the analysis was completed by the North Central Climate Science Center (NCCSC). Over the period 1895-2010, the PRISM data exhibited a trend towards warming for both maximum (Tmax) and minimum (Tmin) average annual temperature, and a decline in average monthly precipitation (Figure 7A, B). The linear warming trends are 0.8 °C (1.4 °F) per century for Tmax and 0.7 °C (1.3 °F) per century for Tmin (NCCSC 2015)[1]. These trends were determined to be statistically significant, with p-values of 0.0003 and 0.0004 respectively (NCCSC 2015). Annual precipitation exhibited a -2.4% per century decline, though it was determined to not be statistically significant (Figure 7C, NCCSC 2015). Another analysis shows that summer conditions over the past 10-30 years, on average, were warmer than 95% of the historical range of conditions going back to 1901 at the park (Monahan and Fisichelli 2014).

[1] A change in temperature of 1 °C = a change of 1.8 °F

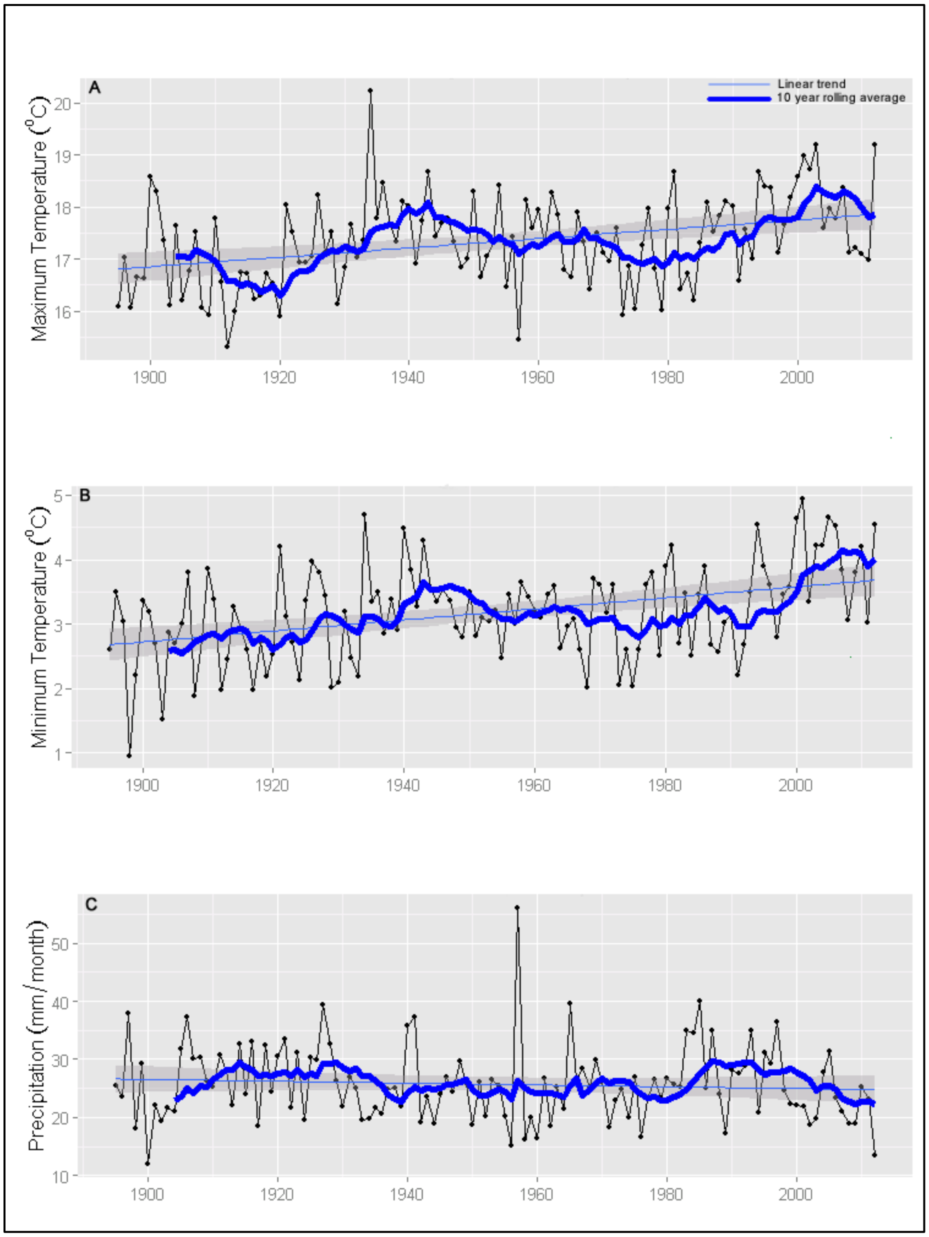

Figure 7. Trends in (A) maximum monthly temperature, (B) minimum monthly temperature, and (C) annual precipitation for COLM. The linear regressions for Tmax and Tmin were significant ($P < 0.001$). The dark blue line is the calculated 10-year rolling average and the light blue line is the linear trend. Data analysis provided by NCCSC (2015).

Projected Climate Trends (2050 and 2100)

Across the Southwest Region, the annual average temperature is projected to rise by 1.4 °C to 3.1 °C (2.5 °F to 5.5 °F) by 2040-2070 and by 3.1 °C to 5.3 °C (5.5 °F to 9.5 °F) by 2070-2100 under the high greenhouse gas emissions ("business as usual") pathway, Representative Concentration Pathway (RCP) 8.5 (Garfin et al. 2014). Temperatures are projected to have greater increases in the summer and fall (Garfin et al. 2014). Under an emissions pathway with a substantial reduction in global emissions after mid-century (RCP 4.5), projected temperature increases are somewhat lower with a

1.4 °C to 2.5 °C (2.5 °F to 4.5 °F) increase by 2040-2070 and a 1.9 °C to 3.1 °C (3.5 °F to 5.5 °F) increase by 2070-2100 (Garfin et al. 2014). In general, precipitation is projected to increase, but there is considerable variation in projections and confidence in precipitation projections is much lower than for temperature projections (Garfin et al. 2014).

For COLM, climate models project an increase in annual temperature and projections for all RCPs are indistinguishable until after about 2050, illustrating the 'commitment' to continuing climate change over the coming decades regardless of emissions pathway (Figure 8A). Average annual temperature is projected to increase 1.6 °C (2.9 °F) by 2030 with a 5.7 °C (10.2 °F) increase by the end of the century under RCP 8.5 (NCCSC 2015). This can be compared to a 0.5 °C (0.9 °F) increase over the period of 1980-2009 (NCCSC 2015). Precipitation at COLM is generally projected to slightly increase, but there is considerable variation in the projections (Figure 8B). While confidence in projections of seasonal or total precipitaiton is low, the models consistently project increased variation in both seasonal and annual precipitation. Such enhanced variation in the precipitation regime may manifest as both wetter and drier conditions, including heavier rain events and longer droughts (Melillo et al. 2014). Average monthly precipitation for COLM is projected to increase by 2.5 mm (0.1 in) by 2020 and by 3.6 mm (0.14 in) by 2080 (NCCSC 2015). Projected change in temperature and precipitation under various RCPs is given in Table 2. Precipitation changes projected by the climate models reflect the general tendency for warmer climates to generate convection storms, and the projections overall suggest that the warmer seasons – spring and summer – are likely to experience an average increase in precipitation. The climate data used in these analyses provided no information on patterns of precipitation (e.g., drizzles vs. thunderstorms), but general predictions are for more temperature extremes and associated weather (Diffenbaugh and Ashfaq 2010, IPCC 2011, Gonzales 2013).

Overall, the climate is likely to be much hotter and plant-available moisture will likely decline due to changes in evapotranspiration. Evapotranspiration (ET) is the amount of moisture returned to the atmosphere through the combination of evaporation and plant transpiration. Climate scientists are concerned with two aspects of ET: actual evapotranspiration (AET) and potential evapotranspiration (PET). As its name suggests, AET is the amount of evapotranspiration that is actually occurring. PET is "a measure of the ability of the atmosphere to remove water from the surface" (Cowell and Urban 2010, p. 741). Higher temperatures will drive greater rates of evapotranspiration, thus even with an increase in precipitation, soil water levels are projected to decrease (Cowell and Urban 2010). By the end of the 21st century, Cowell and Urban (2010) project an increase in PET of 227 mm (8.9 in) for the Colorado River Basin region. The projected increase in PET for the Colorado River Basin region is nearly 10 times the projected increase in precipitation, resulting in a huge increase (176 mm [6.9 in]) in soil water deficit (Cowell and Urban 2010).

The ratio of AET to PET is used as an 'aridity index' that indicates the amount of moisture available to plants (Evan Girvetz, The Nature Conservancy (TNC), Senior Scientist, e-mail communication, 7 June 2011). For example, a 0.15 decrease in this ratio can be interpreted as a 15% increase in aridity, or 15% less moisture available for plants (Girvetz, e-mail communication, 8 June 2011). While aridity is not expected to change much during the winter and summer, projections for the COLM region overall indicate an 8-13% increase in aridity (from a 1960-1990 reference period) during the fall and spring by 2050 (ClimateWizard 2014). By 2100, aridity is projected to increase by approximately 13-17% in the fall and spring under RCP 8.5 (ClimateWizard 2014).

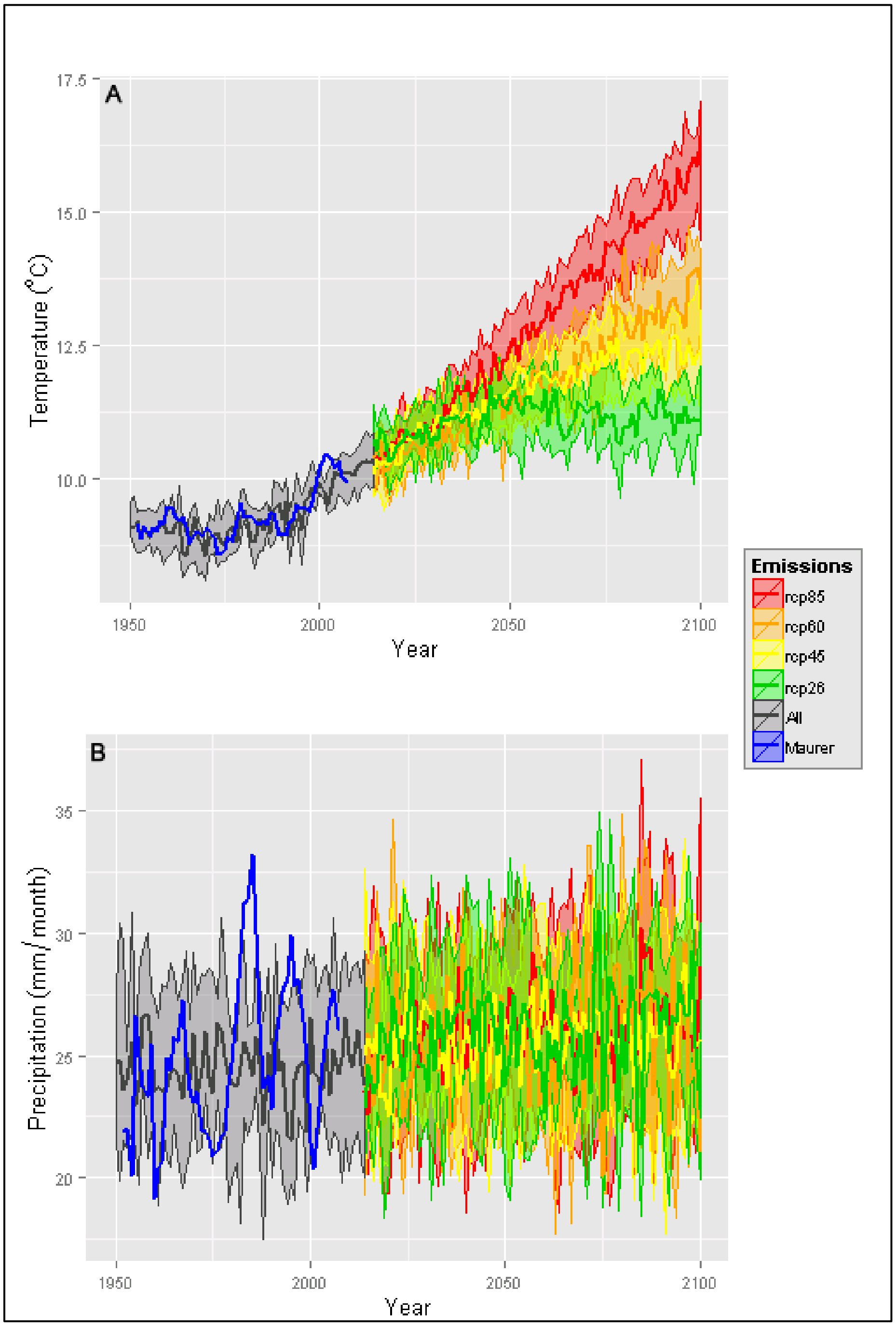

Figure 8. Projected (A) average annual temperature and (B) total annual precipitation from a suite of models, driven by RCP scenarios. The solid line represents the mean of the models and shaded area represents the 25 and 75% quartiles. Data analysis was conducted by NCCSC (2015).

Table 2. Projected changes in average annual temperature and precipitation compared to the baseline period of 1980-2009. The value represents the mean for all available model predictions for each RCP. Data analysis was conducted by NCCSC (2015).

	Change in Temperature (°C)			Change in Precipitation (Average mm/month)		
Year	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
1980 to 2009		**0.52**			**3.33**	
2020	1.55	1.53	1.62	2.57	2.39	2.48
2040	2.34	2.17	2.77	2.73	2.73	2.76
2060	2.95	3.03	4.16	2.95	2.72	3.49
2080	3.37	3.97	5.68	3.22	3.6	3.6

To summarize, models are very consistent in projecting a much warmer climate for COLM. Projections of trends in the amount of precipitation are much less certain, but the overall warming trend is very likely to result in greater seasonal and annual variation in the amount of precipitation. Projected combinations of higher temperatures, little or no increase in the amount of precipitation, and increased variation in rainfall, will very likely result in more frequent short-term and multi-year droughts.

2.1.3 Visitation Statistics

From 2010 to 2014, COLM received nearly 430,000 recreational visitors per year on average, with most visitations occurring between May and September (NPS 2015c). During this 5-year period, visitation peaked in 2012 with a record 454,510 recreational visitors (NPS 2015c, Kim Hartwig, COLM Chief of Resources Management, written communication, 30 January 2016). In 2014, COLM received nearly 417,000 visitors, which was slightly below average over the latest 5-year period (NPS 2015c). Visitation in 2015 set new records for total visitors (recreational and non-recreational) and recreational visitors (Hartwig, written communication, 30 January 2016). Overall 919,835 people visited the park in 2015, with 588,006 being recreational visitors (Hartwig, written communication, 30 January 2016). Under the current method for collecting and analyzing visitation numbers (in place since 1978) the previous record of 780,710 total visitors was established in 1993, and as mentioned above, the record for recreational visitors was set in 2012 (Hartwig, written communication 30 January 2016).

Many visitors come to the park to travel Rim Rock Drive (Photo 1), stopping at pull outs to view the incredible monoliths and canyons. There are 16 scenic overlooks along Rim Rock Drive, as well as several tunnels and switchback turns, making the drive a memorable experience (Figure 3). The park also features hiking trails, a campground, picnic areas, and the Saddlehorn visitor center. Hiking trails vary in length and intensity, and provide opportunities to photograph the park’s scenic beauty and encounter wildlife.

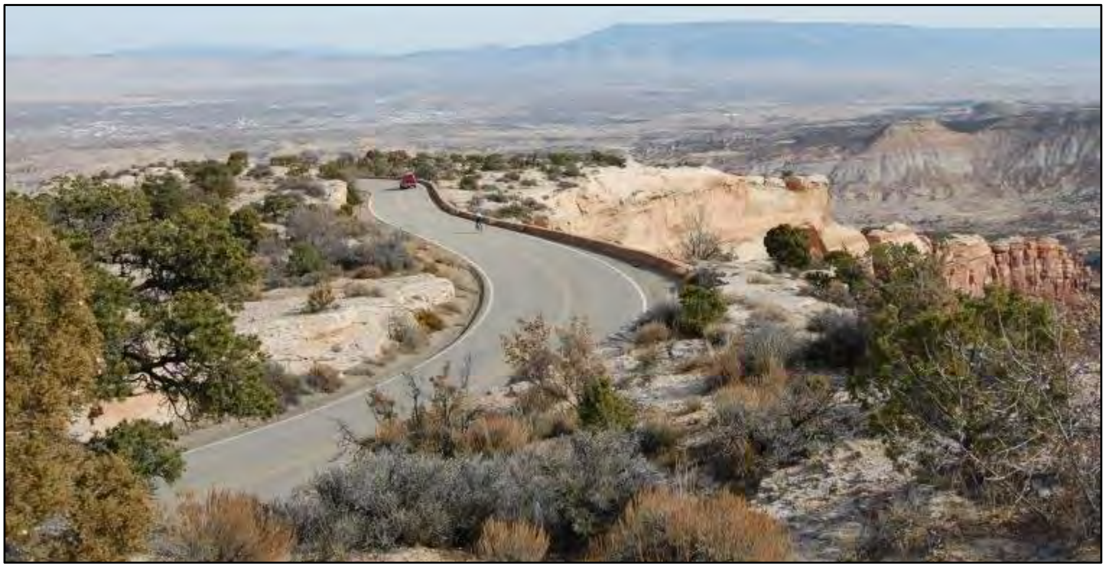

Photo 1. Rim Rock Drive (NPS photo).

2.2 Natural Resources

2.2.1 Ecological Units and Watersheds

This area of western Colorado where COLM is located is part of the Colorado Plateau (Figure 9) (KellerLynn 2006). This physiographic province is an eroded desert landscape that covers parts of Colorado, Utah, Arizona, and New Mexico (Figure 9) (KellerLynn 2006). The park is situated in the northeastern portion of the Canyon Lands Division of the Colorado Plateau, on the northeast side of the topographic feature known as the Uncompahgre Plateau (Lohman 1965, KellerLynn 2006, Tweet et al. 2012). The Uncompahgre Plateau is a high, relatively flat elongated area that extends from Ridgeway, Colorado in a northwesterly direction to near Cisco, Utah (KellerLynn 2006).

This area of Colorado falls within the Environmental Protection Agency's (EPA) Colorado Plateaus Level III Ecoregion. According to the EPA (2010, p. 3), the Colorado Plateau is "an arid sagebrush steppe and grassland, surrounded on all sides by moister, predominately forested, mountainous ecological regions." The EPA Level III Ecoregions are subdivided into smaller units and COLM is located within the Semiarid Benchlands and Canyonlands EPA Level IV Ecoregion (Figure 10).

This Level IV Ecoregion is characterized by broad grass-, shrub-, and woodland-covered benches and mesas (EPA 2010). The Gunnison River joins the Colorado River just to the east of the park, and their drainage roughly parallels the parks eastern and northern boundaries (Figure 11) (Tweet et al. 2012). The park is located within the Colorado Headwater Plateau Subbasin of the Upper Colorado Region. The park is entirely within the Big Salt Wash-Colorado River Watershed and the canyons of the park are drained by a variety of subwatersheds (Figure 11).

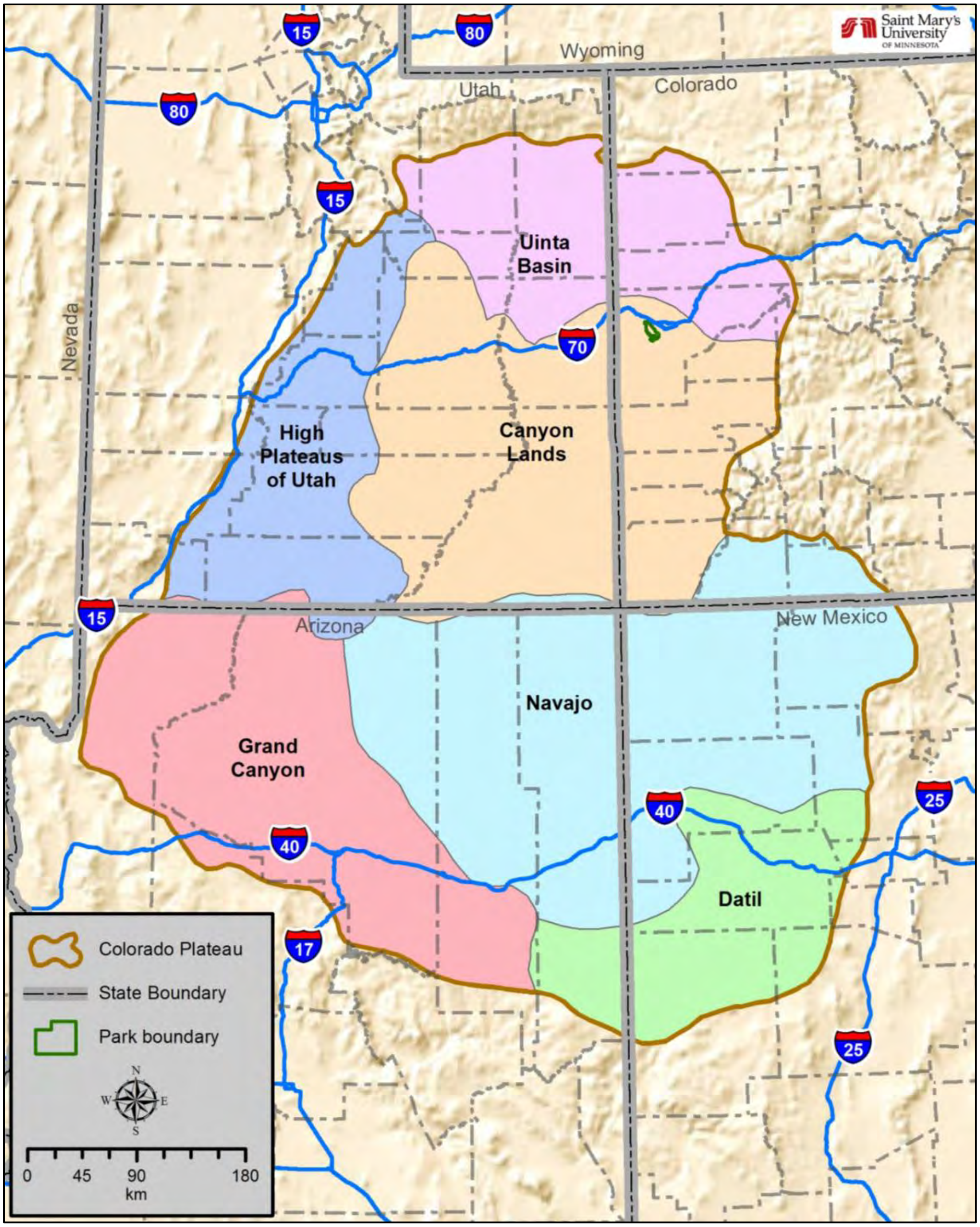

Figure 9. The Colorado Plateau and associated physiographic divisions (USGS 2011).

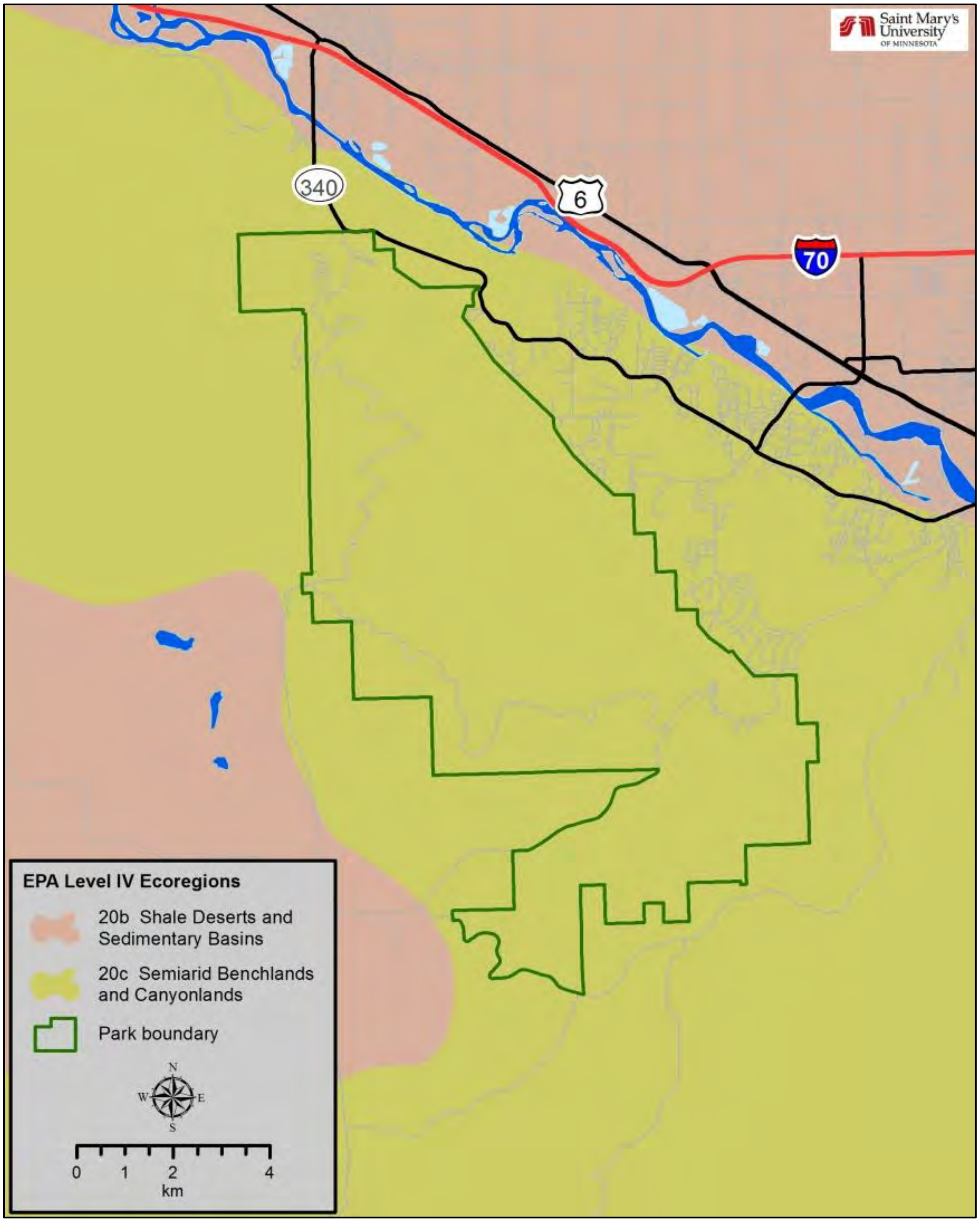

Figure 10. Level IV ecoregions for COLM.

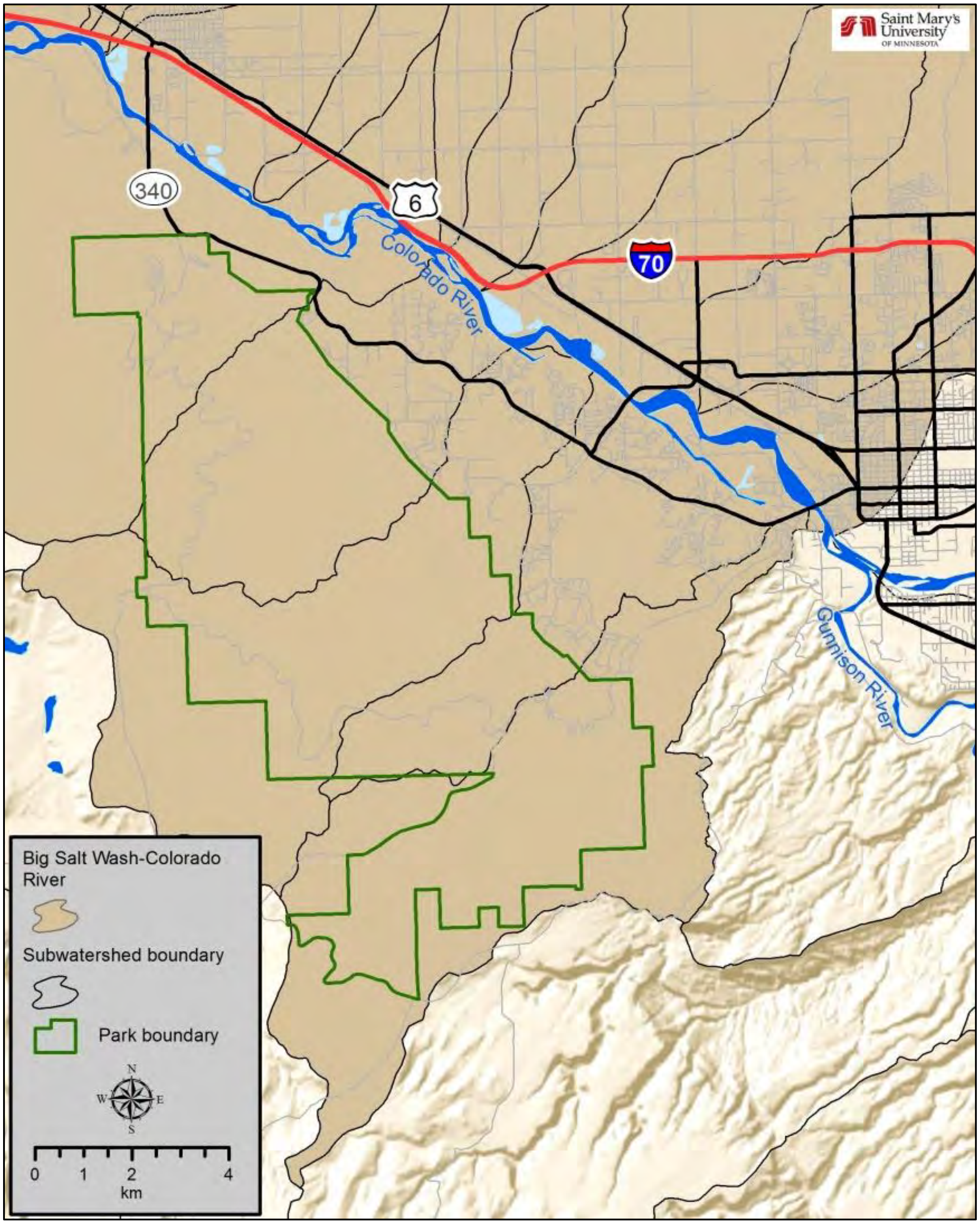

Figure 11. Big Salt Wash-Colorado River watershed and sub-watersheds.

2.2.2 Resource Descriptions

COLM preserves one of the grand landscapes in the American West (NPS 2015a). It is an area of sheer-walled canyons, towering monoliths, and colorful formations (NPS 2015a). It is also home to a representative example of an intact high desert ecosystem (NPS 2015a). Geologic processes, including sedimentation, faulting, uplifting, erosion, landslides, rockfalls, and flash flooding have resulted in the many landforms and geologic features within the park (NPS 2015a).

COLM has a variety of notable geologic features, including hanging canyons, rock layers that contain a record of the geologic history of the area, and the park's distinctive monoliths and canyons (NPS 2015a). The tops of formations, such as pedestals and spires, are isolated, ranging from approximately 1,700-2,100 m (5,600-6,900 ft) and have little soil that is accumulated through wind (eolian) processes (Kennard and Moore 2013). Canyon and monolith walls have occasional patches of vegetation that has taken root on ledges and holes.

No Thoroughfare Canyon, one of several canyons in COLM, has rock exposures that predate the formation of continental North America (1.74 billion years old) and have been uplifted and eroded into beautiful spires, valleys, and mesas (Tweet et al. 2012). The basement rocks of the canyon bottoms contain a disconformity of 1.5 billion years that alludes to the significant changes to the continental conditions and is studied throughout the extent of the Colorado Plateau Networks (Northern Colorado Plateau Network [NCPN] and Southern Colorado Plateau Network [SCPN]); the park serves as a key to understanding earth's dynamisms (NPS 2005). The events that took place have created the beautiful shapes and colors seen along Rim Rock Drive, the main park road. Layers of depositional periods are easily differentiated in sedimentary rock faces; the color and texture are strikingly contrasted in some areas (Photo 2).

Photo 2. The layers of sedimentary rock are exposed by erosional forces along many parts of Rim Rock Drive in the park; each horizontal layer represents a period of deposition through geologic time (Photo by Anna Davis, SMUMN GSS).

Ecoregionally distinct vegetation communities, such as old-growth pinyon-juniper forests, hanging gardens and tinajas can be found within the boundaries of COLM (Von Loh et al. 2007, NPS 2015a). Other notable vegetation communities found within the park include riparian and wetland communities, native grasslands, and sagebrush shrublands (Von Loh et al. 2007, NPS 2015a). Dwarfed woodlands and sparse shrublands are the dominant vegetation types within the park (Von Loh et al. 2007). Within these types, pinyon-juniper woodland is the most widespread vegetation community on the upper mesas of COLM (Von Loh et al. 2007). These woodlands are primarily composed of two-needle pinyon pines (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) trees (Von Loh et al. 2007). Tree canopy cover in these communities ranges up to 45%, and there is a sparse shrub and herbaceous understory (less than 5% total cover) (Von Loh et al. 2007). Biological soil crusts (BSCs) are also well developed between plants in these areas (Von Loh et al. 2007). There are more pinyon pines than junipers in terms of density, largely due to high numbers of small pinyon pines (Kennard and Moore 2013). However, the junipers are by far the older of the two species. The oldest juniper trees are estimated to be over 900 years old (Kennard and Moore 2013). Sagebrush shrublands are dominant in areas where deeper eolian soil deposits occur (Von Loh et al. 2007, Kennard and Moore 2013). Basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*), Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*), and black sagebrush (*A. nova*) are the most common species found in these communities (Von Loh et al. 2007). Mixed salt desert scrub is distributed in patches throughout the park and is also reliant on BSCs (Von Loh et al. 2007).

Riparian habitat occurs along dry washes where seeps, springs, and intermittent flows during rain events support diverse biota (Von Loh et al. 2007). The riparian zones stand out against the more barren, rocky land adjacent to them, with tall cottonwoods visible from the mesa tops; these habitats are crucial to the ecology within COLM (Von Loh et al. 2007). The hanging gardens of COLM's canyon walls are mesophytic plant communities that establish upon seeps and springs that lack actual surface flow (May et al. 1995). Water fed to these micro-habitats comes from seeps and springs within the bedrock (capillary fringe) and are isolated from the surrounding plant communities (May et al. 1995). The name "hanging garden" describes the behavior of vegetation which hangs from the roots, hugging the wetted surface of the cliff where "groundwater sapping" feeds the vegetation and creates a shelter from the otherwise arid climate (May et al. 1995). Tinajas are "ephemeral water pockets or scour pools in the American Southwest". These potholes in the bedrock often form below waterfalls that are fed by seeps and springs that achieve streamflow during big rain events or melting periods (Osterkamp 2008).

BSCs are a valued feature of dryland ecosystems such as the Colorado Plateau (Belnap et al. 2008). BSCs are composed of intertwined communities of lichens, mosses, and cyanobacteria (Belnap et al. 2008). These communities, along with green algae and microfungi, hold eolian silt and sand in place, creating slow-growing bacterial mats (NPS 2015b). Soil crusts are an essential part of the ecosystems where they occur, influencing soil stability, soil fertility, local hydrology, and soil biodiversity (Belnap et al. 2008). Simply stated, they create an environment that facilitates the germination of seeds from a variety of plants (NPS 2015b). Due to their fragile, slow-growing nature, measures are needed to avoid damaging these soil crusts (NPS 2015b).These measures include educating visitors on the delicate nature of the soil crusts and posting signs instructing hikers to stick to the established trails (NPS 2015b).

COLM supports a variety of mammals, occupying various habitats. Common species include the desert cottontail (*Sylvilagus audubonii*), mule deer (*Odocoileus hemionus*), bats (Order Chiroptera), and many small mammals. Visitors occasionally spot coyotes (*Canis latrans*; Photo 3), bighorn sheep (*Ovis canadensis*), and gray foxes (*Urocyon cinereoargenteus*) (NPS 2014b).

Photo 3. A coyote at COLM (NPS photo).

There are many resident, migratory, and breeding bird species that occur in COLM and rely on park resources for survival. COLM is recognized as an Important Bird Area (IBA) by the National Audubon Society (NAS); the park's pinyon-juniper woodland habitat is largely intact and provides a valuable research opportunity in a protected setting (NAS 2013). Falcons, hawks, and owls of various species are found in COLM's habitats as well as hummingbirds and songbirds, making the park an attractive scene for bird enthusiasts.

Paleontological resources are present at COLM, and all the formations with the exception of the Proterozoic units and the Dakota Formation, contain fossils (Table 3). The Dakota Formation is included as a source of fossils found based on the descriptions of Scott et al. (2011). Certain rock layers are considered most likely to bear fossils. The fossil-bearing sedimentary units found in COLM are listed by age, formation name, and depositional environment in Table 3.

Table 3. The geology of COLM is rich in fossil-bearing sedimentary rock formations (recreated from Tweet et al. 2012).

Formation	Age	Fossils found in COLM	Depositional Environment
Quaternary Sediments	Pleistocene-Holocene	Plant fossils, a mammoth or mastodon tooth, bones of nine other mammal and bird taxa, and packrat middens	Alluvial, eolian, fluvial, and landslide deposits
Dakota Formation	Early–Late Cretaceous	Possibly plant fossils, root traces, and invertebrate traces	Terrestrial (especially fluvial) becoming shallow marine over time
Burro Canyon Formation	Early Cretaceous	Petrified wood, root traces, invertebrate traces, and dinosaur bones	Fluvial, floodplain, and lacustrine settings

Table 3 (continued). The geology of COLM is rich in fossil-bearing sedimentary rock formations (recreated from Tweet et al. 2012).

Formation	Age	Fossils found in COLM	Depositional Environment
Morrison Formation	Late Jurassic	Bivalves, gastropods, horseshoe crab traces, a lungfish tooth plate, bones of turtles, crocodile relatives, and dinosaurs, and a pterosaur footprint	Fluvial, floodplain, and lacustrine settings
Wanakah Formation	Middle Jurassic	Invertebrate traces and possible pterosaur feeding traces	Mud flats and/or shallow lakes
Entrada Sandstone	Middle Jurassic	Bioturbation	Coastal dunes and sand flats
Kayenta Formation	Early Jurassic	Local bioturbation and two bones	Primarily fluvial settings
Wingate Sandstone	Late Triassic–Early Jurassic	Bioturbation from roots and burrows, and tracks of dinosaurs, other reptiles, and mammal relatives	Desert with large eolian sand dunes
Chinle Formation	Late Triassic	Root traces, invertebrate traces, and rare bones	Fluvial, floodplain, and lacustrine settings, becoming drier over time

COLM encompasses some 8,094 ha (20,000 ac) of which approximately 6,070 ha (15,000 ac) has been identified or proposed as wilderness (Figure 12) (NPS 2015a). The original proposal in January 1976 submitted a recommendation to Congress to designate 4,168 ha (10,300 ac) of COLM's remote, rugged canyons as wilderness (NPS 1978). In January 1978, the NPS submitted a revised recommendation that expanded the proposed wilderness area to 5,602 ha (13,842 ac) and included an additional 379 ha (937 ac) be reserved as potential wilderness (NPS 1978). While the designation is still under consideration, the proposed area is managed under NPS policy as wilderness (NPS 2015a).

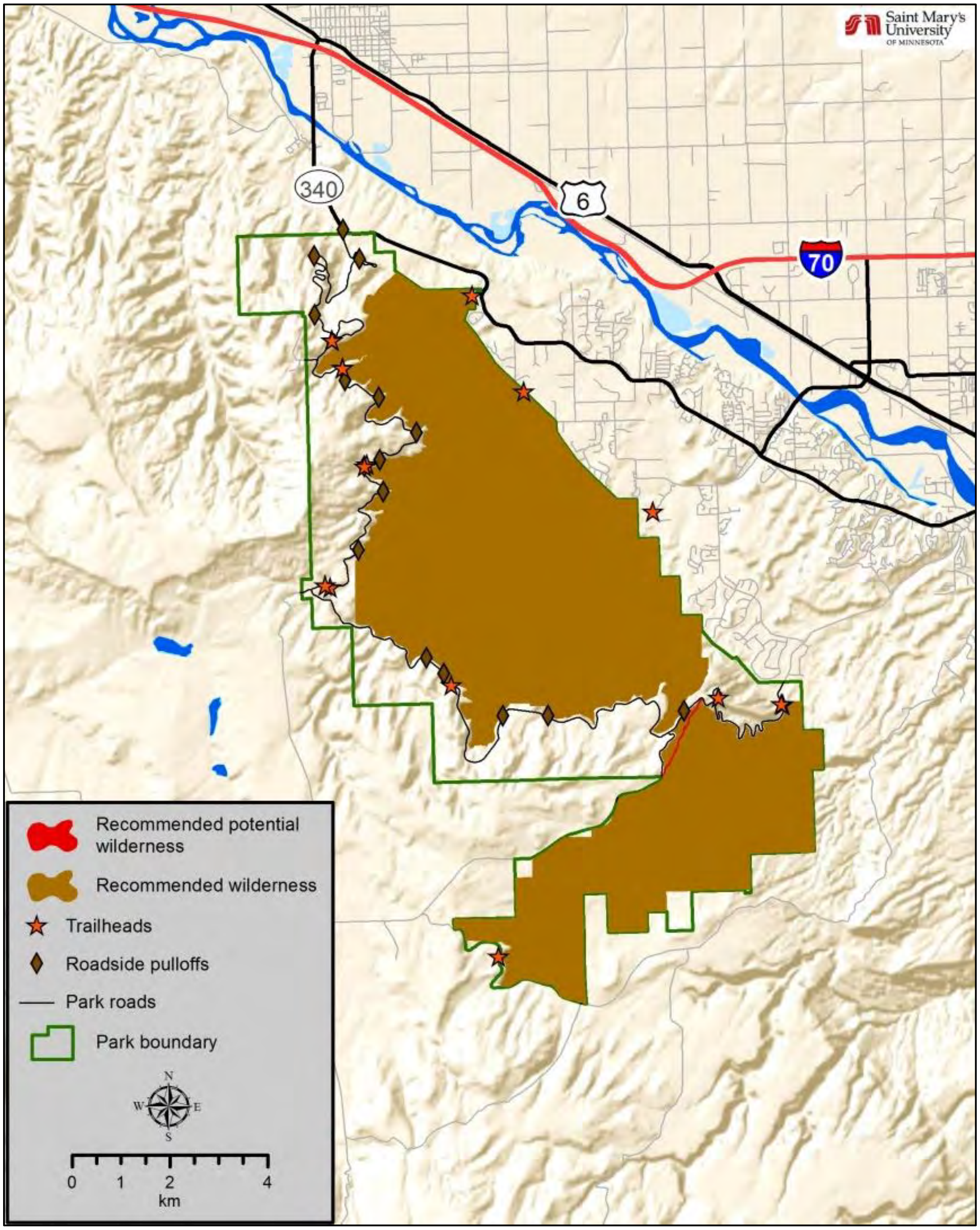

Figure 12. Location of proposed wilderness area within COLM.

2.2.3 Resource Issues Overview

Climate change is an issue that will affect not only natural and cultural resources within COLM, but also visitation patterns (Fisichelli et al. 2015). The recent rapid changes in Earth's climate are well documented and include such impacts as significant increases in average temperatures and precipitation in the last 50 years, as well as increased incidence of extreme weather events (e.g., extended drought, heavy rainstorms) (IPCC 2007). These climatic shifts have already been linked to a number of impacts to natural systems, including such phenological changes as earlier onset of plant greenness, earlier insect emergence and flowering of plants, shifts in the onset of migration and breeding seasons, and changes in geographic ranges (summarized in Stein and Glick 2011).

In order to develop meaningful conservation strategies, managers must understand the wide range of impacts, risks, and uncertainties associated with projected climate changes, and try to estimate the relative vulnerability of different ecosystems and species to these projected changes. For instance, more vulnerable species and systems are more likely to experience greater impacts from climate change and would require a greater effort in conservation planning, while less vulnerable species and systems will be less affected, or may even benefit; this may require less intensive conservation planning relative to a changing climate. Managing for such changes in natural systems is rapidly becoming a priority for conservation agendas.

The control of non-native and invasive plant species is a high priority for the NPS (Perkins 2014). They are a significant threat to maintaining the integrity of natural ecosystems and to biodiversity (Scott and Wilcove 1998, Perkins 2014). Non-native and invasive species monitoring has been conducted at COLM since 2003 (Perkins 2014). This monitoring is based on a priority species list developed by the NCPN and park staff (Perkins 2014). Field crews are trained to conduct a focused search for the priority species, rather than for every possible invasive species (Perkins 2014).

Monitoring of invasive exotic species (IEPs) based on this priority list allows for the comparison across multiple survey years; however, the priority (or targeted species) in 2003 was different than for the 2009-2013 surveys (Perkins 2014). COLM is part of a long-term monitoring program for IEPs developed by the NCPN that focuses on early detection (Perkins 2014). The first survey of IEPs in the park was conducted in 2003 by Dewey and Anderson (2005). The initial survey in 2003 detected 15 IEP species (Dewey and Anderson 2005). Since the 2003 survey, there have been three IEP monitoring surveys (2009, 2011, and 2013); the non-native species detected each year are shown in Table 4. In the 2009, 2011, and 2013 field seasons, 16, 22, and 14 species were detected, respectively (Perkins 2010, 2012, 2014).

Table 4. IEP species that have been detected in COLM. Priority species are in bold.

Scientific Name	Common Name	Dewey and Anderson (2005)	Perkins (2010)	Perkins (2012)	Perkins (2014)
Acroptilon repens	**Russian knapweed**		**X**	**X**	**X**
Agropyron cristatum	crested wheatgrass			X	
Alyssum desertorum	desert madwort			X	
Arctium minus	**burdock**				**X**
Asparagus spp.	asparagus		X		
Bassia sieversiana	summer cypress			X	
Bromus inermis	smooth brome			X	
Bromus tectorum	cheatgrass	X	X	X	X

Table 4 (continued). IEP species that have been detected in COLM. Priority species are in bold.

Scientific Name	Common Name	Dewey and Anderson (2005)	Perkins (2010)	Perkins (2012)	Perkins (2014)
Cardaria latifolia	**broad-leaf pepperwort**		**X**		**X**
Carduus nutans	musk thistle		X	X	
Centaurea solstitialis	yellow starthistle		X		
Cirsium arvense	**Canada thistle**		**X**		
Cirsium vulgare	**bull thistle**		**X**	**X**	**X**
Conium maculatum	poison hemlock	X			
Convolvulus arvensis	**field bindweed**	**X**	**X**	**X**	**X**
Cylindropyrum cylindricum	jointed goatgrass			X	
Elaeagnus angustifolia	**Russian olive**	**X**	**X**	**X**	**X**
Erodium cicutarium	redstem stork's bill	X		X	
Halogeton glomeratus	saltlover	X			
Halogeton glomeratus	halogeton			X	
Lactuca serriola	prickly lettuce	X			
Medicago sativa	alfalfa				X
Melilotus officinalis	**yellow sweetclover**	X	X	X	X
Orthoceras spp.	bur buttercup			X	
Poa bulbosa	bulbous bluegrass				X
Rumex crispus	curly dock	X			
Salsola kali	Russian thistle	X	X	X	
Sisymbrium altissimum	tall tumblemustard	X			
Tamarix ramosissima	saltcedar	X	X	X	X
Tragopogon dubius	yellow salsify	X	X	X	
Ulmus pumila	**Siberian elm**		**X**	**X**	**X**
Verbascum thapsus	**woolly mullein**	**X**	**X**	**X**	**X**
Populus alba	white poplar			X	

Dewey and Anderson (2005) conducted non-native plant surveys along routes in Gold Star Canyon, Monument Canyon, No Thoroughfare Canyon, and Ute Canyon. Perkins (2009-2014) surveyed those canyons as well as Columbus Canyon, Kodels Canyon, Red Canyon, Wedding Canyon, East Glade Park Road, and Rim Rock Drive South.

Results of the most recent survey (conducted between 31 July and 16 August 2013) showed for the areas that have been monitored in all years, Russian olive (*Elaeagnus angustifolia*) declined to its lowest levels in 2013, following increases in the two previous surveys (2009 and 2011) (Perkins 2014). The occurrence of Russian olive infestations dropped by 77% between 2011 and 2013, and declined on every route that was monitored in all years (Perkins 2014). Saltcedar (*Tamarix* *ramosissima*) has also declined over the period, with four infestations in 2013 (Perkins 2013). This represented an 81% reduction in tamarisk (*Tamarix* spp.) infestations since 2011, and a 96% reduction since 2003 (Perkins 2014). The decline in saltcedar is likely due to manual control efforts by seasonal park staff and volunteers (Perkins 2014). The park expects to expand these efforts to include Russian olive in the near future (Perkins 2014). Yellow sweetclover (*Melilotus officinalis*) (added to the priority list in 2011) exhibited an increase in number of infestations between 2011 and 2013 (Perkins 2014). It is unclear if this is due to actual changes in IEP presence or if it reflects environmental variation (e.g., varying weather could favor certain species) and/or slight differences in the timing and focus of surveys. The frequency of cheatgrass (*Bromus tectorum*) occurrences has been variable, ranging from 1% of transects surveyed in 2009 to appearing in 68% of transects in 2011 (Perkins 2014). This increase between the 2009 and 2011 surveys was likely due to the wet spring in 2011 (Perkins 2014). In the latest survey (2013), the frequency of cheatgrass occurrences declined to 48% (Perkins 2014).

Concerted control efforts by park staff have been instrumental in reducing the infestations of priority species, both in number of infestations and aerial extent. Currently this program is no longer funded, and lack of another viable program to fund future efforts is a major threat to maintaining this decrease in IEP infestations within the park (Hartwig, written communication, 30 January 2016).

Under the historic fire regime, fires were likely infrequent and low intensity. The study conducted by Kennard and Moore (2013) estimated that significant fires occurred anywhere from 588 to 1,428 years apart. Small, isolated fires at COLM are common; park staff describe the often-seen single tree burning caused by lightning strike, explaining that these small fires tend to stay isolated to one tree unless there are high winds that can blow sparks to a nearby tree. This phenomenon is indicative of the park having the persistent type of pinyon-juniper woodlands with low fire frequency, as was observed in the evidence of past fires in Kennard and Moore's (2013) survey. Lack of understory fuels and open canopy stands contribute to this low frequency fire ecology where soil is thin to non-existent and inhibits growth of fuels. The introduction of non-native species, especially cheatgrass, creates a fuel source to spread fire, and the potential to alter the natural fire regime.

The park does not limit foot travel to established trails. This has led to the creation of an extensive social trail network (Hartwig, written communication, 18 November 2015). These social trails are found across all habitat types within the park, and increasing visitor use of these trails can lead to trampling of vegetation and potentially to an increase in erosion rates. Both of these factors can eventually lead to loss of habitat. An increase in recreational climbing within the park is another potential source of visitor impact to resources that is of a concern to park resource managers. This activity is a major threat to hanging garden vegetation and other cliff-face vegetation communities as well as to the wildlife species such as bats and raptors that use these cliff-faces.

Some of the park's canyon areas were particularly impacted by a herd of bison (*Bison bison*) that grazed there from the 1930s until the 1980s (KellerLynn 2006). The bison were initially introduced in an effort to attract visitors to the park (KellerLynn 2006), but the herd's presence had some negative impacts on sagebrush, scrub, grassland vegetation communities and the seep and spring communities (Wasser 1977). For example, species such as fourwing saltbush (*Atriplex canescens*) and some native grasses appeared to decrease under grazing pressure (Wasser 1977). Some invasive species, such as cheatgrass and saltcedar, seemed to increase as it appears the bison provided a vector for their introduction into the vegetation communities (Wasser 1977, O'Dell et al. 2005, KellerLynn 2006). The bison also disturbed BSCs and compacted soils, resulting in reduced water infiltration rates (Wasser 1977, KellerLynn 2006). As the main source of water in the park, the bison also disturbed the seeps and springs communities through trampling of vegetation and soil compaction. The lingering impacts of this bison grazing on the canyon communities they inhabited have not been assessed.

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

COLM is part of the National Park System, and is preserved for having a natural resource in the form of grand geologic, ecologic, and historical value to the people (NPS 2005). The NPS General Management Plan outlines the current mission and purpose of COLM as follows:

> **Mission -** *Bold, big, and brilliantly colored, the steep-walled canyons and towering masses of naturally sculpted rock provide an introduction to the red rock country of the Colorado Plateau. Easily accessible, Colorado National Monument provides awe-inspiring vistas and opportunities for solitude and personal connection to the cultural and natural heritage of the Grand Valley of western Colorado. The National Park Service will work in a spirit of partnership and collaboration to promote the understanding, appreciation, and protection of this national treasure (NPS 2005).*
>
> **Purpose -** *The purpose of Colorado National Monument is to provide for the understanding, preservation, and enjoyment of the extraordinary erosional, geological, and historical landscapes of great scientific interest, the Rim Road, and all other natural and cultural resources for present and future generations (NPS 2005).*

2.3.2 Status of Supporting Science

The NCPN identifies key resources network-wide and for each of its parks that can be used to determine the overall health of the parks. These key resources are called Vital Signs. In 2005, the NCPN completed and released a Vital Signs monitoring plan (O'Dell et al. 2005). Table 5 shows the network vital signs selected for monitoring in COLM.

Table 5. NCPN Vital Signs selected for monitoring in COLM (O'Dell et al. 2005). Bold indicates Vital Signs that currently are or will be monitored by the NCPN. Italics indicate Vital Signs being monitored by a network park, another NPS program, or another federal or state agency, using other funding.

Category	NCPN Vital Signs
Air and Climate	Air quality (ozone, wet and dry deposition, visibility and particulate matter), *weather and climate*
Geology & Soils	Stream/ river channel characteristics, soil function and dynamics

Table 5 (continued). NCPN Vital Signs selected for monitoring in COLM (O'Dell et al. 2005). Bold indicates Vital Signs that currently are or will be monitored by the NCPN. Italics indicate Vital Signs being monitored by a network park, another NPS program, or another federal or state agency, using other funding.

Category	NCPN Vital Signs
Water	Water chemistry, ground and surface water dynamics, aquatic macroinvertebrates and algae
Biological Integrity	**Invasive/exotic plants,** insect pests, animal diseases, riparian communities, freshwater communities, grassland vegetation, shrubland vegetation, amphibians, **birds**, bats, predominant plant communities, threatened and endangered species (T&E) (e.g., peregrine falcon) and T&E plant populations
Human Use	**Consumptive use, non-point source human effects,** *visitor usage*
Ecosystem Pattern and Processes	Fire and fuel dynamics, **land cover and use,** night sky, soundscape, nutrient dynamics, **productivity**

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3. Study Scoping and Design

This NRCA is a collaborative project between the NPS and Saint Mary's University of Minnesota Geospatial Services (SMUMN GSS). Project stakeholders include the COLM resource management team and NCPN Inventory and Monitoring Program staff. Before embarking on the project, it was necessary to identify the specific roles of the NPS and SMUMN GSS. Preliminary scoping meetings were held, and a task agreement (issued against the Pacific Northwest Cooperative Ecosystem Studies Unit [PNW CESU] and Joint Venture Agreement H8W07110001), and a scope of work document were created cooperatively between the NPS and SMUMN GSS.

3.1 Preliminary Scoping

3.1.1 Natural Resource Condition Assessment

A preliminary scoping meeting was held on 11-13 December 2013. At this meeting, SMUMN GSS and NPS staff confirmed that the purpose of the NRCA was to evaluate and report on current conditions, critical data and knowledge gaps, and selected existing and emerging resource condition influences of concern to COLM managers. Following NRCA program guidance, this NRCA, includes the following:

- Condition assessments are conducted using existing data and information;
- Identification of data needs and gaps is driven by the project framework categories;
- The analysis of natural resource conditions includes a strong geospatial component;
- Resource focus and priorities are primarily driven by COLM resource management.

This condition assessment provides a "snapshot-in-time" evaluation of the condition of a select set of park natural resources that were identified and agreed upon by the project team. Project findings will aid COLM resource managers in the following objectives:

- Develop near-term management priorities (how to allocate limited staff and funding resources);
- Engage in watershed- or landscape-scale partnership and education efforts;
- Consider new park planning goals and take steps to further these;
- Report program performance (e.g., Department of Interior Strategic Plan "land health" goals, Government Performance and Results Act [GPRA]).

Specific project expectations and outcomes included the following:

- For key natural resource components, consolidate available data, reports, and spatial information from appropriate sources including: COLM resource staff, the NPS Integrated Resource Management Application (IRMA) website, NPS I&M Vital Signs program, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project.

- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point.
- Clearly identify "management critical" data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process.
- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually.
- Utilize "gray literature" and reports from third party research to the extent practicable.

3.1.2 Climate Change Vulnerability Assessment Pilot Study

The NPS is considering strategies to integrate climate change resource vulnerability into the park NRCAs. In March 2014, NPS partnered with SMUMN GSS to implement a pilot project to assess the feasibility of slightly modifying existing NRCA project scopes to accommodate an assessment of resource vulnerability to climate change. This effort was collaboration between the SMUMN GSS Principle Investigator (PI) for the COLM NRCA project, the NPS involved principles (including the Climate Change Response Program [CCRP]), the NRCA Program, the NRCA regional coordinators, COLM staff, and the North Central Climate Science Center (NCCSC).

The pilot project's goal was to seek creative approaches to considering climate change vulnerabilities in the context of a NRCA project. A number of on-going NRCA projects were included in this pilot, so in order to provide comparative assessments; a fundamental general approach was developed. Each NRCA project in the pilot study used the following basic criteria to assess resource vulnerability to climate change:

- Information about modeled and downscaled climate change data needed to assess vulnerability was developed using existing resources through the NCCSC, the NPS CCRP, and the NPS I&M program;
- Discussion with park resource managers was conducted to identify park species, habitats, processes, communities, or landscapes viewed as most significant, iconic, or best indicator of park resource vulnerability;
- Climate change vulnerability assessments (CCVA) for selected park resources, processes, or landscapes was completed using national, regional, or local scale readily available information, literature searches, and discussion with park resource experts or others deemed relevant to this determination.

The overall expectations and outcome of the pilot project included the following:

- Minimally impact the ongoing NRCA,
- Implemented as a qualitative process,
- Inform the need or urgency to conduct a formal park resource CCVA,
- Inform the feasibility and potential benefits of integrating a CCVA into the NRCA process.

3.2 Study Design for Natural Resource Condition Assessment

3.2.1 Indicator Framework, Focal Study Resources and Indicators

Selection of Resources and Measures

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

"Components" in this process are defined as natural resources (e.g., birds, plant communities), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current park management. Each key resource component has one or more "measures" that best define the current condition of a component being assessed in the NRCA. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of a component. In addition to measures, current condition of components may be influenced by certain "stressors," which are also considered during assessment. A "stressor" is defined as any agent that imposes adverse changes upon a component. These typically refer to anthropogenic factors that adversely affect natural ecosystems, but may also include natural processes or disturbances such as floods, fires, or predation (adapted from GLEI 2010).

During the NRCA scoping process, key resource components were identified by NPS staff and are represented as "components" in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the park, it includes resources and processes that are unique to the park in some way, or are of greatest concern or highest management priority in COLM. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

Selection of Reference Conditions

A "reference condition" is a benchmark to which current values of a given component's measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., a bison herd of at least 200 individuals) (adapted from Stoddard et al. 2006).

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

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science's "State of Our Nation's Ecosystems 2008" (Heinz Center 2008). Key resources for the park were adapted from the NCPN Vital Signs monitoring plan (O'Dell et al. 2005).

This initial framework was presented to park resource staff to stimulate meaningful dialogue about key resources that should be assessed. Significant collaboration between SMUMN GSS analysts and NPS staff was needed to focus the scope of the NRCA project and finalize the framework of key resources to be assessed.

The NRCA framework was finalized in March 2014 following acceptance from NPS resource staff. It contains a total of 21 components (Figure 13) and was used to drive analysis in this NRCA. This framework outlines the components (resources), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each component for comparison to current conditions.

Colorado National Monument
Natural Resource Condition Assessment

	Component	Measures	Stressors	Reference Condition
Biotic Composition				
Ecological Communities				
	Pinyon-juniper Woodlands/Savannas	community extent and change over time, percent cover biological soil crusts, percent bare ground, community composition, trends in invasive infestation, soil stability	exotic invasive species, unnatural fire regimes, trails (authorized and unauthorized), drought	Current pinyon-juniper woodlands on the mesa tops in the middle of the monument
	Sagebrush Shrublands/Shrub Steppe	community extent and change over time, percent cover biological soil crusts, percent bare ground, community composition, trends in invasive infestation, soil stability, canopy gap size	exotic invasive species (cheat grass), unnatural fire regime, trails (authorized and unauthorized), drought, regional climate change	Within the natural variability of the current system, particularly in the center of the monument away from the boundary (currently a data gap)
	Riparian Habitats/Large dry washes (including cottonwoods)	community extent and change over time, community composition, trends in invasive infestation, cottonwood regeneration, channel geomorphology, frequency and discharge of flash floods	exotic invasive species, trails (authorized and unauthorized), channelization outside park boundaries, regional climate change	Condition of riparian habitats prior to regional settlement
	Seeps and Springs and Tinaja Babitats	vegetation community extent and change over time, vegetation community composition, trends in invasive infestation, water quality, discharge	exotic invasive species, drought, development in surrounding communities (groundwater withdrawal and wastewater contamination), trails (authorized and unauthorized)	Condition of seeps, springs, and tinajas prior to regional settlement
	Mixed Salt Desert Scrub/Semi-desert Grassland	community extent and change over time, community composition, trends in invasive infestation, soil stability, percent cover biological soil crusts, percent bare ground	exotic invasive species (cheat grass), unnatural fire regime, trails (authorized and unauthorized), drought, regional climate change	Condition of mixed salt desert scrub and semi-desert grassland prior to regional settlement
	Canyon Walls and Monolith Vegetation Communities	community extent and change over time, community composition	exotic invasive species, recreational climbing, proximity of road to habitat, graffitti, regional climate change	Condition of this communities prior to regional settlement
	Montane shrubland	community extent and change over time, community composition, trends in invasive infestation, soil stability, percent cover biological soil crusts, percent bare ground	exotic invasive species (cheat grass & crested wheatgrass), unnatural fire regimes, trails (authorized and unauthorized), drought, regional climate variation	Within the natural variability of the current community (currently a data gap)

Figure 13. Colorado National Monument natural resource condition assessment framework.

Colorado National Monument
Natural Resource Condition Assessment

		Component	Measures (Significance Level)	Stressors	Reference Condition
Biotic Composition					
	Herptiles				
		Herptiles	amphibian richness, amphibian abundance, amphibian distribution, reptile richness, reptile abundance, reptile distribution	roadway mortality, habitat loss, regional climate change, drought, disease, visitor/human impacts (social trails), potential invasion of bull frogs	2002 herpetofauna inventory
	Birds				
		Birds	summer breeding bird richness, year-round bird richness	land cover change, habitat degradation and fragmentation, regional climate variation, predation by domestic/feral cats	Undefined
		Raptors	raptor richness, abundance, productivity, number of active nest sites	climbing activity disrupting nesting, recreation disturbance	Undefined
	Mammals				
		Small Mammals	species richness, abundance, distribution	vehicle traffic, roadway mortality, drought, regional climate change, feral/domestic cats, disease, habitat loss	1964 report on the distribution of mammals within COLM
		Mountain Lion	abundance, distribution, reproductive success	hunting (outside COLM boundary), conflicts with local landowners (ranchers), habitat loss (outside of COLM), negative impact of roads, encroachment of human activities	NPS historical reports (1939-1962)
		Bighorn Sheep	abundance, distribution, reproductive success	vehicle traffic, visitor activity, disease/parasites from domestic sheep, natural predators, hunting (outside COLM)	1995 CPW desert bighorn sheep management plan
		Kit Fox	abundance, distribution, reproductive success	roads and vehicle mortality, habitat loss and fragmentation, off-road recreation	CPW trapping harvest numbers (1975-1991) and statewide population (c. 1996)
		Bats	species richness, abundance, number of hibernation/roost sites, number of maternity sites	likely some threatened and endangereds, disease potential, habitat loss, pesticides, collisions, disturbance from climbers	Undefined exept for species richness and abundance data from 1989 and 1994 bat surveys

Figure 13 (continued). Colorado National Monument natural resource condition assessment framework.

Colorado National Monument
Natural Resource Condition Assessment

	Component	Measures (Significance Level)	Stressors	Reference Condition
Environmental Quality				
	Air Quality	atmospheric deposition of sulfur/nitrogen, ozone, particulate matter, visibility, atmospheric deposition of mercury	oil and gas development, vehicle emissions, smoke from wildfire and woodburning stoves, visibility impacts from haze and inversions	NPS ARD ratings for air quality conditions base don ecosystem thresholds and visibility improvement goals
	Dark Night Skies	sky glow from anthropogenic light, light pollution ratio for horizontal and vertical luminance, average sky luminance, vertical illuminance, Bortle Class/Zenith Limiting Magnitude, Unihedron Sky Quality Meter	existing lighting structures and other sources of anthropogenic light (within the surrounding area)	Dark night sky conditions during presettlement of the region (The ratio of anthropogenic hemisphere illuminance to natural hemisphere illuminance does not exceed 20%)
	Viewscape	noncontributing structures visible from within the recommended wilderness area, immediate viewscape at points along Rim Rock Drive	urban development, radio towers on adjacent lands, haze, management activities not contributing to immediate viewscape along Rim Rock Drive, commercial vehicle traffic	Viewscape at time of park creation (1911) from Rim Rock Drive and the overall grand viewscape
	Soundscape and Acoustic Environment	occurrence of human-caused sound (loudness and percent of time audible), occurrence of human-caused sound within and outside of proposed wilderness area	vehicle traffic, overflights from air traffic	Natural ambient sound level (environment of sound that would exist in the absence of anthropogenic-caused noise)
Physical Characteristics				
Geology				
	Paleontological Resources	changes in specimen abundance at localities, documentation and inventory of paleontological sites in the park, incidence of theft, amount paleontological resources eroded out each year, erosion rate at paleontological sites	erosion, weathering, regional climate change, theft, vandalism, recreation impacts (climbing)	Undefined
	Geologic Features and Processes	changes in rates of erosion, frequency of rock falls or slides, frequency of heavy rain and sustained wind events, frequency and discharge of flash floods	regional climate change (extreme weather events), vistior activities, park management activities	Undefined

Figure 13 (continued). Colorado National Monument natural resource condition assessment framework.

3.2.2 Reporting Area

Unless specifically noted, the current condition summaries describe the condition of the resource within the boundaries of COLM.

3.2.3 General Approach and Methods

This study involved gathering and reviewing existing literature and data relevant to each of the key resource components included in the framework. No new data were collected for this study; however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations. After all data and literature relevant to the measures of each component were reviewed and considered, a qualitative statement of overall current condition was created and compared to the reference condition when possible.

<u>Data Mining</u>

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

<u>Data Development and Analysis</u>

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available for the component, as well as recommendations from NPS reviewers and sources of expertise including NPS staff from COLM and the NCPN. Specific approaches to data development and analysis can be found within the respective component assessment sections located in Chapter 4 of this report.

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

Significance Level

A set of measures are useful in describing the condition of a particular component, but all measures may not be equally important. A “Significance Level” represents a numeric categorization (integer scale from 1-3) of the importance of each measure in assessing the component’s condition; each *Significance Level* is defined in Table 6. This categorization allows measures that are more important for determining condition of a component (higher Significance Level) to be more heavily weighted in calculating an overall condition. Significance Levels were determined for each component measure in this assessment through discussions with park staff and/or outside resource experts.

Table 6. Scale for a measure's *Significance Level* in determining a components overall condition.

Significance Level (SL)	Description
1	Measure is of low importance in defining the condition of this component.
2	Measure is of moderate importance in defining the condition of this component.
3	Measure is of high importance in defining the condition of this component.

Condition Level

After each component assessment is completed (including any possible data analysis), SMUMN GSS analysts assign a *Condition Level* for each measure on a 0-3 integer scale (Table 7). This is based on all the available literature and data reviewed for the component, as well as communications with park and outside experts.

Table 7. Scale for *Condition Level* of individual measures.

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

Weighted Condition Score

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

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

The resulting WCS value is placed into one of three possible categories: good condition (WCS = 0.0 – 0.33); condition of moderate concern (WCS = 0.34 - 0.66); and condition of significant concern (WCS = 0.67 to 1.00). Table 8 displays the potential graphics used to represent a component's condition in this assessment. The colored circles represent the categorized WCS; red circles signify a significant concern, yellow circles a moderate concern and green circles that a resource is in good condition. White circles are used to represent situations in which SMUMN GSS analysts and park staff felt there were currently insufficient data to make a statement about the condition of a component. For example, condition is not assessed when no recent data or information are available, as the purpose of an NRCA is to provide a "snapshot-in-time" of current resource conditions. The arrows inside the circles indicate the trend of the condition of a resource component, based on data and literature from the past 5-10 years, as well as expert opinion. An upward pointing arrow indicates the condition of the component has been improving in recent times. A horizontal arrow indicates an unchanging condition or trend, and an arrow pointing down indicates deterioration in the condition of a component in recent times. These are only used when it is appropriate to comment on the trend of condition of a component. In situations where the trend of the component's condition is currently unknown, no arrow is given.

Table 8. Description of symbology used for individual component assessments.

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

<u>Examples of how the symbols should be interpreted:</u>

Resource is in good condition, its condition is improving, high confidence in the assessment.

Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.

Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.

Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

Preparation and Review of Component Draft Assessments

The preparation of draft assessments for each component was a highly cooperative process among SMUMN GSS analysts and COLM and NCPN staff. Though SMUMN GSS analysts rely heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also plays a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step is especially important when data or literatures are limited for a resource component.

The process of developing draft documents for each component began with a detailed phone or e-mail conversation with an individual or multiple individuals considered local experts on the resource components under examination. These conversations were a way for analysts to verify the most relevant data and literature sources that should be used and also to formulate ideas about current condition with respect to the NPS staff opinions. Upon completion, draft assessments were forwarded to component experts for initial review and comments.

Development and Review of Final Component Assessments

Following review of the component draft assessments, analysts used the review feedback from resource experts to compile the final component assessments. As a result of this process, and based on the recommendations and insights provided by COLM resource staff and other experts, the final component assessments represent the most relevant and current data available for each component and the sentiments of park resource staff and outside resource experts.

Format of Component Assessment Documents

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

Description

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

Measures

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

Reference Conditions/Values

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

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

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

Threats and Stressor Factors
This section provides a summary of the threats and stressors that may impact the resource and influence to varying degrees the current condition of a resource component. Stressors are defined as long-term changes in natural processes that may impact a natural resource, while threats are imminent events, actions, or factors that impact natural resources. Relevant stressors were described in the scoping process and are outlined in the NRCA framework. However, these are elaborated on in this section to create a summary of threats and stressors based on a combination of available data and literature, and discussions with resource experts and NPS natural resources staff.

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

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

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

3.3 Study Design for Climate Change Vulnerability Assessment Pilot

3.3.1 Component Selection and Assessment Variables

Selection of Resources
A landscape scale community-based assessment was employed for the purpose of this pilot study. The selection of this type of assessment was based on the premise that plant communities and their related landscapes are the foundations for habitat and species. Plant communities are often priority resources that park managers express concern over when looking at ongoing park threats and long-term park resource sustainability. SMUMN GSS, the COLM NRCA project team, and the NPS climate change integration pilot team worked together to select two vegetation communities from the NRCA framework for an analysis of potential impacts from ongoing and future climate change. By selecting communities from this framework, the climate change integration pilot study would be a park-centric approach and it could build on the established NRCA process. Several considerations were taken into account during the discussions on selecting the components for inclusion in the pilot study. A specific set of selection criteria was not established, however COLM resource managers were asked to consider their long-term management as part of the selection process. With guidance from SMUMN GSS and the NPS climate change integration team, COLM resource managers selected pinyon-juniper woodlands/savanna, an iconic and important park plant community, and seep, spring and tinaja habitats, which depend upon unique physical resources, as the two communities to include in the pilot study. It is important to note that the seeps and springs and tinaja habitat climate assessment will be based on how representative plant communities within these habitats could be affected by climate change. This assessment will only have a limited analysis of how climate change will affect the availability of water or the overall aquatic habitat.

Variables of Interest
The approach utilized in this study is based on a modified community assessment methodology used by Amberg et al. (2012) in a climate change vulnerability assessment completed for Badlands National Park (BADL). Amberg et al. (2012) employed a modified adaptation of an approach originally developed by Hector Galbraith (Manomet Center for Conservation Sciences, Manomet, MA) that was used to assess the vulnerability of habitats in 13 northeastern states. Galbraith's original approach used 11 variables to assess vulnerability (Galbraith 2011). Figure 14 illustrates how each variable was designed to capture to some degree either sensitivity, exposure, or adaptive capacity of a diversity of ecological communities, in an effort to assess their overall vulnerability to climate shifts. Amberg et al.'s (2012) adaptation of Galbraith's approach selected six of the original variables to assess the vulnerability of the BADL plant communities to climate change. These six variables are (descriptions based on Galbraith 2011):

1. **Location in geographical range of plant community.** Plant communities close to the southern extremes of their distributions and that may be close to the southern edges of their range of climatic tolerances may be more vulnerable to a warming climate than communities that are further north of these bioclimatic edge zones. Plant communities closer to the northern edge of their current range may be more likely to persist in place and may benefit by being able to extend northward.

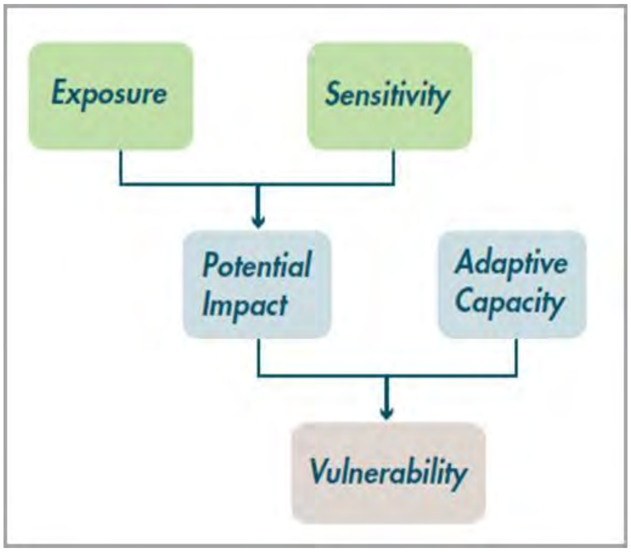

Figure 14. Relationship between exposure, sensitivity, and adaptive capacity (Source: Stein et al. 2011).

2. **Sensitivity to extreme climatic events.** Some plant communities may be more vulnerable than others to extreme climatic events or climate-induced events (drought, floods, ice storms, windstorms). Such events are projected to become more frequent and/or intense under climate change.
3. **Dependence on specific hydrologic conditions.** Some plant communities are confined to areas with specific and relatively narrow hydrologic conditions. Changes in precipitation amount, type (snow vs. rain), and timing are projected under all climate change models (though the direction and degree of change vary across models), potentially threatening these community types.
4. **Intrinsic adaptive capacity.** While all plant communities are likely to have characteristics that may enable them to withstand the effects of a changing climate, their adaptive capacities (their ability to resist or recover from stress) will vary, depending on their intrinsic and extrinsic characteristics and their condition:
    a. The physical diversity within which a plant community exists may affect its resilience and adaptive capacity: communities with diverse physical and topographical characteristics (variety in aspects, slopes, geologies and soil types, elevations) may be more able to survive climate change than communities that are less varied, since the former, by existing across widely differing conditions, may be at lower risk of being eliminated by any future climatic conditions.
    b. Some plant communities may be intrinsically more resistant to stressors because (for example) they have more rapid regeneration times. Communities in which the recovery period from the impacts of stressors is shorter (<20 years) may have greater intrinsic adaptive capacities than slower developing communities (recovery times of >20 years). For example, woodlands may take a hundred years or more to recover from fire or pest impacts. This may render them intrinsically more vulnerable to the

potential intervening effects of climate change than plant communities that have shorter recovery periods (e.g., grasslands or shrub communities).

c. The current conditions of plant communities will also affect their adaptive capacities. Communities that support their full complement of species (or close to that), have high biodiversity, and that are relatively free from non-climate stressors are likely to be both more resistant and resilient to the effects of a changing climate. In contrast, plant communities that are in "poorer" condition with comparatively impoverished species representation and biodiversity, or that are being impacted by other stressors, may be less resilient and have lower adaptive capacity.

5. **Vulnerability of ecologically influential species to climate change.** Ecologically influential species are those that have substantial influences on community structure. Examples are abundant tree species in woodlands, such as pinyon pine in dry coniferous woodlands, or Mancos columbine (*Aquilegia micrantha*) in hanging gardens, whose disappearance from the system would significantly alter plant composition and community structure. If there is reason to believe that ecologically influential species in a plant community are particularly vulnerable to climate change, the whole community may be in jeopardy.
6. **Potential for climate change to exacerbate impacts of non-climate stressors.** For some plant communities, it is likely that significant impacts of climate change will be expressed through their exacerbating or mitigating effects on current or future non-climate stressors. One example is the potential magnifying effects of warming temperatures on cold-limited pest species or invasive species (e.g., pinyon ips bark beetle [*Ips confusus*]). In this variable it is the intent to capture the potential effects of this interaction between climate change and non-climate change stressors.

3.3.2 General Approach and Methods

This pilot study involved gathering and reviewing existing literature and data relevant to the two ecological communities selected for the CCVA. No new data were collected for this study; however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations.

<u>Data Mining</u>

Recent historical climate patterns for COLM were evaluated using PRISM gridded climate data. These data are produced by the PRISM climate group at Oregon State University (Daly et al. 2002, PRISM 2015), and the analysis was completed by the NCCSC.

The PRISM climate group uses point data, a digital elevation model, and other spatial data sets to generate gridded estimates of monthly, yearly, and event-based climatic parameters, such as precipitation, temperature, and dew point. PRISM is constantly updated to map climate in all situations, including high mountains, rain shadows, temperature inversions, coastal regions, and other complex climatic regimes. The PRISM system uses data from about 8,000 climate observation stations, and the results are considered state-of-the-art (Daly et al. 2002).

While PRISM data are both spatially and temporally complete, older data are estimated from fewer on-the-ground observations and these data are thus generally less reliable than more modern observations. PRISM data for the COLM area are likely highly reliable for analyses at the spatial and temporal scale of this analyses. Davey et al. (2006) inventoried climate observation stations relevant to monitoring parks in the NCPN, and their report included 10 records of stations relevant to evaluating COLM. Two of these 10 stations included climate observations from earlier than 1910. PRISM uses correlations between stations for infilling missing data, and the more than 100 years of observations provides a very rich data set to develop and evaluate these relationships. PRISM data are well-suited for evaluating regional-scale and longer-term climate patterns and dynamics, but they cannot capture weather dynamics at the scale of local convection storms that occur between observation stations, for example.

Climate projection summaries for COLM were produced using statistically downscaled model projections for temperature (minimum and maximum), precipitation and aridity. These datasets provide bias-corrected and spatially downscaled climate projections and are typically referred to as Bias Correction followed by Spatial Disaggregation (BCSD) (Wood et al. 2004). They have been corrected for model-observation biases in mean monthly temperature and then processed at various spatial scales (i.e., disaggregated) to accommodate mismatches between the global model outputs and local topographical and other effects (Wood et al. 2004).

Data Development and Analysis

For this assessment, historical climate patterns and projected climate changes out to the year 2100 were examined for the COLM region. Historical climate patterns (mean minimum and maximum temperatures and total precipitation) were analyzed to create a picture of climate in COLM during the past century. Using PRISM climate data, historical temperature and precipitation patterns for the COLM area were summarized and evaluated to build a context of historical climate to which future climatic projections may be compared. Specifically, mean monthly minimum and maximum temperature (°C) and total monthly precipitation (mm) from 1895 to present were examined.

Given the limited funding and scope of this pilot project, analyses were only possible for a single future climate projection. For the purposes of the vulnerability assessments in this study, the climate change integration team selected the "business as usual" RCP 8.5 scenario and a general circulation model (GCM) ensemble average. This is recognized as a necessary limitation of this pilot effort. The high emissions RCP 8.5 is considered a "baseline" scenario, as it does not assume a climate mitigation target (Riahi et al. 2011). For more information on the RCPs and how they were developed, please refer to Appendix A.

Scoring Methods and Assigning Vulnerability Scores

Each of the six variables defined above were independently assessed and assigned a "best estimate" score from 1 (least vulnerable) to 5 (most vulnerable) on the likely vulnerability of a plant community to future climate change and non-climate stressors (based on the available scientific literature, data, and expert opinion). Scores were summed to produce an overall score for a plant community's vulnerability. The total minimum score was six and the total maximum score was 30.

The overall score was then organized into one of four categories: critically vulnerable, highly vulnerable, moderately vulnerable, and less vulnerable (Table 9). These translate into community response categories ranging from a plant community likely to be eradicated or greatly reduced in extent within the study area to a plant community that may sustain modest reduction or actually increase in extent within the study area.

Table 9. Scale for results of climate change vulnerability analysis.

Vulnerability Score	Description
6-13	Least vulnerable - plant communities that may not be at adverse risk from climate change, or that may benefit and increase their extent within the study area.
14-19	Moderately vulnerable – plant communities at risk of being considerably reduced (by 20-50%) in extent by climate change.
20-25	Highly vulnerable – plant communities at high risk of being greatly reduced (>50%) in extent by climate change.
26-30	Critically vulnerable – plant communities at high risk of being eliminated entirely from the study area by climate change.

Uncertainty Evaluation and Confidence in Vulnerability Assessments

Uncertainty is inherent at many stages in assessing climate change vulnerability, including the climate modeling process, assumptions about vulnerabilities of resources to climate shifts and/or non-climate stressors (and how these interact), and assumptions about the adaptive capacities of the resources. Many uncertainties are unavoidable despite the best modeling and data gathering efforts. It is crucial to provide a comprehensive and detailed appraisal of how certain analysts can be about vulnerability scores so that resource managers can determine how best to use the vulnerability information presented to them on the potential impacts of climate change.

Uncertainty in the plant community assessments is addressed in two ways: certainty evaluations/scores and alternative scores. Certainty scores are a method of documenting how confident analysts are regarding the validity and accuracy of the original vulnerability scores assigned to each variable (not the alternative scores). The scale of certainty scores used in this draft assessment is the same scale used by Galbraith (2011) in the Northeast habitat vulnerability assessments, which is an adaptation of a category scale developed by Moss and Schneider (2000) for the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report. One of three certainty scores – low (1), moderate (2), or high (3) – was applied to the original assigned vulnerability score for each variable. The certainty scores for each variable were then summed up to determine a certainty evaluation for the overall vulnerability score of the plant community. The total minimum score was six (6) and the total maximum score was 18. These certainty scores translate to a level of confidence – low, moderate, or high confidence – about the judgments made regarding the vulnerability scores for each variable (Table 10).

Table 10. Scale for results of CCVA uncertainty analysis.

Uncertainty Score	Description
6-10	Low confidence - Low certainty
11-14	Moderate confidence - Moderate certainty
15-18	High confidence - High certainty

When a clear "best estimate" vulnerability score did not stand out, the analyst had the option of assigning an alternative score (a highly possible but less likely outcome than the best estimate) in addition to the best estimate score. The alternative score is the "next best estimate" of vulnerability for a variable, taking into account the uncertainty attached to a variable (i.e., the lack of information or understanding about a plant community or a species). These alternative scores, in conjunction with the best estimate vulnerability score, serve to capture the range of highly likely possibilities that may exist for the vulnerability of a plant community (adapted from Galbraith and Price 2011). When certainty is high, vulnerability will likely be represented by a single value; when certainty is low, vulnerability will be represented by a range of scores. The alternative scores also show the potential direction of the vulnerability, in that an alternative score for a variable may reflect a lesser or greater vulnerability due to uncertainty or data gaps in the literature (see Table 11 below as an example). For instance, the sensitivity of an ecologically influential plant or tree species in a community to extended periods of drought (variable = sensitivity to extreme climatic events) may be debated in the scientific literature in that several sources show a drought tolerance while another source reports an intolerance or sensitivity to drier conditions. In this case, alternative scores could represent lesser or greater vulnerability due to conflicting scientific literature. As another example, a resource may be assigned an alternative score that represents a higher degree of vulnerability due to high uncertainty related to very little or no available scientific data or information.

Table 11. An example of certainty and alternative vulnerability scores for plant community assessment variables. For individual variables, 3 = high certainty, 2 = moderate certainty, and 1 = low certainty; total ranges are 6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence.

Variable	Certainty Score	Vulnerability Score	Alternative Scores
Location in geographical range/distribution of plant community	3	3	
Sensitivity to extreme climatic events (e.g., drought, flash floods, windstorms)	2	4	3,5
Dependence on specific hydrologic conditions	2	4	
Intrinsic adaptive capacity	1	3	4
Vulnerability of ecologically influential species to climate change	2	4	3
Potential for climate change to exacerbate impacts of non-climate stressors	2	5	
Total	**12**	**23**	**21-25**

Preparation and Review of Climate Change Vulnerability Analysis
Narratives for each assessment were created to clearly explain why certain assumptions and/or scores were adopted over other possibilities. It is important that this explanation provide sufficient detail and transparency to allow a reader to be able to clearly and easily follow the process and logic-steps that lead analysts to conclusions about vulnerability. The purpose of the narratives is to clearly outline the review and evaluation of the scientific literature and the thought processes and assumptions that result in assigning the vulnerability scores to each of the variables of interest. When appropriate, GIS products, such as maps of distributions and ranges, were developed and included in the assessment to add depth and graphical representation to the interpretation of literature and data.

Once each narrative assessment was completed, it went through an iterative review process among SMUMN GSS analysts for consistency. Assessments were then provided to COLM resource experts and other outside experts (e.g., university researchers, government scientists) for an external review in which the document was examined for accuracy of content, validity and accuracy of categorizations, and appropriateness of interpretation of available scientific literature, and feedback was provided on how to refine the assessment. Following review by experts, the vulnerability assessment was modified to reflect feedback.

Integration of Climate Change Analysis into Natural Resource Condition Assessment Document
The resource component assessments will be presented in the standard format as described in Section 3.2.2 with the following changes made to incorporate the climate change analysis.

Current Condition and Trend
This section will be amended to include the discussion of the components vulnerability to climate change. This section will precede the “Threats and Stressors” section. This includes how the projected change in climate will affect the variables of interest.

Overall Condition
This section provides a qualitative summary statement of the current condition that was determined for each of the resource components using the WCS method as described in Section 3.2.2. In addition, the vulnerability scoring for components that are part of the pilot study will be incorporated here, just prior to the “*Weighted Condition Score*” section. The vulnerability score is determined after thoughtful review of available literature and data regarding the components vulnerability to climate change that was presented in the Current Condition and Trend section. Also included in this section is a table with the results of the component’s climate change vulnerability assessment. This section will also include a brief summary of any uncertainty and related alternative scoring that may have been applied to the analysis of climate change vulnerability.

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4. Natural Resource Conditions

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

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

The order of components follows the project framework (Figure 13):

4.1 Pinyon-juniper Woodlands/Savannas
4.2 Sagebrush Shrublands/Shrub Steppe
4.3 Riparian Habitats/Large Dry Washes
4.4 Seeps and Springs and Tinaja Habitats
4.5 Mixed Salt Desert Scrub/Semi-desert Grassland
4.6 Canyon Walls and Monolith Vegetation Communities
4.7 Montane Shrubland
4.8 Herptiles
4.9 Birds
4.10 Raptors
4.11 Small Mammals
4.12 Mountain Lion
4.13 Bighorn Sheep
4.14 Kit Fox
4.15 Bats
4.16 Air Quality
4.17 Dark Night Skies
4.18 Viewscape
4.19 Soundscape
4.20 Paleontological Resources
4.21 Geologic Features

4.1 Pinyon-juniper Woodlands/Savannas

4.1.1 Description

Photo 4. An example of an open-canopy pinyon-juniper woodland/savanna upon a mesa top in COLM (Photo by Anna Davis, SMUMN GSS).

Pinyon-juniper woodlands/savannas in COLM consist primarily of two-needle pinyon pines and Utah juniper trees with various mixtures of other shrubs and herbaceous vegetation. These woodlands are typically situated on flat and mildly sloped mesa tops (Photo 4) and are distributed across a large portion (4,751 ha [11,740 ac]) of the park, comprising over half (57.4%) of the entire park area (Von Loh et al. 2007). The two-needle pinyon pines are widely distributed across a broad geographic range in North America that includes the western states of Colorado, Utah, Arizona, Nevada, California, New Mexico, Wyoming, Oklahoma, and Texas as well as part of Chihuahua, Mexico (USDA 2015a). The Utah juniper has a similar range with the addition of Montana and Idaho, and excluding Texas (USDA 2015b). The two-needle pinyon pine produces nutrient-rich pine nuts that are a staple in the diets of wildlife, often providing crucial sustenance to animals, particularily in harsh winters when deep snow accumulates (Nesom 2003). The various plant communities of pinyon-juniper woodlands and savannas are diverse and include several unique alliances that are considered rare, which contributes greatly to the overall biodiversity of the park (Von Loh et al. 2007). There have been uncertainties regarding the historic role of fire in pinyon-juniper woodlands/savannas, with assumptions that fire exclusion and livestock grazing have allowed unnatural encroachment of pinyon-juniper woodlands/savannas into other vegetation communities, such as grasslands (Johnson 2013; Kennard and Moore 2012, 2013). The pinyon-juniper woodlands/savannas of COLM offer a unique opportunity to study the fire history of several persistent stands that have been largely unaltered; the estimated age of the oldest juniper in one COLM stand is 920 years (Kennard and Moore 2012, 2013).

Pinyon jays (*Gymnorhinus cyanocephalus*) can be found year-round in these woodlands (Hanophy and Teitelbaum. 2003). Other birds that can be found foraging and nesting in this habitat include the bushtit (*Psaltriparus minimus*) and lark sparrow (*Chondestes grammacus*) (Hanophy and Teitelbaum. 2003). Raptors such as red-tailed hawks (*Buteo jamaicensis*), golden eagles (*Aquila chrysaetos*), American kestrels (*Falco sparverius*) and prairie falcons (*Falco mexicanus*) forage on the pinyon mouse (*Peromyscus truei*) and bush-tailed woodrat (*Neotoma cinerea*) commonly found in these woodlands (Hanophy and Teitelbaum. 2003). This vegetation community also supports two lizard species, the eastern collared lizard (*Crotaphytus collaris*) and the plateau side-blotched lizard (*Uta stansburiana uniformis*) (Hanophy and Teitelbaum. 2003). Other mammals found within this habitat include: ringtail (*Bassariscus astutus*), mule deer, elk (*Cervus elaphus*) and mountain lion (*Puma concolor*) (Hanophy and Teitelbaum. 2003).

4.1.2 Measures

- Community extent and change over time
- Community composition
- Percent cover biological soil crusts
- Percent bare ground
- Trends in invasive infestation
- Soil stability

4.1.3 Reference Conditions/Values

The reference condition for this component is based on the current pinyon-juniper woodlands on the mesa tops in the middle of the park. These woodlands are considered by park resource managers to be intact examples of the community, and any degradation from this state is in the future is to be considered a deviation. This current state is defined by the vegetation mapping and descriptions of pinyon-juniper woodlands/savannas within the entire park as mapped by Von Loh et al. (2007). At that time the community composition, estimated amount of bare ground, and percent vegetation/canopy cover for each pinyon-juniper woodland/savanna vegetation classification (12 alliances) were also documented and will serve as a baseline for future assessments (Von Loh et al. 2007). The reference condition for IEP infestation is the assumption that only native species present prior to European settlement in the area.

4.1.4 Data and Methods

Kennard and Moore (2012, 2013) studied fire history, spatial structure, and mortality in a COLM pinyon-juniper woodland to identify the driving mechanisms of temporal dynamics and spatial patterns. One purpose of the study was to provide a baseline of these factors to assess the potential changes possible from climate change in the coming decades (Kennard and Moore 2012, 2013). The research focused on pinyon-juniper woodlands that are situated on mesa tops, where they are the predominant vegetation. In order to estimate the fire history and the age of the pinyon-juniper stands, the study looked for evidence of large (>100 ha [247.1 ac]) stand-replacing fires (Kennard and Moore 2012, 2013). Kennard and Moore (2012) used an approach that was developed particularly for pinyon-juniper woodlands because of the difficulty in using fire scar analysis, the usual method, with these species. This is because both trees are easily killed by fire and thus there is generally not detectable fire scarring on pinyon pine and juniper trees (Kennard and Moore 2012, 2013).

To detect previous fires the researchers looked for landscape-scale fire scars. The two tree species are very slow to regenerate, leaving a detectable perimeter around an area of markedly younger trees (Kennard and Moore 2012, 2013). Within the perimeter, the oldest tree ages are used to estimate the time of the last large fire. A spatial grid of sample points was developed to map the approximate age structure of the stands within the grid (Kennard and Moore 2012, 2013). The grid points were located using a GPS unit over a 3-year period (September 2007 to June 2010). Regression equations developed from tree ring analyses were used to estimate the ages of the largest pinyon pine and juniper trees that were within 10 m (32.8 ft) of each grid point. Additionally, at each grid point where the largest trees were measured, a 100 m^2 (1076.4 ft^2) circular plot was established (Kennard and

Moore 2012, 2013). Individual trees within these plots were measured at the trunk base or stem base to establish a size class for each tree (Kennard and Moore 2012, 2013). A review of records kept by COLM on fire occurrence, which included size and location of fires since 1942, was used to characterize more recent fires for comparison with field observations of charred wood (Kennard and Moore 2013).

Von Loh et al. (2007) conducted a vegetation mapping project for the park and surrounding areas. The purpose of the project, conducted between 2003 and 2005, was to classify, describe, and map vegetation and fuels at COLM (Von Loh et al. 2007). Surrounding areas were included to support management of the urban-wildland interface and coordinated management on adjacent public lands (Von Loh et al. 2007). A team of ecologists, botanists, and photo interpreters worked together to identify the plant associations within the park. Vegetation mapping was completed through the use of aerial photography and computer modeling. The resultant maps were refined through a combination of ground sampling and accuracy assessments using vegetation plot and observation point sampling (Von Loh et al. 2007). A complete detailed methodology of the computer modeling and sampling design can be found in Von Loh et al. (2007).

Johnson (2013) studied aerial photos of COLM from 1937 and 2007 to establish the historic and current extent of both pinyon-juniper woodland/savanna and sagebrush communities. The goal was to spatially describe the historic extent of pinyon-juniper woodland/savannas in relation to sagebrush communities. This was in response to a lack of reliable data needed to understand the historic fire regime within the pinyon-juniper woodland/savannas in the park. Trends in community expansion and contraction, presence of charred wood, and community structure and composition were examined to determine whether best-management practices for pinyon-juniper woodland/ savannas should include prescribed burning (Johnson 2013).

Dewey and Anderson (2005) inventoried invasive plant species in COLM during 2003. The objectives included documenting the distribution and abundance of target invasive plants in the park, identifying potential sources of introduction and vectors for spreading the invasive plants, and testing and refining data collection methods and field inventory techniques (Dewey and Anderson 2005). Eleven invasive plant species were identified as high-priority and were systematically sought by inventory crew members.

Perkins (2010, 2012, and 2014) conducted IEP monitoring in COLM during the 2009, 2011, and 2013 field seasons. Methodology for field work and analysis was similar for all three field seasons. For the assessment of condition in this NRCA, the most recent report (Perkins 2014) will be the primary source since it includes data from the previous reports. The field work for these monitoring efforts included transect and quadrat sampling with emphasis on roads, trails, and waterways (Perkins 2010, 2012, 2014). A list of IEP priority species was developed for the park prior to each year of monitoring, based on previously detected species and literature reviews (Perkins 2010, 2012, 2014). Monitoring was conducted on foot and IEPs were detected visually. For each monitoring route, transect, and quadrat, each IEP detected was recorded, listing the IEP species, infestation size class, and canopy cover class (Perkins 2014).

This synthesis of the relevant scientific data and information does not include the climate data and information used in conducting the climate change vulnerability assessment for this resource. Please refer to Chapters 2.1.3 and 3.2.3 and Appendix A for a discussion of the data and methodology used in the climate change analysis.

4.1.5 Current Condition and Trend

Community Extent and Change over Time

Vegetation patterns vary across a landscape and a classification system is used to recognize and organize vegetation communities. Von Loh et al. (2007) employed the National Vegetation Classification (NVC) system, which is the standard used for all NCPN vegetation mapping projects (TNC and ESRI 1994, NatureServe 2003). The NVC is a hierarchical system that uses seven levels to classify vegetation; the upper five levels are based on physiognomic characters and the two lower levels are based on floristic data (TNC and ESRI 1994, NatureServe 2003). The two lower levels (alliance and association) are distinguished by variability in their floristic composition (TNC and ESRI 1994, NatureServe 2003). These two lower levels are used throughout this NRCA in the assessment and discussion of the vegetation communities of COLM.

The alliance and association levels are determined by the most abundant species (or diagnostic species) comprising the strata of a homogenous vegetation community (TNC and ESRI 1994, NatureServe 2003). Associations are defined as a vegetation community type that exhibits a consistent species composition, uniform physiognomy, and similar habitat conditions (Flahault and Schroter 1910). Associations are differentiated by their species composition (TNC and ESRI 1994a). An alliance is a grouping of plant associations sharing one or more dominant species (Reid et al. 1999). Von Loh et al. (2007) identified several distinct types of pinyon-juniper woodland/savannas in COLM. The pinyon-juniper woodland/savanna communities mapped by Von Loh et al. (2007) were selected for assessment of the community extent. These associations and alliances are dominated by two-needle pinyon pine and Utah juniper. Various combinations of other plant species are found within these alliances and associations. The areal extent of pinyon-juniper woodland/savannas as mapped by Von Loh et al. (2007) is shown in Table 12 (Von Loh et al. 2007).

Table 12. Areal extent of pinyon-juniper woodland/savanna vegetation alliances found in COLM (Von Loh et al. 2007).

Alliances	Acres	Hectares	Percent of total park area
Pinyon-juniper woodland/savannas (all)	11,740	4,751	57.4%
Two-needle pinyon pine–Utah juniper/multiple shrub woodland	6,133	2,482	30.0%
Two-needle pinyon pine–Utah juniper/Wyoming big sagebrush woodland	2,763	1,118	13.5%
Two-needle pinyon pine–Utah juniper/black sagebrush woodland	1,682	681	8.2%
Two-needle pinyon pine–Utah juniper/sparse understory woodland	1,162	470	5.7%

One map unit, the two-needle pinyon pine–Utah juniper/multiple shrub woodlands, consists of seven distinct vegetation associations and was the most extensive vegetation community within COLM boundaries. The other three map units are one alliance each. Using the observation points and map units created by Von Loh et al. (2007), these vegetation alliances and associations are displayed in Figure 15.

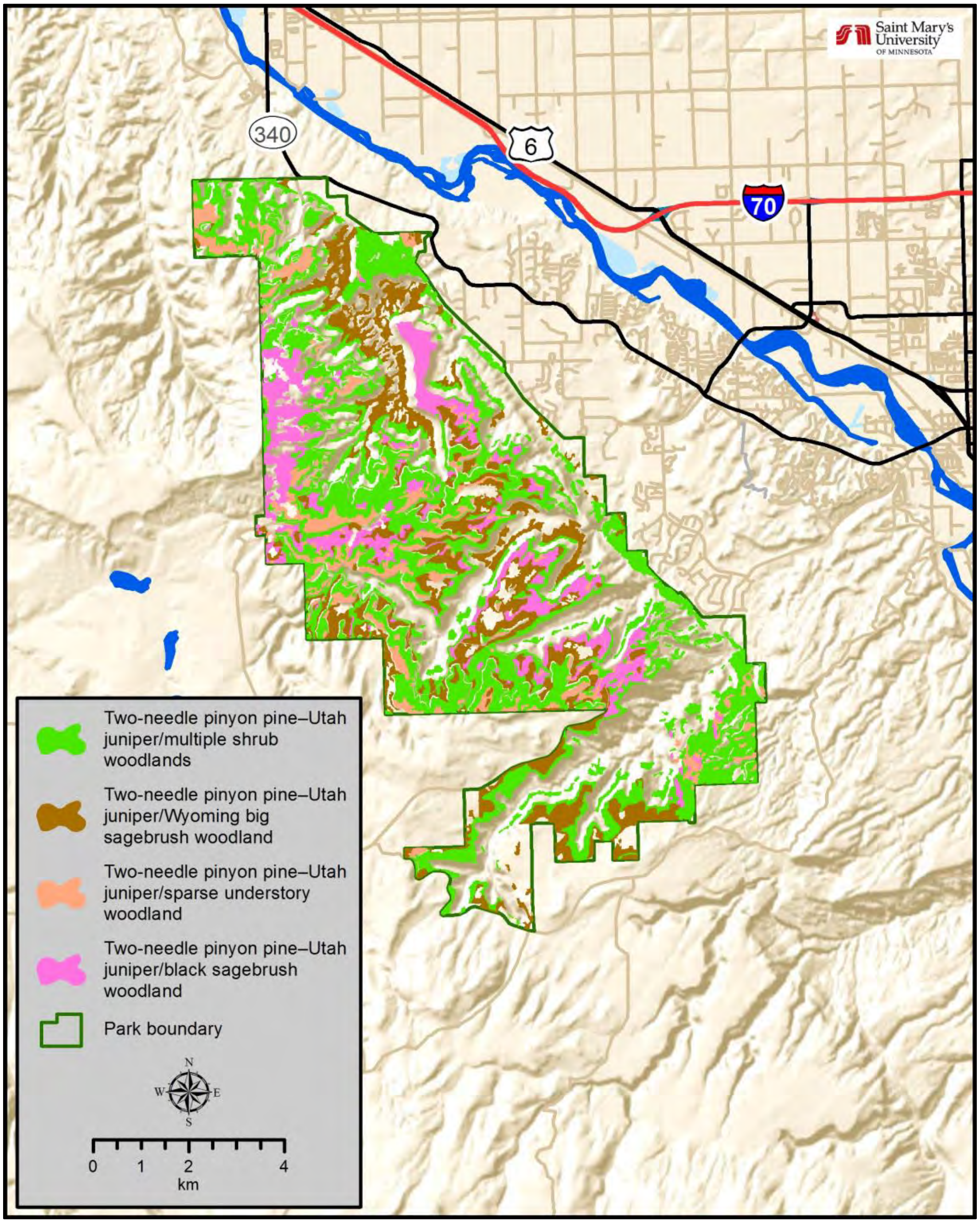

Figure 15. The location of pinyon-juniper woodland/savanna alliances within COLM (Von Loh et al. 2007).

Two alliances that were described in Von Loh et al. (2007) as a type of pinyon-juniper woodland/savanna are not shown in Figure 15. These are the two-needle pinyon-Utah juniper/Utah serviceberry (*Amelanchier utahensis*) woodlands and the blue spruce (*Picea pungens*)-two-needle pinyon-Utah juniper/Gambel's oak (*Quercus gambelii*) woodland. All stands of these two types identified at COLM were below the minimum mapping unit of 0.5 ha (1.2 ac). The two-needle pinyon-Utah juniper/Utah serviceberry woodlands were observed and sampled near the south and west entrance to COLM and near Alcove Trail (Von Loh et al. 2007). The blue spruce two-needle pinyon-Utah juniper/Gambel's oak woodland was a single stand of four to six blue spruce trees, and one sapling at one other site (Von Loh et al. 2007). The single stand of blue spruce two-needle pinyon-Utah juniper/Gambel's oak woodland was observed and recorded near the terminus of Echo Canyon and the sapling was observed in Red Canyon (Von Loh et al. 2007).

Johnson (2007) compared the aerial photos of COLM from 1937 and 2007 in an attempt to identify changes in the extent of pinyon-juniper woodlands. Due to distortions in the 1937 imagery determination of actual percent estimates of change were problematic (Dr. Deborah Kennard, Colorado Mesa University, Department of Physical and Environmental Sciences, written communication 18 November 2015). Based on simple ocular comparisons of the aerial photos from 1937 and 2007, Johnson (2013) concluded that pinyon-juniper woodlands were expanding into the park's sagebrush shrublands. Due to the distortions in the 1937 images Johnson estimated the loss of sagebrush shrubland/shrub steppe due to the expansion of woodland species ranged from approximately 10% to 30% in certain areas of COLM (Johnson 2013). This suggests that pinyon-juniper woodland extent has likely increased at COLM in recent decades or, at the least, has not decreased.

Community Composition

The following descriptions of community composition for pinyon-juniper woodlands/savannas found in COLM are the results of the Von Loh et al. (2007) vegetation mapping project that included field work to determine dominant species of plants and other associated plants. All communities are open woodlands dominated by two-needle pinyon pine and Utah juniper along with a few other plant species that determine their individual classifications (Von Loh et al. 2007).

Two-needle pinyon-(oneseed juniper [*Juniperus monosperma*], Utah juniper)/needle and thread (*Hesperostipa comata*) woodlands are dominated by a canopy of two-needle pinyon pine and Utah juniper with only a few other species scattered below (Table 13; Von Loh et al. 2007). The open canopy cover is typically 2-5 m (6.6-16.4 ft) tall, with Mormon tea (*Ephedra viridis)* shrubs beneath, and 1-5% cover of needle and thread (Von Loh et al. 2007). An herbaceous layer provides up to 10% cover; all plant species documented in this association are shown in Appendix B (column A) (Von Loh et al. 2007). A total of eight plant species, including two trees, one shrub, three graminoids, and two forbs, were observed in this woodland type (Appendix B, column A; Von Loh et al. 2007).

Table 13. Dominant plant species (by strata) within the two-needle pinyon-(one-seed juniper, Utah juniper)/needle and thread woodlands of COLM (Von Loh et al. 2007).

Two-needle pinyon-(one-seed juniper, Utah juniper) / needle-and-thread woodland		
Scientific Name	**Common Name**	**Strata**
Pinus edulis	two-needle pinyon pine	Tree canopy
Juniperus osteosperma	Utah juniper	Tree canopy
Ephedra viridis	Mormon tea	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Hesperostipa comata	needle and thread	Herb

Two-needle pinyon-Utah juniper/Utah serviceberry woodlands are dominated by five plant species (Table 14). These include the typical two-needle pinyon pine and Utah juniper open tree canopy, averaging 2-10 m (6.6-32.8 ft) in height (Von Loh et al. 2007). Utah serviceberry, saline wildrye (*Leymus salina*), and cheatgrass, a non-native invasive annual grass, are also dominant and provide moderate cover (Von Loh et al. 2007). There were 14 other associated plant species (Appendix B, column B), including three trees, seven shrubs, four graminoids, and five forb species (Von Loh et al. 2007).

Table 14. Dominant plant species (by strata) within the two-needle pinyon-Utah juniper/Utah serviceberry woodlands (Von Loh et al. 2007).

Two-needle pinyon-Utah juniper/Utah serviceberry woodland		
Scientific Name	**Common Name**	**Strata**
Pinus edulis	two-needle pinyon pine	Tree canopy
Juniperus osteosperma	Utah juniper	Tree canopy
Amelanchier utahensis	Utah serviceberry	Tall shrub/sapling
*Bromus tectorum**	cheatgrass	Herb
Leymus salina	saline wildrye	Herb

*Indicates a non-native species.

The two-needle pinyon-Utah juniper/Bigelow's sagebrush (*Artemisia bigelovii*) woodlands are dominated by 2-5 m (6.6-16.4 ft) tall two-needle pinyon pine and Utah juniper trees which provide 2-20% cover (Von Loh et al. 2007). Other dominant plants include Harriman's yucca (*Yucca harrimaniae*), needle and thread, cheatgrass, James' galleta (*Hilaria jamesii*), and hairy false goldenaster (*Heterotheca villosa*) (Von Loh et al. 2007). Many other plant species occur within this association (a total of 42) in various combinations; those observed in COLM are listed in Appendix B (column C) (Von Loh et al. 2007). Species of plants that were observed included three trees, 17 shrubs, eight graminoids, and 14 forbs (Von Loh et al. 2007).

Table 15. Dominant plant species (by strata) within the two-needle pinyon-Utah juniper/Bigelow's sagebrush woodlands (Von Loh et al. 2007).

Two-needle pinyon-Utah juniper/Bigelow's sagebrush woodland		
Scientific Name	**Common Name**	**Strata**
Juniperus osteosperma	Utah juniper	Tree canopy
Pinus edulis	two-needle pinyon pine	Tree canopy
Artemisia bigelovii	Bigelow's sagebrush	Shrub/sapling
Yucca harrimaniae	Harriman's yucca	Shrub/sapling
*Bromus tectorum**	cheatgrass	Herb
Hesperostipa comata	needle and thread	Herb
Heterotheca villosa	hairy false goldenaster	Herb
Hilaria jamesii	James' galleta	Herb

*Indicates a non-native species.

Two-needle pinyon-Utah juniper/black sagebrush woodlands are dominated by 14 species, including two-needle pinyon pines and Utah junipers which are around 2-10 m (6.6-32.8 ft) in height with 3-35% canopy cover (Table 16; Von Loh et al. 2007). Additional plant species that occur in this alliance are listed in Appendix B (column D), and include three trees, 14 shrubs, eight graminoids, and 21 forbs for a total of 46 observed plant species (Von Loh et al. 2007).

Table 16. Dominant plant species (by strata) within the two-needle pinyon-Utah juniper/black sagebrush woodlands in COLM (Von Loh et al. 2007).

Two-needle pinyon-Utah juniper/black sagebrush woodland		
Scientific Name	**Common Name**	**Strata**
Pinus edulis	two-needle pinyon pine	Tree Canopy/subcanopy
Juniperus osteosperma	Utah juniper	Tree Canopy/subcanopy
Artemisia nova	black sagebrush	Short shrub/sapling
Ephedra viridis	Mormon tea	Short shrub/sapling
Opuntia fragilis	brittle pricklypear	Short shrub/sapling
Opuntia polyacantha	plains pricklypear	Short shrub/sapling
Yucca harrimaniae	Harriman's yucca	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Gutierrezia sarothrae	broom snakeweed	Herb
Heterotheca villosa	hairy false goldenaster	Herb
Hilaria jamesii	James' galleta	Herb
Leptodactylon pungens	prickly phlox	Herb
Leymus salina	saline wildrye	Herb
Petradoria pumila	rock goldenrod	Herb

Two-needle pinyon-Utah juniper /littleleaf mountain-mahogany (*Cercocarpus ledifolius* var. *intricatus*) woodlands are dominated by eight species of plants, which include the typical open tree canopy of two-needle pinyon pine and Utah juniper trees (Table 17; Von Loh et al. 2007). The tree canopy provides sparse coverage, between 1% and 15%, with average heights of 2-10 m (6.6-32.8 ft) (Von Loh et al. 2007). This alliance had a total of 33 plant species observed by Von Loh et al. (2007), including three tree, nine shrub, eight graminoid, and 13 forb species (Appendix B, column E).

Table 17. Dominant plant species (by strata) within the two-needle pinyon-juniper/ littleleaf mountain-mahogany woodlands in COLM (Von Loh et al. 2007).

Two-needle pinyon-Utah juniper/littleleaf mountain-mahogany woodland		
Scientific Name	**Common Name**	**Strata**
Pinus edulis	two-needle pinyon pine	Tree canopy
Juniperus osteosperma	Utah juniper	Tree canopy
Fraxinus anomala	singleleaf ash	Tall shrub/sapling
Artemisia bigelovii	Bigelow's sagebrush	Short shrub/sapling
Cercocarpus ledifolius var. *intricatus*	littleleaf mountain-mahogany	Short shrub/sapling
Yucca harrimaniae	Harriman's yucca	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Aristida purpurea	purple three-awn	Herb
Hesperostipa comata	needle and thread	Herb

The two-needle pinyon-Utah juniper/mixed shrubs talus woodlands of COLM have a diverse community composition dominated by 14 plant species (Table 18). Two-needle pinyon pine, Utah juniper, and an occasional singleleaf ash (*Fraxinus anomala*) form the open tree canopy (Von Loh et al. 2007). The canopy composition is variable between two tree species; with Utah juniper typically providing up to 45% cover while the two-needle pinyon pine provides up to 15% cover (Von Loh et al. 2007). A total of 45 plant species were observed within this association, including three trees, 14 shrubs, 11 graminoids, and 17 forbs (Appendix B, column F; Von Loh et al. 2007).

Table 18. Dominant plant species (by strata) within the two-needle pinyon-Utah juniper/mixed shrubs talus woodlands in COLM (Von Loh et al. 2007).

Two-needle pinyon-Utah juniper/mixed shrubs talus woodland		
Scientific Name	**Common Name**	**Strata**
Pinus edulis	two-needle pinyon pine	Tree canopy
Juniperus osteosperma	Utah juniper	Tree canopy
Fraxinus anomala	singleleaf ash	Tall shrub/sapling
Artemisia bigelovii	Bigelow's sagebrush	Short shrub/sapling
Ephedra viridis	Mormon tea	Short shrub/sapling
Opuntia erinacea	grizzlybear pricklypear	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Bouteloua gracilis	blue grama	Herb

Table 18 (continued). Dominant plant species (by strata) within the two-needle pinyon-Utah juniper/mixed shrubs talus woodlands in COLM (Von Loh et al. 2007).

Two-needle pinyon-Utah juniper/mixed shrubs talus woodland		
Scientific Name	**Common Name**	**Strata**
Pinus edulis	two-needle pinyon pine	Tree canopy
Juniperus osteosperma	Utah juniper	Tree canopy
Fraxinus anomala	singleleaf ash	Tall shrub/sapling
Artemisia bigelovii	Bigelow's sagebrush	Short shrub/sapling
Ephedra viridis	Mormon tea	Short shrub/sapling
Opuntia erinacea	grizzlybear pricklypear	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Bouteloua gracilis	blue grama	Herb
Brickellia microphylla	littleleaf brickellbush	Herb
*Bromus tectorum**	cheatgrass	Herb
Hesperostipa comata	needle and thread	Herb
vLeymus salina	saline wildrye	Herb
Poa fendleriana	mutton grass	Herb
Selaginella densa	dense spikemoss	Herb

*Indicates a non-native species.

Two-needle pinyon-Utah juniper/grassy rockgoldenrod (*Petradoria pumila*) woodlands are dominated by five plant species, including the usual two-needle pinyon pine and Utah juniper that create an open tree canopy (Table 19; Von Loh et al. 2007). The tree canopy is between 2-10 m (6.6-32.8 ft) tall, with two-needle pinyon pine providing 1-5% cover and Utah juniper providing around 1-25% cover (Von Loh et al. 2007). The 23 plant species observed within this alliance are listed in Appendix B (column G) and include two trees, five shrubs, five graminoids, and 11 forbs (Von Loh et al. 2007).

Table 19. Dominant plant species (by strata) within the two-needle pinyon-Utah juniper/grassy rock-goldenrod woodlands (Von Loh et al. 2007).

Two-needle pinyon-Utah juniper/grassy rockgoldenrod woodland		
Scientific Name	**Common Name**	**Strata**
Pinus edulis	two-needle pinyon pine	Tree canopy
Juniperus osteosperma	Utah juniper	Tree canopy
Opuntia fragilis	brittle pricklypear	Shrub
Gutierrezia sarothrae	broom snakeweed	Herb
Petradoria pumila	grassy rockgoldenrod	Herb

Two-needle pinyon-Utah juniper/sparse understory woodlands are dominated exclusively by two-needle pinyon pine and Utah juniper trees; therefore, a table of dominant species is not included for this alliance (Von Loh et al. 2007). The tree canopy provides anywhere from 1-45% cover with trees that are typically 2-10 m (6.6-32.8 ft) tall (Von Loh et al. 2007). According to Von Loh et al. (2007), this association has a total of 50 plant species, although, as the name implies, the understory is sparsely vegetated. The various plant species observed in these woodlands are listed in Appendix B (column H) (Von Loh et al. 2007). There were three tree, 15 shrub, nine graminoid, and 23 forb species observed within this alliance (Von Loh et al. 2007).

Two-needle pinyon pine-Utah juniper/Wyoming big sagebrush woodlands are dominated by 12 plant species (Table 20; Von Loh et al. 2007). The two-needle pinyon pines provide 0-25% canopy cover and Utah junipers provide 2-65% canopy cover, with an average tree height of 2-5 m (6.6-16.4 ft) (Von Loh et al. 2007). A total of 45 plant species were observed in this alliance, including two trees, 13 shrubs, 10 graminoids, and 20 forbs (Appendix B, column I; Von Loh et al. 2007).

Table 20. Dominant plant species (by strata) within the two-needle pinyon pine-Utah juniper-juniper species/(Wyoming big sagebrush, mountain big sagebrush) woodlands of COLM (Von Loh et al. 2007).

Two-needle pinyon pine-Utah juniper/Wyoming big sagebrush woodland		
Scientific Name	**Common Name**	**Strata**
Pinus edulis	two-needle pinyon pine	Tree canopy
Juniperus osteosperma	Utah juniper	Tree canopy
Artemisia bigelovii	Bigelow's sagebrush	Short shrub/sapling
Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush	Short shrub/sapling
Ephedra viridis	Mormon tea	Short shrub/sapling
Opuntia fragilis	brittle pricklypear	Short shrub/sapling
Opuntia polyacantha	plains pricklypear	Short shrub/sapling
Yucca harrimaniae	Harriman's yucca	Short shrub/sapling
*Bromus tectorum**	cheatgrass	Herb
Descurainia pinnata ssp. *halictorum*	western tansymustard	Herb
Gutierrezia sarothrae	broom snakeweed	Herb
Hesperostipa comata	needle and thread	Herb

*Indicates a non-native species.

Two-needle pinyon-juniper species/mountain mahogany (*Cercocarpus montanus*)-mixed shrub woodlands are dominated by two-needle pinyon pines, Utah juniper trees, and six other plant species that are listed in Table 21 (Von Loh et al. 2007). The tree canopy consists of two-needle pinyon pine and Utah juniper, which are generally 2-5 m (6.6-16.4 ft) tall and provide 1-25% canopy cover (Von Loh et al. 2007). There was one individual ponderosa pine (*Pinus ponderosa*) tree observed within this alliance and it provided 40% canopy cover due to its large size, which is typical of this species (Von Loh et al. 2007). The total number of plant species observed within this alliance was 53 (Appendix B, column J), including five trees, 20 shrubs, 10 graminoids, and 18 forbs (Von Loh et al. 2007).

Table 21. Dominant plant species (by strata) within the two-needle pinyon-juniper species/mountain-mahogany-mixed shrub woodlands of COLM (Von Loh et al. 2007).

Two-needle pinyon-juniper species/mountain-mahogany-mixed shrub woodland		
Scientific Name	**Common Name**	**Strata**
Juniperus osteosperma	Utah juniper	Tree canopy
Pinus edulis	two-needle pinyon pine	Tree canopy/Tree subcanopy
Cercocarpus montanus	true mountain mahogany	Tall shrub/sapling
Purshia mexicana var. *stansburyana*	cliffrose	Tall shrub/sapling
Ephedra viridis	Mormon tea	Short shrub/sapling
*Bromus tectorum**	cheatgrass	Herb
Heterotheca villosa	hairy false goldenaster	Herb
Petradoria pumila	grassy rockgoldenrod	Herb
Tetraneuris acaulis	Arizona hymenoxys	Herb

*Indicates a non-native species.

The dominant tree species of two-needle pinyon-juniper species/saline wildrye grass woodlands is the Utah juniper (Von Loh et al. 2007). The open canopy consists of trees that are 2-5 m (6.6-16.4 ft) tall, ranging in cover from 1% to 25%, with surface cover of 1-15% provided primarily by bunchgrass (saline wildrye) (Von Loh et al. 2007). There were a total of 32 plant species observed in this alliance, including two trees, eight shrubs, five graminoids, and 17 forbs (Appendix B, column K; Von Loh et al. 2007).

Table 22. Dominant plant species (by strata) within the two-needle pinyon-juniper species/saline wildrye grass woodlands of COLM (Von Loh et al. 2007).

Two-needle pinyon-juniper species/saline wildrye grass woodland		
Scientific Name	**Common Name**	**Strata**
Juniperus osteosperma	Utah juniper	Tree Canopy
Atriplex confertifolia	shadscale	Herb
Chrysothamnus viscidiflorus	yellow rabbitbrush	Herb
Leymus salina	saline wildrye	Herb

Blue spruce-two-needle pinyon-Utah juniper/Gambel's oak woodlands are dominated by blue spruce, two-needle pinyon pine, Utah juniper, Utah serviceberry, Gambel's oak, and skunkbush sumac (*Rhus aromatica* var. *pilosissima*) (Table 23, Von Loh et al. 2007). The Von Loh et al. (2007) description is based on one stand in Echo Canyon where the composition of graminoids and forbs could not be determined due to difficulty reaching its location. The stand that is described is the only one of its kind within the park, although a single blue spruce sapling was observed in Red Canyon (Von Loh et al. 2007). The total number of plant species that may occur in this woodland type is unknown, but the species identified by Von Loh et al. (2007) are listed in Appendix B, column L.

The plant species observed within these 12 alliances, a total of 108, serve as a baseline plant list for comparing and updating subsequent vegetation inventories and monitoring efforts in COLM (Von Loh et al. 2007). The plant species list includes six tree, 32 shrub, 15 graminoid, and 55 forb species. There may be additional plant species within these various vegetation associations. In particular, the blue spruce-two-needle pinyon-Utah juniper/Gambel's oak woodland that was in a difficult to access location was not assessed in terms of the graminoid and forb composition. This association, and others, will likely have additional species added as the NCPN continues with inventory and monitoring efforts. Some pinyon-juniper woodlands/savannas may be the target of invasive plant management and may become free of cheatgrass in the future.

Table 23. Dominant plant species (by strata) within the blue spruce-two-needle pinyon-Utah juniper/Gambel's oak woodlands in COLM (Von Loh et al. 2007).

Blue spruce-two-needle pinyon-Utah juniper/Gambel's oak woodland		
Scientific Name	**Common Name**	**Strata**
Juniperus osteosperma	Utah juniper	Tree canopy
Picea pungens	blue spruce	Tree canopy
Pinus edulis	two-needle pinyon pine	Tree canopy
Amelanchier utahensis	Utah serviceberry	Tall shrub
Quercus gambelii	Gambel's oak	Tall shrub
Rhus aromatica var. *pilosissima*	skunkbush sumac	Tall shrub

Percent Cover Biological Soil Crusts

BSCs have been studied extensively in arid ecosystems and research has revealed the important role they play in these systems, particularly in protecting surfaces from wind erosion (Belnap 1992, KellerLynn 2006). These BSCs form as a dark, crumbly looking surface of unvegetated soil and are fragile and highly susceptible to disturbances such as grazing animals and human activities (Dunne 1989). They form very slowly and are comprised of a microfloral entanglement that spans the surface and subsurface of soils, effectively holding soil, moisture, and organic matter essential to vegetation establishment in arid lands (Dunne 1989, Miller 2005). They consist of cyanobacteria, moss, lichens, and fungi, many of which contribute carbon and nitrogen to the nutrient cycles of typically nutrient-poor ecosystems (Miller 2005, KellerLynn 2006).

BSC cover was briefly mentioned in Von Loh et al. (2007) for each vegetation classification. Although percent BSC cover was not a focus of this study, it provides a starting point for future assessments in order to make comparisons and identify trends in BSCs. BSCs are most developed in areas where there is adequate soil for them to develop upon. Some of the pinyon-juniper woodlands and savannas have very limited BSCs due to the lack of soil in those areas, particularly on rocky soils, areas with high surface litter cover, or where bedrock is exposed. The descriptions of BSC cover in the 12 various pinyon-juniper woodland/savanna alliance descriptions are given in Table 24 (Von Loh et al. 2007).

Table 24. Approximate BSC cover for each COLM pinyon-juniper community (Von Loh et al. 2007)

Community	BSC Cover
Two-needle pinyon-(one-seed juniper, Utah juniper)/needle-and-thread woodlands	Well-developed, but patchy
Two-needle pinyon-Utah juniper/Utah serviceberry woodlands	Was not mentioned as being present in alliance description
Two-needle pinyon-Utah juniper/Bigelow's sagebrush woodlands	Variable with some stands having very little, occasionally up to 50%
Two-needle pinyon-Utah juniper/black sagebrush woodlands	Variable with some stands having very little, occasionally up to 75%
Two-needle pinyon-Utah juniper/littleleaf mountain-mahogany woodlands	Sparse due to very little soil in stands for establishment
Two-needle pinyon-Utah juniper/mixed shrubs talus woodlands	Absent or sparse on these active slopes
Two-needle pinyon-Utah juniper/grassy rock-goldenrod woodlands	Sparse, typically less than 5%
Two-needle pinyon-Utah juniper/sparse understory woodlands	Variable with some stands having very little, occasionally up to 65%
Two-needle pinyon-Utah juniper/Wyoming big sagebrush woodlands	Variable with some stands having very little, occasionally up to 20%
Two-needle pinyon-juniper species/mountain-mahogany-mixed shrub woodlands	Variable with some stands having very little, occasionally up to 60%
Two-needle pinyon-juniper species/saline wildrye grass woodlands	May be totally absent or up to 35%
Blue spruce-two-needle pinyon-Utah juniper/Gambel's oak woodlands	Was not mentioned as being present in alliance description

Percent Bare Ground

In areas within the pinyon-juniper woodland/savannas of COLM where the surface is unvegetated, the percentage of bare ground may be high. Bare ground lacks any surface cover, including standing or fallen dead vegetation, litter, gravel, rock, bedrock, or BSCs. Areas with bare ground are more prone to erosive forces and increased runoff. A greater exposure to sunlight can lead to higher evaporation and saltation (Belnap 1992). The vegetation descriptions in Von Loh et al. (2007) briefly mention the ground surface conditions for each community as well as general vegetative cover percentages. In general, each of the pinyon-juniper woodlands/savannas was highly variable in the percent of bare ground, depending on where the observations were made. COLM has many areas with exposed bedrock where soil doesn’t tend to settle or accumulate unless there is something to hold it there, such as plant litter, rocks, gravel, or cracks and crevices. Table 25 summarizes vegetative cover and general ground surface conditions for each pinyon-juniper woodland/savanna vegetation alliance in COLM.

Table 25. Approximate vegetative cover for each COLM pinyon-juniper community along with notes on ground surface conditions (Von Loh et al. 2007).

Community	Ground Cover	Notes
Two-needle pinyon-(one-seed juniper, Utah juniper)/needle-and-thread woodlands	45%	Mostly gravel and large rock
Two-needle pinyon-Utah juniper/Utah serviceberry woodlands	26-43%	Bedrock, large and small rocks, low to moderate litter
Two-needle pinyon-Utah juniper/Bigelow's sagebrush woodlands	11-44%	Low to high bare soil
Two-needle pinyon-Utah juniper/black sagebrush woodlands	15-68%	Low to moderate bare soil
Two-needle pinyon-Utah juniper/littleleaf mountain-mahogany woodlands	15-44%	Moderate to high rock and bedrock, sparse bare soil
Two-needle pinyon-Utah juniper/mixed shrubs talus woodlands	4-61%	Low to high bare soil, bedrock, and rocks
Two-needle pinyon-Utah juniper/grassy rock-goldenrod woodlands	17-51%	Moderate to high bare ground, bedrock, and litter
Two-needle pinyon-Utah juniper/sparse understory woodlands	8-47%	Moderate to high gravel, rocks, and bedrock
Two-needle pinyon-Utah juniper/Wyoming big sagebrush woodlands	12-62%	Low to moderate bare ground, bedrock and rocks
Two-needle pinyon-juniper species/mountain-mahogany-mixed shrub woodlands	10-45%	High bedrock, rock, and bare ground (variable)
Two-needle pinyon-juniper species/saline wildrye grass woodlands	7-20%	Moderate to high bare ground and rocks
Blue spruce-two-needle pinyon-Utah juniper/Gambel's oak woodlands	59%	High litter and downed wood, bare ground absent

Trends in Invasive Infestation

COLM is part of a long-term monitoring program for IEPs developed by the NCPN that focuses on early detection (Perkins 2014). The first survey of IEPs in the park was conducted in 2003 by Dewey and Anderson (2005). The latest monitoring was conducted during the 2013 field season and will be used to assess this measure, since it includes the previously collected data on IEP infestations in COLM. A full discussion of IEPs park-wide, including a discussion of trends can be found in Chapter 2.2.2. In summary, during this 8-year time span (2003-2011), there was an overall decrease in Russian olive, tamarisk and woolly mullein (*Verbascum thapsus*) (Perkins 2014). However, the number of field bindweed infestations more than doubled during this same period (Perkins 2014).

In the most recent survey, conducted in 2013, a total of 462 IEP infestation points were identified within the park (Perkins 2014). The most frequently documented species of IEP were yellow sweetclover and cheatgrass. Several pinyon-juniper alliances included cheatgrass, and in some, as a dominant plant species (Von Loh et al. 2007). Two-needle pinyon-Utah juniper/Utah serviceberry woodlands, two-needle pinyon-Utah juniper/Bigelow's sagebrush woodlands, and two-needle pinyon-juniper species/mountain-mahogany-mixed shrub woodland descriptions all listed cheatgrass as a dominant herbaceous species (Von Loh et al. 2007). Alliances where cheatgrass was identified during vegetation mapping were two-needle pinyon-Utah juniper/black sagebrush woodlands, two-needle pinyon-Utah juniper/littleleaf mountain-mahogany woodlands, two-needle pinyon-Utah juniper/grassy rock-goldenrod woodlands, two-needle pinyon-Utah juniper/sparse understory woodlands, and two-needle pinyon-juniper species/(Wyoming big sagebrush, mountain big sagebrush) woodlands (Von Loh et al. 2007).

Trends in invasive plants have not been assessed specifically by vegetation association at COLM. To identify invasive species infestations associated with pinyon-juniper communities, spatial queries were performed using the data from the 2013 IEP survey and select pinyon-juniper vegetation communities mapped by Von Loh et al. (2007). Not all of the pinyon-juniper communities identified by Von Loh et al. (2007) could be mapped using a polygon representation of their location. These were mapped using a point representation, as they did not meet the MMU standard. The spatial queries were run using only the vegetation communities that were mapped as polygons. The spatial queries selected IEP points that were either within a mapped location of pinyon-juniper woodland or within 100 m (328 ft) of one of these communities. The analysis identified 79 (approximately 17%) of the IEP points met the criteria (Figure 16, Table 26). The most common IEPs selected by these queries were yellow sweetclover (37) and cheatgrass (27). All but two of the yellow sweetclover occurrences were located within polygons representing pinyon-juniper communities. All of the cheatgrass occurrences were within 100 m (328 ft) of a pinyon-juniper community. The results for all IEP occurrences that satisfied the spatial queries can be found in Table 26.

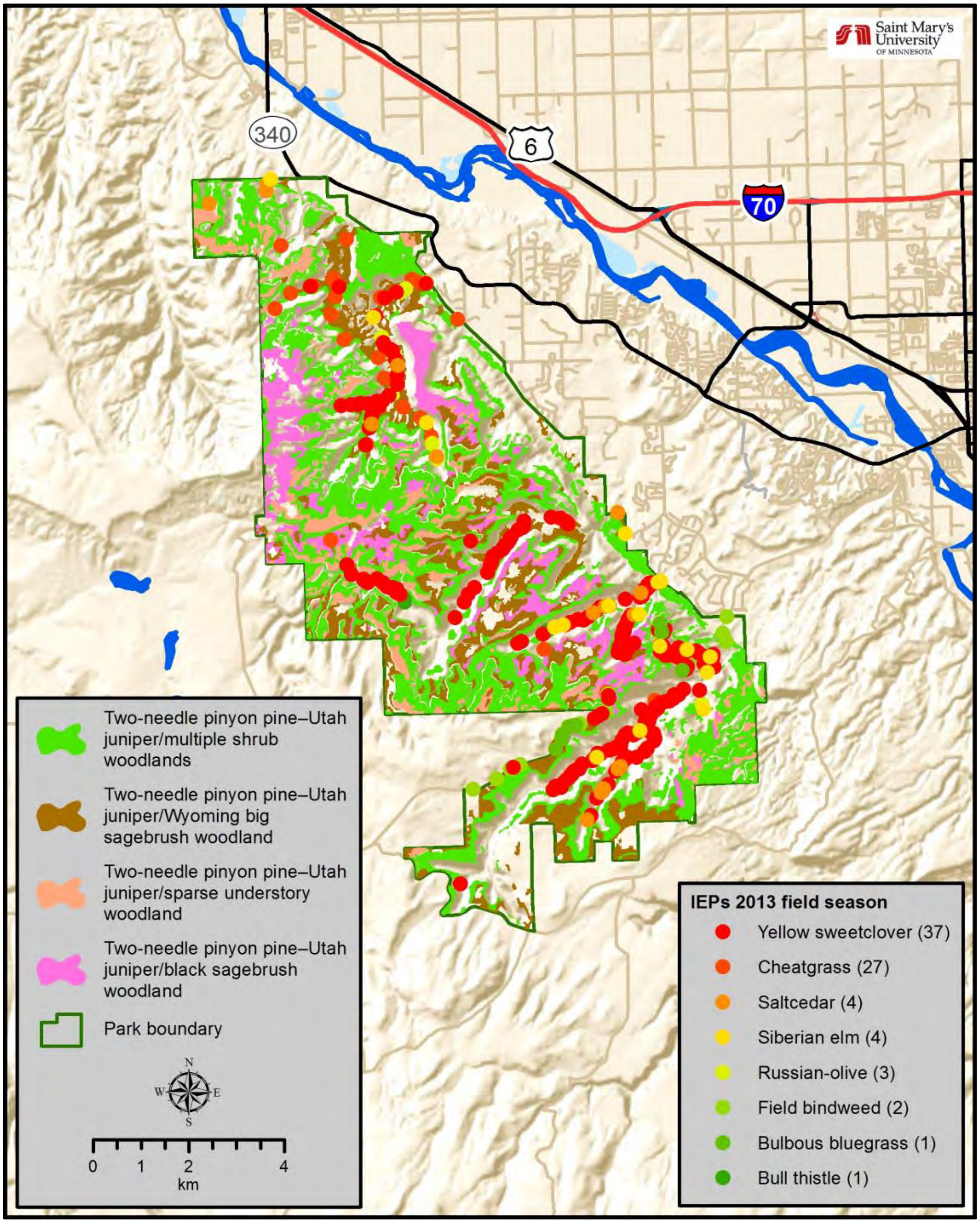

Figure 16. IEP infestations associated with mapped pinyon-juniper woodland/savannas.

Table 26. Number and location of non-native species occurrences in relation to pinyon-juniper woodlands/savannas.

Scientific Name	Common Name	Number Within	Number Adjacent	Total Number
Melilotus officinalis	yellow sweetclover	35	2	37
Bromus tectorum	cheatgrass		27	27
Tamarix ramosissima	saltcedar	4		4
Ulmus pumila	Siberian elm	4		4
Elaeagnus angustifolia	Russian olive	3		3
Convolvulus arvensis	field bindweed	2		2
Poa bulbosa	bulbous bluegrass	1		1
Cirsium vulgare	bull thistle	1		1
	Totals	**50**	**29**	**79**

Soil Stability

A direct assessment of soil stability in the pinyon-juniper woodlands/savannas has not been conducted. In general, soil stability is dependent upon the soil aggregate composition (i.e., amount of clay, sand, and organic matter) (USDA 2008). Soil aggregate stability determines the resilience of soil against erosive forces, specifically raindrop impact, water erosion, abrasion, and wind erosion (USDA 2008). Slope can also influence soil stability, as steeper slopes generally experience faster or more intense surface runoff and face more pressure from gravity.

In the dry, windswept, desert environment of COLM, the stability of soils is largely reliant on BSCs (Belnap 1992, 1994; Miller 2005). The absence of this living armor leaves soil vulnerable to the erosive forces of wind and water. Bare soil is also less able to facilitate ecological functions such as water infiltration and seed germination (Belnap 1992). In general, the pinyon-juniper woodlands/savannas are found on well-drained sandy loam soils, with slopes ranging from gentle to steep (Von Loh et al. 2007). Vegetation descriptions by Von Loh et al. (2007) contain information on the make-up of the unvegetated surfaces in pinyon-juniper woodlands; however, specific data on the percent bare ground are not available. The unvegetated ground cover is generally comprised of mixtures of litter/duff, gravel and rocks, exposed bedrock, down wood, cryptogams, and bare ground (Von Loh et al. 2007).

Vulnerability to Climate Change

The pinyon-juniper woodlands/savannas communities at COLM were selected (along with Seeps and Springs and Tinaja Habitats [Chapter 4.4.5]) for additional analysis on their vulnerability to climate change (See Chapter 3.1.2). The vulnerability of the two-needle pinyon pine-Utah juniper woodlands will be assessed based on five factors: location within the community's geographic range, sensitivity to extreme climatic events, dependence on hydrologic conditions, the community's adaptive capacity, vulnerability of ecologically influential species, and the potential for climate change to increase the impacts of non-climate stressors. A detailed description of this methodology and definition of these five variables is presented in Chapter 3.3 of this report.

The two-needle pinyon pine and Utah juniper can be found throughout the southern Rocky Mountains region (Figure 17). Within COLM, the pinyon-juniper woodlands/savannas are found at elevations ranging from 1,472 to 2,518 m (4,829 to 8,261ft) and generally on north or east aspects, although they are found on other aspects throughout the park (Von Loh et al. 2007). COLM is located in the north-central portion of the pinyon pine latitudinal range and on the eastern edge of the central part of the Utah juniper latitudinal range (Figure 17).

Based on COLM's location within the geographical ranges of pinyon pine and Utah juniper, this alone would not cause them to be significantly vulnerable to an increase in temperature. These woodlands are adapted to cold winter minimum temperatures and low rainfall, and are often a transitional community between grassland or desert shrubland and montane conifer systems (Brown 1994, Peet 2000).

Pinyon pine growth is strongly dependent on two climatic variables: the availability of sufficient precipitation prior to their growing season (winter through early summer), and cooler June temperatures (Barger et al. 2009). Both of these variables are projected to change to conditions that are less favorable for pinyon pine (Decker and Rondeau 2014). Climate models project warmer and drier (more arid) conditions for COLM by 2100 using the RCP 8.5 scenario. Summertime temperatures (June-August) at COLM are projected to increase by up to 5.7 °C (10.3 °F) by 2100 (Figure 18, ClimateWizard 2014). Higher temperatures will result in greater evapotranspiration rates which, despite a predicted increase in annual precipitation, would lead to an increase in aridity in all seasons, especially fall (September-November) and spring (March-May) (Figure 19, ClimateWizard 2014). Under the RCP 8.5 scenario, the climate models predict an increase in mean annual temperature of 4.8 °C (8.6 °F) with up to a nearly 17% increase in mean annual aridity (Figure 20, ClimateWizard 2014).

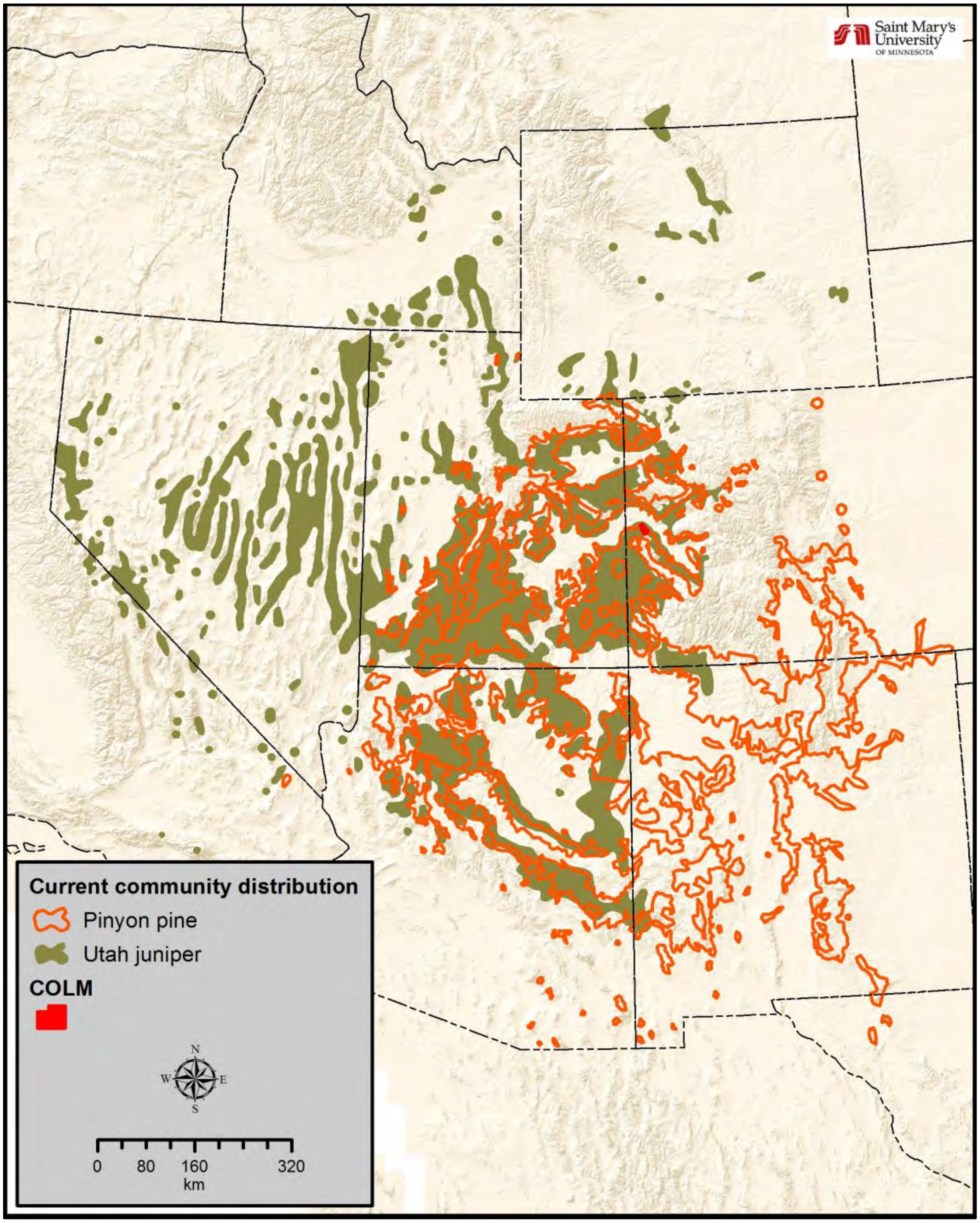

Figure 17. Current geographic extent of pinyon-juniper keystone species (two-needle pinyon pine and Utah juniper) used in the climate change vulnerability analysis. The geographic extents are from Little 1971.

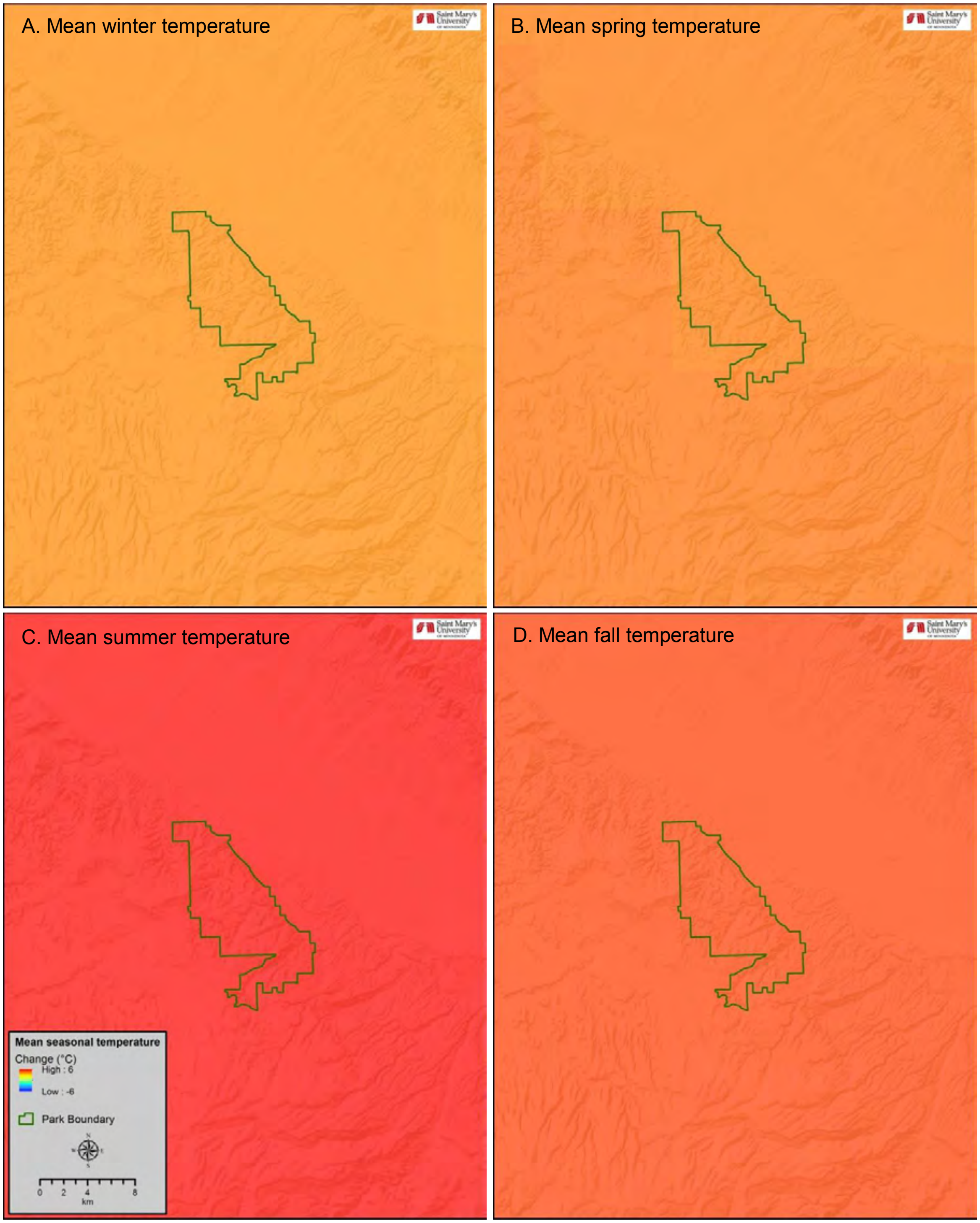

Figure 18. Change in mean A) winter, B) spring, C) summer, and D) fall seasonal temperatures for COLM by the year 2100 (ClimateWizard 2014). Temperatures are from the E50 ensemble with the RCP 8.5 scenario; change is determined as the departure from a 1961-1990 baseline. A 1 °C change equals a 1.8 °F change in temperature.

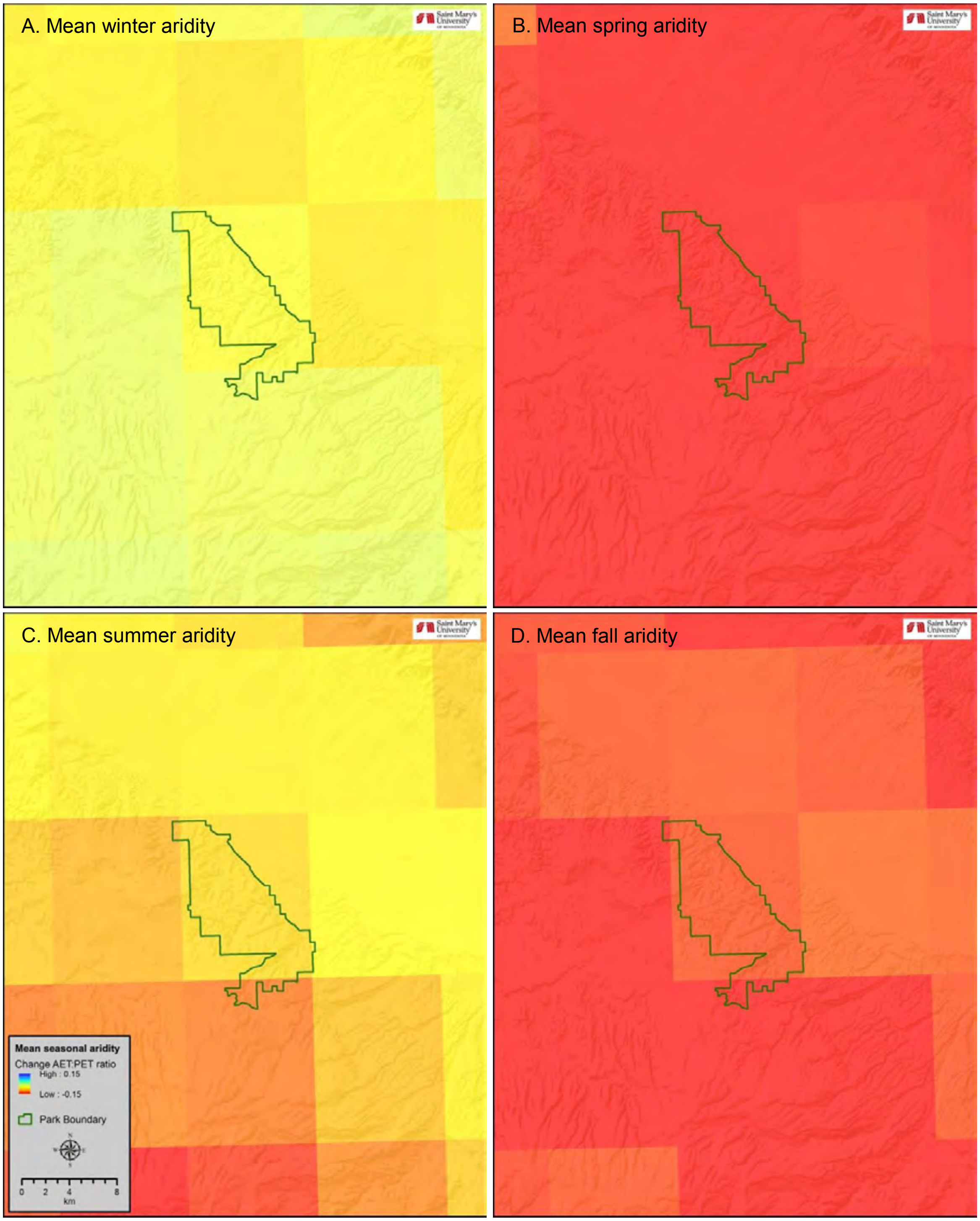

Figure 19. Change in mean A) winter, B) spring, C) summer, and D) fall seasonal aridity for COLM by the year 2100 (ClimateWizard 2014). Aridity values are presented as the change in the ratio of actual evapotranspiration to potential evapotranspiration. Aridity values are from the E50 ensemble with the RCP 8.5 scenario; change is determined as the departure from a 1961-1990 baseline.as the percent change from the baseline period of 1961-1990. A -0.15 change is equal to a 15% increase in aridity.

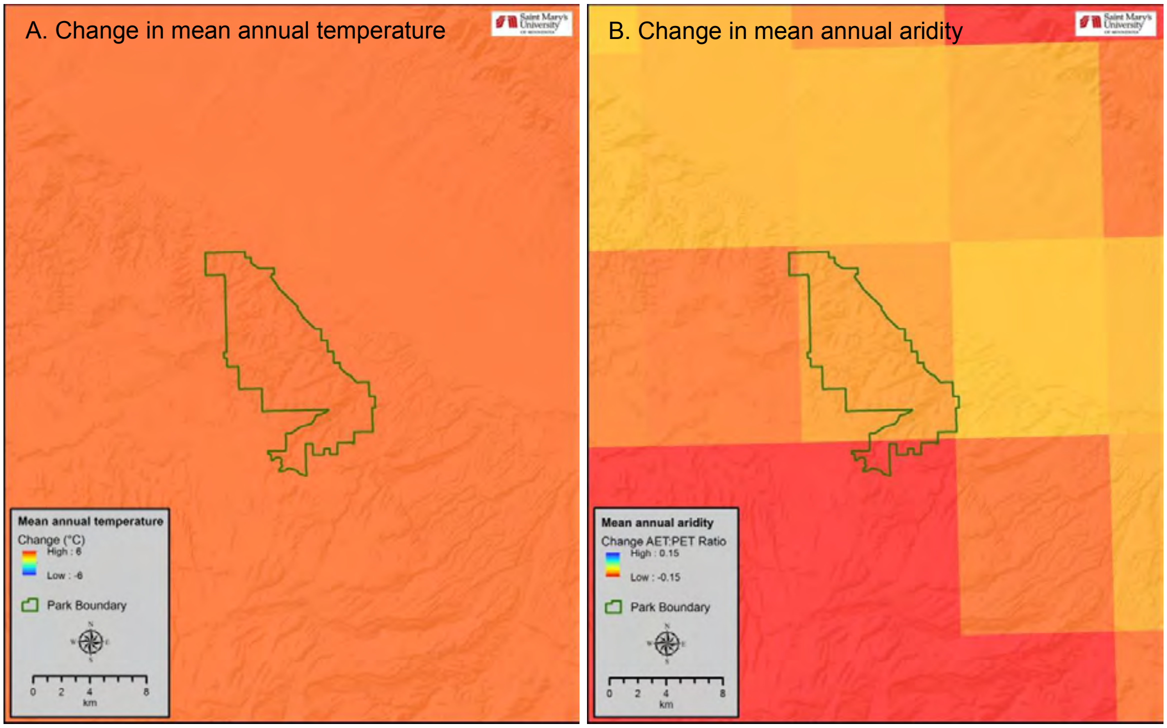

Figure 20. Changes in A) mean annual temperature and B) mean annual aridity for COLM by the year 2100 (ClimateWizard 2014, NCCSC 2015). Temperature and aridity values are from the E50 ensemble with the RCP 8.5 scenario; change is determined as the departure from a 1961-1990 baseline.

Rehfeldt et al. (2006) conducted species-specific bioclimate modeling for a number of western tree species. The bioclimate model uses each species' climate condition requirements (temperature, precipitation) and calculates how well the projected climate conditions match the current climate requirements, producing a map of viability scores for each species (Rehfleft et al. 2006). The higher the viability score, the closer the projected climate conditions are to the current climate requirements, and the more likely the species can be viable under the projected climate conditions (Rehfeldt et al. 2006). The maps can be used to estimate the location and overall geographic extent where western tree species could be found under the various RCP scenarios. The results of the bioclimate mapping are considered to have a high degree of accuracy, as testing of the models produced current mapped climate profiles that were in good agreement with current range maps (Rehfeldt et al. 2006). The bioclimate modeling under the RCP 8.5 scenario for pinyon pine and Utah juniper shows a predicted shift, primarily to the north and somewhat eastward. The model also predicts that both species will be able to exist far to the northwest, extending as far north as the Okanagan Valley in British Columbia (Figure 21, Figure 22) (Rehfeldt et al. 2006). Within COLM, the bioclimate maps for pinyon pine and Utah juniper show an overall decline in each species' viability scores by the year 2100 (Figure 21, Figure 22) (Rehfeldt et al. 2006). The models predict a climate at COLM that is less than 60% compatible with current climate conditions for both pinyon pine and Utah juniper by 2100 (Figure 21, Figure 22) (Rehfeldt et al. 2006). Overall, the projected climate under the RCP 8.5 scenario is at the low end of viability for both pinyon pine and Utah juniper.

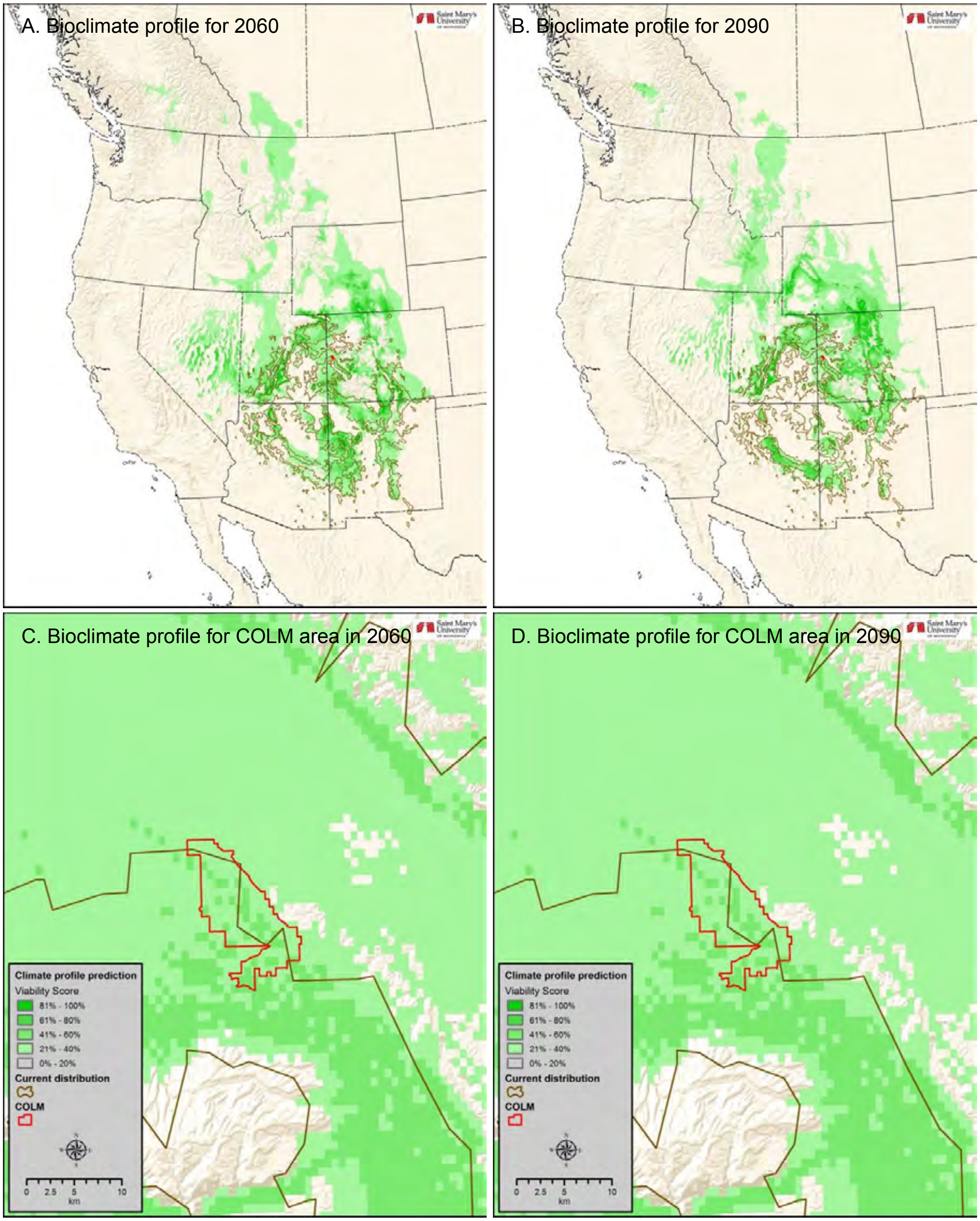

Figure 21. Modeled bioclimate profiles for pinyon pine (Rehfeldt 2006) overlaid on the digitized range maps of the current distribution (from Little 1991). Map A represents modeled total geographic extent for 2060 and Map B represents the modeled total geographic extent for 2090. Maps C and D are the modeled results for 2060 and 2090, respectively, but are zoomed in to show the general area around COLM. The bioclimate profiles are based on the RCP 8.5 scenario. The values are species viability scores in the range of 0 to 100%, where low numbers indicate that the climate is not consistent with where the species grows and high numbers indicates consistency (0%–20%, no color; 20%–40%, lightest green; 40%–60%, light green; 60%–80% dark green; and 80%–100%, darkest green).

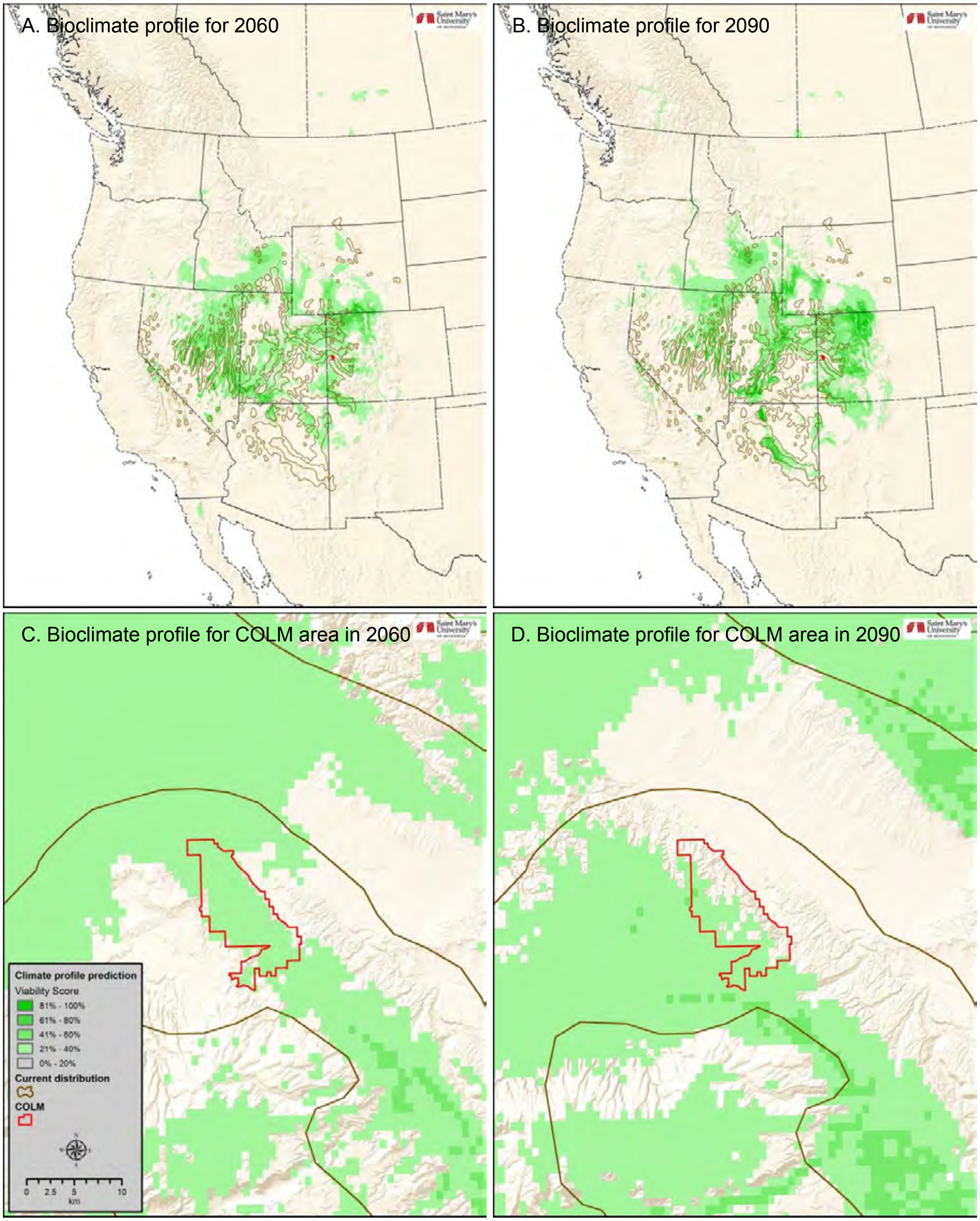

Figure 22. Modeled bioclimate profiles for Utah juniper (Rehfeldt 2006) overlaid on the digitized range maps of the current distribution (from Little 1991). Map A represents modeled total geographic extent for 2060 and Map B represents the modeled total geographic extent for 2090, Maps C and D are the modeled results for 2060 and 2090, respectively, but are zoomed in to show the general area around COLM. The bioclimate profiles are based on the RCP 8.5 scenario. The values are species viability scores in the range of 0 to 100%, where low numbers indicate that the climate is not consistent with where the species grows and high numbers indicates consistency (0%–20%, no color; 20%–40%, lightest green; 40%–60%, light green; 60%–80% dark green; and 80%–100%, darkest green).

The climate models' predictions for extended periods of drought has the potential to cause greater tree mortality, especially in pinyon pine, as it is more susceptible to drought than the Utah juniper (Breshears et al. 2008). The drought experienced in 2002-2003 has been associated with mortality in pinyon pine and Utah juniper in the Southwest (Richardson et al. 2012). Extended periods of drought can also increase the frequency and intensity of insect outbreaks and wildfire (Miller 2005, Decker and Rondeau 2014). Pinyon pine are also susceptible to the fungal pathogen *Leptographuum wageneri* var. *wageneri*, which causes black stain root disease and infestations of the pinyon ips bark beetle (*Ips confusus*) (Kearns and Jacobi 2005, Miller 2005). During the drought of early 2000, pinyon pine and Utah juniper mortality increased at COLM, believed to be due to a root fungus that was likely exacerbated by drought (NPS 1999). While both species are susceptible to drought, the differences in the degree of susceptibility of pinyon pine and juniper could result in these woodlands becoming dominated by juniper under the projected climate conditions for the RCP 8.5 scenario (Decker and Rondeau 2014).

The pinyon-juniper woodlands are expected to have significant adaptive capacity. These woodlands are tolerant to the warmer, more arid climate currently being projected by the climate models under the RCP 8.5 scenario. Since the last glacial period, the distribution of the pinyon-juniper woodlands and their abundance has fluctuated with changing climate conditions (Decker and Rondeau 2014). Warming conditions over the last two hundred years, along with other factors such as changing fire regimes and nutrient enrichment from atmospheric pollution, have increased the potential for this community to expand into neighboring vegetation communities at higher and lower elevations (Tausch 1999). Both pinyon pine and Utah juniper have large ecological amplitudes, and are suited to the warmer, more arid conditions projected by the climate models under the RCP 8.5 scenario (Decker and Rondeau 2014).

As discussed in Chapter 2.1.2, the GCMs predict higher temperatures and slight increases in precipitation for this region. While there is a slight projected increase in precipitation, the higher temperatures (for all seasons) will create higher evapotranspiration rates, ultimately resulting in drier conditions. These hotter and drier conditions expected in COLM over the next century will likely exacerbate many of the current non-climate stressors of the pinyon-juniper woodland plant community. Researchers believe that drought and warmth across western North America over the past decade have already led to extensive insect outbreaks and increased mortality in many forest types (Miller 2005, Breshears et al. 2008, Allen et al. 2010, Richardson et al. 2012). Higher summer temperatures typically accelerate the development and reproductive rates of insects, while drought stress may increase many tree species' vulnerability to insect attack (Allen and Breshears 1998, Kearns and Jacobi 2005, Miller 2005, Ayers and Lombardero 2000, Allen et al. 2010) and previous vulnerability assessments may have underestimated the mortality rate due to this synergy (Allen et al. 2015).

It is difficult to assess how the warmer and drier conditions predicted for COLM will affect the non-native plants already invading the pinyon-juniper communities. While Dukes and Mooney (1999) suggested that most aspects of global climate change will favor non-native species over natives, it is unknown if this pattern will apply to already arid environments such as COLM. The non-native species already present in COLM (Figure 16, Table 26) would likely be tolerant of warmer conditions, but may not survive the even drier predicted conditions. Drier conditions may also increase the potential for wildfires, which could be more intense due to the presence of invasive annual grasses in the understory of pinyon-juniper woodlands (Decker and Rondeau 2014).

Threats and Stressor Factors

There are several factors that are a concern in terms of the pinyon-juniper woodland/savannas at COLM. Park resource manager identified IEPs, unnatural fire regimes, social trails, drought, and climate change as the primary concerns in terms of this resource.

Exotic invasive species are a formidable threat to the pinyon-juniper woodland/savannas. IEPs disrupt the natural structure of native vegetation communities by displacing both plants and animals that are native to the community (Perkins 2014). Invasive plants can also alter the natural fire regime by accumulating fuels (e.g., dead grass) on the ground, a critical danger to pinyon-juniper woodland/savannas (Kennard and Moore 2013).

Altered fire intervals are a serious threat to the pinyon-juniper woodland/savannas, particularly where large, stand-replacing fires were historically infrequent (Kennard and Moore 2013). Kennard and Moore (2013) studied the fire histories of some of COLM's pinyon-juniper woodland/savannas to identify drivers of community structure. The results indicated that these woodlands and savannas have very long (588-1,428 years) fire rotations, particularly in persistent stands like those found on mesa tops in COLM (Kennard and Moore 2013). Lighting-ignited fires are not uncommon; however they tend to be small in size, at times burning only a single tree (Kennard and Moore 2013). Fire within pinyon-juniper habitats can lead to conditions where these habitats are replaced by grasslands dominated by invasive species. Considering these findings, using prescribed burning as a management tool would likely prove detrimental to the pinyon-juniper woodland/savannas in COLM, since cheatgrass is present and has the potential of expanding its cover with fire.

Visitor impacts within the park's pinyon-juniper habitats include damage to BSC present within these environments. Hikers, particularly those using unauthorized "social" trails, cause damage to these fragile habitats and the continued disturbance does not allow for the time needed for BSCs to regenerate. This can lead to invasive species encroaching and potentially replacing BSC habitats.

As a result of climate change, droughts are projected to increase in frequency, intensity, and duration throughout the southwestern states, including Colorado (Garfin et al. 2014). Extreme precipitation events, which often cause soil erosion, are also projected to increase in frequency and intensity (Garfin et al. 2014, Melillo et al. 2014). Temperatures will rise, accelerating evaporation and transpiration rates, and putting plants under further moisture stress (Garfin et al. 2014).

Data Needs/Gaps

A lack of an explicitly focused study on the pinyon-juniper woodland/savannas' soil stability, percent cover of CBC and bare ground makes an assessment of current condition difficult. There are some brief descriptions of soil type, percent tree canopy cover, and the unvegetated surface composition in Von Loh et al. (2007). These provide a starting point for future research, as mentioned in the descriptions above. In addition, more information is needed on how the effects of a warmer, drier climate will change the non-native species composition of the pinyon-juniper woodlands. Research on the impacts from the proliferation of social trails within the park is also recommended.

Currently a guaranteed funding source for the invasive species removal/control has not been identified. Failure to secure funding for this management action will result in the loss of the gains that have been made in eradicating IEPs within the park. Additionally, another programmatic need for COLM is a trail management plan. Currently, visitors face no restrictions in their access to any areas within the park.

<u>Overall Condition</u>

Community Extent and Change over Time
A *Significance Level* of 3 was assigned to the community extent and change over time measure. In several western states, the extent of pinyon-juniper woodlands/savannas has reportedly increased, as they have encroached into sagebrush communities (Soule et al. 2003, Johnson 2013). Johnson (2013) concluded that pinyon-juniper woodlands potentially have expanding into the park's sagebrush shrublands, which suggests that woodland extent has increased, or at least has not decreased. Therefore, a *Condition Level* of 1 has been assigned, indicating low concern.

Community Composition
The community composition measure was assigned a *Significance Level* of 3. Von Loh et al. (2007) reports plant species lists for each of the 12 pinyon-juniper alliances within COLM. The presence of non-native plants within these alliances, in some cases as a dominant species, indicates somewhat serious degradation to the community (Von Loh et al. 2007). Based on the assumption that the original community composition included only native plants, the *Condition Level* was assigned a 2.

Percent Cover Biological Soil Crusts
The percent cover of BSC is largely a data gap, with only superficial estimates of the amount of BSC coverage described in Von Loh et al. (2007). This measure was assigned a *Significance Level* of 3, but cannot be assigned a *Condition Level* at this time. The percentage estimates described in the vegetation mapping field data (Von Loh et al. 2007) may be useful in assessing this measure in subsequent studies.

Percent Bare Ground
This measure was assigned a *Significance Level* of 2. The bare ground coverage was described briefly in Von Loh et al. (2007), but was not reported as an actual percentage. The descriptions are of the general surface conditions, not specific to bare ground. For this reason, a *Condition Level* cannot be assigned at this time.

Trends in Invasive Infestation
This measure was assigned a *Significance Level* of 3 by the project team. Over the last decade the park has focused control efforts on eradication of IEP's. Future funding for these control measures is not available, so the potential for increased infestations is high (Hartwig, written communication 18 November 2015). Considering this along with the presence of IEPs within the pinyon-juniper

woodland/savannas detected in recent years, as well as several pinyon juniper woodland/savanna alliances now having cheatgrass as a dominant member of the community (Von Loh et al. 2007), the *Condition Level* has been assigned a 2.

Soil Stability

The soil stability measure was assigned a *Significance Level* of 2 and is largely a data gap. Von Loh et al. (2007) does provide short descriptions of soil type and percent slope, although this doesn't address all parameters needed to assess overall soil stability in the pinyon-juniper woodland/savannas. A *Condition Level* cannot be assigned at this time since soil stability parameters have not been directly assessed in the pinyon-juniper woodland/savannas.

Climate Change Vulnerability Assessment

Analysis of the pinyon-juniper community within COLM showed that it is moderately vulnerable to the projected impacts to climate change, with an overall score of 17 (Table 27). While the confidence in the assessment is within the high range, with a value of 15, half of the variable scores were rated as "moderate" confidence due to a number of factors.

Table 27. Certainty and alternative vulnerability scores for woodland plant community assessment variables.

Variable	Certainty Score[1]	Vulnerability Score[2]	Alternative Scores[3]
Location in geographical range/distribution of plant community	2	4	3
Sensitivity to extreme climatic events (e.g., drought, flash floods, windstorms)	3	3	
Dependence on specific hydrologic conditions	3	1	
Intrinsic adaptive capacity	3	3	
Vulnerability of ecologically influential species to climate change	2	3	4
Potential for climate change to exacerbate impacts of non-climate stressors	2	3	4
Total	**15**	**17**	**16-19**

[1]For individual variables, certainty scores are 3 = high, 2 = moderate, and 1 = low

[2]The certainty ranges are 6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence

[3]The vulnerability ranges are 6-13= least vulnerable, 14-19 = moderately vulnerable, 20-25 = highly vulnerable, 26-30 = critically vulnerable

To address some of the uncertainty within this assessment, alternative scores were identified for several variables in addition to the best estimate scores (Table 27). Alternative scores create a range of likely vulnerability for the plant community. The "location in the geographic range/distribution of the plant community" and the "vulnerability of ecologically influential species to climate change" variables were assigned alternative scores due to the variations in the climate models' seasonal and annual precipitation projections. The potential for climate change to exacerbate impacts of non-climate stressors was given an alternative score due to uncertainty of what effect the warmer, dryer climate would have on non-native species. When factored in, the range of vulnerability scores for the pinyon-juniper woodland community is 16 to 19, all of which are still within the "moderately vulnerable" category. With the high confidence certainty score, this suggests that, despite some uncertainty in climate projections and individual community variables, the classification of pinyon-juniper woodlands as moderately vulnerable appears fairly robust. The scoring worksheet developed for the pinyon-juniper woodlands is included in Appendix C.

Weighted Condition Score
The *Weighted Condition Score* for pinyon-juniper woodland/savannas is 0.56, which indicates moderate concern. This WCS is primarily due to the widespread presence of IEP species, which are major threats to the ecological health of the pinyon-juniper woodland/savannas in COLM.

Pinyon-juniper Woodlands/Savannas			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.56**
Community Extent and Change over Time	3	1	
Community Composition	3	2	
Percent Cover Biological Soil Crusts	3	n/a	
Percent Bare Ground	2	n/a	
Trends in Invasive Infestation	3	2	
Soil Stability	2	n/a	

4.1.6 Sources of Expertise
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4.2 Sagebrush Shrublands/Shrub Steppe

4.2.1 Description

The sagebrush shrublands/shrub steppe association within COLM is comprised of the following plant communities: basin big sagebrush/cheatgrass semi-natural shrubland, black sagebrush and grasses shrubland-graminoids, Wyoming big sagebrush/seeded grasses semi-natural shrubland, and Wyoming big sagebrush shrubland (Von Loh et al. 2007). The primary sagebrush species found within these communities are: basin big sagebrush, Wyoming big sagebrush, and black sagebrush (Von Loh et al. 2007).

Photo 5. Big Sagebrush (*Artemisia tridentata*) (NPS Photo).

Basin big sagebrush/cheatgrass semi-natural shrubland communities within COLM are found on gentle slopes (0-10%) between 1,524 and 1,926 m (5,000 and 6,319 ft) in elevation (Von Loh et al. 2007). Soils are generally loamy sand, sandy loam, silt loam, or clay loam (Von Loh et al. 2007). This community is found along drainages or on terraces along the canyon bottom drainages and on alluvial fans (Von Loh et al. 2007).

Black sagebrush and grasses shrubland-graminoids communities are generally found on relatively gentle slopes (4-18%) between 1,641 and 1,983 m (5,384 and 6,506 ft) in elevation (Von Loh et al. 2007). This community is found on the midslopes of hills and ridges and on an erosion fan with clay loam or silty clay soils (Von Loh et al. 2007).

Wyoming big sagebrush/seeded grasses semi-natural shrubland communities can be found on gentle slopes (2-10%) between 2,024 and 2,128 m (6,640 and 6,982 ft) in elevation with sandy loam or loamy sand soils (Von Loh et al. 2007). This community is found on mesa tops to the west and south of No Thoroughfare Canyon (Von Loh et al. 2007).

Wyoming big sagebrush shrubland communities are found on gentle to moderately steep (0-30%) slopes between 1,439 and 2,147 m (4,721 and 7,044 ft) in elevation (Von Loh et al. 2007). Soils are generally sandy loam (Von Loh et al. 2007). This community is found on the midslopes of canyons, along washes, in swales, valleys, and canyons, on both mesa tops and plains, and along drainage benches and terraces (Von Loh et al. 2007).

Basin big sagebrush/alkali sacaton (*Sporobolus airoides*) shrubland can be found approximately 2 km (1.2 mi) north of the Monument Canyon trailhead, adjacent to the eastern boundary fence. This community was observed in a narrow gully at the toeslope of a low ridge. This site has a gentle slope (9%) and occurred at 1,873 m (6,145 ft) in elevation. Soils at this location are silty clay (Von Loh et al. 2007).

Wyoming big sagebrush – shadscale (*Atriplex confertifolia*) shrubland can be found near the east entrance, adjacent to the park boundary fence. This community was observed on the midslopes of a hill. This site has a gentle slope (9%) and occurred at 1,438 m (4,718 ft) in elevation with silty clay soils (Von Loh et al. 2007).

Sagebrush shubland/shrub steppe communities at COLM support a variety of wildlife species. These communities provide shade, shelter and nesting/burrowing sites for a variety of small animals (Hanophy and Teitelbaum 2003). Reptile species such as the eastern collared lizard and the side-blotched lizard (*Uta stansburiana*) can be found within the sagebrush shrublands (Hanophy and Teitelbaum 2003). The California myotis (*Myotis californicus*) is known to roost in sagebrush (Hanophy and Teitelbaum 2003). Mexican woodrats (*Neotoma mexicana*), deer mice (*Peromyscus maniculatus*), Ord's kangaroo rat (*Dipodomys ordii*), and black-tailed jackrabbits (*Lepus californicus*) are some of the small rodents that can be found in these habitat (Hanophy and Teitelbaum 2003). Red-tailed hawks, owls, coyotes, and gray fox actively forage for prey within these vegetation communities (Hanophy and Teitelbaum 2003). Large mammals such as mule deer and elk also forage in these habitats (Hanophy and Teitelbaum 2003). Several avian species are closely associated with sagebrush habitat including the sage sparrow (*Artemisiospiza belli*) and the sage thrasher (*Oreoscoptes montanus*) (Hanophy and Teitelbaum 2003). Other birds commonly found in these habitats include the western scrub jay (*Aphelocoma californica*) and horned lark (*Eremophila alpestris*) (Hanophy and Teitelbaum 2003).

4.2.2 Measures

- Community extent and change over time
- Community composition
- Percent cover biological soil crusts
- Percent bare ground
- Trends in invasive infestation
- Soil stability
- Canopy gap size

4.2.3 Reference Conditions/Values

An ideal reference condition for this component would use the natural variability of the current system, particularly in the center of COLM away from the boundary (e.g., Liberty Cap Trail). However, not enough information is available regarding the range of variability for the selected measures to determine clear reference conditions at this time. Conditions will be assessed based on best professional judgment given the available data.

4.2.4 Data and Methods

A vegetation mapping project by Von Loh et al. (2007) shows the locations of all dominant cover types present in COLM in the early 2000s. The methodology for this project included vegetation classification and attribute development based on the NVC, field reconnaissance and mapping, and development of a spatial database. The study area for the project included COLM, plus an additional area beyond the park border. Mapping was completed using both traditional photo interpretation and biophysical modeling. This allowed for consistent and accurate mapping in a cost effective manner. The project resulted in vegetation data and maps for COLM and its immediate vicinity.

The impacts of pinyon-juniper woodland encroachment were analyzed by Johnson (2013). This study used aerial photos from 1937 and 2007 to determine the change in sagebrush shrubland habitat within a portion of COLM. Polygons were delineated for each photo using ArcMap™ and area was calculated allowing for both visual and numerical comparisons.

Hogan et al. (2009) developed a comprehensive list of plant species found within the park (Appendix D). This effort involved reviewing existing literature and re-examining specimens in the COLM herbarium. It also included field work to confirm unverified species and to potentially locate new species. This list includes plants by habitat type, one of which is sage shrub, which includes plants from “communities dominated by big sagebrush” (Hogan et al. 2009).

Invasive non-native plant species monitoring and mapping has occurred since 2003 (Dewey and Anderson 2005). The NCPN completed the most recent inventory in 2013 (Perkins 2014). Perkins (2014) was based on a list of priority IEPs that had been developed by the staff at COLM and the NCPN. A minimum detection target size (MDTS) of 40 m^2 (431 ft^2 or approximately 20 x 20 ft) was also established for use in the ongoing monitoring program. Monitoring routes and quadrats were established along the roads, major drainages, and trails in the park. In addition to invasive exotic species composition, information was collected on several other attributes, including infestation size and cover (Perkins 2014).

4.2.5 Current Condition and Trend

Community Extent and Change over Time

Von Loh et al. (2007) represents the most recent estimate of sagebrush shrublands/shrub steppe extent in the park. Data from this vegetation mapping projects shows that sagebrush shrublands/shrub steppe comprise 819 ha (2,023 ac), or approximately 10% of the COLM landscape (Table 28, Figure 23). Black sagebrush and grasses shrubland-graminoids communities within COLM can be found at the western Liberty Cap trailhead and adjacent to the Liberty Cap Trail. Basin big sagebrush/ cheatgrass semi-natural shrubland communities within COLM can be found in upper and middle Ute Canyon, upper and lower No Thoroughfare Canyon, near the East Entrance, and in Fruita Canyon (Von Loh et al. 2007).Wyoming big sagebrush/seeded grasses semi-natural shrubland communities within COLM can be found on the mesa south of No Thoroughfare Canyon to Little Park Road, on the west end of Old Gordon Road (Trail) and along DS Road (Von Loh et al. 2007).

Table 28. Areal extent of sagebrush shrublands/shrub steppe alliances found in COLM (Von Loh et al. 2007).

Alliances	Area ha (ac)	Percentage: Sagebrush shrublands/shrub steppe	Percentage: Total Vegetation
Basin big sagebrush/cheatgrass semi-natural shrubland	209.4 (84.7)	10.4%	1.0%
Black sagebrush and grasses shrubland-graminoids	664.6 (268.9)	32.9%	3.2%
Wyoming big sagebrush/seeded grasses semi-natural shrubland	347.4 (140.6)	17.2%	1.7%
Wyoming big sagebrush shrubland	801.3 (324.3)	39.6%	3.9%
Sagebrush shrublands/shrub steppe total	**2,022.7 (818.5)**	**100%**	
Park total	**20,450 (8,275.8)**		

Wyoming big sagebrush shrubland communities within COLM can be found near Liberty Cap trail, at the mouth of Lizard Canyon, east of Kissing Couple in Monument Canyon, upper Monument canyon, near the Rim Rock Drive, on the mesa north of Red Canyon, on Rimrock Drive near the head of Ute Canyon, west of Columbus Canyon, mesa south of Ute Canyon, along Glade Park Road, on the No Thoroughfare Canyon Mesa, near the mouth of Monument Valley, south of Devil's Kitchen Trail, near the park's western boundary, and east of the Cold Shivers turnout (Von Loh et al. 2007).

Two-needle pinyon and Utah juniper are the dominant woodland species in COLM (Von Loh et al. 2007). For the past 150 years, they have expanded into sagebrush shrublands/shrub steppe habitats as they have become more broadly distributed and formed denser woodlands (Soulé et al. 2003). The sagebrush shrublands/shrub steppe are being crowded out and out-competed by the expanding pinyon-juniper woodlands (Johnson 2013). According to Johnson (2013), the loss of sagebrush shrubland/shrub steppe due to the expansion of woodland species ranged from approximately 10% to 30% in certain areas of COLM over the past 70 years. As stated previously, distortions in the 1937 imagery do not allow for an exact determination of percent change (Kennard, written communication 18 November 2015). Ocular examination of the differences in the imagery does suggest that sagebrush shrubland/shrub steppe habitat has been lost to pinyon-juniper encroachment (Johnson 2013). It is unclear if this is the result of human influence, an environmental change, or simply a natural successional process.

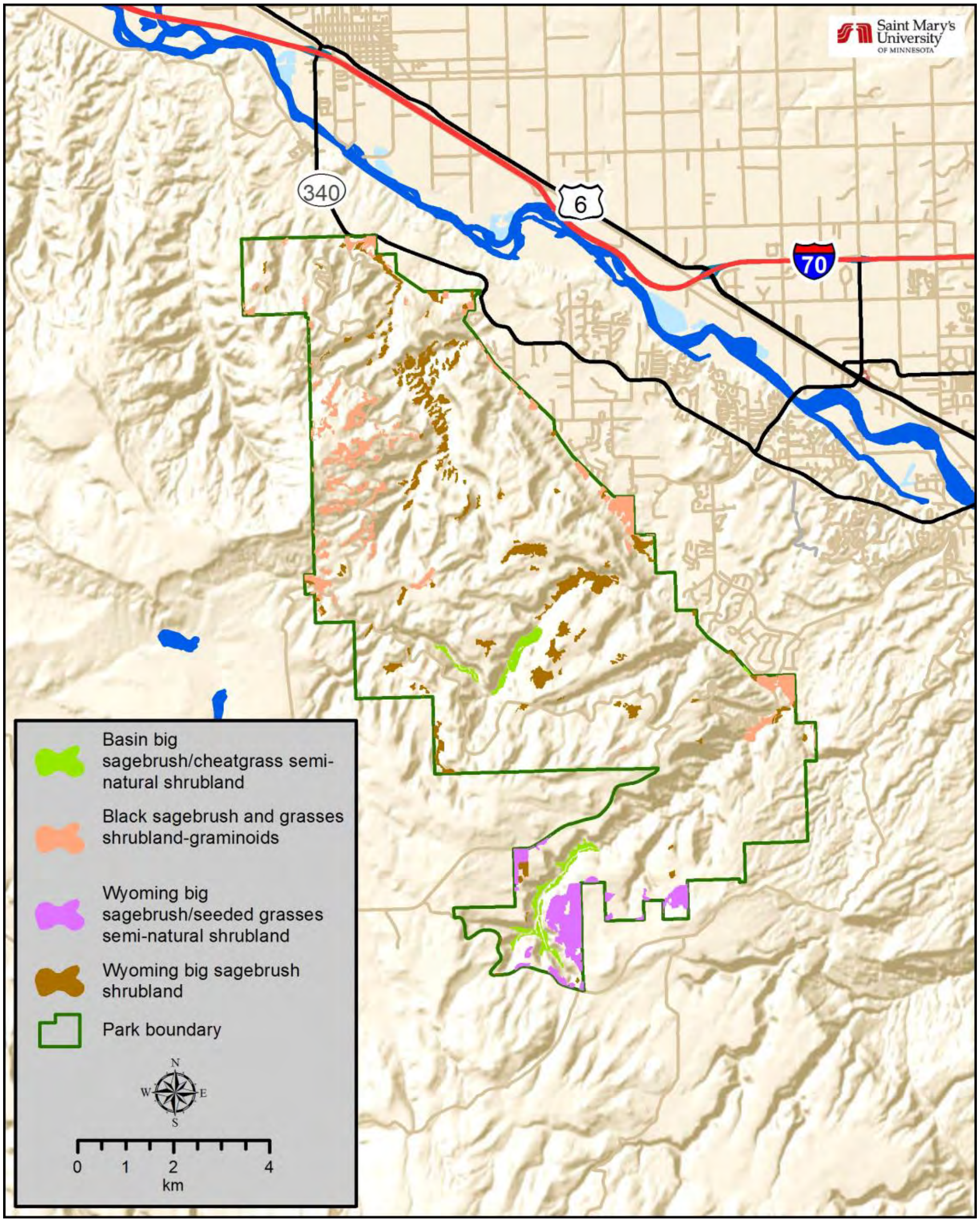

Figure 23. The location of sagebrush shrubland/shrub steppe alliances within COLM (Von Loh et al. 2007).

<u>Community Composition</u>

A comprehensive plant species list was developed by Hogan et al. (2009). A total of 289 plant species were identified that are either "present" or "reported" in sagebrush shrublands/shrub steppe communities (Appendix D). Species were considered present if a confirmed specimen or observation has been made since 1970. Species were considered reported if they have been listed in existing literature (Hogan et al. 2009). This total was comprised of three trees, 42 shrubs, 142 perennial forbs, 52 annual forbs, 35 perennial graminoids, 14 annual graminoids, and one fern (Hogan et al. 2009). Of these plants, 48 (16.6%) are introduced species while the remaining 241 (83.4%) are native species (NPS 2015).

The black sagebrush and grasses shrubland-graminoids communities contain a diverse shrub layer that includes black sagebrush, shadscale, yellow rabbitbrush (*Chrysothamnus viscidiflorus*) Torrey's Mormon tea (*Ephedra torreyana*), Mormon tea, spiny hopsage (*Grayia spinosa*), broom snakeweed (*Gutierrezia sarothrae*), winterfat (*Krascheninnikovia lanata*), claretcup (*Echinocereus triglochidiatus*), Mojave pricklypear (*Opuntia phaeacantha* var. *major*), and plains pricklypear (*Opuntia polyacantha*) (Von Loh et al. 2007). The herbaceous layer is diverse but sparse, including graminoids such as Indian ricegrass (*Achnatherum hymenoides*), cheatgrass, six weeks fescue (*Vulpia octoflora*), needle and thread, James' galleta, muttongrass (*Poa fendleriana*), and Sandberg's bluegrass (*Poa secunda*) and forbs such as Fendler's sandwort (*Eremogone fendleri*), Gunnison's mariposa (*Calochortus gunnisonii*), western tansymustard (*Descurainia pinnata* ssp. *halictorum*), dwarf draba (*Draba reptans*), Arizona hymenoxys (*Tetraneuris acaulis*), western stickseed (*Lappula occidentalis* var. *occidentalis*), grassy rockgoldenrod, and scarlet globemallow (*Sphaeralcea coccinea* ssp. *coccinea*) (Von Loh et al. 2007). The most abundant species within this community by stratum can be found in Table 29.

Table 29. Dominant plant species (by strata) within the black sagebrush and grasses shrubland-graminoids community of COLM (Von Loh et al. 2007).

Black sagebrush and grasses shrubland-graminoids		
Scientific Name	**Common Name**	**Strata**
Artemisia nova	black sagebrush	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Hesperostipa comata	needle and thread	Herb
Hilaria jamesii	James' galleta	Herb
Lappula occidentalis var. *occidentalis*	western stickseed	Herb
Poa fendleriana	muttongrass	Herb
Sphaeralcea coccinea ssp. *coccinea*	scarlet globemallow	Herb
Tetraneuris acaulis	Arizona hymenoxys	Herb

The basin big sagebrush/cheatgrass semi-natural shrubland communities are characterized by an open to closed canopy of basin big sagebrush, typically 1 to 5 m (3 to 16 ft) tall (Von Loh et al. 2007). Skunkbush sumac is also present in this community, though it represents less than 5% of the total cover (Von Loh et al. 2007). A few trees are present, providing up to 3% cover (Von Loh et al. 2007). These trees include Utah juniper and two-needle pinyon and are typically 2 to 5 m (7 to 16 ft) tall (Von Loh et al. 2007). Other short and dwarf shrubs that contribute sparse to low cover in these communities include fourwing saltbush, Mormon tea, rubber rabbitbrush (*Ericameria nauseosa*), fringed sagebrush (*Artemisia frigida*), broom snakeweed, Mojave pricklypear, and plains pricklypear (Von Loh et al. 2007). The herbaceous layer is generally sparse, though can have high cover of cheatgrass (Von Loh et al. 2007). Other graminoids in this community include Indian ricegrass, squirreltail (*Elymus elymoides*), six weeks fescue, needle and thread, foxtail barley (*Hordeum jubatum*), muttongrass, and sand dropseed (*Sporobolus cryptandrus*) (Von Loh et al. 2007). Forbs commonly found in this community include tapertip onion (*Allium acuminatum*), goosefoot (*Chenopodium* spp.), western tansymustard, flixweed (*Descurainia sophia*), smallflower dragonhead (*Dracocephalum parviflorum*), stork's bill (*Erodium cicutarium*), scarlet gilia (*Ipomopsis aggregata* ssp. *aggregata*), prickly lettuce (*Lactuca serriola*), western stickseed, mountain pepperweed (*Lepidium montanum*), woolly plantain (*Plantago patagonica*), western groundsel (*Senecio integerrimus*), and tumble mustard (*Sisymbrium altissimum*) (Von Loh et al. 2007). The most abundant species within this community by stratum can be found in Table 30.

Table 30. Dominant plant species (by strata) within the basin big sagebrush/cheatgrass semi-natural shrubland community of COLM (Von Loh et al. 2007).

Basin big sagebrush/cheatgrass semi-natural shrubland community		
Scientific Name	**Common Name**	**Strata**
Artemisia tridentata ssp. *tridentata*	basin big sagebrush	Tall shrub/sapling
Rhus aromatica var. *pilosissima*	skunkbush sumac	Tall shrub/sapling
Atriplex canescens	fourwing saltbush	Short shrub/sapling
Ericameria nauseosa	rubber rabbitbrush	Short shrub/sapling
*Bromus tectorum**	cheatgrass	Herb
Hesperostipa comata	needle and thread	Herb
Lappula occidentalis var. occidentalis	western stickseed	Herb
Sporobolus cryptandrus	sand dropseed	Herb

*Indicates a non-native species.

The Wyoming big sagebrush/seeded grasses semi-natural shrubland communities are characterized by Wyoming big sagebrush and crested wheatgrass (*Agropyron cristatum*). These two species account for 4 to 40% cover and 1 to 25% cover, respectively (Von Loh et al. 2007). When present, a tree canopy of Utah juniper and two-needle pinyon (typically 2 to 5 m [7 to 16 ft] tall) provide up to 8% cover (Von Loh et al. 2007). The remaining short/dwarf shrub layer is generally low in diversity and cover and includes yellow rabbitbrush, rubber rabbitbrush, Utah juniper, two-needle pinyon, tarragon (*Artemisia dracunculus*), fringed sagebrush, broom snakeweed, brittle pricklypear (*Opuntia fragilis*), and plains pricklypear (Von Loh et al. 2007). The herbaceous layer is also low in diversity and cover (Von Loh et al. 2007). Graminoids present include Indian ricegrass, purple three-awn (*Aristida purpurea*), blue grama (*Bouteloua gracilis*), cheatgrass, squirreltail, six weeks fescue, needle and thread, muttongrass, and sand dropseed (Von Loh et al. 2007). Forbs commonly found in this community include hoary dusty-maiden (*Chaenactis douglasii*), wavy-leaf thistle (*Cirsium undulatum* var. *undulatum*), western tansymustard, dwarf draba, hairy goldenaster, western stickseed, silvery lupine (*Lupinus argenteus*), sweetclover species (*Melilotus* spp.), pale evening primrose (*Oenothera pallida* ssp. *trichocalyx*), woolly plantain, western groundsel, and scarlet globemallow (Von Loh et al. 2007). The most abundant species within this community by stratum can be found in Table 31.

Table 31. Dominant plant species (by strata) within the Wyoming big sagebrush/seeded grasses semi natural shrubland community of COLM (Von Loh et al. 2007).

Wyoming big sagebrush/seeded grasses semi natural shrubland		
Scientific Name	**Common Name**	**Strata**
Juniperus osteosperma	Utah juniper	Tree canopy
Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush	Short shrub/sapling
Ericameria nauseosa	rubber rabbitbrush	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
*Agropyron cristatum**	crested wheatgrass	Herb
*Bromus tectorum**	cheatgrass	Herb
Chrysothamnus viscidiflorus	yellow rabbitbrush	Herb
Elymus elymoides	squirreltail	Herb
Gutierrezia sarothrae	broom snakeweed	Herb
Heterotheca villosa	hairy false goldenaster	Herb
Opuntia phaeacantha var. *major*	Mojave pricklypear	Herb
Senecio integerrimus	western groundsel	Herb
Sporobolus cryptandrus	sand dropseed	Herb

*Indicates a non-native species.

The Wyoming big sagebrush shrubland communities are characterized by Wyoming big sagebrush, providing 1 to 45% cover (Von Loh et al. 2007). Utah juniper and two-needle pinyon pine are occasionally present as canopy trees, generally 2 to 5 m (7 to 16 ft) tall and provide up to 5% cover (Von Loh et al. 2007). These communities contain a highly variable shrub layer that include skunkbush sumac, black greasewood (*Sarcobatus vermiculatus*), fourwing saltbush, shadscale, yellow rabbitbrush, Mormon tea, rubber rabbitbrush, spiny hopsage, black sagebrush, broom snakeweed, winterfat, and prickly phlox (*Linanthus pungens*), claretcup, Mojave pricklypear, brittle pricklypear, berry pricklypear (*Opuntia phaeacantha*), plains pricklypear, Simpson's hedgehog cactus (*Pediocactus simpsonii*), and Harriman's yucca (Von Loh et al. 2007). The herbaceous layer is diverse and provides low to moderate cover. This layer includes graminoids such as Mormon needlegrass (*Achnatherum aridum*), Indian ricegrass, crested wheatgrass, purple three-awn, blue grama, cheatgrass, squirreltail, needle and thread, junegrass (*Koeleria macrantha*), saline wildrye, western wheatgrass (*Pascopyrum smithii*), James' galleta, muttongrass, and six weeks fescue (Von Loh et al. 2007). Forbs present in this layer include Fendler's sandwort, fringed sagebrush, woolly milkvetch (*Astragalus mollissimus*), smallflower milkvetch (*Astragalus nuttallianus*), Gunnison's mariposa, sagebrush buttercup (*Ranunculus testiculatus*), hoary dusty-maiden, bastard toadflax (*Comandra umbellata*), cryptantha (*Cryptantha* spp.), Nuttall's larkspur (*Delphinium nuttallianum*), western tansymustard, dwarf draba, fleabane (*Erigeron* spp.), cushion buckwheat (*Eriogonum ovalifolium* var. *ovalifolium*), stork's bill, hairy false goldenaster, prickly lettuce, western stickseed, prairie pepperwort (*Lepidium densiflorum*), mountain pepperweed, blue flax (*Linum lewisii*), silvery lupine, pale evening primrose, crenulate phacelia (*Phacelia crenulata*), longleaf phlox (*Phlox longifolia*), woolly plantain, western groundsel, sleepy catchfly (*Silene antirrhina*), scarlet globemallow, desert princesplume (*Stanleya pinnata*), long-beak fiddle-mustard (*Streptanthella* *longirostris*), and hoary townsendia (*Townsendia incana*) (Von Loh et al. 2007). The most abundant species within this community by stratum can be found in Table 32.

Table 32. Dominant plant species (by strata) within the Wyoming big sagebrush shrubland community of COLM (Von Loh et al. 2007).

Wyoming big sagebrush shrubland		
Scientific Name	**Common Name**	**Strata**
Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush	Short shrub/sapling
Chrysothamnus viscidiflorus	yellow rabbitbrush	Short shrub/sapling
Opuntia fragilis	brittle pricklypear	Short shrub/sapling
Opuntia polyacantha	plains pricklypear	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Aristida purpurea	purple three-awn	Herb
Astragalus nuttallianus	smallflower milkvetch	Herb
Bouteloua gracilis	blue grama	Herb
*Bromus tectorum**	cheatgrass	Herb
Descurainia pinnata ssp. *halictorum*	western tansymustard	Herb
Elymus elymoides	squirreltail	Herb
Hesperostipa comata	needle and thread	Herb
Hilaria jamesii	James' galleta	Herb
Lappula occidentalis var. occidentalis	western stickseed	Herb
Linanthus pungens	prickly phlox	Herb
Leymus salina	saline wildrye	Herb
Oenothera pallida ssp. *trichocalyx*	pale evening primrose	Herb
Poa fendleriana	muttongrass	Herb
Sphaeralcea coccinea ssp. *coccinea*	scarlet globemallow	Herb

*Indicates a non-native species.

Percent Cover Biological Soil Crusts

Belnap et al. (2008, p. 1,257) defines BSCs as intertwined communities of lichens, mosses, and cyanobacteria commonly found on soil surfaces in dryland regions. These communities are a very important part of the ecosystem because of their influence on local hydrology, soil stability and fertility, and overall biodiversity (Belnap et al. 2008). Biological soil crusts aggregate soil particles, making the soil stronger and less susceptible to erosional forces of wind and water, thereby retaining nutrients, organic matter, and seeds in the underlying soils (Miller 2005). BSCs within COLM are most commonly found on sites that are protected from disturbance and are also found to be re-developing in areas that were once grazed or other-wise disturbed (Von Loh et al. 2007). Because of the ecological benefits provided by BSCs, they should be included in ecological monitoring programs where present (Belnap et al. 2008).

The percent cover of BSCs within COLM's sagebrush shrublands/shrub steppe varies based on community type. Black sagebrush and grasses shrubland-graminoids communities usually have low percent cover of BSC, though it may be as high as 45% in some stands (Von Loh et al. 2007). Cover of BSCs within basin big sagebrush/cheatgrass semi-natural shrubland communities is low and ranges from 3-10% (Von Loh et al. 2007). Wyoming big sagebrush/seeded grasses semi-natural shrubland communities have absent to low percent cover of BSCs, not exceeding 5% (Von Loh et al. 2007). The percent cover of BSCs within Wyoming big sagebrush shrubland communities is variable, from sparse to as high as 85% (Von Loh et al. 2007).

Percent Bare Ground

Percent bare ground is important because it can impact soil stability, as vegetation helps prevent wind erosion (Witwicki et al. 2013). Areas where bare ground is the primary component of total ground cover have been associated with increased susceptibility to water erosion (NRCS 2010, Kachergis et al. 2011). Studies have also shown that large areas of bare ground can be indicative of low site stability and high erosion potential (Haveren 2000).

Percent bare ground of sagebrush shrublands/shrub steppe varies with community type. In black sagebrush and grasses shrubland-graminoids communities, total vegetation canopy cover ranges from 15 to 24% with low ground cover of litter and high ground cover of rocks and bare ground (Von Loh et al. 2007). Basin big sagebrush/cheatgrass semi-natural shrubland communities have total vegetation canopy cover that ranges from 33 to 120% with high ground cover of litter and low to high ground cover of bare ground (Von Loh et al. 2007). In Wyoming big sagebrush/seeded grasses semi-natural shrubland communities, total vegetation canopy cover ranges from 11 to 56% with moderate to high ground cover of litter and bare ground (Von Loh et al. 2007). Vegetation cover in Wyoming big sagebrush shrubland communities ranges from 11 to 62%, with low to high ground cover of litter, rocks, and bare ground (Von Loh et al. 2007).

Trends in Invasive Infestation

COLM is part of a long-term monitoring program for IEPs developed by the NCPN which focuses on early detection (Perkins 2014). The first survey of IEPs in the park was conducted in 2003 by Dewey and Anderson (2005). The latest monitoring was conducted during the 2013 field season (Perkins 2014) and will be used to assess this measure, since it includes the previously collected data on IEP infestations in COLM. A full discussion of IEPs park-wide, including a discussion of trends can be found in Chapter 2.2.2. In summary, during this 8-year time span (2003-2011), there was an overall decrease in Russian olive, tamarisk and woolly mullein (Perkins 2014). However, the number of field bindweed infestations more than doubled during this same period (Perkins 2014).

In the most recent survey, conducted in 2013, a total of 462 IEP infestation points were identified within the park (Perkins 2014). The most frequently documented species of IEP were yellow sweetclover and cheatgrass. One of the sagebrush shrubland/shrub steppe alliances at COLM is named for its cheatgrass content (basin big sagebrush/cheatgrass semi-natural shrubland). The Wyoming big sagebrush shrubland and Wyoming big sagebrush/seeded grasses semi-natural shrubland descriptions lists cheatgrass as a dominant herbaceous species (Von Loh et al. 2007). Cheatgrass is also listed as being present in the black sagebrush grasses shrubland alliance (Von Loh et al. 2007).

Trends in IEP's have not been assessed specifically by vegetation association at COLM. To identify invasive species infestations associated with sagebrush shrubland/shrub steppe vegetation communities' spatial queries were performed using the data from the 2013 IEP survey and the sagebrush shrubland/shrub steppe vegetation communities mapped by Von Loh et al. (2007). The spatial queries selected IEP points that were either within a mapped location of sagebrush shrubland/shrub steppe or within 100 m (328 ft) of one of these communities. The analysis identified 141 (approximately 33%) of the IEP points met the criteria (Figure 24, Table 33). The most common IEP's selected by these queries were yellow sweetclover (65) and cheatgrass (44). The majority of these occurrences were within 100 m (328 ft) of a mapped sagebrush shrubland/shrub steppe community. In total, nearly 75% of the observed occurrences where found in close proximity (100 m [328 ft]) to sagebrush shrubland/shrub steppe communities. Yellow sweetclover and cheatgrass accounted for 83% of the infestations that occurred within a sagebrush shrubland/shrub steppe communities. The results for all IEP occurrences that satisfied the spatial queries can be found in Table 33.

Table 33. Number and location of non-native species occurrences in relation to sagebrush shrubland/shrub steppe.

Scientific Name	Common Name	Number Within	Number Adjacent	Total Number
Melilotus officinalis	yellow sweetclover	20	45	65
Bromus tectorum	cheatgrass	10	34	44
Elaeagnus angustifolia	Russian olive	3	4	7
Arctium minus	burdock		6	6
Convolvulus arvensis	field bindweed		5	5
Tribulus terrestris	puncture vine	1	3	4
Ulmus pumila	Siberian elm	1	2	3
Verbascum thapsus	woolly mullein	1	2	3
Tamarix ramosissima	saltcedar		2	2
Cirsium vulgare	bull thistle		2	2
	Totals	**36**	**105**	**141**

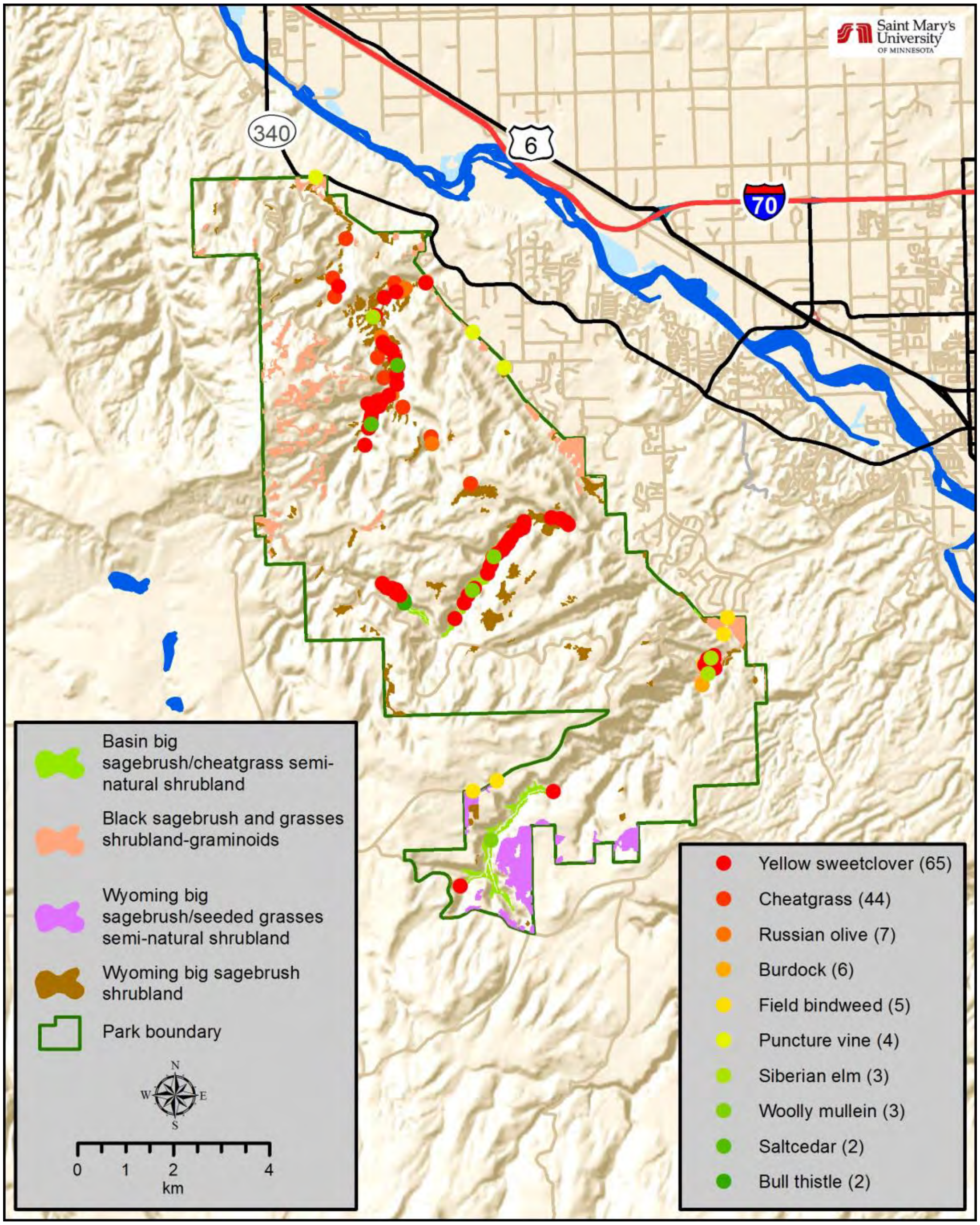

Figure 24. IEP infestations associated with mapped sagebrush shrubland/shrub steppe.

Soil Stability

Soil stability depends on a number of factors. The presence of BSCs, litter/duff, other non-vegetative ground cover, slope, soil composition, and soil texture are some of the factors that can influence soil stability (NRCS 1996, Belnap et al. 2008, Witwicki et al. 2013). Vegetative conditions (e.g., basal cover, height) also greatly influence soil stability (Whisenant 1985). Soil loss can be influenced by rainfall intensity, size and frequency of bare ground, soil type, topography, and plant cover, especially following a fire. Vegetation and slope are the best determinants of soil erosion in severe rainfall storms. Studies in various plant communities show that 60-70% vegetation cover appears necessary to ensure soil stability against erosion during rainfall (Packer 1963, Orr 1970, Whisenant 1985). Specific data on soil stability within COLM are not available. A condition assessment of this measure is not possible due to lack of available data.

Canopy Gap Size

Canopy gap size is important because vegetative canopy cover can protect soils from wind and water erosion (BLM 2013, Witwicki et al. 2013). Canopy gap is defined by the NCPN as an area where the distance between plant canopies is greater than 20 cm (7.9 in) (Witwicki et al. 2013). While Von Loh et al. (2007) contains information on the canopy cover and basal ground cover within each of the communities, data are not available that could be used to determine canopy gap size.

Threats and Stressor Factors

NPS staff identified several potential threats and stressors to the sagebrush shrublands/shrub steppe community: exotic invasive species (particularly cheat grass), unnatural fire regimes, drought, and regional climate variation. In general, the introduction of exotic invasive species can cause economic or environmental damage and pose a danger to human health (Executive Order 13112), and they are the second greatest threat to biodiversity in the country, behind habitat loss (Wilcove et al. 1998). Exotic invasive plant species negatively impact the natural environment by fragmenting native ecosystems, displacing native plants and animals, and altering ecosystem function (Scott and Wilcove 1998, Perkins 2014). In addition, exotic invasive species can alter fire regimes and increase trail maintenance requirements (Kennard and Moore 2013, Perkins 2014). Riparian corridors, roads, and trails provide possible pathways for IEPs to enter a park (Perkins 2014).

Fire can affect an ecosystem by altering the vegetation composition and structure and eliminating fire intolerant plant species (Miller 2005). The sagebrush and pinyon-juniper communities at COLM are closely associated. Studies have shown that pinyon-juniper may have encroached into sagebrush habitat at COLM (Johnson 2013). Since these two habitats are closely tied, the impacts of fire on pinyon-juniper habitat also impact sagebrush habitat. Altered fire intervals are a serious threat to the pinyon-juniper woodland/savannas, particularly where large, stand-replacing fires were historically infrequent (Kennard and Moore 2013). Kennard and Moore (2013) studied the fire histories of some of COLM’s pinyon-juniper woodland/savannas to identify drivers of community structure. The results indicated that these woodlands and savannas have very long (588-1,428 years) fire rotations, particularly in persistent stands like those found on mesa tops in COLM where pinyon-juniper habitat is intermixed with sagebrush habitat (Kennard and Moore 2013). It can be assumed that the sagebrush habitats have a similar fire regime.

Fire is also a concern for nearby residential areas. Fire within big sagebrush shrublands prior to European/American settlement was likely characterized by long rotations of high severity fires. These fire rotations were likely 100-240 years at a minimum and were stand replacing fires (Baker et al. 2006). In recent years, Utah juniper and two-needle pinyon mortality has increased due to a root fungus probably brought on by drought (NPS 1999). These dead trees, along with the increasing cheatgrass cover, provide fuel for fires (NPS 1999). This fuel can cause the area to burn more frequently. After a fire, native bunchgrasses or non-native, invasive grasses may become established in the area, making it difficult for sagebrush to become a dominant species again (Witwicki et al. 2013).

Visitor impacts within the park's sagebrush shrubland/shrub steppe habitats include damage to BSC present within these environments. Hikers, particularly those using unauthorized "social" trails, cause damage to these fragile habitats and continued disturbance does not allow for the time needed for BSCs to regenerate. This can lead to invasive species encroaching and potentially replacing BSC habitats.

Drought can cause widespread mortality among the vegetation in COLM (Miller 2005). This can increase susceptibility to fire and insect outbreak as well as lower vegetation resistance to other stressors (Miller 2005). COLM averages 29 cm (11 in) of precipitation annually (WRCC 2015). With the exception of minor peaks in the spring and late summer, the precipitation pattern is distributed relatively evenly throughout the year. Any alteration in precipitation patterns due to climate change could result in longer and more frequent dry periods, which would stress the region's sagebrush shrublands (Bradley 2010).

Data Needs/Gaps

Although general descriptions of the percent cover of BSCs and percent bare ground are available for COLM communities (Von Loh et al. 2007), no actual data could be found for these measures. Data for soil stability and canopy gap size measures also were not available for COLM. Witwicki et al. (2013) briefly touch on these topics but only discuss a monitoring protocol, no actual data are included. Data referencing the IEP composition for each specific vegetation community is also a data gap at this time. Research on the impacts from the proliferation of social trails within the park is also recommended.

Currently a guaranteed funding source for the invasive species removal/control has not been identified. Failure to secure funding for this management action will result in the loss of the gains that have been made in eradicating IEPs within the park. Additionally, another programmatic need for COLM is a trail management plan. Currently, visitors face no restrictions in their access to any areas within the park.

Overall Condition

Community Extent and Change over Time

This measure was assigned a *Significance Level* of 3. Utah juniper and two-needle pinyon expanded into sagebrush shrublands/shrub steppe communities over the past 150 years (Soulé et al. 2003). This expansion has caused the sagebrush communities to decline by 9% to 29% over the past 70 years (Johnson 2013). As mentioned previously, it is unclear if this is the result of human influence, an environmental change, or simply a natural successional process. Because the extent of sagebrush shrublands/shrub steppe communities of COLM appears to be slowly decreasing, this measure was assigned a *Condition Level* of 1, indicating low concern.

Community Composition

A *Significance Level* of 3 was assigned to the community composition measure. According to Hogan et al. (2009), a total of 289 plant species are present in the sagebrush shrublands of COLM (Appendix D). Of these plant species, approximately 83% are native. With a high species richness and relatively high nativity, the *Condition Level* assigned to this measure is 1, indicating low concern.

Percent Cover Biological Soil Crusts

The percent cover of BSCs measure was assigned a *Significance Level* of 3. This measure is highly variable depending on sagebrush community type, with cover values ranging from zero to 85%. However, a reference condition is necessary to determine what appropriate values are for each community type. A *Condition Level* was not assigned to this measure due to lack of available data.

Percent Bare Ground

A *Significance Level* of 2 was assigned to this measure. Percent bare ground varies with community type. Total vegetation cover in the sagebrush shrublands/shrub steppe of COLM ranges from 11% to 120%. Where vegetation is absent, cover of litter, rocks, and bare ground vary from low to high. Although some data exist for the percent bare ground measure, a reference condition and more detailed data are needed to determine the current overall condition of the measure. Due to this, a *Condition Level* could not be assigned.

Trends in Invasive Infestation

This measure was assigned a *Significance Level* of 3. Invasive species are one of the greatest threats to biodiversity in the United States (US) (Wilcove et al. 1998). Recent IEP surveys performed indicate many different species occur within COLM (Perkins 2010, 2012, 2014). Most IEP occurrence remained relatively constant from year to year based on number of infestations. Cheatgrass infestations have increased in number and size since 2009. Cheatgrass infestations account for a large portion of the total number of IEP's in the most recent survey. Over the last decade the park has focused control efforts on eradication of IEP's. Future funding for these control measures is not available, so the potential for increased infestations is high (Hartwig, written communication 18 November 2015). Due to these factors a *Condition Level* of 2 was assigned for this measure.

Soil Stability

The soil stability measure was assigned a *Significance Level* of 2. Specific data on soil stability within the sagebrush shrublands/shrub steppe of COLM were not available. Many variables that may contribute to soil stability are outlined throughout the document, though these often contain a range of values, making it difficult to accurately determine the soil stability within COLM. A *Condition* Level was not assigned to this measure because specific data on soil stability are not available.

Canopy Gap Size

A *Significance Level* of 3 was assigned to this measure. Data on canopy gap size within the sagebrush shrublands/shrub steppe communities was not available for COLM. A *Condition Level* was not assigned to this measure due to the lack of available data.

Weighted Condition Score

A *Weighted Condition Score* was not calculated for this component because a *Condition Level* could not be assigned to over 50% of the measures due to lack of available data. Until more data becomes available for the other measures, the condition of sagebrush shrublands in COLM will be unknown.

Sagebrush Shrublands/Shrub Steppe			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Community Extent and Change over Time	3	1	
Community Composition	3	1	
Percent Cover Biological Soil Crusts	3	n/a	
Percent Bare Ground	2	n/a	
Trends in Invasive Infestation	3	2	
Soil Stability	2	n/a	
Canopy Gap Size	3	n/a	

4.2.6 Sources of Expertise

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4.3. Riparian Habitats/Large Dry Washes

4.3.1 Description

Riparian habitats/large dry washes are of considerable ecological importance in COLM. There are different types of riparian habitat within the park; most are found along washes in the canyon bottoms that are periodically fed by snowmelt and rainfall from the mesas, and seeps and springs in the canyon rock faces (Photo 6). The vegetation communities that comprise these riparian habitats have adapted to their surroundings by utilizing the limited available water supply.

Photo 6. The riparian habitat shown in this canyon bottom is discernable from the surrounding vegetation and grows along a large dry wash (Photo by Anna Davis, SMUMN GSS 2013).

These riparian habitats provide critical cover and forage for desert amphibian species, such as red-spotted toads (*Anaxyrus punctactus*) and canyon tree frogs (*Hyla arenicolor*). Within Colorado, riparian and wetland communities contain the greatest diversity of bird species of any ecosystem (Hanophy and Teitelbaum 2003). Vireos (*Vireo* spp.), warblers, orioles (*Icterus* spp.), blackbirds, grosbeaks, finches and flycatchers (*Empidonax* spp.) can be found within COLM's riparian habitats (Hanophy and Teitelbaum 2003). Raptors, such as golden eagles, prairie falcons, Cooper's hawks (*Accipiter cooperii*), American kestrels, and great horned owls (*Bubo virginianus*) utilize these habitats for roosting and hunting (Hanophy and Teitelbaum 2003). Desert cottontail mice, voles, and raccoons (*Procyon lotor*) are commonly found in these habitats along with larger mammals such as elk and deer (Hanophy and Teitelbaum 2003).

4.3.2 Measures

- Community extent and change over time
- Community composition
- Trends in invasive infestation
- Cottonwood regeneration
- Channel geomorphology
- Frequency and discharge of flash floods

4.3.3 Reference Conditions/Values

The reference condition of riparian/large dry wash habitats would ideally be from pre-settlement times or at the time of park establishment (1911) when the area was minimally developed. Although specific data aren't available to determine a reference condition for each measure, the assumption for the community composition and trends in invasive species measures is that vegetation communities in riparian habitat and large dry washes historically included only native plant species.

4.3.4 Data and Methods

Several sources were used to address the measures listed for this component and are briefly described below. The studies and projects provided information on conditions pertaining to riparian and large dry washes located in the park.

Richard (2004) compiled data on flash flooding in the area in and around COLM. The report provided data on topography, soil permeability, slope, and precipitation. It also included a literature review that created a record of flash floods originating from COLM drainages. Major drainages within the park were mapped, encompassing the areas where major flash flooding has occurred since establishment of the park (Richard 2004). The flooding records from NPS records and the Grand Junction newspaper archives, dating from 1921 through 2003 are included in this report (Richard 2004).

Von Loh et al. (2007) conducted a vegetation mapping project for COLM and close vicinity. The purpose of the project, conducted between 2003 and 2005, was to classify, describe, and map vegetation and fuels at COLM (Von Loh et al. 2007). A team of ecologists, botanists, and photo interpreters worked together to identify the plant associations within the park (Von Loh et al. 2007). Vegetation mapping was completed through the use of aerial photography and computer modeling (Von Loh et al. 2007). The resultant maps were refined through a combination of ground sampling and accuracy assessments using vegetation plot and observation point sampling (Von Loh et al. 2007). A complete detailed methodology of the computer modeling and sampling design can be found in Von Loh et al. (2007).

Hogan et al. (2009) compiled a comprehensive list of plant species within COLM. The project included conducting a review of park plant specimen collections, including specimens in the park herbarium and from the University of Colorado herbarium (Hogan et al. 2009). Field surveys were also conducted to confirm unverified species and to document previously unlisted species (Hogan et al. 2009). The products from this project included an annotated checklist with additional information about the flora found within COLM (e.g., geographic range, flowering period).

Fertig et al. (2012) updated the plant species list provided and maintained by Hogan et al. (2009). The focus of this study was to identify any previously undocumented species or the discovery of new species (Fertig et al. 2012). This report also provided a 2011 update to the NPSpecies database plants list for COLM (Fertig et al. 2012).

Kennard and Rogowski (2015) assessed the health of the cottonwood population in COLM. This study characterized the cottonwood populations' structure, percent dead trees, and assessed regeneration, and examined the size versus age relationship within the parks cottonwood stands (Kennard and Rogowski 2015).

4.3.5 Current Condition and Trend

Community Extent and Change over Time

The riparian communities were mapped and classified by Von Loh et al. (2007) as part of the vegetation mapping project in COLM. Von Loh et al. (2007) utilized the national standard minimum mapping unit (MMU) of 0.5 ha (1.2 ac). A total of 11 associations and alliances comprise the riparian/large dry wash vegetation habitats at COLM. The selection was based on the vegetation classifications that Von Loh et al. (2007) identified as Riparian, Wetland, and Mesic Ecological Systems in the classification schema used for the vegetation mapping project.

Even though a large number of riparian/large dry wash habitats occur at the park, these areas comprised only 1% of the park's vegetation, and should be considered rare within the park (Von Loh et al. 2007). Von Loh et al. (2007) could be used as a baseline for any subsequent, similar vegetation projects to determine what, if any, changes in extent or composition has occurred to the riparian/large dry wash habitats. Figure 25 shows the location of the habitats that were mapped as polygons, and a summary of the areal extent is provided in Table 34. Not all the riparian/large dry wash habitats identified during the project meet the MMU. For those habitats area is assumed to be less than the MMU.

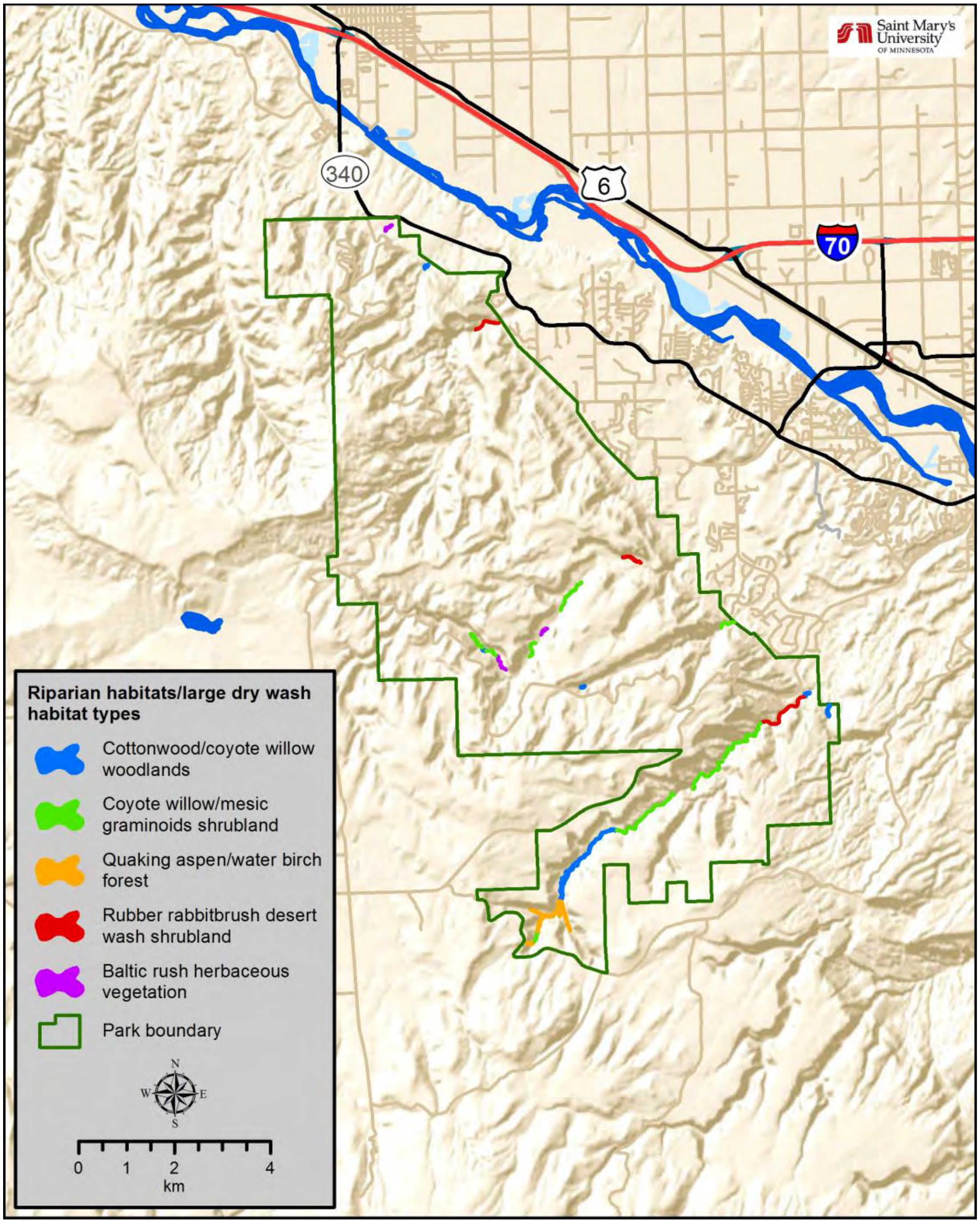

Figure 25. The location of riparian vegetation alliances within COLM (Von Loh et al. 2007).

Table 34. Areal extent of alliances associated with riparian habitat/large dry washes within COLM (Von Loh et al. 2007).

Alliances	Scientific Name	Hectares (ha)	Acres (ac)
Cottonwood/coyote willow woodland	*Populus deltoides/Salix exigua*	10.6	26.3
Coyote willow/mesic graminoids shrubland	*Salix exigua*	9.2	22.8
Quaking aspen/water birch forest	*Populus tremuloides/Betula occidentalis*	6.5	16
Rubber rabbitbrush desert wash shrubland	*Ericameria nauseosa*	3.0	7.4
Baltic rush herbaceous vegetation	*Juncus balticus*	1.5	3.8
Box elder/disturbed understory woodland	*Acer negundo*	<0.5	<1.2
Quaking aspen western chokecherry forest	*Populus tremuloides-Prunus virginiana*	<0.5	<1.2
Singleleaf ash woodland	*Fraxinus anomala*	<0.5	<1.2
Skunkbush intermittently flooded shrubland	*Rhus aromatica*	<0.5	<1.2
Smooth horsetail herbaceous vegetation	*Equisetum laevigatum*	<0.5	<1.2
Water birch/starry false Solomon's-seal shrubland	*Betula occidentalis/Maianthemum stellatum*	<0.5	<1.2
	Total (excluding values <0.5 ha [<1.2 ac])	**30.8**	**76.3**

Cottonwood (*Populus deltoides*)/coyote willow (*Salix exigua*) woodlands are restricted to narrow drainages in canyon bottoms and alcoves where there is intermittent surface flow and groundwater seepage (Von Loh et al. 2007). This type of riparian woodland is considered the most common, occupying a total of 10.6 ha (26.3 ac) within COLM (Figure 26) (Von Loh et al. 2007). Its distribution is very patchy with the majority found in No Thoroughfare Canyon and the remainder scattered in small stands or clumps in Ute, Red and Columbus Canyons (Von Loh et al. 2007).

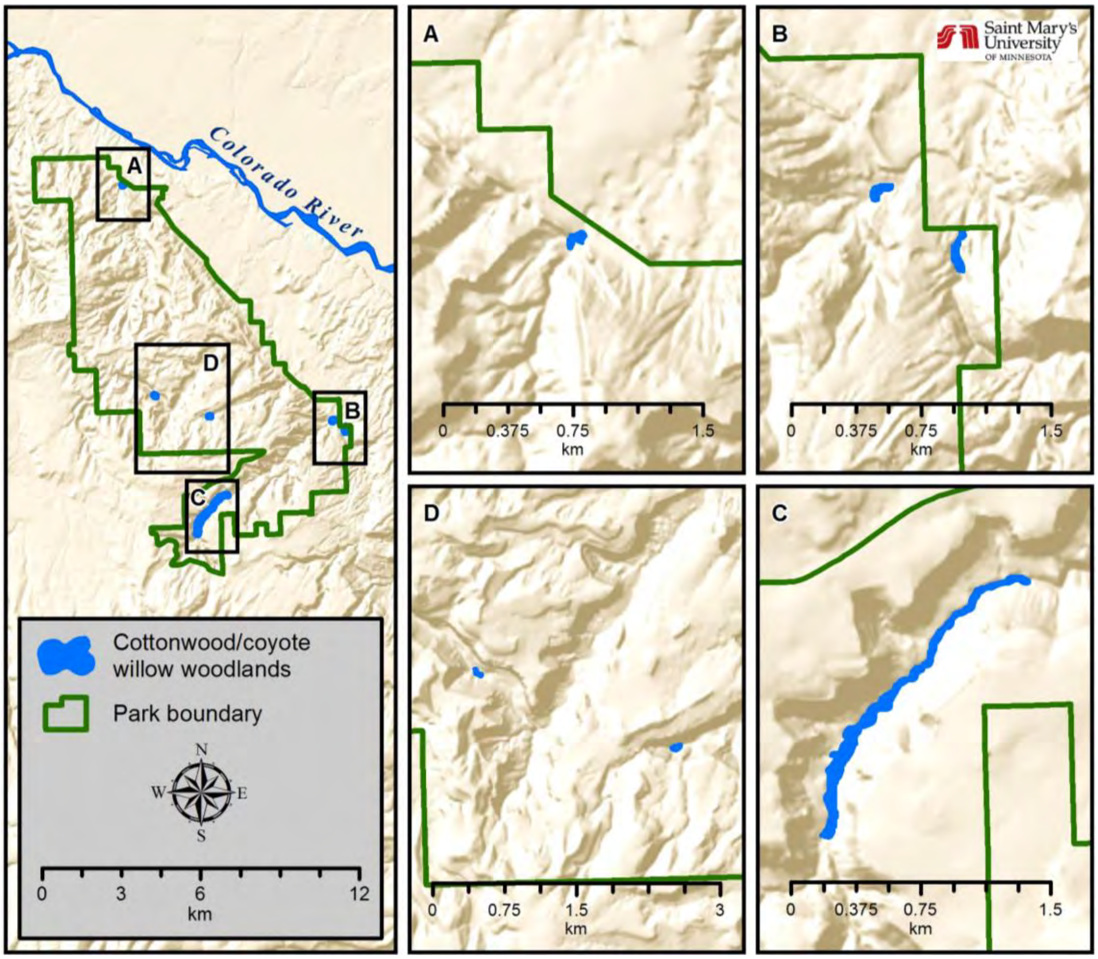

Figure 26. Location of cottonwood/coyote woodlands within COLM (Von Loh et al. 2007).

Coyote willow/mesic graminoids shrubland type were mapped in Ute, No Thoroughfare, Red, and Columbus Canyon bottoms (Von Loh et al. 2007). This habitat was found in confined drainages that are subject to flash flooding (Von Loh et al. 2007). There were 9.2 ha (22.8 ac) of this habitat in the park (Von Loh et al. 2007). The majority (5.3 ha/13.2 ac) was found in the bottom of No Thoroughfare Canyon, with approximately 3.4 ha (8.5 ac) in Ute Canyon, and a small 0.5 ha (1.1 ac) plot at the confluence of Red Canyon and Columbus Canyon (Figure 27) (Von Loh et al. 2007).

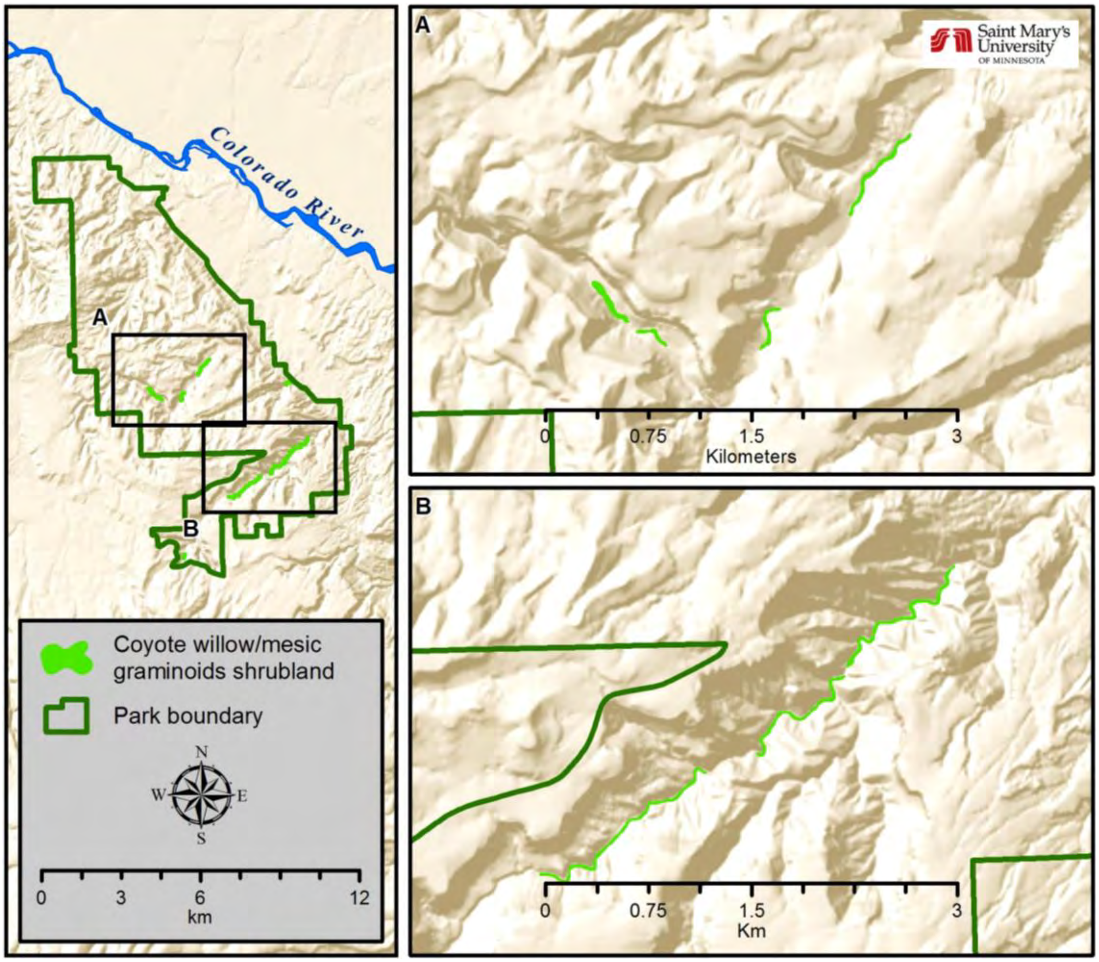

Figure 27. Location of coyote willow/mesic graminoid shrublands within COLM (Von Loh et al. 2007).

Quaking aspen (*Populus tremuloides*)/water birch (*Betula occidentalis*) forest occurs in only one known site at COLM. Two stands, totaling of 6.5 ha (16 ac) (Table 34), were found in the upper No Thoroughfare Canyon bottom (Figure 28) (Von Loh et al. 2007).

The rubber rabbitbrush desert wash shrublands are considered very rare and generally occur as 5 to 10 m wide (16.4 to 32.8 ft) corridors along drainage channels that are subject to periodic flash flooding (Von Loh et al. 2007). A total of only 3.0 ha (7.4 ac) was mapped in small patches in three separate canyons in COLM (Von Loh et al. 2007). They were located in No Thoroughfare (1.4 ha/3.6 ac), Ute (0.8 ha/2.1 ac), and Monument Canyons (0.7 ha/1.7 ac) (Figure 29) (Von Loh et al. 2007).

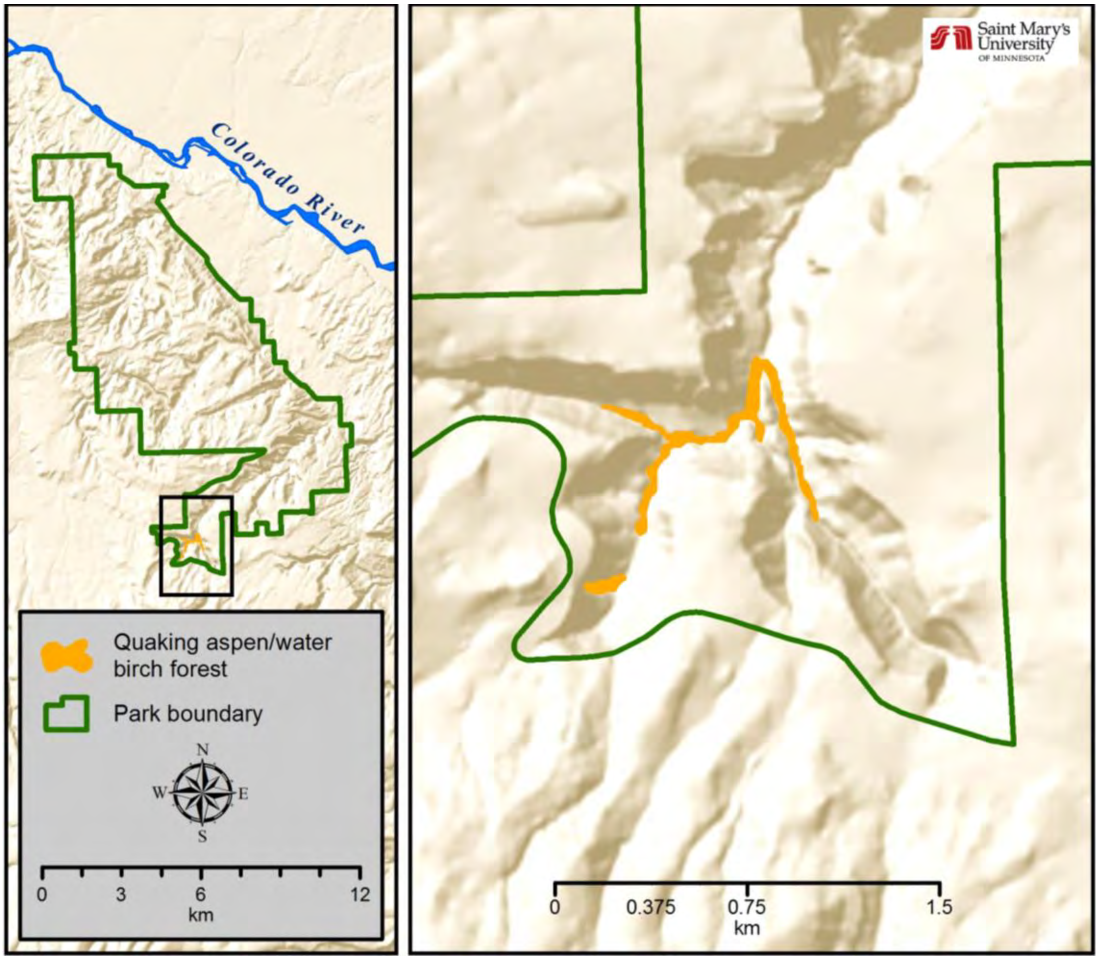

Figure 28. Location of quaking aspen/water birch forests within COLM. This riparian habitat was only found in No Thoroughfare Canyon during the vegetation mapping project (Von Loh et al. 2007).

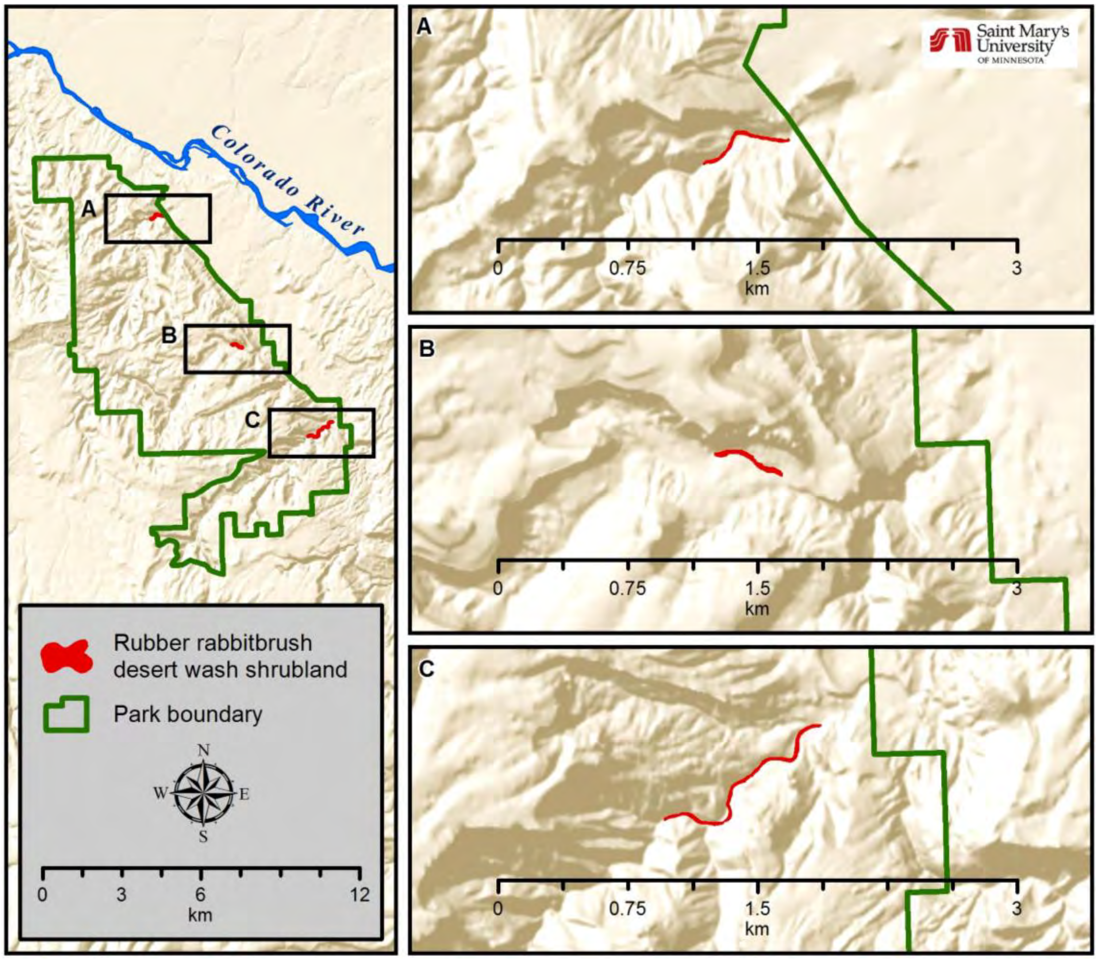

Figure 29. Location of rubber rabbitbrush desert wash shrublands within COLM (Von Loh et al. 2007).

Baltic rush (*Juncus balticus*) herbaceous vegetation is confined to drainages with seepage and intermittent surface flow (Von Loh et al. 2007). There were 1.5 ha (3.8 ac) in total of this habitat occurring in two regions within COLM (Von Loh et al. 2007). One small area of Ute Canyon had two separate stands (totaling 1.1 ha/2.8 ac) and was located in the central part of the park, and the second 0.4 ha (1 ac) stand was in the northern portion of the park near the park boundary (Figure 30) (Von Loh et al. 2007).

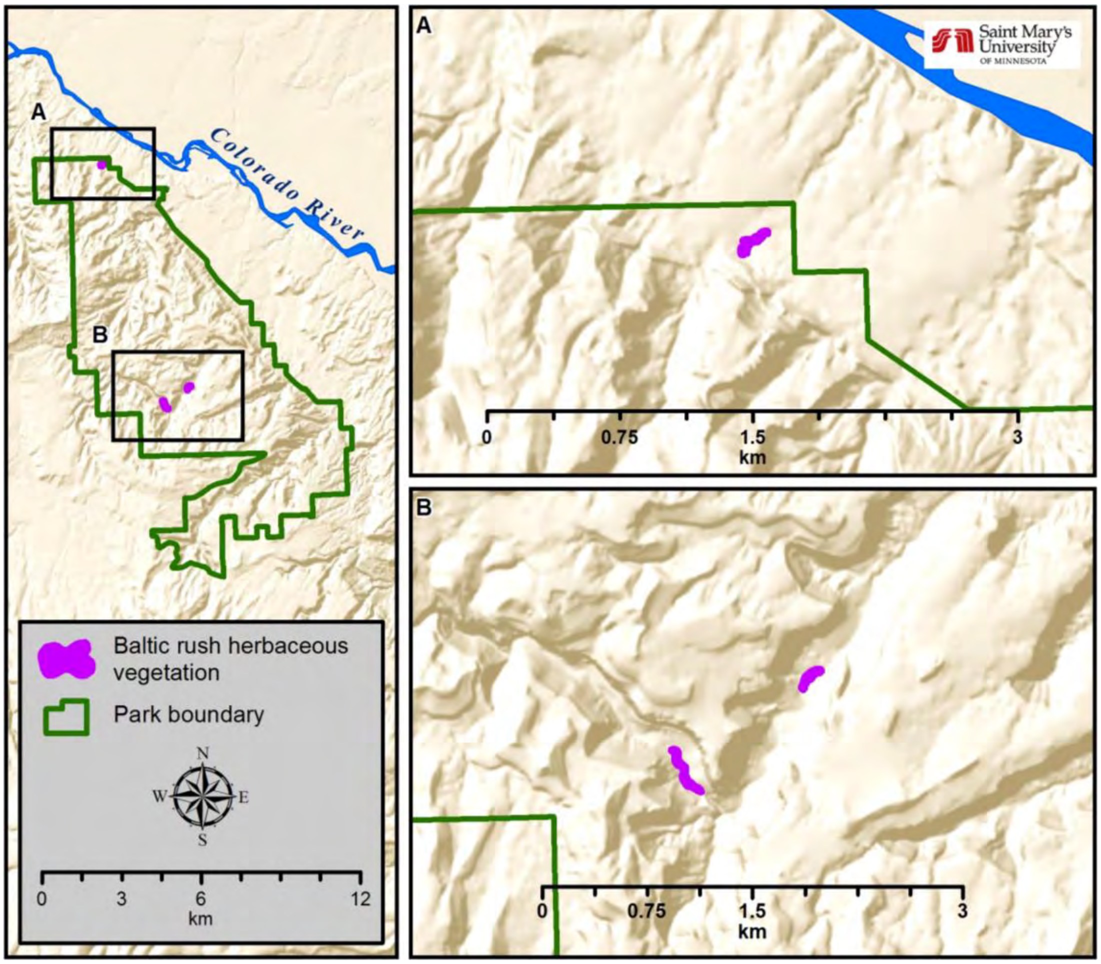

Figure 30. Location of Baltic rush herbaceous vegetation within COLM (Von Loh et al. 2007).

The remaining riparian and large dry wash habitats described in Von Loh et al. (2007) were mapped as points instead of polygons as they did not meet the MMU. Due to the large size of the park, these points would have to be mapped at an exaggerated size in order to be visible. For this reason, maps for these habitats were not included in this assessment, but the locations of these communities are described in the paragraphs below. As with all riparian habitats, these are considered uncommon in COLM (Von Loh et al. 2007).

Box elder (*Acer negundo*)/disturbed understory woodlands consisted of one stand that occurred at the base of an ephemeral waterfall in Kodels Canyon (Von Loh et al. 2007). Von Loh et al. (2007) noted that this habitat may also occur in other canyons of COLM where similar conditions are found.

Quaking aspen western chokecherry (*Prunus virginiana*) forest was also found in only one location, at the head of a sub-canyon within No Thoroughfare Canyon (Von Loh et al. 2007). It was located along a large pour-off that has periodic surface flows (Von Loh et al. 2007).

Singleleaf ash woodlands were located along intermittent drainages, predominantly on eastern toeslopes (Von Loh et al. 2007). These woodlands were located in Fruita Canyon on narrow drainages lined with cobble and boulders (Von Loh et al. 2007).

Skunkbush (*Rhus aromatica*) intermittently flooded shrubland was found at only one location, in an alcove situated at the head of a canyon in Ute Canyon (Von Loh et al. 2007). It is possible that it may also be found in similar locations around COLM (Von Loh et al. 2007).

Smooth horsetail (*Equisetum laevigatum*) herbaceous vegetation occurs only in canyons containing permanent seeps and springs (Von Loh et al. 2007). Nearly pure stands were found in the bottom of Ute Canyon (Von Loh et al. 2007). Smooth horsetail can also be found in association with other palustrine and riparian vegetation types in their limited distribution throughout the canyon bottoms of the park (Von Loh et al. 2007).

Water birch/starry false Solomon's-seal (*Maianthemum stellatum*) shrubland is only known to occur in upper No Thoroughfare Canyon (Von Loh et al. 2007). It is generally found in areas of deep sediment that have water present for at least part of the year (Von Loh et al. 2007).

<u>Community Composition</u>

The 11 riparian/large dry wash habitat communities are comprised of 64 different plant species (Table 35) (Von Loh et al. 2007). The most diverse community, with 32 species, is the cottonwood/coyote willow woodland habitat (Von Loh et al. 2007). A list of the dominant species for each association strata can be found in Appendix E.

In 2011, two non-native riparian species, the white poplar (*Populus alba*) and compressed rush (*Juncus compressus*), had their documentation status updated to "present" based on reported sightings (Fertig et al. 2012).The status of the white poplar was previously listed as "reported" and the compressed rush was previously listed as "potentially" present (Fertig et al. 2012).

Table 35. Number of species by riparian habitat / dry wash habitat associations within COLM (Von Loh et al. 2007).

Riparian/dry wash Habitat Association	Number of Species
cottonwood/ coyote willow woodland	32
coyote willow/mesic graminoids shrubland	14
water birch/starflower false Solomon's-seal shrubland	11
Baltic rush herbaceous vegetation	11
singleleaf ash woodland	9
smooth horsetail herbaceous vegetation	6
quaking aspen/water birch	5
box elder/disturbed understory woodland	4
rubber rabbitbrush desert wash shrubland	3
skunkbush intermittently flooded shrubland	3

Trends in Invasive Infestation

COLM is part of a long-term monitoring program for IEPs developed by the NCPN which focuses on early detection (Perkins 2014). The first survey of IEPs in the park was conducted in 2003 by Dewey and Anderson (2005). The latest monitoring was conducted during the 2013 field season (Perkins 2014) and will be used to assess this measure, since it includes the previously collected data on IEP infestations in COLM. A full discussion of IEPs park-wide, including a discussion of trends can be found in Chapter 2.2.2. Information on the occurrences of IEP infestation in riparian areas is documented in these surveys. Of all the vegetation communities within COLM, the riparian habitats have the most prevalent IEP infestations (Perkins 2014). The most widespread IEPs within the riparian/large dry wash habitats, based on the latest available survey (Perkins 2014), were yellow sweetclover, woolly mullein, field bindweed, and Siberian elm. Each of these was identified by the park and NCPN as priority IEPs (Perkins 2014). Cheatgrass, while not widespread within the riparian/large dry wash habitats, is the exotic species with the most extensive coverage in COLM and was most frequently encountered in all transects (Perkins 2014).

Total infestation numbers and infestations per 100 meters have declined within the riparian/large dry wash habitats since 2012 (Table 36). This bodes well for the park, considering an overall increase was observed between 2009 and 2012 (Table 36; Perkins 2009, 2012, and 2014). Additionally, the infestations found in Gold Star Canyon and Kodels Canyon in the 2011 survey were not found in the 2013 survey (Perkins 2012, 2014). During the 2011 field season, these canyons averaged 0.29 infestations/100 m and 0.74 infestations/100 m, respectively (Table 36; Perkins 2012, 2014). The decline in exotic plant infestations observed in riparian habitats is attributed to the park staff's aggressive control efforts conducted between 2011 and 2013 (Perkins 2014).

Table 36. Comparison of results from the for the last three IEP surveys for riparian areas within COLM (Perkins 2009, 2012, 2014).

Route Location	Year	Length (m)	Area Covered (ha)	Infestation Total	Infestation Priority Only	Infestations/100m Total	Infestations/100m Priority Only
Columbus Canyon	2009	1,883.0	n/a	0	0	0.00	0.00
	2012	1,881.5	6.11	20	20	3.27	3.27
	2014	1,881.5	2.27	20	19	1.06	1.01
Gold Star Canyon	2009	1,867.0	n/a	2	2	0.11	0.11
	2012	1,531.0	7.00	2	2	0.29	0.29
	2014	1,922.0	2.31	0	0	0.00	0.00
Kodels Canyon	2009	463.0	n/a	0	0	0.00	0.00
	2012	461.9	1.34	1	1	0.74	0.74
	2014	461.9	0.37	0	0	0.90	0.00
Monument Canyon	2009	9,837.0	n/a	35	34	0.36	0.35
	2012	9,591.3	41.00	86	86	2.10	2.10
	2014	9,259.6	10.43	43	43	0.00	0.46
No Thoroughfare Canyon	2009	10,302.0	n/a	39	39	0.38	0.38
	2012	13,678.7	46.22	198	196	4.28	4.24
	2014	12,633.9	11.20	117	117	0.46	0.93
Red Canyon	2009	4,014.0	n/a	19	19	0.47	0.47
	2012	3,873.6	19.10	52	52	2.72	2.72
	2014	4,014.2	3.72	40	40	0.93	1.00
Ute Canyon	2009	7,171.0	n/a	18	18	0.25	0.25
	2012	8,032.5	23.53	82	82	3.49	3.49
	2014	7,949.6	6.35	51	51	1.00	0.64
Wedding Canyon	2009	2,994.0	n/a	7	7	0.23	0.23
	2012	4,250.9	17.08	18	18	1.05	1.05
	2014	4,250.9	5.07	2	2	0.64	0.05
Limekin Gulch	2009	503.0	n/a	0	0	0.00	0.00
Hydro 03	2012	445.6	1.91	2	2	1.05	1.05
	2014	445.6	0.43	4	4	0.00	0.90
Fruita Canyon	2012	2,156.5	12.03	0	0	0.00	0.00
	2014	2,156.5	2.03	0	0	0.00	0.00
Lizard Canyon	2012	1,273.7	5.32	0	0	0.00	0.00
	2014	1273.7	1.01	0	0	0.00	0.00

Perkins (2014) briefly described the trends of several target species of invasive plants. Tamarisk has continued to decline in recent years, now only infesting four areas of COLM (Perkins 2014). This is an 81% reduction from 2011 to 2013 and overall a 96% reduction since 2003. Russian olive has shown a promising pattern of decline as well, with a 77% reduction from 2011 to 2013 (Perkins 2014). Yellow sweetclover has declined significantly in the park in the same time period (2011-2013) with a 68% overall reduction (Perkins 2014). Further monitoring will continue in 2015 (Perkins 2014). Perkins (2014) suggests targeting a few areas for control efforts that have shown the least amount of improvement; these are Columbus, Red, and No Thoroughfare Canyons.

Cottonwood Regeneration

Cottonwoods are an important structural component of riparian habitats, as the roots provide soil stability and increase permeability, which in turn reduces runoff and erosion (D'Amico 1997). Cottonwoods also provide valuable wildlife habitat, as they offer shelter to many species, particularly birds (CSFS 2015). Two cottonwood species, the Rio Grande cottonwood (*Populus deltoides* ssp. *wislizeni*) and the narrow-leaved cottonwood (*Populus angustifolia*), are found in four of the riparian communities in COLM. These species generally require moist, bare soil (e.g., recently deposited stream sediments) for seed germination and seedling establishment (D'Amico 1997). A recent cottonwood assessment study at COLM reported few seedlings and small saplings are present, despite the abundance of large saplings and pole-sized cottonwood trees (Kennard and Rogowski 2015). This lack of a younger regeneration suggests that regeneration conditions over the past 5 years have not been ideal for cottonwood seedling establishment and survival.

Channel Geomorphology

While there are no perennial flowing streams within COLM, there are seeps and washes where riparian habitat is supported by water from permanent and ephemeral water sources (Von Loh et al. 2007). Changes to channel geomorphology can occur due to heavy rainfall events (Richard 2004). Heavy rainfall on the Uncompahgre Plateau creates surface water flows that are the primary channel forming mechanism within the park (KellerLynn 2006). These flash flood events (discussed below) have historically been a phenomenon in the area and are one of the primary mechanisms that helped to create the geological formations in the park (Richard 2004). The impacts on riparian/large dry wash habitats from changes to channels have not been widely studied. However, increased channel incision, caused by flooding events could affect the availability of groundwater (Lamm et al. 2015, Kennard and Rogowski 2015). If channel incision were to reach the water table, the storage capacity of the alluvial fill could be lowered as groundwater would be available to augment stream flow. Other major changes to channel structure that occur during flash floods include the scouring and deposition of large volumes of materials (i.e. mud, rock, and other debris) which inevitably impacts the extent and plant communities within riparian habitats (Richard 2004).

Frequency and Discharge of Flash Floods

The combination of low permeability, bare rock, steep canyons, and sparse vegetation that is typical of COLM tends to concentrate rainfall events into sudden, rushing torrents rather quickly (Richard 2004). While periodic, these flood events are considered normal for the region (Richard 2004). Flash floods move large amounts of material, uprooting vegetation in some areas and burying it with rock, sand, and other debris in others (Richard 2004). Information on impacts on riparian habitat from flash floods is necessary to assess any trends for this measure and an analysis comparing vegetation before and after a known flash flood event would be useful. KellerLynn (2006) recommended the development of a flash flood model, using stage gages and stream channel ratings, in order to better assess and predict the impacts of flood events in COLM.

Threats and Stressor Factors

There are several factors that are a concern in terms of the riparian and large dry wash habitats at COLM. Park resource manager identified IEPs, trail use (authorized and unauthorized), channelization outside park boundaries, and climate change as being of primary concern.

Invasive plants may impact riparian habitats by competing with or replacing native species and altering ecosystem functions (e.g., water and nutrient cycling). Invasive species may use more water than native species. For example, tamarisk infestations have reduced spring flow into rivers in several southwestern states, reducing the amount of water available for riparian vegetation (Westbrooks 1998). Thick stands of tamarisk and other invasive plants can limit the availability of germination sites for cottonwoods and other native riparian species (Westbrooks 1998).

Visitor impacts within the park's riparian habitats include damage to soils and vegetation from hiking (unauthorized and authorized trails). Many of COLM's trails cross or are located in drainages (Hartwig, written communication, 20 September 2015). Disturbance of soils from hiking can increase erosion rates or cause soil compaction, which reduces water infiltration rates (Cole and Landres 1995). Hikers, particularly those using unauthorized "social" trails, can also trample vegetation. This trampling can kill sensitive plant species while those that survive often exhibit reduced vigor and reproductive success (Cole and Landres 1995).

Climate change is a concern since changes in precipitation, particularly large storm events that result in heavy rainfall and flash flood events have major impacts on the vegetation in large dry washes and riparian habitats. As a result of global climate change, western Colorado is expected to experience an increase in temperature with longer and hotter summer heat waves, an increased potential for drought, and an increase in precipitation falling as very heavy events (Lamm et al. 2014, Melillo et al. 2014). Even with the projected increase in precipitation, a hotter, drier environment could increase the rates at which surface water and soil moisture are lost to evaporation, meaning the moisture will be available to plants and wildlife for a shorter time (Lamm et al. 2014).

Data Needs/Gaps

Cottonwood regeneration is considered a data gap for the riparian/large dry wash habitat assessment. A preliminary study of cottonwood regeneration took place in the park during the summer of 2015, and additional, related research was planned for the fall of 2015. Additionally, the geomorphology (change in channel structure) and flash flood discharge and frequency are also considered data gaps at this time since the information available has not specifically addressed the impacts on riparian habitats. Research on the impacts from the proliferation of social trails within the park is also recommended.

Currently a guaranteed funding source for the invasive species removal/control has not been identified. Failure to secure funding for this management action will result in the loss of the gains that have been made in eradicating IEPs within the park. Additionally, another programmatic need for COLM is a trail management plan. Currently, visitors face no restrictions in their access to any areas within the park.

Overall Condition

Community Extent and Change over Time
The project team assigned this measure a *Significance Level* of 3. Available literature and data suggest that it is unlikely that the extent of riparian communities has undergone unnatural change since the creation of the park. A *Condition Level* of 1, or of low concern, was assigned to this measure. The vegetation mapping project completed by Von Loh et al. (2007) may serve as a baseline for future assessments and analyses.

Community Composition
While it can be assumed that the pre-settlement reference condition consisted of all native species within the riparian/large dry wash communities, the exact species composition is unknown at the time of park establishment. There are lists available from the Von Loh et al. (2007) vegetation mapping project to specifically list plant species in the riparian and large dry wash habitats and is the earliest documentation available to assess community composition. This measure was assigned a *Significance Level* of 3; at this time a *Condition Level* of 1, or of low concern, has been assigned due to the presence of IEPs which are a threat to native flora.

Trends in Invasive Infestation
The *Significance Level* of invasive infestations is assigned a 3. A reference condition of little to no invasive species infestations can be assumed. Over the last decade the park has focused control efforts on eradication of IEP's. Future funding for these control measures is not available, so the potential for increased infestations is possible (Hartwig, written communication 18 November 2015). A *Condition Level* of 1 was assigned, or of low concern, since there are still infestations occurring within riparian habitats that can repopulate other areas and efforts to control invasive plants should continue to be a park priority.

Cottonwood Regeneration
The project team assigned this measure a *Significance Level* of 2. Kennard and Rogowski (2015) reported that the adult cottonwood population in COLM appears to be healthy, however their appears to be a lack of regeneration due to the low number of seedlings and small saplings Due to this factor a *Condition Level* of 1, low concern was assigned. Continued monitoring is recommended in order to determine if this is a short term condition or a more long-term change that may be associated with groundwater availability (Kennard and Rogowski 2015).

Geomorphology (Change in Channel)
This measure was assigned a *Significance Level* of 3. Changes in channel morphology could influence the extent and composition of riparian and large dry wash plant communities. Data also were not available to establish a reference condition or to assess current condition for this measure at COLM. As a result, assigning a *Condition Level* is not possible at this time.

Frequency and Discharge of Flash Floods
The physical characteristics of COLM (e.g., steep canyon walls, bare rock areas) make the area prone to flash flooding (Richard 2004). This measure was assigned a *Significance Level* of 2, but due to data gaps, a *Condition Level* cannot be assigned at this time. If the recommendations from

KellerLynn (2006) are carried out, data can be used to assess any trends in the frequency and discharges of subsequent flood events at COLM.

Weighted Condition Score
A *Weighted Condition Score* of 0.33 was calculated for the riparian habitat/large dry washes at COLM, indicating that the resource is in good condition. Currently no trends could be identified for this component. Future efforts focused on gathering additional data for these measures should be a priority for assessing any trends in the health and condition of riparian/large dry wash vegetation communities. Overall, the riparian/large dry washes should be priority habitat to monitor considering their importance to the desert ecology in COLM.

Riparian Habitats / Large Dry Washes			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.33**
Community Extent and Change over Time	3	1	
Community Composition	3	1	
Trends in Invasive Infestation	3	1	
Cottonwood Regeneration	2	1	
Geomorphology	3	n/a	
Frequency and Discharge of Flash Floods	2	n/a	

4.3.6 Sources of Expertise
Dusty Perkins, Program Manager, Northern Colorado Plateau Network

Rebecca Weissinger, Ecologist NPS Northern Colorado Plateau Network

Kim Hartwig, COLM Chief of Resources Management

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4.4 Seeps and Springs and Tinaja Habitats

4.4.1 Description

Seeps, springs, and tinajas (rocky, water-holding potholes) provide important water sources and habitats for plants and wildlife in semi-arid regions (Springer et al. 2006). Springs support some of the most diverse and productive ecosystems on the Colorado Plateau, but are also among the most threatened communities (Springer et al. 2006). Seeps and springs can serve as indicators of change in local and regional aquifers due to their reliance on groundwater, which is most often recharged by precipitation (SCPN 2012).

COLM's seeps and springs emerge from three different sources: Wingate sandstone, alluvial valley fill, and fractures in Precambrian metamorphic "basement" rock (Lamm et al. 2014). Of the 38 seeps and springs identified in the park in 2014, 15 originated in Wingate sandstone, 16 from alluvial valley fill, and seven from Precambrian metamorphic rock (Lamm et al. 2014). Seeps and springs are commonly found in canyon heads, and along drainage channels. Historically, springs were also found at the ends of mesas (Nancy Lamm, GeoCorps Guest Scientist in the Park, written communication, 24 November 2015). A recent survey of these springs reported that flows have diminished from what was reported in historic accounts (Lamm, written communication, 27 November 2015). Discharge from some seeps in COLM is minimal and ephemeral, and may only be notable as a wet surface on a rock or as discoloration from dried salts on the rock face. Other springs produce enough water to support small pools and riparian vegetation (as described previously in Chapter 4.3 of this document) (Lamm et al. 2014; Photo 7). These water sources may also support "hanging gardens", pockets of vegetation on nearly vertical canyon walls (Von Loh et al. 2007), which will be further described in Chapter 4.6 of this document.

Photo 7. A seep-fed pool in No Thoroughfare Canyon (left) and riparian vegetation at Lost Lunch Spring in Ute Canyon (Photos from Lamm et al. 2014).

The seeps and springs habitats at COLM are closely associated with the riparian habitats discussed in the previous chapter. Many of the same species that utilize those habitats also can be found within and around the seep and springs communities. This is especially true for amphibian species within COLM as the seep, spring and tinaja habitats provide shelter and a source of water (Platenberg and

Graham 2003, Von Loh et al. 2007). A variety of aquatic macroinvertebrates and insects can be found within these communities and provide a major food source for COLM herptiles (NPS 2015).

4.4.2 Measures

- Vegetation community extent and change over time
- Vegetation community composition
- Trends in invasive infestation
- Water quality
- Discharge

4.4.3 Reference Conditions/Values

The ideal reference condition for this component would be the condition of seeps, springs, and tinajas prior to settlement. However, little information is available from this time, making reference conditions a challenge to determine. For this assessment, conditions will be assessed based on best professional judgment given the available data. The information presented in this chapter may be used as baselines for future assessments.

4.4.4 Data and Methods

Lamm et al. (2014) conducted an inventory of COLM seeps and springs from May to July 2014. Thirty-eight seep- and spring-associated sites were visited. Data collected at each site included estimated discharge (i.e., flow), flora and fauna observations, and when sufficient amounts of water were available for testing; selected water quality parameters (temperature and specific conductance) were collected. A map of each site was also drawn and photographs were taken to document features of interest. Water samples were taken from four sites in late June for more detailed water quality analysis in a lab (Lamm et al. 2014).

Many of the sites inventoried by Lamm et al. (2014) had previously been visited and assessed by the United States Geological Survey (USGS) in 2000 and 2001 (Butler et al. 2003). The USGS assessment involved field measurements of discharge and water quality (e.g., temperature, pH, specific conductance, and dissolved oxygen) at 10 sites, and collection of water samples for detailed lab analysis. The USGS visited numerous additional sites for reconnaissance purposes but did not record any data (Butler et al. 2003).

Springer et al. (2006) inventoried 75 springs across 26 NPS units in the NCPN and SCPN. Field work was conducted in 2005 and included vegetation and invertebrate surveys, water quality analyses, and water quantity measurements (Springer et al. 2006). Two springs were surveyed at COLM: Echo Canyon Spring (lower) and No Thoroughfare Canyon (NTC) Spring.

Von Loh et al. (2007) conducted a vegetation classification and mapping project for COLM and surrounding areas. The resulting map shows the locations of all dominant vegetation types present within COLM in the early 2000s. The project involved traditional aerial photo interpretation and field sampling of 288 plots between May and October 2003 (Von Loh et al. 2007). Because most vegetation communities surrounding seeps and springs are smaller than the 0.5 ha (1.2 ac) minimum mapping unit used in this project, seep and spring vegetation communities were mapped as points rather than polygons. As a result, the total areal extent of these communities cannot be calculated.

This synthesis of the relevant scientific data and information does not include the climate data and information used in conducting the climate change vulnerability assessment for this resource. Please refer to Chapters 2.1.3 and 3.2.3 and Appendix A for a discussion of the data and methodology used in the climate change analysis.

4.4.5 Current Condition and Trend

Vegetation Community Extent and Change over Time

Spring, seep, and tinaja communities can be challenging to map, given their typically small size and sparse distribution across the landscape. Some of these features are also ephemeral and may be dry for portions of the year, making them difficult to identify. During a vegetation mapping and classification project, Von Loh et al. (2007) identified 17 point locations that supported seep and spring vegetation (Figure 31). Areal extent information (i.e., community/stand size) was not included with these data.

Lamm et al. (2014) visited 38 spring, seep, and tinaja sites. This report represents the evaluation of the known sites as well as new sites that were identified during the field inventory. However, it does not represent a complete inventory of all seeps and springs located within COLM (Lamm, written communication, 27 November 2015). Lamm et al. (2014) did visit some (but not all) of the locations mapped by Von Loh et al. (2007). These locations are displayed in Figure 32. While Lamm et al. (2014) recorded some observations on the sizes of pools or the distance water/moisture extended from a source, no uniform measurements of each site's areal extent were conducted. Any differences in seep and spring location between Von Loh et al. (2007) and Lamm et al. (2014) are likely due to differences in methodology (e.g., areas of focus) rather than any change in seep or spring locations between studies. Lamm et al. (2014) also noted that time constraints prevented them from visiting every canyon in the park.

Vegetation Community Composition

Springer et al. (2006) surveyed vegetation at two COLM springs: Lower Echo Canyon (LEC) and No Thoroughfare Canyon (NTC) Springs. A combined total of 57 plant species were recorded at the two sites. Twenty-three species were documented at NTC Spring (18 native, five non-native) and 41 species (34 native, seven non-native) at Lower Echo Canyon Spring (Springer et al. 2006). These species are listed in Appendix F.

Lamm et al. (2014) provides a more comprehensive record of plant community composition specific to COLM's seep, spring, and tinaja habitats. At the 34 seeps and springs inventoried, 96 different plant species were documented, 19 of which were non-native (Lamm et al. 2014). On average, native plants made up 84% of the species at each site. Species richness per site ranged from six (Red Canyon) to 51 (NTC). Sites with low diversity were generally very small or included large areas of bare rock (Lamm et al. 2014).

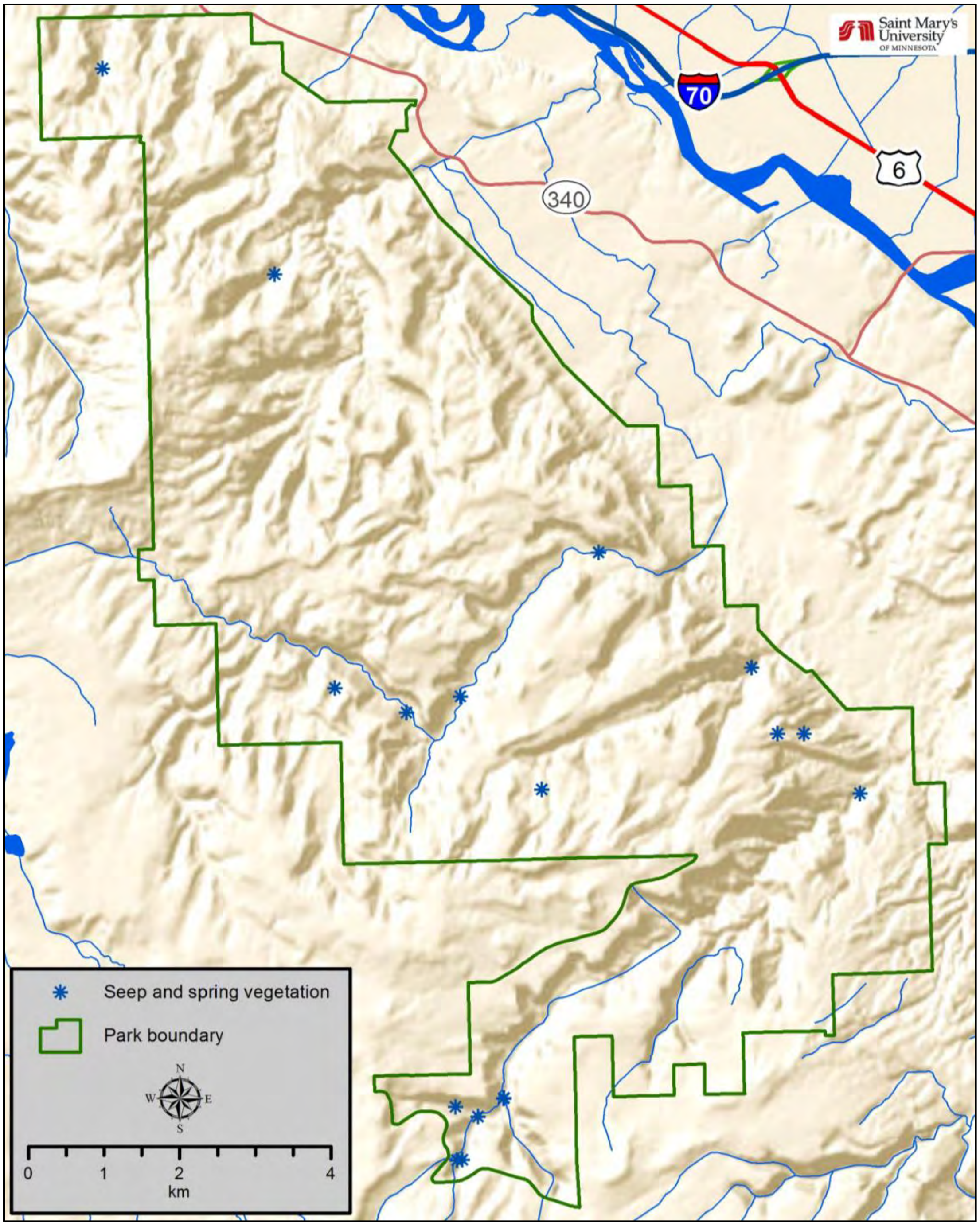

Figure 31. Seep and spring vegetation locations in COLM mapped by Von Loh et al. (2007).

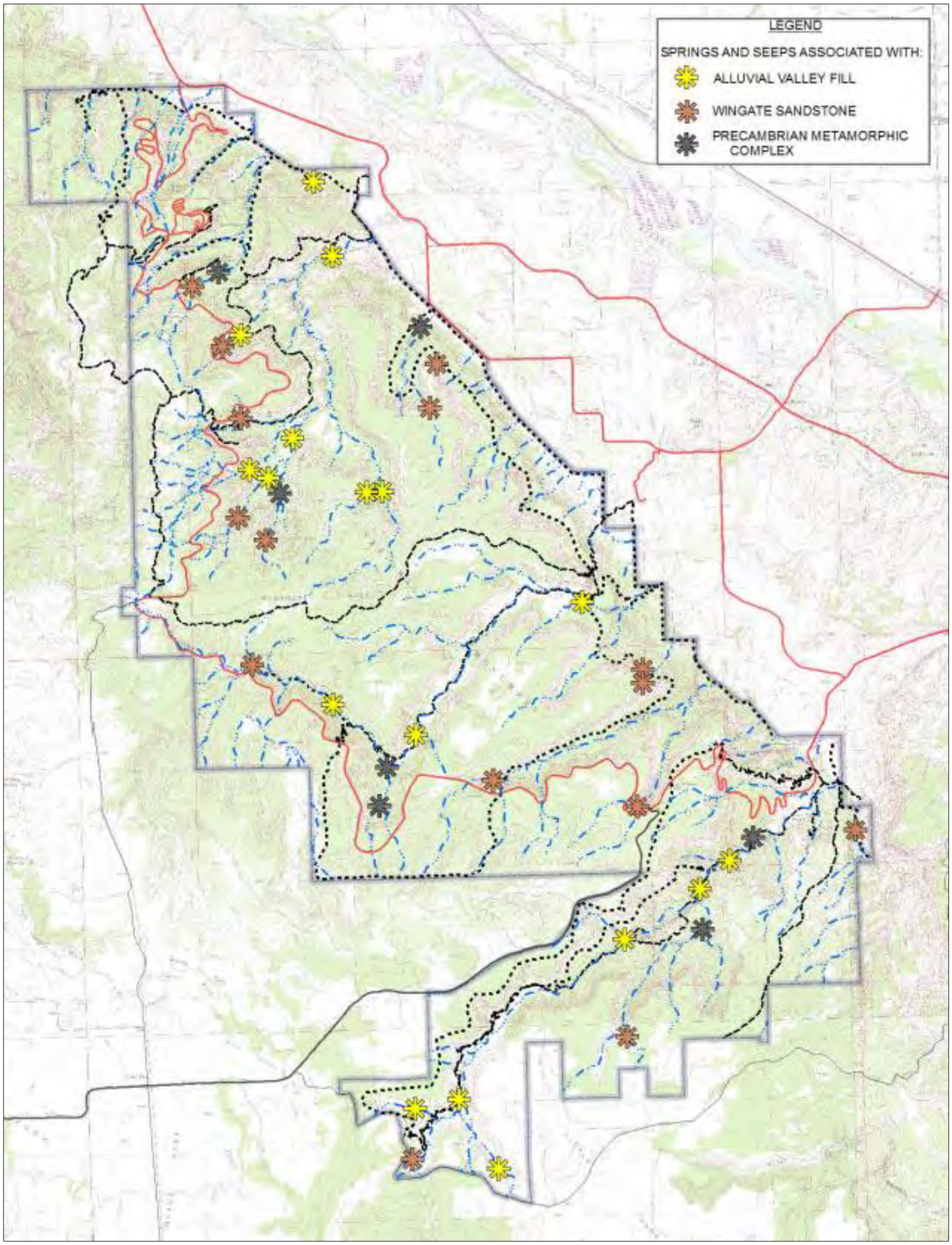

Figure 32. Seep, spring, and tinaja sites inventoried by Lamm et al. (2014) (Reproduced from Lamm et al. 2014).

The most common native species were desert saltgrass (*Distichlis spicata*), Baltic rush, hairy false goldenaster, narrow-leaved cottonwood, willows (*Salix* spp.), and Utah serviceberry (Lamm et al. 2014). Non-native species observed include tamarisk, cheatgrass, bull thistle (*Cirsium vulgare*), burdock (*Arctium minus*), poison-hemlock (*Conium maculatum*), woolly mullein, and yellow sweetclover (Lamm et al. 2014). Woody species (e.g., trees and shrubs) were present at all but one site, with 20 of the 34 sites supporting a tree canopy over 4 m (13.1 ft) high (Lamm et al. 2014). A full list of plant species documented by Lamm et al. (2014), by canyon, is included as Appendix G.

Trends in Invasive Infestation

A total of 22 IEP species have been detected at COLM's seeps, springs, and tinajas (Springer et al. 2006, Lamm et al. 2014; Appendix G). According to Lamm et al. (2014), non-native invasive plants do not dominate species richness or cover at the 34 seep and spring sample sites where vegetation was inventoried. The highest proportion of non-native species was at a site in NTC (Sunscreen Seep) where four of the eight plant species documented were non-native (Lamm et al. 2014). The only invasive species found at more than half the sites (25 of 34) was cheatgrass, although only trace amounts (<1% cover) were found at 14 of the 25 sites. However, one Wedding Canyon site (Stone Cistern Spring) had approximately 90% cheatgrass cover, and 25-50% cover was noted at a site in Upper Ute Canyon (Lamm et al. 2014). Potentially problematic levels of cheatgrass (10-25% cover) were also reported at two sites in Monument Canyon. The second most common non-native species was sweetclover, found at 14 of 34 sites. Only two sites in NTC showed potentially problematic levels (10-25%) of this species (Lamm et al. 2014). Tamarisk, classified as a noxious weed in Colorado, was found at four sites in four different canyons (NTC, Monument, Wedding, and Echo). The species comprised 10-25% cover at a Monument Canyon site (Bedrock Spring), 1-10% at an NTC site, and <1% at the remaining two sites. Lamm et al. (2014) recommended removal of the species from all sites. Other species classified as noxious weeds were found at only trace amounts (<1%) at one site (bull thistle, poison-hemlock, woolly mullein) or two sites (burdock) (Lamm et al. 2014).

Water Quality

Water quality has a significant impact on organisms living in and around a water body, and on potential uses of that water (e.g., human or livestock consumption, recreation) (USGS 2010). Chemistry parameters of interest include pH, dissolved oxygen (DO), dissolved solids, ion levels (e.g., nitrates, phosphates, metals, salts), and contaminants of concern (e.g., surfactants, pharmaceuticals, pesticides). Butler et al. (2003) recorded field measurements (water temperature, specific conductance) at several park seeps and springs (Table 37) and collected samples from 11 seeps and springs for detailed water quality analysis in a lab (Table 38). Springer et al. (2006) recorded field measurements and collected water samples for analysis from two COLM springs (Table 38). Most recently, Lamm et al. (2014) reported field measurements (water temperature, specific conductance) for 27 park seeps and springs (Table 37, Table 38); the remaining 11 sites visited by Lamm et al. (2014) did not have enough standing/flowing water to conduct measurements. Water quality information may not be directly comparable among surveys, as sampling may be conducted at different times of year, and it is not always clear if measurements were taken at the exact same location (i.e., the same pool or distance from spring source). Water temperature and specific conductance (SC) readings were highly variable (Table 37). There are a variety of factors that could be responsible for this variability. Seasonal differences in sampling could account for this variability. The variation in SC can also be correlated to different groundwater residence times (Don Weeks, NPS Water Resources Division (WRD) Climate Change Resource Planner, written communication, 27 November 2015). High SC readings during the winter months may be due to stagnant conditions (Lamm et al. 2014).

Table 37. Water temperature (°C) and specific conductance (µS/cm) field measurements from sampled seeps and springs in COLM (Butler et al. 2003, Lamm et al. 2014). All 2014 data were collected in June or July of that year.

Site	Sampling Period	Temp (°C)	Specific conductance (µS/cm)	Site	Sampling Period	Temp (°C)	Specific conductance (µS/cm)
WC-1[1]	11/2000	6.5	1,380	**UC-3**	2014	15.3	913
WC-2	2014	28.1	728	**UC-6**	2014	21.7	1,060
MC-2	2014	25.7	1,949	**RC/UC-1**	10/2000	12.2	397
					2014	27.0	3,660
MC-3	1/2001	0.1	1,380	**NTC-2**	2014	24.4	943
	2014	20.9	476	**NTC-3**	11/2000	--	1,430
MC-6	11/2000	3.4	1,040		2014	21.0	1,260
	2014	20.8	870	**NTC-4**	2014	22.3	1,390
MC-7	2014	23.5	1,836	**NTC-5**	2014	13.9	1,290
MC-10	2014	23.5	885	**NTC-6**	2014	22.5	1,640
MC-11	2014	26.2	1,270	**NTC-8**	2014	14.8	980
UC-1	2014	15.1	1,060	**NTC-10**	2014	11.0	1,005
UC-2	2014	16.4	1,090				

[1] Not enough water was available at this site in 2014 for testing.

Tributaries of the Colorado River (including surface water systems in COLM) are listed as impaired waters due to selenium concentrations (EPA 2015). Selenium is a natural occurring mineral and at high concentrations it has many toxic impacts upon fish and wildlife (Paschke et al. 2014). Selenium is commonly associated with upper Cretaceous marine sedimentary rocks such as the Mancos Shale formation at COLM (O'Dell 2005). Groundwater in contact with this formation is susceptible to elevated selenium levels (Paschke et al. 2014).

DO levels below 5.0 mg/L are generally considered low, and the data for COLM springs for the most part is near or below this level. While low DO values are quite common for springs within the NCPN, they can create very stressful aquatic environments (Rebecca Weissinger, NPCN Ecologist, written communication, 16 November 2015). Although only one sample (NTC-7 collected in 2005) exceeded EPA the drinking water quality standards (EPA 2009) for dissolved solids and sulfate (Table 38) (Springer et al. 2006), the DO levels and potential for high selenium concentrations suggest that the water quality of COLM seeps and springs is variable and can create extreme conditions (Weissinger, written communication, 16 November 2015)

Table 38. Water quality measurements for springs with detailed sample analysis by Butler et al. (2003) or Springer et al. (2006), along with field measurements from Lamm et al. (2014). Values are in mg/L, unless otherwise indicated. All 2014 data were collected in June or July of that year.

Site or Subsite	Sampling Period	Temp (°C)	SC (µS/cm)	pH	DO	Dissolved Solids[3]	Sulfate[4]	Chloride[4]	Nitrogen[5] (NO_2 + NO_3)
MC-4	4/2001	9.7	590	8.30	8.0	337	31.8	8.3	0.008
	11/2001	8.2	632	8.30	7.8	371	40.0	13.0	<0.013
	2014	20.7	582						
MC-8	11/2000	1.6	3,670						
	4/2001	22.0	1,430	8.01	5.6	936	256	71.0	0.006
seep in E. trib.	2014	14.1	1,030						
seep in W. trib	2014	24.8	1,216						
distal end of a.v.f.	2014	27.8	2,430						
MC-9	11/2000	1.4	580						
	4/2001	14.6	580	8.56	6.6	340	42.1	5.4	0.006
	11/2001	8.0	544	8.71	11.3	344	38.0	5.9	0.124
	2014	18.7	522						
GS-1[1]	11/2000	1.6	1,170						
	4/2001	13.0	646	8.83	5.2	400	91.1	13.4	5.080
UC-5[1]	12/2000	8.5	600						
	4/2001	10.5	589	7.51	5.0	341	26.1	7.7	0.077
	11/2001	11.6	727	7.30	1.5	353	15.3	10.4	est. 0.010
RC-1	4/2001	11.9	696	7.88	3.4	405	32.6	12.6	<0.005
	11/2001	8.9	579	7.40	0.4	338	6.0	5.5	--
	2014	16.2	870						

[1] Not enough water was available at these sites in 2014 for testing.

[2] This spring had completely dried up when Lamm et al. (2014) visited in 2014.

[3] The recommended maximum contaminant level (MCL) for total dissolved solids in drinking water is 500 mg/L (EPA 2009).

[4] The recommended MCL for sulfate and chloride in drinking water are 250 mg/L (EPA 2009).

[5] The required MCLs for nitrogen in drinking water are 1 mg/L for NO_2 and 10 mg/L for NO_3 (EPA 2009).

Table 38 (continued). Water quality measurements for springs with detailed sample analysis by Butler et al. (2003) or Springer et al. (2006), along with field measurements from Lamm et al. (2014). Values are in mg/L, unless otherwise indicated. All 2014 data were collected in June or July of that year.

Site or Subsite	**Sampling Period**	**Temp (°C)**	**SC (µS/cm)**	**pH**	**DO**	**Dissolved Solids[3]**	**Sulfate[4]**	**Chloride[4]**	**Nitrogen[5] (NO_2 + NO_3)**
CC-1	11/2000	0.5	647						
	4/2001	10.3	646	7.95	7.2	376	38.6	10.2	0.167
	11/2001	11.3	775	7.90	7.4	467	52.0	15.7	0.105
from pool	2014	27.5	375						
NTC-1	1/2001	2.6	789						
	5/2001	10.0	826	7.70	9.0	482	49.6	22.4	<0.005
	2014	12.5	468						
NTC-7	7/2005	16.0	805	8.21	6.5	700	281.6	4.7	0.020
	2014	9.3	900						
EC-1	4/2001	12.7	628	7.38	5.2	381	72.3	8.2	0.023
	11/2001	14.0	611	7.53	4.0	386	71.0	10.0	0.019
	7/2005	15.3	512	7.01	4.5	400	71.9	8.6	0.030
	5/13/2014	21.8	488						
	5/28/2014	30.3	644						
Butler's Sp-6B[2]	5/2001	9.9	767	7.21	3.1	441	23.4	9.7	<0.005
	11/2001	7.2	275	8.00	5.4	155	2.2	1.8	<0.013

[1] Not enough water was available at these sites in 2014 for testing.

[2] This spring had completely dried up when Lamm et al. (2014) visited in 2014.

[3] The recommended maximum contaminant level (MCL) for total dissolved solids in drinking water is 500 mg/L (EPA 2009).

[4] The recommended MCL for sulfate and chloride in drinking water are 250 mg/L (EPA 2009).

[5] The required MCLs for nitrogen in drinking water are 1 mg/L for NO_2 and 10 mg/L for NO_3 (EPA 2009).

Discharge

Availability of discharge data for COLM's seeps and springs is limited. Butler et al. (2003) reported flows from ten park springs in April and/or November of 2001. These flows ranged from <0.04 liters per minute (lpm) (<0.01 gallons per minute [gpm]) to a reported 21.0 lpm (8.2 gpm) (Table 39). Springer et al. (2006) measured discharge at NTC and Lower Echo Canyon Springs in July 2005 (Table 39). Lastly, Lamm et al. (2014) estimated discharge rates and noted those with no flow in June and July 2014. Discharges ranged from no flow to approximately 18.9 lpm (5.0 gpm) downstream from Echo Canyon Spring (Table 39). Nine springs or seeps had no noticeable flow, although wet soil or small pools were sometimes present, and an additional 14 springs had estimated discharges <0.95 lpm (<0.25 gpm). Lamm et al. (2014) noted that the timing of their sampling may have influenced water quantity at seeps and springs, as these sites are often drier during warm summer weather. Discharge rates may not be directly comparable between surveys, as it is not always clear if measurements were taken at the exact same location or with similar methodologies.

Table 39. Discharge measurements for surveyed COLM seep and spring sites. Values are given in lpm (with gpm in parentheses), unless otherwise noted.

Site or Subsite*	Butler et al. (2003)	Lamm et al. (2014)	Springer et al. (2006)
WC-1		no flow	
WC-2		<0.95 (<0.25)	
W-MC-1		<0.95 (<0.25)	
MC-1	a couple drops/min	not measurable	
MC-2		approx. 3.8 (1.0)	
MC-3		not measurable	
MC-4	2.7 (0.72) (April)	1.9 (0.5)	
MC-5		approx. 1.9 (0.5)	
MC-6		no flow; pools present	
MC-7		3.8 (1.0)	
MC-8	1.8 (0.48) (April)		
eastern trib.		<0.95 (<0.25)	
western trib.		<0.95 (<0.25)	
MC-9	est. 1.9 (0.5) (April); <0.4 (<0.1) (Nov.)	<0.95 (<0.25)	
MC-10		<0.95 (<0.25)	
MC-11		no flow; pools present	
GS-1	<0.04 (<0.01) (April)	<3.8 (<1.0)	
GS-2		<3.8 (<1.0)	
GS-3		no flow, wet soils	
UC-1		no flow, pools and wet soils present	
UC-2		<18.9 (<5.0) highest flow area	

*WC = Wedding Canyon, MC = Monument Canyon, UC = Ute Canyon, GS = Gold Star Canyon, RC = Red Canyon, CC = Columbus Canyon, NTC = No Thoroughfare Canyon, EC = Echo Canyon.

Table 39 (continued). Discharge measurements for surveyed COLM seep and spring sites. Values are given in lpm (with gpm in parentheses), unless otherwise noted.

Site or Subsite*	Butler et al. (2003)	Lamm et al. (2014)	Springer et al. (2006)
UC-3		7.6 (2.0)	
UC-4		<3.8 (<1.0)	
UC-5	22.0 (5.8) (April); 31.0 (8.2) (Nov.)	no flow, small pool	
UC-6		<3.8 (<1.0)	
RC/UC-1		<3.8 (<1.0)	
RC/UC-2	wet spots on rock	no flow/pools	
RC-1	1.4 (0.38) (April)	no flow; pools present	
CC-1	1.8 (0.48) (April); <0.4 (<0.1) (Nov.)	5-10 drops/minute from several seeps	
NTC-1	0.8 (0.2) (May)	<0.95 (<0.25)	
NTC-2		3.8 (1.0)	
NTC-3		100 mL/min (<0.25)	
NTC-4		50 mL/min (<0.25)	
NTC-5		0.75 mL/min (<0.25 gpm) (6 m downstream from seeps)	
NTC-6		30 mL/min (<0.25 gpm) (6 m downstream from spring)	
NTC-7		1.9 (0.5)	1.4 (0.4) (35 m downstream)
NTC-8		approx. 3.8 (1.0)	
NTC-9		no flow	
NTC-10		approx. 0.95 (0.25)	
EC-1	18.6 (4.9) (April); 20.4 (5.4) (Nov.)	3.8 (1.0) at upper end, approx. 18.9 (5.0) downstream	10.3 (2.7)

*WC = Wedding Canyon, MC = Monument Canyon, UC = Ute Canyon, GS = Gold Star Canyon, RC = Red Canyon, CC = Columbus Canyon, NTC = No Thoroughfare Canyon, EC = Echo Canyon.

Lamm et al. (2014) noted a pattern of minimal or diminished flow from Wingate sandstone springs when compared to previous accounts, particularly in the eastern portion of the park. Several springs documented by Butler et al. (2003) were no longer viable water sources (e.g., Spring 6B in Monument Canyon, Spring 19 in Upper NTC). Lamm et al. (2014) theorized that groundwater flow to some portions of the park has been restricted by channel incision in canyon drainages. This is a naturally occurring phenomenon of canyon morphology over time and not the result of recent erosion. In these areas, channel incision has “downcut” through the entire thickness of the Wingate sandstone layer, stopping water movement through the aquifer (typically in a northeasterly direction) (Lamm et al. 2014). This appears to be occurring along Monument Mesa, between Ute and Red Canyons, and between Red and No Thoroughfare Canyons.

Vulnerability to Climate Change

The seep, spring, and tinaja habitats at COLM were selected (along with pinyon-juniper woodlands/savannas [Chapter 4.1.5]) for additional analysis of their vulnerability to climate change

(See Chapter 3.1.1). Von Loh et al. (2007) describes several vegetation classifications within COLM that are found near or associated with seeps, springs, tinajas, or hanging gardens. The vegetation communities within these classifications are discussed in detail in Chapter 4.3 (Riparian habitats/large dry washes) and Chapter 4.6 (Canyon walls and monolith vegetation communities [hanging gardens]), respectively. For this climate change analysis, three vegetation associations were selected from these classifications to determine the vulnerability of seep, spring, and tinaja habitats to climate change. They are: the Mancos columbine herbaceous vegetation community, the smooth horsetail herbaceous vegetation community, and the cottonwood/coyote willow woodlands. The Mancos columbine herbaceous vegetation association was chosen as it is restricted to perennial seeps in the crevices, ledges, and alcoves in canyons walls and is found only in the canyons of western Colorado, eastern Utah, and eastern Arizona (Von Loh et al. 2007). The smooth horsetail herbaceous vegetation community within COLM is classified as a palustrine wetland community occurring only in canyons with permanent seeps and springs (Von Loh et al. 2007). The cottonwood/coyote willow woodland is also classified as a palustrine wetland community by Von Loh et al. (2007) and is found exclusively in mesic canyon bottoms, intermittent drainage banks or terraces, and alcoves (Von Loh et al. 2007). The most extensive stands of this community occupy stream banks in upper No Thoroughfare Canyon, where perennial flow is provided from runoff, seeps, and springs (Von Loh et al. 2007).

In order to assess the vulnerability of the seeps and springs, and tinaja habitats to climate change, using the landscape scale community-based methodology discussed in Chapter 3.3, representative plant species were selected. The namesake species where selected from each of the vegetation associations discussed above as representatives. These species were assessed using the methodology described in Chapter 3.3 to provide the climate change vulnerability of the seeps and springs and tinaja habitats at COLM. The representative species selected were Mancos columbine, smooth horsetail, Rio Grande cottonwood, and coyote willow. Their vulnerability to climate change will be assessed based on five factors: location within the community's geographic range, sensitivity to extreme climatic events, dependence on hydrologic conditions, the community's adaptive capacity, vulnerability of ecologically influential species, and the potential for climate change to increase the impacts of non-climate stressors. A detailed description of this methodology and definition of these five variables is presented in Chapter 3.3 of this report.

The Rio Grande cottonwood and Mancos columbine have a limited geographic extent, with Mancos columbine only found in western Colorado, southeastern Utah, and northeastern Arizona (Figure 33 and Figure 34, NRCS 2015). Coyote willow is widespread throughout the western United States and western Canada, while smooth horsetail is found throughout much of the northeast and western United States, Northern Great Plains, and Canada (Figure 33 and Figure 34, NRCS 2015). Within COLM, these four species are found between 1,511 and 1,833 m (4,957 to 6014 ft) in elevation and at north to easterly aspects (Von Loh et al. 2007). The Rio Grande cottonwood/coyote willow association can also be found along southeast aspects (Von Loh et al. 2007). COLM is more or less centrally located within the latitudinal range of smooth horsetail and coyote willow; however, it is located along the north and eastern margins of the latitudinal extent of both the Rio Grande cottonwood and Mancos columbine (Figure 33 and Figure 34, NRCS 2015).

Based on COLM's location within the geographical ranges of Rio Grande cottonwood and Mancos columbine, location alone would not cause them to be significantly vulnerable to an increase in temperature and aridity caused by a northern and/or westward shift in these species preferred climatic conditions. These species are dependent on specific hydrologic regimes. These species are also dependent on the availability of shallow groundwater in their rooting zone (Decker and Rondeau 2014). An abrupt or prolonged change in this availability through periods of drought or changing precipitation patterns can have a severe impact on the vegetation associated with seeps, springs, and tinajas (Evenden et al. 2002, Decker and Rondeau 2014, Lamm et al. 2014). As was previously discussed in Chapter 4.1.5, the climate models project warmer and drier (more arid) conditions for COLM by 2100. Western Colorado is expected to experience an increase in temperature with longer and hotter summer heat waves (Chapter 4.1.5 -Figure 18), an increased potential for drought and wildfires, and an increase in precipitation falling during very heavy events (ClimateWizard 2014, Lamm et al. 2014, Melillo et al. 2014). While the climate models predict an increase in annual precipitation, higher temperatures will result in greater evapotranspiration rates, leading to increased aridity in all seasons, especially fall (September-November) and spring (March-May) (Chapter 4.1.5 - Figure 19, ClimateWizard 2014).

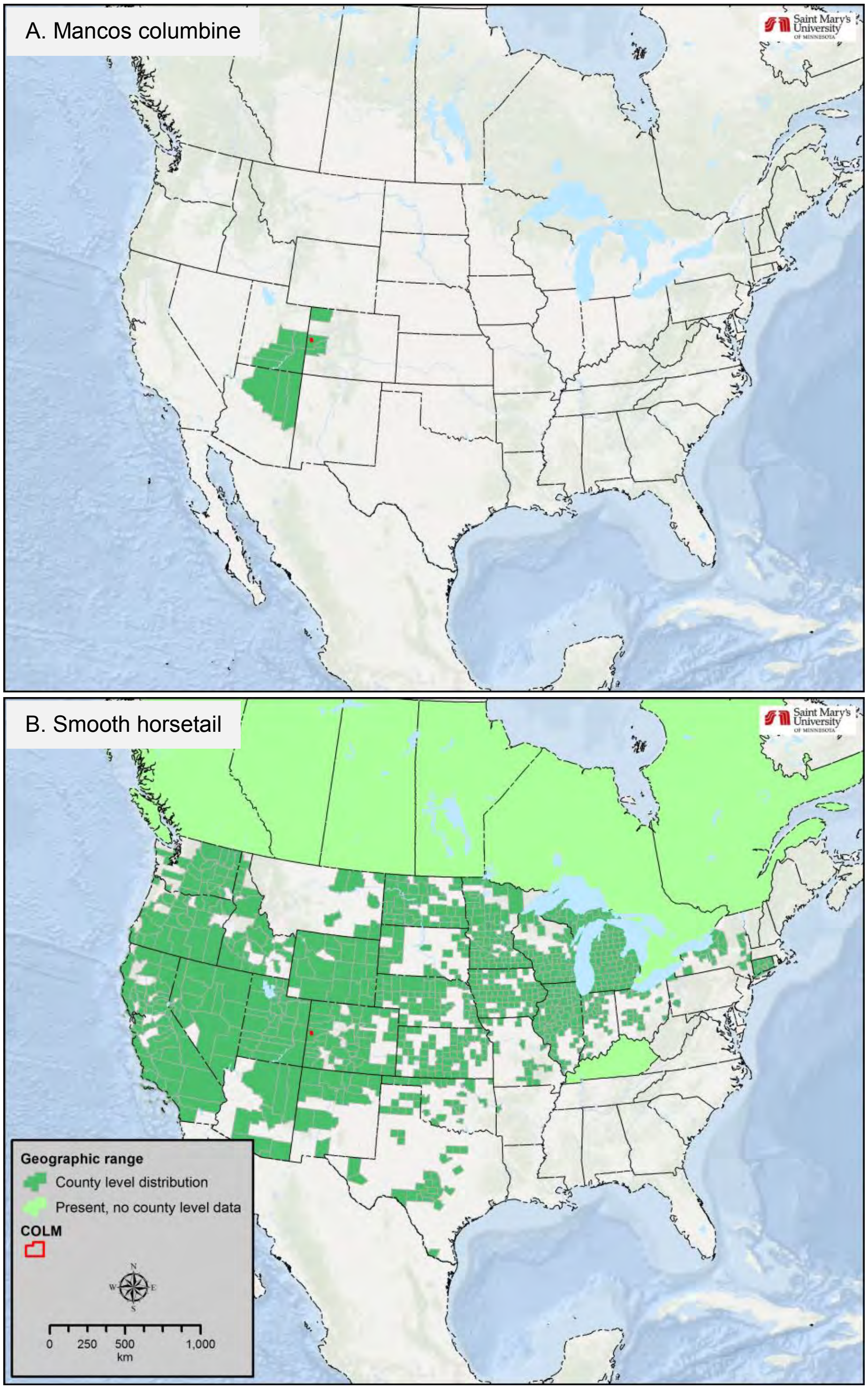

Figure 33. Current geographic extent of seep, spring, and tinaja habitats keystone species (A. Mancos columbine and B. smooth horsetail) used in the climate change vulnerability analysis. The geographic extents are based on county level data from NRCS 2015.

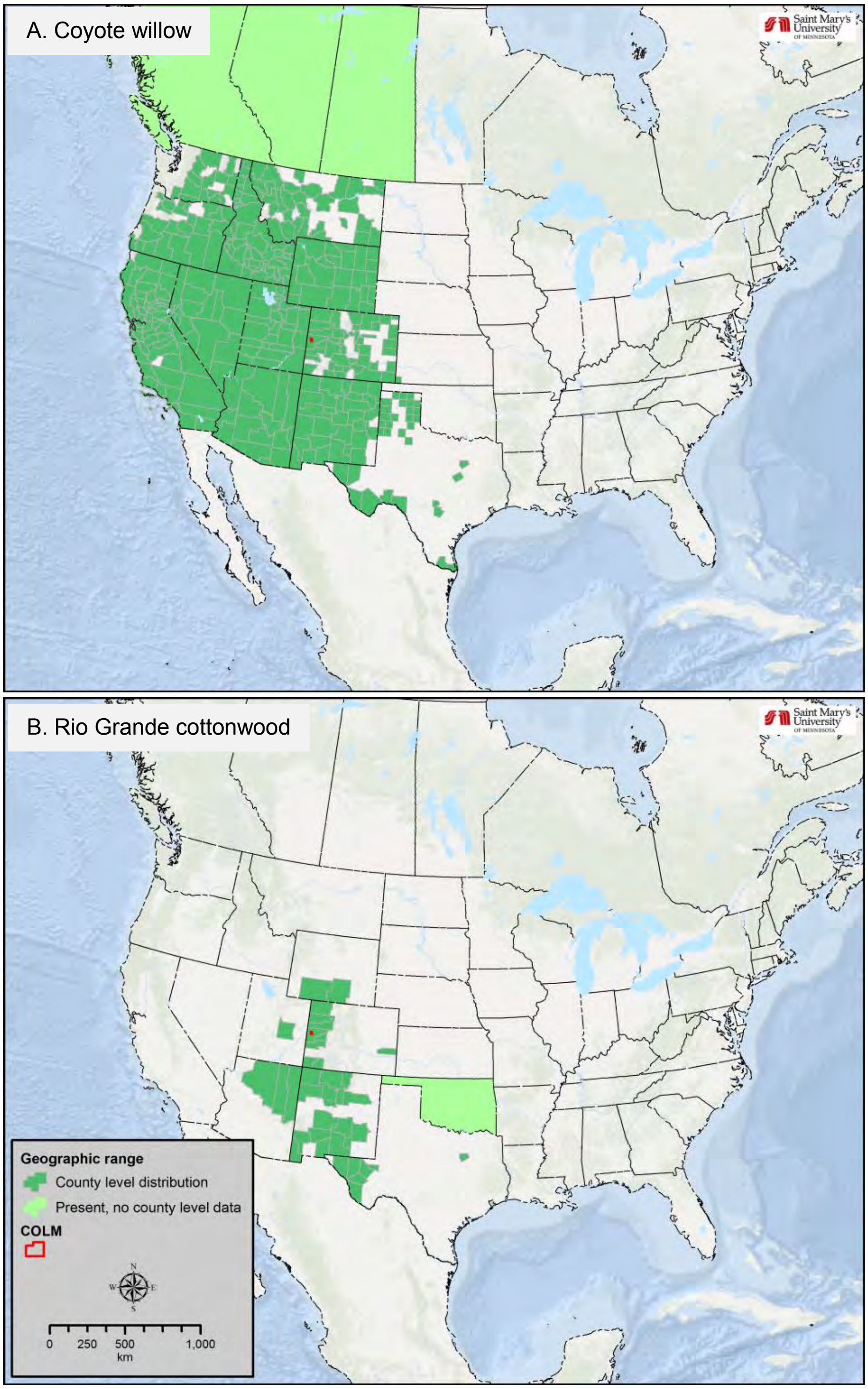

Figure 34. Current geographic extent of seep, spring, and tinaja habitats keystone species (A. coyote willow and B. Rio Grande cottonwood) used in the climate change vulnerability analysis. The geographic extents are based on county level data from NRCS 2015.

The groundwater supply that feeds COLM's seeps and springs, particularly those in the alluvial valley fill, is strongly influenced by annual and seasonal precipitation (Lamm et al. 2014). While the alluvial valley fill aquifers will be directly impacted on a seasonal basis, the impact to the bedrock aquifers will take a much longer period of time before they become apparent in spring discharge (Lamm et al. 2014). In many cases the recharge to these bedrock aquifers is directly related to the groundwater availability in the overlying alluvial valley fill (Lamm, written communication, 27 November 2015). During droughts, groundwater recharge will decline and, in turn, contribute to a decline in seep and spring discharge. Reduced water availability will negatively impact the vegetation and wildlife that rely on these sites, potentially reducing biodiversity. Weather extremes of heavy precipitation and flooding also pose a threat to seeps and springs (Richard 2004). These events can trigger mudslides, move boulders and trees, and erode stream banks, all of which could alter or destroy spring, seep, and tinaja habitats (Richard 2004). Heavy precipitation could accelerate erosion of the alluvial valley fill aquifer, reducing water storage capacity and potentially eliminating springs or seeps (Lamm et al. 2014).

The vegetation communities that rely on the soil moisture and groundwater supplied by seeps, springs, and tinajas at COLM do not have significant adaptive capacity. A hotter, drier environment could increase the rate at which water from seeps and springs or in tinajas is lost to evaporation, meaning it will be available to plants and wildlife for a shorter time (Chapter 4.1.5 - Figure 20, ClimateWizard 2014, Lamm et al. 2014). The projected changes in precipitation, temperature, and evaporation rates are likely to reduce the number of tinajas that hold water (Evenden et al. 2002). Warmer, drier conditions will likely lead to the loss of these vegetation communities to other, more xeric vegetation communities or non-native species (Decker and Rondeau 2014).

As discussed in Chapter 2.1.2, the GCM predict higher temperatures and slight increases in precipitation for this region. While there is a slight projected increase in precipitation, the higher temperatures (for all seasons) will create higher evapotranspiration rates, ultimately resulting in drier conditions. These hotter and drier conditions expected in COLM over the next century will likely exacerbate many of the current non-climate stressors of the seep, spring, and tinaja habitats at COLM. Development in the surrounding communities along with changes in other adjacent land uses has the potential to negatively impact groundwater resources. If groundwater withdrawals for agricultural or domestic uses were to increase in the region, seep and spring flow could be negatively impacted. In the case of COLM, there is concern that residential development in the Glade Park area southwest of COLM may already be affecting groundwater flow and supply to park springs (Martin 2013, Lamm et al. 2014). Wells in this development primarily draw water from the Wingate Sandstone aquifer (Martin 2013). As of 2009, there were 440 residences in this area, 150 of which were very close to the COLM boundary (Sharrow 2009). The cumulative impact of so many wells could lower the water table or capture recharge that otherwise would flow towards the park, decreasing groundwater flow to COLM's seeps and springs (Martin 2013).

It is difficult to assess how the warmer and drier conditions predicted for COLM will affect the IEPs already invading the seep, spring, and tinaja communities. While Dukes and Mooney (1999) suggested that most aspects of global climate change will favor invasive species over natives, it is unknown if this pattern will apply to already arid environments such as COLM. Currently, IEP species are not found in significant numbers or areal coverage in the seeps, springs, and tinaja habitats at COLM (Lamm et al. 2014). Tinaja and other springs that are protected from flooding tend to be resilient to IEPs, due to the lack of room for germination (Weissinger, written communication, 16 November 2015). Increased numbers of IEPs may occur in flood-prone springs, although the saturated conditions in the springs themselves will prevent the invasion of any IEP that is not phreatophytic (Weissinger, written communication, 16 November 2015). However, future drier conditions could cause areas that currently have spring-related vegetation to convert to more xeric species, both native and non-native. These drier conditions are expected to be more favorable for tamarisk and cheatgrass (Bradley et al. 2009, Bradley and Wilcove 2009), which are presently two of the more common non-native species in these habitats. Currently, cheatgrass and tamarisk are found in small amounts, but future conditions could lead to an increase in the extent of these and other non-native species, especially if an IEP removal program is not maintained.

Threats and Stressor Factors

Park resource managers identified influences from a changing climate (e.g. increase in mean and annual temperature, increase in extreme drought /precipitation events), increases in IEPs, visitor impacts, and development in surrounding communities (e.g. groundwater removal and wastewater contamination) as the primary concerns in terms of this resource.

The threats associated with climate change are addressed in detail above. Invasive plants may impact spring, seep, and pond communities by competing with or replacing native species and altering ecosystem functions (e.g., water and nutrient cycling). Invasive species may use more water than native species and can cause changes in soil nutrients; for example, tamarisk and Russian olive also concentrate salt in their foliage and cause increases in soil salinity (Westbrooks 1998).

Several of the park's seeps and springs are near hiking trails, which often provide a vector for the introduction and spread of invasive species (Lamm et al. 2014). The way in which visitors use the parks trail system also contributes to impacts to seeps and spring habitat in the park. The park does not limit foot travel to established trails. The major trail systems are located in the drainages at COLM, providing easy access to seep and spring sites (Hartwig, written communication, 18 November 2015). Due to COLM's high desert environment, water is an attraction for visitors. Visitors entering the larger spring pools can lead to the introduction of contaminants (sunscreen). The social trails also lead to trampling of vegetation and increased erosion, which can contribute to loss of habitat.

Adjacent development has the potential to threaten seep and spring water quality. Increased demands for groundwater by wells in the vicinity coupled with the potential for declining recharge due to climate change are two of the more significant threats to seeps and springs. Groundwater is a finite resource, and as these two factors deplete the available amounts of groundwater any contaminant levels can become more concentrated. In addition, much of the residential development bordering parks is considered low density, and wastewater is disposed through septic systems, which discharge directly into the ground nearby (Sharrow 2009). This septic discharge could potentially contaminate groundwater aquifers which supply park seeps and springs. A category of compounds called “emerging contaminants” (ECs) are of particular concern. These ECs can be natural or synthetic and are most often found in domestic and industrial wastewater (Sharrow 2009). These compounds include domestic pesticides, disinfectants, industrial solvents, surfactants, flame retardants, plasticizers, and pharmaceuticals (Zaugg et al. 2007, Sharrow 2009). A particular group of ECs called endocrine-disrupting chemicals (EDCs) can impact reproductive and development processes in fish and other wildlife species (EPA 1997) and are known to have such effects at very low concentrations (Kaiser 2000, Sharrow 2009).

Data Needs/Gaps

Limited information is available regarding the water quality and discharge for COLM’s seep, spring, and tinaja habitats. Additionally the potential for endemic plant and animal species is high but unconfirmed. Consistent monitoring, in both frequency and methodology, would allow for a more thorough assessment of these measures. While the locations of most of the park’s seeps and springs have been mapped, several potential sites in Lizard Canyon, Kodels Canyon, and tributaries of NTC have not been visited recently to confirm the existence of water sources (Lamm et al. 2014). A list of potential addition spring sites to be evaluated has been submitted to COLM resource staff (Lamm, written communication, 27 November 2015). The full extent of associated habitats at mapped sites also has not been measured. Regular monitoring of invasive plant species would be helpful in identifying any trends in or impacts of these species on the sensitive seep and spring sites. Monitoring of groundwater resources could also be useful in understanding the condition of the park’s seeps and springs, particularly how current climate conditions influence spring flows (Lamm et al. 2014) and how projected climate futures might influence groundwater resources.

Overall Condition

Vegetation Community Extent and Change over Time

The project team assigned this measure a *Significance Level* of 2. While the locations of many springs, seeps, and tinajas in COLM are known, the extent of the communities/habitats supported by these features is not known. Differences in seep and spring locations mapped by Von Loh et al. (2007) and Lamm et al. (2014) were noted, but these are likely due to differences in methodology (e.g., areas of focus) or project constraints (e.g., time, terrain) rather than any change in seep or spring locations between studies. Because the full extent of spring, seep, and tinaja habitats is not known, a *Condition Level* could not be assigned for this measure.

Vegetation Community Composition

The community composition measure was assigned a *Significance Level* of 3. Lamm et al. (2014) documented a total of 98 plant species at 34 park seeps and springs, 19 of which were non-native. On average, native plants made up 84% of the species per site (Lamm et al. 2014). Since species richness is relatively high and not dominated by non-native species, so at this time the measure is of low concern (*Condition Level* = 1). However the potential for greater invasion is present and conditions could rapidly change (worsen) due to factors such as climate change.

Trends in Invasive Infestation
This measure also received a *Significance Level* of 3. Lamm et al. (2014) found that non-native invasive plants did not dominate species richness or cover at their 34 inventory sites in COLM. Tamarisk, a state noxious weed, was found at four sites and its removal is recommended (Lamm et al. 2014). Park-wide current infestations of tamarix appear to be at control levels mainly due to the control efforts by volunteers and park staff (Perkins 2014). Cheatgrass was the most common invasive species, occurring at a majority of sites (25 of 34), but with potentially problematic cover levels at only four sites. Increasing visitation is likely to increase the spread of cheatgrass (Perkins 2014). Russian olive infestations are also increasing (Perkins 2014). Over the last decade the park has focused control efforts on eradication of IEP's. Future funding for these control measures is not available, so the potential for increased infestations is high (Hartwig, written communication 18 November 2015). Therefore, this measure is assigned a *Condition Level* of 2, indicating moderate concern.

Water Quality
The water quality measure was also assigned a *Significance Level* of 3. Water quality data for COLM's seeps and springs are limited, and it is unclear if methodologies (e.g., exact sampling locations and timing) were similar enough among studies to be comparable. However, available data and information suggest that water from COLM's seeps and springs is of variable quality and has the potential to exhibit extreme conditions. Therefore, this measure is considered of moderate concern (*Condition Level* = 2).

Discharge
This measure was assigned a *Significance Level* of 3. Discharge from COLM's seeps and springs has been measured or estimated several times since 2000 (Butler et al. 2003, Springer et al. 2006, Lamm et al. 2014). However, these data represent single points in time, and discharge has not been consistently measured at any sites in the park. Lamm et al. (2014) did note minimal or diminished flow from several Wingate sandstone springs, likely related to natural incision/erosion in the park's canyons. Because of this concern, the discharge measure is assigned a *Condition Level* of 2.

Climate Change Vulnerability Assessment
Analysis of the seeps, springs, and tinaja habitats within COLM showed that they are highly vulnerable to the projected impacts of climate change, with an overall score of 24 (Table 40). While the certainty scores are in the "high" category with a value of 18, alternative scores were assigned to some of the variables as the degree of impact is difficult to assess due to the differences in the assessed species' geographic ranges and overall adaptability.

To address some of the uncertainty in the potential impact of climate change on individual species within this assessment, alternative scores were identified for several variables in addition to the best estimate scores (Table 40). Alternative scores create a range of likely vulnerability for the plant community. The "location in the geographic range/distribution of the plant community" and the "vulnerability of ecologically influential species to climate change" variables were assigned alternative scores due to the wide ranging differences in the geographic extents of the four species used in the analysis and the potential for a worst-case scenario of the potential for loss of the species under projected future climate conditions. The "intrinsic adaptive capacity" and "potential for climate change to exacerbate impacts of non-climate stressors" were given the higher alternative scores due to the potential for total loss of these vegetation communities under projected climate change and increased water use scenarios. When factored in, the range of vulnerability scores for seep, spring, and tinaja habitats is 22 to 26, placing it potentially in the "critically vulnerable" category under a worst-case scenario. With the high certainty score, this suggests that, despite some uncertainty in the degree of impact to the selected species, the classification of seep, spring, and tinaja habitats as highly vulnerable is fairly robust. The scoring worksheet developed for the seep, spring, and tinaja habitats is included in Appendix H.

Table 40. Certainty, vulnerability, and alternative vulnerability scores for seep, spring, and tinaja plant community assessment variables.

Variable	Certainty Score[1]	Vulnerability Score[2]	Alternative Scores[3]
Location in geographical range/distribution of plant community	3	4	3
Sensitivity to extreme climatic events (e.g., drought, flash floods, windstorms)	3	4	
Dependence on specific hydrologic conditions	3	4	
Intrinsic adaptive capacity	3	4	5
Vulnerability of ecologically influential species to climate change	3	4	3
Potential for climate change to exacerbate impacts of non-climate stressors	3	4	5
Total	**18**	**24**	**22-26**

[1]For individual variables, certainty scores are 3 = high, 2 = moderate, and 1 = low

[2]The certainty ranges are 6-10 = low confidence,11-14 = moderate confidence,15-18 = high confidence

[3]The vulnerability ranges are 6-13= least vulnerable, 14-19 = moderately vulnerable, 20-25 = highly vulnerable, 26-30 = critically vulnerable

Weighted Condition Score

The *Weighted Condition Score* for this component is 0.58, indicating moderate concern. Because data are limited to single points in time for most measures, a trend could not be assigned.

Seeps and Springs and Tinaja Habitats			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.58**
Community Extent and Change over Time	2	n/a	
Community Composition	3	1	
Trends in Invasive Infestation	3	2	
Water Quality	3	2	
Discharge	3	2	

4.4.6 Sources of Expertise

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4.5 Mixed Salt Desert Scrub/Semi-desert Grassland

4.5.1 Description

Photo 8. Fourwing saltbush (NPS Photo).

Mixed salt desert scrub and semi-desert grassland communities are two of the less common ecological systems found in COLM. Mixed salt desert scrub communities found in COLM include fourwing saltbush and fourwing saltbush –Mormon tea talus shrubland (Von Loh et al. 2007). Fourwing saltbush scrub is located on alluvial fans and on the toeslopes of ridges near COLM's eastern border (Von Loh et al. 2007). Shadscale desert scrub communities are also found within the park (Table 41). Grasslands primarily occur in small patches on the eastern side of the park. The most common semi-desert grasslands in COLM are stands of cheatgrass and crested wheatgrass (Von Loh et al. 2007). These species were introduced to COLM as a result of livestock management practices near the park (Von Loh et al. 2007). Native grass species found in COLM's semi-desert grasslands include Indian ricegrass, needle and thread, and James' galleta (Von Loh et al. 2007). Western wheatgrass also occurs in some areas; although native to the western U.S., this species may have been introduced to COLM (Von Loh et al. 2007).

Table 41. Vegetation alliances found within the mixed salt desert scrub and semi-desert grassland plant associations of COLM (Von Loh et al. 2007).

Plant Association	Vegetation Alliance
Inter-Mountain Basins Mixed Salt Desert Scrub	Fourwing saltbush shrubland
	Fourwing Saltbush - Mormon tea talus shrubland
	Shadscale/James' galleta shrubland
	Shadscale - black greasewood shrubland
Inter-Mountain Basins Semi-Desert Grassland	Crested wheatgrass semi-natural herbaceous alliance
	Indian ricegrass - cheatgrass semi-natural herbaceous vegetation
	Cheatgrass semi-natural herbaceous vegetation
	Needle and thread Great Basin herbaceous vegetation)
	Plains pricklypear/James' galleta shrubland
	Western wheatgrass herbaceous vegetation
	James' galleta herbaceous vegetation

A wide variety of wildlife can be seen within these habitats. Rodents and small mammals found within these communities include: rabbits, mice, bats, chipmunks, gophers, shrews, weasels, and skunks (Hanophy and Teitelbaum 2003, DW 2016). These habitats also provide cover, foraging and nesting habitat for a wide variety of birds (Hanophy and Teitelbaum 2003, DW 2016). Hawks, golden eagles, owls and other raptors utilize these habitats for foraging (Hanophy and Teitelbaum 2003, DW 2016). Other predators found within these habitats include coyotes, foxes, and badgers (*Taxidea taxus)* (DW 2016). Mule deer also can be found foraging within these habitats (Hanophy and Teitelbaum 2003).

4.5.2 Measures

- Community extent and change over time
- Community composition
- Trends in invasive infestation
- Soil stability
- Percent cover biological soil crusts
- Percent bare ground

4.5.3 Reference Conditions/Values

The ideal reference condition for the mixed salt desert scrub and semi-desert grassland areas of COLM is the condition of these communities prior to regional settlement. Unfortunately, little information is available from this time, making reference conditions difficult to determine. For this assessment, conditions will be assessed based on best professional judgment given the available data. The information presented here may be used as baselines for future assessments.

4.5.4 Data and Methods

A comprehensive list of plant species within COLM was compiled by Hogan et al. (2009). This effort included a review of existing literature and a reexamination of specimens from the COLM herbarium. This project also conducted field surveys to confirm unverified species as well as to document previously unlisted species (Hogan et al. 2009). The products from this project included an annotated checklist with additional information about the flora found within COLM. Although Hogan et al. (2009) identified species that occurred within some of the major plant communities of COLM, species that occurred within mixed salt desert scrub or semi-desert grasslands were not highlighted.

A vegetation classification system and map were generated for COLM and surrounding areas by Von Loh et al. (2007). The results show the spatial distribution of dominant cover types present within and around the park during the early 2000s. Surrounding areas were included to support management of the urban-wildland interface and coordinated management on adjacent public lands (Von Loh et al. 2007). The report also includes descriptions of the vegetation associations identified during the project.

The NCPN funded the first park-wide invasive plant inventory and mapping project in 2003 (Dewey and Anderson 2005). Later, Perkins (2010, 2012, 2014) conducted IEP monitoring in COLM during the 2009, 2011, and 2013 field seasons as part of an ongoing NCPN monitoring program. The methodologies for field work and data analysis were similar for all three of these more recent field seasons, with surveys conducted between late June and August each year. For the purpose of this assessment of condition, Perkins (2014) will be the primary source since it includes data from the previous reports. The field work for these monitoring efforts included transect and quadrat sampling with an emphasis on roads, trails, and waterways (Perkins 2010, 2012, 2014). A list of IEP priority species was developed for COLM prior to monitoring, and was based on previously detected species and literature reviews (Perkins 2010, 2012, 2014). Monitoring was conducted on foot and IEPs were detected visually. For each monitoring route, transect and quadrat, each IEP detected was recorded by species, infestation size class, and canopy cover class (Perkins 2010, 2012, 2014).

4.5.5 Current Condition and Trend

Community Extent and Change Over Time

Von Loh et al. (2007) represent the most recent estimate of vegetation community extent in the park. Unfortunately, several of the mixed salt desert scrub and semi-desert vegetation classes occurred only in patches below the project's MMU size of 0.5 ha (1.2 ac). As a result, the extent of the following vegetation classes cannot be calculated: shadscale/James' galleta shrubland, Indian ricegrass - cheatgrass semi-natural herbaceous vegetation, needle and thread Great Basin herbaceous vegetation, plains prickly-pear/James' galleta shrubland, western wheatgrass herbaceous vegetation, and James' galleta herbaceous vegetation. Von Loh et al. (2007) did note that western wheatgrass herbaceous vegetation and needle and thread Great Basin herbaceous vegetation were both rare, each observed at only two locations in the park.

The three mixed salt desert scrub vegetation classes that were mapped covered a total of 60.9 ha (150.5 ac) or 0.3% of COLM's total area (Table 42) (Von Loh et al. 2007). Just over half of this area consisted of shadscale – black greasewood shrubland (Figure 35). The two mapped semi-desert grassland communities totaled just 16.6 ha (41.0 ac), or only 0.1% of the park, with the cheatgrass vegetation class covering nearly four times as much area as the crested wheatgrass class (Von Loh et al. 2007(Table 42)). However, it is worth noting that both of these grassland types are dominated by non-native species.

Table 42. Areal extent of mixed salt desert scrub and semi-desert grassland vegetation associations found in COLM (Von Loh et al. 2007).

Plant Association	Vegetation Alliance	Area in ha (ac)	Percent of Park
Mixed salt desert scrub	Fourwing saltbush shrubland	15.3 (37.8)	<0.1%
	Fourwing Saltbush - Mormon tea talus shrubland	14.4 (35.6)	<0.1%
	Shadscale - black greasewood shrubland	31.2 (77.1)	0.2%
	Total	**60.9 (150.5)**	**0.3%**
Semi-desert grasslands	Crested wheatgrass semi-natural herbaceous alliance	3.5 (8.6)	<0.1%
	Cheatgrass semi-natural herbaceous vegetation	13.1 (32.4)	<0.1%
	Total	**16.6 (41.0)**	**0.1%**

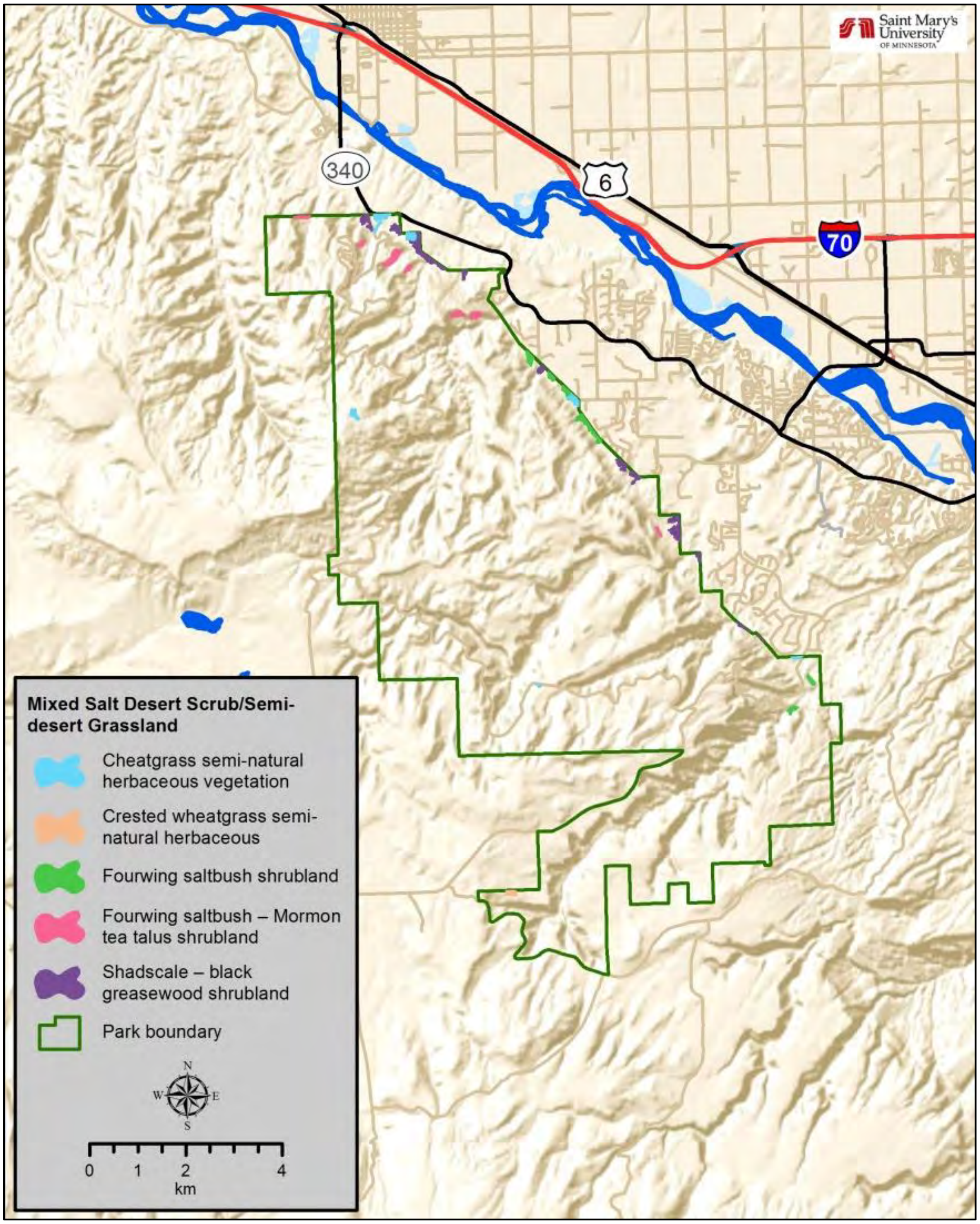

Figure 35. Mixed salt desert scrub and semi-desert grassland locations within COLM (Von Loh et al. 2007).

<u>Community Composition</u>

Four different types of mixed salt desert scrub and seven types of semi-desert grassland were identified within COLM by Von Loh et al. (2007) (Table 41). Community composition information was provided by Von Loh et al. (2007) for all but the crested wheatgrass semi-natural herbaceous alliance, as sampling of this community was limited.

Fourwing saltbush shrubland communities are characterized by fourwing saltbush, with canopy coverage from 8-12% (Von Loh et al. 2007). Other shrubs and succulents include Wyoming big sagebrush, Mormon tea, brittle pricklypear, berry pricklypear, and plains pricklypear (Von Loh et al. 2007). The herbaceous layer in this community includes the graminoids Indian ricegrass, crested wheatgrass, cheatgrass, six weeks fescue, needle and thread, James' galleta, and sand dropseed and the forbs smallflowered milkvetch, western tansymustard, sleepy catchfly, tumble mustard, and scarlet globemallow (Von Loh et al. 2007). The most abundant species within this community by stratum are listed in Table 43.

Table 43. Dominant plant species (by strata) within the fourwing saltbush shrublands of COLM (Von Loh et al. 2007).

Fourwing saltbush shrublands		
Scientific Name	**Common Name**	**Strata**
Artemisia tridentata spp. *wyomingensis*	Wyoming big sagebrush	Short shrub/sapling
Atriplex canescens	fourwing saltbush	Short shrub/sapling
Opuntia phaeacantha	berry pricklypear	Short shrub/sapling
Opuntia polyacantha	plains pricklypear	Short shrub/sapling
Astragalus nuttallianus	smallflowered milkvetch	Herb
Descurainia pinnata ssp. *halictorum*	western tansymustard	Herb
*Erodium cicutarium**	stork's bill	Herb
Hesperostipa comata	needle and thread	Herb
Hilaria jamesii	James' galleta	Herb
Sporobolus cryptandrus	sand dropseed	Herb

*Indicates a non-native species.

Fourwing saltbush - Mormon tea talus shrubland communities are characterized by fourwing saltbush and Mormon tea (Von Loh et al. 2007). Other shrubs and succulents include Bigelow's sagebrush, claretcup, Torrey's Mormon tea, broom snakeweed, winterfat, grizzlybear pricklypear (*Opuntia polyacantha* var. *erinacea*), berry pricklypear, and skunkbush sumac. Utah juniper provides sparse canopy cover, usually less than 5% (Von Loh et al. 2007). The herbaceous layer in this community includes the graminoids Indian ricegrass, purple three-awn, cheatgrass, needle and thread, and James' galleta and the forbs western tansymustard, milkvetch (*Astragalus* spp.), fleabane, stork's bill, desert trumpet (*Eriogonum inflatum*), prairie pepperwort, mountain pepperweed, scarlet globemallow, and long-beak fiddle-mustard (Von Loh et al. 2007). The most abundant species within this community by stratum are listed in Table 44.

The rare shadscale – black greasewood shrubland communities are characterized by black greasewood and shadscale (Von Loh et al. 2007). Other shrubs and succulents include claretcup, grizzlybear pricklypear, plains pricklypear, and broom seepweed (*Suaeda calceoliformis*) (Von Loh et al. 2007). The herbaceous layer in this community is sparse and includes the graminoids cheatgrass, six weeks fescue, James' galleta, and sand dropseed and the forbs smallflowered milkvetch and western tansymustard (Von Loh et al. 2007). Table 45 lists the most abundant species within this community.

Table 44. Dominant plant species (by strata) within the fourwing saltbush - Mormon tea talus shrublands of COLM (Von Loh et al. 2007).

Fourwing saltbush – Mormon tea talus shrublands		
Scientific Name	**Common Name**	**Strata**
Juniperus osteosperma	Utah juniper	Tree canopy
Atriplex canescens	fourwing saltbush	Short shrub/sapling
Ephedra torreyana	Torrey's Mormon tea	Short shrub/sapling
Ephedra viridis	Mormon tea	Short shrub/sapling

Table 45. Dominant plant species (by strata) within the shadscale - black greasewood shrublands of COLM (Von Loh et al. 2007).

Shadscale - black greasewood shrublands		
Scientific Name	**Common Name**	**Strata**
Atriplex confertifolia	shadscale	Short shrub/sapling
Sarcobatus vermiculatus	black greasewood	Short shrub/sapling
Opuntia polyacantha	plains pricklypear	Short shrub/sapling
*Bromus tectorum**	cheatgrass	Herb
Hilaria jamesii	James' galleta	Herb

*Indicates a non-native species.

Shadscale/James' galetta shrubland is common within COLM, and consists of an open canopy of shadscale with a sparse herbaceous layer of James' galetta (Von Loh et al. 2007). Trees such as Utah juniper and singleleaf ash are present but are rare (Von Loh et al. 2007). Additional shrub species present include Wyoming big sagebrush, Mormon tea, Torrey's Mormon tea, winterfat, black greasewood, bud sagebrush (*Picrothamnus desertorum*), yellow rabbitbrush, slender wild buckwheat (*Eriogonum microthecum* var. *laxiflorum*), broom snakeweed, broom seepweed, and spineless horsebrush (*Tetradymia canescens*) (Von Loh et al. 2007). Other shrubs and succulents found within this community are similar to those found in the previously described, with the addition of Whipple's fishhook cactus (*Sclerocactus whipplei*) and Harriman's yucca (Von Loh et al. 2007). The herbaceous layer is also similar to previous communities, but also includes muttongrass, Sandberg's bluegrass, Gunnison's mariposa, yellow-eye crypantha (*Cryptantha flavoculata*), longleaf wild buckwheat (*Eriogonum lonchophyllum*), western stickseed (*Lappula occidentalis* var. *occidentalis*), pale evening primrose, woolly plantain, oblongleaf basindaisy (*Platyschkuhria integrifolia*), large-flowered breadroot (*Pediomelum megalanthum*), and western groundsel (Von Loh et al. 2007). The most abundant species by stratum within this community are listed in Table 46.

Table 46. Dominant plant species (by strata) within the shadscale/James' galetta shrublands of COLM (Von Loh et al. 2007).

Shadscale/James' galetta shrubland		
Scientific Name	**Common Name**	**Strata**
Atriplex confertifolia	shadscale	Short shrub/sapling
Opuntia polyacantha	plains pricklypear	Short shrub/sapling
Astragalus nuttallianus	smallflowered milkvetch	Herb
*Bromus tectorum**	cheatgrass	Herb
Descurainia pinnata ssp. *halictorum*	western tansymustard	Herb
*Erodium cicutarium**	stork's bill	Herb
Hilaria jamesii	James' galleta	Herb
Lappula occidentalis var. *occidentalis*	western stickseed	Herb
Picrothamnus desertorum	bud sagebrush	Herb
Sporobolus cryptandrus	sand dropseed	Herb

*Indicates a non-native species.

Although panhandle pricklypear/James' galleta shrubland has "shrubland" in its name, Von Loh et al. (2007) classified it as a semi-desert grassland community. It is a low succulent community where plains pricklypear became common due to historical grazing (Von Loh et al. 2007). Utah juniper occurs rarely, along with Wyoming big sagebrush, fourwing saltbush, yellow rabbitbrush, Mormon tea, shadscale, slender wild buckwheat, winterfat, spiny hopsage, black greasewood, broom snakeweed, and berry pricklypear (Von Loh et al. 2007). Common herbaceous layer species include Indian ricegrass, cheatgrass, six weeks fescue, needle and thread, sand dropseed, smallflowered milkvetch, western stickseed, prairie pepperwort, scarlet globemallow, and long-beak fiddle-mustard (Von Loh et al. 2007). Table 47 lists the most abundant species by stratum within this community.

Table 47. Dominant plant species (by strata) within the plains prickly pear/James' galetta shrublands of COLM (Von Loh et al. 2007).

Plains pricklypear/James' galetta shrubland		
Scientific Name	**Common Name**	**Strata**
Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush	Short shrub/sapling
Atriplex canescens	fourwing saltbush	Short shrub/sapling
Atriplex confertifolia	shadscale	Short shrub/sapling
Ephedra viridis	Mormon tea	Short shrub/sapling
Opuntia polyacantha	plains pricklypear	Short shrub/sapling
Astragalus nuttallianus	smallflowered milkvetch	Herb
*Bromus tectorum**	cheatgrass	Herb
Gutierrezia sarothrae	broom snakeweed	Herb
Hilaria jamesii	James' galleta	Herb
Vulpia octoflora	six weeks fescue	Herb

*Indicates a non-native species.

Cheatgrass semi-natural herbaceous vegetation is characterized by cheatgrass, which accounted for up to 55% of vegetative cover in this community (Von Loh et al. 2007). Other graminoids present include Indian ricegrass, crested wheatgrass, purple three-awn, smooth brome (*Bromus inermis*), desert saltgrass, squirreltail, smooth horsetail, western wheatgrass, sand dropseed, and the non-natives Kentucky bluegrass (*Poa pratensis*) and wheat (*Triticum aestivum*) (Von Loh et al. 2007). Forbs and shrubs are also sparse and include both native and non-native species (Von Loh et al. 2007). Additional non-native species found in this community include tumble mustard, sagebrush buttercup, yellow salsify (*Tragopogon dubius*), little-pod false flax (*Camelina microcarpa*), Russian thistle (*Salsola kali*), and tamarisk (Von Loh et al. 2007). The most abundant species within this community by stratum can be found in (Table 48).

Table 48. Dominant plant species (by strata) within the cheatgrass semi-natural herbaceous vegetation community of COLM (Von Loh et al. 2007).

Cheatgrass semi-natural herbaceous vegetation		
Scientific Name	**Common Name**	**Strata**
Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush	Short shrub/sapling
Ericameria nauseosa	rubber rabbitbrush	Short shrub/sapling
Sarcobatus vermiculatus	black greasewood	Short shrub/sapling
Aristida purpurea	purple three-awn	Herb
*Bromus tectorum**	cheatgrass	Herb
Descurainia pinnata ssp. *halictorum*	western tansymustard	Herb
*Erodium cicutarium**	stork's bill*	Herb
Hesperostipa comata	needle and thread	Herb
Hilaria jamesii	James' galleta	Herb
Krascheninnikovia lanata	winterfat	Herb
Poa secunda	Sandberg's bluegrass	Herb
*Salsola kali**	Russian thistle	Herb
*Sisymbrium altissimum**	tumble mustard	Herb
Sphaeralcea coccinea ssp. *coccinea*	scarlet globemallow	Herb

*Indicates a non-native species.

Western wheatgrass herbaceous vegetation occurs in moderately vegetated patches (28-36% cover) (Von Loh et al. 2007). In addition to western wheatgrass, the non-native graminoids crested wheatgrass, cheatgrass, field brome (*Bromus arvensis*), and Kentucky bluegrass were also present (Von Loh et al. 2007). The shrubs rubber rabbitbrush and basin big sagebrush are present but uncommon, as are weedy, native forbs such as povertyweed (*Iva axillaris*), goldenrod (*Solidago* spp.), and the non-native yellow salsify (Von Loh et al. 2007). The most abundant species by stratum within this community are shown in Table 49.

The rare needle and thread Great Basin herbaceous vegetation community is characterized by sparsely vegetated grasslands (Von Loh et al. 2007). These grasslands are dominated by needle and thread and James' galetta, with some Indian ricegrass, cheatgrass, muttongrass, and six weeks fescue

(Von Loh et al. 2007). Forbs are uncommon but include smallflowered milkvetch, western tansymustard, fleabane, long-beak fiddle-mustard, and gilia (*Gilia* spp.) when present (Von Loh et al. 2007). Shrubs are also sparse but diverse (Von Loh et al. 2007). Table 50 lists the most abundant species by stratum within this community.

Table 49. Dominant plant species (by strata) within the western wheatgrass herbaceous vegetation community of COLM (Von Loh et al. 2007).

Western wheatgrass herbaceous vegetation		
Scientific Name	**Common Name**	**Strata**
*Agropyron cristatum**	crested wheatgrass	Herb
*Bromus tectorum**	cheatgrass	Herb
Pascopyrum smithii	western wheatgrass	Herb
*Poa pratensis**	Kentucky bluegrass	Herb

*Indicates a non-native species.

Table 50. Dominant plant species (by strata) within the needle and thread Great Basin herbaceous vegetation community of COLM (Von Loh et al. 2007).

Needle and thread Great Basin herbaceous vegetation		
Scientific Name	**Common Name**	**Strata**
Chrysothamnus viscidiflorus	yellow rabbitbrush	Short shrub/sapling
Gutierrezia sarothrae	broom snakeweed	Short shrub/sapling
Opuntia polyacantha	plains pricklypear	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Astragalus nuttallianus	smallflowered milkvetch	Herb
Hesperostipa comata	needle and thread	Herb
Hilaria jamesii	James' galleta	Herb

James' galleta herbaceous vegetation is dominated by James' galetta; other grasses such as Indian ricegrass, cheatgrass, needle and thread, purple three-awn, muttongrass, and sand dropseed are also present (Von Loh et al. 2007). Trees such as Utah juniper and pinyon pine trees are found within this community, but are rare occurrences (Von Loh et al. 2007). Forbs are diverse with a composition similar to the shadscale/James' galetta shrubland community, with the addition of Fendler's sandwort, pallid milkweed (*Asclepias cryptoceras*), ridge-seeded spurge (*Euphorbia glyptosperma*), red dome blanketflower (*Gaillardia pinnatifida*), canaigre dock (*Rumex hymenosepalus*), and prickly phlox (Von Loh et al. 2007). The most abundant species by stratum are found in Table 51.

Indian ricegrass-cheatgrass herbaceous vegetation communities are sparsely vegetated and dominated by either Indian ricegrass or cheatgrass (Von Loh et al. 2007). Species diversity is high for the community as a whole but is typically low within individual patches (Von Loh et al. 2007). Additional grasses include purple three-awn, squirreltail, saline wildrye, six weeks fescue, needle and thread, James' galleta, and muttongrass (Von Loh et al. 2007). Utah juniper and pinyon pine occur at some sites, and short shrubs are common (Von Loh et al. 2007). Table 52 lists the most abundant species by stratum within this community.

Table 51. Dominant plant species (by strata) within the James' galleta herbaceous vegetation community of COLM (Von Loh et al. 2007).

James' galleta herbaceous vegetation		
Scientific Name	**Common Name**	**Strata**
Juniperus osteosperma	Utah juniper	Tree canopy
Pinus edulis	two-needle pinyon pine	Tree canopy
Opuntia polyacantha	plains pricklypear	Shrub
Opuntia polyacantha var. *erinacea*	grizzlybear pricklypear	Shrub
Aristida purpurea	purple three-awn	Herb
Astragalus nuttallianus	smallflowered milkvetch	Herb
Atriplex confertifolia	shadscale	Herb
*Bromus tectorum**	cheatgrass	Herb
*Erodium cicutarium**	stork's bill*	Herb
Hesperostipa comata	needle and thread	Herb
Hilaria jamesii	James' galleta	Herb
Lappula occidentalis var. *occidentalis*	western stickseed	Herb
Sphaeralcea coccinea ssp. *coccinea*	scarlet globemallow	Herb

*Indicates a non-native species.

Table 52. Dominant plant species (by strata) within the Indian ricegrass-cheatgrass herbaceous vegetation community of COLM (Von Loh et al. 2007).

Indian ricegrass-cheatgrass herbaceous vegetation		
Scientific Name	**Common Name**	**Strata**
Juniperus osteosperma	Utah juniper	Tree canopy
Pinus edulis	two-needle pinyon pine	Tree canopy
Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush	Short shrub
Ericameria nauseosa	rubber rabbitbrush	Short shrub
Gutierrezia sarothrae	broom snakeweed	Dwarf shrub
Opuntia polyacantha var. *erinacea*	grizzlybear pricklypear	Dwarf shrub
Achnatherum hymenoides	Indian ricegrass	Herb
*Agropyron cristatum**	crested wheatgrass	Herb
*Bromus tectorum**	cheatgrass	Herb
Elymus elymoides	squirreltail	Herb
Grindelia squarrosa	curlycup gumweed	Herb
Hesperostipa comata	needle and thread	Herb
Heterotheca villosa	hairy false goldenaster	Herb
Lepidium montanum	mountain pepperweed	Herb
Leymus salinus	saline wildrye	Herb

*Indicates a non-native species.

Trends in Invasive Infestation

COLM is part of a long-term monitoring program for IEPs developed by the NCPN which focuses on early detection (Perkins 2014). The first survey of IEPs in the park was conducted in 2003 by Dewey and Anderson (2005). The latest monitoring was conducted during the 2013 field season (Perkins 2014) and will be used to assess this measure, since it includes the previously collected data on IEP infestations in COLM. A full discussion of IEPs park-wide, including a discussion of trends can be found in Chapter 2.2.2. The mixed salt desert scrub and semi-desert grasslands are along the urban-interface, which is considered an area at high risk of invasive plant infestations.

Trends in invasive plants have not been assessed specifically by vegetation association at COLM. To identify invasive species infestations associated with mixed salt desert scrub and semi-desert grasslands, spatial queries were performed using the data from the 2013 IEP survey and the mixed salt desert scrub and semi-desert grasslands mapped by Von Loh et al. (2007). The spatial queries selected IEP points that were either within a mapped location of mixed salt desert scrub and semi-desert grasslands or within 100 m (328 ft) of one of these communities.

During the latest field season (2013), Perkins (2014) detected a total of 462 IEP infestation points within COLM. Spatial queries conducted using the 2013 data identified nine (2%) IEP occurrences were associated with the mixed salt desert scrub and semi-desert grasslands (Figure 36). Cheatgrass (7) and puncture vine (2) (*Tribulus terrestris*) were the only two IEP species detected within the mixed salt desert scrub and semi-desert grasslands. All nine of these infestations were located within the mapped vegetation boundaries. Puncture vine is considered a priority IEP species in the park (Perkins 2014). Differences in the number of infestations and species detected between 2003 (Dewey and Anderson 2005) and 2013 (Perkins 2014) is due to differences in methodology and areas monitored rather than actual change over time.

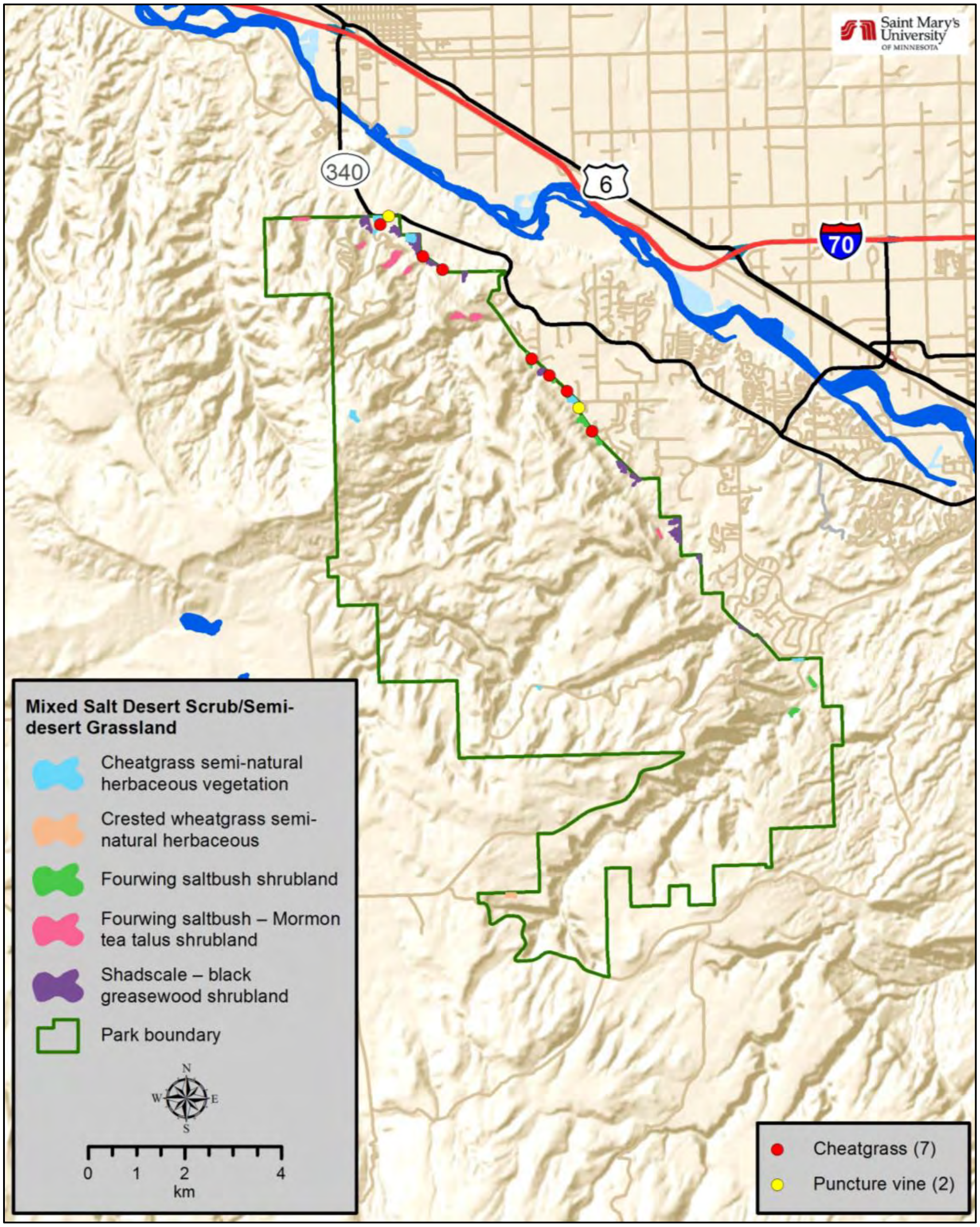

Figure 36. IEP observations within mapped mixed salt desert scrub and semi-desert grassland vegetation communities from 2003 and 2013 field seasons.

Soil Stability

As discussed in previous chapters, soil stability depends on a number of factors, including slope, soil composition, and the presence of BSC or other ground cover (NRCS 1996, Belnap et al. 2008, Witwicki et al. 2013). The presence of BSC and other cover within COLM's mixed salt desert scrub and semi-desert grasslands will be addressed in the following two sections. Specific data on soil stability within COLM's vegetation communities are not available at this time.

Percent Cover Biological Soil Crusts

BSC are a very important part of desert and semi-desert ecosystems, as they influence local hydrology and soil stability, fertility, and biodiversity (Belnap et al. 2008). The organisms within BSC aggregate soil particles, making the soil stronger and less likely to erode from wind or water. These crusts also aid in retention of mineral nutrients, organic matter, and seeds (Miller 2005). BSC within COLM are most common on sites that are protected from disturbance and are re-developing in areas that were once grazed or otherwise disturbed (Von Loh et al. 2007). Some of the park's canyon areas were particularly impacted by a herd of bison that grazed there from the 1940s until the 1980s (KellerLynn 2006). Although Von Loh et al. (2007) noted that BSC were present in the Indian ricegrass - cheatgrass semi-natural herbaceous vegetation community, specifics on the percent cover of BSCs in COLM vegetation communities was not provided.

Percent Bare Ground

Percent bare ground impacts soil stability, as vegetation helps prevent wind and water erosion (Kachergis et al. 2011, Witwicki et al. 2013). Sufficient data could not be found to assess the condition of percent of bare ground within COLM's mixed salt desert scrub and semi-desert grassland communities. Von Loh et al. (2007) describes these communities as sparsely to moderately vegetated, so it is highly likely that bare ground is present and may be prevalent in some areas.

Threats and Stressor Factors

Threats to COLM's mixed salt desert scrub and semi-desert grassland areas identified by natural resource staff include IEPs, unnatural fire regimes, drought, and regional climate variation. Cheatgrass and crested wheatgrass are two exotic plants known to occur within COLM's semi-desert grasslands (Von Loh et al. 2007). Cheatgrass was first documented in COLM in 1948 and crested wheatgrass in 1962 (Hogan et al. 2009). Cheatgrass, which is currently on the Colorado state noxious weed list (Hogan et al. 2009), is notable in formerly burned areas of COLM (Von Loh et al. 2007).

Both naturally occurring and prescribed fires can alter vegetation composition and structure by damaging or eliminating fire-intolerant plant species (Miller 2005). Historically, low intensity fires may have played a role in preventing woody vegetation from invading some semi-desert grassland communities (Miller 2005). When fire is excluded for long periods of time, fuels accumulate in grassland and scrub communities; when fires do occur, they are usually more damaging and of a higher intensity than those from a more natural fire regime (O'Dell et al. 2005). The loss of vegetative cover, as a result of intense fires, can increase soil erosion in these communities (Miller 2005). The invasion of some exotic plants, particularly cheatgrass, has contributed to an unnatural buildup of fuels in arid plant communities (Brooks et al. 2004). This fuel may increase fire frequency and extent in some areas to a point where native species have difficulty recovering (Brooks et al. 2004). In certain plant communities, such as desert scrub and semi-desert grasslands, prescribed fire may actually contribute to the dominance of exotic annual grasses (Miller 2005). The park's proximity to an urban area may increase the risk of human-caused fires, which could spread into the park (Hartwig, written communication, 20 September 2015).

Visitor impacts within the park's mixed salt desert scrub/semi-desert grassland habitats include damage to BSC present within these environments. Hikers, particularly those using unauthorized "social" trails, cause damage to these fragile habitats and continued disturbance does not allow for the time needed for BSCs to regenerate. This can lead to invasive species encroaching and potentially replacing BSC habitats.

Drought can cause widespread mortality in the vegetation at COLM. It can also lower a plants resistance/resilience to other stressors, such as fire and insect outbreaks (Miller 2005). At the opposite extreme, heavy precipitation and flooding can also impact vegetation community structure and function (Miller 2005). In western Colorado, global climate change is expected to cause an increase in temperature with longer and hotter summer heat waves, an increased potential for drought and wildfires, and an increase in heavy precipitation events (Lamm et al. 2014, Melillo et al. 2014). All of these changes could impact the park's desert scrub and semi-desert grassland communities.

Data Needs/Gaps

Though there are data available regarding community extent and community composition, insufficient data exist within COLM for the analysis of the percent cover of BSC, percent bare ground, or soil stability measures. Witwicki et al. (2013) briefly touches on these topics but only discusses a monitoring protocol, no actual data are presented. Although data are available for IEP infestations in the park as a whole, it is unclear how these species are impacting specific native plant communities (Perkins 2012). Research on the impacts from the proliferation of social trails within the park is also recommended.

Currently a guaranteed funding source for the invasive species removal/control has not been identified. Failure to secure funding for this management action will result in the loss of the gains that have been made in eradicating IEPs within the park. Additionally, another programmatic need for COLM is a trail management plan. Currently, visitors face no restrictions in their access to any areas within the park.

Overall Condition

Community Extent and Change over Time

This measure was assigned a *Significance Level* of 3. The presence of mixed salt desert scrub and semi-desert grasslands including cheatgrass and crested wheatgrass has been noted by various researchers (Von Loh 2007) (Perkins 2012). However, not enough data are available to confidently assess any change in community extent over time. Therefore, the *Condition Level* was not assigned to this measure.

Community Composition

A *Significance Level* of 3 was assigned to the community composition measure. Von Loh et al. (2007) reports that many of COLM's mixed salt desert scrub and semi-desert grassland communities show high plant species diversity. However, many of the most dominant plant species are non-natives (e.g., cheatgrass, crested wheatgrass, stork's bill). As a result, the *Condition Level* assigned to this measure is 2, indicating moderate concern.

Trends in Invasive Infestation

This measure was assigned a *Significance Level* of 3. The number of IEPs documented in or near mixed salt desert scrub or semi-desert grasslands is relatively low. However, the invasive species cheatgrass and crested wheatgrass are known to dominate two of COLM's semi-desert grassland types and cheatgrass is present in many other grasslands and desert scrub communities (Von Loh et al. 2007). Over the last decade the park has focused control efforts on eradication of IEP's. Future funding for these control measures is not available, so the potential for increased infestations is high (Hartwig, written communication 18 November 2015).While it is unclear from this recent monitoring if or how invasive infestations are impacting mixed salt desert scrub or semi-desert grassland areas, these species are still a cause for moderate concern (*Condition Level* = 2).

Soil Stability

The soil stability measure was assigned a *Significance Level* of 2. Data on soil stability within COLM do not exist. Because there are no available data, a *Condition Level* could not be assigned.

Percent Cover Biological Soil Crusts

The percent cover BSC measure was assigned a *Significance Level* of 3. Data on the percent cover of BSCs are not currently available. Due to the lack of data related to this measure, a *Condition Level* was not assigned.

Percent Bare Ground

A *Significance Level* of 3 was assigned to this measure. No data are available on percent bare ground within COLM. Due to the lack of data, a *Condition Level* could not be assigned.

Weighted Condition Score

A *Weighted Condition Score* was not calculated for this component because *Condition Levels* could not be assigned to greater than 50% of the measures due to lack of available data. Until more data become available for the other measures, the condition of mixed salt desert scrub/semi-desert grassland areas in COLM will be unknown.

Mixed Salt Desert Scrub/Semi-Desert Grassland			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Community Extent and Change over Time	3	n/a	
Community Composition	3	2	
Trends in Invasive Infestation	3	2	
Soil Stability	2	n/a	
Percent Cover Biological Soil Crusts	3	n/a	
Percent Bare Ground	3	n/a	

4.5.6 Sources of Expertise

Dusty Perkins, Program Manager, Northern Colorado Plateau Network

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4.6 Canyon Walls and Monolith Vegetation Communities

4.6.1 Description

Photo 9. Hanging gardens on a vertical canyon wall in COLM (Photo by Shannon Amberg, SMUMN GSS, 2013).

Canyon walls and monoliths are important geological features in COLM. The deep canyons, canyon walls, and monoliths are characteristic of the Upper Colorado Plateau region and played a large part in the establishment of the park (NPS 2005). Monoliths are a great example of the powers of erosion and other ecological processes as they are formed when sections of the canyon walls collapse (Harris 1985). The canyon walls and monoliths in COLM have vertical slopes that are sparsely vegetated. Hanging gardens are one of the only vegetative communities that grow on these vertical walls (Photo 9).

A hanging garden is a unique wetland habitat. Hanging gardens are associated with permanent seeps on vertical canyon walls (Malanson and Kay 1980). This habitat is a result of seeps creating favorable growing conditions by eroding the canyon wall enough to create a small ledge with a slighter slope. Hanging gardens are described as "pocketed wetlands" with draping vegetation located along cliff faces (Von Loh et al. 2007). According to Von Loh et al. (2007), there are three types of hanging gardens (alcove, terrace, and windowblind); these types exist in slightly different areas, depending on geologic formation and whether or not joint systems (series of connecting breaks in the canyon wall that allow for water to pass through) are present. Most of the vegetation in hanging gardens is short (<1 m [<3 ft]) herbaceous species; tree saplings and shrubs have also been known to grow in these habitats (Malanson and Kay 1980). These gardens are an important water source for rare plants in COLMs semi-arid climate (KellerLynn 2006). Common maidenhair (*Adiantum capillus-veneris*) and Eastwood's monkeyflower (*Mimulus eastwoodiae*) are examples of rare plants that have been known to occur in hanging gardens (CSU 2013). The Eastwood's monkeyflower has a global rank of G3G4 and is considered "highly vulnerable" (CSU 2013).

These communities provide important nesting and roosting areas for a variety of species of birds and bats. The hanging garden communities also provide a source of water that can support the variety of amphibian species found within the park.

4.6.2 Measures

- Community extent and change over time
- Community composition

4.6.3 Reference Conditions/Values

The reference condition for the vegetation on canyon walls and monoliths in COLM is the condition of this vegetation prior to regional settlement. Prior to settlement, the canyon wall and monolith vegetation would have been undisturbed and unaffected by anthropogenic stressors (e.g., invasive species, recreational climbing, development of Rim Rock Drive, graffiti).

4.6.4 Data and Methods

Von Loh et al. (2007) conducted a vegetation classification and mapping project for COLM and surrounding areas. The NVC plant associations known to occur in the Upper Colorado Plateau were used as a preliminary community list. Then historic COLM vegetation reports were consulted to refine the number of possible plant associations to 176 for the project area. In the end, the study area was divided into 67 plant associations. Prior to the field study, the park was first divided into five biophysical classes (relatively flat mesa tops, gently sloping alluvial fans, steep-walled canyons, ridges, and tilted bedrock formations), then divided again into biophysical units (BPUs). BPUs were categorized by their aspect and geology. BPUs were combined with orthoimages to create maps for the field study. Photo interpretation of true color digital orthoimagery was performed to help identify vegetation and landuse in a plot. Approximately 12,685 ha (31,344 ac) in the park and on Bureau of Land Management (BLM) land surrounding the park were mapped (Figure 37). There were 288 plots sampled. Field samples were collected at the plots between May and October 2003. Most sampling occurred in large patches of homogeneous vegetation; however, small patches were sampled if there were rare species or associations present (hanging gardens, wetlands, or relict plant communities). The report includes descriptions of the ecological systems and plant associations (globally and in COLM) as well as listing common plants in those associations.

4.6.5 Current Condition and Trend

<u>Community Extent and Change over Time</u>

At the time of publication, there were no complete data regarding hanging garden community extent in COLM, so an assessment of change over time could not be made. Von Loh et al. (2007) may have documented vegetation throughout the park, however, hanging gardens on canyon walls and monoliths were difficult and in some cases too dangerous to access and accurately assess. Two hanging gardens were documented at one plot during this study in COLM (Figure 37). These hanging gardens were observed in alcoves, on both sides (above and below) of Rim Rock Drive near the eastern tunnel, which is located in the southeast portion of the park. The alcoves contained loamy sand soil and were located at 1,716 m (5,630 ft) and 1,786 m (5,860 ft) in elevation, on slopes ranging from 3% to 40% (Von Loh et al. 2007).

Historical reports would also be needed to compare the change over time. Data on hanging community extent and change over time are important because changes in extent may indicate a lack of water (e.g., dried up seep, presence of invasive species) or presence of other stressors. The presence of hanging gardens or lack thereof may give park staff an idea of other factors influencing hanging gardens other than permanent seeps.

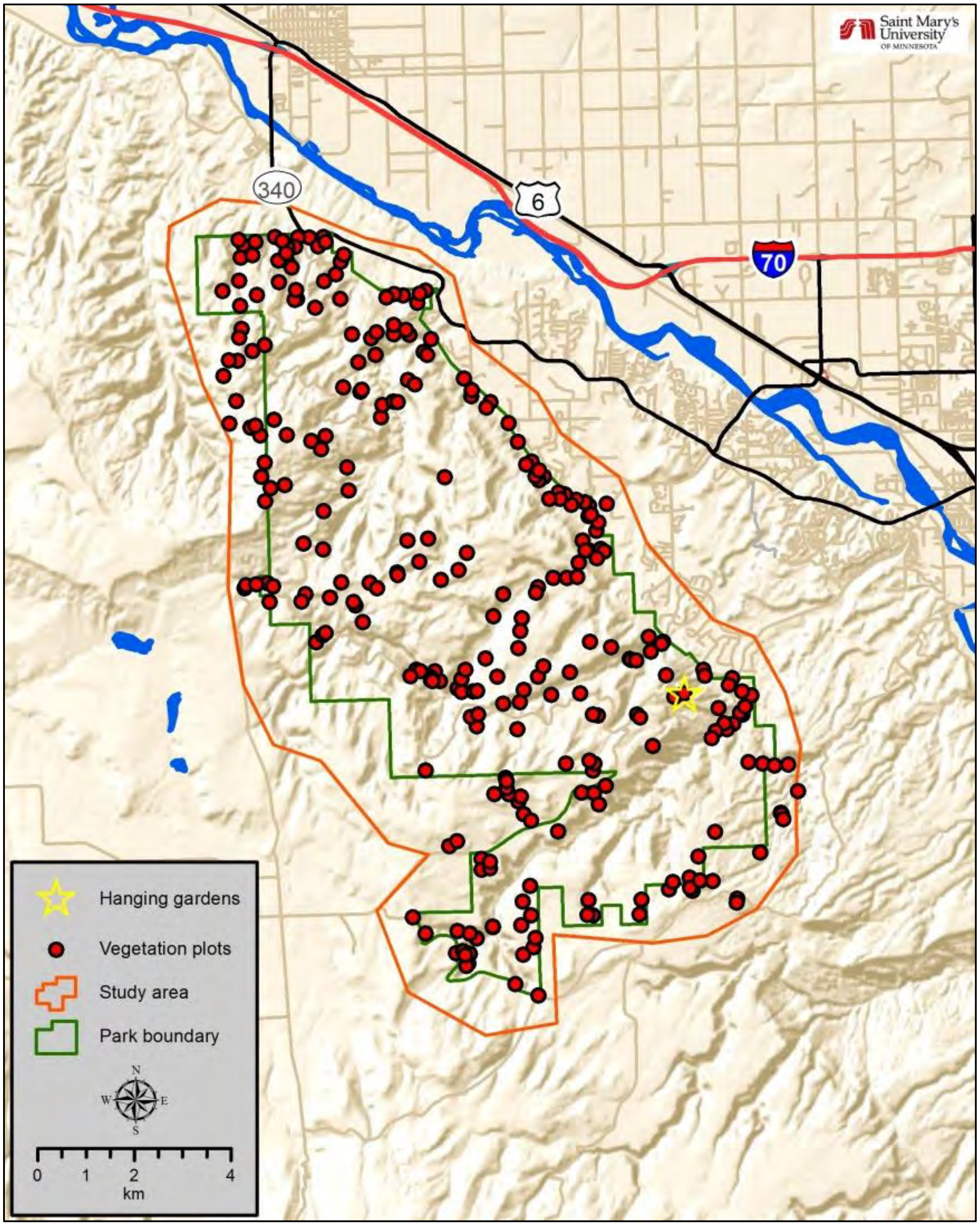

Figure 37. Plots sampled in COLM and on surrounding BLM land in 2003 (Von Loh et al. 2007).

Community Composition

Von Loh et al. (2007) documented one NVC plant association that has been known to occur in hanging gardens on COLM's canyon walls. That association was Mancos herbaceous vegetation. The vegetation cover in these hanging gardens ranged from 45% to 95%, which is considered moderately to densely vegetated. A total of 27 species were observed in the two hanging gardens sampled (Table 53) (Von Loh et al. 2007). Fourteen of those species were considered more abundant than the others.

Mancos columbine was the most abundant species recorded; contributing 3% to 35% of the vegetative cover (Von Loh et al. 2007). The two-needle pinyon was the most abundant tree sapling observed (Von Loh et al. 2007). All three tall shrub species documented were considered abundant. Longleaf brickellbush (*Brickellia longifolia*), fendlerbush (*Fendlera rupicola*), and oceanspray (*Holodiscus discolor* var. *dumosus*) were abundant short shrubs, and the non-native Kentucky bluegrass was the only abundant graminoid species (Von Loh et al. 2007). Other abundant forbs included Cainville thistle (*Cirsium arizonicum* var. *bipinnatum*) and brown-plume wire-lettuce (*Stephanomeria pauciflora*) (Von Loh et al. 2007).

Table 53. Plant species within the two COLM hanging gardens surveyed in 2003.

Scientific Name	Common Name	Strata
Juniperus osteosperma	Utah juniper	Tree canopy
Pinus edulis†	two-needle pinyon	Tree canopy
Populus deltoides ssp. wislizeni	Rio Grande cottonwood	Tree canopy
Amelanchier utahensis†	Utah serviceberry	Tall shrub
Cercocarpus ledifolius* var. *intricatus†	littleleaf mountain-mahogany	Tall shrub
Fraxinus anomala†	singleleaf ash	Tall shrub
Brickellia longifolia†	longleaf brickellbush	Short/dwarf shrubs
Ephedra viridis	Mormon tea	Short/dwarf shrubs
Ericameria nauseosa	rubber rabbitbrush	Short/dwarf shrubs
Fendlera rupicola†	fendlerbush	Short/dwarf shrubs
Holodiscus discolor* var. *dumosus†	oceanspray	Short/dwarf shrubs
Opuntia polyacantha	plains pricklypear	Short/dwarf shrubs
*Dactylis glomerata**	orchard grass	Graminoids
Muhlenbergia richardsonis	mat muhly	Graminoids
Poa pratensis*†	Kentucky bluegrass	Graminoids
Apocynum spp.	dogbane	Forbs
Aquilegia micrantha†	Mancos columbine	Forbs
Artemisia ludoviciana	Louisiana wormwood	Forbs
Castilleja scabrida	Eastwood's paintbrush	Forbs
Cirsium arizonicum* var. *bipinnatum†	Cainville thistle	Forbs
Galium coloradoense†	Colorado bedstraw	Forbs
Lepidium montanum	mountain pepperweed	Forbs
Solidago simplex	Mt. Albert goldenrod	Forbs
Stephanomeria pauciflora†	brown plume wire lettuce	Forbs
Toxicodendron rydbergii	western poison ivy	Forbs
Trifolium spp.	clover	Forbs
Clematis ligusticifolia	white virgin's bower	Liana

*Indicates a non-native species.

†Were the most abundant species (also in bold).

Threats and Stressor Factors

COLM staff identified several possible threats to the vegetation communities found on canyon walls and monoliths in the park. Those threats include invasive species, recreational climbing, climate change, proximity of the road to habitats, and graffiti. While the ecological impacts of graffiti or its extent in COLM have not been studied, its occurrence clearly degrades the natural character of the park's canyons and monoliths (Photo 10).Invasive species are a threat to the hanging garden plant communities in COLM. Von Loh et al. (2007) recorded two non-native species in the hanging gardens in the park: Orchard grass (*Dactylis glomerata*) and Kentucky bluegrass. Invasive species are a threat because they outcompete native species and can change the nutrient cycle (NPS 2015). According to KellerLynn (2006), the Fruita pipeline may have been a source of the spread of invasive species to the hanging gardens in the park. The pipeline is no longer in use, but it leaked water when it was in use, which resulted in artificial habitat for exotic species.

As mentioned in previous chapters, western Colorado is expected to experience an increase in temperature with longer and hotter summer heat waves, an increased potential for drought, and an increase in precipitation falling as very heavy events as a result of global climate change (Lamm et al. 2014, Melillo et al. 2014). Since canyon vegetation communities such as hanging gardens often rely on seeps that are recharged by precipitation, any shifts in climate could impact the water supply to these communities. Shifts in climate could also change erosion patterns (Peizhen et al. 2001), which have shaped and continue to influence COLM's canyon walls and monoliths

Photo 10. Graffiti on COLM's canyon walls (NPS photo).

Recreational climbing may also cause unneeded stress on the canyon wall vegetation and wildlife, including bats, birds, and raptors (Camp and Knight 1998). Approximately 300 climbing routes have been documented in COLM, with heavy use in areas such as Independence Monument, Lower Monument Slabs, and Liberty Cap Buttress (Zacher and Hertenstein 2014). Climbing activity may result in damage or removal of vegetation in the hanging gardens. Vegetation could be pulled from the hanging garden or crushed if the ledge were used as a foot- or handhold (Camp and Knight 1998). Rocks or soil could also be loosened by climbers, resulting in them falling on and/or covering the vegetation.

Data Needs/Gaps

There are no historic or current data on hanging garden community extent in COLM. This makes assessing the change in community extent impossible until a baseline study has been conducted. Von Loh et al. (2007) located a hanging garden community in the "wilderness area" of COLM, but it was difficult to assess the full extent and composition of these gardens in the park because of their inaccessible location. The Von Loh et al. (2007) mapping project is also 10 years old and cannot be considered current, but may be considered a baseline for future study. If a more accurate and safe method of studying hanging gardens is discovered in the future, it would aid park managers in documenting community composition and extent in COLM.

Overall Condition

Community Extent and Change over Time
The project team defined the *Significance Level* for community extent and change over time as a 2. There are no historic or current data for vegetation community extent on canyon walls and monoliths, so an assessment of change over time is not possible. Hanging gardens and their associated vegetation are of special concern to COLM because the park is located in an arid climate where water is a limited resource. Two hanging gardens were recorded during the Von Loh et al. (2007) assessment, but the complete community extent could not be determined due to difficult-to-reach and dangerous locations high on the canyon walls. As a result, a *Condition Level* could not be assigned for this measure.

Community Composition
The project team defined the *Significance Level* for community composition as a 3. Von Loh et al. (2007) documented plant community composition for two COLM hanging gardens in 2003. There were 27 species (trees, shrubs, graminoids, forbs, vines) observed at the two hanging gardens, with 14 species considered abundant. The vegetation cover in these hanging gardens ranged from 45% to 95%, which is considered moderately to densely vegetated. Although community composition was reported, only two gardens were analyzed. A complete community composition description for all hanging gardens in COLM could not be due to their hazardous locations. Therefore, a *Condition Level* was not assigned for this measure.

Weighted Condition Score
A *Weighted Condition Score* was not calculated for canyon walls and monolith vegetation in COLM due to a lack of historic and current community extent and composition data. Von Loh et al. (2007) documented community composition in the two observable hanging gardens in 2003; however, data from two hanging gardens may not accurately represent the community composition throughout the park.

Canyon Walls and Monolith Vegetation Communities			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Community Extent and Change over Time	2	n/a	
Community Composition	3	n/a	

4.6.6 Sources of Expertise

Dusty Perkins, Program Manager, Northern Colorado Plateau Network

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4.7 Montane Shrublands

4.7.1 Description

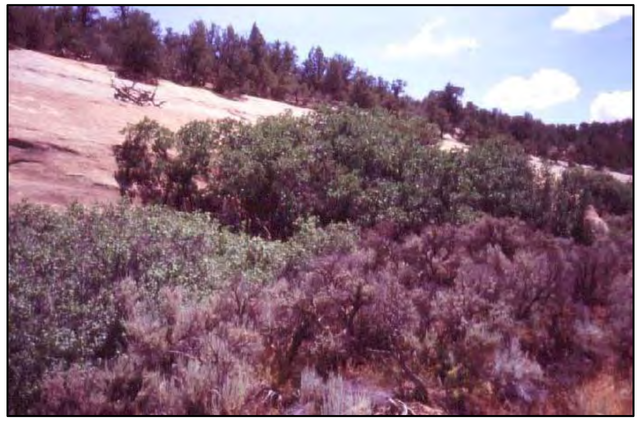

Photo 11. Gambel's oak/skunkbush shubland at COLM (Von Loh et al. 2007 Photo).

Montane shrublands are a transitional zone between grasslands and montane forest (Hanophy and Teitelbaum 2003). Pinyon-juniper woodlands or sagebrush shrublands border these montane shrublands at the lower limits of their elevation, while ponderosa pine can be found at the upper edge of their elevation (Vankat 2013). The montane shrublands association within COLM is comprised of the following plant communities: Gambel's oak/skunkbush sumac woodland, littleleaf mountain-mahogany/slickrock sparse vegetation, and Utah serviceberry shrubland. Common shrubs of these communities include Gambel's oak, true mountain-mahogany, and Utah serviceberry (Von Loh et al. 2007).

Gambel's oak/skunkbush sumac woodland communities within COLM can be found on moderately steep slopes (6-16%) between 1,814 and 1,948 m (5,951 and 6,391 ft) in elevation (Von Loh et al. 2007). Soils are generally sandy loam or loam (Von Loh et al. 2007). This community can be found on the colluvial slope and associated terrace in canyons, at the base of sandstone formations adjacent to small canyons, in canyon bottoms, midslopes in canyons, and on the upper slopes of canyons (Von Loh et al. 2007).

Littleleaf mountain-mahogany/slickrock sparse vegetation communities within COLM are found on gentle to steep slopes (6-60%) between 1,586 and 1,953 m (5203 and 6,407 ft) in elevation (Von Loh et al. 2007). Soils are generally sandy loam, silty clay, or clay loam (Von Loh et al. 2007). This community can be found on talus or rockfall slopes in canyons, upper slopes in canyons, midslopes of ravines, midslopes of ridges, ridgetops, and in alcoves.

Utah serviceberry shrubland communities within COLM can be found on moderately steep to steep slopes (16-76%) between 1,481 and 2,028 m (4,859 and 6,654 ft) in elevation (Von Loh et al. 2007). Soils are generally silt loam (Von Loh et al. 2007). This community type can be found on high slopes and midslopes of canyons or on areas of talus or rockfall (Von Loh et al. 2007).

Mice, chipmunks, ground squirrels, and other rodents are present in this ecosystem due to the abundance of seeds, acorns, and berries (Hanophy and Teitelbaum 2003). Desert cottontails, mule deer, elk, raccoons, and black bears (*Ursus americanus*) can also be found foraging in these areas (Axelson 2002, Hanophy and Teitelbaum 2003). Gray fox, red fox (*Vulpes vulpes*), bobcats (*Lynx rufus*), skunks, long-tailed weasels (*Mustela frenata*), and coyotes actively hunt rodents and reptiles in this ecosystem, while mountain lion pursue deer (Hanophy and Teitelbaum 2003). Reptiles within montane shrublands include midget faded rattlesnakes (*Crotalus oreganus concolor*), bullsnakes (*Pituophis catenifer*), eastern fence lizards (*Sceloporus undulatus*), side-blotched lizards, and plateau striped whiptails (*Aspidoscelis velox*). Birds of montane shrublands include golden eagles, Swainson's hawks (*Buteo swainsoni*), red-tailed hawks, sharp-shinned hawks (*Accipiter striatus*), western scrub jays, lazuli buntings (*Passerina amoena*), western tanagers (*Piranga ludoviciana*), black-headed grosbeaks (*Pheucticus melanocephalus*), spotted towhees (*Pipilo maculatus*), dusky flycatchers (*Empidonax oberholseri*), and wild turkeys (*Meleagris gallopavo*) (Hanophy and Teitelbaum 2003).

4.7.2 Measures

- Community extent and change over time
- Community composition
- Trends in invasive infestation
- Soil stability
- Percent cover biological soil crusts
- Percent bare ground

4.7.3 Reference Conditions/Values

An ideal reference condition for the montane shrublands of COLM would use the natural variability of the current community. However, not enough information is available regarding the range of variability for the selected measures to determine clear reference conditions at this time. Conditions will be assessed based on best professional judgment given the available data.

4.7.4 Data and Methods

A checklist of vascular plants was developed by Weber et al. (1982), documenting 66 families, 250 genera, and 450 species within COLM and adjacent Mesa County. A number of other collectors, researchers, and specialists also documented new plant species in COLM during this time (Hogan et al. 2009).

Abbey (c. 1985) developed a vegetation map of COLM consisting of 24 classes. The Colorado Natural Heritage Program completed an inventory for Mesa County in 1996, documenting the locations of 14 state sensitive plant species within COLM (Lyon et al. 1996). The NCPN funded a park-wide invasive plant inventory and mapping project in 2003 (Dewey and Anderson 2005). The NCPN reviewed the checklist of vascular plants developed by Weber et al. (1982) in 2005, and updated the vascular plant list to include 58 families and 351 species (Von Loh et al. 2007).

A vegetation mapping project conducted by the Von Loh et al. (2007) shows the locations of all dominant vegetation types present in COLM in the early 2000s. The methodology for this project included vegetation classification and attribute development based on the NVC, field reconnaissance and mapping, and development of a spatial database. The study area for the project included COLM, plus an additional area beyond the park border. Mapping was completed using both traditional photo interpretation and biophysical modeling. This allowed for consistent and accurate mapping in a cost effective manner. The project resulted in vegetation data and maps for COLM and its immediate vicinity.

Hogan et al. (2009) developed a comprehensive list of plant species found within the park. This effort involved reviewing existing literature and re-examining specimens in the COLM herbarium. It also included field work to confirm unverified species and to potentially locate new species. This list includes plants by habitat type, one of which is sage shrub, which includes plants from "woodlands dominated by Gambel's oak and other montane shrubs".

Invasive species monitoring and mapping has occurred within COLM since 2003 (Dewey and Anderson 2005). The most recent inventory was completed in 2014 (Perkins 2014). This inventory was based on a list of priority IEPs that had been developed by the staff at COLM and the NCPN (Perkins 2014). A MDTS of 40 m^2 (431 ft^2 or approximately 20 x 20 ft) was established for use in the ongoing monitoring program. Monitoring routes and quadrats were established along the roads, major drainages, and trails in the park. In addition to invasive species composition, information was also collected on additional attributes, including size and canopy.

4.7.5 Current Condition and Trend

Community Extent and Change over Time

Von Loh et al. (2007) represent the most recent estimate of the extent of montane shrublands at COLM. Data from this vegetation mapping projects show that montane shrublands comprise 579 ha (1,431 ac), or 7% of the COLM landscape (Table 54, Figure 38). Gambel's oak/skunkbush sumac woodland communities within COLM can be found at the head of Ute Canyon and its associated drainages on the mesa tops and at the head of No Thoroughfare Canyon (Von Loh et al. 2007). Littleleaf mountain-mahogany/slickrock sparse vegetation communities of COLM can be found in Fruita Canyon, Ute Canyon, above Kodels Canyon, Monument Canyon near Kissing Couple, near the Highland View overlook on Rimrock Drive, near the Artist's Point overlook on Rimrock Drive, and along Liberty Cap Trail, No Thoroughfare Canyon, and Wedding Canyon (Von Loh et al. 2007). Utah serviceberry shrubland communities of COLM can be found in Kodels, Gold Star, and No Thoroughfare Canyon. Because this community is present on steep slopes, it is more widespread than sampling indicates (Von Loh et al. 2007).

Table 54. Areal extent of montane shrubland alliances found in COLM (Von Loh et al. 2007).

		Percentage	
Alliances	**Area ha (ac)**	**Montane shrublands**	**Total vegetation**
Gambel's oak/skunkbush woodland	51.3 (20.8)	3.6%	0.3%
Littleleaf mountain-mahogany/slickrock sparse vegetation	93.2 (37.7)	6.5%	0.5%
Utah serviceberry shrubland	1,286.4 (520.6)	89.9%	6.3%
Montane shrublands total	**1,430.9 (579.1)**	**100%**	**7.0%**
Park total	**20,450 (8,275.8)**		

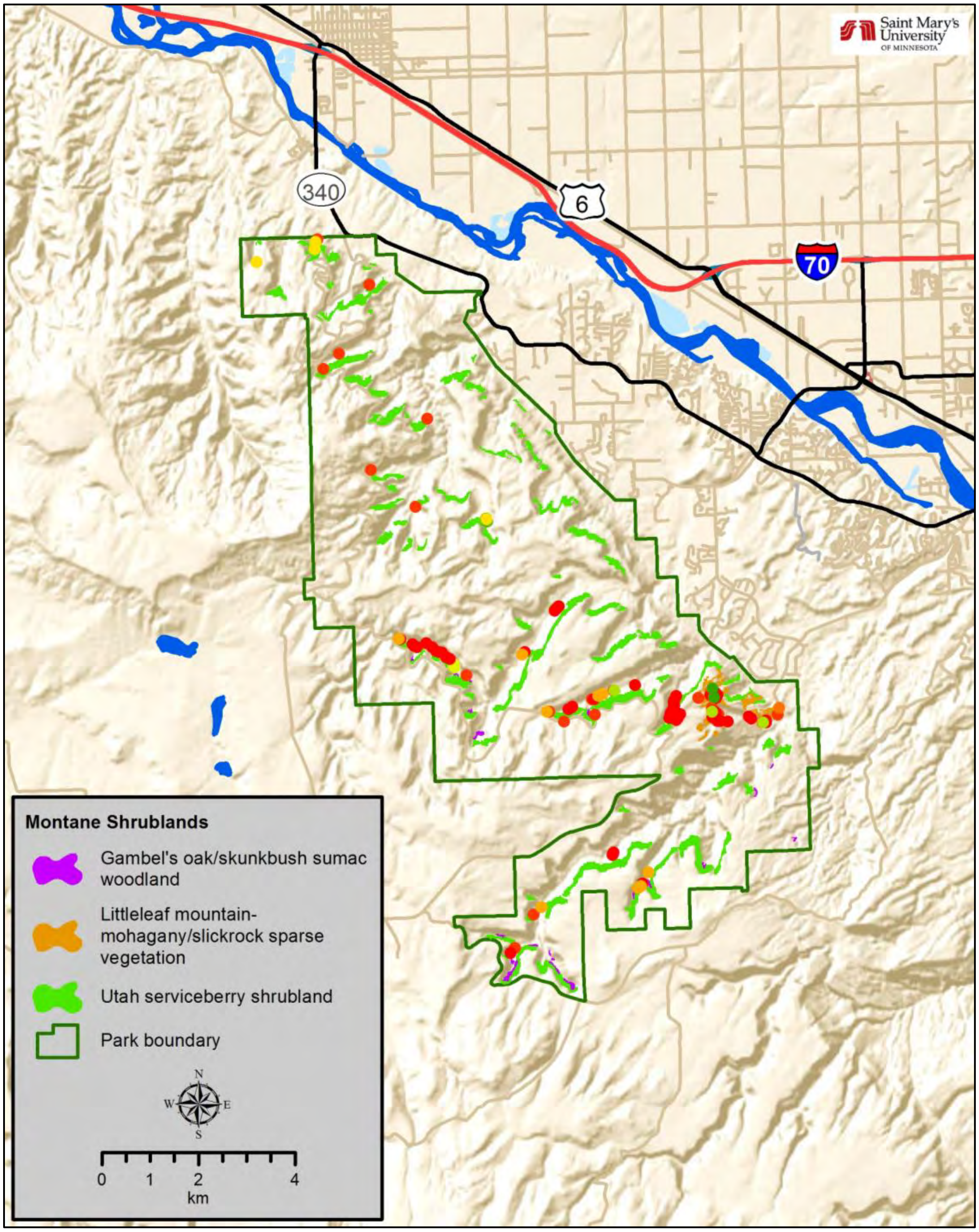

Figure 38. Montane shrubland locations within COLM (Voh Loh et al. 2007).

Community Composition

A comprehensive plant species list was developed by Hogan et al. (2009). A total of 136 plant species were classified as either "present" or "reported" in montane shrubland communities (Appendix I). Species were considered "present" if a confirmed specimen or observation has been made since 1970. Species are considered "reported" if they have been listed in existing literature (Hogan et al. 2009). This total was comprised of six trees, 25 shrubs, 70 perennial forbs, 14 annual forbs, 15 perennial graminoids, two annual graminoids, and four ferns and allies (Hogan et al. 2009). Of these plants, seven (5.2%) are introduced, while the remaining 129 (95%) are native (NPS 2015).

The Gambel's oak/skunkbush woodland communities are characterized by a closed tree canopy of Gambel's oak, typically 2 to 10 m (7 to 33 ft) tall (Von Loh et al. 2007). Utah juniper and two-needle pinyon may also provide some canopy cover in these stands. (Von Loh et al. 2007) The shrub layer in these stands is diverse, and includes plants such as skunkbush sumac, Utah serviceberry, basin big sagebrush, true mountain-mahogany, rubber rabbitbrush, and western chokecherry (Von Loh et al. 2007). Short and dwarf shrubs in this community include Wyoming big sagebrush, rubber rabbitbrush, Gambel's oak, western snowberry (*Symphoricarpos occidentalis*), Oregon grape, and plains pricklypear (Von Loh et al. 2007). The herbaceous layer includes graminoids such as Indian ricegrass, crested wheatgrass, slender wheatgrass (*Elymus trachycaulus*), cheatgrass, squirreltail, littleseed ricegrass (*Piptatherum micranthum*), and muttongrass and forbs such as tarragon, lambsquarters, bastard toadflax, western tansymustard, hairy false goldenaster, littleleaf alumroot (*Heuchera parvifolia*), prairie pepperwort, mountain pepperweed, starry false Solomon's-seal, sleepy catchfly, tumble mustard, long-beak fiddle-mustard, and American vetch (*Vicia americana*) (Von Loh et al. 2007). The liana white virgin's bower (*Clematis ligusticifolia*) was found in one stand (Von Loh et al. 2007). The most abundant species within this community by stratum can be found in Table 55.

Table 55. Dominant plant species (by strata) within the Gambel's oak/skunkbush sumac woodlands of COLM (Von Loh et al. 2007).

Gambel's oak/skunkbush woodland		
Scientific Name	**Common Name**	**Strata**
Quercus gambelii	Gambel's oak	Tree canopy
Artemisia tridentata ssp. *tridentata*	basin big sagebrush	Tall shrub/sapling
Prunus virginiana	western chokecherry	Tall shrub/sapling
Quercus gambelii	Gambel's oak	Tall shrub/sapling
Rhus aromatica var. *pilosissima*	skunkbush sumac	Tall shrub/sapling
Rosa woodsii	Woods' rose	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Berberis repens	Oregon grape	Herb
*Bromus tectorum**	cheatgrass	Herb
Elymus trachycaulus	slender wheatgrass	Herb
Maianthemum stellatum	starry false Solomon's-seal	Herb
Piptatherum micranthum	littleseed ricegrass	Herb
Poa fendleriana	muttongrass	Herb

*Indicates a non-native species.

The littleleaf mountain-mahogany/slickrock sparse vegetation communities are characterized by a tall shrub canopy of Utah serviceberry and true mountain-mahogany, typically 2 to 10 m (7 to 33 ft) tall (Von Loh et al. 2007). A sparse canopy layer in these communities includes singleleaf ash, Utah juniper, and two-needle pinyon (Von Loh et al. 2007). The shrub layer is sparse and diverse, including plants such as basin big sagebrush, Bigelow's sagebrush, white sagebrush (*Artemisia ludoviciana* ssp. *albula*), Wyoming big sagebrush, Mormon tea, rubber rabbitbrush, skunkbush sumac, littleleaf brickellbush, yellow rabbitbrush, rimrock wild buckwheat (*Eriogonum corymbosum* var. *orbiculatum*), and broom snakeweed, and the succulents plains pricklypear, Whipple's fishhook cactus, and Harriman's yucca (Von Loh et al. 2007). The herbaceous layer typically accounts for less than 5% cover and includes graminoids such as Indian ricegrass, cheatgrass, squirreltail, six weeks fescue, needle and thread saline wildrye, muttongrass, and bluebunch wheatgrass (*Pseudoroegneria spicata*) and forbs such as Fendler's sandwort, hoary dusty-maiden, ridge-seeded spurge, plateau yellow cryptanth (*Cryptantha flava*), western tansymustard, dwarf draba, Colorado bedstraw (*Galium coloradoense*), hairy false goldenaster, mountain pepperweed, grassy rockgoldenrod, longleaf phlox, sharpleaf twinpod (*Physaria acutifolia*), western groundsel, sleepy catchfly, scarlet globemallow, desert princesplume, and long-beak fiddle-mustard (Von Loh et al. 2007). The most abundant species within this community by stratum can be found in Table 56.

Table 56. Dominant plant species (by strata) within the littleleaf mountain-mahogany/slickrock sparse vegetation community of COLM (Von Loh et al. 2007).

Littleleaf mountain-mahogany/slickrock sparse vegetation		
Scientific Name	**Common Name**	**Strata**
Fraxinus anomala	singleleaf ash	Tree canopy
Juniperus osteosperma	Utah juniper	Tree canopy
Pinus edulis	two-needle pinyon	Tree canopy
Amelanchier utahensis	Utah serviceberry	Tall shrub/sapling
Cercocarpus montanus	true mountain-mahogany	Tall shrub/sapling
Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush	Short shrub/sapling
Ephedra viridis	Mormon tea	Short shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
Artemisia bigelovii	Bigelow's sagebrush	Herb
*Bromus tectorum**	cheatgrass	Herb
Chaenactis douglasii	hoary dusty-maiden	Herb
Galium coloradoense	Colorado bedstraw	Herb
Leymus salina	saline wildrye	Herb
Poa fendleriana	muttongrass	Herb
Pseudoroegneria spicata	bluebunch wheatgrass	Herb

*Indicates a non-native species.

The Utah serviceberry shrubland communities are characterized by Utah serviceberry shrubs, typically 2 to 5 m (7 to 16 ft) tall. (Von Loh et al. 2007) Two-needle pinyon and Utah juniper provide some canopy cover in these communities. (Von Loh et al. 2007)The shrub layer is sparse and consists of the tall shrub singleleaf ash and the short shrubs; Wyoming big sagebrush, yellow rabbitbrush, Mormon tea, and skunkbush sumac, and the dwarf shrubs; white sagebrush, broom snakeweed, prickly phlox, and plains pricklypear (Von Loh et al. 2007). The herbaceous layer is typically sparse and includes graminoids such as Indian ricegrass, purple three-awn, cheatgrass, six weeks fescue, needle and thread, saline wildrye, James' galleta, and muttongrass and forbs such as pallid milkweed, Eastwood's paintbrush (*Castilleja scabrida*), sulfur wild buckwheat (*Eriogonum umbellatum*), common hyalineherb (*Hymenopappus filifolius*), mountain pepperweed, Colorado four o'clock (*Mirabilis multiflora*), and sharpleaf twinpod (Von Loh et al. 2007). The most abundant species within this community by stratum can be found in Table 57.

Table 57. Dominant plant species (by strata) within the Utah serviceberry shrubland of COLM (Von Loh et al. 2007).

Littleleaf mountain-mahogany/slickrock sparse vegetation		
Scientific Name	**Common Name**	**Strata**
Amelanchier utahensis	Utah serviceberry	Tall shrub/sapling
Achnatherum hymenoides	Indian ricegrass	Herb
*Bromus tectorum**	cheatgrass	Herb
Hymenopappus filifolius	common hyalineherb	Herb

*Indicates a non-native species.

Trends in Invasive Infestation

COLM is part of a long-term monitoring program for IEPs developed by the NCPN which focuses on early detection (Perkins 2014). The first survey of IEPs in the park was conducted in 2003 by Dewey and Anderson (2005). The latest monitoring was conducted during the 2013 field season (Perkins 2014) and will be used to assess this measure, since it includes the previously collected data on IEP infestations in COLM. A full discussion of IEPs park-wide, including a discussion of trends can be found in Chapter 2.2.2. In summary, during this 8-year time span (2003-2011), there was an overall decrease in Russian olive, tamarisk and woolly mullein (Perkins 2014). However, the number of field bindweed infestations more than doubled during this same period (Perkins 2014).

In the most recent survey, conducted in 2013, a total of 462 IEP infestation points were identified within the park (Perkins 2014). The most frequently documented species of IEP were yellow sweetclover and cheatgrass. Several IEP species were documented as present in the descriptions of the vegetation associations by Von Loh et al. (2007). Von Loh et al. (2007) identified cheatgrass as one of the dominant herbaceous species in all three associations used to describe montane shrublands in this assessment; the Gambel's oak/skunkbush sumac woodland, the littleleaf mountain-mahogany/slickrock sparse vegetation, and the Utah serviceberry shrubland.

Trends in invasive plants have not been assessed specifically by vegetation association at COLM. To identify invasive species infestations associated with montane shrublands, spatial queries were performed using the data from the 2013 IEP survey and the montane shrubland communities mapped by Von Loh et al. (2007). The spatial queries selected IEP points that were either within a mapped location of a montane shrubland or within 100 m (328 ft) of one of these communities.

The analysis identified 118 (approximately 26%) of the IEP points met the criteria (Figure 39, Table 58). The most common IEP's selected by these queries were yellow sweetclover (57) and cheatgrass

(26). Nearly all of the occurrences of yellow sweetclover, and all but one of the cheatgrass occurrences were within 100 m (328 ft) of a mapped montane shrubland (Table 58). Overall, nearly 90% of the IEP occurrences selected by the spatial queries met the proximity criterion (within 100 m [328 ft]). The results for all IEP occurrences that satisfied the spatial queries can be found Table 58.

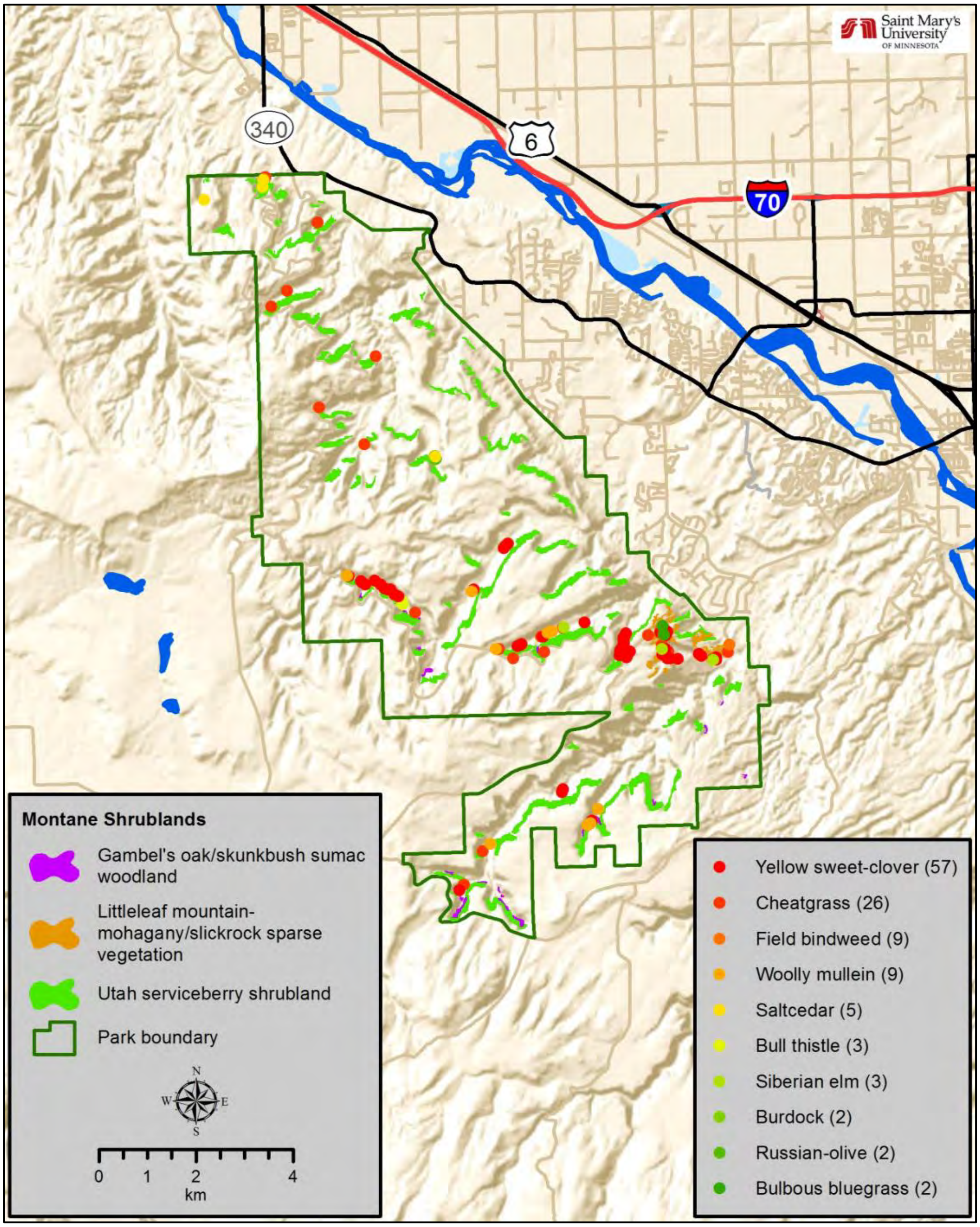

Figure 39. IEP infestations associated with mapped montane shrublands.

Table 58. Number and location of non-native species occurrences in relation to montane shrubland.

Scientific Name	Common Name	Number Within	Number Adjacent	Total Number
Melilotus officinalis	yellow sweetclover	6	51	57
Bromus tectorum	cheatgrass	1	25	26
Convolvulus arvensis	field bindweed	1	8	9
Verbascum thapsus	woolly mullein	1	8	9
Tamarix ramosissima	saltcedar	2	3	5
Cirsium vulgare	bull thistle		3	3
Ulmus pumila	Siberian elm	1	2	3
Arctium minus	burdock		2	2
Elaeagnus angustifolia	Russian olive		2	2
Poa bulbosa	bulbous bluegrass	1	1	2
	Totals	**13**	**105**	**118**

Yellow sweetclover and cheatgrass accounted for 70% of the infestations that occurred within or in close proximity to montane shrublands. These two species are also the most widespread IEPs in COLM (Perkins 2014). Yellow sweetclover had not been detected in previous years, primarily as it was not part of the priority species list until 2011 (Perkins 2014).

Soil Stability

Soil stability depends on a number of factors. The presence of cryptobiotic crusts, litter/duff, other non-vegetative ground cover, slope, soil composition, and soil texture are some of the factors that can influence soil stability (NRCS 1996, Belnap et al. 2008, Witwicki et al. 2013). Vegetative conditions also greatly influence soil stability (Whisenant 1985). Soil loss can be influenced by rainfall intensity, size and frequency of bare areas, soil type, topography, and plant cover, especially following a fire. Vegetation and slope are the best determinants of soil erosion in severe rainfall storms. Studies in various plant communities show that 60-70% vegetation cover appears necessary to ensure soil stability against erosion during rainfall (Orr 1970, Whisenant 1985). Specific data on soil stability within COLM were not available; therefore a condition assessment of this measure is not possible.

Percent Cover Biological Soil Crusts

Belnap et al. (2008, p. 1,257) defines BSCs as “intertwined communities of lichens, mosses, and cyanobacteria commonly found on soil surfaces in dryland regions”. These communities are a very important part of the ecosystem because of their influence on local hydrology, soil stability and fertility, and overall biodiversity (Belnap et al. 2008). BSCs aggregate soil particles, making the soil stronger and less susceptible to erosional forces of wind and water, thereby retaining nutrients, organic matter, and seeds in the underlying soils (Miller 2005). BSCs within COLM are most commonly found on sites that are protected from disturbance and are re-developing in areas that were once grazed or otherwise disturbed (Von Loh et al. 2007). Because of the ecological benefits provided by BSCs, they should be included in ecological monitoring programs where present

(Belnap et al. 2008). Cover of BSCs within littleleaf mountain-mahogany/slickrock sparse vegetation communities is sparse, rarely reaching 5% cover (Von Loh et al. 2007). Data on percent cover of cryptobiotic crusts and soils for the Gambel's oak/skunkbush sumac woodland and Utah serviceberry shrubland communities are not available. Due to lack of available data, a condition assessment is not possible for this measure.

Percent Bare Ground

Percent bare ground is important because it can impact soil stability, as vegetation helps prevent wind erosion (Witwicki et al. 2013). Refer to the percent bare ground measure of the sagebrush shrublands/shrub steppe component (Chapter 4.2.5) for more information regarding the importance of percent bare ground.

Percent bare ground of montane shrublands varies with community type. In the Gambel's oak/skunkbush sumac woodland communities, total vegetation canopy cover ranges from 67 to 106% with high ground cover of litter in the form of oak mast in unvegetated areas (Von Loh et al. 2007). Littleleaf mountain-mahogany/slickrock sparse vegetation communities have total vegetation canopy cover that ranges from 10 to 50% with low to moderate ground cover of litter and low to high ground cover of bedrock, large rocks, small rocks, and bare soil in unvegetated areas (Von Loh et al. 2007). In Utah serviceberry shrubland communities, total vegetation canopy cover ranges from 17 to 27% with high ground cover of bedrock, large rocks, small rocks, and bare soil in unvegetated areas (Von Loh et al. 2007).

Threats and Stressor Factors

NPS staff identified several potential threats and stressors to the montane shrubland community: IEPs (particularly cheat grass and crested wheatgrass), unnatural fire regimes, drought, and regional climate variation. Refer to the threats and stressor factors section of the sagebrush shrublands/shrub steppe component for more detailed discussions regarding the IEPs, drought, and regional climate variation at COLM.

Fire can affect an ecosystem by altering the vegetation composition and structure and eliminating fire intolerant plant species (Miller 2005). Montane shrublands are highly susceptible to fire due to their high density and tall shrubs (Witwicki et al. 2013). After a fire kills the above ground portions of Gambel's oak and serviceberry, these plants resprout prolifically through roots, rhizomes, and lignotubers (Floyd et al. 2000). Mountain mahogany may resprout or reestablish by seed after being killed by a fire. Because of their dense structure, leaf litter, and the continuous fuel of grasses and forbs in between shrubs, many stands of Gambel's oak shrubland are highly flammable (Floyd et al. 2000). Brown (1958) suggests that dense stands of Gambel's oak occurring on steep slopes may be due to the tendency for fire to spread over larger areas and burn more thoroughly on steep slopes than on level ground, causing a more widespread resprouting.

Visitor impacts within the park's montane shrubland habitats include damage to BSC present within these environments. Hikers, particularly those using unauthorized "social" trails, cause damage to these fragile habitats and continued disturbance does not allow for the time needed for BSCs to regenerate. This can lead to invasive species encroaching and potentially replacing BSC habitats.

Data Needs/Gaps

Though data exist within COLM for the community extent and change over time and percent bare ground measures, a reference condition is necessary for these measures to determine whether or not the collected data are unusual for these communities. Data for soil stability were not available for COLM. Witwicki et al. (2013) briefly touch on this topic but only discuss monitoring protocol, no actual data are presented. Data for each community type for percent cover of BSCs as well as a reference condition are needed in order to accurately assess the condition for this measure. Research on the impacts from the proliferation of social trails within the park is also recommended.

Currently a guaranteed funding source for the invasive species removal/control has not been identified. Failure to secure funding for this management action will result in the loss of the gains that have been made in eradicating IEPs within the park. Additionally, another programmatic need for COLM is a trail management plan. Currently, visitors face no restrictions in their access to any areas within the park.

Overall Condition

Community Extent and Change over Time

This measure was assigned a *Significance Level* of 3. Though the community extent of montane shrublands has been documented in the vegetation mapping project (Von Loh et al. 2007), data for land cover change analysis were not available. Since land cover change analysis could not be done, a *Condition Level* was not assigned to this measure.

Community Composition

The community composition measure was assigned a *Significance Level* of 3. According to Hogan et al. (2009), a total of 136 plant species are present in the montane shrublands of COLM. Of these plant species, 95% are native. With relatively high species richness and nativity, the *Condition Level* assigned to this measure is 1, indicating low concern.

Trends in Invasive Infestation

A *Significance Level* of 3 was assigned to this measure. Invasive species are one of the greatest threats to biodiversity in the U.S. (Wilcove et al. 1998). Invasive exotic plant surveys performed by Perkins (2010, 2012) indicate many different species of IEPs occurring within COLM. Analysis conducted for this assessment showed that many of these IEPs occur within the 100 m (328 ft) of montane shrublands of COLM, the most common of which are yellow sweetclover and cheatgrass. Based on the number of infestations, most IEP occurrence remained relatively constant from year to year. Over the last decade the park has focused control efforts on eradication of IEP's. Future funding for these control measures is not available, so the potential for increased infestations is high (Hartwig, written communication 18 November 2015). Because cheatgrass makes up such a large portion of the total IEPs, a *Condition Level* of 2 was assigned for this measure.

Soil Stability

A *Significance Level* of 2 was assigned to the soil stability measure. Specific data on soil stability within the sagebrush shrublands/shrub steppe of COLM were not available. Many variables that may contribute to soil stability are outlined throughout the document, though these often contain a range of values, making it difficult to accurately determine the soil stability within COLM. A *Condition* Level was not assigned to this measure because specific data on soil stability are not available.

Percent Cover Biological Soil Crusts
This measure was assigned a *Significance Level* of 3. Data for this measure only exist for one of the three montane shrubland community types. Data for the remaining community types are needed to accurately assess the condition for this measure. A *Condition Level* was not assigned to this measure due to lack of available data.

Percent Bare Ground
The percent bare ground measure was assigned a *Significance Level* of 2. Percent bare ground varies with community type. Where vegetation is absent, cover of litter, rocks, and bare soil vary from low to high. Although some data exist for the percent bare ground measure, a reference condition is needed to determine the current overall condition of the measure. Because a reference condition is not available, this measure was not assigned a *Condition Level*.

Weighted Condition Score
A *Weighted Condition Score* was not calculated for this component because *Condition Levels* could not be assigned to greater than 50% of the measures due to lack of available data. The condition of montane shrublands in COLM will remain unknown until more data are available for the selected measures.

Montane Shrublands			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Community Extent and Change over Time	3	n/a	
Community Composition	3	1	
Trends in Invasive Infestation	3	2	
Soil Stability	2	n/a	
Percent Cover Biological Soil Crusts	3	n/a	
Percent Bare Ground	2	n/a	

4.7.6 Sources of Expertise
Dusty Perkins, Program Manager, Northern Colorado Plateau Network

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4.8 Herptiles

4.8.1 Description

Herptiles include two ectothermic vertebrate groups: reptiles and amphibians. Amphibians require water for a portion of their lifecycle and are considered a high priority Vital Sign for monitoring at COLM (O'Dell et al. 2005). A total of 22 native herptile species (five amphibians and 17 reptiles) occur within COLM's boundaries, with two additional species that likely occur but are currently unconfirmed (NPS 2014). Common species include the red-spotted toad, whiptails (*Aspidoscelis* spp.), and the eastern collared lizard (Photo 12) (NPS 2014). Despite limited water resources, COLM offers a variety of habitats that support herpetofauna, from canyon bottoms to the mesa tops.

Photo 12. The eastern collared lizard is one of several lizard species that inhabit the park (NPS Photo by Lynne Mager).

Riparian corridors line ephemeral washes that are interspersed throughout the canyon bottoms and alcoves and are fed by seeps and springs which provides a somewhat mesic environment (Von Loh et al. 2007). This is often where herptiles have been spotted, as these habitats provide shelter from the semi-arid desert climate (Platenberg and Graham 2003). The mesa tops are pocked with natural potholes (solution pits or tinajas) that hold water after rain events and collect wind-blown dust (NPS 2015). Natural potholes and riparian habitats are important land features relied on by herpetofauna as well as insects for breeding and survival through the juvenile/larval stages (NPS 2015).

4.8.2 Measures

- Amphibian richness
- Amphibian abundance
- Amphibian distribution
- Reptile richness
- Reptile abundance
- Reptile distribution

4.8.3 Reference Conditions/Values

The reference condition for herptiles at COLM is based on the herpetofauna inventory survey conducted in 2002 (Platenberg and Graham 2003); this survey had an estimated inventory completeness of 52% for the park. There are no other published surveys or studies on reptiles or amphibians in COLM since Platenberg and Graham (2003), and there are no data indicative of herptile richness, abundance, or distribution prior to the inventory.

4.8.4 Data and Methods

Platenberg and Graham (2003) inventoried COLM herpetofauna in 2002 from 21-24 June and again from 7-9 August. The primary goal of the survey effort was to obtain 90% documentation of species present as a baseline inventory for the NCPN units; determining general abundance and distribution was a secondary goal. General visual encounter surveys (VES) with a global positioning system (GPS) device comprised the bulk of survey efforts at COLM; some night driving, nighttime VES, and habitat/time/area constrained searches (TACS) were also conducted. The inventory also included data mining efforts for documentation of species not observed during field work to revise and update the NPS master species lists for all NCPN parks.

From March to early September of 2011, Board (2011) recorded weekly observations of amphibian species at a known breeding location in No Thoroughfare Canyon. The main site was a small seasonal “plunge pool” 1.9 km (1.2 mi) from the trailhead near Grand Junction. Board (2011) documented water level and temperature, along with the amphibian species present (calls and visual observations, calling activity, evidence of reproduction (e.g., eggs and tadpoles).

Lamm et al. (2014) conducted an inventory of COLM seeps and springs from May to July 2014. Thirty-eight seep- and spring-associated sites were visited during this period. This number does not represent the total number of seeps and springs within the park (Lamm, written communication 27 November 2015). Data collected at each site included estimated discharge (i.e., flow), flora and fauna observations, and when sufficient amounts of water were available for testing selected water quality parameters (temperature and specific conductance) were collected. Lamm et al. (2014) found amphibians at 15 of the sites surveyed, although most of the sightings were tadpoles. The majority of amphibian sightings occurred in Monument Canyon (Lamm et al. 2014).

4.8.5 Current Condition and Trend

<u>Amphibian Richness</u>

Platenberg and Graham (2003) listed two amphibian species that were confirmed during the herpetofauna inventory in 2002: Woodhouse’s toad (*Anaxyrus woodhousii*) and Great Basin spadefoot (*Spea intermontana*). Table 59 lists the five amphibian species documented at COLM and one unconfirmed species, according to NPS (2014). Board (2011) identified four amphibian species at a No Thoroughfare Canyon pool in 2011. During the 2014 seeps and springs survey, Lamm et al. (2014) observed five species of amphibians (including tadpoles and frogs eggs). A sighting of the northern leopard frog, a species of “special concern” in the state of Colorado, was reported by Board (2011) at the site in the summer of 2010 after a flooding event. Lamm et al. (2014) reported two sightings of the northern leopard frog, one each in Echo and Ute Canyon.

<u>Amphibian Abundance</u>

There are no detailed abundance data for amphibians at this time. There are general abundance descriptions provided in the NPS species list for COLM (Table 60).

Table 59. Amphibian species known to occur or unconfirmed at COLM (NPS 2014).

Scientific Name	Common Name	NPS (2014)	Board (2011)	Lamm et al. (2014)
Ambystoma tigrinum	eastern tiger salamander	X		
Anaxyrus punctatus	red-spotted toad	X	X	X
Anaxyrus woodhousii	Woodhouse's toad	X	X	X
Hyla arenicolor	canyon treefrog	U	X	
Lithobates pipiens	northern leopard frog	X		X
Spea intermontana	Great Basin spadefoot	X	X	

U = unconfirmed

Table 60. Amphibians included in the NPS species list with abundance column (NPS 2014).

Scientific Name	Common Name	Abundance
Ambystoma tigrinum	eastern tiger salamander	Rare
Anaxyrus punctatus	red-spotted toad	Common
Anaxyrus woodhousii	Woodhouse's toad	Uncommon
Lithobates pipiens	northern leopard frog	Unknown
Spea intermontana	Great Basin spadefoot	Uncommon

Amphibian Distribution

Amphibians within COLM utilize areas with available water and vegetation cover. Distribution of amphibians generally follows these riparian habitats located throughout the canyon bottoms of COLM. Platenberg and Graham (2003) used GIS to record the locations where amphibians were observed during the herpetofauna inventory survey effort in 2002 (Figure 40). Board (2011) confirmed the presence of four amphibian species in No Thoroughfare Canyon in 2011. Lamm et al. (2014) also reported amphibians Monument, Ute, and Echo Canyons.

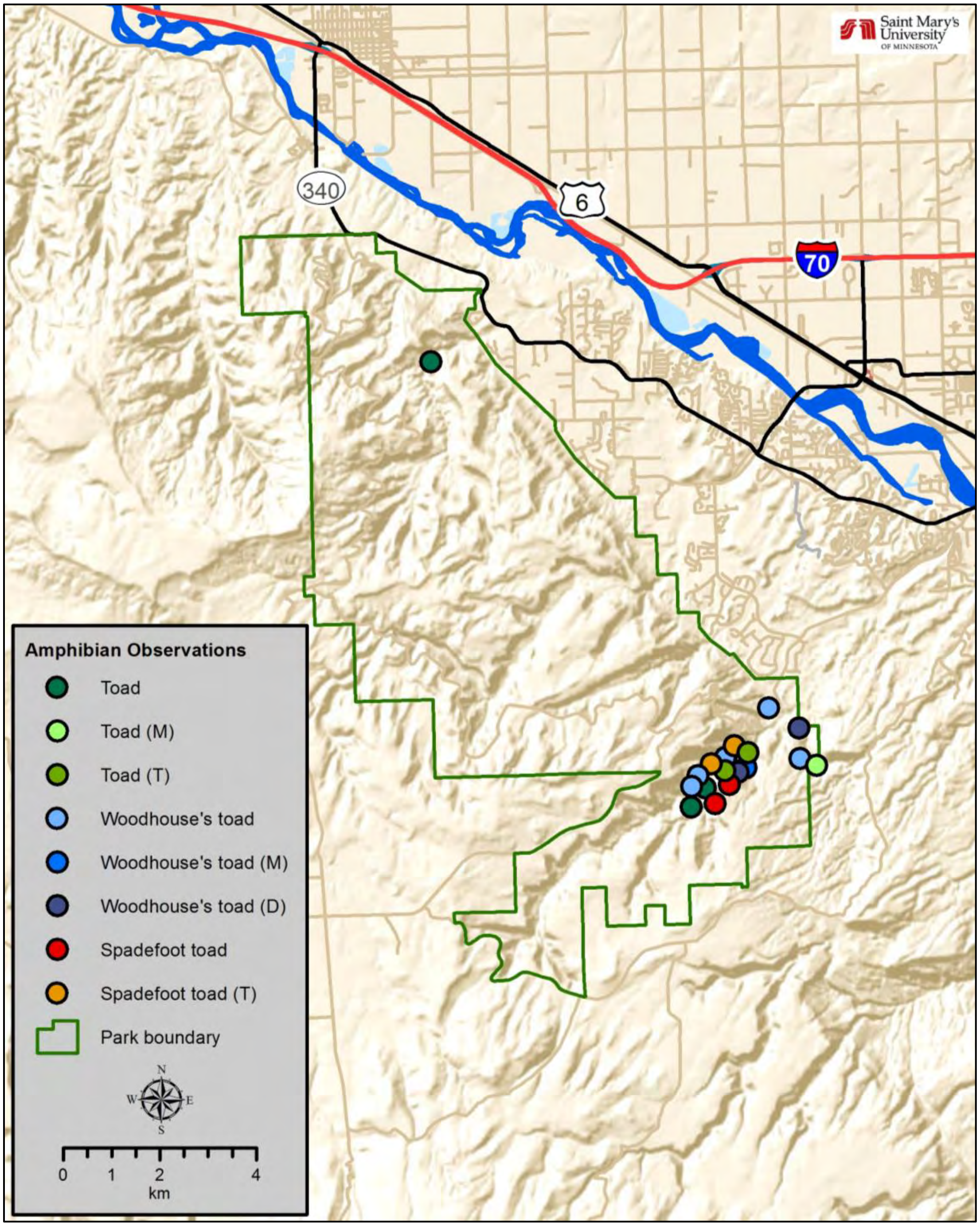

Figure 40. Mapping of locations within COLM where amphibians were observed by Platenberg and Graham (2003); it should be noted that some data points are offset slightly to reveal overlap. Key: T=tadpoles, M=metamorphs, and D=dead

Reptile Richness

The NPS (2014) lists 17 reptile species as occurring at COLM, with one additional species likely to occur but currently unconfirmed (Table 61). Platenberg and Graham (2003) confirmed the presence of seven lizard and three snake species during the inventory effort at COLM in 2002. During the 2014 seeps and springs survey, Lamm et al. observed four reptile species within the park.

Table 61. Reptiles documented or expected to occur in COLM.

Scientific Name	Common Name	NPS (2014)	Platenberg and Graham (2003)	Lamm et al. (2014)
Aspidoscelis tigris septentrionalis	plateau tiger whiptail	X	X	
Aspidoscelis velox	plateau striped whiptail	X	X	X
Coluber constrictor	North American racer	U		
Coluber taeniatus	striped whipsnake	X	X	
Crotalus oreganus concolor	midget faded rattlesnake	X	X	
Crotaphytus collaris	eastern collared lizard	X	X	
Gambelia wislizenii	long-nosed leopard lizard	X		
Hypsiglena chlorophaea loreala	Mesa Verde nightsnake	X	X	
Lampropeltis triangulum	milksnake	X		
Pantherophis emoryi	Great Plains ratsnake	X		
Phrynosoma hernandesi	greater short-horned lizard	X		
Pituophis catenifer	gophersnake	X		
Sceloporus graciosus graciosus	northern sagebrush lizard	X	X	X
Sceloporus tristichus	plateau fence lizard	X	X	
Tantilla hobartsmithi	Smith's black-headed snake	X		
Thamnophis elegans	terrestrial gartersnake	X		X
Urosaurus ornatus wrighti	northern tree lizard	X	X	
Uta stansburiana uniformis	plateau side-blotched lizard	X	X	X

U = unconfirmed

Reptile Abundance

There are no detailed abundance data for reptiles at this time. General abundance descriptions are provided in the NPS species list for COLM (Table 62).

Table 62. Reptiles included in the NPS species list with abundance (NPS 2014).

Scientific Name	Common Name	Abundance
Aspidoscelis tigris septentrionalis	plateau tiger whiptail	Common
Aspidoscelis velox	plateau striped whiptail	Common
Coluber constrictor	North American racer	Unconfirmed
Coluber taeniatus	striped whipsnake	Uncommon
Crotalus oreganus concolor	midget faded rattlesnake	Unknown
Crotaphytus collaris	eastern collared lizard	Common
Gambelia wislizenii	long-nosed leopard lizard	Rare
Hypsiglena chlorophaea loreala	Mesa Verde nightsnake	Rare
Lampropeltis triangulum	milksnake	Unknown
Pantherophis emoryi	Great Plains ratsnake	Unknown
Phrynosoma hernandesi	greater short-horned lizard	Uncommon
Pituophis catenifer	gophersnake	Uncommon
Sceloporus graciosus graciosus	northern sagebrush lizard	Common
Sceloporus tristichus	plateau fence lizard	Common
Tantilla hobartsmithi	Smith's black-headed snake	Unknown
Thamnophis elegans	terrestrial gartersnake	Uncommon
Urosaurus ornatus wrighti	northern tree lizard	Uncommon
Uta stansburiana uniformis	plateau side-blotched lizard	Common

Reptile Distribution

Reptiles can be found throughout COLM. Platenberg and Graham (2003) used GIS to record the locations where reptiles were observed during the herpetofauna inventory survey effort in 2002 (Figure 41).

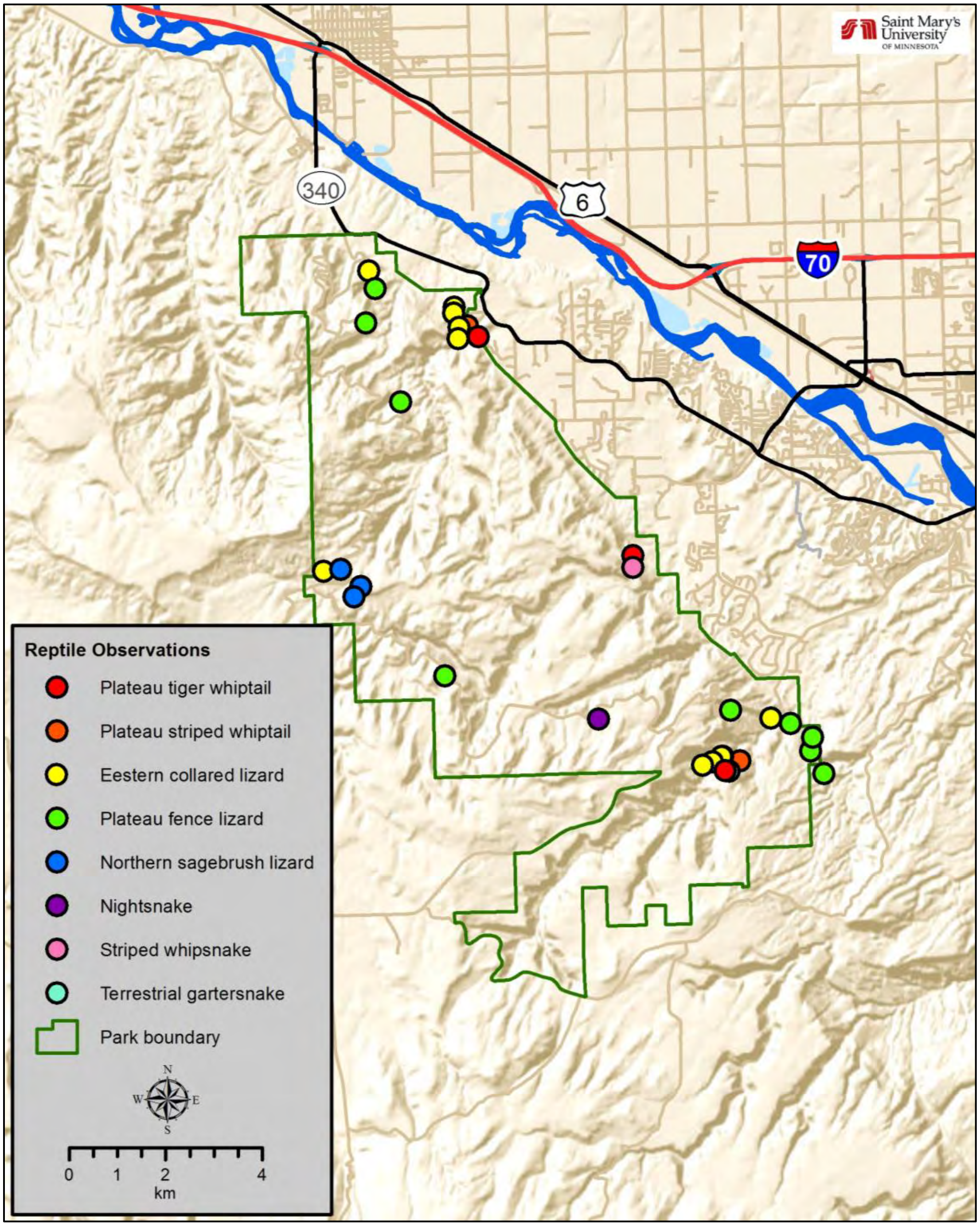

Figure 41. Mapping of locations within COLM where reptiles were observed by Platenberg and Graham (2003; it should be noted that some data points are offset slightly to reveal overlap).

Threats and Stressor Factors

There are several factors that are a concern to herptiles at COLM. Roadway mortality, habitat loss, climate change, disease, drought, radiation, visitor/human impact, and possible bull frog (*Lithobates catesbeianus*) invasion were of primary concern to park resource managers.

The indirect effects that roadways have on herpetofauna have been poorly studied; much of the research on this topic has been dedicated to mammalian and avian species (Jochimsen et al. 2004). Nocturnal reptiles frequently use roadways for thermal heating, resulting in an increased likelihood of mortality. Roads often serve as a boundary between habitat types, sometimes separating breeding areas from foraging areas (Patla 1997), and fragmenting normally continuous habitats. Furthermore, certain species may use roads as corridors for movement increasing their risk of vehicular strike. Snakes and lizards are frequently struck by motor vehicles as they are slow-moving and difficult to see as they cross roadways. Roads are also corridors that provide a pathway for exotic/invasive species to become established in new areas. Seabrook and Dettmann (1996) observed that the roads and trails across Australia allowed for the range expansion of an introduced toad species. The fragmentation of habitat by roads is thought to have contributed to altered distribution patterns in reptiles (Rudolph et al. 1998), lower recolonization rates and increased extinction risks in local reptile populations (Vos and Chardon 1998), and lowered species richness in snakes (Kjoss and Litvaitis 2001).

The loss and fragmentation of habitat poses one of the largest threats to herptile populations (Cushman 2006). The potential negative impacts of habitat loss from fire-fuel removal methods on the distribution, abundance, and diversity of lizards in pinyon-pine woodland habitats was studied at COLM over a 10-year period by James and M'Closkey (2003) who observed preferential use of standing dead trees by both terrestrial and arboreal lizard species in the Colorado Plateau during 1990, 1992, and 2000. A reduction in dead vegetation, such as standing trees, eliminates this micro-habitat feature that lizards, and many other animals, are reliant upon for foraging and cover. The lizards included for the study were the side-blotched lizard, common sagebrush lizard, tree lizard, and the eastern fence lizard (James and M'Closkey 2003). World-wide amphibian decline has been linked with regional changes to the hydrologic landscape that are occurring with global climate change (McMenamin et al. 2008). This phenomenon has been documented in Yellowstone National Park where amphibian habitat has been reduced due to drought conditions associated with the changing climate. The landscape has changed as annual precipitation has decreased while annual warm-season temperature has risen; desiccation of wetlands and extreme disruptions to pulse-driven biota has caused drastic amphibian declines at the park (McMenamin et al. 2008).

The herptiles of COLM rely on the availability of water and moist soils, especially amphibians. Potholes where water collects are used as foraging sites by reptiles. The groundwater supply that feeds COLM's seeps and springs, particularly those in the alluvial valley fill, is strongly influenced by annual and seasonal precipitation (Lamm et al. 2014). During droughts, groundwater recharge will decline and, in turn, contribute to a decline in seep and spring discharge. Reduced water availability will negatively impact the vegetation and wildlife that rely on these sites, potentially reducing biodiversity. The opposite weather extremes of heavy precipitation and flooding can also pose a threat to seeps and springs (Richard 2004). These events can trigger mudslides, move boulders and trees, and erode stream banks, all of which could alter or destroy spring, seep, and tinaja habitats (Richard 2004). Heavy precipitation could accelerate erosion of the alluvial valley fill aquifer, reducing water storage capacity and potentially eliminating springs or seeps (Lamm et al. 2014).

The hotter and drier conditions expected in COLM over the next century will likely exacerbate many of the current non-climate stressors of the aquatic and riparian habitats at COLM. A hotter, drier environment could increase the rate at which water is lost to evaporation from aquatic and riparian habitats, meaning it will be available to plants and wildlife for a shorter time (ClimateWizard 2014, Lamm et al. 2014).

The aquatic *Batrachochytrium dendrobatidis* (Bd), or chytrid fungus, causes chytridiomycosis, a lethal skin disease in amphibians that is linked to population declines in many areas of the world, including the Rocky Mountain region (Weldon et al. 2004, Hossack et al. 2009). The fungus parasitizes the host's keratinized skin and mouthparts; and is afflicting hundreds of species around the world (Kriger 2006). In several locations within the state of Colorado, the fungus has been positively identified in amphibians (Olson 2014). The nearest positive sample was in the Kannah Creek drainage in Grand Mesa, where 13 out of 39 individuals tested positive. Test conducted on specimens collected in 2000 from Echo Canyon had negative results for chytid fungus (Olson 2014). Six Woodhouse's toads and one canyon treefrog (*Hyla arenicolor*) were tested, however the entire sample size is unknown (Olson 2014). Specimen collection specifically for detection of the chytrid fungus has not been conducted in COLM.

According to Blaustein et al. (1998), some amphibian species are highly susceptible to the deleterious effects of ultraviolet B (UV-B) radiation at the embryonic stage and have had very high embryonic mortality rates as a result of exposure. Experiments conducted to assess amphibian declines suggested that there are at least three factors that seem to be exacerbated when combined with UV-B exposure; pathogenic algae called *Saprolegnia ferax* (embryos infected with it turn white and die before they hatch), low pH, and a polycyclic aromatic hydrocarbon called fluoranthene which is a component of petroleum contamination (Blaustein et al. 1998). Whether or not these factors could be impacting amphibians at COLM is unknown.

Anthropogenic impacts affect the conditions at COLM in a number of ways. General presence of visitors in the park affects wildlife behavior and can also unintentionally alter the landscape. Vehicle traffic, discussed below, tends to be a stressor to wildlife because of the noise and collisions, most of which are fatal. Foot traffic has long been a source of visitor-caused biological soil crust destruction at the park, a natural and crucial component of the ecosystem that is highly fragile (Belnap 2013). General human disturbances, such as biological soil crust damage, are likely to have unknown negative impacts to amphibian and reptile populations via habitat alteration. The way in which visitors use the parks trail system also contributes to habitat fragmentation. The park does not limit foot travel to established trails. Several of these trails lead directly to and are located within riparian areas. Due to COLM's high desert environment, water is an attraction for visitors. Visitors entering these aquatic habitats can lead to the introduction of contaminants (sunscreen). The social trails also lead to trampling of vegetation and increased erosion, which can contribute to loss of habitat.

According to Peterson et al. (2013), the bullfrog is a threat to local native amphibian populations. They are transport vectors of deadly amphibian pathogens, including chytrid fungus, and have also been connected with general native amphibian declines (Peterson et al. 2013). Bullfrogs are predators and competitors of native amphibians. Bullfrogs have been introduced in over 40 countries and have spread far beyond their native range within North America as well. Bullfrogs are spread by humans, often deliberately, but also unintentional introductions have resulted in breeding populations that disperse to new aquatic habitats opportunistically. While the potential presence of bullfrogs within COLM is currently a data gap, they are a concern to managers.

Other issues that pose a threat to the herptiles within COLM are illegal specimen collection, especially collared lizards and midget-faded rattlesnakes. Another threat, primarily along the urbanized border of the park, comes from domestic cats, which like to prey on these species.

Data Needs/Gaps

COLM has had only one park-wide herpetological inventory (Platenberg and Graham 2003), which was conducted in 2002. This may serve as a baseline, but regular monitoring of herptiles is needed to make any assessments on their condition or trends in population or community dynamics. There are no data available to assess abundances of any herptiles at this time.

Overall Condition

Species Richness

The project team defined the *Significance Level* for both amphibian and reptile species richness as a 3. While current herptile species lists are available, a lack of consistent monitoring over time does not allow for assessment of any changes in species richness. COLM's only park-wide herpetological inventory was conducted over a decade ago (Platenberg and Graham 2003) and conditions may have changed since that time. Therefore, *Condition Levels* cannot be assigned.

Species Abundance

The project team defined the *Significance Level* for amphibian and reptile species abundance as a 2. Because of a lack of data for this measure, *Condition Levels* also cannot be assigned.

Species Distribution

The project team defined the *Significance Level* for amphibian and reptile species distribution as a 1. Again, due to a significant data gap for this measure, *Condition Levels* cannot be assigned.

Weighted Condition Score

A *Weighted Condition Score* for herptiles in COLM was not assigned since the only available data are outdated and has no baseline. Rather, the available data (Platenberg and Graham 2003) will serve as the baseline for comparison with future monitoring and inventory efforts.

Herptiles			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Amphibian Richness	3	n/a	
Amphibian Abundance	2	n/a	
Amphibian Distribution	1	n/a	
Reptile Richness	3	n/a	
Reptile Abundance	2	n/a	
Reptile Distribution	1	n/a	

4.8.6 Sources of Expertise

This assessment relied on published literature as the primary source of expertise, with review by NPS staff.

4.8.7 Literature Cited

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4.9 Birds

4.9.1 Description

Bird populations often act as excellent indicators of an ecosystem's health (Morrison 1986, Hutto 1998, NABCI 2009). Birds are often highly visible components of ecosystems, and bird communities often reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010). The unique ecosystems and physical formations in COLM provide bird species with a wealth of habitat types and food sources. Due to COLM's intact pinyon-juniper (P-J) habitats, steep-walled cliffs, and settings that are conducive to intensive bird research, the park has been recognized by the National Audubon Society as a State Important Bird Area (NAS 2013).

Photo 13. Gambel's quail (*Callipepla gambelii*) (NPS photo).

COLM has confirmed the presence of more than 160 species of birds, and about 29% of these birds are migratory species on their way to breeding grounds in the park or farther north (NPS 2015). Long-distance migratory species are highly informative indicator species, as their overall health depends on several different ecosystems. Global Christmas Bird Count (CBC) data indicate significant declines in migratory bird numbers in recent years (Peterjohn and Sauer 1999, Vickery and Herkert 2001). Nearctic-Neotropic migrants, hereafter Neotropical migrants, are bird species that breed in the temperate latitudes of the U.S. and Canada, but migrate to the tropical latitudes of Central and South America in the winter months (Figure 42). Stotz et al. (1996) estimates that approximately 420 bird species are classified as Neotropical migrants.

Not all of the species found in COLM are traveling to/from their breeding grounds, however, as several species breed in the park or maintain year-round populations in the park. Examples of common breeding species in COLM include the Gambel's quail (*Callipepla gambelii*), rock wren (*Salpinctes obsoletus*), and the gray (*Vireo vicinior*) and plumbeous vireos (*V. plumbeus*) (NPS 2015). Additionally, COLM is home to a large number of resident species (i.e., species that remain in the park throughout the year). Examples of some common resident species include the American robin (*Turdus migratorius*), the juniper titmouse (*Baeolophus ridgwayi*), and the black-billed magpie (*Pica hudsonia*).

4.9.2 Measures

- Summer breeding bird richness
- Year-round bird richness

Figure 42. Zoogeographic regions of the world; shaded areas represent transition areas between regions (TPWD 2015).

4.9.3 Reference Conditions/Values

The reference condition for birds in COLM is currently undefined. While NPS (2015) represents the park's certified species list, it is likely that species not included on that list frequent the park. Continuation of the Rocky Mountain Bird Observatory (RMBO) monitoring in the park, combined with past records of species (including, but not limited to Giroir 2001 and NPS 2015) could be used in the future as a reference condition for species richness in the park.

4.9.4 Data and Methods

The NPS Certified Bird Species List (NPS 2015) for COLM was used to both determine the confirmed species in the park and to determine residency of species for this assessment; this list represents all of the confirmed and probably present bird species in the park (Appendix J). In instances where NPS (2015) did not assign residency, the American Ornithologists' Union and the Cornell University Lab of Ornithology's Birds of North America Online Database (http://bna.birds.cornell.edu/bna/) was used to approximate a species' residency as either breeding, migratory, resident, or vagrant. This component's measures separate species richness discussions for breeding birds and for resident (year-round) birds. Species in NPS (2015) that had residency designations of "Breeder" and "Resident" are discussed in the summer breeding bird richness measure, as NPS (2015) defines breeder as a species that reproduces within the park and resident as a species with a year round presence in the park. Only species that had residency designations of "Resident" are discussed in the year-round bird richness measure, as this classification refers only to species that occur in the park at year round. There will be some degree of overlap between these metrics, as resident species will be discussed in both measures. However, this is due to the fact that resident species are often breeding species as well and overlap is ultimately inevitable when using these two metrics as indicators of condition. While raptor species are also discussed separately in Chapter 4.10 of this document, these species are still included in the richness estimates for the identified measures of this component.

Giroir (2001) conducted a breeding bird inventory in COLM during the spring of 2000, and represents one of the first comprehensive bird studies to occur within the park. The objective of Giroir (2001) was to establish a baseline of breeding bird information for the park, and the author utilized distance sampling methodologies (similar to those described in Buckland et al. 1993) to sample the population. Traditionally, distance sampling uses both line and point transects; however, Giroir (2001) chose to use only point transects as they tend to be the preferred transect type for rough terrain (Fancy and Sauer 2000). Twenty-seven transects, each with 10 points on them, were randomly chosen within COLM, with replacement random transects being chosen when a location was deemed too hazardous. Points were spaced 250 m (820 ft) apart along a transect, and were observed for 5 minutes each. All species observed (aurally or visually) were recorded.

The RMBO, in a partnership with the NPS, has conducted annual landbird monitoring across the NCPN since 2005, with McLaren (2014) representing the most recent publication (covering the 2013 field season). The surveys conducted provide park managers with long-term trend data for most regularly occurring landbird species throughout the NCPN, as each year's data are pooled to allow for more accurate estimates of density and abundance. The RMBO monitoring is habitat-based (i.e., only specific habitat types are surveyed), and in COLM, only the P-J habitat type is surveyed. This habitat type typically occurs at elevations just above 1,500 m (4,921 ft), and is dominated by pinyon pine and juniper species (*Juniperus* spp.); P-J habitat habitats often contain a significant sagebrush component as well.

RMBO methodology utilized "…GIS and the Southwest Regional Re-GAP Analysis Project to randomly select sites from a pool of habitat 'stands' that were large enough to accommodate transects (Lowry et al. 2005)" (McLaren 2014, p. 3). Areas with >50% slope were excluded from this pool in order to include only areas that could be safely surveyed by foot. Areas that were determined to be appropriate stands have been surveyed every year since 2005. Surveys consist of 15-minute point counts at each point location on a transect, and each location is spaced approximately 250 m (820 ft) apart. Sites have been surveyed twice a summer, and typically occur between one half-hour before sunrise and five hours after sunrise (McLaren 2014). In COLM, there are two transects (CP-PJ06 and CP-PJ07); each is located in a P-J habitat, and has been surveyed every year of the study. Data related to the RMBO surveys of COLM were retrieved from the Rocky Mountain Avian Data Center (http://rmbo.org/v3/avian/ExploretheData.aspx).

The Grand Junction CBC falls within COLM boundaries; this CBC is part of the International CBC, which started in 1900 and is coordinated internationally by the Audubon Society. Grand Junction's CBC has been conducted regularly since 1950, although 3 years of data from the early 1920s also exist. During a CBC, multiple volunteers survey a 24-km (15-mi) diameter on one day, typically between 14 December and 5 January; the center point of the 24-km (15 mi) diameter count circle for the Grand Junction CBC is 39°7'14.9478" N, -108°36'29.25" W (Figure 43). Unlike typical breeding bird surveys, the CBC surveys overwintering and resident birds that are not territorial and singing; this often results in different survey results than those conducted during the breeding season. The total number of species and individuals are recorded each year; data for the Grand Junction CBC is current through 2013. Counts were completed in 2014; however the data are not yet available through the Audubon data retrieval database.

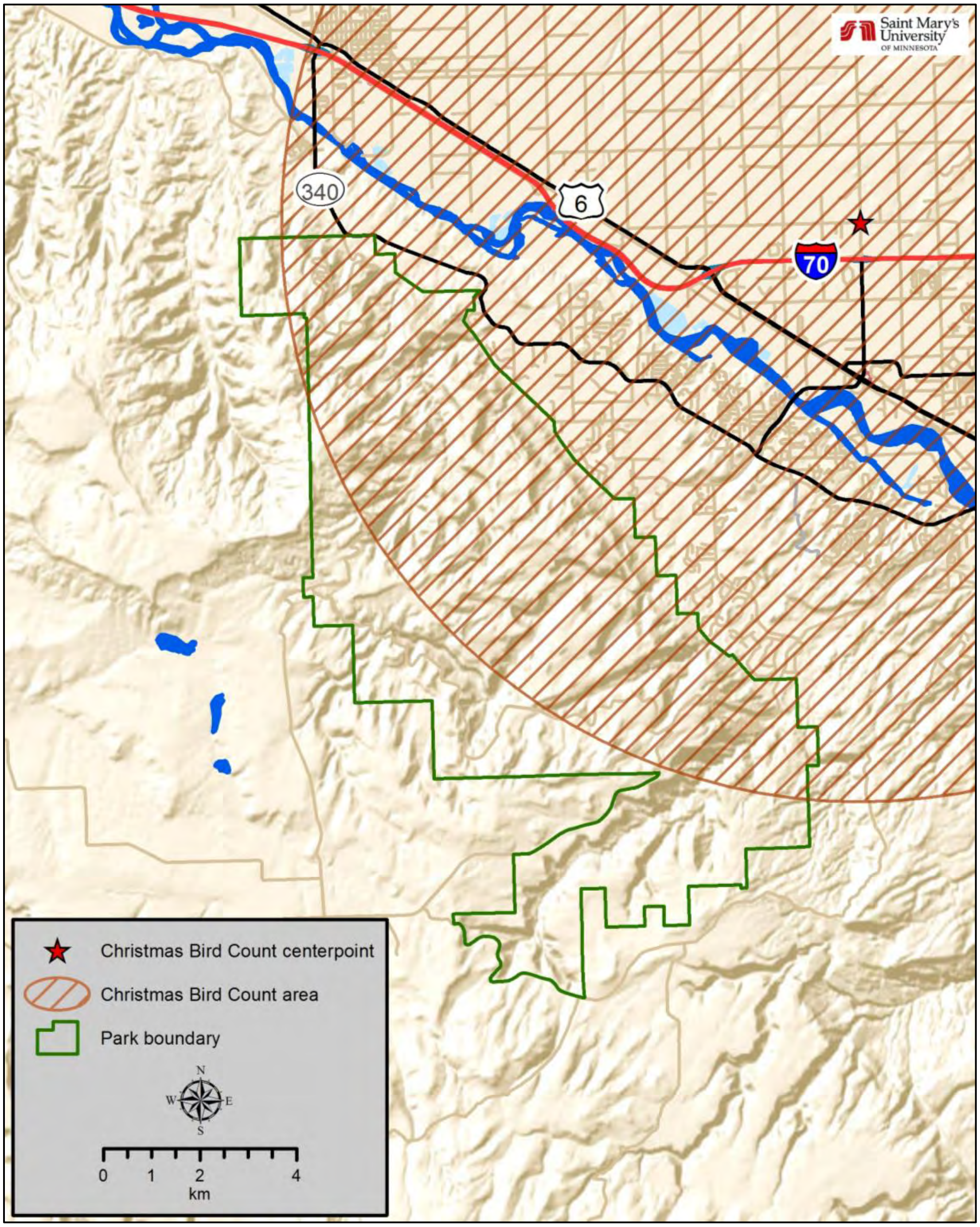


Figure 43. The CBC area that falls within COLM land. The diameter of the count circle is 24-km (15 mi) and is surveyed by volunteers each winter.

The organization of the COLM CBC data (obtained from http://netapp.audubon.org/CBCObservation/Historical/ResultsByCount.aspx#) required SMUMN

GSS to make some adjustments. These adjustments were made to update the data to the currently accepted taxonomic standards, and to eliminate duplicate or historic references that were erroneous. After the adjustments were made, the data were analyzed and organized for an accurate assessment of the survey's results. An annotated list of all adjustments is provided in Appendix K. The CBC samples areas outside the park that contains habitats that are not truly representative of the habitat types typical of COLM (e.g., the Colorado and Gunnison Rivers). Because of this, the CBC will frequently report observations of species that would not typically occur in the park, notably species that associate with riparian areas. Individual observation points are not recorded during the CBC, so it is not possible to exclude those species that were observed outside of the park's boundaries; care should be taken when observing the CBC data, as it is highly likely that some species included on the CBC list have not been observed within COLM boundaries.

4.9.5 Current Condition and Trend

<u>Summer Breeding Bird Richness</u>

Species richness measures represent a total count of the number of species observed in an area or population. For this measure, only the richness of the summer breeding birds in COLM is discussed. Breeding birds are defined as species identified with a residency of "Breeder" or "Resident" by NPS (2015). As this measure discusses the summer species richness of the park, the CBC data are not discussed in this measure.

NPS Certified Bird Species List (NPS 2015)

The NPS Certified Bird Species List contains 161 species, 26 (16%) of which are "Breeders" and 84 (52%) of which are "Resident" and are discussed in this section (Appendix J). An analysis of annual species richness is not possible using these data alone, as no record of when the species was observed is recorded.

Giroir (2001)

During one of the first surveys of the bird community of COLM in 2000, Giroir (2001) documented 60 species that were either breeding species (10 species; 17%) or resident species (50 species; 83%) Table 63 identifies the 10 species identified as breeding birds that were observed in COLM in 2000. One of the biases of Giroir's (2001) methodology (and many bird surveys in general) was that species that are more likely to be calling or vocalizing during surveys are more likely to be detected. Because of this, several species that is less vocal and more reclusive/difficult to see may not have been adequately observed or represented in the data.

Table 63. The 10 breeding bird species observed in COLM during Giroir (2001)'s breeding bird point counts.

Common Name	Scientific Name
black-throated sparrow	*Amphispiza bilineata*
bushtit	*Psaltriparus minimus*
Gambel's quail	*Callipepla gambelii*
golden eagle	*Aquila chrysaetos*
gray vireo	*Vireo vicinior*
mourning dove	*Zenaida macroura*
peregrine falcon	*Falco peregrinus*
plumbeous vireo	*Vireo plumbeus*
prairie falcon	*Falco mexicanus*
rock wren	*Salpinctes obsoletus*

RMBO Landbird Monitoring (2005-present)

The number of summer breeding bird species observed in COLM was variable during RMBO monitoring between 2005 and 2014, with the average total number of summer breeding bird species observed between the two routes being 36.7. The total number of observed summer breeding species was 67, of which 15 were breeders (22%) and 52 were residents (78%).

Fifty-one different summer breeding bird species were observed on route CP-PJ06 (42 resident species, nine breeding species), while 57 species were observed on route CP-PJ07 (45 resident species, 12 breeding species). When looking at both routes combined, peak summer breeding species richness values were reported in 2005 (46 species), while the lowest species richness values were observed in 2013 (30 species) (Figure 44). Route CP-PJ06 reported lower species richness values in every year of the RMBO monitoring (Figure 44).

The summer breeding bird richness values observed in 2014 were below average for both routes. In fact, both routes reported the lowest species richness value for the duration of the 10-year study (Figure 44). The 2014 species richness value for the CP-PJ06 route (18 species) was below the 10-year average for that route (24 species). The 2014 richness value for the CP-PJ07 route was 24 species, which was below the 10-year average for that route as well (31.6 species). When species richness values from 2014 were combined for both routes in COLM, 31 species were observed in the park, which fell below the 10-year average for both routes combined which were 36.7.

There are a few factors that may have influenced the RMBO species richness estimates in COLM. RMBO monitoring sites are located in only P-J habitat types, and may miss breeding species that occur outside of this habitat zone. Additionally, and as has been previously mentioned, species such as raptors that are not highly vocal species during the breeding season are less likely to be observed during point counts. The terrain of the point counts may make the observation of these non-vocal species difficult, unless the species are flying directly overhead.

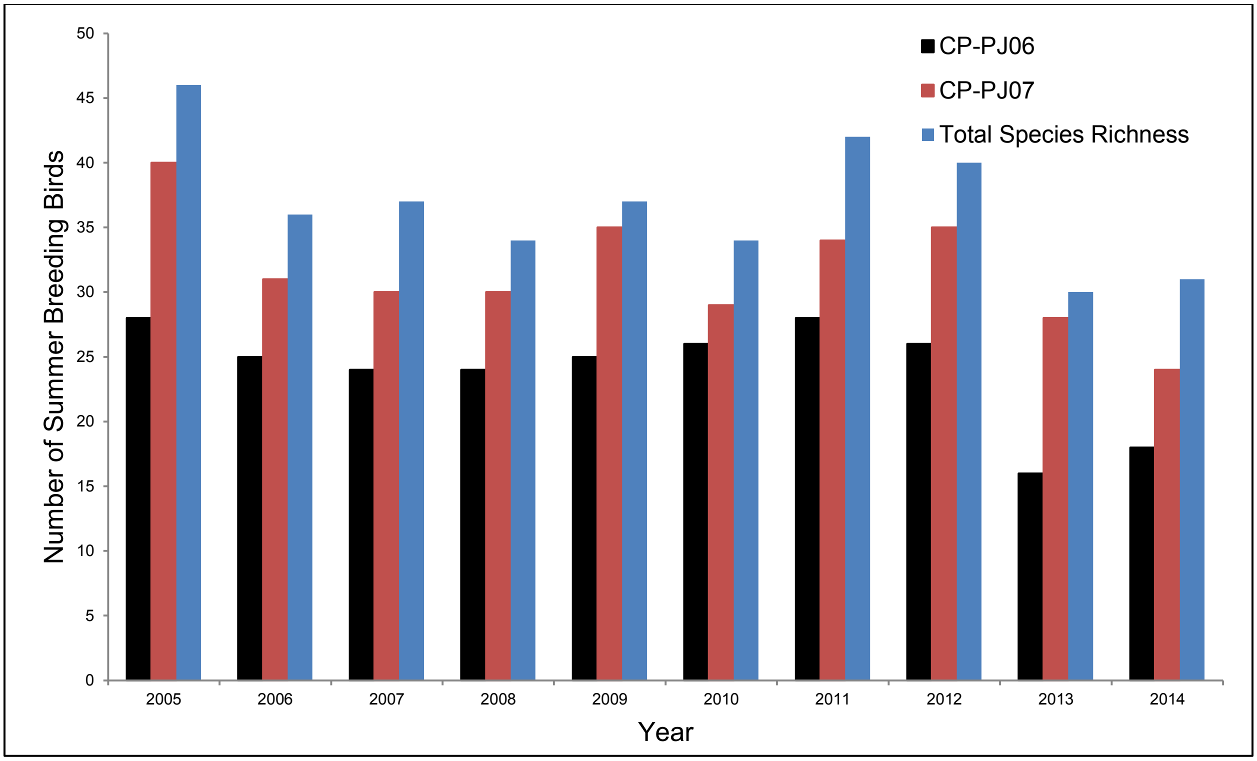


Figure 44. Breeding species richness observed on both of the RMBO landbird monitoring routes in COLM. Surveys have been conducted annually since 2005, and only report the landbird species observed in P-J habitats of the park. Data were retrieved from the Rocky Mountain Avian Data Center (http://rmbo.org/v3/avian/ExploretheData.aspx).

Year-Round Bird Richness

NPS Certified Bird Species List (NPS 2015)

The NPS Certified Bird Species List contains 161 species, 84 (52%) of which are "Resident" (Appendix J). As previously described, an analysis of annual year-round species richness is not possible using these data alone, as no record of when the species was observed is recorded.

Giroir (2001)

Giroir (2001) observed 50 resident species (as defined by NPS 2015) during surveys of COLM in 2000 (Appendix J). Giroir (2001) also indicated that surveys took place in order to coincide with the peak of singing for species that frequent the P-J habitat. Because of this, several species that begin their breeding and singing cycles earlier in the year (e.g., western-scrub jay, common raven [*Corvus corax*], and juniper titmouse) may not have been accurately represented in the data.

RMBO Landbird Monitoring (2005-present)

Year-round species richness has fluctuated during RMBO landbird monitoring in COLM, with richness estimates ranging between 22 species (2013) and 36 species (2005, 2011) (Figure 45). The average species richness estimate for year-round landbird species, with both routes combined, was 29.4 species. The CP-PJ07 route has had higher species richness during every year of the RMBO monitoring (Figure 45), and has averaged 24.9 year-round species/year compared to route CP-PJ06's 19.1 year-round species/year.

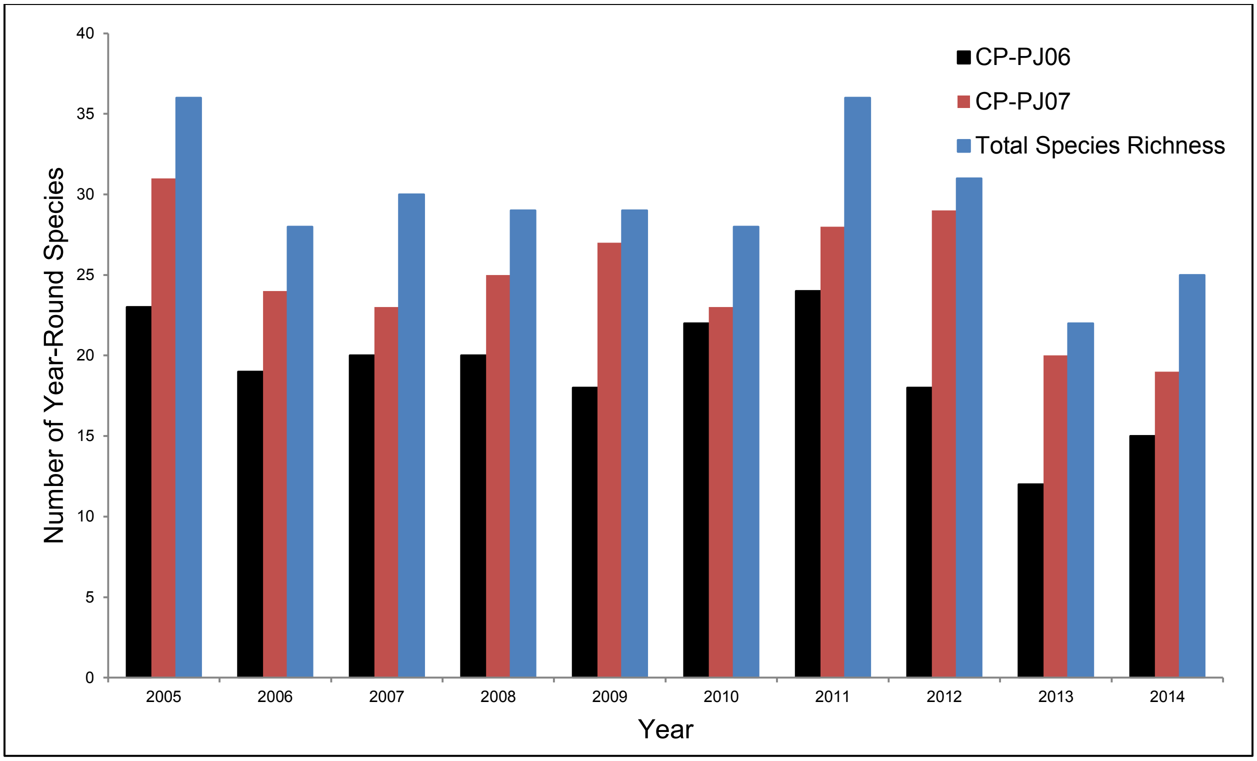


Figure 45. Number of year-round bird species observed on both survey routes in COLM's P-J habitat during RMBO landbird monitoring from 2005-2014. Species classified as either resident, migratory, or vagrant by NPS (2015) are included in the richness values of this figure. Data related to the RMBO surveys of COLM were retrieved from the Rocky Mountain Avian Data Center (http://rmbo.org/v3/avian/ExploretheData.aspx).

Perhaps somewhat concerning is the fact that the two most recent surveys in the park (2013 and 2014) have produced the lowest estimates of species richness for both routes (Figure 45). Overall species richness estimates in 2014 (25 species) for COLM fell below the 10-year average for the park (29.4), as did each individual route's species richness estimate (CP-PJ06: 15 compared to 19.1 species; CP-PJ07: 19 compared to 24.9 species).

Grand Junction Christmas Bird Count

The Grand Junction, CO CBC represents the most continuous source of bird data in the COLM region, with counts occurring almost every year from 1950-present (counts also exist from 1922-24, and 1945). The CBC methodology is an example of an index count, which is a methodology that tallies the number of bird detections during surveys of points, transects, or other defined regions (Kendeigh 1944, Verner 1985, Bibby et al. 1992, Ralph et al. 1995, Rosenstock et al. 2002). Index counts quantify bird species' distribution, occurrence, habitat relationships, and population trends (Rosenstock et al. 2002).

The Grand Junction CBC surveys only a portion of COLM (Figure 43), so results from the survey are not indicative of the species richness trends for resident and overwintering species in the entire park. Counts such as the CBC (or other index counts, e.g., breeding bird surveys) are neither censuses nor density estimates, and results should only be viewed as indices of population size (Link and Sauer

1998). Possible bias of count locations, weather on the day of the count, and the number of observers limit the overall usefulness of index count data, and it is often not advisable to estimate overall population sizes from these data alone (Link and Sauer 1998); these biases may influence how many individuals are observed in a given year, and may potentially explain the annual variation observed in species each year. The effects of observer bias are especially apparent in the early years of the Grand Junction CBC, when only one observer participated. Additionally, the CBC samples areas and habitat types outside the park that are not typical of habitats found within COLM (e.g., Colorado and Gunnison Rivers). Because of this, some species identified on the CBC may not be actually utilizing COLM lands.

For the duration of the Grand Junction CBC, 76 species of year-round residents were observed (Appendix J); the average number of species observed during a count year was 39.8 species. The highest number of species observed during a count year occurred in 2004 when 58 species were observed, while the lowest species richness value during the CBC was eight species, which was recorded in 1924. Many of the historically low species richness estimates for COLM (see 1922-1964) occurred during years with only single-digit numbers of observers. The first year to eclipse the double-digit observer mark was 1965; the number of species observed each year appeared to coincide with the number of observers in a given year (Figure 46).

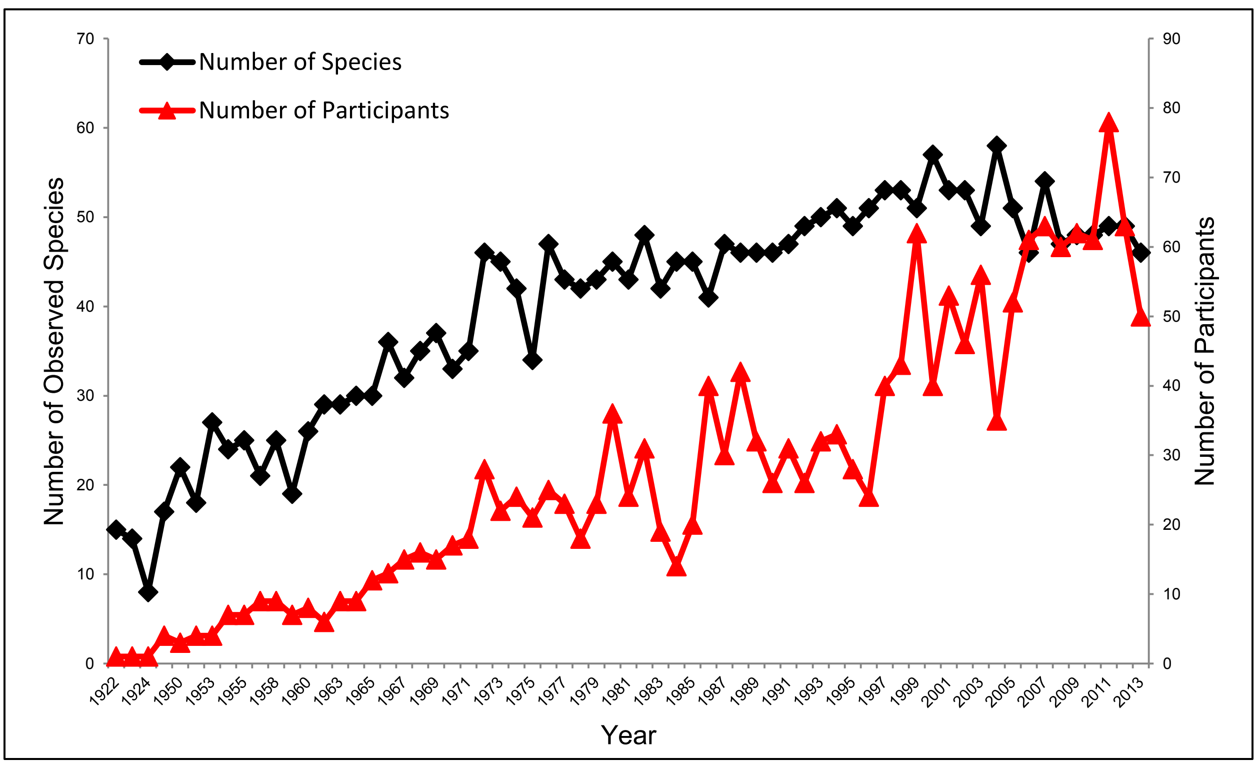


Figure 46. The number of species observed during each year of the Grand Junction CBC (black, primary Y-axis) and the number of participants in the Grand Junction CBC (red, secondary Y-axis) from 1922-2013. Data retrieved from http://netapp.audubon.org/CBCObservation/Historical/ResultsByCount.aspx#.

Threats and Stressor Factors

One of the major threats facing bird populations across all habitat types is land cover change (Morrison 1986). Land cover change is not restricted to the breeding habitat; many species depend on specific migratory and wintering habitat types that are also changing. Altered habitats can also compromise the reproductive success or wintering survival rates of species adapted to that habitat.

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

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

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

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

Domestic and feral cats (*Felis catus*) are one of the largest causes of bird mortality in the United States. According to Loss et al. (2012), annual bird mortality caused by outdoor cats is estimated to be between 1.4 and 3.7 billion individuals. The median number of birds killed by cats was estimated at 2.4 billion individuals, and almost 69% of bird mortality due to cat predation was caused by un-owned cats (i.e., strays, barn cats, and completely feral cats) (Loss et al. 2012). The relatively close proximity of COLM to Grand Junction and Fruita likely increases the risk for cat predation, as stray and house cats may enter the park and surrounding areas.

Data Needs/Gaps

As was mentioned previously, this assessment did not incorporate the recently published McLaren (2015), which summarizes the results of the landbird monitoring in the park during 2014. Continuation of the RMBO's annual landbird monitoring in the park will provide park managers with a valuable long-term data set that will accurately depict trends in abundance, density, and richness in the P-J habitat of COLM, however the design of this study is done to make inference to the entire NCPN set of parks, so if park-specific trend information is desired, more monitoring would need to be added. Expansion of the survey methodology to include a variety of habitat types would provide a more complete picture of the avifauna of the park as a whole. Additionally, the expansion of survey timing would also help managers obtain a better understanding of the trends and status of year-round bird species in the park. Current methodology samples the breeding population of the park, and the CBC in the area samples the overwintering population, but no survey exists during the spring and fall migration period.

Overall Condition

Summer Breeding Bird Richness

The project team defined the *Significance Level* for summer breeding bird richness as a 3. Compared to the RMBO 10-year average (36.7 species), COLM has had below average summer breeding bird richness estimates in recent years. 2013 had the lowest species richness estimate for both routes combined, and for the CP-PJ06 route (Figure 44). In 2014, overall species richness slightly increased (from 30 to 31 species) but still remained below the 10-year average of 36.7. Both of the routes had below average richness values in 2014, and the CP-PJ07 route exhibited the lowest species richness estimate that had been observed in the 10 years of RMBO monitoring.

The Gunnison sage grouse (*Centrocercus minimus*) is one species absent from the park that historically occupied habitats within COLM; however, this species has spatially isolated habitat patches across its former range, and has experienced dramatic declines over the past few decades. Due primarily to low recent estimates of species richness observed during the RMBO monitoring of P-J habitats, the summer breeding bird richness measure was assigned a *Condition Level* of 2, indicating moderate concern.

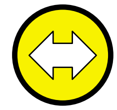
Year-Round Bird Richness

The project team defined the *Significance Level* for year-round bird richness as a 3 during project scoping. The RMBO landbird monitoring has provided species richness values for year-round residents during the breeding season since 2005.Species richness values for resident species steadily increased during the CBC efforts in the park, with a peak value reaching 58 species in 2004. Recent (2008-2013) species richness values from the CBC in the park have ranged from 46 (2013) to 49 (2011, 2012) species (Figure 46), which are above the historic average of approximately 40 species. As was mentioned previously, the CBC estimates and trends need to be interpreted carefully, as variations in survey locations and the number of observers can all influence the number of species reported each year.

During the RMBO landbird surveys, total species richness values (both routes combined) have ranged from 22 (2013) to 36 (2005, 2011) species (Figure 45). While route CP-PJ07 has had higher species richness values in every year of the study, both routes have experienced the lowest species richness estimates of the study during the last 2 years (2013, 2014; Figure 45).

Despite relatively long-term stability in species richness values for year-round species in COLM, recent declining trends in richness are worth mentioning and warrant future monitoring. While it is certainly possible that these are simply natural, temporal variations in richness, monitoring may help to identify long-term trends or issues. The year-round bird richness measure was assigned a *Condition Level* of 1, indicating low concern.

Weighted Condition Score
The bird's component was assigned a *Weighted Condition Score* of 0.5, indicating a current condition of moderate concern. A stable trend arrow was assigned to the component, although there is some minor evidence that the trend may be declining as is evidenced by recent declines in abundance observed during RMBO efforts.

Birds			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.50**
Summer Breeding Birds Richness	3	2	
Year-Round Bird Richness	3	1	

4.9.6 Sources of Expertise

Dusty Perkins, Program Manager, Northern Colorado Plateau Network

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4.10 Raptors

4.10.1 Description

Photo 14. Peregrine falcon (USFWS Photo).

Raptors are top-level predators and are excellent bioindicators of the health of their associated ecosystem (Morrison 1986, Hutto 1998). In the 1940s, raptor populations across North America experienced a substantial population decline due to the use of organophosphates (e.g., dichlorodiphenyltrichloroethane – DDT) as insecticides. Bioaccumulation of these chemicals (particularly DDE, a persistent metabolite of DDT) inhibited calcium metabolism in many raptor species (Fischer 2000). DDT magnified though the food chain, and more chemicals were concentrated within apex predators than in other animals within the same environment (Connell 1999). As a result, affected birds laid eggs that were too thin for successful incubation; eggs that did not break during incubation often contained dead embryos, and mortality rates for hatchlings were high (Ratcliffe 1993, Fischer 2000).

DDT was banned in the United States in December 1972 and reproductive success rates subsequently increased following this ban (Fischer 2000). Species especially affected by the use of organochlorines, such as the peregrine falcon (*Falco peregrinus*), experienced a dramatic population recovery following the ban. The peregrine falcon populations in the continental United States rebounded to over 2,000 breeding pairs in 2002 (White et al. 2002, as cited in USFWS 2003), and the Colorado population of peregrine falcons was estimated to have increased tenfold in the 35 years following the ban on DDT. The COLM population of peregrine falcons served as a refuge for the species during this decline, and was utilized as part of the range-wide captive breeding and reintroduction effort (Hartwig, written communication, 4 August 2015). These affected raptor species recovered to population levels that allowed for their removal from the Endangered Species List (the peregrine falcon was delisted in 1999) (USFWS 2003).

The many diverse habitats of COLM (e.g., canyon walls, sagebrush shrublands, and montane shrublands) can support a variety of different raptor species. The canyon walls of COLM are of particular importance to nesting prairie (*Falco mexicanus*) and peregrine falcons. In addition to the prairie and peregrine falcons, common raptor species in COLM include the red-tailed hawk, golden eagle, northern pygmy owl (*Glaucidium gnoma*), and the turkey vulture (*Cathartes aura*).

Due to COLM's intact pinyon-juniper habitats, steep-walled cliffs, and settings that are conducive to intensive bird research, the park has been recognized by the National Audubon Society as a State Important Bird Area (NAS 2013). Monitoring of these apex level avian predators will provide park managers with not only a current understanding of the health of the raptor population, but also a snapshot into the overall health of the ecosystems and microhabitats that they frequent.

4.10.2 Measures

- Raptor richness
- Abundance
- Productivity
- Number of active nest sites

4.10.3 Reference Conditions/Values

The reference condition for raptors in COLM is currently undefined. While NPS (2015) represents the park's certified species list, it is likely that some raptor species included on that list may be rare visitors to the park. With no raptor-specific monitoring taking place in the park, it is difficult to assess current condition. Additionally, each species of raptor is likely to have variable productivity and occupancy requirements that would indicate a stable population (e.g., bald eagles may have different productivity/occupancy goals than peregrine falcons). For this assessment, a reference condition is not provided, and best professional judgment will be used to assess current condition for the metrics that have available data.

4.10.4 Data and Methods

The NPS Certified Bird Species List (NPS 2015) for COLM was used for this assessment; this list includes all of the confirmed raptor species present in the park. As this component deals only with raptor species, NPS (2015) was adjusted to include only raptor species. For a detailed discussion of all bird species, see Chapter 4.9 of this assessment.

The only raptor-specific monitoring project to occur within COLM (Lambeth 1996) occurred in 1994 and 1995, and focused on monitoring three peregrine falcon nests within the park. Lambeth (1996) monitored all peregrine falcon nesting sites on BLM and adjacent lands within the Grand Junction District (which included COLM). Sites were monitored beginning in April of 1994 and 1995, and observations continued periodically until after fledging occurred, typically in mid-June.

Outside of Lambeth (1996), no raptor-specific monitoring has been conducted within COLM boundaries. However, additional inventories, surveys, and monitoring efforts of all bird species in the park have taken place, and raptor species were frequently documented. The results of the studies described below have been adjusted to only include raptor species for this assessment.

Giroir (2001) conducted a breeding bird inventory in COLM during the spring of 2000, and represents one of the first comprehensive bird studies to occur within the park. The objective of Giroir (2001) was to establish a baseline of breeding bird information in the park, and the author utilized distance sampling methodologies (similar to those described in Buckland et al. 1993) to sample the population. Traditionally, distance sampling uses both line and point transects; however, Giroir (2001) chose to use only point transects as they tend to be the preferred transect type for rough terrain (Fancey and Sauer 2000). Twenty-seven transects, each with 10 points on them, were randomly chosen within COLM, with replacement random transects being chosen when a location was deemed too hazardous. Points were spaced 250 m (820 ft) apart along each transect, and were observed for 5 minutes each. All species observed (aurally or visually) were recorded. One of the biases of Giroir's (2001) methodology (and many bird surveys in general) was that species that are more likely to be calling or vocalizing during surveys are more likely to be detected. Because of this, several species that are less vocal and more reclusive/difficult to see (e.g., raptors) may not have been adequately observed or represented in the data.

The RMBO, in a partnership with the NPS, has conducted annual landbird monitoring across the NCPN since 2005, with McLaren (2014) representing the most recent publication (covering the 2013 field season). McLaren (2015) was completed and published in 2015, and summarizes the results of the 2014 field season. However, this publication was not available during the initial writing of this document and has not been incorporated. The surveys conducted provide park managers with long-term trend data for most regularly occurring landbird species throughout the NCPN, as each year's data are pooled to allow for more accurate estimates of density and abundance. The RMBO monitoring is habitat-based (i.e., only specific habitat types are surveyed), with these habitats being selected due to the fact that they represent distinct bird communities. In COLM, only the P-J habitat type is surveyed. This habitat type typically occurs at elevations just above 1,500 m (4,921 ft), and is dominated by pinyon pines and juniper species; P-J habitats often contain a significant sagebrush component as well.

RMBO methodology utilized "…GIS and the Southwest Regional Re-GAP Analysis Project to randomly select sites from a pool of habitat 'stands' that were large enough to accommodate transects (Lowry et al. 2005)" (McLaren 2014, p. 3). Areas with >50% slope were excluded from this pool in order to include only areas that could be safely surveyed by foot. Areas that were determined to be appropriate stands have been surveyed every year since 2005. Surveys consist of 15-minute point counts at each point location on a transect, and each location is spaced approximately 250 m (820 ft) apart. Sites have been surveyed twice a summer, typically between one half-hour before sunrise and five hours after sunrise (McLaren 2014). In COLM, there are two transects (CP-PJ06, and CP-PJ07); each is located in a P-J habitat, and has been surveyed every year of the study. As was previously mentioned, species such as raptors are not highly vocal species during the breeding season and are less likely to be observed during point counts. The terrain of the point counts may make the observation of these non-vocal species difficult, unless the species were flying directly overhead.

The Grand Junction CBC falls within COLM boundaries; this CBC is part of the International CBC, which started in 1900 and is coordinated internationally by the Audubon Society. The park's CBC has been conducted regularly since 1946, although 3 years of data from the early 1920s also exist. During a CBC, multiple volunteers survey a 24-km (15-mi) diameter on one day, typically between 14 December and 5 January; the center point of the 24-km (15-mi) diameter count circle for the Grand Junction CBC is 39°7'14.9478" N, -108°36'29.25" W (Figure 47). Unlike typical breeding bird surveys, the CBC surveys overwintering and resident birds that are not territorial and singing; this results in different survey results than those conducted during the breeding season. The total number of species and individuals are recorded each year; data for the Grand Junction CBC is current through 2013. Counts were completed in 2014; however the data are not yet available through the Audubon data retrieval database.

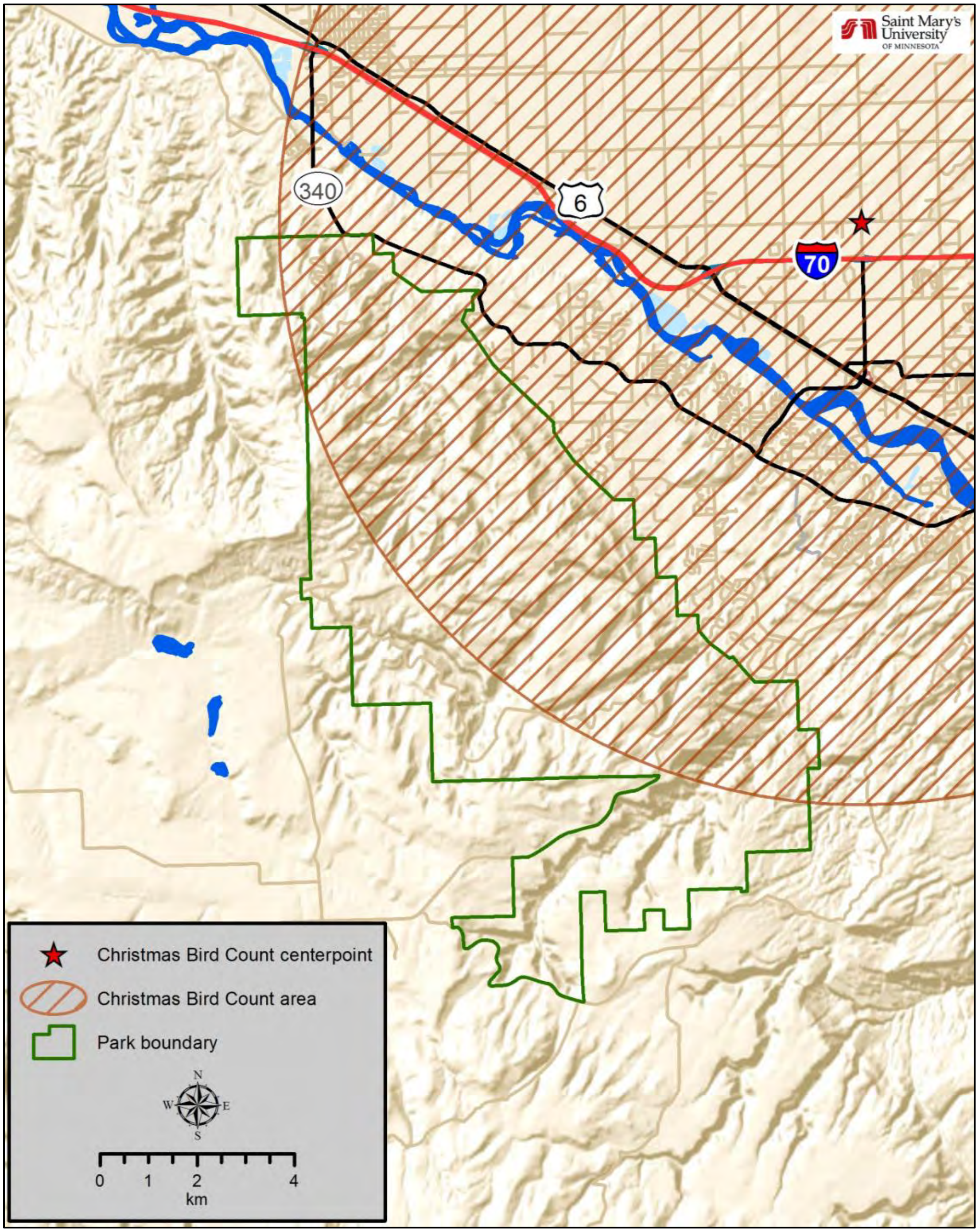

Figure 47. The CBC area that falls within COLM land. The diameter of the count circle is 24-km (15 mi) and is surveyed by volunteers each winter.

4.10.5 Current Condition and Trend

<u>Raptor Richness</u>

Species richness measures represent a total count of the number of species observed in an area or population. For this measure, only the richness of the raptors in COLM is discussed.

NPS Certified Bird Species List (NPS 2015)

The NPS Certified Bird Species List contains 161 species, 24 (15%) of which are raptors and are discussed in this section (Table 64). This list, however, does not allow for a specific analysis of annual species richness, as no yearly data are collected.

Table 64. Raptor species identified on NPS (2015).

Common Names		
American kestrel	long-eared owl	prairie falcon
bald eagle	merlin*	red-tailed hawk
barn owl*	northern goshawk	rough-legged hawk*
burrowing owl*	northern harrier	sharp-shinned hawk
Cooper's hawk	northern pygmy-owl	Swainson's hawk*
ferruginous hawk*	northern saw-whet owl	turkey vulture
golden eagle	osprey	western screech-owl
great horned owl	peregrine falcon	zone-tailed hawk

*Indicates a species listed as “probably present” in the park.

Giroir (2001)

During one of the first surveys of the bird community of COLM in 2000, Giroir (2001) documented 60 bird species, seven of which were raptor species. Species classified as raptors made up approximately 12% of all bird observations during the study. The seven raptor species identified during Giroir (2001) included: American kestrel, golden eagle, northern pygmy owl, peregrine falcon, prairie falcon, sharp-shinned hawk, and turkey vulture.

RMBO Landbird Monitoring (2005-present)

RMBO monitoring efforts in COLM have focused on two survey routes, both of which are located in P-J habitats. Route CP-PJ06 has had relatively low raptor richness values during the study, with a peak raptor richness value of three species occurring in 2011 and 5 years where no raptors were observed (2007-2010, 2013; Figure 48). Raptors have been observed on Route CP-PJ07 in every year of the surveys, although numbers were also relatively low (Figure 48). Peak richness values for raptors on this route (three species) were observed in 2009, 2010, and 2014. The lowest species richness for raptors reported during the survey (one species) was in 2013. Overall species richness (i.e., number of unique species observed between both routes combined) for the survey peaked at four species (Figure 48).

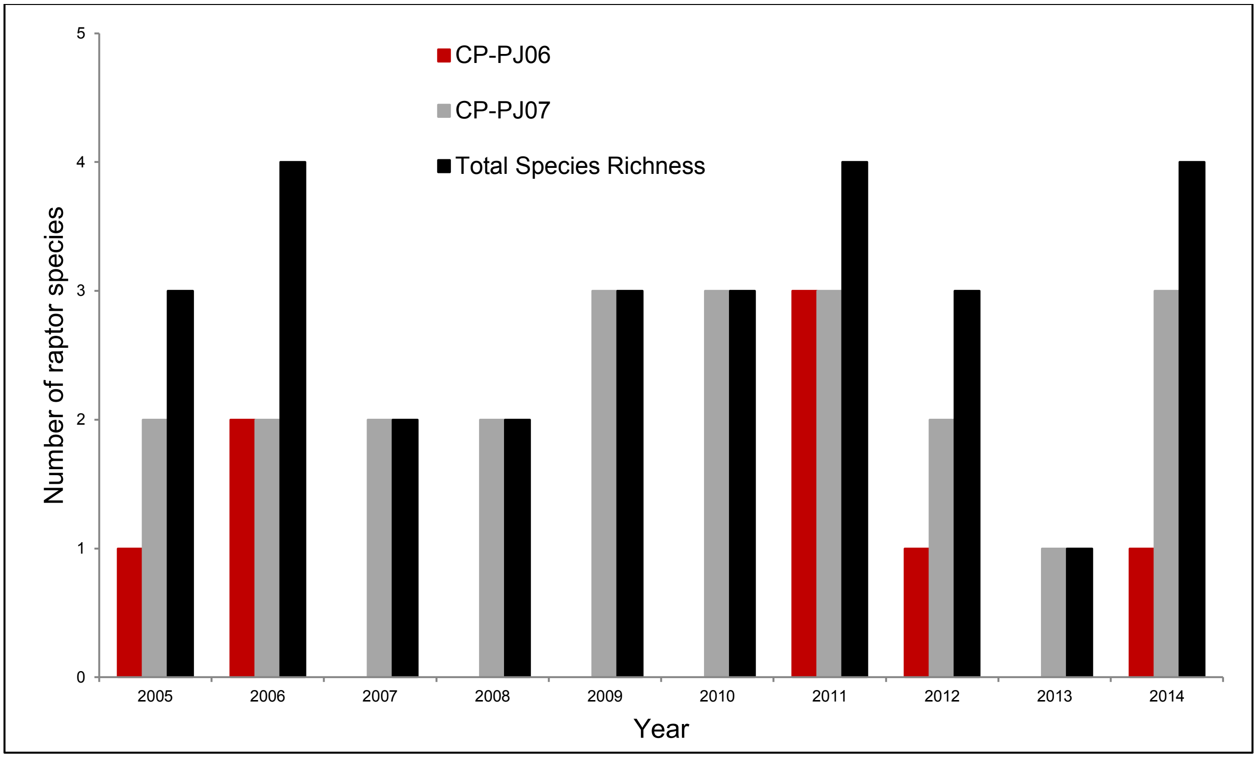

Figure 48. Number of raptor species observed on both survey routes in COLM's pinyon-juniper habitat during RMBO monitoring from 2005-2014. Data were retrieved from the Rocky Mountain Avian Data Center (http://rmbo.org/v3/avian/ExploretheData.aspx).

Grand Junction Christmas Bird Count

The Grand Junction, CO CBC represents the most continuous source of raptor data in the COLM region, with counts occurring almost every year from 1950-present (counts also exist from 1922-24, and 1945). The CBC methodology is an example of an index count, which is a methodology that tallies the number of bird detections during surveys of points, transects, or other defined regions (Kendeigh 1944, Verner 1985, Bibby et al. 1992, Ralph et al. 1995, Rosenstock et al. 2002). Index counts quantify bird species' distribution, occurrence, habitat relationships, and population trends (Rosenstock et al. 2002).

The Grand Junction CBC surveys only a portion of COLM (Figure 47), so results from the survey are not indicative of the raptor species richness trends for the entire park. Counts such as the CBC (or other index counts, e.g., breeding bird surveys) are neither censuses nor density estimates, and results should only be viewed as indices of population size (Link and Sauer 1998). Possible bias of count locations and the number of observers limit the overall usefulness of index count data, and it is often not advisable to estimate overall population sizes from these data alone (Link and Sauer 1998); these biases may influence how many individuals are observed in a given year, and may potentially explain the annual variation observed in species each year. The effects of observer bias may be especially apparent in the early years of the Grand Junction CBC, when only one observer participated.

For the duration of the Grand Junction CBC, 22 species of raptors were observed (Table 65); the average number of raptor species observed during a count year was 10 species. The highest number of raptor species observed during a count year occurred in 2000 and 2004 when 18 species were observed, while the lowest raptor species richness value during the CBC was one species, which was recorded in 1924 and 1945. Many of the historically low species richness estimates for COLM (see 1922-1964) occurred during years with only single-digit numbers of observers. The first year to eclipse the double-digit observer mark was 1965; the number of species observed each year appeared to coincide with the number of observers in a given year (Figure 49).

Table 65. Raptor species observed during the Grand Junction CBC from 1922-2013.

Common Name	
American kestrel	northern pygmy-owl
bald eagle	northern saw-whet owl
barn owl	peregrine falcon
Cooper's hawk	prairie falcon
ferruginous hawk	red-shouldered hawk
golden eagle	red-tailed hawk
great horned owl	rough-legged hawk
long-eared owl	sharp-shinned hawk
merlin	Swainson's hawk
northern goshawk	turkey vulture
northern harrier	western screech-owl

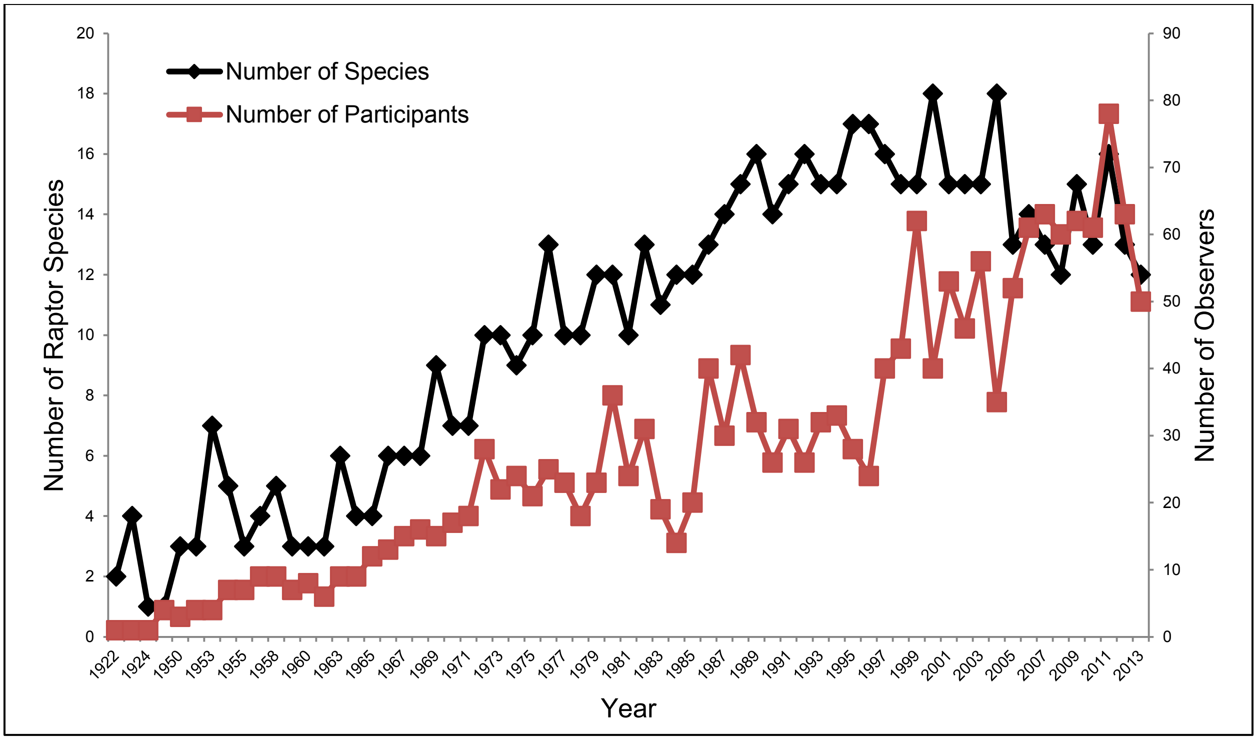

Figure 49. The number of raptor species observed during each year of the Grand Junction CBC (black, primary axis) and the number of participants in the Grand Junction CBC (red, secondary Y-axis) from 1922-2013. Data retrieved from http://netapp.audubon.org/CBCObservation/Historical/ResultsByCount.aspx#.

Abundance

Giroir (2001)

Of the seven raptor species observed during Giroir (2001), the turkey vulture was the most abundant with 11 individuals being observed along six transects throughout the park (Table 66; Giroir 2001). Golden eagles (five individuals), peregrine falcons (five individuals), and American kestrels were all observed more than once during Giroir (2001).

Table 66. Raptor abundance observed in COLM in 2000 during Giroir (2001). n=number of individuals, k=number of transects a species was detected on.

Species	n	k
turkey vulture	11	6
sharp-shinned hawk	1	1
golden eagle	5	5
American kestrel	3	2
prairie falcon	1	1
peregrine falcon	5	4
northern pygmy-owl	1	1

RMBO Landbird Monitoring (2005-present)

RMBO monitoring efforts in the pinyon-juniper habitats of COLM resulted in 83 individual raptors being observed between 2005 and 2014. Of the two routes surveyed in COLM, route CP-PJ07 had the highest abundance estimates, with 69 individuals observed. The peak abundance values for this route were reported in 2010, when 15 individuals were observed (Figure 50). The lowest raptor abundance value for route CP-PJ07 was reported in 2013, when only two individuals were observed.

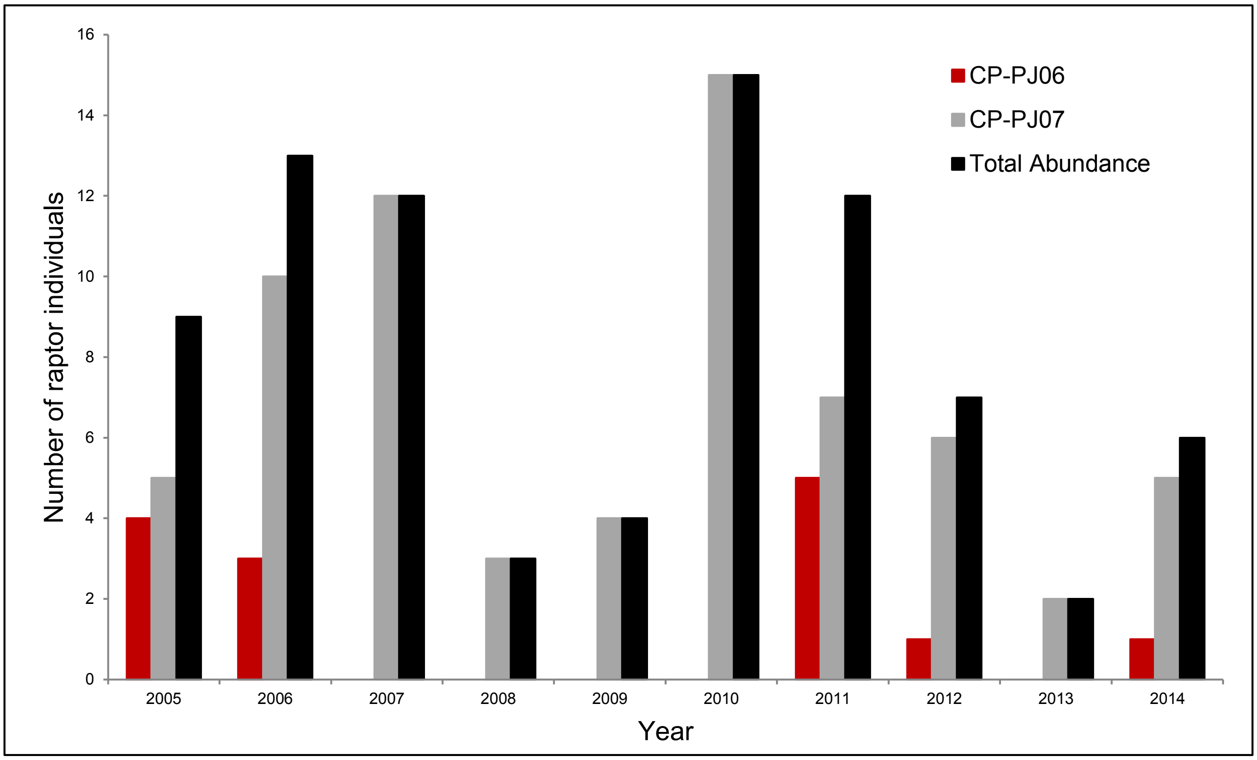

Figure 50. Number of raptor individuals observed on both survey routes in COLM's pinyon-juniper habitat during RMBO monitoring from 2005-2014. Data were retrieved from the Rocky Mountain Avian Data Center (http://rmbo.org/v3/avian/ExploretheData.aspx).

Route CP-PJ06 had much lower abundance values, with only 14 individuals being observed between 2005 and 2014. The highest number of individuals observed in a year was in 2011, when three raptors were observed. There were 5 years where no raptors were observed on route CP-PJ06 (2007-2010, 2013).

Grand Junction Christmas Bird Count

Average raptor abundance during the Grand Junction CBC was 142.57 individuals/year. The highest number of individuals observed in a count year occurred in 2000, when 332 individual raptors were observed. The lowest number of raptors observed during a count year was five, which occurred twice (1922, 1945), although both of these counts had only single-digit numbers of participants (Figure 51). The most abundant species during the CBC was the American kestrel, which was recorded an average of 45.85 observations/year. Other frequently observed raptor species during the Grand Junction CBC included the red-tailed hawk (32.89 observations/year), western screech-owl

(*Megascops kennicotti*) (13.54 observations/year), and the northern harrier (*Circus cyanus*) (13.42 observations/year) (Table 67).

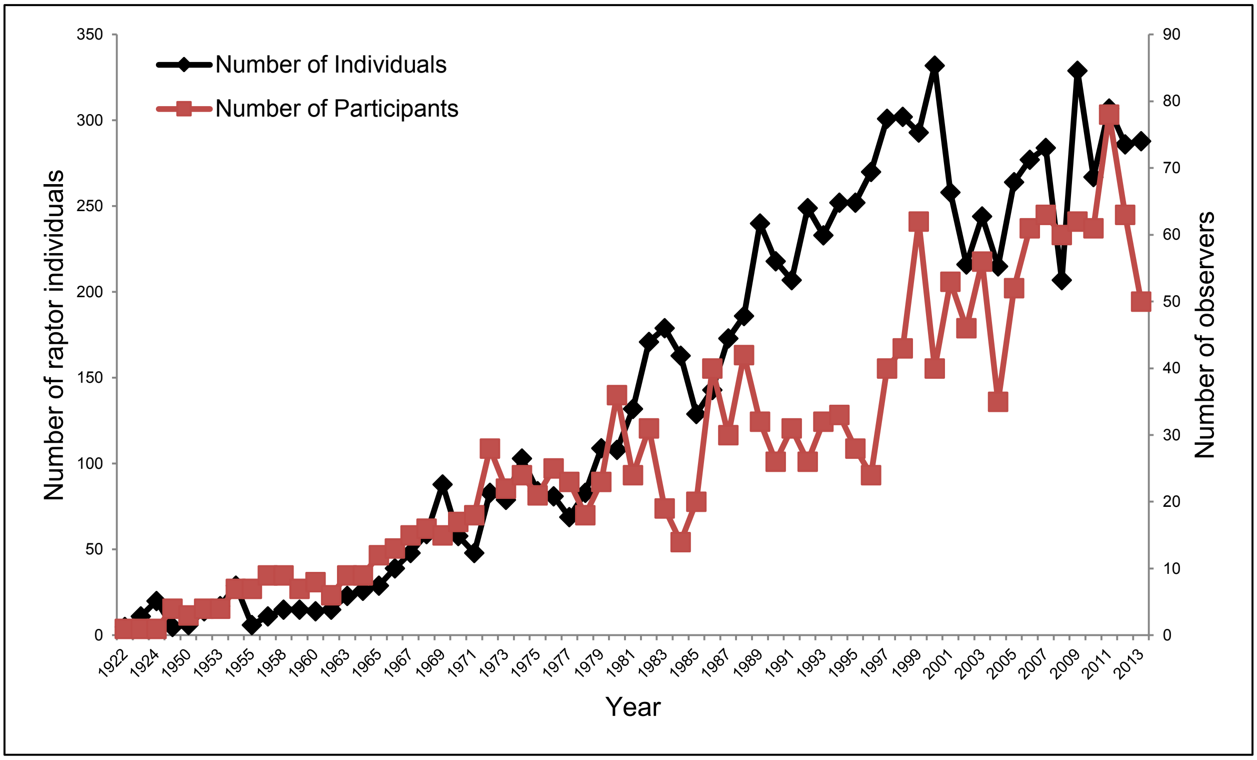

Figure 51. The number of individuals observed during each year of the Grand Junction CBC (black, primary Y-axis) and the number of participants in the Grand Junction CBC (red, secondary Y-axis) from 1922-2013. Data retrieved from http://netapp.audubon.org/CBCObservation/Historical/ResultsByCount.aspx#.

Table 67. Average annual raptor abundance during the Grand Junction CBC from 1922-1924, 1945, 1950, and 1952-2013. Data have not been standardized by the number of CBC observers per year and should be interpreted with caution. Data retrieved from http://netapp.audubon.org/CBCObservation/Historical/ResultsByCount.aspx#.

Common Name	Avg. # of Ind./Year
American kestrel	45.85
red-tailed hawk	32.89
western screech-owl	13.54
northern harrier	13.42
bald eagle	7.08
sharp-shinned hawk	6.72
Cooper's hawk	6.26
golden eagle	4.98
prairie falcon	2.49
great horned owl	2.35
merlin	1.68
long-eared owl	1.16
barn owl	1.03
ferruginous hawk	0.91
northern goshawk	0.83
peregrine falcon	0.57
rough-legged hawk	0.55
red-shouldered hawk	0.31
northern pygmy-owl	0.11
turkey vulture	0.06
northern saw-whet owl	0.03
Swainson's hawk	0.03

CBC results from the last 5 years (2009-2013) indicate similar trends as those observed for the duration of the CBC (Table 68). Red-tailed hawks continued to be the most abundant species in the Grand Junction area (82.6 individuals/year), with American kestrels and western screech-owls also being frequently observed. Species that were observed historically but were absent in the last 5 years included: long-eared owl (*Asio otus*), barn owl (*Tyto alba*), red-shouldered hawk (*Buteo lineatus*), northern pygmy-owl, turkey vulture, and the Swainson's hawk.

Table 68. Raptor species abundance during the last 5 years (2009-2013) of the Grand Junction CBC. Average yearly abundance was calculated using only the 5 years of data presented in the table, and total abundance represents the sum of all individuals of a species observed over the 5 years.

Species	2009	2010	2011	2012	2013	Average Yearly Abundance	Total Abundance
red-tailed hawk	94	68	86	88	77	**82.6**	**413**
American kestrel	56	89	70	59	55	**65.8**	**329**
western screech-owl	33	33	54	64	52	**47.2**	**236**
bald eagle	49	11	16	9	27	**22.4**	**112**
northern harrier	40	14	13	17	13	**19.4**	**97**
Cooper's hawk	18	18	22	11	27	**19.2**	**96**
sharp-shinned hawk	16	14	19	13	12	**14.8**	**74**
great horned owl	4	3	11	10	14	**8.4**	**42**
golden eagle	3	4	6	6	3	**4.4**	**22**
merlin	7	3	3	4	3	**4**	**20**
peregrine falcon	2	5	1	0	3	**2.2**	**11**
prairie falcon	1	4	3	3	0	**2.2**	**11**
rough-legged hawk	2	1	1	1	2	**1.4**	**7**
ferruginous hawk	3	0	1	0	0	**0.8**	**4**
northern goshawk	1	0	0	1	0	**0.4**	**2**
northern saw-whet owl	0	0	1	0	0	**0.2**	**1**
Total Yearly Abundance	**179**	**110**	**151**	**139**	**156**		**1,477**

Productivity

Raptor productivity can be reported many ways, often depending upon the species of interest. For example, Ambrose et al. (2008) reported productivity for peregrine falcons as the number of nestlings per total and successful pairs, while Postupalski (1974) defined productivity for bald eagles as the number of fledglings or large young per occupied nest. Similarly, the reference conditions for the minimum productivity levels to support a raptor population are also variable and understudied. According to data collected pre-1955 and post-1985 (Hickey and Anderson 1969; Enderson and Craig 1974; Radcliffe 1993; USFWS 2003), a healthy peregrine falcon population typically has nest success rates of 45-66%. For bald eagles, a nesting success rate of 50% and 0.7 young per occupied nest has been suggested for bald eagle populations to maintain themselves (Tetreau 1998). Because of the variability observed in productivity requirements for different raptor species, a specific reference condition is likely not broadly applicable for this measure.

Only one study has occurred within COLM that has documented raptor productivity (Lambeth 1996), and this study was specific to peregrine falcons. During Lambeth (1996), peregrine falcon occupancy and productivity were observed during the 1994 and 1995 breeding seasons. Three active eyries were documented in COLM: Colorado National Monument eyrie (CNM), Ute Canyon eyrie, and No Thoroughfare eyrie. From 1994-1995, approximately 14 peregrine falcon chicks fledged from these three nest sites. The CNM eyrie fledged two females and one male in both 1994 and 1995. The Ute

Canyon eyrie had four chicks banded in 1994, although these chicks likely did not survive until fledgling age (reported as failed in July 1994). In 1995, the Ute Canyon nest fledged two female chicks. The No Thoroughfare eyrie fledged two females and one male in both 1994 and 1995.

Prior to the Lambeth (1996) report, the CNM eyrie had been previously observed from 1986-1993, and the Ute Canyon eyrie had been observed in 1993. The results of historic monitoring are presented in Lambeth (1996), although the methodology and timing of the observations are not indicated. Productivity estimates for all eyries in COLM from 1986-1995 are presented in Table 69.

Table 69. Peregrine falcon productivity at three eyries in COLM, with values to the right of the dashed line representing productivity estimates observed by Lambeth (1996). An * indicates a re-nesting effort by a pair (production of a second nest after the first one failed).

Eyrie	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
CNM Eyrie	2	4	4	2	3*	3	2	2	3	3
Ute Canyon Eyrie								3	?	2
No Thoroughfare Eyrie									3	3

<u>Number of Active Nest Sites</u>

While there are likely many raptors that nest within the park, only the nest sites of the peregrine falcon have been studied in COLM. Lambeth (1996) documented peregrine nest sites in three different locations in the park: the CNM eyrie was located just to the southwest of Independence Monument, the Ute Canyon eyrie was located in the central portion of Ute Canyon, on the east rim of the canyon, and the No Thoroughfare eyrie was located just south of Devils Kitchen in the No Thoroughfare Canyon.

Despite the fact that the nesting sites of other raptors have been understudied, COLM likely offers important nesting habitats for many species. Counting the number of *active* nests in a territory, rather than all the nests in a territory is crucial, as several species (e.g., bald eagle, golden eagle) may construct several alternate nests in a territory. Counting all nests in a territory, rather than only the active nests, would yield an incorrect estimate of productivity and occupancy for raptors in the park. The tall cliffs of COLM provide excellent nesting platforms for species such as the peregrine falcon, prairie falcon, red-tailed hawk, and golden eagles. The juniper stands of the park also provide potential nesting habitat (or adequate cover for ground nests) for red-tailed hawks, ferruginous hawks, and northern harriers. Some species, such as the western screech-owl, prefer the hollowed out cavities of dead trees or rock crevices. This measure represents a data gap in the park, and warrants future monitoring and investigation.

<u>Threats and Stressor Factors</u>

According to Postovit and Postovit (1987), human activities impact raptors in at least three ways: 1) by directly harming (physically) or killing eggs, young, or adults; 2) by altering raptor habitats; and 3) by disturbing or disrupting normal raptor behavior. Recreational activities often result in incidental disturbance to raptors, and in COLM one such activity is rock climbing. Rock climbing has the potential to have severe impacts on nesting raptors, even if the climbers do not directly come into contact with the nest site or nesting birds (Richardson and Miller 1997). The shouting, yelling, or other disruptive noises produced by climbers may be loud enough to flush nesting raptors from the nest (Call 1979, Ratcliffe 1980); even short periods away from eggs or nestlings could cause nest failure in many species (Suter and Joness 1981, Richardson and Miller 1997). The ferruginous hawk and peregrine falcon, both commonly observed species in COLM, are known to abandon nests if exposed to nearby rock climbing or human activity (Snow 1972, Olsen and Olsen 1980, White and Thurow 1985). Furthermore, Boeker and Ray (1971) found that human disturbances were the primary cause of 85% of nesting losses for golden eagles. Careful monitoring of the raptor nests in areas of high recreational use will be critical to observe potential trends in occupancy or productivity in nearby nesting raptors.

<u>Data Needs/Gaps</u>

As was mentioned previously, this assessment did not incorporate the recently published McLaren (2015), which summarizes the results of the landbird monitoring in the park during 2014. Annual monitoring of the raptor population of COLM is needed to assess this component's current condition. Currently, no data exist relating specifically to raptor richness, abundance, productivity, or the number of active nest sites in the park. Some bird studies have taken place in the park and have documented raptor presence. However, these studies have not focused on raptors specifically, and monitoring methodology (and timing) may have certain biases that make detecting raptors more difficult. A monitoring program dedicated to the park's raptor population, and that samples during the breeding, migration, and winter seasons, would allow for a more complete assessment of condition for this resource.

<u>Overall Condition</u>

Raptor Richness

The project team defined the *Significance Level* for raptor richness as a 3. NPS (2015) identifies 24 raptor species as either present or probably present in the park; this list can only be used as a checklist for comparison as the list is not the direct result of one specific field-based study. No raptor-specific monitoring effort has taken place in COLM (outside of limited productivity monitored by Lambeth [1996] from 1994-95), but two studies of the bird community in COLM have taken place during the breeding season in the past two decades. Giroir (2001) sampled the avifauna of COLM exclusively during the breeding season and documented seven raptors. RMBO monitoring efforts in COLM have focused on the pinyon-juniper habitats during the breeding season from 2005-2014. Between the two routes, RMBO staff observed seven different raptor species in the park, with yearly combined species richness peaking at four species (Figure 48). Many of the historically low species richness estimates for COLM (see 1922-1964) occurred during years with only single-digit numbers of observers.

RMBO monitoring results have been relatively low when looking at raptors only, but this may be due in part to sampling biases that exist in the survey methodology, as has been previously discussed. However, there is limited recent and long-term data and assessment of current condition and trends would likely be speculative at best. Because of this, the *Condition Level* for raptor richness in COLM was determined to be unknown.

Abundance
The abundance measure was assigned a *Significance Level* of 2 during project scoping. While Giroir (2001) and RMBO monitoring have produced some raptor abundance statistics, the surveys were not specific to raptors, and utilized a methodology that made it difficult for raptor species to be observed (i.e., raptors are not highly vocal, and transects were in areas where only raptors directly overhead would be observed). Because of this, raptor abundance levels were low during the two studies.

Although a good deal of data exists from the Grand Junction CBC, there are inherent biases that exist in the survey's methodology that makes assessment of current condition problematic. The Grand Junction CBC surveys only a portion of COLM (Figure 47), so results from the survey are not indicative of the abundance trends for all raptor species, individual count points, or the entire park. Count locations and the number of observers limit the overall usefulness of index count data, and it is often not advisable to estimate overall population sizes (i.e., abundance) from these data alone (Link and Sauer 1999); these biases may influence how many individuals are observed in a given year, and may potentially explain the annual variation observed in species each year.

Two of the five most abundant raptor species observed on the Grand Junction CBC exhibited range-wide declines when comparing breeding bird survey (BBS) data from 1966-2010 (Sauer et al. 2011). The American kestrel experienced a population decline of approximately 1.5% per year from 1966-2010, which resulted in a cumulative population decline of 48% over that time period (Sauer et al. 2011). The northern harrier declined 0.8% per year, and experienced a population decline of 30% over the same time period (Sauer et al. 2011). Conversely, the red-tailed hawk, which was the most abundant raptor during CBC efforts, has increased in population size over the same period and has expanded much of its range in North America (Sauer et al. 2011). Until raptor abundance is more closely monitored in COLM, neither a *Condition Level* nor a current trend can be assigned.

Productivity
Productivity was assigned a *Significance Level* of 3 by COLM and NPS managers. Outside of some peregrine falcon nest monitoring efforts in the late 1980s and early 1990s, there has not been any active monitoring of raptor productivity in the park. The canyon walls, pinyon juniper forests, and shrublands of the park likely provide critical nesting habitat for many of the raptor species in the park. How productivity is monitored for each species often varies; however, some sort of monitoring protocol is needed in the park in order to assess the current condition of this resource. Because of this data gap, a *Condition Level* was not assigned to this measure.

Number of Active Nest Sites
The number of active nest sites in COLM was assigned a *Significance Level* of 3 during project scoping. Outside of Lambeth (1996) there has been no project that documented the number of active nesting sites in the park. Lambeth (1996) only focused on nesting peregrine falcons; there are numerous other raptor species in the park that nest in a variety of habitats. Until these nesting sites are documented, a *Condition Level* cannot be assigned to this measure.

Weighted Condition Score

A *Weighted Condition Score* was not assigned to the Raptors measure due to a lack of data for three of the four specified measures. Similarly, a trend designation was also not made. Until data are collected that specifically relates to abundance, productivity, and the number of active nest sites, the current condition of this resource is unable to be determined.

Raptors			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Abundance	2	n/a	
Raptor Richness	3	n/a	
Productivity	3	n/a	
Number of Active Nest Sites	3	n/a	

4.10.6 Sources of Expertise

This assessment relied on published literature as the primary source of expertise, with review by NPS staff.

4.10.7 Literature Cited

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4.11 Small Mammals

4.11.1 Description

Small mammals are important as prey items for predatory birds, herpetofauna, and other mammals, and also as influential members of the ecological communities where they occur (Cook et al. 2006). Small mammals can directly affect successional dynamics in their habitats by feeding on plants and insects at various intensities, depending on their abundance and composition (Cook et al. 2006).

Determining what constitutes a small mammal versus a medium to large mammal is somewhat loosely defined. Merrit (2010) defined “small” to include all mammals weighing less than 5 kg (11 lbs). Since this criterion is rather arbitrary in nature, there is room for inclusion of a mammal that may reach a slightly heavier weight. Typical small mammals found in COLM include rabbits, squirrels, rats, mice, bats, chipmunks, gophers, shrews, weasels, and skunks (Photo 15). North American porcupines (*Erethizon dorsatus*) are also included, but tend to range in weight from 5kg to 11.5 kg (11 lbs to 25 lbs), which will be the largest of the small mammal included here (Roze 2009). Bats are also considered small mammals; however they are not discussed in this section, as they are discussed in depth in Chapter 4.15 of this report.

Photo 15. Desert cottontail (top) (Anna Davis, SMUMN GSS), Ord’s kangaroo rat (middle), and deer mouse (bottom) are all examples of small mammals found in COLM (NPS Photos).

4.11.2 Measures

- Species richness
- Abundance
- Distribution

4.11.3 Reference Conditions/Values

The reference condition for small mammals consists of data collected by Miller (1964). Data in this report include species observed, relative abundance, and general descriptions of where each type of mammal was most often observed and where there were successful collections.

4.11.4 Data and Methods

Miller (1964) conducted mammal sampling in the park in 1961 and 1962. The purpose was to document and catalog the extent of mammals that inhabited the park and to describe their ecological distributions (Miller 1964). Sampling was conducted at 30 sites during the two year period and notes were recorded on the site area, vegetation association, elevation, and the sample dates. Sampling was accomplished though the trapping and shooting of specimens. Traps including museum special traps, Victor rat traps, and mouse traps were set in lines intended to cross-section the area's major habitat types and were set approximately 2.4-3.0 m (8-10 ft) apart (Miller 1964).

Miller (1980) compiled a list of mammal species that occur in COLM as well as some species that are likely to occur in the park due to known species ranges or existence of suitable habitat. This list was later revised by Armstrong (1988). While not mammal field surveys or studies, they were compilations of information from natural history reports and anecdotal accounts of mammal observations. Armstrong (1988) also provided some details on where species were usually observed and the general abundance of each species. This list includes all mammals, but for the purposes of this assessment, the larger and winged mammals were excluded.

NPS (2015) contains a list of species that have been confirmed within the park or have overlapping geographic ranges and suitable habitat in the park, and therefore probably occur.

4.11.5 Current Condition and Trend

Species Richness

The NPS Certified Species List (2015) lists a total of 28 small mammal species that are either confirmed as occurring within the park (20), probably present (6) or unconfirmed (2). Miller (1964) confirmed 21 small mammal species occurring within the park. Miller (1980) identified 21 species occurring within the park and four that hypothetically could occur in the park. Armstrong (1988) identified 22 species within COLM and another six species outside park boundaries but nearby. A comparison to the NPS certified species list (NPS 2015) is shown in Table 70.

Table 70. The species of small mammals, (excluding bats) that have been documented or may occur in COLM.

Scientific Name	Common Name	Miller (1964)	Miller (1980)	Armstrong (1988)	NPS (2015)
Ammospermophilus leucurus	white-tailed antelope squirrel	X	X	X	X
Bassariscus astutus	ringtail	X	X	X	X
Cynomys leucurus	white-tailed prairie dog	X	X	X	U
Dipodomys ordii	Ord's kangaroo rat	X	X	X	X
Erethizon dorsatus	North American porcupine	X	X	X	X
Lepus californicus	black-tailed jackrabbit	X	X	X	X
Lepus townsendii	white-tailed jackrabbit	X	X	X	X
Marmota flaviventris	yellow bellied marmot			X	X
Mephitis mephitis	striped skunk	X	X	X	X
Microtus longicaudus	long-tailed vole		H	Z	P
Mus musculus	house mouse	X	X	X	X
Mustela frenata	long-tailed weasel			X	X
Neotoma cinerea	bushy-tailed woodrat	X	X	X	X
Neotoma lepida	desert woodrat		H	Z	
Neotoma mexicana	Mexican woodrat	X	X	X	X
Notiosorex crawfordi	Crawfords' desert shrew				P
Onychomys leucogaster	northern grasshopper mouse		H	Z	P
Perognathus flavescens	plains pocket mouse	X	X	X	X
Peromyscus boylii	brush mouse				P
Peromyscus crinitus	canyon mouse	X	X	X	X
Peromyscus maniculatus	deer mouse	X	X	X	X
Peromyscus truei	pinyon mouse		X	X	X
Reithrodontomys megalotis	western harvest mouse	X	X	X	X
Spermophilus lateralis	golden-mantled ground squirrel		H	Z	U
Spermophilus variegatus	rock squirrel	X	X	X	X
Spilogale gracilis	western spotted skunk	X	X	X	X
Sylvilagus audubonii	desert cottontail	X	X	X	X
Tamias minimus	least chipmunk	X	X	Z	P
Tamias rufus	Hopi chipmunk			X	X
Thomomys bottae	Botta's pocket gopher		H	Z	P

X = confirmed, U = unconfirmed, P=probably present, H=hypothetically occurs, Z = not documented in COLM, but nearby

Abundance

Knowing the abundances of small mammals is useful for assessing the ecological health of the park since they are a primary food source and can directly influence the population dynamics of many other fauna (Cook 2001). Data regarding the abundance of small mammals in COLM is very limited. Miller (1964) is used as the reference condition, and other than the certified species list (NPS 2015), the other report that was used for comparison was Armstrong (1988). Though not a field study, it does contain information on abundance. According to Miller (1964), 14 species were common or abundant and six species were uncommon or rare. The NPS (2015) lists the abundance of most small mammals as “unknown”; only one species is considered common, one uncommon, and one rare. A comparison is shown in Table 71.

Table 71. General abundance information for small mammals in COLM.

Scientific Name	Common Name	Miller (1964)	Armstrong (1988)	NPS (2015)
Ammospermophilus leucurus	white-tailed antelope squirrel	uncommon	fairly common	unknown
Bassariscus astutus	ringtail	common	possibly common	unknown
Cynomys leucurus	white-tailed prairie dog	rare	frequent at lower elevations	unknown
Dipodomys ordii	Ord's kangaroo Rat	common	abundant	unknown
Erethizon dorsatus	North American porcupine	common	common	unknown
Lepus californicus	black-tailed jackrabbit	common	common most years	uncommon
Lepus townsendii	white-tailed jackrabbit	common	uncommon most years	rare
Marmota flaviventris	yellow bellied marmot	-	uncommon	unknown
Mephitis mephitis	striped skunk	uncommon	common	unknown
Mus musculus	house mouse	common (only near buildings)	common	unknown
Mustela frenata	long-tailed weasel	-	reported increasingly since 1981	unknown
Neotoma cinerea	bushy-tailed woodrat	common	common	unknown
Neotoma mexicana	Mexican woodrat	common	common	unknown
Perognathus flavescens	plains pocket mouse	uncommon	common	unknown
Peromyscus crinitus	canyon mouse	common	common	unknown
Peromyscus maniculatus	deer mouse	abundant	abundant	unknown
Peromyscus truei	pinyon mouse	abundant	common	unknown
Reithrodontomys megalotis	western harvest mouse	common	common	unknown
Spermophilus variegatus	rock squirrel	very common	fairly common	unknown
Spilogale gracilis	western spotted skunk	uncommon	fairly common	unknown

Table 71 (continued). General abundance information for small mammals in COLM.

Scientific Name	Common Name	Miller (1964)	Armstrong (1988)	NPS (2015)
Sylvilagus audubonii	desert cottontail	abundant	frequently common; fluctuates	common
Tamias minimus	least chipmunk	uncommon	undocumented	unknown
Tamias rufus	Hopi chipmunk	-	abundant	unknown

<u>Distribution</u>

The distribution of small mammals within the park has not been assessed since Miller (1964), which serves as both the reference condition as well as the only source describing distributions of the listed mammal species in the park (Table 72). Current condition and trend is not available and is considered a data gap. Surveying the park to determine the distribution of small mammals would be useful for many of the same reasons abundances are useful.

Table 72. General description of small mammal distributions relative to the parks area (Miller 1964).

Scientific Name	Common Name	Distribution
Lepus californicus	black-tailed jackrabbit	lower elevations, but also throughout the park areas
Lepus townsendii	white-tailed jackrabbit	higher abundances at 2km (6500 ft) and above, but distributed throughout the park
Sylvilagus audubonii	desert cottontail	throughout the park
Dipodomys ordii	Ord's kangaroo rat	areas with deep sandy soils
Perognathus flavescens	plains pocket mouse	areas with sparse vegetation and loose, sandy soils, possibly dependent on prickly pear
Mus musculus	house mouse	observed only in employee residences sporadically as imported with human activities; a permanent population was suspected in the warehouse
Neotoma cinerea	bushy-tailed woodrat	throughout the park
Neotoma mexicana	Mexican woodrat	throughout the park, but most found in piñon-juniper
Peromyscus crinitus	canyon mouse	rocky areas
Peromyscus maniculatus	deer mouse	throughout the park
Reithrodontomys megalotis	western harvest mouse	sparsely vegetated areas with sandy soils
Ammospermophilus leucuru	white-tailed antelope squirrel	lower elevations preferred, greasewood-saltbrush-sagebrush flats
Tamias minimus	least chipmunk	wide altitudinal distributions, recorded from 2 to 3.8 km (6500 to 12500 feet)

Table 72 (continued). General description of small mammal distributions relative to the parks area (Miller 1964).

Scientific Name	Common Name	Distribution
Spermophilus variegatus	rock squirrel	throughout the park, but most found in piñon-juniper
Erethizon dorsatus	North American porcupine	populated canyon floors and rim communities where coniferous forest was most dense
Bassariscus astutus	ringtail	rocky canyons and canyon rims
Spilogale gracilis	western spotted skunk	most observed near canyon rims and near the camping area
Mephitis mephitis	striped skunk	most sightings occurred near the camping area; frequently caught dumpster diving

Threats and Stressor Factors

Several factors were identified by park natural resource managers that are considered threats or stressors to the small mammal populations and habitats at COLM. Vehicle traffic and roadway mortality, regional climate change and drought, feral and domestic cats, disease, and habit loss were the primary threats expressed by park resource managers.

Road traffic poses a potential threat to the small mammals of COLM. NPS staff observed a high number of small mammal fatalities along park roadways each year (Hartwig, written communication, 14 August 2015). The effects of roadways have also been the topic of many research studies (Jochimsen et al. 2004). While species react differently to the presence of roads, some mortality in small mammals is expected to occur. Observations suggest that species active during the day are likely more vulnerable to road mortality at the park, as traffic volumes are higher than at night (Hartwig, written communication, 14 August 2015). Some small mammals actually favor the unique habitat in road rights-of-way (Adams and Geis 1983), which may increase their risk of being struck by vehicles. In addition to direct mortality, roads can fragment habitat, restrict animal movements, and provide a vector for the introduction of exotic species (Bissonette and Rosa 2009).

Drought can have adverse effects on small mammals. Regional climate change may impact the ranges of small mammals (Moritz et al. 2008). In response to global warming, certain species may expand their range to higher elevations to compensate for the temperature change, leading to a shift in community composition (Moritz et al. 2008). Damage to desert habitats during severe droughts can be catastrophic when combined with regional increases in anthropogenic activities such as livestock grazing, energy exploration and developments, and certain types of recreational activities (USGS 2007). The Upper Colorado River Basin, where the park is located, has been experiencing increases in these anthropogenic activities, and others, while simultaneously being one of the driest regions in the U.S. (USGS 2007). These factors make protected areas, such as COLM, important habitat areas for small mammal communities and the wildlife that rely upon them (USGS 2007). Even within a protected area such as COLM, losses of nitrogen-fixing organisms and flora often result when drought periods become extensive due to increased temperatures and drier conditions that are associated with global climate change (USGS 2007). The ecosystem processes within COLM are highly dependent on the structural and functional services of various grasses, lichens, and biological soil crusts; damage to these key ecosystem components can negatively impact small mammals, as many are reliant on them for food and habitat (USGS 2007).

Feral cats are considered a threat to small mammals and, in some scenarios, have been implicated in numerous wildlife extinctions (Loss et al. 2013). Feral cats likely prey on small mammals at COLM, particularly near the eastern urban boundary. According to Loss et al. (2013), feral cats have substantial, negative impacts on various wildlife species and may require controls to reduce their impact. The estimate of mammal mortalities caused by feral cats annually is between 6.8 and 20.7 billion, with differences between landscape types (Loss et al. 2013). The findings indicated that 75-100% of the prey taken by feral cats consist of native species, even in areas where non-native counterparts are the dominant taxa (Loss et al. 2013).

Sylvatic plague is a concern to park management since it can infect many species of mammals, including humans. The plague is a bacterial (*Yersinia pestis*) disease spread by fleas and infects various wild rodent species (USGS 2013). Several small mammals are likely susceptible to plague, including chipmunks (*Tamias* spp.) and prairie dogs (*Cynomys* spp.). Prairie dogs are especially susceptible to plague; prairie dog colonies in some regions have been completely wiped out by plague with an estimated ≥90% mortality rate (USGS 2013). COLM's prairie dog population is thought to be extirpated, likely due to plague (Hartwig, written communication, 14 August 2015). Another disease of concern is tularemia, caused by the bacteria *Francisella tularensis*. This disease occurs naturally in rodents and lagomorphs (e.g., rabbits) and can be transmitted to a variety of other vertebrates, including humans (OIE 2008).

Porcupines were once abundant in COLM. Wildlife reports dating back to the 1940's cite the presence of porcupines and that the evidence of their activity could be found throughout the park (Smith 1941, Finch 1942). In fact, in his 1942 wildlife report, Finch noted that "…these animals are becoming more numerous, or more correctly, are becoming thick" (Finch 1942 p. 2). A wildlife distribution study of COLM in the 1960's reported that the majority of the porcupine population was located in the canyon floors and rim communities (Miller 1964). Miller (1964) based this on the frequency of sight records and porcupine sign in these more dense coniferous forest areas. Miller (1964) noted that porcupines had caused extensive damage to pinyon pines in many locations throughout the park. Miller (1964) also noticed annual fluctuations in the porcupine population. During this period, the Protection Division was authorized to control porcupines in certain locations within the park (Miller 1964). During the period 1960-1964 approximately 80 porcupines were killed along Rim Rock Drive (Miller 1964). Miller (1964) recommended that the porcupine reduction policy be evaluated periodically, as to determine the validity of controlling the porcupine population on the basis that they are not compatible with the pinyon pine. Miller (1964) suggested an alternative control method where only porcupines found in the immediate vicinity of developments, such as the residential and visitor center areas should be eliminated. Miller (1964) further stated that the "indiscriminate killing of porcupines over the entire length of the Rim Rock Drive does not presently appear to be necessary or desirable as a continuous practice" (Miller 1964 p. 74).

Current records of the presence of porcupines within COLM could not be found, with the exception of Miller (1980), Armstrong (1988), and NPS (2015). Miller (1980) noted that porcupines were present within COLM, while Armstrong (1988) noted they were present and common. NPSpecies lists porcupines as present, but the abundance is unknown (NPS 2015). Porcupine or porcupine sign have not been reported to park staff in recent memory (Hartwig, written communication, 19 November 2015). Road kill is a normally a good indicator of the presence of porcupine, but park staff have not observed or received any reports of porcupines being struck by vehicles (Hartwig, written communication, 19 November 2015). There appears to be growing evidence and concern that, similar to the prairie dog, porcupines were once abundant but are no longer present within COLM. Further study would be needed to confirm this assumption.

A major threat to small mammal communities, as well as other wildlife, is loss of suitable habitat. Habitat loss can occur by fragmentation, disturbances (natural and anthropogenic), and regional climate changes. Fragmentation is often caused by land developments such as roadway construction, urban development, recreation, grazing, and energy exploration and development; all of these activities are occurring around the park boundaries.

Habitat loss and fragmentation contributed to the significant decline in prairie dog populations during the 20th century (Antolin et al. 2002). According to Miller (1964), the white tailed prairie dog had once been present in COLM. Miller (1964) interviewed a former park employee that described colonies of white tailed prairie dogs that occurred near the west entrance and along the Redlands Road during the 1940s. Surveys found abandoned colonies near the east entrance and one road-kill specimen was obtained within COLM on Rim Rock Drive (Miller 1964). Miller (1964) suspected soil depth and precipitation may have been limiting factors in the lack of white tailed prairie dog presence in COLM at that time (1958-1962). However, Armstrong and Rector (1988) described the white tailed prairie dog presence in the park as “frequent at lower elevations”; unfortunately, the details as to precise localities was not included for the time period of this particular observation. According to NPS (2015), the species is currently “unconfirmed” within COLM. NPS staff believes they are extirpated from the park (Hartwig, written communication, 14 August 2015). Five prairie dogs were observed at one colony near White Rocks in 1991; other former colonies appeared abandoned (Rodgers 1991). When the colonies were revisited in 2003, no prairie dogs or signs of activity were located (Rodgers 2003).

Data Needs/Gaps

Small mammal species richness, abundance, and distribution have been briefly and anecdotally documented by Miller (1964) and Armstrong and Rector (1988); these data sources are now outdated. The establishment of a routine small mammal survey that could document species richness, abundance, and distribution would provide managers with meaningful information that can be used to assess the condition of small mammals in the future. This survey, or a similar one, could establish whether the North American porcupine has been extirpated from the park.

Overall Condition

Species Richness
The species richness measure was assigned a *Significance Level* of 3. Outside of the NPS Certified Species List (NPS 2015), only two outdated sources of data are available (Miller 1964, Armstrong and Rector 1988); there are no recent data available to assess the overall condition or determine any trends. Because of this data gap, a *Condition Level* cannot be assigned at this time.

Abundance
This measure was assigned a *Significance Level* of 3. Recent data regarding the abundance of small mammals within COLM are not available for comparison with the reference condition (Miller 1964), which is outdated. Due to this data gap a *Condition Level* could not be assigned to this measure.

Distribution
A *Significance Level* of 2 was assigned to the distribution measure. No data are available on the distribution of small mammals within COLM specifically; Miller (1964) has some distribution descriptions of small mammal ranges and notes where species have been observed in the park. Since there are only outdated, generalized information regarding distributions, a *Condition Level* could not be assigned.

Weighted Condition Score
A *Weighted Condition Score* was not calculated for this component since there are no recent data available for the selected measures. Until data becomes available for these three measures, the current condition and trends in small mammal populations in COLM cannot be assessed.

Small Mammals			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Species Richness	3	n/a	
Abundance	3	n/a	
Distribution	2	n/a	

4.11.6 Sources of Expertise
This assessment relied on published literature as the primary source of expertise, with review by NPS staff.

4.11.7 Literature Cited

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4.12 Mountain Lion

4.12.1 Description

The mountain lion (also referred to as cougar, puma or panther) is the largest of the wild cat species found in Colorado (Photo 16). Male lions weigh approximately 68 kg (150 lbs) and may be 2.4 m (8 ft) in length (CPW 2015a). Females are smaller and weigh on average 42.8 kg (90 lbs) and are up to 2.1 m (7 ft) in length. The body of a mountain lion is covered in short, tawny or beige colored fur. The underbody and chest are paler or white in color. The mountain lion has a distinctive long tail with a black tip. Black tips are also found on the ears of mountain lions (CPW 2015a).

Photo 16. Mountain lion (NPS photo).

The mountain lion has an extensive range in areas where terrain and vegetation cover provide access to adequate prey populations. Suitable habitat for the mountain lion is found in many parts of Colorado, including the western portion of the state where COLM is located (CPW 2015a). Indicators of mountain lion presence in COLM were first documented in a 1939 wildlife report (NPS 1939). The home ranges of individual male mountain lions are greater than those of females (CPW 2015a). Females typically reproduce every other year beginning at 1 ½ - 2 ½ years of age. Most litters are born between May and October and average three kittens (CPW 2015a). The young are nursed for approximately two months, then stay with their mother until they are 11-18 months old (CPW 2015a).

A staple of the mountain lion's diet are ungulates, particularly deer. Mountain lions also prey on elk and bighorn sheep, as well as a variety of other small mammals such as mice, squirrels, raccoons, or rabbits. Livestock (e.g., cattle and sheep) as well as domestic pets may also fall prey to mountain lions (CPW 2015a). Classified as a predator, a bounty system was used to control the presence of mountain lions throughout the state of Colorado from 1929 through the mid-1960s (Watkins 2004). In 1965, the state of Colorado classified the mountain lion as a big game species. At that time, a quota system was employed and the collection of harvest data has since been recorded by the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) (Watkins 2004).

4.12.2 Measures

- Abundance
- Distribution
- Reproductive success

4.12.3 Reference Conditions/Values

Reference conditions for the abundance of mountain lions in COLM include historic accounts of occurrence documented in the park's annual wildlife reports from 1939 to 1962 (NPS 1939-1962).

The earliest report noted the status of the mountain lion in COLM as “occasionally reported” (NPS 1939). In each of the subsequent Annual Wildlife Reports available, the number of mountain lions was estimated at zero to five individuals. They were considered to be uncommon and only drifting through COLM (NPS 1939-1962).

The distribution reference condition for mountain lions in COLM is also based on historical COLM wildlife reports (NPS 1939-1962, Miller 1964), which give only general location data. Historical sightings occurred at various locations in the park and were not concentrated in any particular areas. Again, it should be noted that mountain lions were thought to be passing through COLM occasionally as part of their extended territory (NPS 1939-1962).

The reference condition for reproductive success of mountain lions in COLM is not defined. Very little information is available regarding the reproductive success of mountain lions utilizing COLM and Miller (1964) stated that “it is unlikely that lions den in the Monument very often”.

4.12.4 Data and Methods

The mountain lion was documented by COLM personnel in summary wildlife reports prepared annually or biannually for the park service between 1939 and 1962 (1939, 1941-1951, 1953-1959, 1962). These reports included occurrence estimates based on mountain lion tracks and actual sightings reported by park staff and visitors. The general location of each observation was sometimes included. Miller (1964) included a review of COLM wildlife reports dating back to 1938 and previously collected specimens, as well as interviews and field connections. No mountain lion specimens were collected; however, observation and track set records were summarized.

Armstrong and Rector (1988) completed an annotated checklist of mammals for COLM. This list includes a physical description as well as very general information about the distribution of the mountain lion. Field recognition signs for the mountain lion were also described including scrapes, prey, and the use of rock shelters near brush or woodlands (Armstrong and Rector 1988).

When the mountain lion was reclassified as a big game species in the state, CPW began collecting mortality statistics within each Game Management Unit (GMU) (Watkins 2004). These data include the number of hunting days, mortality, and sex of harvested lions for GMU 40 where COLM is located (Watkins 2004) (Figure 52). GMUs are further grouped into data analysis units (DAUs) to address broader management needs; COLM falls within DAU L-22 (Figure 52). A management plan for DAU L-22 was released in 2004 (Watkins 2004). This plan includes a summary of harvest/mortality history, a population estimate, and harvest objectives for the DAU as a whole (Watkins 2004). Hunting is not allowed within COLM, but harvest data for the GMU or DAU may provide some insight into the status of mountain lions in the region surrounding the park.

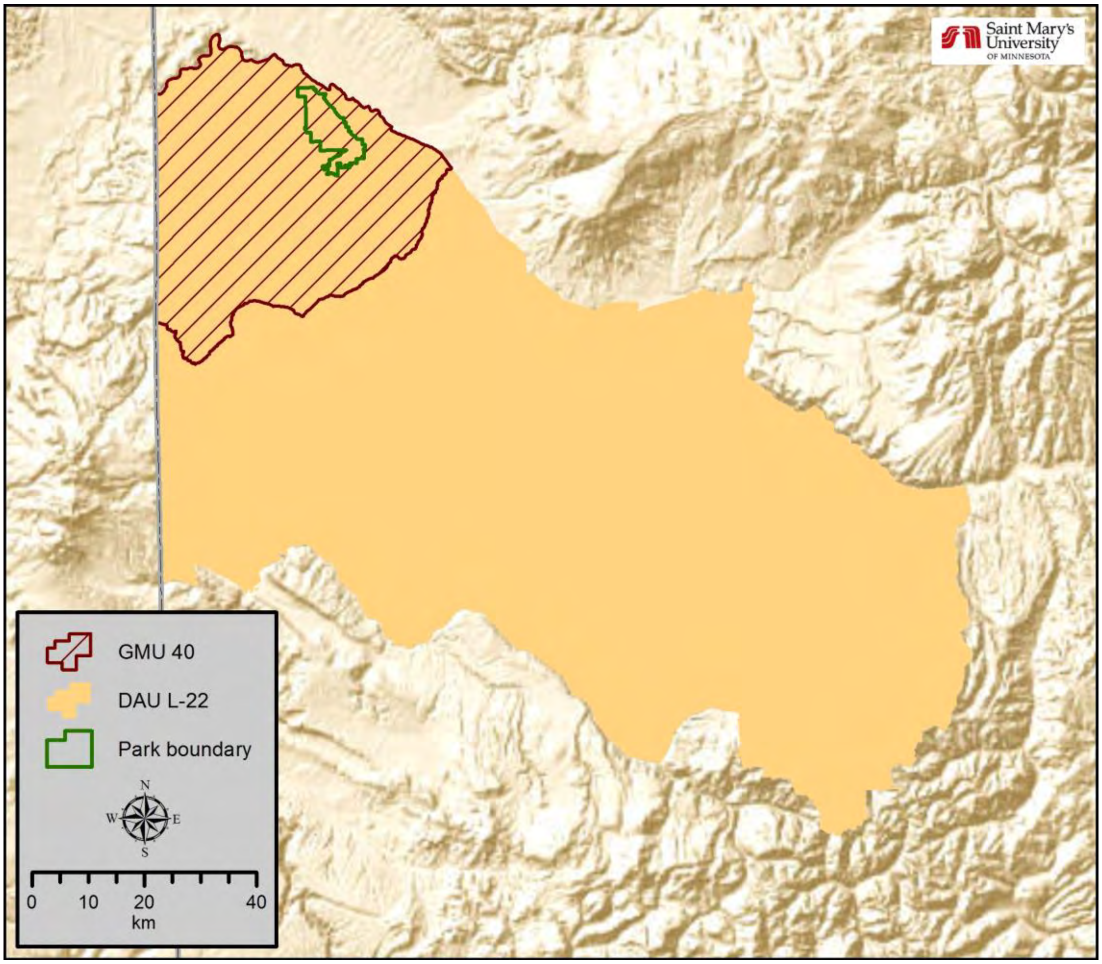

Figure 52. The location of COLM within GMU 40 and DAU L-22 (CPW 2015b).

4.12.5 Current Condition and Trend

Abundance

Estimating mountain lion abundance is challenging, due to the species' large home ranges, low density, and secretive nature (Watkins 2004). Historical wildlife reports from COLM estimate the number of mountain lions in the park between zero and five individuals (NPS 1939-1962). No more recent abundance estimates specific to the park are available. According to Watkins (2004), the portion of GMU 40 in which COLM is located is likely to be a "high density" mountain lion area (4.6 lions/100 km^2), due to the presence of favorable habitat (pinyon-juniper and mixed mountain shrub) and relatively high prey populations in the area. Given this estimate and the size of COLM (<100 km^2), it is unlikely that the park could support more than four mountain lions.

Distribution

Historical COLM wildlife reports (NPS 1939-1962) included only general mountain lion distribution data and were based on three sightings within the park: in the vicinity of Ute Canyon in 1944, around Coke Ovens in 1949, and a visitor sighting on Rim Rock Drive in 1950. Mountain lion tracks were also observed in areas adjacent to the park and within COLM near the northwest boundary and in Ute Canyon (NPS 1939-1962). Miller (1964) reported 12 observations of mountain lions or tracks within

COLM (Table 73), some of which likely overlapped with the NPS (1939-1962) reports. The only more recent information on the distribution of the mountain lion within COLM was the report of a distinct print at No Thoroughfare Canyon Alcove Spring in the summer of 2014 (Lamm et al. 2014). Park staff receives several unconfirmed reports of mountain lion sightings each year. These sightings are often brief encounters of an animal crossing in front of a vehicle or occasional reports of animals spotted on trails. These sightings have been reported throughout the park.

Table 73. Locations of historical mountain lion or track observations within COLM, 1938-1962 (Miller 1964).

Location	Date	Notes
Mouth of Fruita Canyon	May 1938	
East Glade Park Rd.	September 1942	Chasing two fawns
Black Ridge	October 1942	
Near Red Canyon	November 1944	
Fruita Canyon	October 1949	
Near Artists Point	February 1953	Tracks in snow
Near Red Canyon	August 1954	
50 yds north of Artists Point	November 1958	Tracks in snow
Kodels Canyon	Early October 1959	Tracks and deer carcass
Lower end of Kodels Canyon	Late October 1959	Tracks
¾ mile west of West Glade Park Road on Rim Rock Drive	July 1962	
Rim Rock Drive at West Glade Park Road junction	August 1962	Lying alongside road

The CPW considers the current extent of mountain lion habitat in the state to encompass COLM and surrounding lands (Figure 53; Watkins 2004). Since lions are present year round in the park and surrounding area, this is most likely the reason why he number of sightings also tends to be higher in the higher visitation months when the increased number of visitors provides more opportunities to encounter lions.

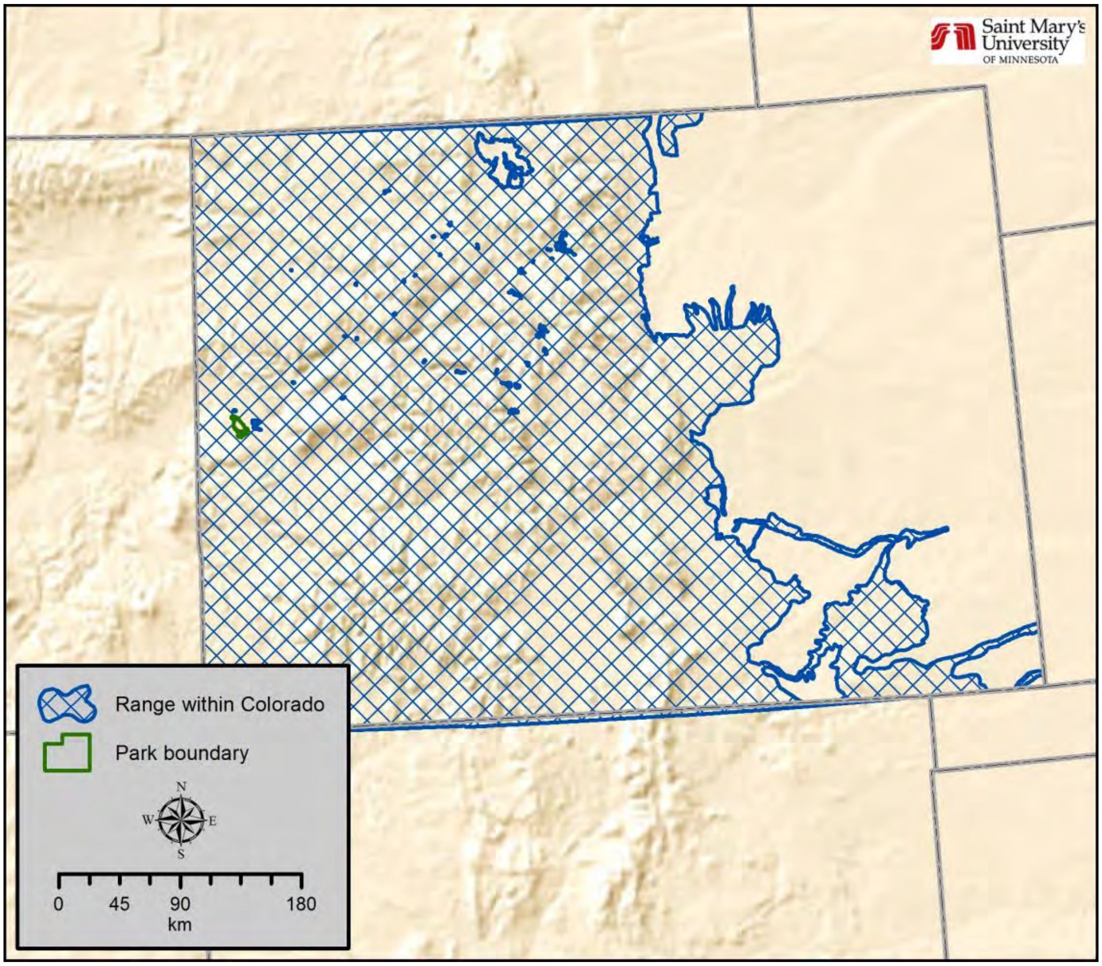

Figure 53. Mountain lion range within the state of Colorado (CPW 2014a).

Reproductive Success

No research was found that can be cited regarding the current reproductive success of the mountain lion within the boundaries of COLM or the surrounding area. No mountain lion dens or young have ever been reported within park boundaries, but it is possible that they are present.

Threats and Stressor Factors

Hunting outside park boundaries is a potential threat to mountain lions that utilize COLM. Data on mountain lion harvest in GMU 40 (Figure 53), which surrounds COLM, was obtained from the CPW website (CPW 2014b). Annual harvests between 2002 and 2013 ranged from one to eight mountain lions, with an annual mean of 4.7 lions (Table 74).

The predatory nature of mountain lions often leads to conflicts with rural landowners, particularly ranchers. Mountain lions using or moving through COLM may prey on the livestock of nearby landowners. An annual average of six loss claims were filed in the L-22 mountain lion DAU from 1995 to 2003 (Watkins 2004). The lion management plan for the L-22 area allows for the removal of mountain lions preying on livestock or causing public safety threats. The CPW (2014c) reported that on average four mountain lions were killed annually as a result of nuisance in the L-22 area between

2009 and 2014. A longer-term average, from 1989 to 2014, is 1.4 nuisance or “control” kills per year, which suggests that nuisance kills may have increased in recent years (CPW 2014c). While a female mountain lion suspected of preying upon several domestic sheep was killed by CPW just outside the park’s southern boundary, near Glade Park in August 2013, the park has not received or recorded any negative mountain lion conflicts with park visitors (Hartwig, written communication 30 January 2016). The safety of park visitors and mountain lions is a management priority and areas are posted when the presence of a mountain lion is reported (Hartwig, written communication, 30 January 2016).

Table 74. Mountain lion harvest in GMU 40, 2002-2013 (CPW 2014b).

Year	Males	Females	Total
2002	1	3	4
2003	0	4	4
2004	0	1	1
2005	1	0	1
2006	4	0	4
2007	7	1	8
2008	3	1	4
2009	5	2	7
2010	3	1	4
2011	4	3	7
2012	3	4	7
2013	4	1	5

A primary threat to the mountain lion includes the loss of habitat outside of COLM. The growth and increasing urbanization of the Grand Junction area is impacting suitable wildlife habitat along park boundaries (Evenden et al. 2002, NPS 2005). The result is habitat loss and increased fragmentation, which can impair the range and movements of large animals such as the mountain lion. Urban growth and development can lead to increased interactions and conflicts between humans and mountain lions (Hartwig, written communication, 20 September 2015). This could lead to increased control/removal efforts of “nuisance” mountain lions and limited tolerance for the species as a whole.

As a wide-ranging species, mountain lions are vulnerable to negative impacts from roads. These include vehicle-caused mortality, habitat fragmentation, and limitation of animal movements (Forman and Alexander 1998, Watkins 2004). The encroachment of human activities also threatens the mountain lion in COLM. These threats may be the result of increasing visitation, various recreational activities, and the need for associated infrastructure. In the 1980s and 1990s, park visitation averaged around 330,000 people annually (NPS 2015). In the past 5 years (2010-2014) visitation at COLM has risen to an average of nearly 430,000 visitors annually (NPS 2015). This increased visitation also raises concerns over potential human-mountain lion interactions, which could have negative impacts for both the mountain lions and the humans.

Data Needs/Gaps

Very few studies have documented mountain lion abundance and distribution in COLM and no studies of reproductive success have occurred (Evenden et al. 2002). Regular surveys or monitoring of mountain lions in COLM and the surrounding area would allow for more adequate assessment of this resource. Future studies on mountain lion movements in and around COLM would help managers better understand the status of the park's mountain lion population and potentially reduce the occurrence of mountain lion/human conflicts (Hartwig, written communication, 20 September 2015).

Overall Condition

Abundance

The abundance measure was assigned a *Significance Level* of 3. Though some data for the mountain lion in Colorado exists, there is no abundance data for the species specifically within COLM. Therefore, a *Condition Level* could not be assigned.

Distribution

The distribution measure was assigned a *Significance Level* of 2. Although some historic observation locations have been noted, there is no recent distribution data for mountain lion within COLM. Due to this lack of data, a *Condition Level* could not be assigned

Reproductive Success

The reproductive success measure was assigned a *Significance Level of 3*. No mountain lion dens have been reported within the park, but it is possible that they are present. Because there is no specific reproductive data on the mountain lion in COLM, a *Condition Level* was not assigned to this measure.

Weighted Condition Score

A *Weighted Condition Score* could not be assigned for mountain lions in COLM due to a lack of recent data. The current condition of the species within the park is unknown.

Mountain Lion			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Abundance	3	n/a	
Distribution	2	n/a	
Reproductive Success	3	n/a	

4.12.6 Sources of Expertise
Kim Hartwig, COLM Chief of Resources

Mike Wrigley, United State Forest Service (USFS) Wildlife Biologist

Stephanie Durno, CPW Biologist

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4.13 Bighorn Sheep

4.13.1 Description

Desert bighorn sheep (*Ovis canadensis nelsoni*) are present in COLM solely as the result of reintroduction efforts that began in Colorado in the 1970s (George et al. 2009). Desert bighorn sheep are a subspecies of bighorn sheep and are adapted to the desert ecosystems found in the southwestern areas of North America (Douglas 1999, George et al. 2009; Photo 17). These medium-sized ungulates forage on various trees, shrubs, grasses, and forbs. As a ruminant species, their four chambered stomachs feature high rates of nutrient extraction from the vegetation they consume (Armstrong 1988, Douglas 1999). Desert bighorn sheep generally reproduce in their third year, with breeding occurring in autumn and births in the spring (Douglas 1999). Typically, a single lamb is born after approximately a 6-month gestation period (Douglas 1999).

Photo 17. Two desert bighorn rams at COLM (NPS photo).

Desert big horn sheep are present at COLM due to the translocation of herds from Arizona and Nevada (George et al. 2009). This translocated herd is known as the Black Ridge Unit, S-56, or Devil's-Mee Canyon Unit herd (George et al. 2009). For the sake of consistency, this assessment will refer to it as the Black Ridge Unit herd. The historical occurrence of bighorn sheep in the park is uncertain, with only a few skeletal remains and Native American pictographs of sheep suggesting that the species once occupied the area near the park (BLM and CPW 1989, Sloan 1995).

Statewide, desert bighorn sheep experienced drastic declines in Colorado from the late 1800s into the 1970s, with estimations of the total U.S. population declining by nearly 70% from 1915 to 1970 (McCutchen 1995, George et al. 2009). The arrival of human settlers and their domestic livestock (e.g., sheep and goats) in the early 1800s competed with bighorn sheep for space, harvested them for food, and inadvertently introduced exotic diseases and parasites (Singer et al. 1996, George et al. 2009). These factors are thought to have heavily contributed to the decline in Colorado's bighorn sheep population (Singer et al. 1996, George et al. 2009).

4.13.2 Measures

- Abundance
- Distribution
- Reproductive success

4.13.3 Reference Conditions/Values

Graham (1995) outlined short- and long-term management objectives for the Black Ridge Unit bighorn sheep herd. The short-term goal was to increase the population to 200 individuals by 2000. The long-term goal is to support an estimated population of 400 sheep (Graham 1995, Holland and

Broderick 2013). These objectives will serve as reference conditions for the abundance measure. Reproduction is known to occur in the park, as lambs are regularly observed (Hartwig, written communication, 15 September 2015), but reproductive success has not been directly assessed and a reference condition has not been identified.

4.13.4 Data and Methods

Armstrong (1988) conducted a habitat inventory and population monitoring project in the Grand Junction, Colorado area. The population study monitored two separate bighorn sheep populations, the Black Ridge Unit herd and the Dominquez herd, from 28 April to 27 September 1988. This assessment primarily references the Black Ridge Unit herd as it resides in COLM. The range use of the Black Ridge Unit herd was also inventoried from 28 April to 4 September 1988 (Armstrong 1988).

The BLM and CPW published a management plan for Colorado's desert bighorn sheep in 1989. This was preceded by the 1987 desert bighorn sheep management plan, and was tailored to include restoration guidance for projects occurring on public lands (BLM and CPW 1989). Evaluation and monitoring for population status, crucial use areas, artificial water units, and forage composition and trends are outlined, with recommendations and guidance for future activities (e.g., introductions, baseline studies, and habitat improvement) (BLM and CPW 1989).

Graham (1995) produced a management update for the COLM-Black Ridge Unit herd. This report officially updated the unit name in the plan, from the "Devils-Mee Canyon Unit" to the "Black Ridge Unit" to better reflect the geographical distribution of the herd. In 1997, the 1989 BLM/CPW management plan was updated and included an overview of the history and trends of the population, recommendations for continued monitoring, and a discussion of management concerns (Graham 1997).

Sloan (1995) prepared a history of the Black Ridge Unit herd, with a focus on their use of COLM. This history covers the initial planning stages for the reintroduction through early 1995. The fates of each relocated bighorn group are addressed, along with threats to the population (e.g., hunting, disease, habitat alteration, and early population survey results (1991-1994) are included.

Singer et al. (1996) is a collaborative assessment of bighorn sheep populations in 15 Rocky Mountain region national park units. Five scientific advisory committees, consisting of 14 scientists from 11 institutions, were convened to assess the bighorn sheep research and management needs for these parks. The intent of the advisory committees was to outline management strategies that would address the "commonality of needs on a regional, subregional, or metapopulation basis" (Singer et al. 1996). The final report included a brief history of the COLM Black Ridge Unit herd along with recommendations to managers at the park for general future management strategies (Singer et al. 1996).

Duckett (2006) also describes the Black Ridge Unit herd in terms of its history, distribution, population status, and management concerns. Population estimates were determined through the use of helicopter and ground surveys (Duckett 2006). Duckett (2006) determined that the ground and air survey results were insufficient to produce an accurate population model; however, a population estimate was produced using the ground and air surveys in conjunction with anecdotal accounts from local entities such as employees of BLM, CPW and USFS, sheep hunters and other members of the public (Duckett 2006).

Sheep in the Black Ridge Unit herd were radio-collared and monitored by CPW between 2007 and 2012 to determine population size, range, survival rates, fecundity, and mortality causes (Stephanie Durno, CPW Biologist, written communication, 16 October 2015).

George et al. (2009) produced a 10-year management plan (2009-2019) for bighorn sheep in Colorado, including the Black Ridge Unit herd within COLM. Topics discussed in the plan include historical trends, current status, statewide objectives and planning, inventory and population estimation, population and harvest management, habitat management, health monitoring and management, and threats to the species (George et al. 2009).

Holland and Broderick (2013) produced an addendum to the 1997 Colorado bighorn sheep management plan. It also included a 2012 post-hunt population estimate of the Black Ridge Unit herd and percent of herd that resides within COLM (Holland and Broderick 2013).

4.13.5 Current Condition and Trend

<u>Abundance</u>

Prior to the reintroduction of bighorn sheep to the park in 1979-1980, there were no records that indicated a population had ever been sustained specifically within COLM. The last known population of bighorn sheep nearest to COLM was in what is now Dinosaur National Monument (George et al. 2009). This herd was reportedly extirpated as a result of an all-age die-off that occurred in 1933 (George et al. 2009).

Translocation preparations began in 1977, and the first group of 11 desert bighorn sheep was released in Devil's Canyon, just west of COLM, in November 1979 (Sloan 1995). This was done as part of the original BLM-led state-wide desert bighorn sheep restoration effort (BLM and CPW 1989). The initial goals for the Black Ridge Unit herd were to attain and sustain a minimum population of 400 animals (BLM and CPW 1989). The translocation program eventually relocated an additional nine bighorn sheep into Devil's Canyon, bringing the initial population to 20 (Sloan 1995). Relocated desert bighorn sheep were also reintroduced into Monument Canyon, with the release of 16 individuals (seven rams and nine ewes) in June 1980 (Sloan 1995). These sheep were captured from a wild population in Lake Mead National Recreation Area in Nevada (Sloan 1995). A summary of reintroductions by age group and sex is shown in Table 75.

Hunting is prohibited within COLM, but the Black Ridge Unit herd is susceptible to hunting in areas outside the park. Post-hunt population estimates for the Black Ridge Unit herd include those desert bighorn sheep that utilize the park for all or part of the year. Post-hunt population estimates for the Black Ridge Unit from 1986-2014 are shown in Figure 54. The population fluctuated from 1989-1995, but for the most part remained stable (George et al. 2009). The Black Ridge Unit herd has exhibited an overall decline over the period of record, from a peak of 150 in 1992 to low of 70 from

1995-2006, with a slight increase to 75 animals in 2007 (George et al. 2009). The most recent post-hunt population estimate published for the Black Ridge Unit is from 2012. This estimated the population of the Black Ridge Unit herd at 200, with approximately 40 animals (20%) occupying COLM (Holland and Broderick 2013). According to CPW unpublished data (received from Stephanie Durno, October 2015), the population estimate showed a large increase up to 230 sheep in 2010, and has remained stable at 200 animals since 2011. This represents an increase of 125 since 2007; while the population likely has increased since the early 2000s, survey methodologies have also improved to produce a refined and more accurate population estimate (Durno, written communication, 16 October 2015).

Table 75. Record of bighorn sheep translocations in the Black Ridge Unit (recreated from Duckett 2006).

Year	Release Site	Rams:Ewes:Lambs	Total
1979	Devil's Canyon	3:8:0	11
1980	Monument Canyon	4:7:5	16
1981	Devil's Canyon	0:9:0	9
1995	Knowles Canyon	4:18:0	22

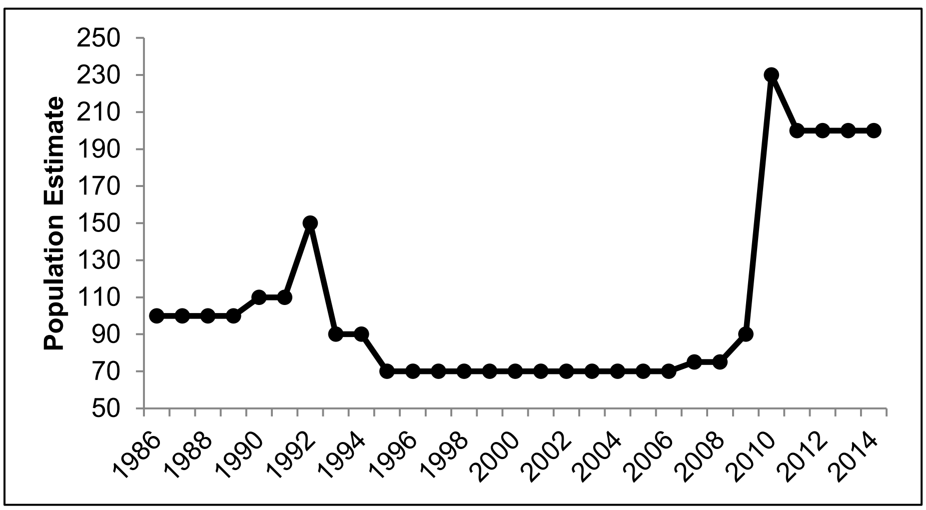


Figure 54. Black Ridge Unit post-hunt population estimates (George et al. 2009; CPW unpublished data from Stephanie Durno).

<u>Distribution</u>

The reintroduced bighorn sheep did not expand their range throughout COLM in the first decades after their release (Duckett 2006). The sheep reintroduced to Monument Canyon unexpectedly left the canyon within a week of their release; most individuals travelled west and out of the park, to the vicinity of Devil's Canyon (Sloan 1995). In the late 1980s, bighorn sheep reportedly occupied only Kodels Canyon in the far northeastern corner of COLM (Armstrong 1988) (Figure 55). Some range expansions were noted during the 1990s, with a group of sheep observed around Balanced Rock and a lone ram reported above the Coke Ovens in 1993-1995 (Sloan 1995). By 2006, lambing had been documented in Monument Canyon (Duckett 2006). According to the CPW (2013), the overall range of bighorn sheep in Colorado includes all of COLM, as well as areas to the northwest and southeast (Figure 56).

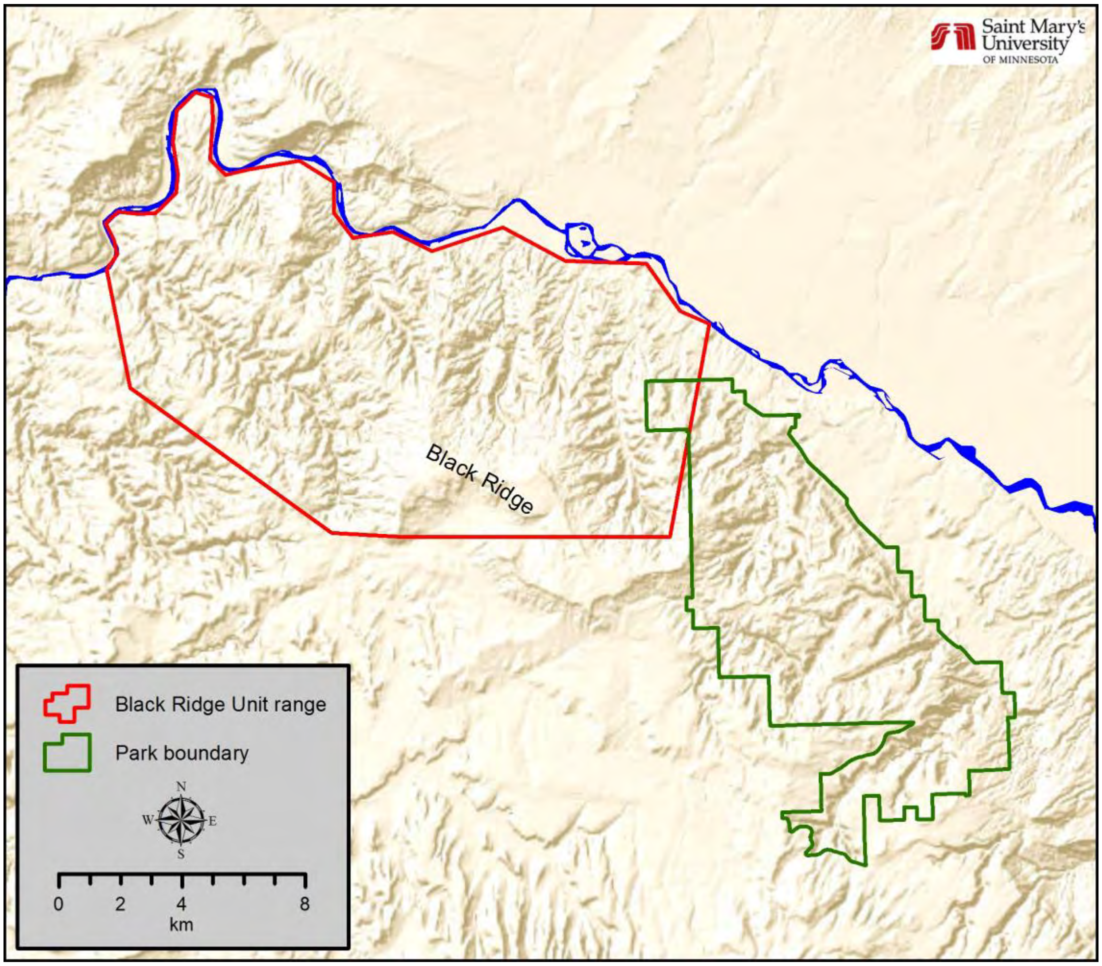


Figure 55. Approximate distribution of the Black Ridge Unit herd as of 1988 (created from a description of population extent in Armstrong [1988]).

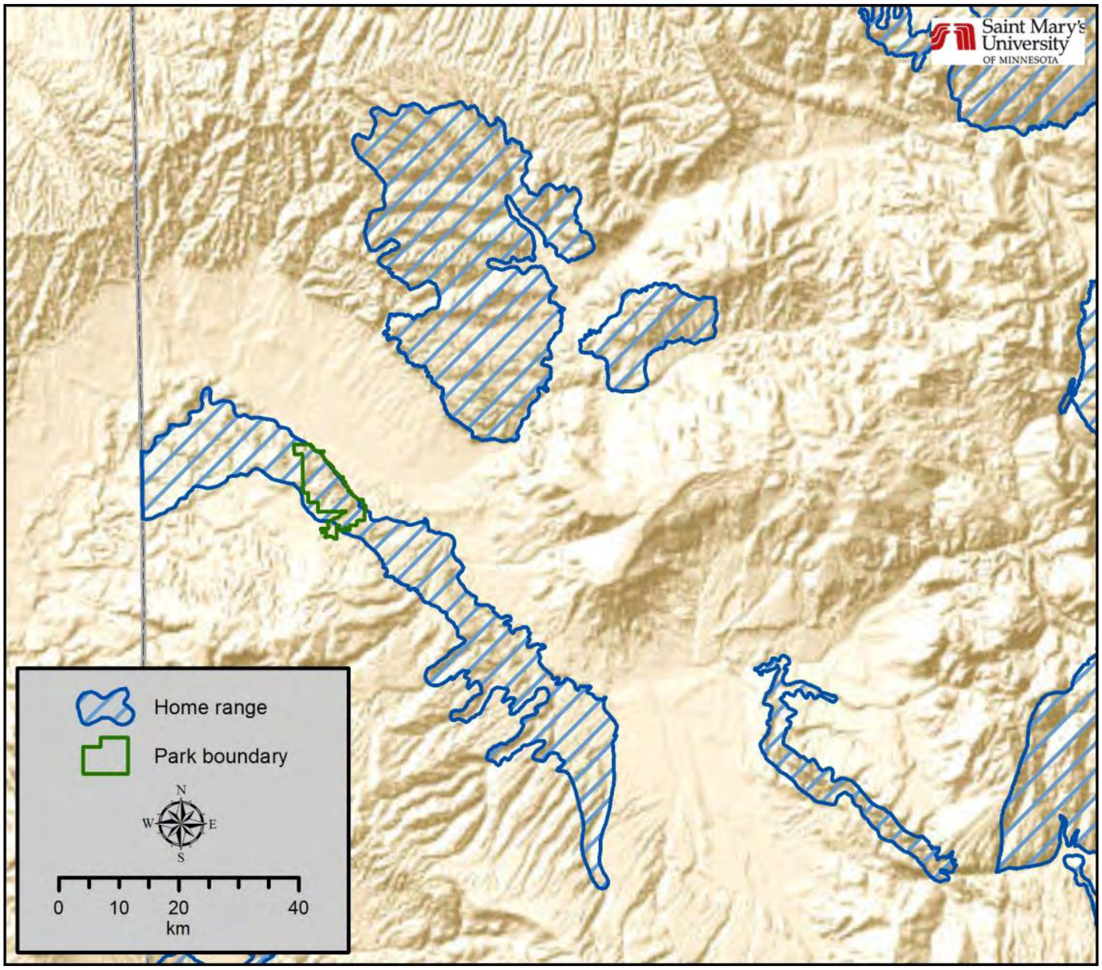


Figure 56. Bighorn sheep range within Colorado (CPW 2013).

<u>Reproductive Success</u>
Although reproductive success has not been directly studied at COLM, regular observations of lambs indicate that reproduction is occurring. Sloan (1995) reported that Devil's Canyon ewes produced lambs in 1982-83, the years immediately following their relocation. Sloan (1995) and Duckett (2006) reported lamb:ewe ratios for the Black Ridge Unit herd in the 1990s and in 2003 (based on CPW helicopter surveys) ranging from 26.7-66.7% (Table 76).

The lowest number is likely due to the different survey timing, as fewer lambs are likely to survive to October. In an April 2014 ground survey of the herd, which included areas of COLM, observers documented 25 ewes and 15 lambs, for a lamb:ewe ratio of 60% (Duckett 2014). Three yearlings were also observed, indicating that some of the previous year's lambs had survived the winter (Duckett 2014).

Table 76. Lamb:ewe ratios observed during helicopter surveys of the Black Ridge Unit bighorn sheep herd (Sloan 1995, Duckett 2006).

Year	Date	Lamb:Ewe ratio
1991	13 June	53.8%
1993	23 June	61.0%
1994	12 October	26.7%
1995	June	50.0%
2003	June	66.7%
2014	24 April	60.0%

Threats and Stressor Factors

While the desert bighorn sheep are protected from hunter disturbance and livestock interaction within COLM, there are several human threats and stressors that have the potential to impact the population within the park. These include vehicle traffic and visitor activity (Armstrong 1988). Sheep utilizing habitats along Rim Rock Drive are often harassed by visitors, particularly photographers trying to get close to individuals (Graham 1997; Hartwig, written communication, 15 September 2015). Six vehicle (motor vehicle-and bicycle) sheep collisions have been reported along Rim Rock Drive; the fate of the injured animals is unknown (Hartwig, written communication, 15 September 2015). It is likely that other collisions have occurred but have gone unreported (Hartwig, written communication, 19 October 2015). In areas outside the park, the herd also faces hunting pressure (Armstrong 1988). Hunting permits are heavily regulated and distributed based on post-hunt population estimates from the previous year on a unit by unit basis. For example, the 2015 desert bighorn sheep hunt had only four resident ram licenses and one nonresident ram license available for the Black Ridge Unit herd during the November desert rifle season (CPW 2015).

Although disease has not been a major cause for concern in the Black Ridge herd recently, it has impacted the population in the past. There was likely a respiratory disease outbreak in the early 1990s, when a sick ewe was observed in the area of Pollock and Rattlesnake Canyons. This coincided with a population decline that reduced the herd to an estimate of <50 individuals. During this same period, three skulls were found that showed signs of chronic sinusitis, which is caused by a species of parasitic fly larvae (Graham 1997). Exposure to domestic sheep can pose a threat to desert bighorn sheep, since there is a high potential for disease transmission (Graham 1997). Management plan recommendations explicitly state that domestic sheep and desert bighorn sheep should not share the same habitat (Graham 1997). An NPS assessment of COLM desert bighorn sheep habitat identified 11 domestic animal allotments that area within 16 km (10 mi) of the park (Gudorf et al. 1995). Since these could potentially expose desert bighorn sheep to domestic sheep, translocations into those areas are considered at an increased risk of disease transmission (Gudorf et al. 1995). Other diseases and parasites that have been observed in desert bighorn sheep include scabies, scab, mange (caused by mites), nasal bots (parasitic fly larvae that causes sinusitis in bighorn sheep), hemorrhagic septicemia-pasteurellosis, lungworms (natural bighorn parasite), and pneumonia (George et al. 2009). Disease testing of 38 sheep during capture by CPW in 2008, 2009, and 2010 showed that animals in the Black Ridge herd have been exposed to parainfluenza (PI3), bovine respiratory syncytial virus (BRSV), and both hemolytic and nonhemolytic strains of *Pasteurellaceae* bacteria (Durno, written communication, 16 October 2015). These animals were also tested for *Mycoplasma* bacteria, and one animal tested positive.

Natural Predators

Mountain lions are a known predator of desert bighorn sheep and are most detrimental to smaller-sized herds where any loss of a member can lead to an inability to maintain a sustainable population (Graham 1997). Predation by mountain lions can have a significant impact on the Black Ridge Unit herd (Graham 1997). During a 5-month period between November 1995 and May 1996, seven radio-collared desert bighorn sheep were found dead; field examinations determined five were killed by a mountain lion and one was likely killed by a mountain lion (Graham 1997). The majority of identifiable mortalities to CPW-collared animals between 2007 and 2012 were from predators (Durno, written communication, 16 October 2015). Additional predators of bighorn lambs include coyotes, bobcats, and golden eagles (George et al. 2009).

Data Needs/Gaps

Reproductive success is considered a data gap at this time; without available genetic history or birth and death rates, the rate of growth is only estimated using the post-hunt population counts. These are of very limited value in the assessment of the reproductive success of the desert bighorn sheep. Any genetic evaluation to assess the rate of exchange in genetic material would require blood sampling to determine genetic lineages in the herds.

CPW plans to capture and GPS-collar ten sheep in the Black Ridge unit in winter 2015-2016 for ongoing monitoring purposes (Durno, written communication, 16 October 2015). This monitoring is expected to improve the ability to observe lamb:ewe ratios, mortality causes, and range usage. CPW will also be developing a DAU management plan beginning in early 2016 (Durno, written communication, 16 October 2015). DAU plans are developed through a public process and compile historical information, known research, and provide management objectives, including population size and harvest priorities for big game herds throughout Colorado.

Overall Condition

Abundance

The *Significance Level* for abundance was assigned a 3. The most recent Black Ridge Unit population estimate published is the 2012 post-hunt estimate of 200 animals (Holland and Broderick 2013). According to Holland and Broderick (2013), about 20% of this population occupies COLM. Survey results show that the population has grown and remained stable at approximately 200 animals for several years, but the herd has not yet met the long-term goal of 400 sheep established in the management plan. For this reason, a *Condition Level* of 1 has been assigned, meaning low concern.

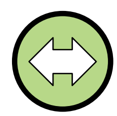
Distribution

The distribution of desert bighorn sheep was assigned a *Significance Level* of 2. The population at COLM resulted from relocation efforts that were part of a larger desert bighorn reestablishment project. According to the CPW (2013) and park staff (Hartwig, written communication, 15

September 2015), bighorn sheep now utilize the entire park area. As a result, a *Condition Level* of 0 has been assigned, indicating no current concern.

Reproductive Success
A *Significance Level* of 3 was assigned for this measure. Reproductive success in the desert bighorn sheep at COLM has not been specifically studied, although reproduction is known to occur. Sloan (1995) and Duckett (2006, 2014) have reported lamb:ewe ratios for the Black Ridge herd ranging from 26.7-66.7%. The most recent survey from April 2014 resulted in a lamb:ewe ratio of 60%. However, due to large temporal gaps in the data, a *Condition Level* cannot be assigned.

Weighted Condition Score
A *Weighted Condition Score* of 0.20 was calculated for COLM's bighorn sheep, indicating the resource is currently in good condition. Future monitoring and management actions should focus on including annual population estimates (possibly more frequent if resources are available) and encouraging research on the reproductive success of the herd.

Bighorn Sheep			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.20**
Abundance	3	1	
Distribution	2	0	
Reproductive Success	3	n/a	

4.13.6 Sources of Expertise
Stephanie Durno, CPW biologist

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4.14 Kit Fox

4.14.1 Description

Photo 18. Desert kit fox (*V. macrotis arsipus*) (NPS Photo).

The kit fox (*Vulpes macrotis*) is a small mammal of the southwest desert weighing about 1.5 to 2.5 kg (3.3 to 5.5 lbs) as adults (Meaney et al. 2006). They stand 30 to 32 cm (0.98 to 1.05 ft) high at the shoulder and are 73 to 84 cm (2.40 to 2.76 ft) in length (Meaney et al. 2006). Kit foxes are similar in appearance to swift foxes found on the eastern plains of Colorado, but they have larger ears and a more angular appearance (Meaney et al. 2006). They have long, black-tipped, bushy tails, dark muzzles, yellow-gray to grizzled dorsal fur, and pale yellow to white ventral fur (Meaney et al. 2006) (Photo 18).

Kit foxes occur in a variety of shrublands including semi-desert shrublands, sagebrush shrublands, and shrubby margins of pinyon-juniper woodlands (Boyle and Reeder 2005). Suitable habitat extends from north of Montrose to Grand Junction, Colorado (BLM 2010). Kit foxes are nocturnal and remain in or near their dens during the day; dens are used for resting, shelter, raising young, and avoiding predators (Meaney et al. 2006). They dig their own dens or sometimes adapt badger diggings or prairie dog burrows into dens (Boyle and Reeder 2005). Kit foxes are opportunistic consumers and scavengers and feed primarily on rabbits (Order Lagomorpha), prairie dogs, and kangaroo rats (*Dipodomys* spp.), but will also eat birds, reptiles, small mammals, and insects (Meaney et al. 2006). They will also cache food to consume at a later time (Meaney et al. 2006). Kit foxes mate some time between December and February, with most litters containing four to five pups (Boyle and Reeder 2005).

The kit fox is a state endangered species in Colorado and is considered one of the state's most vulnerable animals (BLM 2010). Habitat loss, degradation, and fragmentation, competition with coyotes and other foxes, and road strikes are the main causes for the decline of the species (Meaney et al. 2006). Some other potential threats include recreational impacts, domestic livestock grazing, control of predators and rodents, and the decline in white-tailed prairie dogs (*Cynomys leucurus*) (Meaney et al. 2006). The kit fox was once a furbearer in Colorado and has been protected from harvest since 1994 (Boyle and Reeder 2005).

4.14.2 Measures

- Abundance
- Distribution
- Reproductive success

4.14.3 Reference Conditions/Values

Kit fox harvest numbers were reported by trappers returning questionnaires to the CPW from 1975 to 1991, though the numbers were sporadic (Boyle and Reeder 2005). After four years of study, Fitzgerald (1996) speculated that fewer than 100 kit foxes remained in Colorado. Since no data regarding kit foxes specifically within COLM exist, this will serve as the reference condition for abundance. A map created by Boyle and Reeder (2005) shows the historic range of the kit fox (see Figure 58) and will serve as a reference condition for the distribution measure. A reference condition has not been established for reproductive success.

4.14.4 Data and Methods

The most recent kit fox survey in Colorado was done by the CPW (Neubaum and Duckett 2014). The study area encompassed the Grand Valley in west-central Colorado bounded on the north and south by the Mesa County line, the Colorado-Utah state line to the west, and Grand Mesa to the east (Neubaum and Duckett 2014). Eighteen sites within the study area were chosen based on where kit foxes have previously been reported or documented (Neubaum and Duckett 2014). Elevations of sites surveyed ranged from 1,409 m (4,650 ft) in Rabbit Valley to 1,892 m (6,244 ft) in COLM (Neubaum and Duckett 2014). Habitat in the area consisted of semi-desert shrublands with rocky outcrops, often bordered by pinyon pine and oneseed juniper forest (Neubaum and Duckett 2014). The climate in the area is characterized as high desert with an annual precipitation of just over 23.9 cm (9.4 in) and an average temperature of 12 °C (53 °F) (Neubaum and Duckett 2014).

A GPS unit was used to collect coordinates for each camera location (Neubaum and Duckett 2014). Survey duration varied for each site though each camera was run for at least one month (Neubaum and Duckett 2014). Remote cameras were typically placed 1 m (3.3 ft) off the ground on a T-post in a lockable security enclosure (Neubaum and Duckett 2014). A map of the cameras placed for this survey can be found in Figure 57. A scent station baited with skunk lure was placed on a stick or rock approximately 3m (10 ft) out in front of the camera (Neubaum and Duckett 2014). Cameras were typically checked every 7 to 14 days at which time the memory cards and batteries were swapped and the scent lure refreshed (Neubaum and Duckett 2014). Towards the end of the survey a few sites were supplemented with canned mackerel as an additional bait to see if it would attract kit foxes (Neubaum and Duckett 2014). Cameras were programmed to take photos on rapid fire whenever the infrared beam was broken (Neubaum and Duckett 2014). However, no kit foxes were documented by these cameras (Neubaum and Duckett 2014).

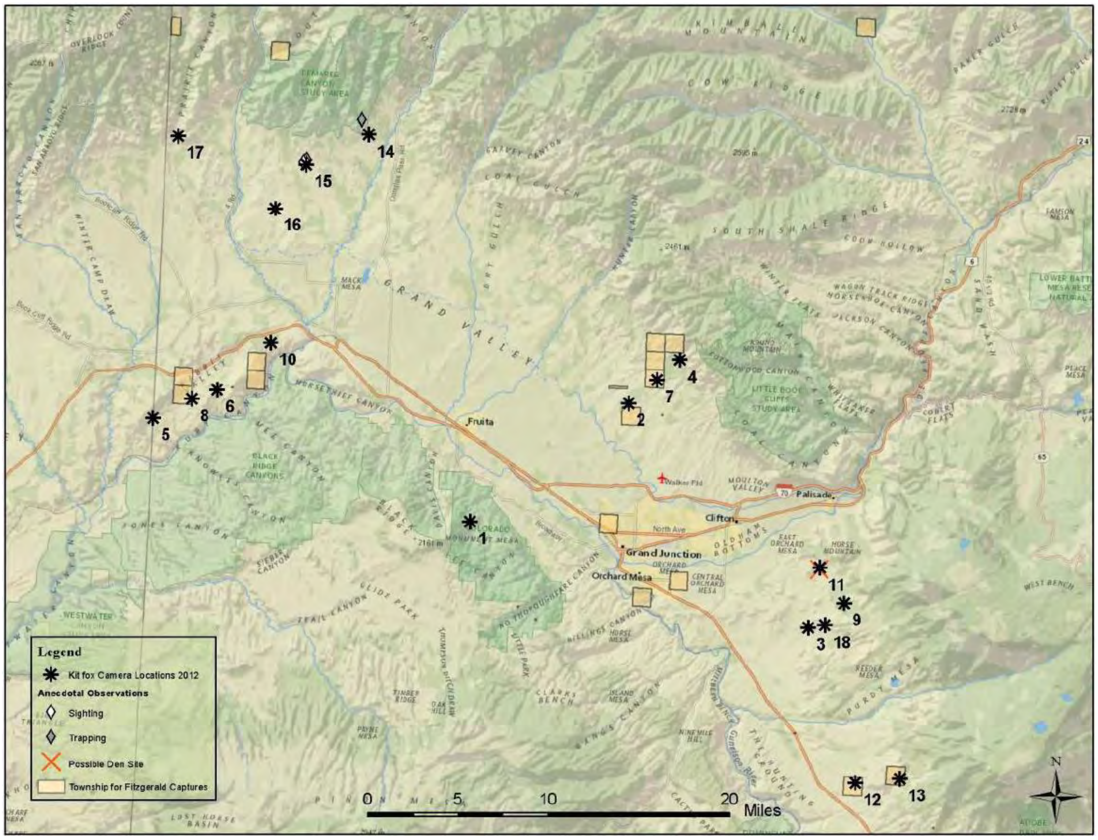


Figure 57. Camera locations for the 2012-2013 kit fox survey (from Neubaum and Duckett 2014). COLM is near the center of the map, where camera 1 was located.

4.14.5 Current Condition and Trend

<u>Abundance</u>

After four consecutive years of study in the early to mid-1990s, Fitzgerald (1996) speculated that fewer than 100 kit foxes were present in Colorado, and that the populations were likely not self-sustaining. Further study by Beck (1999, 2000) strongly suggested that the small fox population had declined and was close to extirpation from the state (Boyle and Reeder 2005). A recent kit fox survey using infrared cameras detected no kit foxes, though interspecific competitors such as gray and red foxes, coyotes, and domestic dogs were documented (Neubaum and Duckett 2014). According to Dan Neubaum (CPW, Wildlife Conservation Biologist, written communication, 4 August 2014), a couple of kit foxes have been documented in COLM, though these are most likely wandering juveniles or unusual sightings. Reliable sightings from the Grand Valley tend to be in much more open portions of the desert where bands of rock occurred, generally at lower elevations than most of COLM. Pinyon-juniper is well established over much of COLM, creating habitat that is more suitable for the gray fox, a competitor of the kit fox, which would likely inhibit the kit fox from using such habitat (Neubaum, written communication, 4 August 2014). Neubaum (written communication, 4 August 2014) also believes it is likely that kit foxes have been extirpated from Colorado or that only a few individuals remain. However, a population is present just over the state line in Cisco, Utah, and could act as a source of immigrating individuals if they do attempt to repopulate the valley (Neubaum, written communication, 4 August 2014).

Distribution

In Colorado, the kit fox's historic range encompassed approximately 1.83 million ha (4.52 million ac) (Figure 58) (Boyle and Reeder 2005). In 2005, there were only about 120,000 ha (296,525 ac) remaining (Boyle and Reeder 2005). Based on historical records, anecdotal reports, known occurrences in adjacent counties in Utah, and the availability of suitable habitat, kit foxes are expected to occur in eight Colorado counties (Boyle and Reeder 2005). However, Fitzgerald (1996) only observed or captured kit foxes in the lower Colorado and lower Gunnison River drainages in Delta, Montrose, Garfield, and Mesa counties. Centers of abundance were southeast of Delta and east of Montrose in the Uncompahgre Valley. The only recorded reports of kit fox observations within COLM are from the early 1960s (Miller 1964). One individual was found at the junction of Rim Rock Drive and West Glade Park Road, on the western boundary of the park, in October 1960 and in June 1962 another was spotted along Rim Rock Drive, 2 km (1.25 mi) west of Red Canyon View (Miller 1964). Figure 58 depicts the 2005 and historic distribution of the kit fox, though as previously mentioned, it is likely that kit foxes have now been extirpated from Colorado.

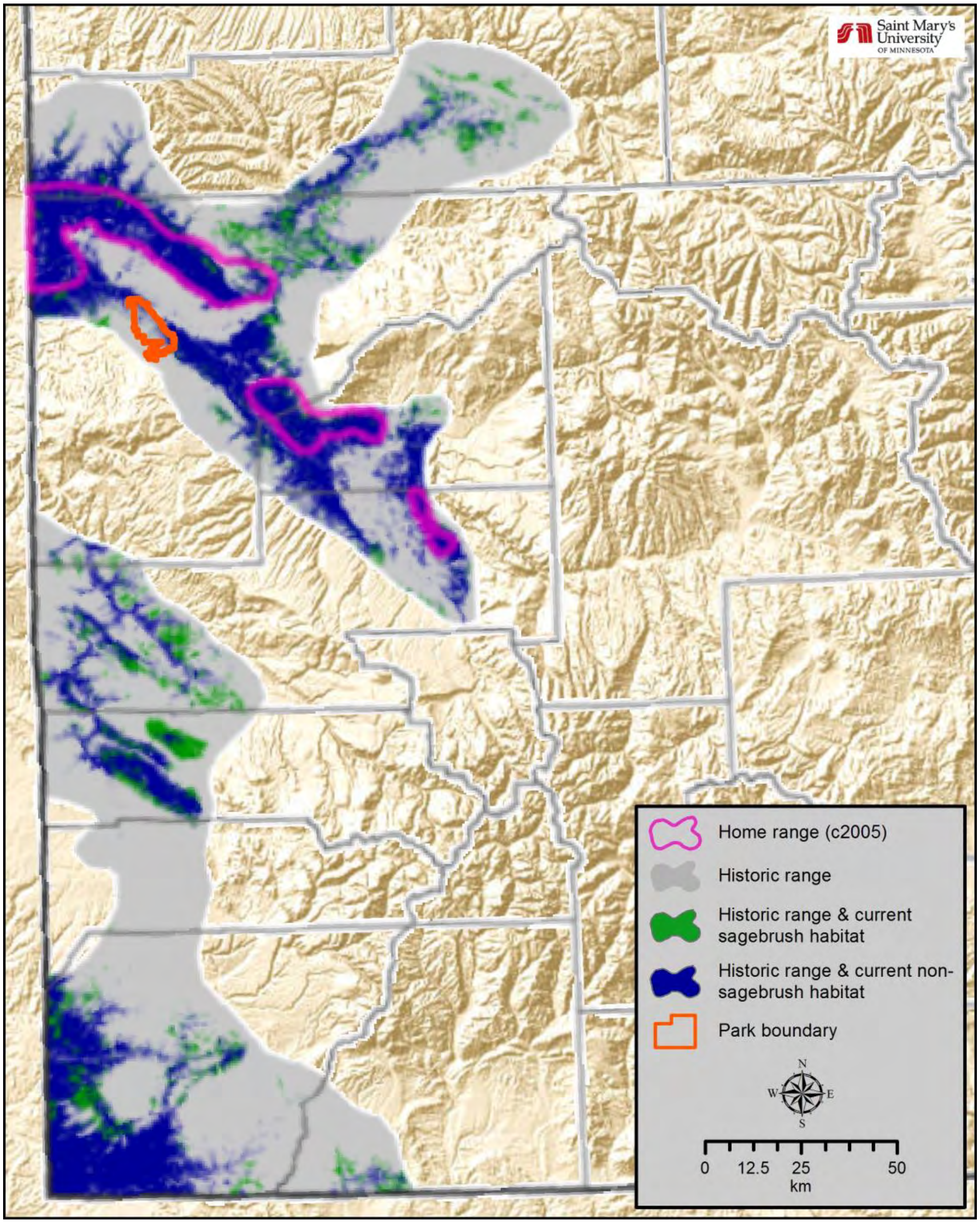


Figure 58. Recent (2005) and historic distribution of the kit fox in Colorado (Recreated from Boyle and Reeder 2005).

Reproductive Success

Data regarding the reproductive success for the kit fox in COLM do not exist. Using reproductive success as a measure to assess the current condition generally works better with a defined, established population. Due to the rarity of kit foxes in Colorado, trail cameras and hair snares are being used to confirm their presence rather than using reproductive success to assess the population, as these methods are less invasive to the animal (Neubaum, written communication, 4 August 2014).

Threats and Stressor Factors

A primary threat to the kit fox in COLM is habitat loss and fragmentation. Habitat that was once considered suitable for kit foxes (lower elevations along the northern boundary) is no longer suitable due to fragmentation and urbanization along the Redlands (Neubaum, written communication, 4 August 2014). With the increase in energy and residential development in western Colorado, the Grand Junction area is one of the fastest growing regions in Colorado. This development may not only degrade and destroy kit fox habitat, but also causes fragmentation which may impair the movement of kit foxes between certain areas. Loss of dispersal corridors is a serious concern because of loss of movement between sub-populations (Meaney et al. 2006). Immigration by reproductive individuals can make a relatively large difference in population persistence, making habitat connectivity crucial (Meaney et al. 2006). This is also important in the long term to prevent genetic inbreeding within small isolated populations (Meaney et al. 2006).

Roads are known to contribute to vehicle-caused mortality and also reduce habitat connectivity for a number of wildlife species (Meaney et al. 2006). The negative impacts to wildlife associated with roadways are proportional to road width, traffic volume, and speed limit (Meaney et al. 2006). As development increases in western Colorado, roads will become wider, carry higher traffic volumes, and become more inhospitable to wildlife. Narrow dirt roads can even pose a threat to the kit fox as they allow easy access to otherwise remote areas, allowing human disturbance to occur (Meaney et al. 2006). This human disturbance by recreational enthusiasts, especially off-road vehicle (ORV) users, can pose a major threat to kit fox denning areas (Meaney et al. 2006).

Data Needs/Gaps

Though abundance data for the kit fox in Colorado exists, there are no abundance data for the kit fox specifically within COLM. A map created by Boyle and Reeder (2005) shows the historical distribution of kit foxes (Figure 58), though more recent distribution data are needed. Data regarding the reproductive success of the kit fox are also not available for COLM. At this time, it is likely that the species is extirpated from Colorado (Neubaum, written communication, 4 August 2014).

Overall Condition

Abundance

The abundance measure was assigned a *Significance Level* of 3. Based on the reports of Fitzgerald (1996), Beck (1999, 2000), Boyle and Reeder (2005), and Neubaum and Ducket (2014), the *Condition Level* for this measure is 3, indicating high concern. Due to habitat loss and fragmentation, along with other threats and stressors to kit foxes, they may now be extirpated from Colorado.

Distribution

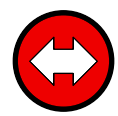
The distribution measure was assigned a *Significance Level* of 2. Boyle and Reeder (2005) created a current and historical distribution map, though according to Dan Neubaum (email communication, 4 August 2014), the species is likely extirpated from Colorado. Given that the distribution of the kit fox possibly now excludes Colorado, the *Condition Level* of this measure is 3, indicating high concern.

Reproductive Success

The reproductive success measure was assigned a *Significance Level* of 3. Because there is no data for COLM and Colorado populations are too low to use reproductive success to assess the condition of the kit fox, a *Condition Level* was not assigned to this measure.

Weighted Condition Score

The *Weighted Condition Score* for this component is 0.83. With kit foxes likely extirpated from Colorado, this species is of high concern to management. More extensive surveys within COLM are necessary to confirm their presence or absence. The condition of the kit fox is currently unchanging, as the population likely cannot decrease further than it already has.

Kit Fox			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.83**
Abundance	3	3	
Distribution	2	3	
Reproductive Success	3	n/a	

4.14.6 Sources of Expertise

Dan Neubaum, CPW Wildlife Conservation Biologist

4.14.7 Literature Cited

Beck, T. D. I. 1999. Kit fox (*Vulpes macrotis*) status in Colorado. *In* Wildlife Research Report, Project No. W-153-R-12, Work Package 0663, Task 1. Colorado Division of Wildlife, Denver, Colorado.

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Boyle, S. A., and D. R. Reeder. 2005. Colorado sagebrush: A conservation assessment and strategy. Colorado Parks and Wildlife, Denver, Colorado.

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Meaney, C. A., M. Reed-Eckert, and G. P. Beauvais. 2006. Kit fox (*Vulpes macrotis*): A technical conservation assessment. Available from http://www.fs.fed.us/r2/projects/scp/assessments/kitfox.pdf (accessed 18 July 2014).

Miller, P. H. 1964. The ecological distribution of mammals in Colorado National Monument, Mesa County, Colorado. Thesis. Oklahoma State University, Stillwater, Oklahoma.

Neubaum, D. J., and S. Duckett. 2014. Use of remote infrared cameras to survey for kit fox (*Vulpes macrotis*) in the Grand Valley, Colorado. Colorado Parks and Wildlife, Grand Junction, Colorado.

4.15 Bats

4.15.1 Description

Bats have the potential to be used as bioindicators for a number of reasons. Bats are important to biodiversity, they possess ecological and economic value as ecosystem components, and they are vulnerable to rapid population declines (O'Shea et al. 2003). Species with specialized roosting requirements and limited suitable roosts are important to monitor, as they are particularly vulnerable to habitat loss and local extirpation (O'Shea et al. 2003). Due to the vast amount of insects they consume, fluctuations in bat populations will affect the agricultural and forestry segments of the economy, ecosystem function, and the overall biodiversity (O'Shea et al. 2003). These fluctuations can be related to climate change, changes in water quality, agricultural intensification, loss and fragmentation of forests, fatalities at wind turbines, disease, pesticide use, and overhunting (Jones et al. 2009). For the reasons listed above, bat monitoring programs would be beneficial to park management.

Photo 19. Big brown bat (*Eptesicus fuscus*) (Photo by Dr. Lloyd Glenn Ingles, California Academy of Sciences).

Based on distributional ranges, 17 different species of bats could potentially occur in COLM (Adams 1989). A recently completed bat inventory of COLM has confirmed the presence of these 17 species within COLM (Hartwig, written communication, 30 January 2016). Availability and abundance of roost sites may be the most important factor concerning the distribution of bats in COLM. Free-standing water (e.g., ponds, lakes, slow-moving streams) is also important because it supports high densities of insects for bats to eat, as well as for drinking while in flight (Adams 1989).

4.15.2 Measures

- Species richness
- Abundance
- Number of hibernation/roost sites
- Number of maternity sites

4.15.3 Reference Conditions/Values

The reference condition for species richness at COLM was established by Adams (1989, 1994). Reference conditions have not been established for abundance, number of hibernation/roost sites, or number of maternity sites.

4.15.4 Data and Methods

A census of bat fauna by Rick Adams began at COLM in 1989. This was the first attempt to identify species richness of bats within COLM. The initial census lasted two years (1989-1990) and was reinitiated in 1993 and 1994 by The Colorado Bat Society (CBS) (Adams 1994). The bats were trapped using Japanese mist nets. All bats were identified to species, weighed, sexed, forearm measured, reproductive condition noted, location of capture noted, and released. No bats were banded or marked in any other way. Areas of COLM which have permanent water were used as trap sites, as well as pinyon-juniper woodland (Adams 1989). At the conclusion of this survey, 12 out of the 17 species expected to be present within COLM were verified. Data from a recently concluded 2014–2015 bat survey of the park will also be useful in future assessments of this resource.

4.15.5 Current Condition and Trend

<u>Species Richness</u>

Populations of 17 of the 18 species of bats known or expected to have distributional ranges including Colorado could potentially occur in COLM (Adams 1989). While the presence of these 17 species has been confirmed by a recent study, published data are not yet available at the time of this writing. In the absence of this new data, the species richness is based currently available information from NPSpecies. A total of 13 different species are present in COLM according to NPSpecies (Table 77; NPS 2014); however, the recently completed 2014-2015 bat survey will provide further insight into this measure. This effort has already documented several bat species in the park that were previously unconfirmed (Neubaum, written communication, 4 August 2014).

<u>Abundance</u>

Data regarding abundance for bats in COLM are very limited. Adams (1989, 1993, 1994) documented the number of individuals of each species captured during the three surveys. However, these results may be influenced by survey effort (e.g., number of sites and days spent surveying) and weather conditions and may not reflect actual abundance within the park. Many more individuals were observed in flight but could not be captured or counted accurately (Adams 1989, 1994). The 2014-2015 bat survey will provide further insight into this measure.

<u>Number of Hibernation/Roost Sites</u>

As mentioned previously, availability and abundance of roost sites is thought to be a key factor influencing the distribution of bats within Colorado (Adams 1989). Therefore, information on the number of hibernation and roost sites could contribute to a better understanding of the park’s bat population. Unfortunately, data on the number of hibernation/roost sites for bats in COLM was not available for inclusion in this assessment. Bats have been observed roosting in west-side auto tunnels (Adams 1989, 1993). The 2014-2015 bat survey is expected to provide insight into this measure.

Table 77. Occurrence of bat species within COLM (Adams 1994; NPS 2014).

Scientific name	Common name	Adams (1994)	NPS (2014)
Antrozous pallidus	pallid bat	Present	Present
Corynorhinus townsendii	Townsend's big-eared bat	Present	Present
Eptesicus fuscus	big brown bat	Present	Present
Euderma maculatum	spotted bat	Unconfirmed	Unconfirmed
Idionycteris phyllotis	Allen's big-eared bat	Unconfirmed	Unconfirmed
Lasionycteris noctivagans	silver-haired bat	Present	Present
Lasiurus cinereus	hoary bat	Unconfirmed	Probably Present
Myotis californicus	California myotis	Unconfirmed	Present
Myotis ciliolabrum	western small-footed myotis	Present	Present
Myotis evotis	long-eared myotis	Unconfirmed	Probably Present
Myotis lucifugus	little brown bat	Present	Present
Myotis thysanodes	fringed myotis	Present	Present
Myotis volans	long-legged myotis	Present	Present
Myotis yumanensis	Yuma myotis	Present	Present
Nyctinomops macrotis	big free-tailed bat	Present*	Present
Parastrellus hesperus	western pipistrelle	Present	Present
Tadarida brasiliensis	Brazilian free-tailed bat	Present	Present

*Found injured on road

Table 78. Number of individuals of each bat species captured in surveys by Adams (1989. 1993, 1994).

Species Name	Common Name	1989 (4 sites)	1993 (3 sites)	1994 (2 sites)
Eptesicus fuscus	big brown bat	5	13	2
Myotis ciliolabrum	western small-footed myotis	1	5	1
Myotis lucifugus	little brown bat	1	1	0
Myotis thysanodes	fringed myotis	0	0	1
Myotis volans	long-legged myotis	0	1	1
Myotis yumanensis	Yuma myotis	13	6	6
Parastrellus hesperus	western pipistrelle	1	3	5
Tadarida brasiliensis	Brazilian free-tailed bat	1	0	0
	Totals	**22**	**29**	**16**

Number of Maternity Sites

Specific data regarding the number of maternity sites in COLM was not available at the time of this assessment; however the recently completed 2014-2015 bat survey did identify several important maternal colony sites (Hartwig, written communication, 30 January 2016). Other studies have documented a maternity colony of Yuma myotis (*Myotis yumanensis*) on the west side of the park and the capture of lactating Brazilian free-tailed bats (*Tadarida brasiliensis*) indicates there is a maternity roost in or near the park (Adams 1989, 1993). The capture of a very young western pipistrelle (*Parastrellus hesperus*) in No Thoroughfare Canyon in 1994 also suggests that the species has a maternity roost site there (Adams 1994).

Threats and Stressor Factors

While there are no threatened or endangered species of bats within COLM, there is one bat (Townsend's big-eared bat [*Corynorhinus townsendii*]) that is listed as a species of state special concern. The main concern for this particular species is disturbance, with recreational caving and abandoned mine closures being the largest threat to the animal (Pierson et al. 1999). Surveys using passive integrated transponder (PIT) tags are currently in place to mark Townsend's big eared bats in Colorado, which will help generate survival estimates for the species for the first time. These estimates may help analyze populations of this species within COLM. In addition to the species of state special concern, there are also several other species that are of concern to federal agencies including the spotted bat (*Euderma maculatum*), the big free-tailed bat (*Nyctinomops macrotus*), and the fringed myotis (*Myotis thysanodes*), all of which occur within COLM (Neubaum, email communication, 4 August 2014).

White-nose syndrome (WNS) is a disease affecting hibernating bats caused by a newly discovered fungus, *Pseudogymnoascus destructans* (USFWS 2014). This fungus is psychrophilic, or cold-adapted, and grows at temperatures of 3 to 15 °C (37.4 to 59 °F) and greater than 90% humidity (Foley et al. 2011). Transmission generally occurs through direct bat-to-bat contact, although exposure to environments in which the fungus is present and human or animal vectors are also possible. In autumn, hibernating bats build up fat reserves in preparation for winter. During hibernation, these bats must arouse to restore homeostatic balance (e.g., drink, urinate, relocate, and probably induce immune functioning), consuming some of the stored body fat. WNS causes bats to arouse more frequently or for longer periods than usual, depleting their body fat prematurely and causing them to starve. Direct mortality from infection of the wings may also occur (Foley et al. 2011). Bats with WNS may act strangely during the winter, including flying outside during the day and clustering near the entrances of caves and other hibernation areas (USFWS 2014).

As of June 2014, bats with WNS were confirmed in 25 states, primarily in the east and central parts of the country, and five Canadian provinces (USFWS 2014). Species on which WNS has been confirmed include the big brown bat (*Eptesicus fuscus*), the eastern small-footed myotis (*Myotis leibii*), the gray bat (*Myotis grisescens*), the Indiana bat (*Myotis sodalis*), the little brown bat (*Myotis lucifugus*), the northern long-eared bat (*Myotis septentrionalis*), and the tricolored bat (*Perimyotis subflavus*). Species on which *P. destructans* has been detected with no confirmation of WNS include the southeastern myotis (*Myotis austroriparius*), the silver-haired bat (*Lasionycteris noctivagans*), and the Virginia big-eared bat (*Corynorhinus townsendii virginianus*) (USFWS 2014).

WNS is not currently present in Colorado. COLM does, however, contain two species that have been confirmed to have WNS (the big brown bat and the little brown bat) and one species on which *P. destructans* has been detected with no confirmation of WNS (the silver-haired bat). Controlling the spread of this fungus is important to maintaining current populations of bats around the country. Public education may encourage people to report cases of WNS, avoid inadvertent spread of the fungus, and avoid disturbance of hibernacula (Foley et al. 2011).

Habitat loss can have negative impacts on the bats of COLM. Roost selections serve a number of functions and vary by season. For many temperate bats, roosts can be separated into winter hibernacula, maternity roosts, and summer roosts. Suitable roost selection is important for growth, development and survival of young, protection from predators, protection from the elements, and reduction of thermoregulatory costs (Agosta 2002). In addition, many bats use specific night roosts in close proximity to foraging areas as resting places and to provide opportunities for social interactions. Examples of potential roosting sites for bats include caves, tunnels, mines, buildings, bat boxes, tree cavities, rock crevices, storm sewers, and wood piles. Human disturbance to these roosts can be harmful to bat populations (Agosta 2002). The greatest contributor to the decline of bats is the loss of roosting habitat due to cave and mine closure, vandalism, intentional habitat destruction, development and deforestation, and the removal of live trees, snags, and hedgerows from agricultural fields, farmlands and other rural landscapes. Managing open fields to provide diversity in vegetation and insect composition and preserving tree roosts such as snags and hedgerows is a good way to promote healthy bat roosting areas (NRCS 1999).

Pesticides have a variety of effects on bats including direct mortality, altered behavior, and transferring toxins to nursing young (Agosta 2002). Pesticides may also indirectly affect insectivorous bats by reducing their food source, though little is known on this topic (McCracken 1989). With organochlorine pesticides (e.g., DDTs) now banned in the U.S. less toxic organophosphate and carbamate pesticides are now being used. Although these are less toxic than organochlorine pesticides, some pesticides being used still cause mortality in birds and mammals. Pesticide exposure may be the cause of decline for some populations of insectivorous bats, particularly those whose diets include agricultural pests (Agosta 2002).

With wind energy becoming one of the fastest growing sources of renewable energy, impacts of wind energy development on bats and other wildlife are increasingly becoming a concern. This topic received little attention in North America until 2003, when estimated 1,400–4,000 bats were killed at the Mountaineer Wind Energy Center in West Virginia (Arnett et al. 2010). Bat fatalities in relation to wind turbines are heavily skewed towards migratory bats, particularly those within the genus *Lasiurus*, and generally occur more often in midsummer through fall. Fatalities are also the highest during periods of low wind speed and are related to weather variables associated with the passage of weather fronts. Red strobe lights recommended by the Federal Aviation Administration (FAA) did not influence bat mortality and fatalities were not concentrated at individual turbines (Arnett et al. 2010). Reducing turbine blade speed and operating time on low-wind nights in summer and fall can substantially reduce bat fatalities (Arnett et al. 2013).

Human disturbance to roosts sites can have adverse effects on bat populations. The increase in recreational climbing routes and their impact on bat populations is of particular concern to COLM resource managers. Disturbance can cause bats to abandon roost sites, sometimes relocating to a less ideal site (Gruver and Keinath 2006). Disturbance raises the general level of activity within roosts, which can result in greater energy expenditure. This may in turn increase foraging demands and cause the bat to spend more time outside where they are vulnerable to predation. Clustering bats gain thermal benefits from being surrounded by other bats. Disturbance may cause the colony size to decrease, which may in turn decrease thermal benefits of the colony (McCracken 1989). Disturbance during hibernation is especially unfavorable as it can cause bats to deplete energy reserves needed for them to survive the winter (Thomas et al. 1990).

Data Needs/Gaps

Bat species richness has been documented by Adams (1989, 1990, 1993, 1994); however, abundance and distribution data are mostly absent from COLM. The bat survey currently in process could be repeated routinely to document species richness, abundance, number of hibernation/roost sites, and number of maternity sites would provide managers with meaningful information that can be used to assess the condition of bats in the future. The results from this CPW bat survey, conducted from 2014-2015 were not available at the time of this writing. The data collected by this survey will help managers to have a better understanding of the current bat populations within COLM.

Overall Condition

Species Richness

The species richness measure was assigned a *Significance Level* of 3. With nearly all species of bat expected to occur within COLM documented (Neubaum, email communication, 4 August 2014), the *Condition Level* of this measure is 0, indicating no concern. The completion of the 2014-2015 bat survey will provide greater insight to this measure.

Abundance

The abundance measure was assigned a *Significance Level* of 3. Data on the abundance of bats within COLM are limited, though the 2014-2015 will likely provide some information. Due to the lack of data related to abundance, a *Condition Level* was not assigned to this measure.

Number of Hibernation/Roost Sites

This measure was assigned a *Significance Level* of 2. Data on hibernation/roost sites of bats within COLM are not currently available. A *Condition Level* was not assigned to this measure due to the lack of data.

Number of Maternity Sites

The number of maternity sites measure was assigned a *Significance Level* of 2. No data are available on maternity sites of bats within COLM, though the 2014-2015 could provide insight into this measure. Due to the lack of data on maternity sites, a *Condition Level* could not be assigned.

Weighted Condition Score

A *Weighted Condition Score* was not calculated for this component since *Condition Level* could only be assigned to one measure (species richness) due to lack of available data. Until data become available for the other measures, possibly at the conclusion of the 2014-2015 bat survey, the condition of bats in COLM will be unknown.

Bats			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Species Richness	3	0	
Abundance	3	n/a	
Number of Hibernation / Roost Sites	2	n/a	
Number of Maternity Sites	2	n/a	

4.15.6 Sources of Expertise

Dan Neubaum, CPW Wildlife Conservation Biologist

4.15.7 Literature Cited

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4.16 Air Quality

4.16.1 Description

Air pollution can significantly affect natural resources and their associated ecological processes, and the health of park visitors. In the Clean Air Act (CAA), Congress set a national goal to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic or historic value (42 U.S.C. §7470(2)). This goal applies to all units of the National Park System. The act includes special provisions for 48 park units, called "Class I" areas under the CAA; all other NPS areas are designated as Class II, including COLM. Class I area designations must be made by Congress and have only been done once, in the 1977 revisions to the CAA. For Class II airsheds, the increment ceilings for additional air pollution above baseline levels are slightly greater than for Class I areas which can allow for more development (EPA 2013a). Additional authority to consider and protect air quality in Class II parks is provided by Title 54 (54 USC 100101(a) et seq.), commonly known as the NPS Organic Act, and the Wilderness Act.

Parks designated as Class I and II airsheds typically use the EPAs National Ambient Air Quality Standards (NAAQS) for criteria air pollutants as the ceiling standards for allowable levels of air pollution. EPA standards are designed to protect human health and the health of natural resources (EPA 2013a). The CAA also establishes that current visibility impairment in Class I areas must be remedied and future impairment prevented (EPA 2013a). To comply with CAA and NPS Organic Act mandates, the NPS established a monitoring program that measures air quality trends in many park units for key air quality indicators, including atmospheric deposition, ozone, and visibility (NPS 2008).

Located along the Grand Valley in Colorado, the primary pollutants likely to affect air quality at COLM include nitrogen (N) and sulfur (S) compounds (nitrate [NO_3-], ammonium [NH_4+], and sulfate [SO_4^{2-}]); ground-level ozone (O_3); haze-causing particles; and airborne toxics (Ksienya Pugacheva, NPS Air Resources Division Natural Resources Specialist, written communication, 11 December 2015). These challenges to air quality are generated by a variety of sources including; local emissions generated by traffic and development, air inversions, and through contaminants carried into the region via prevailing seasonal winds. Air pollution may impair the scenic views that many visitors come to COLM to enjoy.

4.16.2 Measures

- Atmospheric deposition of sulfur and nitrogen
- Ozone
- Particulate matter
- Visibility
- Atmospheric deposition of mercury

Atmospheric Deposition of Sulfur and Nitrogen

Sulfur and nitrogen are emitted into the atmosphere primarily through the burning of fossil fuels, industrial processes, and agricultural activities (EPA 2012a). While in the atmosphere, these emissions form compounds that may be transported long distances and settle out of the atmosphere in the form of pollutants such as particulate matter (e.g., sulfates, nitrates, ammonium) or gases (e.g., nitrogen dioxide, sulfur dioxide, nitric acid, ammonia) (EPA 2012a, NPS 2008). Atmospheric deposition can be in wet (i.e., pollutants dissolved in atmospheric moisture and deposited in rain, snow, low clouds, or fog) or dry (i.e., particles or gases that settle on dry surfaces as with windblown dusts) form (EPA 2012a). Deposition of sulfur and nitrogen can have significant effects on ecosystems including acidification of water and soils, excess fertilization or increased eutrophication, changes in the chemical and physical characteristics of water and soils, and accumulation of toxins in soils, water and vegetation (NPS 2008, reviewed in Sullivan et al. 2011a and 2011b).

Ozone

Ozone occurs naturally in the earth's upper atmosphere where it protects the earth's surface against ultraviolet radiation (EPA 2012a). However, it also occurs at the ground level (i.e., ground-level ozone) where it is created by a chemical reaction between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of heat and sunlight (NPS 2008). Ozone precursors are emitted from a variety of source types, including power plants, industry, motor vehicles, oil and gas development, and others. Forest fires also emit ozone precursors (EPA 2014a).

Ozone is one of the most widespread pollutants affecting vegetation in the U.S. (NPS 2008). Considered phytotoxic, ozone can cause significant foliar injury and growth effects for sensitive plants in natural ecosystems (NPS 2008, EPA 2012b). Specific effects include reduced photosynthesis, premature leaf loss, and reduced biomass; prolonged exposure can increase vulnerability to insects and diseases or other environmental stresses (NPS 2008). Plant species occurring in COLM that are known to be sensitive to ozone include quaking aspen and ponderosa pine (Kohut 2004).

At high concentrations, ozone can aggravate respiratory and cardiovascular diseases in humans, by reduced lung function, acute respiratory problems, and increased susceptibility to respiratory infections (EPA 2012a, 2012c, 2013b). Visitors and staff engaging in aerobic activities in the park, such as hiking, as well as children, the elderly, and people with heart and lung diseases are especially sensitive to elevated ozone levels.

Particulate Matter and Visibility

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets that become suspended in the atmosphere. Particulate matter largely consists of acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (EPA 2013c, 2014a). There are two particle size classes of concern: $PM_{2.5}$ – fine particles found in smoke and haze, which are 2.5 micrometers in diameter or less; and PM_{10} – coarse particles found in wind-blown dust, which have diameters between 2.5 and 10 micrometers (EPA 2012a). Fine particles are a major cause of reduced visibility (haze) in many national parks and wildernesses (EPA 2012a). $PM_{2.5}$ can be directly emitted from sources such as forest fires or they can form when gases emitted from power plants, industry and/or vehicles react with air (EPA 2013c, EPA 2014a). Particulate matter either absorbs or scatters light. As a result, the clarity, color, and distance seen by humans, decreases, especially during humid conditions when additional moisture is present in the air (EPA 2012a, 2013c). $PM_{2.5}$ is also a concern for human health as these particles can easily pass through the throat and nose and enter the lungs (EPA 2012a, 2013c, 2014a). Short-term exposure to these particles can cause shortness of breath, fatigue, and lung irritation (EPA 2012a, 2013c).

Atmospheric Deposition of Mercury

Sources of atmospheric mercury (Hg) include fuel combustion and evaporation (especially coal-fired power plants), waste disposal, mining, industrial sources, and natural sources such as volcanoes and evaporation from enriched soils, wetlands, and oceans (EPA 2008). Atmospheric deposition of Hg from coal-burning power plants has been identified as a major source of Hg to remote ecosystems (Landers et al. 2008). Because of the size and number of coal-burning power plants in the NCPN region, Hg is a potential problem for ecosystems in these parks (Pugacheva, written communication, 11 December 2015).

Mercury deposited into rivers, lakes, and oceans can accumulate in various aquatic species, resulting in exposure to wildlife and humans that consume them (EPA 2008). Mercury exposure can cause liver, kidney, and brain (neurological and developmental) damage (EPA 2008). High mercury concentrations in birds, mammals, and fish can result in reduced foraging efficiency, survival, and reproductive success (Mast et al. 2010; Eagles-Smith et al. 2014).

4.16.3 Reference Conditions/Values

The NPS Air Resources Division (ARD) developed an approach for rating air quality conditions in national parks, based on the current NAAQS, ecosystem thresholds, and visibility improvement goals (NPS 2015c). This approach is discussed by indicator in the following paragraphs and the ratings are summarized in Table 79 and Table 80.

Table 79. National Park Service Air Resources Division air quality index values for wet deposition of nitrogen or sulfur, ozone, particulate matter, and visibility (NPS 2015c).

Condition Level	Wet Deposition of N or S (kg/ha-yr)	Human Health Risk from O_3 (ppb)	Vegetation Health Risk from O_3 (ppm-hrs)	Human Health Risk from PM_{25} (ppb)	Visibility (dv*)
Significant Concern	>3	≥71	>13	≥35.5	>8
Moderate Concern	1–3	55–70	7-13	12.1–35.4	2–8
Good Condition	<1	≤55	<7	≤12	<2

*a unit of visibility proportional to the logarithm of the atmospheric extinction; one deciview represents the minimal perceptible change in visibility to the human eye.

Atmospheric Deposition of Sulfur and Nitrogen

Assessment of current condition of nitrogen and sulfur atmospheric deposition is based on wet (rain and snow) 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 (NPS 2015c). Values for nitrogen (from ammonium and nitrate) and sulfur (from sulfate) wet deposition are expressed as amount of nitrogen or sulfur in kilograms deposited over a one-hectare area in one year (kg/ha/yr). 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 (Sheilbley 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 are assigned *Significant Concern* (NPS 2015c).

Table 80. National Park Service Air Resources Division air quality assessment matrix for mercury status (NPS 2015c). Green = Good condition, yellow = Moderate Concern, and Red = Significant Concern.

	Mercury Wet Deposition Rating				
Predicted Methylmercury Concentration Rating	**Very Low (<3 μg/m^2/yr)**	**Low (≥3–<6 μg/m^2/yr)**	**Moderate (≥6–<9 μg/m^2/yr)**	**High (≥9–<12 μg/m^2/yr)**	**Very High (≥ 12 μg/m^2/yr)**
Very Low (< 0.038 ng/L)	Green	Green	Green	Yellow	Yellow
Low (≥0.038–< 0.053 ng/L)	Green	Green	Yellow	Yellow	Yellow
Moderate (≥0.053–<0.075 ng/L)	Green	Yellow	Yellow	Yellow	Red
High (≥0.075–<0.12 ng/L)	Yellow	Yellow	Yellow	Red	Red
Very High (≥0.12 ng/L)	Yellow	Yellow	Red	Red	Red

Ozone

The primary NAAQS for ground-level ozone is set by the EPA, and is based on human health effects. The 2008 NAAQS for ozone was a 4th-highest daily maximum 8-hour ozone concentration of 75 ppb (parts per billion) (NPS 2015c). On October 1, 2015, the EPA strengthened the national ozone standard by setting the new level at 70 ppb (Pugacheva, written communication, 11 December 2015). The NPS ARD recommends a benchmark for *Good Condition* ozone status in line with the updated Air Quality Index (AQI) breakpoints (NPS 2015c).

Current condition for human health risk from ozone is based on the estimated 5-year 4th-highest daily maximum 8-hour ozone average concentration in ppb (NPS 2015c). Ozone concentrations greater than or equal to 71 ppb are assigned a *Significant Concern* (NPS 2015c). Ozone concentrations from 55–70 ppb are assigned *Moderate Condition* (NPS 2015c). A *Good Condition* is identified when ozone concentrations are less than 55 ppb (NPS 2015c).

In addition to being a concern to human health, long-term exposures to ozone can cause injury to ozone-sensitive plants (EPA 2014b). The W126 metric relates plant response to ozone exposure and is a better predictor of vegetation response than the metric used for the primary (human-health based) standard (EPA 2014b). The W126 metric measures cumulative ozone exposure over the growing season in "parts per million-hours" (ppm-hrs) and is used for assessing the vegetation health risk from ozone levels (EPA 2014b).

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

- $\leq$ 7 ppm-hrs, tree seedling biomass loss is $\leq$ 2 % per year in sensitive species; and
- $\geq$13 ppm-hrs, tree seedling biomass loss is 4–10 % per year in sensitive species.

NPS ARD recommends a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation and is considered *Good Condition*; 7-13 ppm-hrs to be in *Moderate Condition*; >13 ppm-hrs is considered to be of *Significant Concern* (NPS 2015c).

Particulate Matter

The particulate matter condition is based on the NAAQS for $PM_{2.5}$ and PM_{10}, which are established by EPA to protect human health (NPS 2015c). NPS units that are in EPA designated nonattainment areas for particulate matter are assigned *Significant Concern* condition for particulate matter (NPS 2015c). The NAAQS primary standard for $PM_{2.5}$ is a weighted annual mean of 15.0 $\mu g/m^3$ or 35 $\mu g/m^3$ in a 24-hour period over an average of 3 years (EPA 2011a). The primary and secondary NAAQS for PM_{10} measured over a 24-hour period is set at 150 $\mu g/m^3$ (EPA 2011a).

For NPS units that are outside particulate matter nonattainment areas, EPA AQI breakpoints for 24-hour average ($\mu g/m^3$) are used to assign a particulate matter condition (NPS 2015c). $PM_{2.5}$ concentrations greater than or equal to 35.5 ppb are assigned a *Significant Concern* (NPS 2015c). $PM_{2.5}$ concentrations from 35.4–12.1 ppb are assigned *Moderate Condition* (NPS 2015c). A *Good Condition* is identified when $PM_{2.5}$ concentrations are less than or equal to 12 ppb (NPS 2015c).

Visibility

Visibility conditions are assessed in terms of a Haze Index, a measure of visibility (termed deciviews [dv]) that is derived from calculated light extinction and represents the minimal perceptible change in visibility to the human eye (NPS 2011). Conditions measured near 0 dv are clear and provide excellent visibility, and as dv measurements increase, visibility conditions become hazier (NPS 2011). NPS ARD assesses visibility condition status based on the deviation of the estimated current visibility on mid-range days from estimated natural visibility on mid-range days (i.e., those estimated for a given area in the absence of human- caused visibility impairment, EPA-454/B003- 005) (NPS 2015c). The NPS ARD chose reference condition ranges to reflect the variation in visibility conditions across the monitoring network (NPS 2015c). Visibility on mid-range days is defined as the mean of the visibility observations falling within the range of the 40^{th} through the 60^{th} percentiles (NPS 2015c). 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* (NPS 2015c).

Visibility trends are computed from the Haze Index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the CAA and Regional Haze Rule, which include improving visibility on the haziest days and allowing no deterioration on the clearest days (NPS 2015c). 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 (NPS 2015c). Otherwise, the Haze Index trend on the 20% haziest days is reported as the overall visibility trend (NPS 2015c).

Mercury Deposition

The condition of mercury was assessed using estimated 3-year average mercury wet deposition (micrograms per meter squared per year [$\mu g/m^2/yr$]) and the predicted surface water methylmercury concentrations (nanograms per liter [ng/L]) at NPS I&M parks (NPS 2015c). 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 2015c). 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 2015c). Mercury wet deposition and predicted methylmercury concentrations are considered concurrently in the mercury status assessment matrix displayed below to identify one of three park-specific mercury/toxics status categories: *Good Condition*, *Moderate Condition*, and *Significant Concern*. (NPS 2015c)

4.16.4 Data and Methods

Monitoring in the Park

Air quality monitoring in the park has been limited. Ozone was monitored from June 2006 through September 2012 using a portable ozone monitoring station (POMS) (Perkins 2010, EPA 2015). Ozone was also monitored at the park from 1990–1992; while these data are too outdated to be useful in determining current condition, they may provide insight into trends over time. Historic data were obtained through the EPA AirData website (EPA 2015). Atmospheric deposition, $PM_{2.5}$, and visibility have not been measured within COLM.

NPS Data Resources

Although data on most air quality parameters are not actively collected within park boundaries, data collected at several regional monitoring stations for various parameters can be used to estimate air quality conditions in COLM (Figure 59). NPS ARD provides estimates of ozone, wet deposition (nitrogen, sulfur, and mercury), and visibility that are based on interpolations of data from all air quality monitoring stations operated by NPS, EPA, various states, and other entities, averaged over the most recent 5 years (2009–2013). Estimates and conditions data for COLM were obtained from the NPS Air Quality by Park data products page (http://www.nature.nps.gov/air/data/products/parks/index.cfm).

On-site or nearby data are needed for a statistically valid trends analysis. There are no on-site or nearby representative monitors to assess ozone and nitrogen, sulfur and mercury deposition trends. For visibility trend analysis, monitoring data from an Interagency Monitoring of Protected Visual Environments Program (IMPROVE) is required (NPS 2015c). An IMPROVE monitoring site considered being representative of a Class II park has to be between within +/- 30.48 m (100 ft) or

10% of maximum and minimum elevation of the park and at a distance of no more than 150 km (93 mi) (NPS 2015c). The IMPROVE Canyonlands National Park site (CANY1; operational since March 1988) meets this criteria and was used to represent COLM (Figure 59) (NPS 2015c).

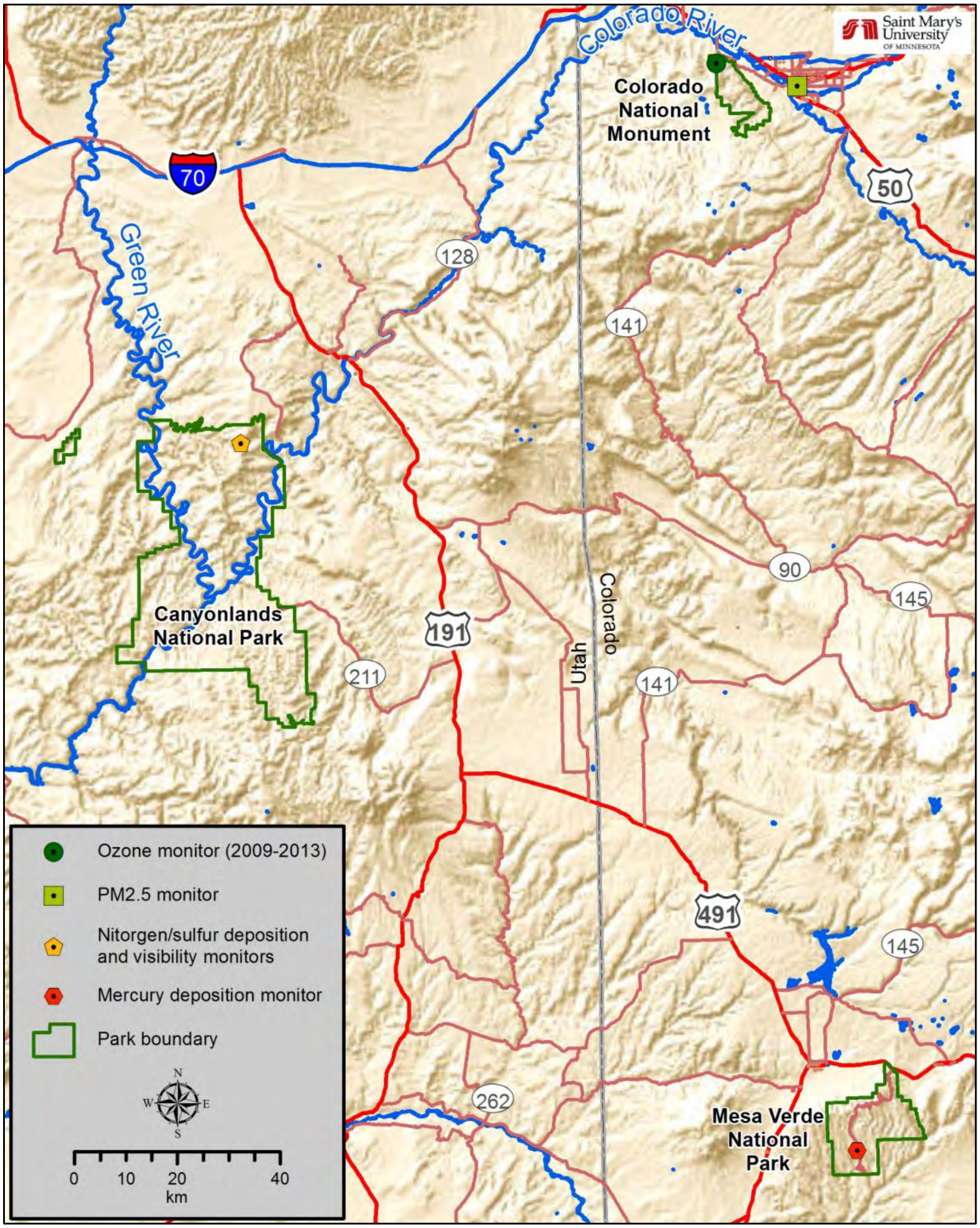

Figure 59. Location of air quality monitoring sites that provided data used in the air quality analysis for COLM.

Other Air Quality Data Resources

The EPA Air Trends Database provides annual average summary data for nitrogen deposition, $PM_{2.5}$ concentrations, and visibility near COLM (EPA 2015). The nearest $PM_{2.5}$ monitor is located in Grand Junction (Powell Building, Site ID: 08-077-0017) and operated by the Colorado Department of Public Health and the Environment (Figure 59). This station, which has collected data from 2002–2015, is located approximately 7 km (4.3mi) from the COLM boundary. Although NPS ARD has not developed national guidelines for selecting representative particulate matter monitoring sites, this location is considered reasonable for evaluating local conditions (Pugacheva, written communication, 11 December 2015).

The National Atmospheric Deposition Program–National Trends Network (NADP NTN) database provides annual average summary data for nitrogen and sulfur concentration and deposition across the U.S. (NADP 2015a). The NADP NTN monitoring site closest to COLM is located at Canyonlands National Park, in eastern Utah (site ID: UT09), approximately 115 km (71.5 mi) southwest of COLM (Figure 59). This site has collected deposition data for the region since 1997 and is currently active in monitoring (NADP 2015a). Data summaries, for this monitor are viewable on the NPS Air Quality by Park data products page (NPS 2015a).

The NADP Mercury Deposition Network (MDN) provides weekly summary data for mercury deposition and concentration (NADP 2015b). Wet mercury deposition trends are evaluated using pollutant concentrations in precipitation (micro equivalents/liter) so that yearly variations in precipitation amounts do not influence trend analyses. Trends are computed for parks with a representative NADP MDN wet deposition monitor that is within 16 km of park boundaries (NPS 2015c). The monitor closest to COLM is at Mesa Verde National Park in southwestern Colorado, nearly 200 km (120 mi) south of COLM (NADP 2015b) (Figure 59). Predicted methylmercury concentrations in surface water were obtained from a model that predicts surface water methylmercury concentrations for hydrologic units throughout the U.S. based on relevant water quality characteristics (pH, sulfate, and total organic carbon) and wetland abundance (USGS 2015).

Special Air Quality Studies

Sullivan et al. (2011a) identified ecosystems and resources at risk to acidification and excess nitrogen enrichment in national parks. These reports provide a relative risk assessment of acidification and nutrient enrichment impacts from atmospheric nitrogen and sulfur deposition for parks in 32 I&M networks. Ecosystem sensitivity ratings to acidification from atmospheric deposition were based on percent sensitive vegetation types, number of high-elevation lakes, length of low- order streams, length of high-elevation streams, average slope, and acid-sensitive areas within the park (Sullivan et al. 2011a). Ecosystem sensitivity ratings to nutrient enrichment effects were based on percent sensitive vegetation types and number of high-elevation lakes within the park (Sullivan et al. 2011b).

Kohut et al. (2004) employed a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks, the Appalachian National Scenic Trail, and the Natchez Trace National Scenic Trail. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

Pardo et al. (2011) synthesizes current research relating atmospheric nitrogen deposition to effects on terrestrial and aquatic ecosystems in the U.S. and to identify empirical critical loads for atmospheric nitrogen deposition.

4.16.5 Current Condition and Trend

Atmospheric Deposition of Nitrogen and Sulfur

Five-year interpolated averages of nitrogen (from nitrate and ammonium) wet deposition and sulfur (from sulfate) wet deposition are used to estimate condition for deposition. The current 5-year average (2009-2013) estimates wet deposition of nitrogen in COLM is 1.1 kg/ha/yr, while wet deposition of sulfur is 0.5 kg/ha/yr (NPS 2015b). Relative to the NPS ratings for air quality conditions (see Table 79 for ratings values), atmospheric deposition of nitrogen is in the *Moderate Condition* category, while sulfur deposition falls into the *Good Condition* category.

In addition to assessing wet deposition levels, critical loads can also be a useful tool in determining the extent of deposition impacts (i.e., nutrient enrichment) to park resources (Pardo et al. 2011). A critical load, defined as the level of deposition below which harmful effects to the ecosystem are not expected (Pardo et al. 2011). For COLM, Pardo et al. (2011) suggested following critical load ranges for total nitrogen deposition (wet plus dry) in the North American Deserts ecoregion:

- 3.0 kg/ha/yr to protect lichen
- 3.0–8.4 kg/ha/yr to protect herbaceous vegetation

The lowest critical load level (3.0 kg/ha/yr) is identified as an appropriate management goal because it will protect the full range of vegetation in the park (Pardo et al. 2011). The estimated 2010–2012 average for total (wet plus dry) nitrogen deposition was 3.0 kg/ha/yr in the North American Deserts ecoregion where COLM is located (Pardo et al. 2011). Therefore, the total nitrogen deposition level in the park is at the minimum ecosystem critical load for some park vegetation communities, suggesting that lichen and herbaceous vegetation is at risk for harmful effects.

Concentrations (mg/L) of nitrogen, sulfur, and ammonium compounds in wet deposition can be used to evaluate trends in deposition of nitrogen and sulfur. Since atmospheric wet deposition can vary greatly depending on the amount of precipitation that falls in any given year, it can be useful to examine concentrations of pollutants, which factor out the variation introduced by precipitation. Annual averages from Canyonlands National Park (1998-2014) suggest that nitrate concentrations in the COLM region have varied between years but with no statistically significant trends (NPS 2015a). Ammonium and sulfate concentrations have remained more stable with no statistically significant trends (NPS 2015a). Figure 60, Figure 61, and Figure 62 show the annual concentration of nitrate, sulfate, and ammonium recorded at the Canyonlands National Park NADP monitor (approximately 115 km [71.5 mi] southwest of the park).

Ecosystems in the park were rated as having high sensitivity to acidification effects and low sensitivity to nutrient enrichment effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011c; Sullivan et al. 2011d).

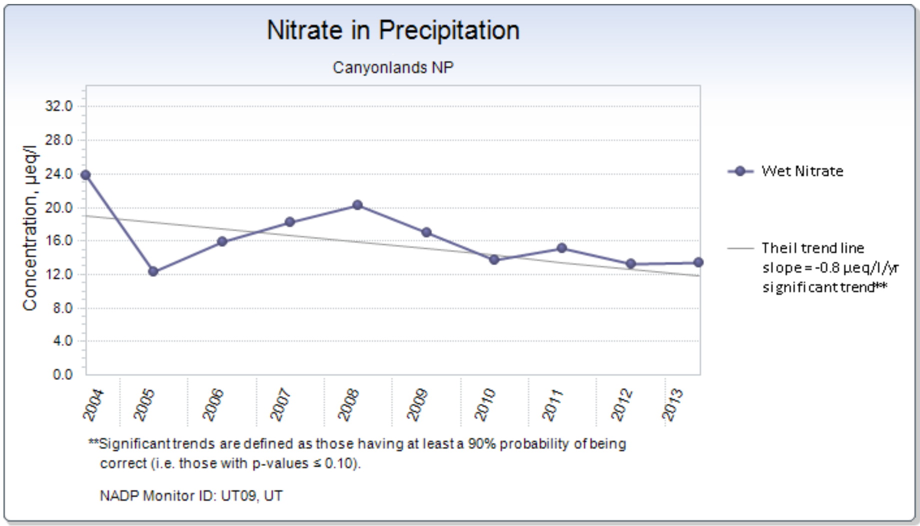

Figure 60. Ten year trend (2004–2013) in annual average concentrations (µeq/l) of nitrate in precipitation at Canyonlands National Park (NADP monitoring site UT09) (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

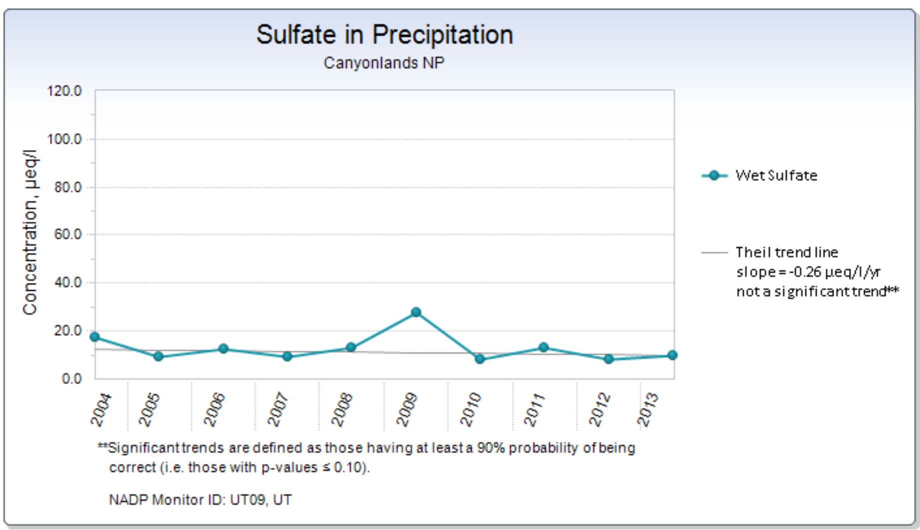

Figure 61. Ten year trend (2004–2013) in annual average concentrations (µeq/l) of sulfate in precipitation at Canyonlands National Park (NADP monitoring site UT09) (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

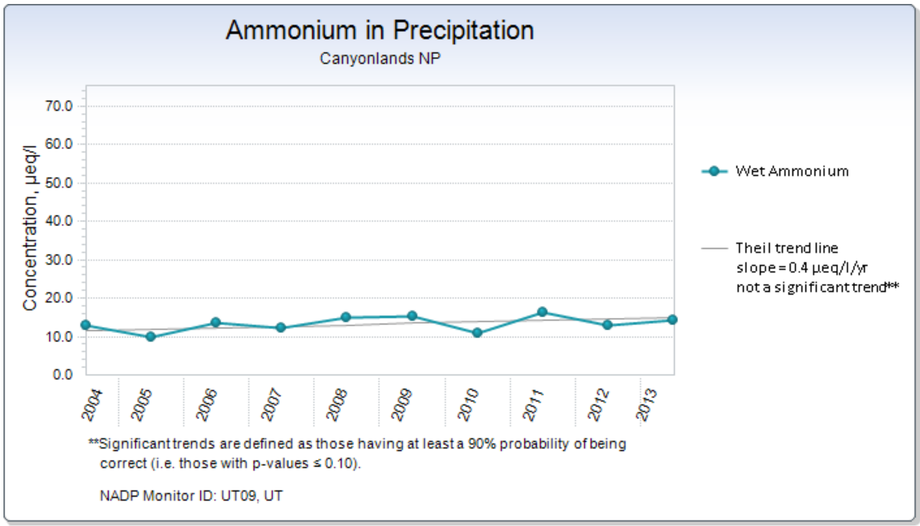

Figure 62. Ten year trend (2004–2013) in annual average concentrations (µeq/l) of ammonium in precipitation at Canyonlands National Park (NADP monitoring site UT09) (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

<u>Ozone</u>

The condition of human risk from ozone in NPS units is determined by calculating the 5-year average of the fourth-highest daily maximum of 8-hour average ozone concentrations measured at each monitor within an area over each year (NPS 2011). The most recent 5-year (2009–2013) estimated average for 4^{th} highest 8-hour ozone concentration at COLM is 65.9 ppb (NPS 2015b), which is considered *Moderate Condition*.

Vegetation health risk from ground-level ozone condition is determined by estimating a five-year average of annual maximum 3-month 12-hour W126 values. The 2009–2013 estimated W126 metric of 9.5 ppm-hrs falls in the *Moderate Condition* category (NPS 2015b).

Ozone was monitored at COLM from June 2006 to September 2012 (Perkins 2010, EPA 2015). Figure 63 illustrates the trend in annual fourth-highest daily maximum 8-hour values during this period. For 2006-2012, the trend in ozone concentration remained relatively unchanged (no statistically significant trend) (NPS 2015b). Concentrations ranged from 58.0 ppb in 2009 to 72.0 ppb for 2006 (June–Dec.) (EPA 2015). All measurements were below the 2008 national standard considered protective of human health, although two years (2006, 2012) were within 5 ppb of the 2008 ozone standard (Figure 63). These concentrations were slightly higher than those measured in COLM from 1990–1992, when ozone ranged from 59 to 66 ppb (EPA 2015).

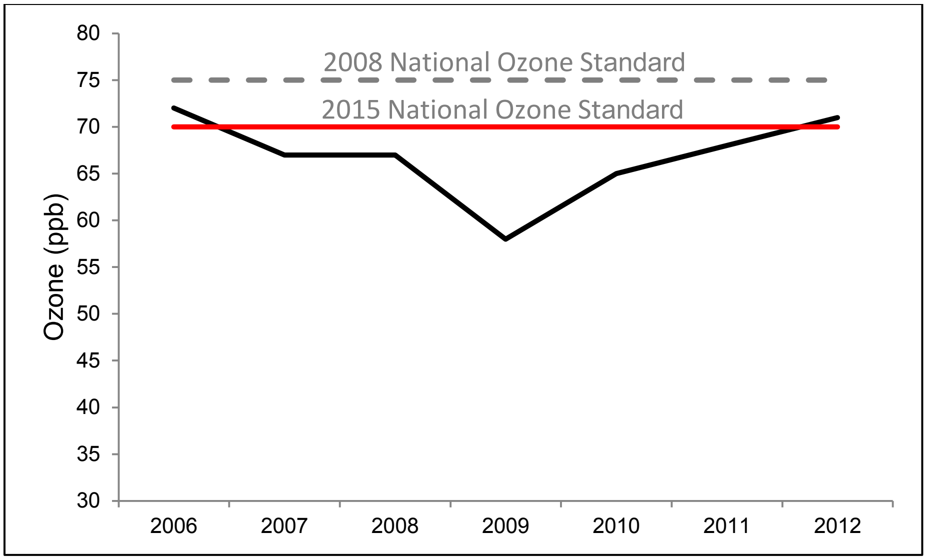

Figure 63. Annual 4th highest 8-hour maximum ozone (O_3) concentrations (ppb) at COLM, 2006-2012 (EPA 2015).

For 2006–2012, the trend in the W126 metric at COLM also remained relatively unchanged (no statistically significant trend) (NPS 2015b). Values ranged from 3.6 to 22.9 ppm-hrs and three of years had values greater than 13 ppm-hr or the significant concern category level (Figure 64, NPS 2015b).

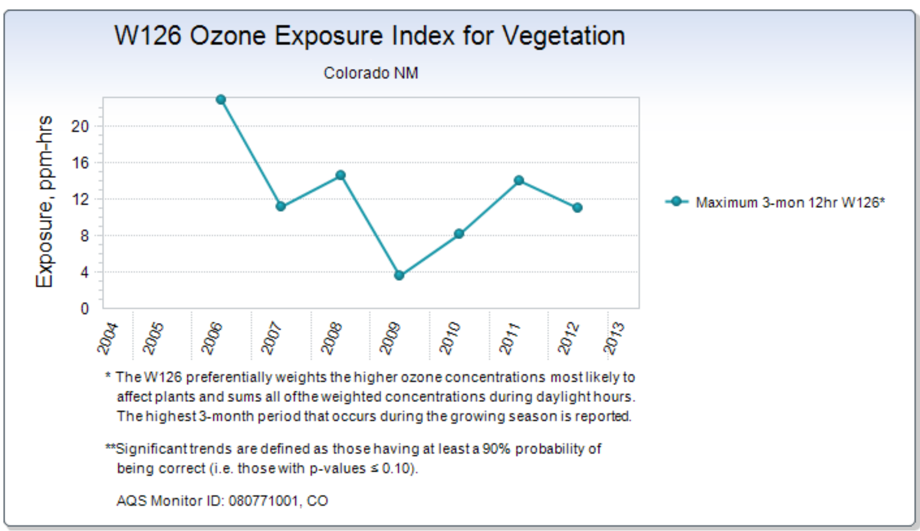

Figure 64. W126 ozone exposure index for vegetation concentrations ((ppm–hrs) at COLM (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

Kohut (2004) assessed ozone concentrations in the NCPN and the risk of injury to plant species that are sensitive to sustained ozone exposure. Estimations by kriging indicate that, from 1995-1999, ambient ozone concentrations in COLM frequently exceeded 60 ppb and only occasionally exceeded 80 ppb (less than 30 hours each year); concentrations exceeded 100 ppb very rarely (total of 7 hours across 5 years of monitoring) (Kohut 2004). Sensitive plant species begin to experience foliar injury when exposed to ozone concentrations of 80-120 ppb/hour for extended periods of time (8 hours or more), and drier soil conditions can decrease the ability of plants to absorb ozone; thus increasing ambient ozone concentrations (Kohut 2004). However, the infrequent incidence of concentrations higher than 80 ppb in COLM and rare or mild drought conditions made the risk of foliar injury from ozone low at that time (Kohut 2004). If the level of risk increases in the future, ozone foliar damage may be assessed using quaking aspen and ponderosa pine as indicator species (Kohut 2004). Ozone sensitive vegetation species found within COLM are common dogbane, coyote willow, Goodding's black willow (*Salix gooddingii*), singleleaf ash, quaking aspen, and Utah serviceberry (NPS 2015d).

Particulate Matter

COLM is located in the Mesa County, Colorado, which meets the NAAQS for the $PM_{2.5}$ 24-hour and annual $PM_{2.5}$ public health standards as well as the 24-hour PM_{10} standard (Pugacheva, written communication, 11 December 2015). Therefore, the park is within an EPA-designated attainment area for both $PM_{2.5}$ and PM_{10} (EPA 2015). Particulate matter concentrations collected at a monitor in Grand Junction are available from 2002 through 2015. The 3-year (2013–2015) average of 98th percentile 24-hour $PM_{2.5}$ concentration at the Grand Junction monitor is 27.3 µg /m^3 and the annual mean $PM_{2.5}$ concentration is 7.5 µg /m^3 (EPA 2015). The 3-year (2013–2015) average of the annual mean PM_{10} concentration is 18 µg /m^3 (EPA 2015). The 98th percentile 24-hour $PM_{2.5}$ concentration falls into the *Moderate Condition* category based on EPA AQI categories (NPA2015c).

Weighted annual average 24-hour $PM_{2.5}$ concentrations for 2005-2015 are shown in Figure 65. Daily hourly values ranged from a minumum of 1.2 µg /m^3 on 7 February 2014 to a maximum of 59.1 µg /m^3 on 1 January 2009 (EPA 2015). Overall, during this 10-year period, the weighted concentrations appeared to be relatively stable in Grand Junction, with a slight decline in recent years (EPA 2015). The weighted concentrations never exceeded 10 µg/m^3, and were well within the EPA standards for levels that are protective of human health during this period (Figure 65).

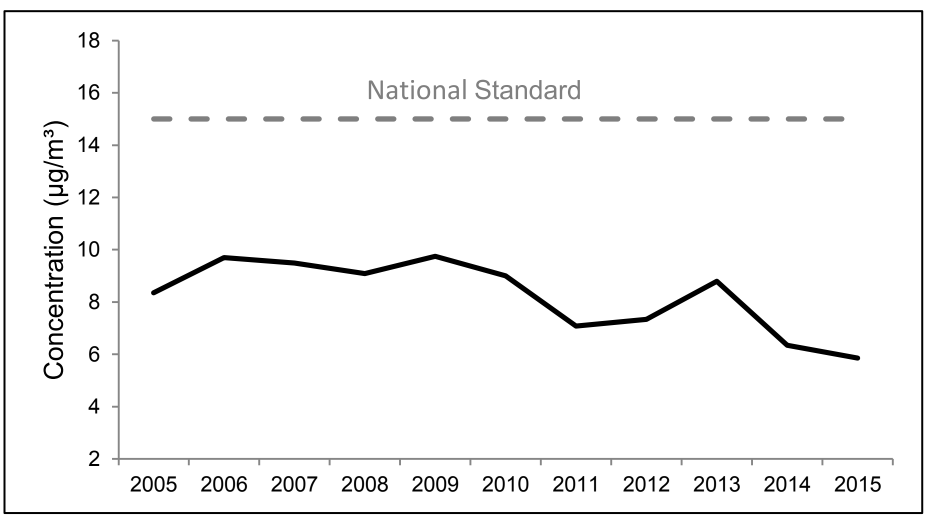

Figure 65. Annual 24-hour particulate matter ($PM_{2.5}$) concentrations (weighted annual mean) near COLM, 2005-2015 (EPA 2015). Monitoring station is located in Grand Junction (Powell Building).

The annual average 24-hour PM_{10} concentrations for 2005-2015 are shown in Figure 66. Daily hourly values ranged from a minumum of 2 µg /m^3 on three occasions (19 April 2005, 1 November 2014, and 1 June 2015) to a maximum of 169 µg /m^3 on 19 April 2005 (EPA 2015). Similar to the 24-hour $PM_{2.5}$ results, during this 10-year period, the weighted concentrations appeared to be relatively stable in Grand Junction, with a slight decline in recent years (EPA 2015). The weighted concentrations never exceeded 150 µg/m^3, and were well within the EPA standards for levels that are protective of human health during this period (Figure 65).

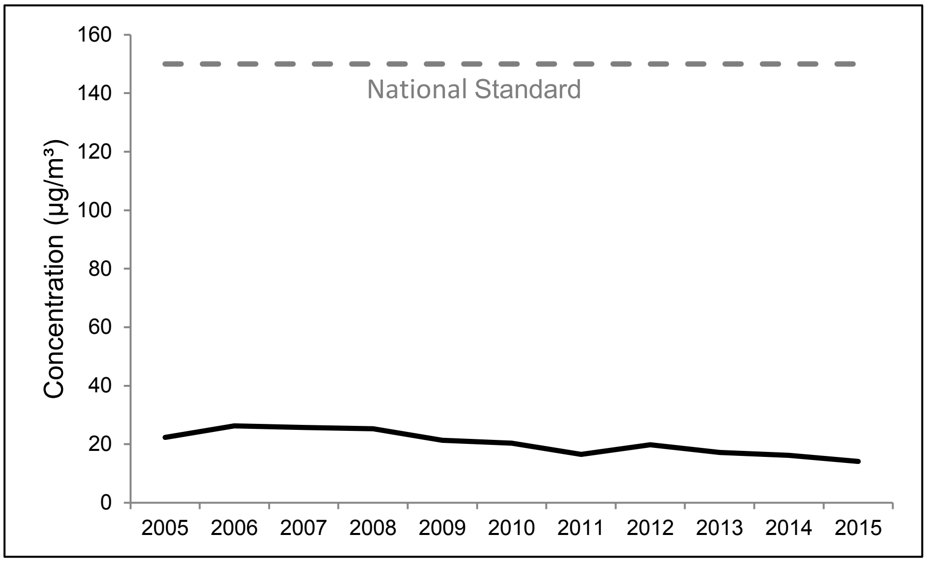

Figure 66. Annual 24-hour particulate matter (PM_{10}) concentrations (weighted annual mean) near COLM, 2005-2015 (EPA 2015). Monitoring station is located in Grand Junction (Powell Building).

<u>Visibility</u>

Five-year estimated averages of visibility on mid-range days minus natural condition visibility on mid-range days is used to estimate condition for visibility. The 2009–2013 estimated visibility on mid-range days was 2.9 dv above estimated natural conditions (NPS 2015c). This estimate falls into the *Moderate Condition* category based on NPS criteria for air quality assessment.

For 2004–2013, the trend in visibility at the Canyonlands IMPROVE monitor remained relatively unchanged (no statistically significant trend) on the 20% clearest days (Figure 67) and remained relatively unchanged (no statistically significant trend) on the 20% haziest days (Figure 68) (NPS 2015a). The primary visibility impairing pollutants on both the clearest and haziest days from 2009–2013 were ammonium sulfate, ammonium nitrate, coarse mass, and organic carbon (Figure 67 and Figure 68, NPS2013b). Ammonium sulfate originates mainly from coal-fired power plants and smelters; ammonium nitrate mainly originates from coal-fired power plants, mobile sources, and oil and gas development; coarse mass consists of wind-blown dust, while organic carbon originates primarily from combustion of fossil fuels and biomass, as well as directly from vegetation (NPS 2015a).

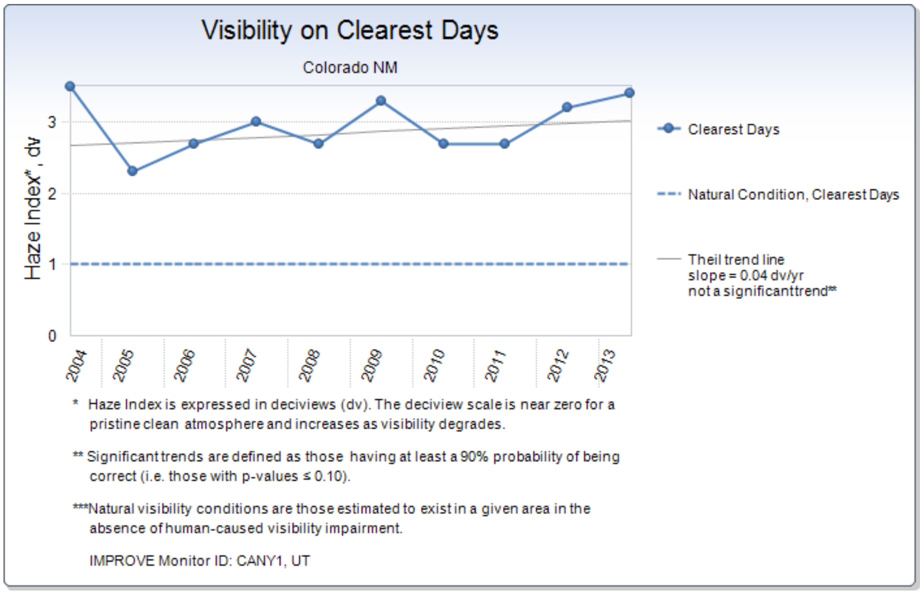

Figure 67. Ten year trend (2004–2013) in visibility for the 20% clearest days (dv) for COLM. Values were interpolated from conditions at Canyonlands National Park (NADP monitoring site UT09) (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

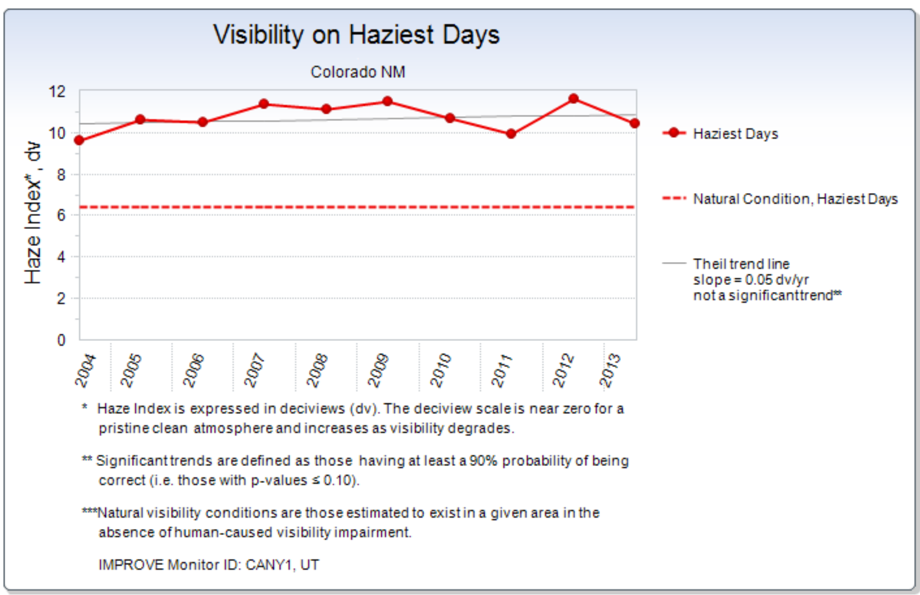

Figure 68. Ten year trend (2004–2013) in visibility for the 20% clearest days (dv) for COLM. Values were interpolated from conditions at Canyonlands National Park (NADP monitoring site UT09) (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

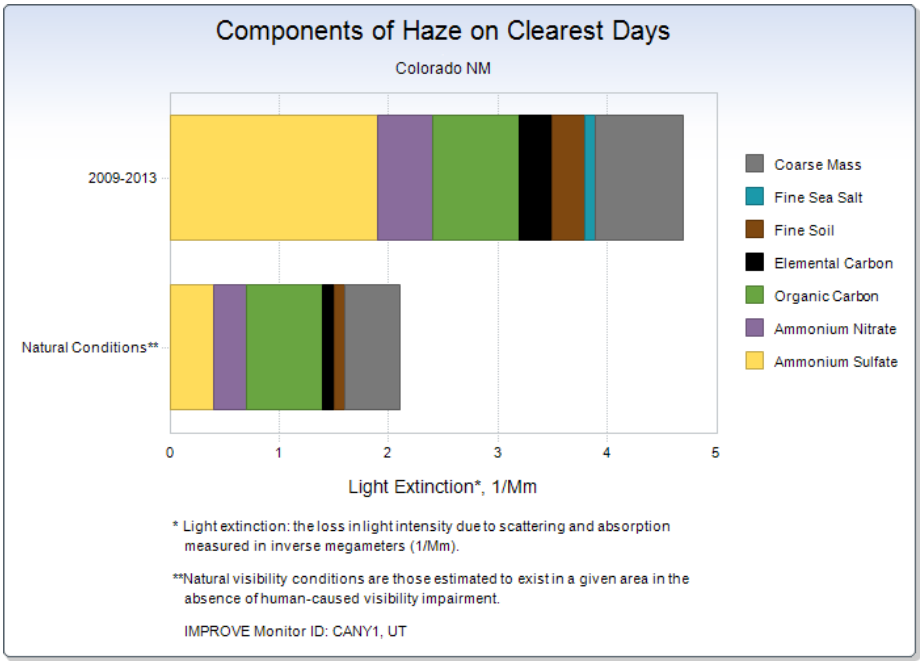

Figure 69. Composition of haze on clearest days (2009–2013) for COLM. Data were interpolated from Canyonlands National Park (NADP monitoring site UT09) (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

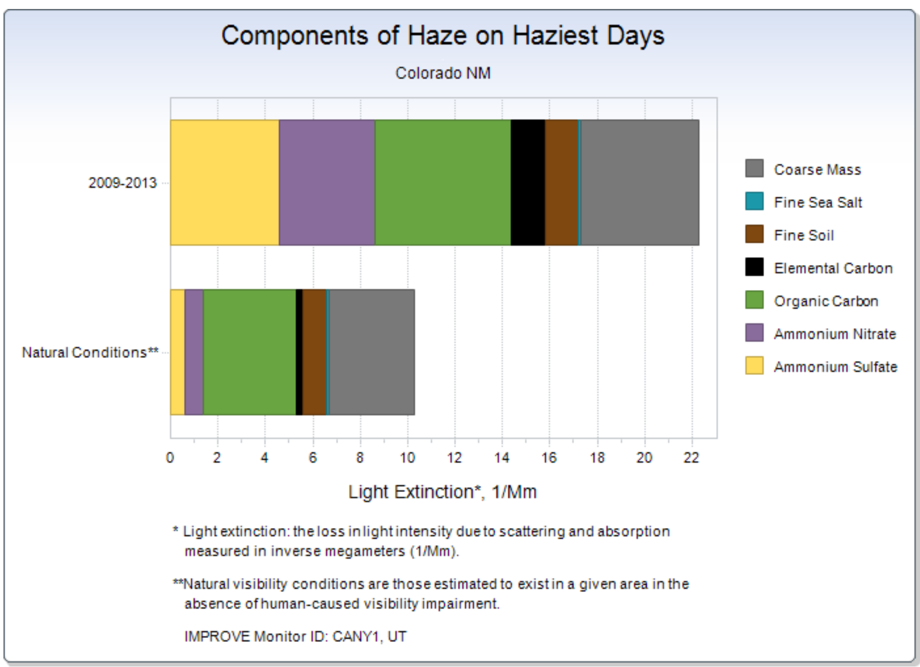

Figure 70. Composition of haze on haziest days (2009–2013) for COLM. Data were interpolated from Canyonlands National Park (NADP monitoring site UT09) (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

Atmospheric Deposition of Mercury

The 2011–2013 estimated wet mercury deposition is low at the park, ranging from 4.9 to 5.7 µg/m2/yr and predicted methylmercury concentrations in surface waters is very high, ranging from 0.11 to 0.12 ng/l (NPS 2015c). To maintain the highest level of protection in the park, the highest values for each factor were compared to mercury status assessment matrix (see Table 80) to determine the *Moderate Condition* status.

The NPS ARD has measured mercury wet deposition at 16 parks across the U.S (NPS 2013). The location closest to COLM where monitoring has occurred is Mesa Verde National Park, approximately 200 km (120 mi) south of COLM (Figure 59). The 3-year (2011–2013) average wet mercury deposition at Mesa Verde is 9.7 ng/l (NADP 2015b). Interpolations based on 2013 data suggest that COLM may be on the edge of a “hot spot” for mercury deposition (Figure 71, NADP 2014). According to the NPS (2013), mercury deposition did not show any trends from 2000-2009. As with nitrogen and sulfur deposition, concentrations of mercury in wet deposition can be used to evaluate trends in mercury deposition.

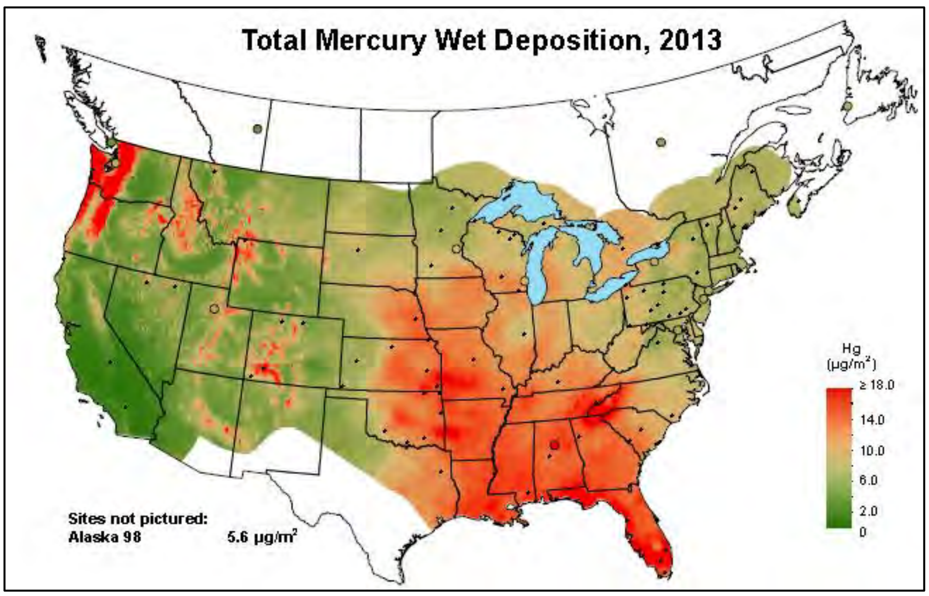

Figure 71. Total annual mercury wet deposition in 2013 (NADP 2014).

The 3-year (2011–2013) average mercury concentration at the Mesa Verde site is of 27.1 ng/l (NADP 2015b). Interpolations suggest that mercury concentrations were relatively high in portions of several western states, including southwest Colorado near COLM (Figure 72, NADP 2014).

Eagles-Smith et al. (2014) examined fish from 21 national parks in the western U.S., including two NCPN parks, Capitol Reef National Park (in the Fremont River) and Zion National Park (Virgin River). This study found elevated mercury levels in small prey fish (speckled dace [*Rhinichthys osculus*]) at both parks. Speckled dace serve as potential prey for predatory fishes and piscivorous birds, and concentrations in dace from both parks exceeded levels associated with biochemical and reproductive effects in fish and reproductive impairment in birds (Eagles-Smith et al. 2014).

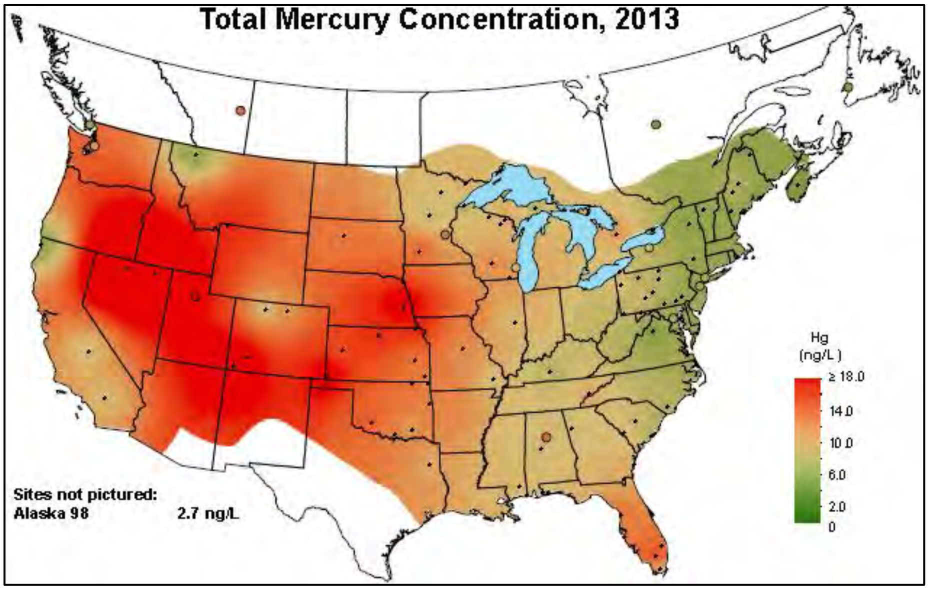

Figure 72. Total mercury concentrations in 2013 (NADP 2014).

Threats and Stressor Factors

COLM NPS natural resource managers identified several potential threats to COLM's air quality including oil and gas development, vehicle emissions from the valley, wildfire smoke and woodburning stoves, and visibility impacts from haze and inversions.

COLM is located within the Uintah-Piceance oil and gas basins, an area with extensive historic and ongoing oil and gas development (NGI 2015). The basins are located in northeastern Utah and northwestern Colorado. According to state agency databases, in 2015 there were approximately 34,382 active, producing, drilling or permitted/permit application well sites within the basin (Pugacheva, written communication, 11 December 2015). In the past 10–12 years, new technologies in the oil and gas industry, such as horizontal drilling and hydraulic fracturing (e.g., unconventional development), have led to a resurgence in oil and natural gas production within the basins (NGI 2015).

There are numerous types of equipment associated with oil and gas development and production, such as drill rigs, fracturing engines, valves, seals, compressors, heaters/treaters, separators, dehydration units, tanks, etc. Each of these individually small "sources" emit air pollutants (NO_x, VOCs, greenhouse gases [GHGs], hydrogen sulfide [H_2S], PM, and Hazardous air pollutants [HAPs] that cumulatively contribute to regional air quality concerns (Pugacheva, written communication, 11 December 2015). In addition, exhaust and dust from motor vehicles on and near COLM emit nitrogen oxide, volatile organic compounds, and particulate matter (Pugacheva, written communication, 11 December 2015).

The majority of existing development within the basin lies to the north and northwest of the park. Significant air quality issues due to oil and gas activity within the basin have been identified, including violations of the ozone standard that occur under specific wintertime conditions and associated potential ozone nonattainment in the most active development regions (Lyman and

Shorthill, 2013, Edwards et al., 2014). While COLM lies just to the south of this activity, and is outside of the areas exhibiting the most significant air quality impacts, NPS modeling results suggest that park air quality may be affected by oil and gas in the region (Pugacheva, written communication, 11 December 2015). Consequently, ongoing air quality monitoring in the region is crucial to track the temporal and geographic extent of air quality issues in the basin, including areas on the periphery like COLM.

Droughts throughout the west have increased the frequency and severity of wildfires (Westerling et al. 2006), which produce particulates and can significantly impair visibility (Perkins 2010). Wildfires may also become more frequent if plant biomass increases as a result of nutrient enrichment from nitrogen deposition. Research in the arid environment of California's Joshua Tree National Park showed that nitrogen deposition as low as 3 kg/ha/yr increased wildfire risk in pinyon-juniper communities, due to increased growth of fine fuels such as annual grasses (Rao et al. 2010).

According to the EPA and IPCC, global climate change is expected to negatively affect air quality (EPA 2011b). Both ozone and particulate pollution are heavily influenced by weather shifts. The EPA projects that climate change could increase summertime average ground-level ozone concentrations in many areas by 2-8 ppb. It could also cause particulate pollution to increase in some regions and decrease in others (EPA 2011b).

Data Needs/Gaps

There are no wet deposition or ozone air quality monitors within the acceptable distance (to accurately represent conditions in the park. The nearest active NADP monitor that provides annual averages for nitrogen and sulfur deposition is located at Canyonlands National Park in eastern Utah, approximately 115 km (71.5 mi) southwest of COLM. The nearest visibility monitoring site is also at Canyonlands. The nearest mercury deposition monitor is even further away, at Mesa Verde National Park approximately 200 km (120 mi) to the south of COLM. Periodic or consistent monitoring of atmospheric deposition, ozone, and particulate matter would help managers better understand the local air quality conditions in and around COLM and how they may affect other park resources.

Overall Condition

Atmospheric Depositon of Sulfur and Nitrogen

The *Significance Level* for this measure was defined as a 3. Current NPS estimated averages for nitrogen deposition are considered to be in *Moderate Condition* while sulfur deposition is in *Good Condition*, based on NPS criteria for rating air quality. Sullivan et al. (2011c, 2011d) rated total nitrogen deposition at COLM at the minimum ecosystem critical load for some park vegetation communities, suggesting lichen and herbaceous vegetation is at risk for harmful effects. Overall, atmospheric deposition was assigned a *Condition Level* of 2, or of moderate concern.

Ozone Concentration

The *Significance Level* for ozone was also defined as a 3. Current human health and vegetation risk from ground-level ozone fall into the *Moderate Condition* category based on NPS criteria for rating air quality condition. Annual 4^{th} highest 8-hour maximum concentrations from 2006 through 2013 were below EPA 2008 standard protective of human health, although two years were within 5 ppb of this level (EPA 2015). These concentrations were also slightly higher than those measured at COLM from 1990-1992 (59-66 ppb), suggesting a possible increasing trend in recent decades. Therefore, the *Condition Level* for ozone concentration was assigned a 2, indicating moderate concern.

Particulate Matter

The *Significance Level* for particulate matter was also defined as a 3. While all measurements were well within the EPA standards for levels that are protective of human health, the 98th percentile 24-hour $PM_{2.5}$ concentration falls into the *Moderate Condition* category based on EPA AQI categories. Weighted annual average $PM_{2.5}$ concentrations at the Grand Junction monitor have been relatively stable, with a slight decline in recent years (EPA 2015). As a result of this, the *Condition Level* for particulate matter was assigned a 2, or of moderate concern.

Visibility

The *Significance Level* for visibility was also defined as a 3. Current interpolated average visibility estimates fall into the *Moderate Condition* category based on NPS criteria. Estimated visibility on the 20% clearest days also falls just within the moderate concern category (close to good condition), while visibility on the 20% haziest days falls into the significant concern category. The *Condition Level* for visibility was assigned a 2, indicating visibility is of moderate concern.

Atmospheric Deposition of Mercury

This measure was assigned a *Significance Level* of 3. Based on estimated wet mercury deposition and predicted methylmercury concentrations in surface waters, the mercury deposition condition falls into the *Moderate Condition* category based on NPS criteria. Due to this the *Condition Level* for atmospheric deposition of mercury deposition was assigned a *Condition Level* of 2, meaning moderate concern.

Weighted Condition Score

The *Weighted Condition Score* for COLM air quality is 0.67, which is on the lower end of the significant concern range. A trend was not assigned, due to the lack of consistent data from within or near the park itself. Because of the use of interpolated air quality estimates for most measures rather than on-site data, the confidence level in this condition assessment is medium.

Air Quality			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.67**
Atmospheric Deposition of Sulfur and Nitrogen	3	2	
Ozone Concentration	3	2	
Particulate Matter	3	2	
Visibility	3	2	
Atmospheric Deposition of Mercury	2	2	

4.16.6 Sources of Expertise

National Park Service Air Resources Division members Ksienya Pugacheva, Andrea Stacy, Barkley Sive, Michael George, John Vimont, Jim Cheatham, and Melanie Peters.

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4.17 Dark Night Skies

4.17.1 Description

A lightscape is a place or environment characterized by the natural rhythm of the sun and moon cycles, clean air, and of dark nights unperturbed by artificial light (NPS 2014). The NPS directs each of its units to preserve, to the greatest extent possible, these natural lightscapes (NPS 2006). Natural cycles of dark and light periods during the course of a day affect the evolution of species and other natural resource processes such as plant phenology (NPS 2006, 2014). Several species require darkness to hunt, hide their location, navigate, or reproduce (NPS 2014). In addition to the ecological importance of dark night skies, park visitors expect skies to be free of light pollution and allow for star observation.

The resource of a dark night sky is important to the NPS for a variety of reasons. First, the preservation of natural lightscapes (the intensity and distribution of light on the landscape at night) will keep the nocturnal photopic environment within the range of natural variability. Excursions outside this natural range may result in a modification to natural ecosystem function, especially to systems involving the behavior and survival of nocturnal animals. The natural night sky is therefore one of the physical resources under which natural ecosystems have evolved. Second, the "scenery" of national park areas does not just include the daytime hours (NPS 2012). A natural starry sky absent of anthropogenic light is one of their key scenic resources, especially large wilderness parks remote from major cities. Third, the history and culture of many civilizations are steeped in interpretations of night sky observations, whether for scientific, religious, or time-keeping purposes (NPS 2012). As such, the natural night sky may be a very important cultural resource, especially in areas where evidence of aboriginal cultures is present. Fourth, the recreational value of dark night skies is important to campers and backpackers, allowing the experience of having a campfire or "sleeping under the stars" (NPS 2012). And fifth, night sky quality is an important wilderness value, contributing to the ability to experience a feeling of solitude in a landscape free from signs of human occupation and technology (NPS 2012).

4.17.2 Measures

During site visits, the NPS Natural Sounds and Night Skies Division (NSNSD) collects data for a suite of measures in order to define the current condition of dark night skies in a park unit. These measures typically include:

- Sky luminance over the hemisphere in high resolution (thousands of measurements comprise a data set), reported in photometric luminance units (V magnitudes per square arc second or milli-candela per square meter) or relative to natural conditions, often shown as a sky brightness contour map of the entire sky. V magnitude is a broadband photometric term in astronomy, meaning the total flux from a source striking a detector after passing through a "Johnson-Cousins V" filter. It is similar to the "CIE photopic" broadband function for wavelengths of light to which the human eye is sensitive (Bessell 1990);
- Integrated measures of anthropogenic sky glow from selected areas of sky that may be attributed to individual cities or towns (known as city light domes), reported in milli-Lux of hemispheric illuminance or vertical illuminance;

- Integration of the entire sky illuminance measures, reported either in milli-Lux of total hemispheric (or horizontal) illuminance, milli-Lux of anthropogenic hemispheric (or horizontal) illuminance, V-magnitudes of the integrated hemisphere, or ratio of anthropogenic illuminance to natural illuminance;
- Vertical illuminance from individual (or groups of) outdoor lighting fixtures at a given observing location (such as the Wilderness boundary), in milli-Lux;
- Visual observations by a human observer, such as Bortle Class and Zenithal limiting magnitude;
- Integrated synthesized measure of the luminance of the sky within 50 degrees of the Zenith, as reported by the Unihedron Sky Quality Meter, in V magnitudes per square arc second.

4.17.3 Reference Conditions/Values

The reference condition for dark night skies in COLM was that of the dark night sky conditions during presettlement of the region. The reference condition for this resource is defined in terms of sky luminance and illuminance at the observer's location from anthropogenic sources as follows:

> *No portion of the sky background brightness exceeds natural levels by more than 200 percent, and the sky brightness at the Zenith does not exceed natural Zenith sky brightness by more than 10 percent. The ratio of anthropogenic hemispheric illuminance to natural hemispheric illuminance from the entire night sky does not exceed 20 percent. The observed light from a single visible anthropogenic source (light trespass) is not observed as brighter than the planet Venus (0.1 milli-Lux) when viewed from within any area of the park designated the naturally dark zone (Dan Duriscoe, NPS NSNSD, pers. comm., 2011).*

Achieving this reference condition for preserving natural night skies is well summarized in the NPS Management Policies (2006) as follows in section 4.10:

> *The Service will preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light.*

Implementing this directive in COLM requires that facilities within the park and local communities around the park meet outdoor lighting standards that provide for the maximum amount of environmental protection while meeting human needs for safety, security, and convenience. This means that outdoor lights within the park:

- produce zero light trespass beyond the boundary of their intended use;
- be of an intensity that meets the minimum requirement for the task, but does not excessively exceed that requirement;
- be of a color that is toward the yellow or orange end of the spectrum to minimize sky glow;
- be controlled intelligently, preventing unnecessary dusk to dawn bright illumination of areas.

4.17.4 Data and Methods

COLM is located in an area of west Colorado that is relatively close to Grand Junction, Colorado (one of Colorado's largest cities). Smaller cities nearby include Fruita and Redlands. The close proximity to a major city may greatly impact the quality of its night sky. It is particularly important that within-park sources of light be contained, eliminating light trespass and minimizing anthropogenic sky glow.

Data were collected for baseline dark sky documentation in COLM from a ridgeline between the Visitor Center and the maintenance yard on 25 September 2014. Images were collected by Bob Meadows of the NPS NSNSD. Data were collected for a suite of measures during this visit. Figure 73 displays the data collection site (Alpine Camp) in relation to the Visitor Center.

4.17.5 Current Condition and Trend

Background for NPS Night Sky Division's Suite of Measures

Anthropogenic light in the night environment can be very significant, especially on moonless nights. Unshielded lamps mounted on tall poles have the greatest potential to cause light pollution, since light directly emitted by the lamp has the potential to follow an unobstructed path into the sky or the distant landscape. This type of light spill has been called glare, intrusive light, or light trespass (Narisada and Schreuder 2004). The dark-adapted human eye will see these individual light sources as extremely bright points in a natural environment. These sources also have the potential to illuminate the landscape, especially vertical surfaces aligned perpendicular to them, often to a level that approaches or surpasses moonlight. The brightness of such objects may be measured as the amount of light per unit area striking a "detector" or a measuring device, or entering the observer's pupil. This type of measure is called illuminance (Ryer 1997).

Illuminance is measured in lux (metric) or foot-candles (English), and is usually defined as luminous flux per unit area of a flat surface (1 lux = 1 lumen/m^2). However, different surface geometries may be employed, such as a cylindrical surface or a hemispheric surface. Integrated illuminance of a hemisphere (summed flux per unit area from all angles above the horizon) is a useful, unbiased metric for determining the brightness of the entire night sky. Horizontal and vertical illuminance are also used; horizontal illuminance weights areas near the Zenith much greater than areas near the horizon, while vertical illuminance preferentially weights areas near the horizon, and an azimuth of orientation must be specified.

Direct vertical illuminance from a nearby anthropogenic source will vary considerably with the location of the observer, since this value varies as the inverse of the square of the distance from light source to observer (Ryer 1997). Therefore, measures of light trespass are usually made in sensitive areas (such as public campgrounds).

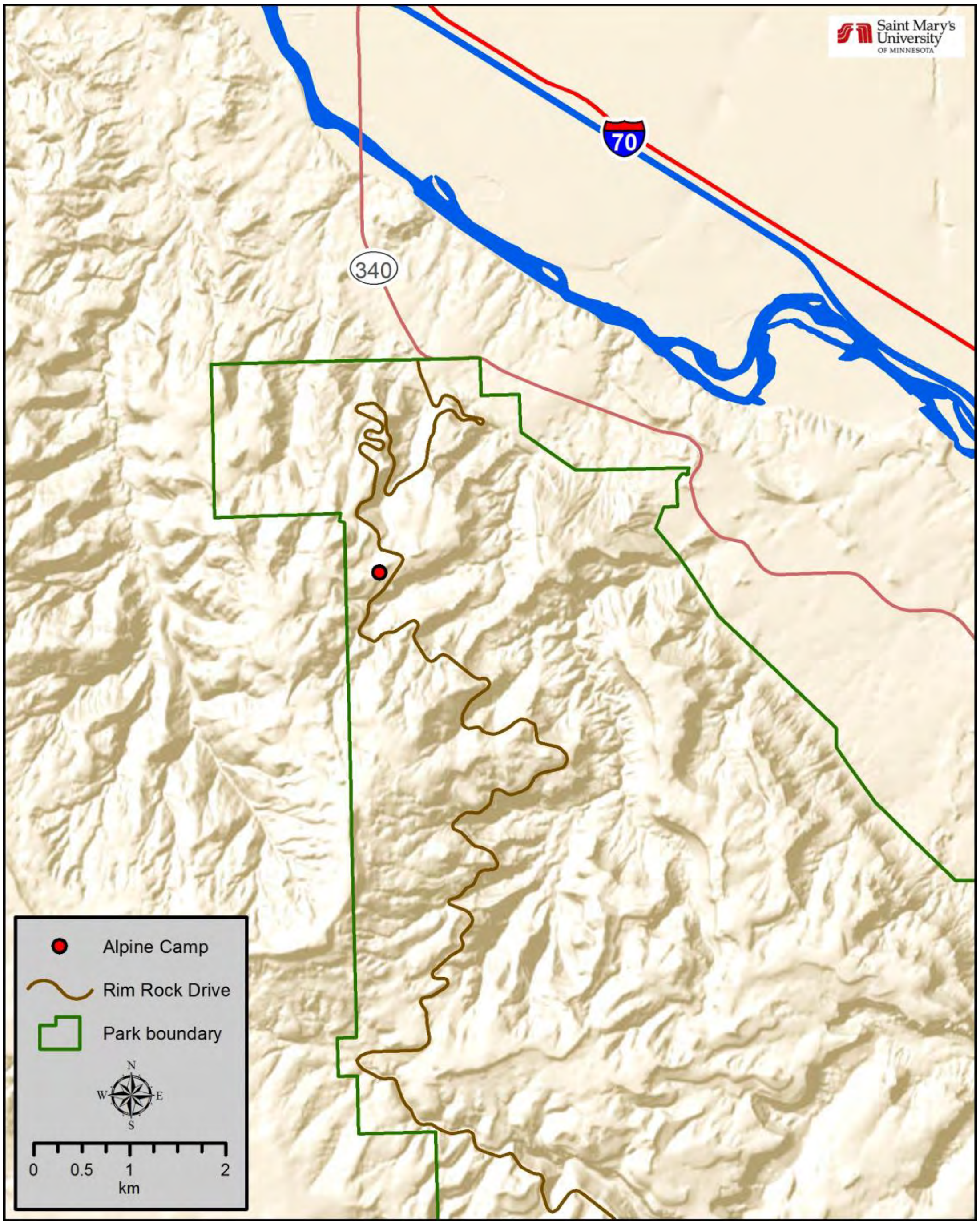


Figure 73. Location of DNS sample site (Alpine Camp) in COLM.

Anthropogenic light which results in an upward component will be visible to an observer as "sky glow". This is because the atmosphere effectively scatters light passing through it. The sky is blue in daytime because of Rayleigh scattering by air molecules, which is more effective for light of shorter wavelengths. For this reason, bluish light from outdoor fixtures will produce more sky glow than reddish light. Larger particles in the atmosphere (aerosols and water vapor droplets) cause Mie scattering and absorption of light, which is not as wavelength-dependent and is more directional.

When the air is full of larger particles, this process gives clouds their white appearance and produces a whitish glow around bright objects (e.g., the sun and moon). The pattern of sky glow as seen by a distant observer will appear as a dome of light of decreasing intensity from the center of the city on the horizon. As the observer moves closer to the source, the dome gets larger until the entire sky appears to be luminous (Garstang 1989).

Light propagated at an angle near the horizon will be effectively scattered and the sky glow produced will be highly visible to an observer located in the direction of propagation. Predictions of the apparent light dome produced by a sky glow model demonstrate this (Luginbuhl et al. 2009). Light reflected off surfaces (e.g., a concrete road or parking area) becomes visible light pollution when it is scattered by the atmosphere above it, even if the light fixture has a "full cutoff" design and is not visible as glare or light trespass to a distant observer. For this reason, the intensity and color of outdoor lights must be carefully considered, especially if light-colored surfaces are present near the light source.

Light domes from many cities, as they appear from a location within Joshua Tree National Park, are shown in Figure 74 and Figure 75, as a grayscale and in false color. This graphic demonstrates that the core of the light dome may be tens or hundreds of times brighter than the extremities. A logarithmic scale for sky luminance and false color are commonly used to display monochromatic images or data with a very large dynamic range, and are used extensively in reports of sky brightness by the NSNSD.

The brightness (or luminance) of the sky in the region of the light domes may be measured as the number of photons per second reaching the observer for a given viewing angle, or area of the sky (such as a square degree, square arc minute, or square arc second). The NPS NSNSD utilizes a digital camera with a large, dynamic range, monochromatic charge-coupled device (CCD) detector and an extensive system of data collection, calibration, and analysis procedures (Duriscoe et al. 2007). This system allows for the accurate measurement of both luminance and illuminance, since it is calibrated on standard stars that appear in the same images as the data and the image scale in arc seconds per pixel is accurately known. Sky luminance is reported in astronomical units of V-magnitudes per square arc second, and in engineering units of milli-candela per square meter. High resolution imagery of the entire night sky reveals details of individual light domes that may be attributed to anthropogenic light from distant cities or nearby individual sources. These data sets may be used for both resource condition assessment and long-term monitoring.

Figure 74 and Figure 75 contain information on natural sources of light in the night sky as well as anthropogenic sources. The appearance of the natural night sky may be modeled and predicted in terms of sky luminance and illuminance over the hemisphere, given the location, date, time, and the relative brightness of the natural airglow (the so-called "permanent aurora" which varies in intensity over time) (Roach and Gordon 1973). The NPS NSNSD has constructed such a model, and uses it in analysis of data sets to remove the natural components. This results in a more accurate measure of anthropogenic sky glow (Figure 76). Figure 75 represents "total sky brightness" while Figure 76 displays "anthropogenic sky glow" or "net light pollution." This is an important distinction, especially in areas where anthropogenic sky glow is of relatively low intensity.

Figure 74. Grayscale representation of sky luminance from a location in Joshua Tree National Park (Figure provided by Dan Duriscoe, NPS NSNSD).

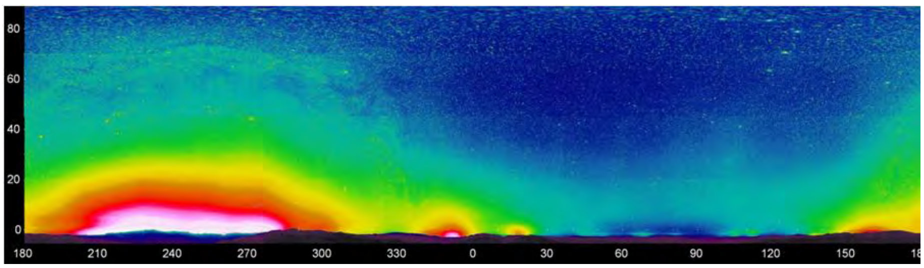


Figure 75. False color representation of Figure 74 after a logarithmic stretch of pixel values (Figure provided by Dan Duriscoe, NPS NSNSD).

The accurate measurement of both anthropogenic light in the night sky and the accurate prediction of the brightness and distribution of natural sources of light allows for the use of a very intuitive metric of the resource condition - a ratio of anthropogenic to natural light. Both luminance and illuminance for the entire sky or a given area of the sky may be described in this manner (Hollan 2010). This so-called "light pollution ratio" is unitless and is always referenced to the brightness of a natural moonless sky under average atmospheric conditions, or, in the case of the NSNSD data, the atmospheric conditions determined from each individual data set.

The reference conditions for anthropogenic sky luminance were identified as no more than 200 percent brighter than natural conditions in *any* area of the sky and no more than 10 percent brighter at the Zenith. These values correspond to light pollution ratios of 2.0 and 0.1, respectively. The NSNSD has obtained values of 50-100 for this measure at the core of city light domes seen from several areas administered by the NPS, including Lake Mead National Recreation Area, Saguaro National Park, and Colorado National Monument (NPS NSNSD, unpublished data). This is because these NPS areas are very close to the cities of Las Vegas, Nevada; Tucson, Arizona; and Grand Junction, Colorado, respectively. COLM is one of these unfortunate locations. As such, the park subjected to bright light domes, which can significantly impair sky quality at distances of 100 mi or more from the center of the city.

A quick and accurate method of quantifying sky brightness near the Zenith is the use of a Unihedron Sky Quality Meter. The Unihedron Sky Quality Meter is a single-channeled hand-held photometric device. A single number in magnitudes per square arc second is read from the front of the device after its photodiode and associated electronics are pointed at the Zenith and the processor completes its integration of photon detection. Because the meter is relatively inexpensive and easy to use, a database of measures has grown since its introduction (see http://unihedron.com/projects/darksky/database/index.php). The NPS NSNSD produces values from each data set as both a synthesized value derived from the high-resolution images and by hand held measures with a Unihedron Sky Quality Meter. The performance of the Sky Quality Meter has been tested and reviewed by Cinzano (2001). While fairly accurate and easy to use, the value it produces is biased toward the Zenith. Therefore, the robustness of data collected in this manner is limited to areas with relatively bright sky glow near the Zenith, corresponding to severely light polluted areas. While not included in the reference condition, a value of about 21.85 would be considered "pristine", providing the Milky Way is not overhead and/or the natural airglow is not unusually bright when the reading is taken.

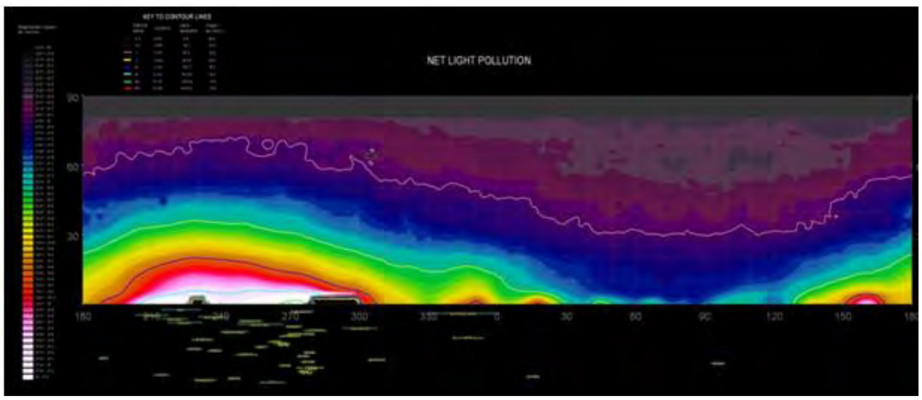


Figure 76. Contour map of anthropogenic sky glow at a location in Joshua Tree National Park, analogous to Figure 75 with natural sources of light subtracted (Figure provided by Dan Duriscoe, NPS NSNSD).

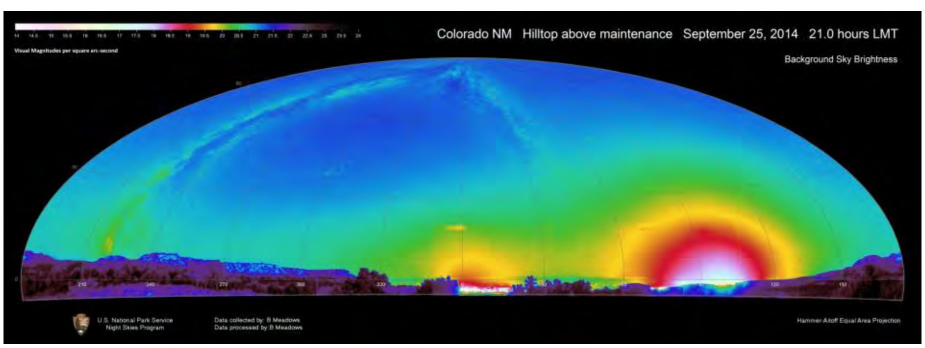


Figure 77. False color mosaic image of the COLM night sky. Image taken from the Alpine Camp near the Visitor Center. Night sky glow from Fruita, CO (north/center) and Grand Junction, CO (east/right) are visible. The Milky Way is also clearly visible as an arc across the mosaic image. Image provided by Dan Duriscoe of the NPS NSNSD.

Visual observations are important in defining sky quality, especially in defining the aesthetic character of night sky features. A published attempt at a semi-quantitative method of visual observations is described in the Bortle Dark Sky Scale (Bortle 2001). Observations of several features of the night sky and anthropogenic sky glow are synthesized into a 1-9 integer interval scale, where class 1 represents a "pristine sky" filled with easily observable features and class 9 represents an "inner city sky" where anthropogenic sky glow obliterates all the features except a few bright stars. Bortle Class 1 and 2 skies possess virtually no observable anthropogenic sky glow (Bortle 2001).

Another visual method for assessing sky quality is Zenithal Limiting Magnitude (ZLM), which is the apparent brightness or magnitude of the faintest star observable to the unaided human eye, which usually occurs near the Zenith. This method involves many factors, the most important of which is variability from observer to observer. A ZLM of 7.0-7.2 is usually considered "pristine" or representing what should be observed under natural conditions; observation of ZLM is one of the factors included in the Bortle Dark Sky Scale. Zenith Limiting Magnitude is often referenced in literature on the quality of the night sky, and is the basis for the international "Globe at Night" citizen-scientist program (see http://www.globeatnight.org/index.html). The NPS NSNSD has experimented with the use of this observation in predicting sky quality, and has found that it is a much coarser measure and prone to much greater error than accurate photometric measures over the entire sky. For these reasons, it is not included in the reference conditions section.

NPS Suite of Measures

NPS NSNSD (2014) documented high levels of light pollution from within the park. Several measures indicated unfavorable dark night sky conditions. According to NPS NSNSD (2014), there was a high level of sky glow as a result of anthropogenic light. The light pollution ratio (LPR) for horizontal and vertical illuminance was 1.04 and 3.65, respectively. The average sky luminance and vertical illuminance were 176% and 365% brighter than the average natural conditions, respectively, most likely as a result of city light domes and unshielded lights. In the false color image, light intrusions from surrounding communities are visible from Alpine Camp. Communities that are visible include Fruita, CO (bearings 350-25), and Grand Junction, CO (bearings 50-135) (Figure 77). The arc of the Milky Way is clearly visible to the west, as is the glow from Fruita, CO on the middle horizon, and the glow from Grand Junction, CO on the right horizon. Table 81 and Table 82 display the photometric statistics from the dark night sky summary data.

Table 81. Photometric statistics for the ML (Finger Lakes MicroLine model camera) instrument data mosaic (reference set only) (Retrieved from NPS NSNSD 2014).

	Average Sky Luminance		Zenith Sky Luminance		Brightest Luminance	Illuminance	
Date	**mag arcsec^{-2}**	**μcd/m^2**	**mag arcsec^{-2}**	**μcd/m^2**	**mag arcsec^{-2}**	**Horizontal**	**Maximum Vertical**
Sep 25	20.46	709	21.15	376	14.18	1.633	2.392

Table 82. Photometric statistics for the anthropogenic sky glow mosaic (reference set only) (Retrieved from NPS NSNSD 2014).

	Average Sky Luminance											Illuminance			
Date	**All Sky**			**Zenith Angle 80˚**		**Zenith Angle 70˚**		**Zenith Luminance**		**Brightest Luminance**		**Horizontal**		**Maximum Vertical**	
	mag arcsec-2	mLux	LPR	ucd/m2	LPR	ucd/m2	LPR	mags	ucd/m2	mags	ucd/m2	mLux	LPR	mLux	LPR
Sep 25	-7.52	2.60	1.77	313.0	-	239.3	-	22.55	103	17.16	14735	0.832	1.04	1.462	3.65

Threats and Stressor Factors

COLM park staff has identified existing lighting structures as a major threat to dark night skies in COLM. Situated in close proximity to a major urban area, COLM is subjected to high levels of anthropogenic light pollution. This light pollution comes from urban development east of the park because there are little to no light fixtures within the park. Many businesses have unobstructed lights that are orientated upwards, and these lights remain on even when the business's operating hours have passed. Lorenz (2006) and Danko (2014) recreated a light pollution map that displays the level of light pollution occurring in Grand Junction and surrounding areas (Figure 78). The park is located in two levels of light pollution ranging from three to four on the Bortle Scale, which means the dark night sky is slightly to moderately impaired.

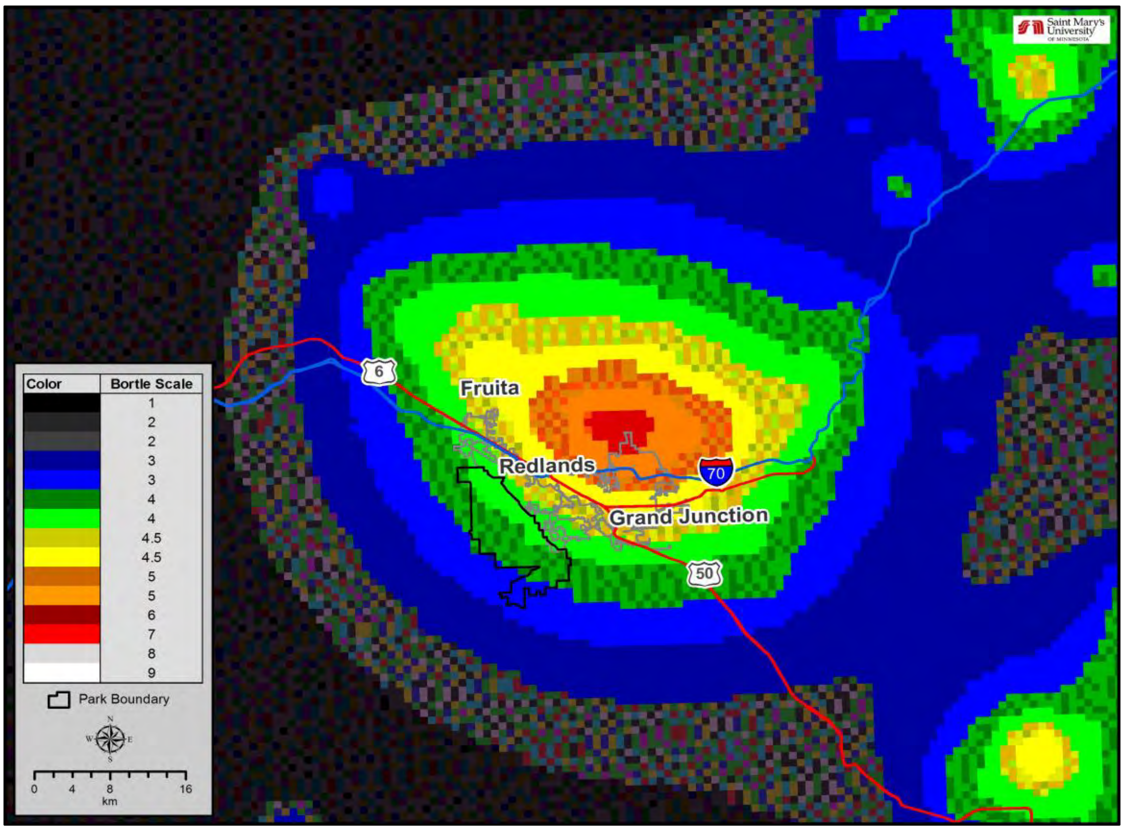


Figure 78. Levels of light pollution occurring in Grand Junction, Colorado and surrounding areas (Lorenz 2006; Danko 2014).

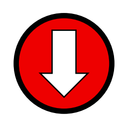
Data Needs/Gaps

There were no data from the period of reference to provide a baseline for comparison. NPS NSNSD (2014) summarized dark night skies data in COLM, which may serve as a baseline dataset for the future management. It should be noted that the NPS NSNSD (2014) summary did not include Bortle Scale or ZLM values. Measurements should occur on a periodic basis, about once every 5 years, with the highest point in the park serving as the preferred observing site, in order to track external threats.

Overall Condition

NPS Night Sky Division's Suite of Measures
During scoping meetings, the COLM NRCA team assigned the NPS NSNSD's suite of measures a *Significance Level* of 3. The NPS NSNSD collected night skies data for the park in the 25 September 2014. This data may serve as a baseline for dark night sky condition in the park. It is clear that the current condition of dark night skies is negatively impacted by urban areas such as Fruita, Colorado (north) and Grand Junction, Colorado (east). The NPS NSNSD (2014) data summary did not include Bortle Scale estimates of ZML; however, the levels of light pollution from Grand Junction, Colorado and the surrounding area estimates from Lorenz (2006) and Danko (2014) could serve as a supplement for this assessment (Figure 78) According to Lorenz (2006) and Danko (2014), the extrapolated Bortle Scale estimate for the park ranged from 3 to 4, which is considered low to moderate impairment. The data suggest that the level of concern for this resource is believed to be of concern. As result, this measure was assigned a *Condition Level* of 2, or moderate concern.

Weighted Condition Score
The *Weighted Condition Score* for Dark Night Skies in COLM was 0.67, indicating an overall condition of high concern. The 2014 COLM dark night sky report serves as a baseline as well as the only dark night skies data. Since urbanization is most likely to continue in areas surrounding the park, a negative trend was assigned to this measure.

Dark Night Skies			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.67**
NPS Night Sky Divisions Suite of Measures	3	2	

4.17.6 Sources of Expertise

National Park Service Night Sky Division members Dan Duriscoe, Chad Moore, Teresa Jiles, Jeremy White, and Robert Meadows

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4.18 Viewscape

4.18.1 Description

A viewshed is the area that is visible from a particular location or set of locations, often developed using GIS analysis tools. Two datasets are required to calculate a viewshed using GIS: a digital elevation model (DEM) and point or polyline data defining points in which a person would be viewing a landscape. With the defined data, GIS software determines visibility to and from a particular cell or set of cells in a DEM resulting in a viewshed layer. This viewshed layer is a raster that defines the visible area on the landscape from the point or set of points contained within an outline of a polygon. Combining viewshed layers with layers that identify areas of undesirable impacts on the landscape creates a quantitative description of visual stress on a viewshed; repeating this process for multiple viewshed layers in a pre-defined landscape, such as a National Park, provides a quantitative description of stress across the viewscape in the area.

Photo 20. View of COLM cliffs, canyons, and monoliths from Book Cliff (Photo by Shannon Amberg, SMUMN GSS).

Multiple studies indicate that people prefer natural compared to develop landscapes (Sheppard and Sheppard 2001, Kearney et al. 2008, Han 2010). The National Park Service Organic Act (16 U.S.C. l) implies the need to protect the viewscapes of National Parks, Monuments, and Reservations. Specifically, the enabling legislation for COLM states the parks should "provide for the understanding, preservation, and enjoyment of the extraordinary erosional, geological, and historical landscapes of great scientific interest, the Rim Rock Drive, and all other natural and cultural resources for present and future generations" (NPS 2005). However, defining a desirable viewscape is widely regarded as a subjective and difficult process, because what is preferable is intrinsically humanistic and varies by individual. In COLM, development is minimal compared to many areas in the conterminous United States, yet some non-natural features still exist. Many of these non-natural features, such as roads, overlooks, trails, and parking areas enable recreational access to the park's resources, which is a primary purpose for the park (NPS 2005). Therefore, this assessment relied on input from park and NCPN staff to determine desirable and undesirable features within the park's viewscape.

4.18.2 Measures

- Immediate viewscape at points along Rim Rock Drive
- Noncontributing structures visible from within the recommended wilderness area

4.18.3 Reference Conditions/Values

The reference condition for the park's viewscape is defined as the viewscape at time of park creation (1911), with emphasis on the viewscape along Rim Rock Drive and Grand viewscape.

4.18.4 Data and Methods

The 16 scenic pullouts and overlooks along Rim Rock Drive were chosen as priority observation points within the park for this analysis: East Entrance, Redlands, Historic Trails, Fruita, Independence, Grand View, Monument Canyon View, Coke Ovens, Monument Canyon, Artist Point, Highland View, Upper and Lower Ute Canyon, Fallen Rock, Red Canyon, and Cold Shivers (Figure 79). Trails located in the recommended wilderness areas were used in an analysis to determine the non-contributing features visible from within the wilderness area. Visitors frequently observe the landscape in the park from the defined observation points. At each of these points, a viewshed was calculated using ESRI's Spatial Analyst Viewshed Tool in ArcGIS 10.2, which requires point or polyline GIS data (representing the viewing location) and a DEM. For each of the observation points, a point shapefile was created for use with the Viewshed tool and the DEM used for each observation point was mosaicked from the National Elevation Dataset (NED), which has a resolution of approximately 10 m. A 1.7-m (5.5-ft) offset was applied to each observation point shapefile to account for average human height. The result of the operation is a theoretical viewshed layer that represents the visible area from a point without correcting for visibility factors (e.g., vegetation, smoke, humidity, heat shimmer, or curvature of the earth).

Ground condition photos were taken in winter 2013 to supplement the GIS data. Photo points, oriented towards cardinal directions, were selected for eight of the observation points. The photos provide an illustration of typical views at each location. However, they are not useful in providing quantifiable information for the viewscape of the park.

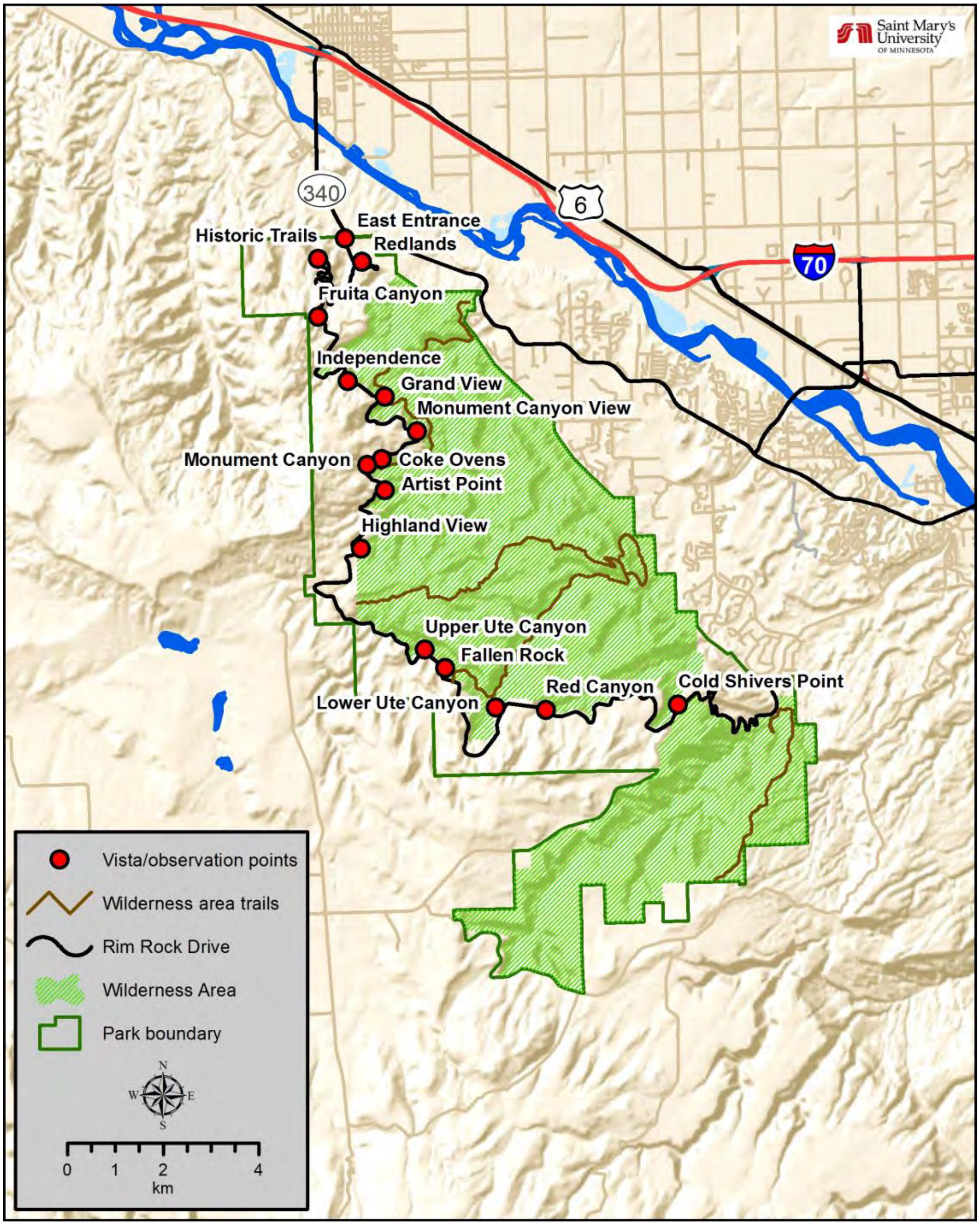


Figure 79. Locations of vista/observation points, the proposed wilderness area, and wilderness trails in COLM.

4.18.5 Current Condition and Trend

Immediate Viewscape at Points along Rim Rock Drive

The composite visible area from all observation points (hereafter, composite viewshed) is 1,674 km^2 (646 m^2) (Figure 79). Approximately 1,324 ha (3,271 ac) of COLM is visible from all of the vistas. That is approximately 16% of the park. Natural landscapes dominate the visible area from all observation points (Photo 21 - Photo 28). Although the road is visible from all selected observation points, there are very few other non-contributing features inside the park. Visibility of development features at observation points may be minimal, but a few development features are visible as visitors travel through the park. The primary park road traverses south to north from the Grand Junction entrance to the Fruita entrance. There are no visible power lines or light poles along the road; however, radio towers on adjacent lands are visible from the road at several vistas. Most of the development features in the park provide safety and are of interpretive value to visitors, such as the viewing platforms, guard rails and the Visitor Center. Other development that is visible from the park vistas is located to the east in Fruita, Redlands, and Grand Junction.

Independence Monument View

Photo 21. View of Independence Monolith from the Independence Monument Overlook observation point, looking east (Photo by Shannon Amberg, SMUMN GSS).

Photo points were acquired for eight of the 16 vistas. Photo points include Independence, Grand, Cook Ovens, Artist Point, Upper Ute Canyon, Fallen Rock, Red Canyon, and Cold Shiver Point (Figure 80). Grand Junction can be seen in the distance from Independence, Grand, Red Canyon, and Cold Shivers Point.

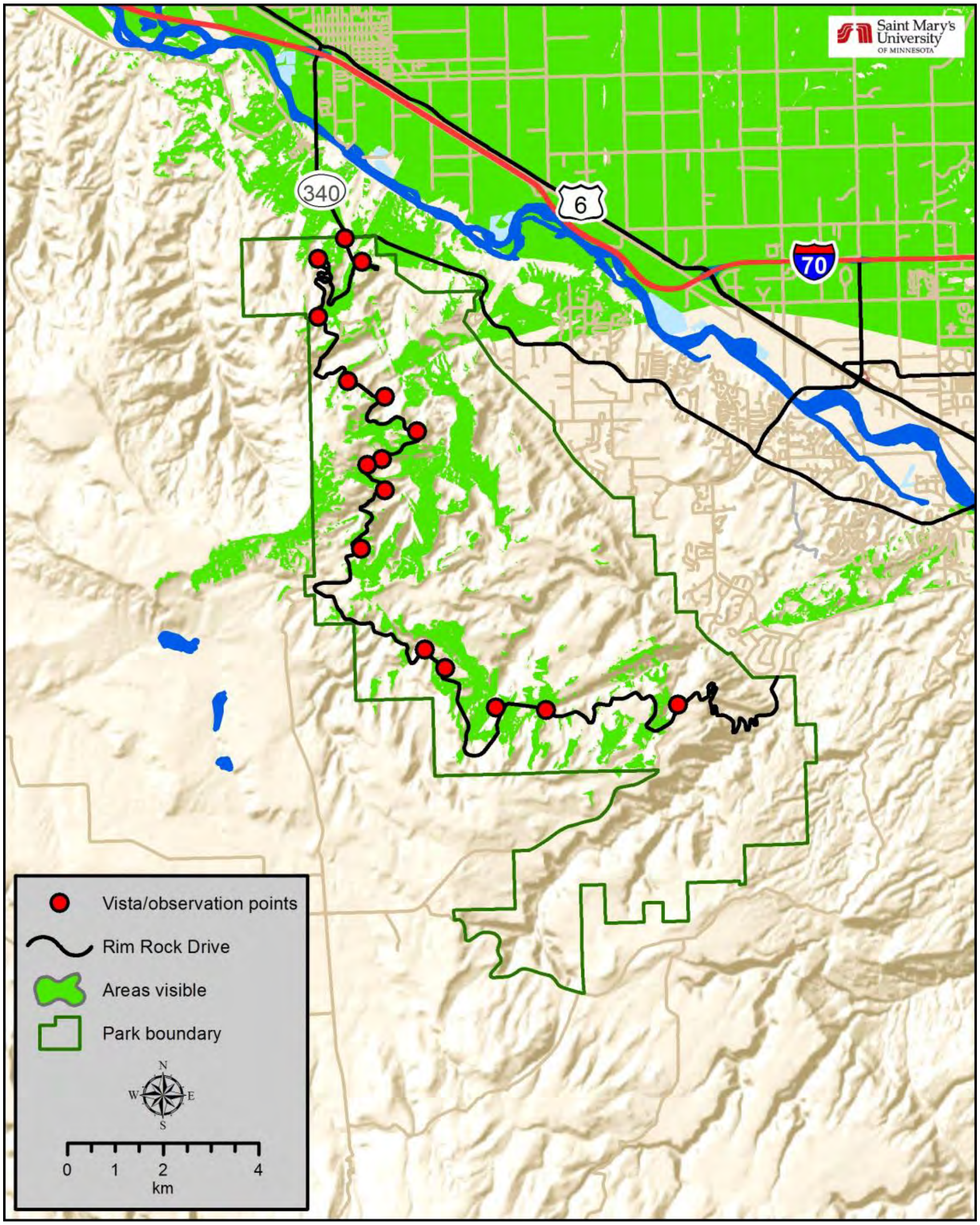


Figure 80. Composite viewscape for observation points along Rim Rock Drive in COLM.

Grand View

Photo 22. View from Grand View Overlook observation point, looking north (top) and east (bottom) (Photos by Shannon Amberg, SMUMN GSS).

Coke Ovens

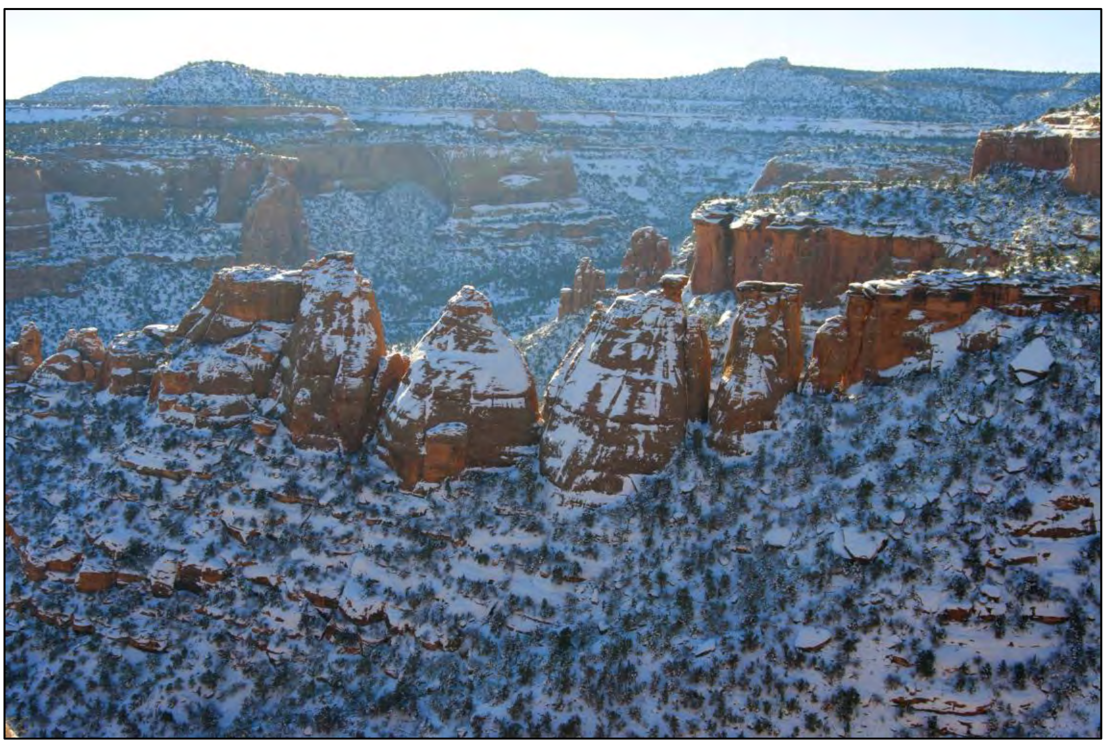


Photo 23. View from Coke Ovens Overlook observation point, looking northeast (top) (Photo by Anna Davis, SMUMN GSS) and southeast (bottom) (Photo by Shannon Amberg, SMUMN GSS).

Artist Point

Photo 24. View of Artist Point Overlook observation point, looking northeast (Photo by Shannon Amberg, SMUMN GSS).

Upper Ute Canyon View

Photo 25. View of Upper Ute Canyon Overlook observation point, looking northeast (Photo by Anna Davis, SMUMN GSS).

Fallen Rock

Photo 26. View of Fallen Rock Overlook observation point, looking southwest (Photo by Shannon Amberg, SMUMN GSS).

Red Canyon View

Photo 27. View of Red Canyon Overlook observation point, looking northeast (Photo by Anna Davis, SMUMN GSS).

Cold Shiver Point

Photo 28. View of Cold Shiver Point Overlook observation point, looking northwest (top) and northeast (bottom) (Photos by Anna Davis, SMUMN GSS).

Noncontributing Structures Visible from within the Recommended Wilderness Area

The composite visible area from the wilderness trails viewshed is 2,512 km^2 (970 m^2) (Figure 81). Approximately 4,467 ha (11,038 ac) of COLM is visible from all of the vistas. That is approximately 54% of the park. The external viewscape includes all of the cities to the east of the park. Black Ridge to the west and the mountains to the east are the features that limit the external viewscape. Within the composite viewshed, the primary anthropogenic features include Rim Rock Drive and the radio towers on Black Ridge. The composite viewscape for the wilderness trails may have more visible area because together they cover a large range of elevations and extend from the west side of the park to the eastern boundary, whereas Rim Rock Drive primarily runs through the west side of the park.

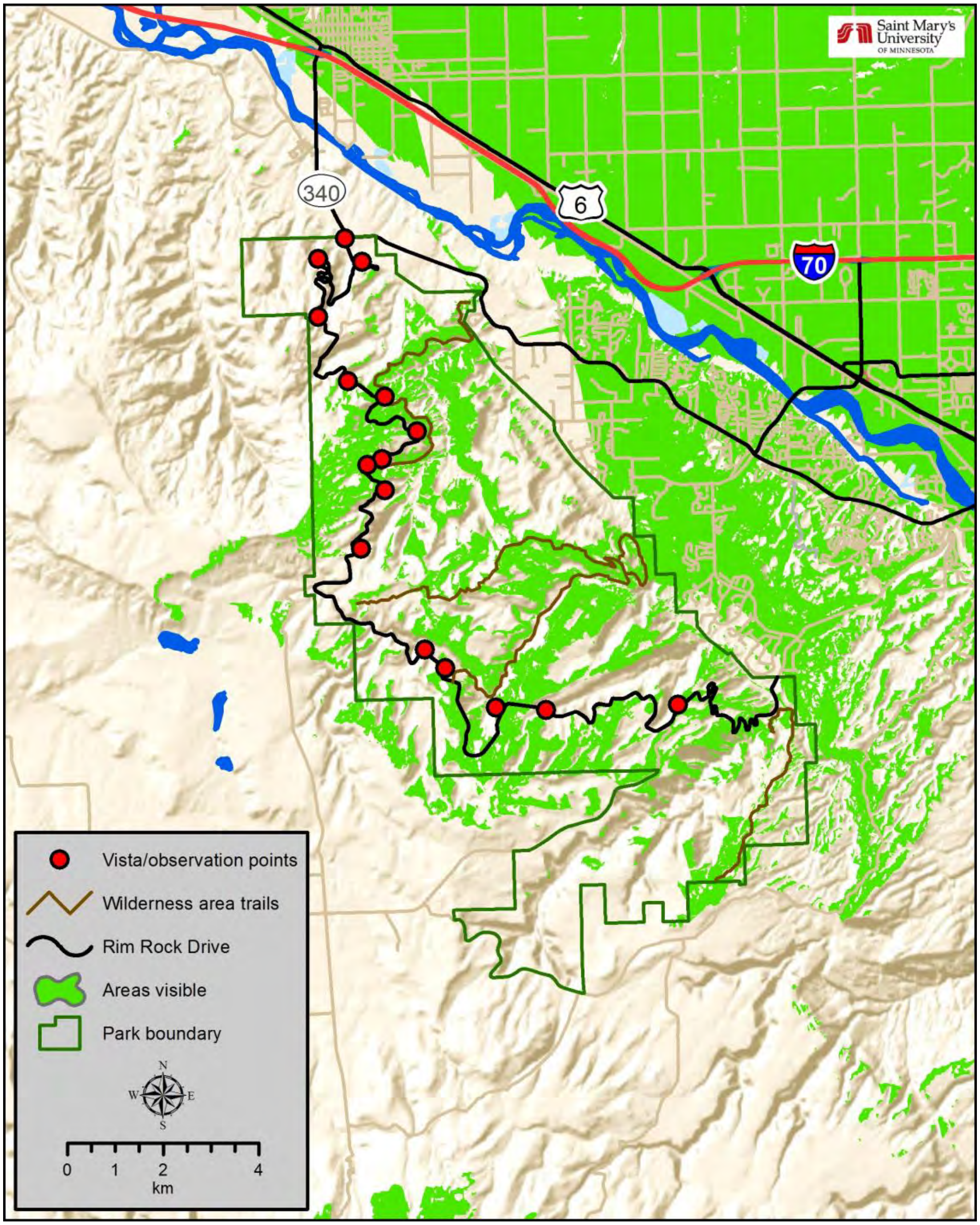


Figure 81. Composite viewscape for trails located in the recommended wilderness area of COLM.

<u>Threats and Stressor Factors</u>

The COLM park staff identified several existent and potential threats to viewscape in the park. These threats include urban development, radio towers located on land adjacent to the park (owned by the BLM), haze, management activities not contributing to vistas along Rim Rock Drive, and commercial vehicle traffic occurring on the east and west side of the park.

Urban development can be a major threat to NPS units, especially those located in or near larger cities. COLM is located just west of Grand Junction, which is a larger city in Colorado. According to NPS (2013), light pollution is a result of urban development and negatively impacts park viewscapes. There was a moderate amount of development in Fruita that is visible from the park. Figure 82 displays changes in urban development that are visible from vistas in COLM (Jin et al. 2011). It should be noted that the data used for the analysis are from 2001 to 2011. Any recent or future developments are not reflected in this data.

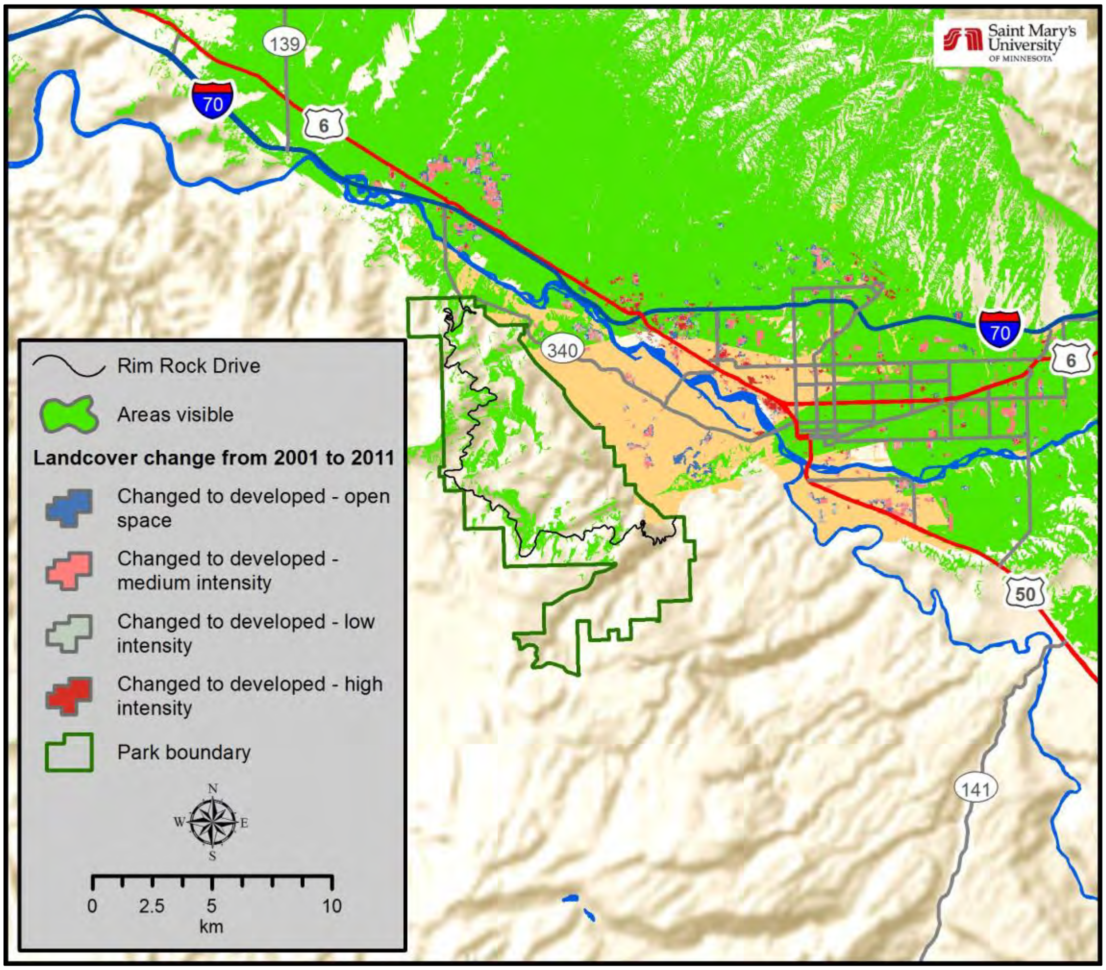


Figure 82. Change in urban development from 2001 to 2011 in cities to the east of COLM visible from Rim Rock Drive Overlook observation points (Jin et al. 2011).

Radio towers and utility poles take away from the natural viewscape. Radio towers are located directly west of the park in the McInnis Canyons National Conservation Area on Black Ridge. These towers can easily be seen to the northwest of Rim Rock Drive where East Black Ridge Trail and Liberty Cap Trail meet (Photo 29).

Photo 29. Radio towers on Black Ridge just west of the park (Photo by Shannon Amberg, SMUMN GSS, Winter 2013).

Air pollution is another threat to the COLM viewscape, especially haze which reduces visibility. Haze occurs when sunlight reflects off pollution particles floating in the air, resulting in a reduction in clarity and color of a vista (EPA 2012) (Photo 30). This reduction in visibility can worsen when weather becomes more humid (EPA 2012).

Management activities not contributing to the immediate viewscape along Rim Rock Drive also detract from the natural viewscape. These include common maintenance and road construction. Special events (e.g., marathons or cycling tours) can attract up to 2,000 people, which may result in impacts to the viewshed (Hartwig, written communication, 12 May 2015).

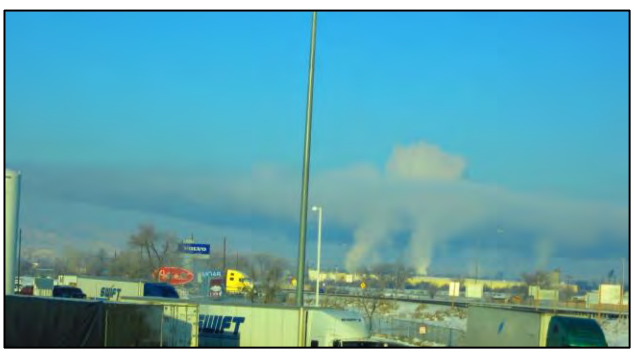


Photo 30. Inversion in Fruita just northeast of the park (Photo by Anna Davis, SMUMN GSS, Winter 2013).

The volume of commercial vehicle traffic can negatively affect a viewscape. The difference in commercial vehicular traffic on the east side of the park versus the west side results in different park experiences. The east side is designated as a public right of way and services commercial traffic traveling to and from the community of Glade Park to the south. This can include cattle trucks, construction dump trucks, and hay hauling semis. In September 2014, 102 tractor trailer loads of paving material traveled the East Hill in an 8-hour period (Hartwig, written communication, 12 May 2015).

Data Needs/Gaps

While this assessment provides some baseline information regarding the park's visual resources, it should not be considered all-inclusive. Incorporation of different and new GIS data sets, such as a higher resolution DEM, additional non-natural feature layers, or land ownership data with more coverage, would enhance a future analysis. Continued development of spatial data that explain landscape change will enable accurate and up-to-date viewshed assessments of the metrics examined in this analysis. In addition, continued monitoring of observation points through on-the-ground photography is a low-cost task that can help document changes in visual resources over time.

Overall Condition

Immediate Viewscape at Points along Rim Rock Drive

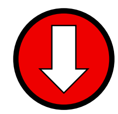
The *Significance Level* for the immediate viewscape at points along Rim Rock Drive is a 2.The natural landscape at COLM is the primary visible feature at all observation points examined along Rim Rock Drive. Most of the development features in the park provide safety or are of interpretive value to visitors, such as the viewing platforms, guard rails and the Visitor Center. Other development that is visible from the park vistas is located to the east in Fruita, Redlands, and Grand Junction. Most of these features are acceptable according to mandates from the park's enabling legislation. There are no visible power lines or light poles along the road; however, some development features on adjacent lands are visible from the road at several vistas. Some features, such as the radio towers and light fixtures on Black Ridge just west of Rim Rock Drive, impair small portions of the natural viewscape within the park. Although these features are visible from only a portion of the road, their impact on the natural character and overall visitor experience can be significant (Hartwig, written communication, 12 May 2015). Therefore, the *Condition Level* for this measure is 2, or of moderate concern.

Noncontributing Structures Visible from within the Recommended Wilderness Area

The *Significance Level* for the noncontributing structures visible from within the "wilderness area" is a 2.The viewscape from within the wilderness area is important because it may provide primitive and unconfined recreation opportunities for visitors wanting to experience remote wilderness areas. The primary anthropogenic features visible in this area include urban development, Rim Rock Drive, and the radio towers on Black Ridge. External viewscape from the wilderness trails extends through most of the valley and to the cities east of the park. The viewscape for the wilderness trails may have more visible area than the immediate viewscape along Rim Rock Drive because together the trails cover a large range of elevations and extend from the west side of the park to the eastern boundary, whereas a majority of Rim Rock Drive is on the west side of the park. Most of the wilderness viewscape may be natural; however, growth in nearby cities is a cause for concern. Therefore, the *Condition Level* for this measure is 2, or of moderate concern.

Weighted Condition Score

The *Weighted Condition Score* for this component is 0.67, which is on the lower end of the significant concern range. The immediate viewscape and ground photos currently display natural landscapes with few or no non-contributing features. The viewscape from the wilderness trails includes few to no non-contributing features within the park; however, urban development outside the park is visible and increased between 2001 and 2011. The significant impression made by the contrast between the visible non-contributing features (e.g., radio towers) and the dramatic natural landscape is the primary cause for concern. The increase in development surrounding COLM suggests a declining trend for viewscape.

Viewscape			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.67**
Immediate Viewscape at Points along Rim Rock Drive	2	2	
Noncontributing Structures Visible from within the Recommended Wilderness Area	2	2	

4.18.6 Sources of Expertise

Kim Hartwig, COLM Chief of Resources

4.18.7 Literature Cited

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4.19 Soundscape and Acoustic Environment

4.19.1 Description

Acoustic resources are physical sound sources, including both natural sounds (wind, water, wildlife, vegetation) and cultural and historic sounds (battle reenactments, tribal ceremonies, quiet reverence) (NPS 2014). The acoustic environment is the combination of all the acoustic resources within a given area, natural sounds and human-caused sounds (NPS 2014). The acoustic environment includes sounds made by geological processes, biological activity, and even sounds that are inaudible to most humans, such as bat echolocation calls (NPS 2014). Soundscape is the component of the acoustic environment that can be perceived by humans (NPS 2014). The character and quality of the soundscape influence human perceptions of an area, providing a sense of place that differentiates from other places (NPS 2014). Noise refers to sound which is unwanted either because of its effects on humans and wildlife, or its interference with the perception or detection of other sounds (NPS 2014). The natural soundscape is an inherent component of the scenery and the natural and historic objects and the wildlife protected by the Organic Act of 1916 (NPS 2014). NPS Management Policies (§ 4.9) require the NPS to preserve the park's natural soundscape, to restore the degraded natural conditions wherever possible, and to prevent or minimize noise (NPS 2014).

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

Noise not only affects visitor experience, it can also alter the behavior of wildlife. Studies have shown that wildlife can be adversely affected by sounds that intrude on their habitats. While the severity of the impacts varies depending on the species being studied and other conditions, research strongly supports the fact that wildlife can suffer adverse behavioral and physiological changes from intrusive sounds (noise) and other human disturbances. Documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, and separation of mothers and young (Selye 1956, Clough 1982, USFS 1992, Anderssen et al. 1993, NPS 1994). Repeated noise can cause chronic stress to animals, possibly affecting their energy use, reproductive success, and long-term survival (Radle, 2007). Even low levels of noise can interfere with ecological processes in surprising and complex ways (Shannon et al. 2015).

4.19.2 Measures

- Occurrence of human-caused sound - loudness and percent of time audible
- Occurrence of human-caused sound -within and outside of proposed wilderness area

4.19.3 Reference Conditions/Values

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

4.19.4 Data and Methods

Sound Science

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

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

In addition to the pitch of a sound, humans also perceive the amplitude (or level) of a sound (NPS 2014). This metric is described in decibels (dB). The decibel scale is logarithmic, meaning that every 10 dB increase in sound pressure level (SPL) represents a tenfold increase in sound energy (NPS 2014). This also means that small variations in sound pressure level can have significant effects on the acoustic environment (NPS 2014). Sound pressure level is commonly summarized in terms of dBA (A-weighted decibels) (NPS 2014). Table 83 provides examples of A-weighted sound levels measured in national parks.

Table 83. Examples of sound levels measured in national parks

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

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

- Sounds produced by birds, frogs or insects to define territories or attract mates
- Sounds produced by bats to navigate or locate prey

- Sounds produced by physical processes such as wind in trees, flowing water, or thunder

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

- Aircraft (i.e., high-altitude and military jets, fixed-wing, helicopters)
- Vehicles
- Generators
- Watercraft
- Grounds care (lawn mowers, leaf blowers)
- Human voices

<u>Monitoring in the Park</u>
The NSNSD conducted baseline acoustical monitoring for COLM from April to May of 2013 (NPS 2013, McFarland 2015). Four sites Figure 83, were selected for acoustic monitoring as they are representative of high (COLM001 and COLM002) and low (COLM003 and COLM004) use areas in the park (Katie Nuessly, NPS Biologist/Modeling Specialist, written communication, 1 December 2015). At the monitoring sites, sound pressure level (SPL) measurements were taken, along with digital audio recordings and meteorological data (McFarland 2015).

Auditory analysis was used to calculate the audibility of sound sources at COLM, using the acoustic monitoring data from each site. Trained technicians at CSU analyzed a subset of audio samples (10 seconds every two minutes for eight days of audio) in order to identify durations of audible sound sources. Staff used the total percent time human-caused sounds were audible to calculate the natural ambient sound level (McFarland 2015).

The goal of impact analysis is to present sound level data in a way that is meaningful and allows park managers to protect the acoustic environment (McFarland 2015). Table 84 summarizes sound levels that relate to human health and speech, as documented in the scientific literature. Human responses can serve as a proxy for potential impacts to other vertebrates because humans have more sensitive hearing at low frequencies than most species (Dooling and Popper 2007).

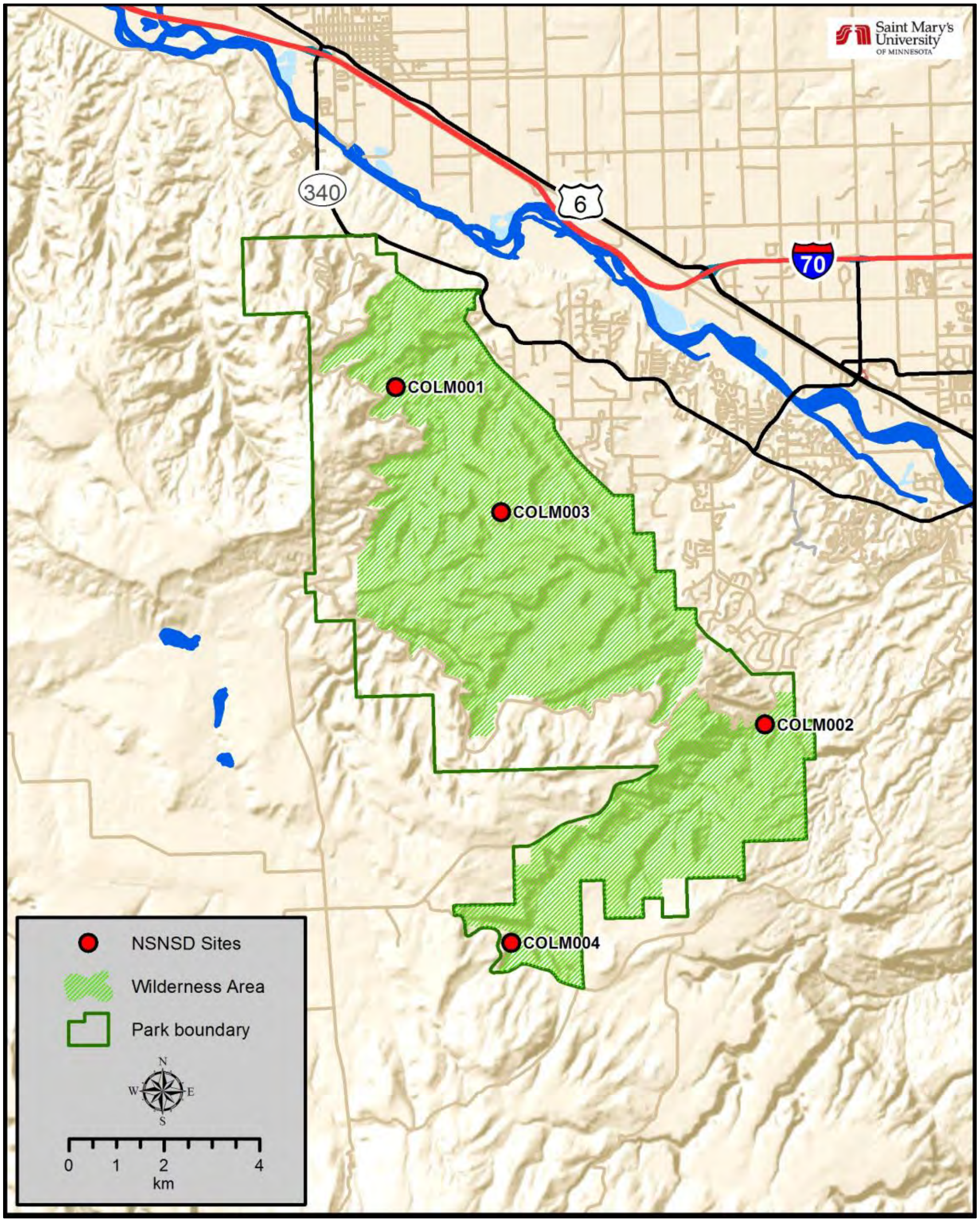


Figure 83. Locations of NSNSD acoustical monitoring sites in COLM (NPS 2013).

The first, 35 dBA, is designed to address the health effects of sleep interruption (McFarland 2015). Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis, 2008). The second value addresses the World Health Organization's (WHO) recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al., 1999). The third value, 52 dBA, is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter (EPA 2014). Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations.

Table 84. Explanation of sound level values, for reference (NPS 2013).

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

4.19.5 Current Condition and Trend

Occurrence of Human-caused Sound - Loudness and Percent of Time Audible

Sources of noise at COLM include vehicles on nearby roads, traffic from nearby metropolitan areas, and aircraft. Table 85 displays median existing sound levels (L_{50}) and median natural ambient sound levels (L_{nat}) for daytime (7 am – 7 pm) and nighttime (7 pm – 7am) conditions. The L_{50} is the sound level exceeded 50% of the hour and is relatively unaffected by transient events like sparse animal vocalizations and isolated military jet operations. The L_{nat} is the natural ambient level and this metric excludes all man-made sound.

Table 85. Median existing and natural ambient levels at the four sites (McFarland 2015).

	Median Existing Ambient (L_{50}) in dBA		Median Natural Ambient (L_{nat}) in dBA	
Site ID	**Day**	**Night**	**Day**	**Night**
COLM001	24.8	18.5	19.3	15.0
COLM002	29.4	22.1	22.9	18.1
COLM003	25.1	20.0	20.0	17.1
COLM004	24.9	15.8	22.2	15.3

Median L_{50} values ranged between 24.9 and 29.4 dBA during the day and 15.8 and 22.1 dBA at night. These values exceeded the baseline condition (median L_{nat}) by 2.7 to 6.5 dBA during the day and 0.5 to 4 dBA at night. A one decibel change is not readily perceivable by the human ear, but any addition to this difference could begin to impact listening ability.

To assess the condition of the acoustic environment, it is useful to consider the functional effects that increases in sound level might produce. For instance, the *listening area,* the area in which a sound can be perceived by an organism, will be reduced when background sound levels increase. The failure to perceive a sound because other sounds are present is called *masking*. Masking interferes with wildlife communication, reproductive and territorial advertisement, and acoustic location of prey or predators (Barber, Crooks, & Fristrup, 2010). However, the effects of masking are not limited to wildlife. Masking also inhibits human communication and visitor detection of wildlife sounds. In urban settings, masking can prevent people from hearing important sounds like approaching people or vehicles, and interfere with the way visitors experience cultural sounds or interpretive programs. Seemingly small increases in sound level can have substantial effects, particularly when quantified in terms of loss of listening area (Payne & Webb, 1971; Barber, Crooks, & Fristrup, 2010). Each 3 dB increase in the background sound level will reduce a given listening area by half.

Therefore, the daytime L_{50} values that exceeded the daytime L_{nat} values by 2.7 to 6.5 dBA resulted in a listening area reduction of 46 to 78%. During the night, the L50 values that exceeded the L_{nat} values by 0.5 to 4 dBA reduced the listening area by 10.9 to 60.2%.

Results also indicated that the natural ambient sound levels at the monitoring sites ranged between 19.3 and 22.9 dBA during the day and 15 and 18.1 dBA at night. For comparison, a comprehensive 1982 study of noise levels in residential areas found that nearly 87% of US residents were exposed to day-night sound levels over 55 dB (and an additional 53% was exposed to day-night sound levels over 60 dB) (EPA 1982). Therefore, the results imply that the natural ambient sound level during the monitoring period was considerably quieter than most residential areas.

However, noise still exists in COLM's acoustical environment. A detailed analysis of audibility at this site (Table 86) found that the two major noise sources (aircraft and vehicles) contributed significant amounts of noise to the acoustical environment (ranging from about 9 to 62 % average audibility in a 24 hour period). These are the sources of noise which have the potential to mask the natural sounds that provide a sense of place at COLM. Of the sites monitored (Figure 83), human caused sounds were audible most often at COLM001, COLM002 and COLM003, and least frequently at COLM004 (5% average percent time audible over 24 hours). The most common noise source at COLM001, COLM002 and COLM003 was vehicle traffic, while the most common noise source at COLM004 was aircraft.

Table 86. Mean percent time audible for all extrinsic sounds, aircraft, and vehicles (McFarland 2015).

	Mean percent time audible (in 24 hour time period)		
Site ID	**All Extrinsic**	**Aircraft**	**Vehicles**
COLM001	13.7	30	61.7
COLM002	14.4	17.4	57.1
COLM003	12.5	29.0	19.6
COLM004	5.2	22.8	8.6

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

Table 87 shows the percent of time that the reference sound levels in Table 84 were exceeded for each sample site during day and nighttime hours. Sound at these sites rarely exceeded 45 dBA. At all four sites, sound levels mainly exceeded the 35 dBA metric with 10 to 26% of daytime hours above this level. As would be expected, existing nighttime sound levels were lower than daytime sound levels (NPS 2013).

Table 87. Percent time above Table 84 reference values during the day (7 a.m. to 7 p.m.) and night (7 p.m. to 7 a.m.) (NPS 2013).

	% Time above sound level: day				% Time above sound level: night			
Site	**35 dBA**	**45 dBA**	**52 dBA**	**60 dBA**	**35 dBA**	**45 dBA**	**52 dBA**	**60 dBA**
COLM001	10.38	1.35	0.03	0.03	2.34	0.20	0.03	0.00
COLM002	16.70	1.52	0.30	0.04	4.43	0.27	0.02	0.00
COLM003	26.00	4.06	0.66	0.08	6.73	0.27	0.06	0.00
COLM004	11.56	1.05	0.19	0.00	3.52	0.23	0.03	0.00

At site COLM001 (closest to the Saddlehorn campground) nighttime sound levels only exceeded the 35 dBA reference value 2.34% of the time. During 2.4% of the nighttime hours, the value at which blood pressure increases in sleeping humans was exceeded. Despite the minimal amount of time this sleeping metric was exceeded, it's important to keep in mind that this reference value refers to sleep inside households, while campers at Saddlehorn campground may be more sensitive to lower noise levels as they are housed in tents. In addition, vehicles were audible nearly 62% of the time at site COLM001. The audibility of this particular noise source, in addition to the audible aircraft (30%) and other extrinsic sounds (14%), may further disrupt campers.

In addition to specific monitoring data that distinguishes between natural and human-caused sound, park-wide acoustic condition assessment and trend are also available. NSNSD estimates these acoustic conditions and trend using predictions from a geospatial sound model (Mennitt et al. 2014). For the model, sound pressure levels for the continental U.S. were predicted using actual acoustical measurements (including the four COLM sites described in this report) combined with a multitude of explanatory variables such as location, climate, landcover, hydrology, wind speed, and proximity to noise sources (roads, railroads, and airports). The model predicts daytime sound levels during midsummer. It should be noted that while the model excels at predicting acoustic conditions over large landscapes, it may not reflect recent localized changes such as new access roads or development (Mennitt et al. 2014).

Model parameters useful for assessing a park's acoustic environment include the understanding of a) natural conditions, b) existing acoustic conditions including both natural and human-caused sounds, and c) the impact of human-caused sound sources in relation to natural conditions. The impact condition demonstrates the influence of human activities to the acoustic environment and is calculated by subtracting the natural condition from the existing condition.

Figure 84 shows the impact between natural and existing acoustic conditions. This provides a condition assessment of the acoustic resource because it tells us how much the area is influenced by human-caused sounds. The mean impact is predicted to be 2.4 dBA (ranging from 0.3 dBA in the least impacted areas to 19.3 dBA in the most impacted areas.) That is, the average existing sound level (including natural and human-caused sound) is predicted to be 2.4 dBA above natural conditions on a typical summer day in the park.

Summary statistics of the L_{50} values for the natural, existing, and impact conditions are provided in Table 88. Average values represent the average L_{50} value occurring within the park boundary and since this value is a mean, visitors may experience sound levels higher and lower than the average L_{50}.

Table 88. Median L_{50} values in each condition: natural, existing, and impact. Values represent the average, minimum and maximum L_{50} measurements in each condition.

	Median L_{50} (dBA)		
Acoustic Environment Condition	**Minimum**	**Maximum**	**Average**
Natural	22.5	28.1	26.9
Existing	27.4	43.7	29.3
Impact	0.3	19.3	2.4

A one decibel change is not readily perceivable by the human ear, but any addition to this difference could begin to impact listening ability. The impact condition value for COLM is 2.4 dBA and this increase would reduce the listening area for wildlife and visitors by 42.5 %. For example, if a predator can hear a potential prey animal in an area of 100 square feet in a setting with natural ambient sounds, that animal's ability to hear would be reduced to 17.5 m^2 (57.5 ft^2) if the sound levels were increased by 2.4 dBA. Similar reduction would occur for visitors and their ability to hear natural sounds or interpretive programs.

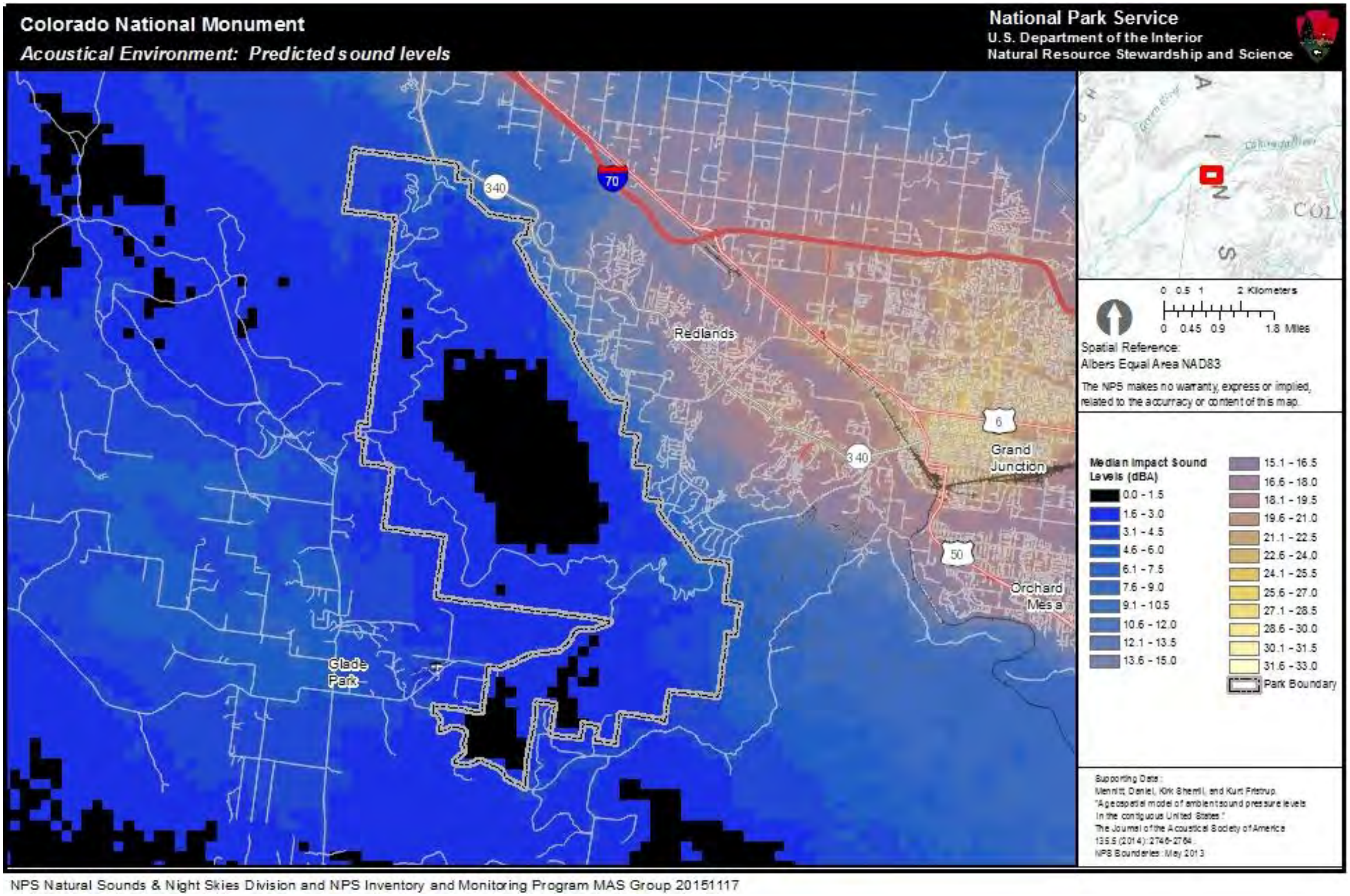


Figure 84. Modeled predicted results for L_{50} dBA impact levels at COLM (Mennitt et al. 2014).

Occurrence of Human-caused Sound - Within and Outside of Proposed Wilderness Area
All four of the sites surveyed by NSNSD were within the proposed wilderness area (NPS 2013) (Figure 85). The difference between human-caused and natural sounds is 2.4 dBA, representing a loss in listening area of 42.5%. The main source of audible noise at COLM001, COLM002, and COLM003 was vehicles and the main source of audible noise at COLM004 was aircraft.

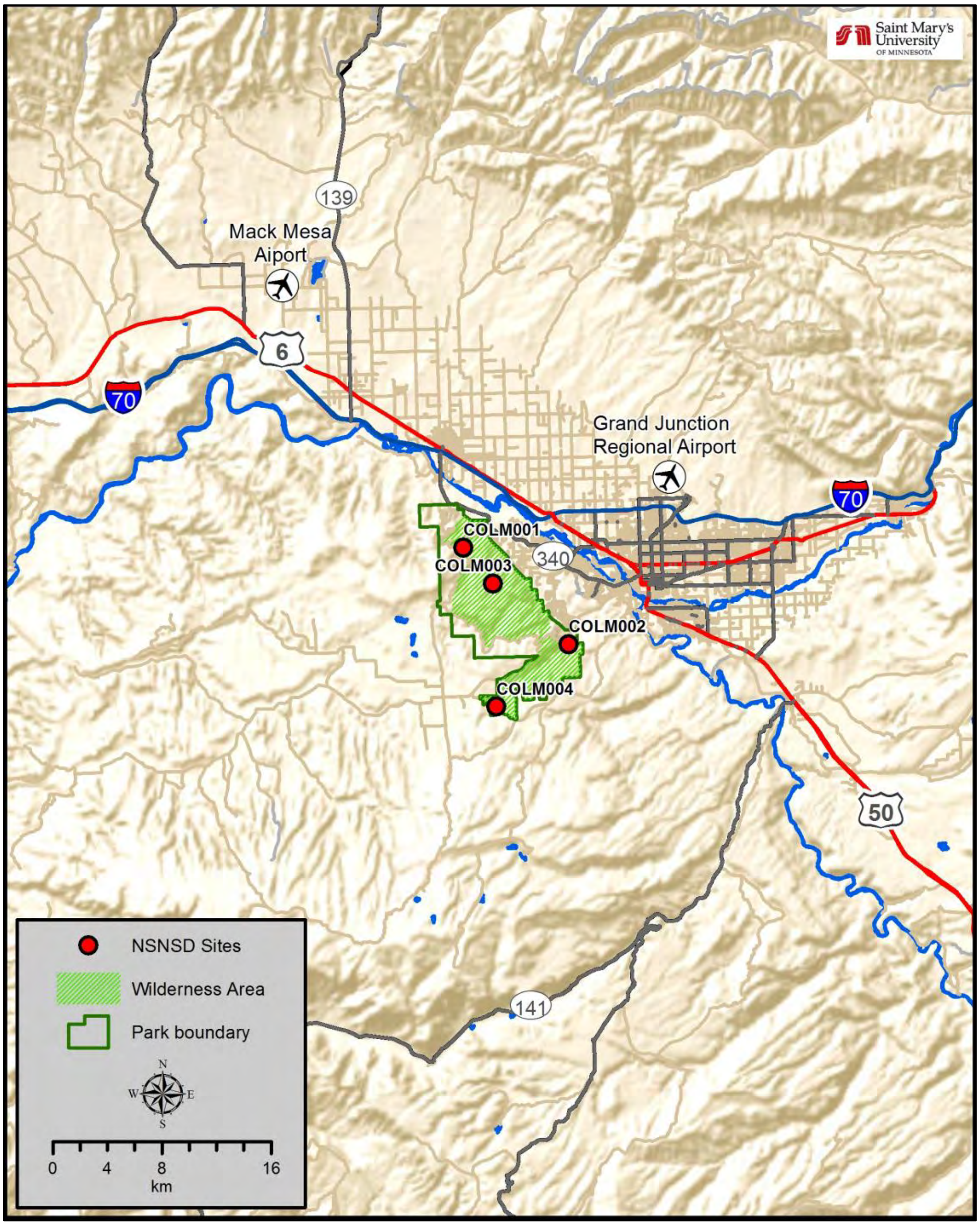


Figure 85. Location of the proposed wilderness area within COLM and the two nearby airports.

Threats and Stressor Factors

Threats to the park's soundscape include vehicle traffic, specifically on the north east side because of Interstate 70 and County Road 340 (seen in sound levels at COLM001, COLM002, and COLM003), and air traffic from two different airports (seen in sound levels at COLM004). Grand Junction Regional Airport (KGJT) and Mack Mesa Airport (10CO) are the two airports that concern COLM staff (Figure 85). Mack Mesa Airport (10CO) is the smaller of the two airports with only one runway, located 25.4 km (15.8 mi) away from the park (AirNav 2014b). An average of only 30 aircraft operations a day goes through Mack Mesa Airport (AirNav 2014b). KGJT has two runways, each larger than Mack Mesa's single runway, and is only 15.5 km (9.6 mi) away from the east border of COLM. According to AirNav (2014a), KGJT is base for 86 single engine planes; nine multi engine planes, four jets, and three helicopters. An average of 140 aircraft operations occur per day at KGJT, causing noise disturbance over most of COLM, especially on the eastern boundary.

Data Needs/Gaps

In 1990, COLM was one of three parks on the Colorado Plateau were acoustic monitoring was conducted to document the perceived low ambient sound levels in these national parks (NPS NSNSD 2013). The goal of this project was to develop baseline sound levels in order to protect sound resources (NPS NSNSD 2013). For unknown reasons, the data collected at COLM was not analyzed by the study researchers (NPS NSNSD 2013). In 2013, the NSNSD collected acoustic measurements at the park from April to May of 2013 (NPS 2013). Due to differences in the equipment and the methodologies the majority of the data collected in 1990 cannot be compared to 2013 (NPS NSNSD 2013). The continuation of annual measurements of sound levels and sound recordings is essential for the management of the park's soundscape. Using the 2013 monitoring results as a baseline, future researchers would have a better understanding of the sound levels in the park and their driving forces (NPS NSNSD 2013).

Overall Condition

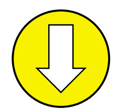
Occurrence of Human-caused Sound - Loudness and Percent of Time Audible

The project team defined the *Significance Level* for this measure as a 3. McFarland (2015) found that sound levels at the four study sites exceeded the 35 dBA reference value less than 25% of the time during the daytime period and less than 7% at night. Sound levels ranged between 19.3 and 22.9 dBA during the day, and 15 and 18.1 dBA at night (McFarland 2015). There are two major noise sources (aircraft and vehicles) that contribute significant amounts of noise to the acoustical environment of COLM (McFarland 2015). Sounds from these sources are present from about 9 to 62 % of the time in a 24 hour period (McFarland 2015). Due to these factors a *Condition Level* of 1 was assigned. The vehicle and air traffic noise has the potential to mask the natural sounds at COLM (McFarland 2015). Due to this factor a declining trend was also assigned to this measure.

Occurrence of Human-caused Sound - Within and Outside of Proposed Wilderness Area

The project team defined the *Significance Level* for this measure as a 3. All four of the sound monitoring points are located within the proposed wilderness area at COLM (Figure 85). Median L_{50} values for these sites ranged from 24.9 and 29.4 dBA during the day and 15.8 and 22.1 dBA at night (McFarland 2015). These values exceeded the baseline condition (median L_{nat}) by 2.7 to 6.5 dBA during the day (listening area reduction of 46 to 78%) and 0.5 to 4 dBA at night (listening reduction of 10.9 to 60.2%) (McFarland 2015). As one of the qualities of wilderness character is the opportunity for solitude or primitive and unconfined recreation these noise levels are an intrusion due to audibility of vehicles 9 to 62% of the time, aircraft (17 to 30%) and other extrinsic sounds (5 to 14%) (McFarland 2015). Due to this a *Condition Level* of 2, or moderate concern was assigned. A declining trend was also assigned due to increases in these noise sources (McFarland 2015).

Weighted Condition Score
The soundscape and acoustic environment was assigned a *Weighted Condition Score* of 0.5, indicating a current condition of moderate concern. Due to the potential for increases in the noise for vehicle and aircraft a downward trend was also assigned.

Soundscape and Acoustic Environment			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.50**
Occurrence of Human-caused Sound - Loudness and Percent of Time Audible	3	1	
Occurrence of Human-caused Sound - Within and Outside of Proposed Wilderness Area	3	2	

4.19.6 Sources of Expertise
Katie Nuessly, NPS Biologist/Modeling Specialist

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4.20 Paleontological Resources

4.20.1 Description

Photo 31. Three-toed dinosaur track from COLM (NPS photo)

COLM hosts a diverse paleontological record contained within rocks that date back to as early as the Precambrian. Although fossiliferous exposures are not well inventoried within the park, investigators have found paleontological materials in the area that include vertebrate, invertebrate, and trace fossils (KellerLynn 2006; Photo 31). One of the first paleontological investigations in COLM was a 1977 inventory of the Morrison Formation that documented 14 fossil localities that contained bivalves, gastropods, turtles, crocodilians, and dinosaurs (Callison 1977, KellerLynn 2006). The majority of these findings were located in the lower Salt Wash and Brushy Basin Members of the Morrison Formation (KellerLynn 2006). The Morrison Formation is world famous for its fossils, in particular its large dinosaurs (Tweet et al. 2012).

The Morrison Formation is the most fossiliferous unit at COLM, and fossils have been discovered in each member of the formation present within COLM (Tweet et al. 20012). Due to the abundance of fossils in the Morrison formation, it is considered to have the highest potential of all the formations within COLM for producing vertebrate fossils (Armstrong and Kihm 1980). A number of significant fossil discoveries have occurred near the park (Armstrong and Kihm 1980, KellerLynn 2006). In 1900, the first skeleton of a *Brachiosaurus*, a giant plant-eating Jurassic dinosaur, was discovered just to the east of COLM at Riggs Hill (KellerLynn 2006). The discovery of the forelimb and shoulder blade of *Camarasaurus* occurred just to the north of COLM (KellerLynn 2006). While the Morrison Formation is known for gigantic and unusual dinosaurs, its exposures in the Fruita area are most well-known for fossils of smaller vertebrates (KellerLynn 2006).

The oldest exposed rocks at COLM, commonly referred to as "basement rocks," consist of gneiss, schist, and granites known as the Black Canyon Group that are 1.7 to 1.5 billion years old (NPS 2014). These Precambrian rocks, overlain by younger igneous dikes dating to the Mesoproterozoic, are extremely unlikely to contain fossils given their lithology and metamorphism (Tweet et al. 2012). With the exception of the Dakota Formation, the younger sedimentary rocks preserved above, deposited by wind and water during the Mesozoic Era, do contain fossil specimens from the Triassic, Jurassic, and Cretaceous periods (Tweet et al. 2012). These sedimentary units, dating from oldest to youngest, include the Triassic Chinle Formation, the Glen Canyon Group (Wingate Sandstone and the Kayenta Formation), the San Rafael Group (Entrada Sandstone and Wanakah Formation), the Morrison Formation, the Burro Canyon Formation, and the Dakota Formation. These stratigraphic units, including their associated depositional environment and paleontological resources within COLM, are present in Table 89.

Table 89. Stratigraphy, fossils, and depositional setting of COLM (table recreated from Tweet et al. 2012). Formations are listed in order of age, from oldest (metamorphosed sedimentary and igneous rocks) to youngest (Quaternary sediments).

Formation	Age	Fossils within COLM	Depositional Environment
Metamorphosed sedimentary and igneous rocks	At least Paleoproterozoic	None to date; fossils are extremely unlikely because of lithology and metamorphism	Not applicable (igneous rocks that solidified at depth and strongly metamorphosed sedimentary rocks)
Igneous dikes	Mesoproterozoic	Unfossiliferous (intrusive igneous rocks)	Not applicable (igneous rocks that solidified at depth)
Chinle Formation	Late Triassic	Root traces, invertebrate traces, and rare bones	Fluvial, floodplain, and lacustrine settings, becoming drier over time
Wingate Sandstone	Late Triassic - Early Jurassic	Bioturbation from roots and burrows, and tracks of dinosaurs, other reptiles, and mammal relatives	Desert with large aeolian sand dunes
Kayenta Formation	Early Jurassic	Local bioturbation and two bones	Primarily fluvial settings
Entrada Sandstone	Middle Jurassic	Bioturbation	Coastal dunes and sand flats
Wanakah Formation	Middle Jurassic	Invertebrate traces and possible pterosaur feeding traces	Mud flats and/or shallow lakes
Morrison Formation	Late Jurassic	Bivalves, gastropods, horseshoe crab traces, a lungfish tooth plate, bones of turtles, crocodile relatives, and dinosaurs, and a pterosaur footprint	Fluvial, floodplain, and lacustrine settings
Burro Canyon Formation	Early Cretaceous	Petrified wood, root traces, invertebrate traces, and dinosaur bones	Fluvial, floodplain, and lacustrine settings
Dakota Formation	Early - Late Cretaceous	Possibly plant fossils, root traces, and invertebrate traces	Terrestrial (especially fluvial) becoming shallow marine over time
Quaternary sediments	Pleistocene - Holocene	Plant fossils, a mammoth or mastodon tooth, bones of nine other mammal and bird taxa, and packrat middens	Alluvial, aeolian, fluvial, and landslide deposits

The Chinle Formation lies above the Precambrian basement and is a heterogeneous terrestrial unit deposited in a variety of fluvial and lacustrine settings in an environment interpreted as a vegetated floodplain or mud flat with shallow ponds and streams that became drier over time (Tweet et al. 2012). Within COLM, only the Red Siltstone Member of the Chinle Formation is present (dating to the late Triassic), and although generally not known for vertebrate fossils, it is fossiliferous within COLM (Tweet et al. 2012). Ichnofossils, possible microbial laminations in the limestone, and general bioturbation are common in this formation (Scott et al. 2001b, Tweet et al. 2012). The bioturbation is represented by disruptions of the sedimentary structures in the form of plant roots, crayfish and beetle larval burrows, and horseshoe crab walking traces (Scott et al. 2001b). A theropod dinosaur track site, interpreted to be *Grallator*-like, was discovered within the Chinle Formation in 1990 near the east entrance of the park (Scott et al. 2001b). Petrified wood may be present in the rocks of COLM as it has been found in the Chinle Formation on the Colorado Plateau (KellerLynn 2006).

Overlying the Chinle Formation is the Glen Canyon Group, which is further divided into the Wingate Sandstone and the Kayenta Formation within COLM. The Wingate Sandstone is a well-sorted, wind-deposited sandstone unit of the Lower Jurassic with large, sweeping crossbeds dating to 200 million years in age (NPS 2014). Vertebrate fossils are rare from the Wingate Sandstone, as aeolian deposition rarely preserves these remains; given the abrasive nature of windblown sand that quickly erodes any vertebrate remains prior to burial and fossilization (Armstrong and Kihm1980). Like the Chinle Formation, the Wingate Sandstone is fossiliferous at COLM in the form of trace discoveries consisting of bioturbation from plant roots and burrows (Scott et al. 2001a). Tracks from mammal relatives, dinosaurs, and other reptiles are also reported, including five localities with 18 trackways and 79 tracks assigned to the theropod ichnogenus *Grallator* (Tweet et al. 2012).

The Kayenta Formation of the Glen Canyon Group is composed of fine- to coarse-grained sandstone with minor shale and conglomerates that date to 190 million years old (NPS 2014). These sediments reflect a return to a fluvial environment, with the nature of the bedding making it possible for the preservation of footprints, as well as the presence of conglomerates increasing the potential for vertebrate fossils (Armstrong 1980). However, within COLM this unit is sparsely fossiliferous with local bioturbation and two bones being reported from a mudstone-pebble conglomerate near the top of this formation (Tweet et al. 2012).

The Entrada Sandstone and the Wanakah Formation compose the San Rafael Group in COLM. The Entrada Sandstone is dominated by aeolian deposits with a distinct red color dating to 165 million years in age (NPS 2014). The Entrada Sandstone is further divided into two geologic units within COLM: the Slick Rock Member and the Board Beds Member. While the Slick Rock Member is interpreted as being a coastal dune field with wet interdunes, the Board Beds Member is interpreted as representing a wet coastal sand flat depositional environment (Tweet et al. 2012). These ancient near-shore environments generally have a low potential for vertebrate remains and age-diagnostic fossils, with preserved footprints having the highest potential (Armstrong and Kihm1980). Both members, however, have been reported to exhibit bioturbation within COLM (Scott et al. 2001a, Tweet et al. 2012).

The younger Wanakah Formation of the San Rafael Group is composed of thin red mudstone, sandstone, and green shale that date to 160 million years in age (NPS 2014). Although this formation is not known for its fossils, within COLM a few invertebrate trace fossils and possible pterosaur feeding traces have been identified (Tweet et al. 2012). Evidence of bioturbation in the form of plant roots and animal burrows are also present within this formation at COLM (KellerLynn 2006).

Photo 32. Lizard tracks on Morrison Formation sandstone (NPS photo).

The most fossiliferous geologic unit at COLM is the Morrison Formation, which represents the last geologic formation of the Jurassic in COLM (Tweet et al. 2012). This fossil assemblage represents a decrease in aridity and an increase in more humid conditions as Pangaea pushed north, allowing for a greater biomass to be supported leading to greater species diversity (Tweet et al. 2012). The Morrison Formation is famous for its fossils, containing one of the best terrestrial fossil records of the Mesozoic Era. Discoveries on the Colorado Plateau have included traces of microbial, faunal, and photosynthetic organisms, invertebrate traces such as brachiopods and gastropods, vertebrates known from body fossils such as turtles and crocodile relatives, and large dinosaurs such as *Allosaurus*, *Brachiosaurus*, and *Stegosaurus* (Tweet et al. 2012). Within COLM, the Morrison Formation is divisible into three geologic units: the Tidwell Member, the Salt Wash Member, and the Brushy Basin Member (NPS 2014). All three members are fossiliferous within COLM, and display evidence of bioturbation in the form of trace fossils such as plant roots and burrows from insects and animals (Tweet et al. 2012). The Tidwell Member is a fluvial and lacustrine unit yielding algal and microbial laminations, charophytes, gastropods, ostracodes, horseshoe crab traces, and a lungfish tooth plate within COLM, as well as containing a dinosaur locality and a pterosaur footprint (Tweet et al. 2012). The Salt Wash Member developed in fluvial, floodplain, and lake settings, and produces charophytes, petrified wood, ostracodes, and bones from theropods and sauropods (Tweet et al. 2012). The Brushy Basin Member is the most poorly exposed unit of the Morrison Formation in COLM due to mass wasting (i.e., landslides) (Scott et al. 2001a). Its depositional environment has been interpreted as a mudflat to shallow lacustrine setting (Scott et al. 2001a). Fossils found within this member at COLM include turtle shell remains and dinosaur bones (Tweet et al. 2012).

The Burro Canyon Formation (early Cretaceous) represents fluvial and floodplain depositional environments, with minor lacustrine deposition found only on Black Ridge (Tweet et al. 2012). Fossils of the Burro Canyon Formation are generally not well known at this time, but the formation possesses plant root traces, bioturbation in the form of burrows, and petrified wood that is locally abundant in sandstone beds within COLM (Scott et al. 2001a, KellerLynn 2006, Tweet et al. 2012). Additionally, dinosaur bones have been reported in fallen Burro Canyon Formation blocks in the park (Tweet et al. 2012).

The Dakota Formation is interpreted as a terrestrial depositional environment (especially fluvial) that became shallow marine over time and is limited to the cap of Black Ridge within COLM (Scott et al. 2001a). Generally regarded as being 100 million years in age, the transgression and regression of the Western Interior Seaway over the land during the deposition of the Dakota Formation caused the age to differ across the landscape as different areas were affected by the encroaching sea at different times (Tweet et al. 2012). The fossils of the Dakota Formation are diverse; however, within COLM this formation is not specifically known to be fossiliferous (Tweet et al. 2012). Recent reports suggest that it may contain fossils, as Scott et al. (2001a) found bioturbation in the form of plant roots and animal burrows to be common within this formation in the COLM area. Other reports of fossils within this formation in the region include plant fossil fragments (particularly angiosperm leaves), invertebrate traces, and vertebrate tracks (KellerLynn 2006, Tweet et al. 2012).

The final geologic unit present in COLM consists of Quaternary sediments deposited through alluvial/fluvial, aeolian, and colluvial (i.e., landslides) processes that date from the Pleistocene through Holocene (Tweet et al. 2012). On the Colorado Plateau, these deposits are sometimes found to contain fossil material useful for paleoecological and paleoclimatological studies (e.g., pollen and packrat middens) (Tweet et al. 2012). Isolated bones of large mammals such as sloths, mammoths, mastodons, horses, and camels have also been found in these deposits (Tweet et al. 2012). Within COLM fossils found in this unit include bone and plant specimens collected from a fissure exposure, a possible mammoth or mastodon tooth, and unpublished pack rat middens (Tweet et al. 2012).

4.20.2 Measures

- Changes in specimen abundance at paleontological localities
- Documentation and inventory of paleontological sites within the park
- Incidence of theft
- Amount of paleontological resources eroded out each year
- Erosion rate at paleontological sites

4.20.3 Reference Conditions/Values

A reference condition/value for paleontological resources was not defined by park staff. Ideally, the 100% documentation of all paleontological sites within the park would provide the best baseline data for reference conditions/values. Currently, a wide variety of fossils have already been discovered at COLM (Tweet et al. 2012). However, a systematic inventory of these fossil resources does not exist at this time (KellerLynn 2006). Until recently, COLM reported annually to the GPRA Goal Ia9 (Paleontological Localities Condition) concerning 75 localities, 72 of which were reported to be in good condition in 2010 (Tweet et al. 2012).

4.20.4 Data and Methods

The remarkable scenic value at COLM places an emphasis on its geologic character, while paleontological components of the park continue to be identified and analyzed (Tweet et al. 2012). Although numerous publications exist that refer to the geology and paleontology of COLM, many only briefly mention the park or deal primarily with faulting and deformation (Tweet et al. 2012). Therefore, these sources are not applicable to a park-wide assessment of the paleontological resource condition.

Reports of fossil findings in the Grand Junction, Colorado area date back to at least 1885 (Chenoweth 1987). The fossil resources found within COLM have historically been overshadowed by discoveries at Morrison Formation sites just outside of park boundaries (Tweet et al. 2012) One of the earliest reports of fossil findings in the area was by Elmer S. Riggs, who extracted fossils from the Morrison Formation just outside the current boundaries of COLM (Tweet et al. 2012). Other early fossil resource inventories were conducted by Holt (1942) and Callison (1977). Holt (1942) collected freshwater invertebrate fossils from the Grand Junction, Colorado area. Callison (1977) discovered 12 vertebrate-fossil producing localities in Morrison Formation rocks within COLM. These were mainly dinosaur bones and bone scrap; however, due to the no-collection policy of the NPS, they were largely unidentified (Armstrong and Kihm 1980). Other reports documenting paleontological resources at COLM include; Hasiotis (1997), Engelmann (1999), Engelmann and Hasiotis (1999), Scott et al. (1999), Engelmann and Fiorillo (2000), and Anderson et al. (2000).

The initial complete paleontological resource inventory and summary at COLM was completed in 2002 by Koch and Santucci (2002). Additional paleontological resource inventories conducted between 2002 and 2006 identified 75 paleontological localities within COLM (Santucci et al. 2006). King et al. (2004) reported at least 79 theropod tracks, identified as the ichogenera *Grallator*, from five localities in the Wingate Sandstone within COLM. Several localities with numerous theropod tracks in the Wingate Sandstone were also reported by Trujillo and Walker (2004, 2005). Lucas et al. (2006) recorded a manus imprint, identified as *Pteraichnus*, from the Summerville Formation (a member of the San Rafael Group). Fossil vertebrate tracks were found in the Salt Wash Member of the Morrison Formation by Lockley and Foster (2006). The tracks included a theropod, small ornithopod dinosaur (ichnogenus *Dinehichnus*) and turtles (ichnogenus *Chelonichnium*) (Lockley and Foster 2006).

Tweet et al. (2012) prepared paleontological summaries with preliminary paleontological resource management recommendations for the parks of the NCPN. This report compiled information through extensive literature reviews and interviews with park staff, geologists, and paleontologists. The report consolidates baseline paleontological resource data for each NCPN park to support management operations, planning, and science-based decision-making (Tweet et al. 2012).

Additional sources with broader overviews that were useful for this assessment include Evenden et al. (2002), KellerLynn (2006), and Scott et al. (2001b). Evenden et al. (2002) is a Phase I natural resources monitoring report summarizing existing information on NPS and related natural resource monitoring programs within the NCPN, presenting overviews of biological and physical resources of network parks, including describing monitoring goals and needs, and presents a theoretical framework with conceptual models for guiding future efforts. KellerLynn (2006) is a geologic resource evaluation report specific to COLM that contains information relevant to resource management and scientific research, and was developed to accompany the digital geologic map of the park. Following the initiation of the first comprehensive inventory of paleontological resources in the national parks and monuments in Colorado in 2000, the Scott et al. (2001b) report presents baseline paleontological resource data obtained during the survey to assist NPS staff with the management and protection of paleontological resources within their respective parks.

Green (2014) conducted a paleontological survey of COLM from 3 June 2013 to 18 October 2013. The goal of this project was two-fold; to locate and evaluate fossils sites documented in previous studies and to explore the park in an attempt to identify new fossil sites (Green 2014). Of the localities identified in previous studies, Green (2014) confirmed that seven had been collected and were located within the COLM museum collection, eight could not be relocated due erosion or illegal collection, nine could not be located due to errors in the recording of the original collection coordinates, and two were not researched due to time constraints. Green (2014) also identified a total of 23 new localities.

4.20.5 Current Condition and Trend

Changes in Specimen Abundance at Paleontological Localities

The potential for future fossil discoveries within COLM are possible, as demonstrated by the Scott et al. (2001b) survey. Due to the abundance of fossils found in the Morrison Formation, especially in the COLM area, this formation has a high potential to yield vertebrate fossils (Armstrong and Kihm 1980). Currently, a wide variety of fossils and other paleontological materials have been documented in and around the park. A systematic inventory of fossil resources would likely result in the discovery of new paleontological resources (KellerLynn 2006). Continued paleontological fieldwork and research would also likely result in new discoveries of fossils in the future (Santucci et al. 2006).

In an attempt to aid in the management of paleontological resources in COLM and the Grand Junction area, Armstrong and Kihm (1980) ranked the geologic units in terms of their relative potential for producing scientifically valuable vertebrate fossils. The units were ranked and divided into four groups (Table 90). Group 1 formations are those that have a proven potential for containing fossil vertebrate resources (Armstrong and Kihm 1980). Group 2 are those formations that have produced fossil vertebrates on the Colorado Plateau. Formations in this group likely contain fossil vertebrate localities, but have not been identified due to limited fieldwork in the area (Armstrong and Kihm 1980). Group 3 includes the formations that have only occasionally produced fossils or localities are at a great distance from the COLM/Grand Junction area. Group 4 contains those formations where there was a general lack of information available (Armstrong and Kihm 1980).

Documentation and Inventory of Paleontological Sites within the Park

COLM has produced a wide variety of fossils, and studies in the surrounding area have produced paleontological materials (KellerLynn 2006). While a systematic, park-wide paleontological inventory and monitoring program has yet to be established at COLM, several investigations within the park have provided data that can be used as a partial paleontological resource inventory baseline dataset (KellerLynn 2006, Tweet et al. 2012). Callison (1977) documented 14 fossil localities within COLM. Scott et al. (2001b) conducted a preliminary inventory of paleontological resources at COLM. Additional paleontological resource inventories include surveys by Koch and Santucci (2002) and Trujillo et al. (2004). These studies, and others, have greatly advanced the paleontological knowledge of the park and indicated the potential for future discoveries (KellerLynn 2006). COLM reported on 75 localities to the GPRA Goal 1A9 (Paleontological Localities Condition), 72 of which were reported to be in good condition as of 2010 (Tweet et al. 2012). COLM also maintains a collection of paleontological specimens. Currently this collection contains 443 catalog numbers (excluding nine educational models); however, this number does include specimens collected from formations not found within COLM (Tweet et al. 2012).

Table 90. Relative potential, by formation, for fossil vertebrates in the COLM area (reproduced from Armstrong and Kihm 1980).

Group	Formation	Relative Rank	Present at COLM	Potential
Group 1	Morrison	1	X	High
	Mancos Shale	2		
	Burro Canyon	3	X	
Group 2	Chinle	4	X	
	Mount Garfield	5		
	Pleistocene deposits	6		
	DeBeque	7		
	Green River	8		
Group 3	Kayenta	9	X	
	Dakota	10	X	
	Wingate Sandstone	11	X	
	Cutler	12		
Group 4	Summerville	13	X	
	Hunter Canyon	14		
	Sego Sandstone	15		
	Entrada Sandstone	16	X	Low

Incidence of Theft

The growing scientific and public interest in paleontological resources within NPS units is paralleled by an increasing number of documented thefts or incidents of vandalism (Santucci et al. 2006). These incidents have ranged from damage due to poor or inappropriate casting techniques to unauthorized collection (Santucci 2006). Fossil theft and vandalism are a concern for COLM resource managers (Tweet et al. 2012). Incidents have occurred at COLM; for example, one locality inventoried by Callison (1997) has been vandalized (Engelmann and Fiorillo 2000, KellerLynn 2006, Tweet et al. 2012). Without a park-wide inventory as a baseline, it is difficult to accurately assess if and/or where paleontological resources within COLM have been lost due to theft or vandalism (KellerLynn 2006).

Amount of Paleontological Resources Eroded Out Each Year

The natural process of erosion is responsible for creating the landforms of COLM (KellerLynn 2006). Erosional processes can cover known resources as well as uncover new paleontological resources (KellerLynn 2006). Slope failure occurs continuously throughout the park and is a constant maintenance issue in areas of COLM like Rim Rock Drive (KellerLynn 2006). Landslides, rockfalls, and debris flows can increase the amount of paleontological resources eroded out, which can be aggravated through human activities such as road construction and vehicle vibration (KellerLynn 2006). Flash floods are another agent that can form and modify the landscape of COLM. Intense summer thunderstorms are common on the Uncompahgre Plateau, supplying large volumes of water in short periods of time to canyon areas (KellerLynn 2006). Increases in both flow rates and flood heights in constricted canyon areas subsequently elevate the amount of sediment eroded out

(KellerLynn 2006). Determination of the amount of paleontological resources eroded out each year is difficult to determine given the lack of a park-wide inventory and monitoring program and is considered a data gap for this assessment.

Erosion Rate at Paleontological Sites

The ecosystem present today within COLM was developed by the work of erosional processes (KellerLynn 2006). The erosional rates of the various formations within COLM are dependent on the susceptibility of rocks to erosion and the thickness of the formation (KellerLynn 2006). The formations with lower erosion rates (less erodibility) generally form cliffs, canyons, and ledges while those with higher erosion rates tend to form slopes (KellerLynn 2006). These highly erodible slopes contain the majority of the paleontological resources found within COLM (KellerLynn 2006). Slope failure can take the form of landslides, rockfalls and debris flows and occurs continually at COLM (KellerLynn 2006). Although a natural process, slope failure can be worsened by human activities such as construction, the use of climbing equipment, and the use of social trails (KellerLynn 2006). Less erodible, fossil-bearing formations such as the Wingate Formation, Kayenta Formation, and the Salt Wash Member of the Morrison Formation formed unstable cliffs that can produce rockfalls. Table 91 provides a brief summary for rates of erosion associated with the formations found within COLM. The rates reflect the degree of erodibility compared to other formations found within COLM.

Table 91. Erodibility of rock formations within COLM (recreated from KellerLynn 2006). The degree of erodibility is in reference to the other formations found within COLM only.

Formation	Erodibility
Precambrian	Low erodibility
Kayenta	↑
Dakota Sandstone	
Wingate Sandstone	
Entrada Sandstone	
Burro-Canyon	
Morrison	↓
Wanakah	
Chinle	High erodibility

Threats and Stressor Factors

There are many environmental and anthropogenic factors and processes that can affect paleontological resources. Figure 86 shows a conceptual diagram of some of these potential threats and stressors to paleontological resources as well as how they interact. Park staff identified several of these as being of concern at COLM: erosion, weathering, climate change, theft, vandalism, and recreation impacts (specifically climbing).

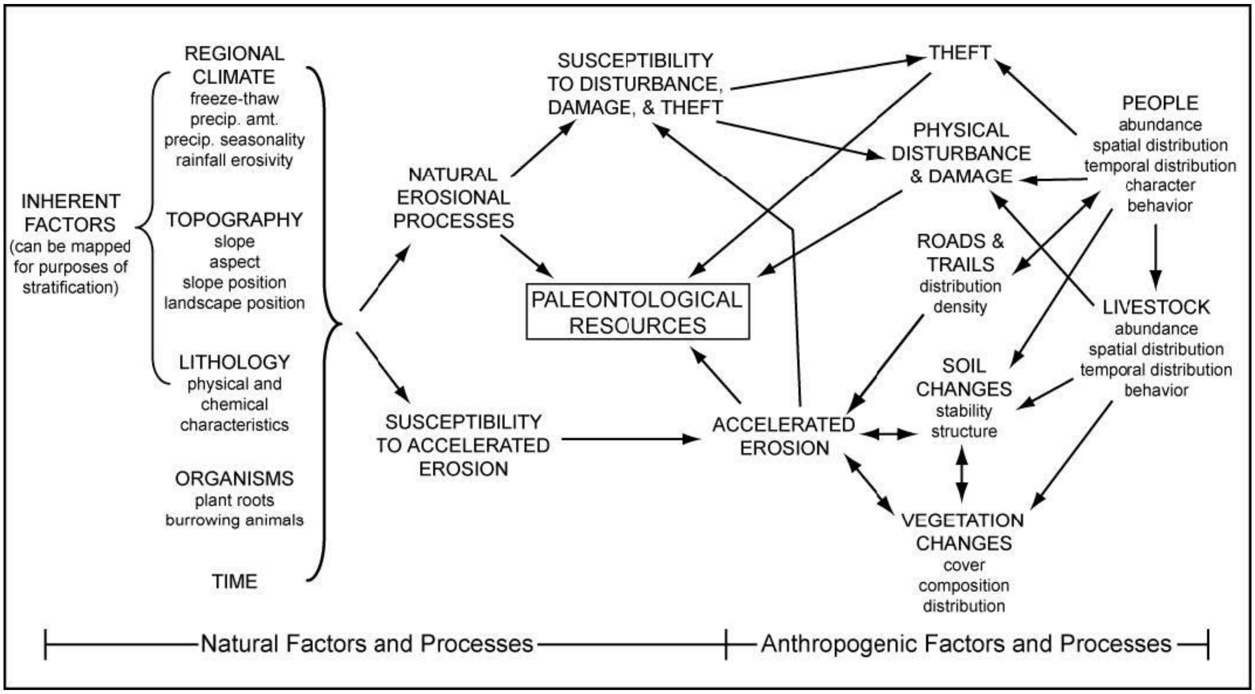

Figure 86. Conceptual diagram illustrating various environmental and anthropogenic factors and processes that might affect the stability of in situ paleontological resources. The graphic is a NPS diagram reproduced from Santucci and Koch (2003).

The process of erosion is responsible for the formation of the colored canyons, arches, natural bridges, alcoves, pinnacles, and balanced rocks that are some of the most important geological features in COLM (KellerLynn 2006). However, erosion through aeolian and hydrologic processes can lead to both the exposure of new fossil resources and the loss of existing fossil resources to natural deterioration (KellerLynn 2006). The erosional processes can also increase the potential for fossil theft and vandalism (KellerLynn 2006).

Wind erosion and freeze-thaw process are forms of weathering of the rock formations that occur within COLM. The wind acts on exposed sediments and friable rock formations, causing erosion (and abrasion) in addition to the collection of airborne sediment and soil particles (KellerLynn 2006). Increased weathering could have a detrimental impact on the quality of exposed paleontological resources.

Changes to the timing, frequency, and duration of precipitation events associated with climate change, coupled with the highly erodible landscape within COLM, has the potential to influence the erosional and weathering rates of paleontological resources within COLM. Climate change could lead to an increase in the timing, frequency, and duration of sudden and extreme precipitation events, which in turn leads to increased runoff and accelerating erosion (Wei et al. 2009), particularly in those formations that are most susceptible to erosion (see Table 91; KellerLynn 2006). Alterations to vegetation and ground cover brought on by climate change could make the landscape more susceptible to wind erosion. Aeolian sand on upland locations within COLM is locally stabilized by trees such as juniper and in other areas by sage, rabbitbrush, and bunch grass (KellerLynn 2006).

Reductions in these vegetation types could further expose paleontological resources to erosion and weathering. Climate change resulting in extreme precipitation events can result in heavy flash flooding increasing erosion activity within the park (KellerLynn 2006).

Theft and vandalism of fossil resources at COLM has been documented (Engelmann and Fiorillo 2000, KellerLynn 2006, Tweet et al. 2012). Increased visitor access and exposure of new fossil resources by erosion can increase the number of paleontological resources that can potentially be impaired or lost to the effects of vandalism and theft (KellerLynn 2006). Increased visitation can impact fossil resources in a number of ways in addition to greater potential for theft and vandalism. The rapid creation of social trails, which is tied to increasing visitation, has caused increased erosion in Monument Canyon, lower Liberty Cap Trail, No Thoroughfare Canyon, the trail between the visitor center and Book Cliffs View, and on Alcove Trail (KellerLynn 2006). Another anthropogenic induced increase in erosion can come from the use of climbing equipment (KellerLynn 2006). The use of bolts and pitons can result in the erosion of rock faces, causing both aesthetic and physical damage to the rocks (KellerLynn 2006).

Data Needs/Gaps

Continued research of the paleontological resources at COLM can provide a better understanding of the past as well as potential future conditions (KellerLynn 2006, Tweet et al. 20102). While only one of the measures (amount of paleontological resources eroded out each year) is considered a data gap, all the measures would benefit from a systematic park-wide inventory of paleontological resources (KellerLynn 2006). In addition to providing baseline information, such a survey would likely discover new fossil resources (KellerLynn 2006). The baseline data could provide a basis for a monitoring program, which would limit the future loss of paleontological material, and ensure its availability for scientific study (KellerLynn 2006). Additionally, a comprehensive inventory would provide a basis for NPS and public understanding of the paleontological resources at the park (KellerLynn 2006).

After compilation of a baseline, the next phase of paleontological resource management is a monitoring program (Tweet et al. 2012). A preliminary strategy for implementing a paleontological monitoring protocol has been presented by Santucci and Koch (2003), which also identified natural and human-related impacts to fossils (Tweet et al. 2012). A more comprehensive strategy including natural and anthropogenic stressors, a study design and case studies was presented by Santucci et al. (2009).

Park staff should be encouraged to observe exposed sedimentary rocks and their eroded deposits for fossil material (KellerLynn 2006). Staff should photo-document and monitor discoveries; however, the fossils and the surrounding rock should be left in place unless they are subject to direct human impact or artificially increased natural processes (KellerLynn 2006). Park staff should also be encouraged to take advantage of opportunities to observe paleontological resources in the field or take part in paleontological field studies with trained paleontologists (KellerLynn 2006).

Overall Condition

Changes in Specimen Abundance at Paleontological Localities

The project team assigned a *Significance Level* of 2 for this measure. The geologic formations within COLM contain significant fossil resources and there is the potential for new discoveries. Visitor impacts through vandalism and theft have impacted the abundance of specimens at paleontological sites within COLM. Other parks with paleontological resources, such as Fossil Butte National Monument, have implemented management actions to minimize the impacts of theft and vandalism. COLM resource managers have expressed concern over fossil theft and vandalism (Tweet et al. 2012). While the potential exists for changes to specimen abundance at localities, only a few instances have been documented. Due to this, the measure has been assigned a *Condition Leve*l of 1, meaning low concern.

Documentation and Inventory of Paleontological Sites within the Park

The project team defined the *Significance Level* of 2 for this measure. In 2010 the GPRA Goal Ia9 report submitted by COLM reported on 75 paleontological localities, 72 of which were determined to be in good condition (Tweet et al. 2012). The current park collection contains 443 catalog numbers for paleontological specimens; however, some of these did not originate within COLM (Tweet et al. 2012). Several preliminary inventories have been completed, but a systematic inventory of fossil resources park-wide has not been completed (KellerLynn 2006, Tweet et al. 2012, Green 2014). Such an inventory would provide a baseline for a monitoring program and provide a basis for better NPS and public understanding of the paleontological resources at COLM (KellerLynn 2006). Based on the lack of this inventory and the impact it would have on all the measures, this measure is assigned a *Condition Level* of 2, meaning moderate concern.

Incidence of Theft

This measure was also assigned a *Significance Level* of 2 by park staff. Incidents of theft and vandalism have been documented within COLM (Engelmann and Fiorillo 2000, KellerLynn 2006, Tweet et al. 2012, Green 2014). Increased visitor access and exposure of new fossil resources by erosion can increase the number of paleontological resources that can potentially be impaired or lost to the effects of vandalism and theft (KellerLynn 2006). While only one documented reference to theft of paleontological resources has been officially recorded, the lack of a comprehensive baseline inventory and associated monitoring likely contributes to this lack of reported instances. Green (2014) was unable to locate eight of the known localities and attributed this to either illegal collection or erosion. Due to these factors, this measure is assigned a *Condition Level* of 2, meaning moderate concern.

Amount of Paleontological Resources Eroded Out Each Year

Park staff assigned this measure a *Significance Level* of 2. While information on erosion rates for the fossil-bearing formations at COLM was available, no information was available to quantify the amount of paleontological resources uncovered by erosion each year. Therefore, this measure is considered a data gap and as such, a *Condition Level* cannot be assigned at this time.

Erosion Rates at Paleontological Sites
Park staff assigned a *Significance Level* of 3 to this measure. The Morrison Formation contains the majority of the fossil resources found at COLM. As can be seen in Table 90 and Table 91, the Morrison Formation along with the Burro Canyon and Chinle Formations have the highest potential for fossil resources in COLM. They also are some of the most erodible formations within COLM. Due to these two factors, a *Condition Level* of 2 has been assigned to this measure.

Weighted Condition Score
The *Weighted Condition Score* for COLM's paleontological resources is 0.59, indicating condition for the paleontological resources warrants moderate concern. Given the lack of a park-wide baseline inventory, a trend assessment was not determined.

Paleontological Resources			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.59**
Changes in Specimen Abundance at Paleontological Localities	2	1	
Documentation and Inventory of Paleontological Sites Within the Park	2	2	
Incidence of Theft	2	2	
Amount of Paleontological Resources Eroded Out Each Year	2	n/a	
Erosion Rate at Paleontological Sites	3	2	

4.20.6 Sources of Expertise
Tim Connors, NPS Geological Resources Division Geologist/Mapping Coordinator

Justin Tweet, Tweet Paleo-Consulting

Vincent Santucci, NPS Geological Resources Division Senior Geologist/Paleontology Program Coordinator

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4.21 Geologic Features and Processes

4.21.1 Description

COLM's erosional and exposed rock geologic features were the driving force behind the establishment of the park and still attract many visitors to the site today (NPS 2005). COLM lies on the northeast edge of the Uncompahgre Plateau, an uplifted area which covers an area approximately 150 km (90 mi) long by 45 km (27 mi) wide (Scott et al. 2001).

Erosion has created a variety of amazing and colorful geologic features at COLM, from sheer canyon walls to impressive monoliths, archways, and balanced rocks. Wind and water wear away the more erodible rock layers (e.g., Wingate sandstone, soft shales), leaving the resistant strata behind, and sometimes in seemingly unnatural shapes (KellerLynn 2006). In Monument Canyon, for example, visitors can view Window Rock, Coke Ovens (Photo 33), and Independence Monument (Photo 34), an erosional remnant that rises 137 m (450 ft) from the canyon floor (KellerLynn 2006).

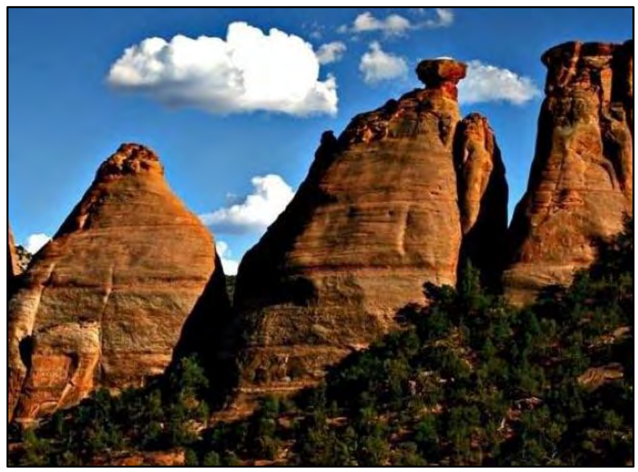

Photo 33. Geological features in COLM include Window Rock (top) and Coke Ovens (bottom) (NPS photos).

The park's geologic features provide an excellent illustration of how various physical processes, particularly erosion and uplift, have shaped the greater Colorado Plateau region (KellerLynn 2006). For example, COLM contains a monocline (i.e., a step-like dip or fold in rock strata) where erosion has exposed a series of rock layers which provide a visual record of geologic history (KellerLynn 2006). This monocline is a classic example of the Laramide orogeny, a period of mountain-building that began 70 million years ago (mya) and continued for approximately 20 million years (Scott 2001). Visitors can observe a remarkable sequence of Mesozoic (252-66 mya) rock layers and even Precambrian (>540

Photo 34. Independence Monument (photo by Anna Davis, SMUMN GSS).

mya) basement rocks (KellerLynn 2006) (Figure 87). The rock layers also show several "unconformities", or places where strata of very different geological ages meet. These are due to the erosion of the rock layer that should have been in between, prior to deposition of the next layer. For example, erosion removed all of the Paleozoic Era (540-252 mya) strata in the park prior to deposition of the Mesozoic Era strata, resulting in a more than one-billion-year gap in the rock layers (Harris and Kiver 1985, KellerLynn 2006) (Figure 87). The major geological formations within COLM are listed by age in Table 92. Rock outcrops on the west side of the park are generally younger and older formations are found on the east side in canyon bottoms (Scott et al. 2001, Tweet et al. 2012).

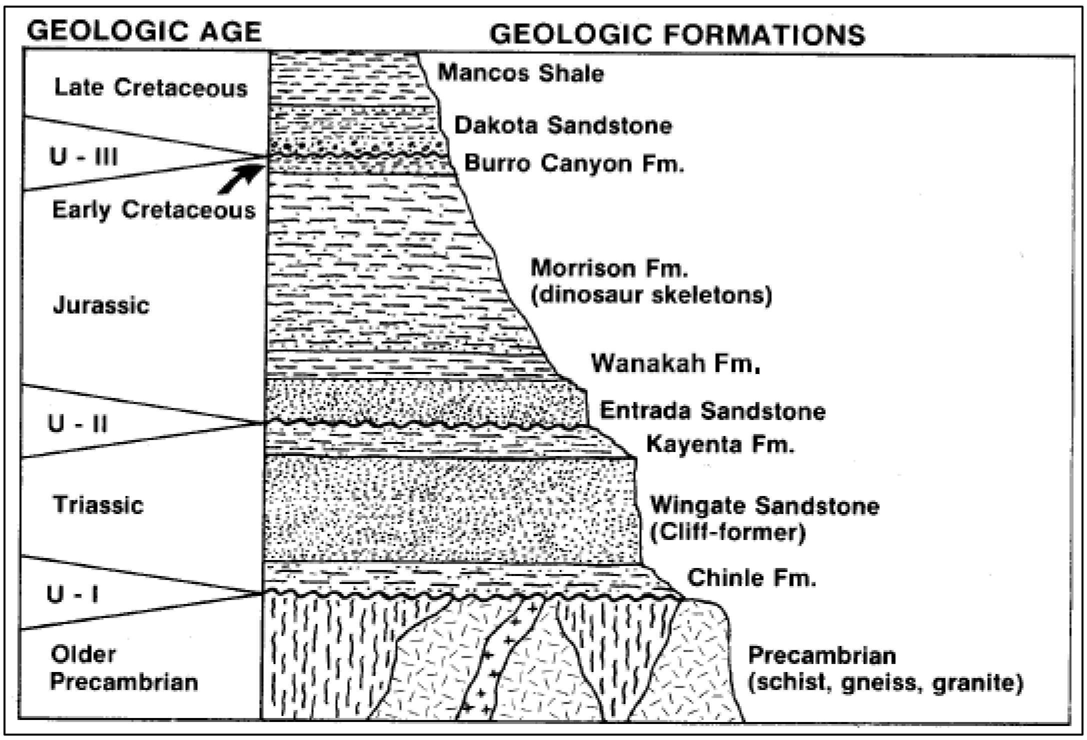

Figure 87. A cross section of the rock layers (geological formations) exposed at COLM (reproduced from NPS 2005, adapted from Lohman 1965). A "U" represents the location of an unconformity. Triassic, Jurassic, and Cretaceous are all periods within the Mesozoic Era.

Photo 35. The characteristic red color of the Chinle Formation (NPS photo).

The oldest geologic formation exposed in COLM is metamorphosed sedimentary rock from Precambrian times, at least 1,740 mya (Tweet et al. 2012). COLM is one of only a few places on the Colorado Plateau where this formation is exposed (KellerLynn 2006). Just above the Precambrian strata is the Chinle Formation. This rock layer is distinguished by the red color that can be seen in many of COLM's canyons (Armstrong and Kihm 1980; Photo 35). The formation contains shales interbedded with thin sandstone and some volcanic sediment, due to eruptions that occurred during the period of deposition (Armstrong and Kihm 1980, Tweet et al. 2012). The next formation on top of the Chinle is Wingate Sandstone. This rock layer was formed during an arid period, when wind-blown sands formed large dunes in the area (Armstrong and Kihm 1980, Tweet et al. 2012). The lime-rich sandstone that resulted is orange-tinted, with brown or reddish siltstone also present within the formation (Tweet et al. 2012). Many of the park's impressive geologic features, including Independence Monument, are composed of Wingate Sandstone (Armstrong and Kihm 1980).

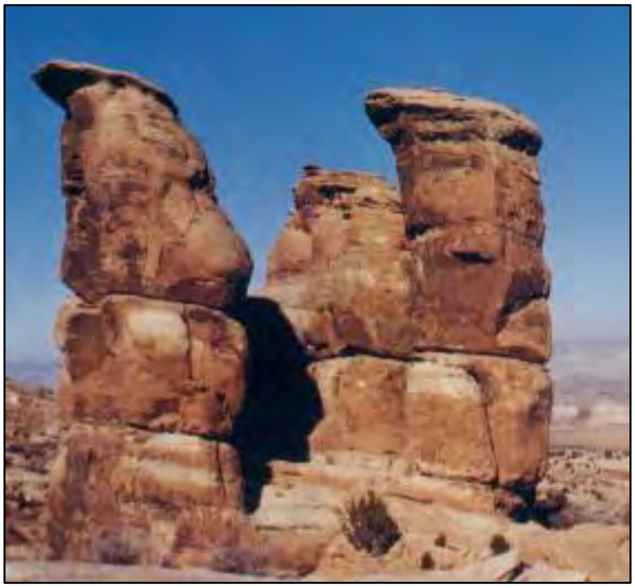

Photo 36. Devils Kitchen in No Thoroughfare Canyon is an example of remnant Wingate sandstone capped and protected from erosion by the Kayenta Formation (USGS photo by T. F. Giles, from Lohman 1981).

The early Jurassic Kayenta Formation consists of red and buff-colored sandstone with some purplish siltstone and shale (Armstrong and Kihm 1980, Tweet et al. 2012). The Kayenta formed during a wetter period when the region was a floodplain, and sediments were deposited by meandering streams and rivers (Tweet et al. 2012). These rocks are more resistant to erosion than the sandstone layers above and below it, and often forms benches or ledges within cliffs. Kayenta Formation "caps" often protect the underlying Wingate Sandstone from erosion, producing some of COLM's spectacular monoliths (Lohman 1981; Photo 36). Without the Kayenta "caps" the Wingate Sandstone would weather into rounded domes (Lohman 1981). The overlying Entrada Sandstone, like the Wingate, was formed during a drier period when sand dunes existed in the region (Tweet et al. 2012). The Entrada can also form impressive cliffs and geologic features, such as the "Saddlehorn" near the COLM visitor center (Lohman 1981). The layer contains a variety of colors including pink (when freshly exposed), red, pale orange, and white (Armstrong and Kihm 1980, Tweet et al. 2012),

Table 92. Major geological formations (i.e., rock layers) within COLM (adapted from Tweet et al. 2012). Notes are from Armstrong and Kihm (1980), Harris and Kiver (1985), and Tweet et al. (2012).

Geologic Era	Formation	Age	Depositional Environment	Notes
Quaternary	Quaternary Sediments	Pleistocene-Holocene (2 mya-present)	Alluvial, eolian, fluvial, and landslide deposits	-
Precambrian	Metamorphosed sedimentary and igneous rocks	At least Paleoproterozoic (2500-1600 mya)	N/A	Highly resistant to erosion; exposed in No Thoroughfare Canyon, one of the few places on the Colorado Plateau where these strata can be seen
	Igneous dikes	Mesoproterozoic (1600-1000 mya)	N/A	Highly resistant to erosion; exposed in No Thoroughfare Canyon, one of the few places on the Colorado Plateau where these strata can be seen
Mesozoic	Chinle Formation	Late Triassic (228-200 mya)	Fluvial, floodplain, and lacustrine settings, becoming drier over time	Distinctive red color; 27-29 m thickness in COLM
	Wingate Sandstone	Late Triassic- Early Jurassic (228-175 mya)	Desert with large eolian sand dunes	Forms many of COLM's impressive geologic features; 95-110 m thickness in COLM
	Kayenta Formation	Early Jurassic (200-175 mya)	Primarily fluvial settings	More resistant to erosion than the under- and over-lying sandstones; 14-24 m thickness
	Entrada Sandstone	Middle Jurassic (175-162 mya)	Coastal dunes and sand flats	Forms prominent cliffs; approximately 47 m in thickness
	Wanakah (formerly Summerville) Formation	Middle Jurassic (175-162 mya)	Mud flats and/or shallow lakes	Distinctive green-over-red coloration; about 9 m thick
	Morrison Formation	Late Jurassic (162-145 mya)	Fluvial, floodplain, and lacustrine settings	Heterogeneous and variegated unit; around 160 m in thickness
	Burro Canyon Formation	Early Cretaceous (145-100 mya)	Fluvial, floodplain, and lacustrine settings	Heterogeneous; lower part of layer forms white to yellowish cliffs; around 30 m thick on Black Ridge
	Dakota Sandstone	Early-Late Cretaceous (145-66 mya)	Terrestrial (especially fluvial), becoming shallow marine over time	Only park unit containing marine sediments; approximately 31 m thick on Black Ridge

The Wanakah Formation is comprised primarily of mudstone and characterized by a distinctive "green-over-red" coloration (Scott et al. 2001). It was deposited during a time when the region supported a shallow lake or mudflats (Armstrong and Kihm 1980, Scott et al. 2001). In COLM, the formation is exposed near the tops of canyon walls and forms gentle, rolling slopes when weathered (Armstrong and Kihm 1980). The overlying Morrison Formation is a diverse rock layer, consisting of a mix of mudstone, claystone, siltstone, sandstone and limestone (Photo 37) (Armstrong and Kihm 1980, Tweet et al. 2012). Colors vary from gray and green, to red and light purple. It is believed to have formed under a semi-arid, seasonal climate, when the Grand Junction area was on the edge of a vast, shallow basin (Tweet et al. 2012). Sediments in the Morrison Formation are most likely lake, mudflat, and floodplain deposits (Armstrong and Kihm 1980, Tweet et al. 2012). The Burro Canyon Formation also formed under a semi-arid climate and includes a mix of sandstone, siltstone, shale, conglomerate, and limestone (Tweet et al. 2012). The lower portion of the layer is dominated by cliff-forming, white to yellowish gray sandstone, while the upper portion is primarily pale red or greenish siltstone. The sandstone portion likely originated from stream and floodplain deposits while the upper siltstone layer is from lake and floodplain deposits (Armstrong and Kihm 1980, Tweet et al. 2012). At COLM, the Burro Canyon Formation is found only on Black Ridge (Tweet et al. 2012).

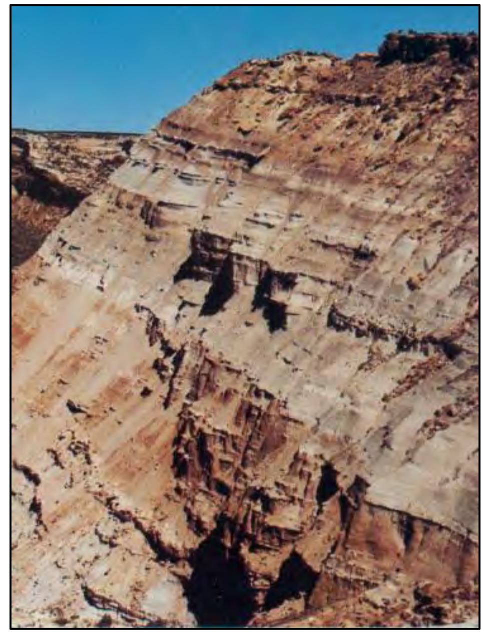

Photo 37. The Morrison Formation, exposed at the mouth of No Thouroughfare Canyon (photo from Lohman 1981).

The youngest of the Mesozoic deposits in COLM is the Dakota Sandstone. It is unique in that it is the only formation in COLM that contains marine deposits, as the Western Interior Seaway advanced and retreated several times during the Cretaceous Period (Lohman 1981, Tweet et al. 2012). The Dakota Sandstone contains a variety of layers, reflecting environmental changes at the time of deposition. The layers include a grayish coaly mudstone, light-colored sandstone, and a sandstone-shale conglomerate (Armstrong and Kihm 1980, Tweet et al. 2012). Outcrops often weather into yellow-brown cliffs and ledges, with broken-off blocks forming talus (i.e., rock debris) slopes (Armstrong and Kihm 1980). Overlying the Dakota Sandstone are Quaternary Sediments, which are primarily surficial units consisting of deposits left by water (alluvium), wind (eolian), and gravity (colluvium) (Tweet et al. 2012). At COLM, Quaternary Sediments include alluvium, eolian sand, colluvium, and rockfall and landslide deposits (KellerLynn 2006).

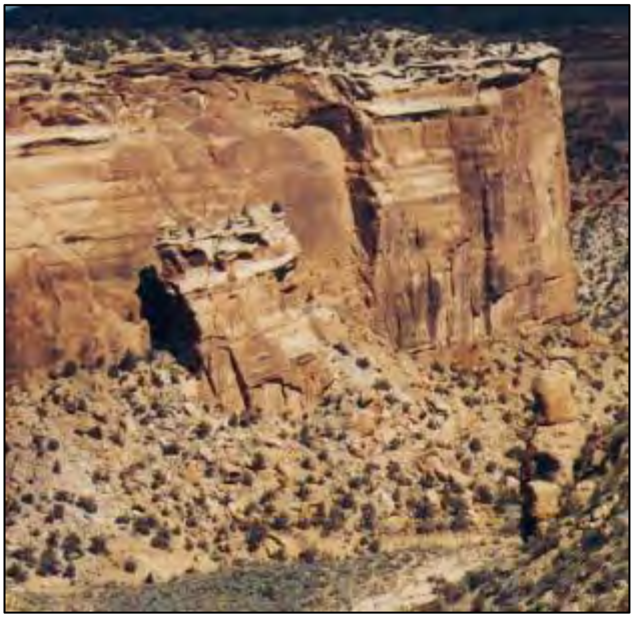

Photo 38. A large slab of fallen rock in Ute Canyon, with slopes of sand and debris at the base of the canyon walls (photo from Lohman 1981).

The erosional processes that carved the canyons of COLM and exposed this series of geological formations continue to act in the park today. The U-shaped canyon valleys were shaped by stream erosion over time; although permanent streams no longer occur in COLM, surface runoff from snowmelt and precipitation feeds intermittent streams, which continue the process of erosion (Harris and Kiver 1985). Streamflow, particularly during flash floods, can erode away less resistant formations underlying more resistant formations, resulting in undercutting. Eventually, large slabs of the overlying, more resistant layer may break off and fall to the canyon floor, leaving sheer cliff walls behind (Lohman 1981, Harris and Kiver 1985). The slabs break up over time, creating slopes of sand and sediment at the base of the canyon walls (Photo 38). These rockfalls can cause safety hazards for park visitors, particularly along canyon hiking trails and at overlooks along Rim Rock Drive (KellerLynn 2006). In addition, some rocks at COLM contain expansive clays, which swell when wet, increasing the likelihood of landslides in the area (KellerLynn 2006). Rapid shifts in temperature experienced at COLM, such as solar heating on summer days and cooling at night, cause rocks to expand and contract, which can cause layers to crack and break off (Lohman 1981). During winter, the freeze-and-thaw cycle of ice/water in cracks near cliff faces can also break apart rocks (Lohman 1981). Lastly, winds can also erode exposed rock surfaces (KellerLynn 2006).

4.21.2 Measures

- Changes in rates of erosion
- Frequency of rock falls or slides
- Frequency of heavy rain and sustained wind events
- Frequency and discharge of flash floods

4.21.3 Reference Conditions/Values

Reference conditions have not been established for geological features and processes. Historical records of rock falls/slides, flash floods, heavy rains, and sustained wind events are not consistent, so it is difficult to identify a "baseline" frequency. The information presented in this assessment for high wind, heavy rain, and flash flood frequency could be used as a baseline for future assessments.

4.21.4 Data and Methods

The geology and notable features of COLM have been described in many publications since the 1960s. Earlier literature utilized in this assessment include Armstrong and Kihm (1980), Lohman

(1981), and Harris and Kiver (1985). In 2001, Scott et al. (2001) published a geologic map of COLM and the surrounding region, which included descriptions of each geologic formation and a discussion of the key geologic processes at COLM. Several years later, the NPS produced a geological resource evaluation report for COLM (KellerLynn 2006). This report summarized the geologic history, features, and processes of the park, as well as geologic issues (e.g., erosion, flash floods, slope failure). More recently, Tweet et al. (2012) prepared a summary of paleontological resource inventory and monitoring in the NCPN, which included descriptions of fossil-bearing geological formations at COLM.

Richard (2004) published a history of flash flooding at COLM from 1921-2003. This summary was based on NPS records and Grand Junction's local newspaper, and is not a comprehensive report of every flood that has occurred adjacent to COLM (Richard 2004). Additional data on extreme weather events (flash floods, high winds, and heavy rain) were obtained from the National Climatic Data Center (NCDC) storm events database (http://www.ncdc.noaa.gov/stormevents/). Records were available for the area around COLM (e.g., Grand Valley, Grand Junction, Fruita, Glade Park) from 1996 through 2014 (NCDC 2015a).

The NPS Geologic Resources Division has recently completed a geohazard assessment for Rim Rock Drive at COLM. This report was not available for review for this assessment, but would be a valuable asset that could provide further insight for future assessments of this resource at COLM.

4.21.5 Current Condition and Trend

Changes in Rates of Erosion

As discussed above, erosion has played a critical role in creating the stunning geologic features of COLM. This natural process continues to act today and will eventually wear away the monoliths and other features that attract visitors to the park. Shifts in environmental conditions (e.g., climate) and human activities can change erosion rates (Lohman 1981, KellerLynn 2006). To date, erosion rates have not been specifically studied at COLM. Pederson et al. (2002) used GIS to estimate erosion and uplift rates on the Colorado Plateau during the Cenozoic Era; investigators estimated that 843 m (2,766 ft) of erosion have occurred over the past 30 million years. This equates to an average of 28.1 m (92.2 ft) of erosion per million years. However, the time scale of this estimate is not practical for measuring or detecting present changes in erosion rates.

Frequency of Rock Falls or Slides

Rock falls, landslides, and debris flow are all types of "slope failure", a natural process that occurs constantly throughout COLM (KellerLynn 2006). Rock falls are common along cliffs of Wingate Sandstone, the Kayenta Formation, and the Salt Wash Member of the Morrison Formation (Scott et al. 2001). Human activities such as road construction and vibrations from heavy vehicles can accelerate this natural process, which is a constant maintenance concern along Rim Rock Drive in the park. Slope failures along Rim Rock Drive and its overlooks are a threat to visitor safety and to access/travel for both staff and visitors (KellerLynn 2006). In January of 2000, car-sized sandstone blocks fell onto Rim Rock Drive and blocked traffic for over a month (Photo 39) (Scott et al. 2001). Slope failure is also a danger along park trails, particularly along Serpents Trail, near the park's east entrance (KellerLynn 2006). The recently completed geohazards assessment of Rim Rock Drive could provide further insight into this measure.

Photo 39. Rock fall onto Rim Rock Drive in January 2000 (NPS photo by Ron Young).

Frequency of Heavy Rain and Sustained Wind Events

Heavy rains and sustained high winds can contribute to sudden, dramatic incidences of erosion, such as the types of slope failures described above. Intense thunderstorms are common during the summer throughout the Uncompahgre Plateau (Scott et al. 2001, KellerLynn 2006). These storms often produce high winds and large amounts of rain in a short time period. Heavy rain and high wind events have not been documented consistently over time at COLM. As a result, it is difficult to determine if their frequency has changed over time. The NCDC storm events database contains records of heavy rain and high or strong wind events in the COLM area from 1996 through 2014 (NCDC 2015a). These records are presented here and may be used to analyze trends in event frequency in the future.

High winds are defined as sustained winds of at least 64 km/hr (40 mph) for an hour or more or any winds over 93 km/hr (58 mph) (NWS 2007). Winds that do not meet these thresholds but result in injuries or significant property damage are categorized as strong wind events (NWS 2007). During the 19 year period of record, 28 high or strong wind events were reported in the Grand Valley/Grand Junction area (Table 93). At least one event occurred in 15 of the 19 years; the highest number of events in a single year was five, occurring in 2009. Events were distributed between late February to early June and from mid-September to late November (NCDC 2015a). No trends in frequency are apparent during this period of record.

Heavy rains are defined as unusually high amounts of rain that do not cause flash flooding but do cause damage (i.e., human/economic impact) (NWS 2007). During the 19 year period of record for the area around COLM, 21 separate heavy rain events were reported (Table 94). All events occurred between late April and early October, with the majority between June and September. The most events in a single year were five in 2006 (NCDC 2015a).

Richard (2004) used 1948-2002 daily precipitation records for June-September to determine recurrence intervals for storms likely to cause flash flooding. According to those calculations, the heaviest rainstorm on record (6.5 cm [2.5 in] in August 1957) had a 100-year recurrence interval (Table 95). Storms with 1.8 cm (0.7 in) of rain occurred approximately every 2 years based on 1948-2002 data. However, in both 2013 and 2014, two rain events of this magnitude or greater were recorded each year at the COLM rain gauge (2.5 cm [1 in] and 1.9 cm [0.7 in] in September 2013, 2.9 cm [1.1 in] and 2.4 cm [0.9 in] in August 2014) (NCDC 2015b).

Table 93. High and strong wind events in the Grand Valley/Grand Junction area, 1996-2014 (NCDC 2015a).

Event Type	Date	Event Type	Date
High wind	10/19/1996	Strong wind	9/21/2005
High wind	3/27/1997	Strong wind	10/4/2005
High wind	10/2/1997	Strong wind	4/17/2006
High wind	10/7/1997	Strong wind	11/14/2006
High wind	11/26/1997	High wind	4/18/2007
High wind	2/24/1998	Strong wind	6/6/2007
High wind	9/29/1998	Strong wind	9/29/2007
High wind	4/18/2000	High wind	3/22/2009
High wind	3/14/2001	High wind	3/29/2009
High wind	4/20/2001	Strong wind	4/15/2009
Strong wind	4/2/2003	Strong wind	4/25/2009
Strong wind	6/16/2003	High wind	9/30/2009
Strong wind	9/17/2003	Strong wind	6/16/2010
Strong wind	6/10/2004	High wind	3/26/2012

Table 94. Heavy rain events in the area around COLM, 1996-2014 (NCDC 2015a).

Location	Date	Location	Date
Grand Junction	7/29/1998	Redlands and Fruita	10/5/2006
Fruita	9/12/1998	Fruita	7/27/2008
Glade Park	6/19/2003	Grand Junction	8/8/2008
Fruita	8/23/2003	Grand Junction	6/18/2009
Fruita	9/10/2003	Grand Junction	6/26/2009
Fruita	4/24/2005	Fruita	8/4/2010
Glade Park and Grand Junction	9/21/2005	Fruita	7/23/2012
Grand Junction	7/19/2006	Glade Park	7/31/2012
Glade Park	8/13/2006	Grand Junction	7/13/2013
Fruita	9/8/2006	Grand Junction	7/17/2013
Grand Junction	10/3/2006		

Table 95. Recurrence intervals for various 24-hour rainfall amounts at the COLM headquarters rain gauge, based on 1948-2002 precipitation data, as calculated by Richard (2004).

	Recurrence Interval (years)				
Parameter	**100**	**50**	**10**	**5**	**2**
Rainfall (cm/in)	6.5 (2.5)	5.8 (2.3)	3.8 (1.5)	2.5 (1.0)	1.8 (0.7)

Frequency and Discharge of Flash Floods

A flash flood is defined by the National Weather Service (NWS) as “a rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level" (NWS 2007, p. 32). The rate and duration of rainfall, soil conditions, topography, and ground cover all contribute to flash flood occurrence (Richard 2004). The physical setting at COLM (steep canyon walls, bare rock surfaces, semi-arid climate) increases the likelihood of flash flood occurrence (Richard 2004). The impermeable rock surfaces prevent precipitation from infiltrating into the ground and the steep canyon walls channels water into small areas, increasing the rate and force of the flow. Within COLM's boundaries, 57% of the area is categorized as rock or soil with moderate to very slow permeability (Richard 2004). During historic floods in COLM's canyons, floodwaters have moved boulders over 2 m (6.6 ft) in diameter (Scott et al. 2001).

Richard (2004) summarized 13 different flash flood events that occurred in or were fueled by COLM's canyons between 1921 and 2003 (Table 96). All reported flash floods occurred between July and early September. Table 96 shows that flash floods are not always correlated with high rainfall amounts at existing rain gauges, demonstrating that flash flood-causing storms can be localized and isolated (Richard 2004).

The NCDC storm events database recorded flash floods in the COLM vicinity between 1996 and 2014 (NCDC 2015a), a period of record which partially overlaps with Richard (2004). During these years, the NCDC documented 16 flash flood events in the area (Table 97). These events cover a wider portion of the year than those documented by Richard (2004), extending from mid-June to early October. The available data (Richard 2004, NCDC 2015a) seem to suggest that flash flood frequency may be increasing over time (13 recorded events from 1921-2003, 16 events from 1997-2014), but this could be due to differences in record-keeping (e.g., less attention given to documenting flash floods in the early mid-20th century) rather than actual change. More attention has been given to flash flooding occurrence and potential since development has increased along the park's eastern boundary (Richard 2004, KellerLynn 2006).

Little information is available regarding the discharge of flash floods in COLM's canyons. The rare and sudden nature of these events likely makes them difficult to study. The only available data are from a USGS analysis of flows from NTC and Red and Columbus Canyons combined during the September 1978 flood. According to USGS estimates, peak discharge from NTC was 263.1 cms (9,290 cfs) with a unit discharge (total discharge volume divided by drainage area) of 5.4 $m^3/sec/km^2$ (494 $ft^3/sec/mi^2$) (Richard 2004). Peak discharge from Red Canyon was 81.8 cms (2,890 cfs) with a unit discharge of 7.3 $m^3/sec/km^2$ (664 $ft^3/sec/mi^2$) (Richard 2004).

Table 96. Historical flash floods (1921-2003) in the COLM vicinity summarized by Richard (2004). KGJT = Grand Junction Airport.

	Rainfall (cm)		
Date	**COLM**	**KGJT**	**Notes**
8/24/1921	-	3.60	Damaged 20 county bridges; made the road between Fruita and Grand Junction impassable
8/8/1948	0.30	2.30	Storm dropped 1.1 cm (0.4 in) of rain in 15 min.; flash flood along the eastern park boundary
7/3/1949	0.40	-	Extensive damage on a southern portion of Rim Rock Drive and Serpents Trail
7/7/1949	0.05	-	
7/28/1950	0.40	0.30	Damaged Rim Rock Drive and two diversion ditches
8/6/1957	6.50	1.40	4.7 cm (1.9 in) fell in 2 hours, damaging fences in East Monument Canyon and causing numerous rock and mud slides on Rim Rock Drive.
8/8/1968	4.90	-	Caused a major washout of Rim Rock Drive between the two tunnels above the west entrance; see Photo 40
9/7/1978	1.70	1.10	Bridge washed away on Monument Road in NTC, and power lines were downed; see Photo 41
9/2/1990	0.70	1.30	Caused rock falls that closed Rim Rock Drive and overtopped a bridge on Monument Road
8/4/1991	-	-	Eroded NTC trail and moved large rocks
7/11/1992	0.05	1.10	Floodwaters threatened to breach one of the Redlands Water & Power Co. canals
7/24/1998	2.30	-	5 cm (2 in) of rain fell in 40 minutes near the east entrance, damaged a large portion of Serpents Trail
7/10/2001	4.10	-	4.1 cm (1.6 in) of rain fell in less than 2 hours, flooding the Visitor Center and other park buildings; Rim Rock Drive was covered in mud near the east entrance

Table 97. Flash flood events reported in the area around COLM, 1996-2014 (NCDC 2015a). The locations for 2014 flooding were reported only as "Mesa County"; it is not known which specific communities where flooding occurred.

Location	Date	Location	Date
Grand Junction	8/5/1997	Fruita	8/11/2005
Grand Junction	7/23/1998	Grand Junction	10/6/2006
Grand Junction	9/19/1999	Redlands	6/18/2009
Redlands	7/10/2001	Glade Park	8/27/2013
Redlands	8/3/2001	Redlands	8/27/2013
Grand Junction	9/12/2002	Mesa County	7/25/2014
Fruita	8/23/2003	Mesa County	7/29-30/2014
Glade Park	8/8/2005	Mesa County	8/4/2014

Photo 40. Section of Rim Rock Drive washed out by flooding above the west entrance in August 1968 (NPS photo).

Photo 41. Wash-out along Monument Road on 7 September 1978 (Photo by Jim Johnson, from Richard 2004).

Threats and Stressor Factors

Threats to COLM's geologic features and processes include climate change (especially extreme weather events), human activities, and park management activities. Management activities that impact park geology include road maintenance, trail creation and maintenance, and drainage management (e.g., culverts, ditches). Many of these activities are necessary to maintain visitor safety and enjoyment.

Human activities influence natural geological processes such as erosion and slope failure, usually increasing their rate or frequency (KellerLynn 2006). The best example of this at COLM is Rim Rock Drive. Traffic along the road, particularly from heavy vehicles such as buses and semi-trucks, causes vibrations that can contribute to rock falls and slope failures (KellerLynn 2006). Development in surrounding areas has increased traffic on Rim Rock Drive, as it is the shortest route from Glade Park to Grand Junction. The existence of the road alone has increased runoff and altered drainage patterns (KellerLynn 2006). The creation of social trails, which often occurs with increased visitation, also contributes to localized erosion (e.g., Monument Canyon, No Thoroughfare Canyon, and the trail from the Visitor Center to Book Cliffs View). Lastly, rock climbing and the use of climbing equipment (e.g., bolts installed in rock faces) can cause erosion and damage to the rock surfaces (KellerLynn 2006).

The semi-arid climate of the COLM region has contributed to the stunning nature of the park's geological features. According to Lohman (1981), a wetter climate would have resulted in a "smoother" landscape, with most of the rocks and geological features obscured by vegetation. The climate in western Colorado is predicted to shift as a result of global climate change (Melillo et al. 2014). Likely changes include an increase in temperature with longer and hotter summer heat waves, an increased potential for drought and wildfires, and an increase in precipitation falling as very heavy events (Lamm et al. 2014, Melillo et al. 2014). More precipitation falling in heavy events would have a direct influence on erosion rates, flash flooding frequency, and slope failures and fluvial resources (Wei et al. 2009). An increased occurrence of wildfires could also contribute to erosion and slope failure, as fire removes vegetation and litter that cover ground surfaces, protecting them from water and wind (KellerLynn 2006, Wei et al. 2009).

Data Needs/Gaps

Additional data are needed for every measure selected for this resource. Erosion rates, which will vary between geological formations, have not been studied in the park. Consistent record-keeping of slope failures is needed to determine their frequency. An inventory of areas with high potential for slope failure along Rim Rock Drive and its overlooks would also be useful for park management (KellerLynn 2006). A simple method for monitoring gradual movement or creep that could indicate risk of slope failure is to place stakes in loose material along the road and track any position changes on an annual or biennial basis (KellerLynn 2006). Additional study on the how much of the surface within the park is in its "native" condition (has not been altered by human activity). The "native" versus altered surfaces could be analyzed in terms of absorption and run-off to gain a better understanding of areas that contribute to flash flooding. Park staff can also monitor cracks in the asphalt along Rim Rock Drive, another potential indicator of slope creep.

Continued collection of weather event data (e.g., heavy rain, high winds, and flash floods) will allow for the detection of any changes in the frequency of these events. Given the localized nature of some heavy precipitation events in the region, the installation of additional weather stations in the park may help managers better understand the relationship between precipitation and flash floods. In addition, repeat photography may be used to document the impact of flash floods on COLM's geological features. Further study of flash flooding (e.g., recurrence intervals, floodplain identification, and discharge rates) would be beneficial in understanding the risks of expanded development downstream of the park's canyons (Richard 2004, KellerLynn 2006). This could involve creating and running flash flood models for each drainage in COLM. Verifying the model would require collecting data on peak flow drainages, which could be obtained by installing crest-stage gages and using the step- backwater method to rate stream channels (KellerLynn 2006).

Overall Condition

Changes in Rates of Erosion
This measure has been assigned a *Significance Level* of 3. Erosion is a natural process and has created the spectacular geological features of COLM. However, changes in erosion rates could threaten these geologic features, as well as the safety and enjoyment of visitors to the park. To date, erosion rates have not been measured within COLM. Therefore, a *Condition Level* cannot be assigned for this measure.

Frequency of Rock Falls or Slides
This measure also received a *Significance Level* of 3. While slope failures such as rock falls and slides are also natural processes, they can be exacerbated by human activities and pose a threat to visitor safety and access within the park. Slope failures are known to occur at COLM and have damaged or closed Rim Rock Drive, but records have not been officially kept regarding their frequency. As a result, a *Condition Level* cannot be assigned for this measure. However, the recently completed geohazards assessment of Rim Rock Drive could provide further insight into this measure.

Frequency of Heavy Rain and Sustained Wind Events
The frequency of these events was assigned a *Significance Level* of 2. Heavy rains and high winds contribute to erosion of COLM's geological features. If these events were to increase in frequency, erosion rates would likely also increase. The NCDC has some records (1996-2014) of heavy rain and high/strong wind events in the COLM vicinity. Using 1948-2002 precipitation data, Richard (2004) estimated that storms producing 1.8 cm of rain occurred once every two years. However, two events of this magnitude occurred annually in 2013 and 2014 (NCDC 2015b), suggesting an increase in the frequency of heavy rain events. A *Condition Level* of 2 was assigned to this measure, indicating moderate concern.

Frequency and Discharge of Flash Floods
This measure received a *Significance Level* of 3. Flash floods have played a key role in shaping the canyons and geological features of COLM (KellerLynn 2006). They are also a threat to people and property both within and outside the park. Flash floods have washed out portions of Rim Rock Drive and various park trails, and covered other portions in mud or debris. Flood waters have also washed

out bridges and caused property damage at the lower ends of COLM's canyons, in the Grand Junction and Redlands areas. Sixteen flash flood events were recorded in the area around COLM from 1996-2014 (NCDC 2015a), while only 13 events were reported from 1921-2003 (Richard 2004). This suggests that flash flood frequency may be increasing, but the change could be at least partially due to differences in record-keeping. The possible increase in heavy precipitation event frequency discussed previously would likely also increase flash flood frequency. Therefore, this measure is also assigned a *Condition Level* of 2 for moderate concern.

Weighted Condition Score
A *Weighted Condition Score* was not calculated for this component due to a lack of data for two of the four measures. The current condition of COLM's geological features and processes is considered unknown.

Geologic Features and Processes			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Changes in Rates of Erosion	3	n/a	
Frequency of Rock Falls or Slides	3	n/a	
Frequency of Heavy Rain and Sustained Wind Events	2	2	
Frequency and Discharge of Flash Floods	3	2	

4.21.6 Sources of Expertise
Tim Connors, NPS Geological Resources Division Geologist/Mapping Coordinator

Hal Pranger, NPS Geologic Resources Division Geologic Features and Systems Branch Chief

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5. Discussion

Chapter 5 provides an opportunity to summarize assessment findings and discuss the overarching themes or common threads that have emerged for the featured components. The data gaps and needs identified for each component are summarized and the role these play in the designation of current condition is discussed. Also addressed is how condition analysis relates to the overall natural resource management issues of the park.

5.1 Component Data Gaps

The identification of key data and information gaps is an important objective of NRCAs. Data gaps or needs are those pieces of information that are currently unavailable, but are needed to help inform the status or overall condition of a key resource component in the park. Data gaps exist for most key resource components assessed in this NRCA. Table 98 provides a detailed list of the key data gaps by component. Each data gap or need is discussed in further detail in the individual component assessments (Chapter 4).

Table 98. Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Pinyon-juniper Woodlands/Savannas	➢ Further vegetation studies that provide information on the percent ground cover of cryptobiotic crusts and soils, percent bare ground, invasive species composition, and soil stability within this vegetation community are needed. ➢ Further research on the effects of climate change on the pinyon-juniper distribution ➢ Research on the overall effects of climate change on the non-native species composition within this habitat ➢ Research on the impact of social trails within all habitat types
Sagebrush Shrublands/Shrub Steppe	➢ Further vegetation studies that provide information on the percent ground cover of cryptobiotic crusts and soils, percent bare ground, canopy gap size, invasive species composition, and soil stability within this vegetation community is needed. ➢ Research on the impact of social trails within all habitat types
Riparian Habitats/Large Dry Washes	➢ Research into amphibian populations within riparian communities. ➢ Additional research or modeling of flash floods and how they impact channel geomorphology. ➢ Research on the impact of social trails within all habitat types
Seeps and Springs and Tinaja Habitats	➢ Additional research on water quality parameters including discharge. ➢ Research and monitoring of riparian dependent species, including amphibians ➢ Research on the presence of invertebrates. ➢ Development of a monitoring program of these habitats. ➢ Complete mapping of all seeps, springs, and tinaja habitats within COLM. ➢ Further research on the effects of climate change on seeps and springs and their associated native and non-native plant species composition

Table 98 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Mixed Salt Desert Scrub/Semi-desert Grassland	➢ Further vegetation studies that provide information on the percent ground cover of cryptobiotic crusts and soils, percent bare ground, invasive species composition, and soil stability within this vegetation community are needed. ➢ Research on the impact of social trails within all habitat types
Canyon Walls and Monolith Vegetation Communities	➢ No historic or current data adequate or detailed enough to assess the current extent or composition of these habitats. ➢ Safety is a concern when conducting vegetation studies on these habitats; discovery of a more accurate and safe method of studying hanging gardens in the future would aid resource managers in documenting the community composition and extent of this habitat.
Montane Shrubland	➢ Further vegetation studies that provide information on the percent ground cover of cryptobiotic crusts and soils, percent bare ground, invasive species composition, and soil stability within this vegetation community are needed. ➢ Research on the impact of social trails within all habitat types
Herptiles	➢ Additional studies and monitoring of herptiles is needed to better understand this resource. This assessment was only able to identify one study of this resource, which was conducted in 2002.
Birds	➢ Continuation of the RMBO's annual landbird monitoring in the park will provide resource managers with a valuable long-term data set that will accurately depict trends in abundance, density, and richness in the P-J habitat of COLM, however the design of this study is done to make inference to the entire NCPN set of parks, so if park specific trend information is desired, more monitoring would need to be added. ➢ Expansion of the survey methodology to include a variety of vegetation communities and habitat types would provide a more complete picture of the avifauna of the park as a whole. ➢ Addition of bird surveys during the winter would provide resource managers with a better understanding of the trends and status of year-round bird species in the park.
Raptors	➢ Annual studies specifically for raptors are needed in order to assess this component. Bird studies have taken place in the park and have documented raptor presence. However, these studies have not focused on raptors specifically, and monitoring methodology (and timing) may have certain biases that make detecting raptors more difficult. The only raptor specific studies were peregrine falcon nest monitoring conducted in 1994 and 1995 (Lambeth 1996). ➢ A monitoring program dedicated to the park's raptor population, and that samples during the breeding season, would allow for a more complete assessment of condition for this resource.
Small Mammals	➢ Development and implementation of a routine small mammal survey that could document species richness, abundance, and distribution would provide managers with meaningful information that can be used to assess the condition of small mammals in the future. ➢ Survey to determine if the North American porcupine has been extirpated from COLM.

Table 98 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Mountain Lion	➢ Regular surveys or monitoring of mountain lions in COLM and the surrounding area would allow for more adequate assessment of this resource. ➢ Studies on mountain lion movements in and around COLM would help resource managers better understand the status of the park's mountain lion population and potentially reduce the occurrence of mountain lion/human conflicts.
Bighorn Sheep	➢ Availability of genetic history or birth and death rates. Projects that included blood sampling would be useful in determining the genetic lineage of the herds within COLM. ➢ GPS-collaring and monitoring of sheep within the Black Ridge Unit by the CPW is expected to take place in 2015-2016. This data will provide information on lamb:ewe ratios, mortality causes, and range use.
Kit Fox	➢ Historical data show the distribution of kit fox within the COLM vicinity. It is currently thought to be extirpated from Colorado.
Bats	➢ A bat survey was recently completed for COLM, but was not published in time to be included in this assessment. The results of this survey should give resource managers a better understanding of the current bat populations at COLM ➢ Continued monitoring of the bat population at COLM would give resource managers a better understanding of this resource.
Air Quality	➢ No active air quality monitors within the distance (16 km [10 mi]) necessary to accurately represent conditions in the park. ➢ Periodic or consistent monitoring of atmospheric deposition, ozone, particulate matter, and visibility would help managers better understand the local air quality conditions in and around COLM and how they may affect other park resources.
Dark Night Skies	➢ Continued monitoring by the NPS NSNSD would provide additional data that could be compared to the 2014 results in order to determine the changes and trends in the dark night skies at COLM.
Viewscape	➢ Continued development of spatial data that explain landscape change as it relates to viewscape analysis is recommended. Additional attributes such as height above surface for would improve the results of this line of sight analysis. ➢ Continued on-the-ground photography from observation points.
Soundscape and Acoustic Environment	➢ Regular measurements (annual or biennial) of sound levels and sound recordings. ➢ Additional focus on the frequency and duration of non-contributing sounds or the percent of time they are audible. ➢ Create a soundscape management plan or integrate soundscape into other planning documents.
Paleontological Resources	➢ Continued research of the paleontological resources at COLM is recommended. ➢ A systematic park-wide inventory of paleontological resources would provide a baseline for future studies, but would also undoubtedly lead to new discoveries. ➢ Development and implementation of an ongoing monitoring program.

Table 98 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Geologic Features and Processes	➢ Studies of erosion rates in the park are needed. ➢ An inventory of areas with high potential for slope failure is recommended. This, coupled with consistent record-keeping of slope failure, would allow an accurate determination of the frequency of their occurrence. ➢ Additional research on how the surface conditions affect the ability to absorb or mitigate run-off from extreme precipitation events ➢ Continuation of ongoing collection of weather event data. ➢ Additional studies (or modeling) of flash flooding and its effects within COLM.

The majority of the park's vegetation communities would benefit from research on habitat elements such as the invasive species occurrences, percent cover of cryptobiotic crusts and soils and other measures related to percent ground cover, for specific vegetation communities. Other outstanding data needs involve continuing monitoring programs to accumulate enough data for identifying any trends over time (e.g., air quality, dark night skies, and paleontological resources). Other components, such as birds, would benefit from sampling efforts specifically focused on the spatial extent of the park.

5.2 Component Condition Designations

Table 99 displays the conditions assigned to each resource component presented in Chapter 4 (definitions of condition graphics are located in Table 100 following Table 99). It is important to remember that the graphics represented are simple symbols for the overall condition and trend assigned to each component. Because the assigned condition of a component (as represented by the symbols in Table 99) is based on a number of factors and an assessment of multiple literature and data sources, it is strongly recommended that the reader refer back to each specific component assessment in Chapter 4 for a detailed explanation and justification of the assigned condition. Condition designations for some components are supported by existing datasets and monitoring information and/or the expertise of NPS staff, while other components lack historic data, a clear understanding of reference conditions (i.e., what is considered desirable or natural), or even current information. Condition could not be determined for 10 of the 21 selected components: sagebrush shrublands/shrub steppe, mixed salt desert scrub/semi-desert grasslands, canyon walls and monolith vegetation communities, montane shrubland, herptiles, raptors, small mammals, mountain lion, bats, and geologic features and processes.

For featured components with available data and/or fewer information gaps, assigned conditions varied. Only two components were considered to be in good condition (riparian habitats/large dry washes and bighorn sheep). Five components (pinyon-juniper woodlands/savannas, seep and springs and tinaja habitats, birds, soundscape, and paleontological resources) were of moderate concern. Four components were of high concern: kit fox, dark night skies, air quality, and viewscape. The high concern for kit fox was due to it being extirpated from the region, and for the other three components, the concern was primarily due to the urban land uses surrounding the park and are largely beyond NPS control.

Table 99. Summary of current condition and condition trend for featured NRCA components.

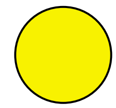
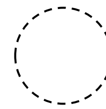
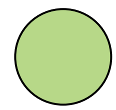
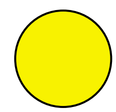
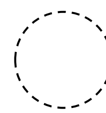
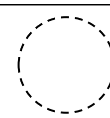
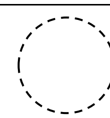
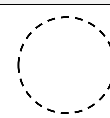
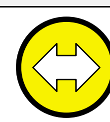
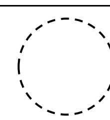
Component	WCS	Condition
Biotic Composition		
Ecological Communities		
Pinyon-juniper Woodlands/Savannas	0.56	
Sagebrush Shrublands/Shrub Steppe	N/A	
Riparian Habitats/Large Dry Washes	0.33	
Seeps and Springs and Tinaja Habitats	0.58	
Mixed Salt Desert Scrub/Semi-desert Grassland	N/A	
Canyon Walls and Monolith Vegetation Communities	N/A	
Montane Shrubland	N/A	
Herptiles		
Herptiles	N/A	
Birds		
Birds	0.50	
Raptors	N/A	

Table 99 (continued). Summary of current condition and condition trend for featured NRCA components.

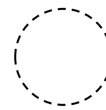
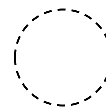
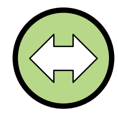
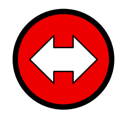
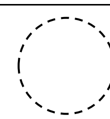
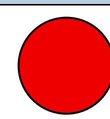
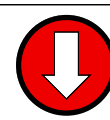
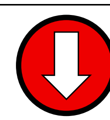
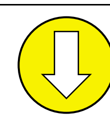
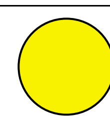
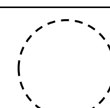
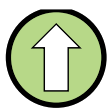
Component	WCS	Condition
Biotic Composition		
Mammals		
Small Mammals	N/A	
Mountain Lion	N/A	
Bighorn Sheep	0.20	
Kit Fox	0.83	
Bats	N/A	
Environmental Quality		
Air Quality	0.67	
Dark Night Skies	0.67	
Viewscape	0.67	
Soundscape and Acoustic Environment	0.50	
Paleontological Resources	0.59	
Geologic Features and Processes	N/A	

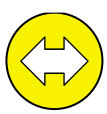
Table 100. Description of symbology used for individual component assessments.

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

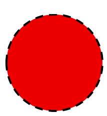
Examples of how the symbols should be interpreted:



Resource is in good condition, its condition is improving, high confidence in the assessment.



Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.



Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.

Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

5.3 Park-wide Condition Observations

Vegetation Communities

COLM is located in a region that exhibits several ecoregionally distinct communities, three of which are found within COLM (old growth pinyon-juniper woodlands, hanging gardens, and tinajas). Other vegetation communities typical to semi-desert upland climates, such as sagebrush and mixed salt desert grasslands are also present within the park. Additionally, riparian communities have established in areas where seeps, springs, and intermittent flows during rain events provide the soil moisture necessary for these habitats. Given a lack of data for several key measures, a condition assessment could not be completed for the majority of the vegetation communities. Data were available to assess the condition of the pinyon-juniper woodlands, riparian habitats/large dry washes, and the seeps and springs and tinaja habitats. Of these three, the riparian habitats were considered to be in good condition, while the other two were determined to be of moderate concern. A trend could not be determined for any of these three communities.

Other Biotics
Other biotic components included in the NRCA were herptiles, birds, raptors, small mammals, mountain lion, bighorn sheep, kit fox, and bats. Given the lack of data for the measures, a condition assessment could only be completed for bighorn sheep, birds, and kit fox. Bighorn sheep were considered to be in good condition with a stable trend. Birds were considered to be of moderate concern with a stable trend. Kit fox was determined to be of significant concern due to its likely extirpation from the region.

Environmental Quality
Environmental quality is important in maintaining healthy functioning ecosystems. The health of terrestrial and aquatic organisms in parks can be affected substantially by the condition of air quality. Air quality was determined to be of significant concern for COLM, although the *Weighted Condition Score* is near the threshold for moderate concern. Monitoring data from inside park boundaries was not available for most of the air quality parameters, so data from representative regional monitoring sites was used to interpret the air quality conditions at COLM. Air quality data collected at COLM would need to be collected to confirm that the interpolated and estimated data used in this NRCA accurately reflect conditions in the park. The park's dark night skies and viewscape are also of high concern. Similar to air quality, the *Weighted Condition Score*s for these two resources were also just above the upper threshold for assigning moderate concern. The soundscape and acoustic environment was determined to be of moderate concern. All four of these components are being negatively impacted due to the urban growth and oil and gas development around the park.

A trend was not assigned to the air quality component, due to the lack of consistent data from within or near the park itself. Since urbanization is most likely to continue in areas surrounding the park, a negative trend was assigned to the dark night skies, viewscape, and soundscape and acoustic environment components.

Physical Characteristics
COLM is widely known for the geologic features that define its landscape. The park also hosts a diverse paleontological record contained within rocks that date back to as early as the Precambrian. Due to data gaps for the majority of the measures identified to assess the geologic features, a condition assessment could not be made. The paleontological resources were determined to be of moderate concern. Given the lack of a park-wide baseline inventory, a trend assessment was not determined.

Park-wide Threats and Stressors
Several threats and stressors influence the condition of multiple resources within COLM. These include invasive plant species, climate change, and the impacts associated with visitor use. Exotic plant species are a threat to all of the park's vegetation communities, as they can out-compete native

plants and alter ecological processes such as fire regime and nutrient cycling (Scott and Wilcove 1998, Perkins 2014).

Other programmatic issues are contributing to degradation of multiple habitats within the park. The invasive species removal/control program has resulted in a significant reduction in the number and areal extent of IEP infestations within the park. Currently, there is no guaranteed funding to continue this program beyond the 2015 field season. Loss of this program, for even one field season, has the potential to erase all the gains that have been made in eradicating IEP's from the park (Hartwig, written communication, 30 January 2016). Another programmatic issue facing the park is the lack of a trail management plan. This has resulted in the proliferation of social trails through the park, including through sensitive areas such as seeps and springs habitat and BSC habitat.

Climate Change Vulnerability Assessment

The objectives of the climate change pilot were threefold: 1) assess the vulnerability of key resources; 2) to provide an understanding of why these resources are vulnerable, including providing insights on the interactions of climate changes with existing threats and stressors to resources; and 3) to serve as a pilot project for integrating climate change vulnerability assessments (in particular a landscape scale community-based assessment) into the existing NRCA process and report template.

Using a framework for vulnerability assessment initially developed by Galbraith (2011) and modified by Amberg et al. (2012), the climate change assessment methodology employed is a multi-scale analysis that focuses on the vulnerability of select ecological communities in COLM (defined by vegetation types). A focus on the overall vulnerability of ecological communities in the park provides an umbrella under which vulnerability may be examined and inferred for key species inhabiting those communities; the degree of vulnerability for a plant community would presumably directly influence the sensitivity and vulnerability of individual animal species residing in that community. For instance, if a specific plant community is expected to change very little despite projected climate shifts (i.e., low vulnerability), it is probable that many of the animal species that rely on the community would also be less vulnerable to many of the potential stresses of climate change. Likewise, if a plant community is expected to experience dramatic changes in composition or distribution, it is highly probable that species dependent upon that community for habitat would also be greatly affected.

This assessment presents a summary of projected climate changes for the COLM region and analysis of the vulnerability of select park natural resources to these changes. As the methodology employed in this pilot was to be a landscape scale community-based assessment, two vegetation communities from the COLM NRCA framework were selected for inclusion in this pilot study. By selecting communities from this framework, the climate change integration pilot study would be a park-centric approach and it could build on the established NRCA process. Several considerations were taken into account during the discussions on selecting the components for inclusion in the pilot study. A specific set of selection criteria was not established, however COLM resource managers were asked to consider their long-term management as part of the selection process. With guidance from SMUMN GSS and the NPS climate change integration team, COLM resource managers selected pinyon-juniper woodlands/savanna, an iconic and important park plant community, and seeps, springs, and tinaja habitats, which depend upon unique physical resources, as the two communities to include in the pilot study. Each assessment considers the exposure of the resource to projected climate changes, the degree of sensitivity to such changes, and the ability to cope with and adapt to these changes.

Historical conditions

Analysis of historical (1895-2010) PRISM data indicates a warming trend for both maximum and minimum average annual temperatures in the COLM region. Maximum average annual temperatures have increased 0.8 °C (1.4 °F) and minimum average annual temperature increased 0.7 °C (1.3 °F) over the past century. Annual precipitation exhibited a -2.4% per century decline, though it was determined to not be statistically significant.

Projected future conditions

Average annual temperatures in the COLM region are projected to increase by 1.6 °C (2.9 °F) by 2030 and by 5.7 °C (10.2 °F) by the end of the century under RCP 8.5 (NCCSC 2015). By 2100, it is estimated that average summer and fall temperatures will increase more than average winter and spring temperatures (Garfin et al. 2014). In general, precipitation is projected to increase by the end of the century, but there is considerable variation in projections and confidence in precipitation projections is much lower than for temperature projections (Garfin et al. 2014). Overall, even with an increase in precipitation, the projected climate by 2050–2100 at COLM is estimated to become much drier, as higher temperatures will drive increased evapotranspiration rates. The projected increase in evapotranspiration is estimated to exceed (substantially) the projected increase in precipitation, which would result in significantly reduced soil moisture. General predictions for the region for 2050–2100 also suggest an increase in extreme temperature (number of excessively hot days) and weather events (increase in strong convective storms).

Vegetation community assessment

Two of the seven ecological communities identified in the NRCA framework were assessed for vulnerability to climate change (pinyon-juniper woodlands/savannas and the seeps and springs and tinaja habitats). Vulnerability was determined by examining six variables: current location of the plant community in its known geographical range, sensitivity to extreme climatic events, dependence on specific hydrologic conditions, intrinsic adaptive capacity, vulnerability of ecologically influential species in the community, and potential for climate change to exacerbate the influence of non-climate stressors. The plant communities range in vulnerability to climate change from least vulnerable to highly vulnerable. Table 101 summarizes the vulnerability of the plant communities examined and the confidence in these vulnerability scores based on current available science.

Table 101. Summary of plant community vulnerability to projected climate change (2050–2100) at COLM.

Community	Climate Change Vulnerability*	Confidence⁺	Alternative Vulnerability Scores
Pinyon-juniper woodland/savannas	Moderate (17)	Moderate (15)	16-19
Seeps, springs, and tinaja habitats	High (24)	High (18)	22-26

*6-13= least vulnerable, 14-19 = moderately vulnerable, 20-25 = highly vulnerable, 26-30 = critically vulnerable

⁺6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence.

Seeps, springs, and tinaja habitats at COLM were determined to be highly vulnerable to climate change. The projected warmer, drier climate conditions and increased variability in precipitation for the region will likely impact the amount of available surface and ground water that supply these habitats. This in turn will have a detrimental impact on the vegetation communities that rely on the moist soil conditions these areas provide. More research is needed to understand the dynamics of these features with regard to available water to better determine overall vulnerability to climate change. The pinyon-juniper woodlands were determined to be moderately vulnerable to climate change. These woodlands are tolerant to the warmer, more arid climate currently being projected by the climate models. Both pinyon pine and Utah juniper have large ecological amplitudes, and are suited to the warmer, more arid conditions projected by the climate models.

Uncertainty in assessing vulnerability. Uncertainty is inherent at every stage of this type of assessment. The future scenarios for climate do not cover the entire range of plausible future conditions and, thus, do not capture the full range of potential resource vulnerability. Uncertainty is also present in the analysis of vulnerability conducted by SMUMN GSS, resulting from a lack of definitive literature and scientific knowledge that characterizes the relationship of many natural resources to climate shifts and/or non-climate stressors and how these resources will respond to climate change. While it is possible to reduce some uncertainties by building better models or by gathering additional data, many are unavoidable and irreducible, and managers must make decisions in the face of uncertainty.

Overall Conclusions

COLM is an extremely diverse park, supporting a range of unique features, sheer-walled canyons, towering monoliths, and colorful formations (NPS 2015). It is also home to a representative example of an intact high desert ecosystem (NPS 2015). This assessment serves as a review and summary of available data and literature for featured natural resources in the park. The information presented here may serve as a baseline against which any changes in condition of components in the future may be compared. Current condition could not be determined for many components due to data gaps. For resources where condition could be assessed, the majority were in moderate condition or of significant concern. Where they could be determined, trends were relatively stable, with dark night skies, viewscape, and soundscape and acoustic environments showing a declining trend.

Understanding the condition of these resources can help managers prioritize management objectives and better focus conservation strategies to maintain the health and integrity of these ecosystems. The changing climate will have impacts on all of these resources to some degree. Traditionally, conservation strategies have been developed before climate change became a major consideration for natural resource managers. However, recent science has increased our awareness of the ecological consequences of climate change, and managers now are tasked with adapting and refining conservation approaches that work to best protect natural resources from the influences of changing climate. Essential to the adaptation effort is identifying and, when possible, quantifying the comparative vulnerabilities of important ecological resources, such as through a vulnerability assessment. This provides natural resource managers with greater understanding of which climate influences or resources require the most immediate attention.

This report incorporates a community-based process for a qualitative assessment of climate change vulnerability for select natural resources in COLM. These resources are characterized using the projected regional downscaled climate changes and the best estimates of resource vulnerabilities based on available literature and professional judgment. The project team believes the statistical downscaling approach to developing regional climate change projections is both appropriate and applicable for vulnerability assessment and the results of the assessment provides resource managers with a credible way of estimating resource vulnerabilities in COLM.

The results of the climate change assessment show that the ecological resources in COLM can exhibit a wide range of climate change vulnerabilities and, consequently, it is likely that managers can expect to see substantial changes in the distribution of many of these resources in the next several decades. This type of assessment is a very important first step in understanding how park resources may change with ongoing and future climate change. It will also provide managers a starting point from which to begin identifying the resources that may not cope well with climate change and those that may be resilient to projected changes.

5.4 Literature Cited

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Appendices

Appendix A. Overview of climate change vulnerability assessments

Climate change has been linked in large part to the long-term and accelerating release of carbon into the atmosphere. The Special Report on Emissions Scenarios (SRES) A1B and A2 family of carbon emissions scenarios are often used to estimate potential future changes in climate; these scenarios are commonly referred to as 'moderate' and 'high' carbon emissions scenarios (Nakicenovic et al. 2000). The difference between these two scenarios can be summarized by differences in the projected emissions of CO_2, the atmospheric component that is primarily responsible for global warming (IPCC 2007). These A1B and A2 emission scenarios have very similar rates of atmospheric CO_2 increases until about 2050, when the A2 (high) scenario diverges with higher projected emissions of greenhouse gases than the A1B (moderate) scenarios. Since these emissions scenarios were published (Nakicenovic et al. 2000), the rate of increase in atmospheric CO_2 has equaled or exceeded the highest projected emissions scenarios examined by the IPCC (Rahmstorf et al. 2007).

Moss et al. (2010) identified the need for new scenarios for the research community. This was due to several factors; the current generation of climate models need more detailed information than what was provided by previous emission scenarios, an increase in interest for scenarios that incorporate the impacts of different climate policies in addition to the no-climate-policy scenarios explored previously (e.g., SRES), and increasing interest in exploring the role of adaptation (van Vuuren 2011). Rather than incorporating this into their process, the IPPC asked the research community to develop a new set of scenarios (IPCC 2007, van Vuuren 2011). This development process was guided by a set of design criteria (Moss et al. 2008, 2010). In order to evaluate how climate might change in the future, the IPCC requested the research community develop a set of scenarios based on the following criteria: provide the current generation of climate models with more detailed information than what was provided by previous emission scenarios, address an increased interest for scenarios that incorporate the impacts of different climate policies in addition to the no-climate-policy scenarios explored in earlier scenarios, and increase interest in exploring the role of adaptation (Moss et al. 2008, 2010, van Vuuren 2011). The research community developed a new set of scenarios, each referred to as a RCP. The term "representative" signifies that each of the RCPs is representative of a larger set of scenarios already defined in the literature (van Vuuren 2011).

As a whole, the RCP's are meant to be compatible with the full range of emissions scenarios available in the current scientific literature both with and without climate policy (van Vuuren 2011). The term "concentration pathway" emphasizes that these RCP's are not final new, fully integrated scenarios, but rather an internally consistent set of projections of the components of radiative forcing (the change in energy in the atmosphere due to GHG emissions) that are to be used in subsequent phases of new or updated scenarios (van Vuuren 2011). The use of "concentration" instead of "emissions" also emphasizes that concentrations are used as the primary product of the RCP's, and they are designed as input to climate models (van Vuuren 2011). Coupled carbon-cycle climate models can then calculate associated emission levels (van Vuuren 2011). A set of four pathways were produced that lead to radiative forcing levels of 8.5, 6, 4.5 and 2.6 W/m^2, by 2100 (van Vuuren

2011). Each of the RCPs covers the 1850–2100 period, and extensions have also been formulated for modeling climate change up to the year 2300 (van Vuuren 2011). Since they were developed with the current emission levels in mind, they can be related to the emission scenarios produced by the IPCC. They represent different possible futures determined in complex ways by demographic development, socio-economic development, and technological change (Nakicenovic et al. 2000, van Vuuren 2011). For the purposes of this report, the main differences in the RCP's can be summarized by differences in greenhouse gas emissions (Figure 88).

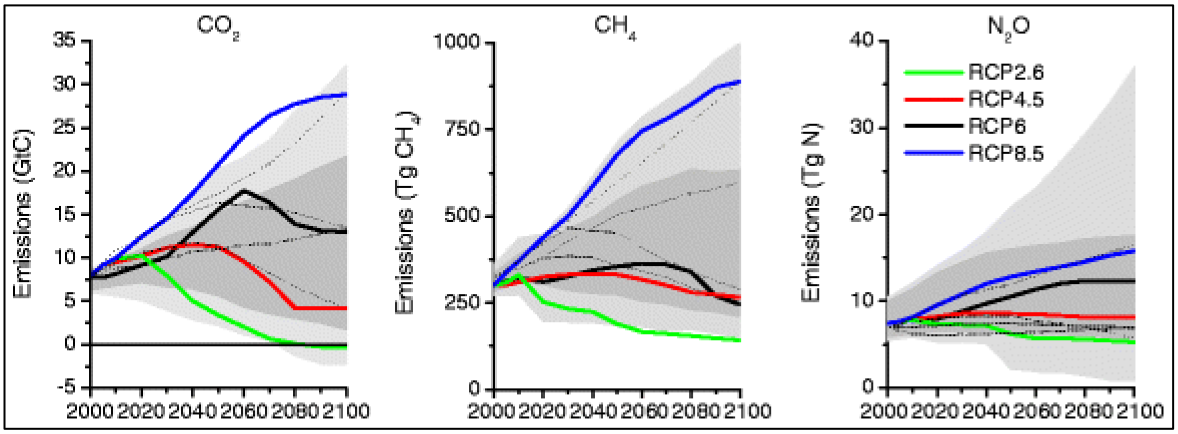

Figure 88. Emission levels of main greenhouse gases by RCPs. The grey areas indicate the 98th and 90th percentiles (light/dark grey) of the literature. The dotted lines indicate four of the SRES marker scenarios (from van Vuuren 2011).

Climate change can impair the natural and cultural resources that the NPS was established to preserve. Jonathon Jarvis, director of the NPS, has referred to climate change as the greatest challenge to maintaining "America's natural and cultural heritage unimpaired for future generations" (Jarvis 2009, p. 2). The NPS recognizes the importance of understanding the impacts and influences of climate change on national park resources and developing adaptation strategies to best conserve species and ecosystems in light of rapidly shifting climate. A recent initiative in the NPS CCRP focuses on building a greater understanding of the effects and influences that projected climate shifts may have on natural and cultural resources across the National Park System. This initiative encourages the use of CCVAs as part of a strategy to determine and better understand natural and cultural resource vulnerability to climate change and the synergistic relationships these changes may have with existing threats and stressors to those resources.

A CCVA is an assessment of the likelihood and extent to which projected climatic shifts (including such variables as precipitation and temperature) will have adverse or beneficial influences on a given natural or cultural resource (e.g., species, plant community, or ecosystem; sacred sites, archeological artifacts) (IPCC 2007, Stein and Glick 2011). As a result, CCVAs are increasingly viewed as a key tool for providing resource managers with information that can be used to aid adaptation planning efforts for vulnerable natural and cultural resources. Specifically, a CCVA makes three main contributions to resource management. First, a vulnerability assessment helps identify ***which*** resources are most or least vulnerable to estimated climate changes, a determination that better enables managers to prioritize resources for enhanced conservation (Stein and Glick 2011). Second, a CCVA can uncover ***why*** resources are vulnerable or resilient (Stein and Glick 2011). The assessment process helps to determine the characteristics of a resource that make it more vulnerable to or better able to cope with climatic shifts and the associated environmental changes; this information can better equip resource managers with the understanding necessary to develop the most appropriate and practical management responses to climatic shifts in their region. Finally, a CCVA can help elucidate gaps in knowledge that exist for certain cultural and natural resources in general, so that these gaps can be filled and the vulnerability of these resources more accurately assessed.

Assessing the vulnerability of natural systems to climate change is a relatively new science and where completed, they have exhibited a wide range of project approaches, primarily in regard to the scale at which analysis occurs. Some projects have focused on the vulnerability of certain ecologically influential species in a natural system, particularly those listed as threatened or endangered (Galbraith and Price 2011). Others have focused on the vulnerability of specifically defined ecosystems within a region (e.g., vulnerability of Massachusetts fish and wildlife habitats [Galbraith and O'Leary 2011]; species vulnerability assessment for the Middle Rio Grande, New Mexico [Finch et al. 2011]) and, based on the vulnerability of the ecosystem as a whole, make inferences about the subsequent effect on the species that primarily use those ecosystems.

The NPS is considering several strategies to integrate climate change resource vulnerability into the park NRCAs. In March 2014, NPS partnered with CSU and SMUMN GSS to implement a pilot project to assess the feasibility of slightly modifying existing NRCA project scopes to accommodate an assessment of resource vulnerability to climate change. The pilot project's goal is to seek creative approaches to considering climate change vulnerabilities in the context of the park's NRCA project.

As part of this effort, SMUMN GSS employed a landscape scale community-based assessment for select resource components of the COLM NRCA. The type of assessment focuses on ecological communities. This type of evaluation casts a broader net in the examination of resources, rather than looking at a list of individual species. By focusing on the community scale it is possible to infer that the degree of vulnerability for a community would directly influence the sensitivity and vulnerability of key species residing in that community. For example, if a community has low vulnerability to climate change and is expected to change very little despite projected climate shifts, it is likely that the diversity of key species residing in that community would also not experience much change or stress due to climate change. Likewise, if a community is estimated to be highly vulnerable to climate change and is expected to experience dramatic changes in composition or distribution, it is likely that the key species dependent upon that community for habitat would also be affected. Thus, a focus on the vulnerability of ecological communities within a landscape (i.e., the ecosystem or community scale) can provide a larger umbrella under which vulnerability may be examined and inferred for species inhabiting those communities. These are also typically priority resources that park managers express concern over when looking at ongoing park threats and long-term park resource sustainability.

SMUMN GSS worked collaboratively with COLM resource staff and the NPS climate change integration pilot team to incorporate climate change analysis into the NRCA. After evaluating the ecological communities represented in the COLM NRCA framework (Chapter 3, Figure 13), the pinyon-juniper woodlands/savannas and seep, spring and tinaja habitats were selected to be evaluated in terms of their vulnerability to climate change. For the purpose of this analysis, vulnerability is defined as “the extent to which a species, habitat, or ecosystem is susceptible to harm from climate change impacts” (Schneider et al. 2007, as cited by Stein and Glick 2011, p. 9). Vulnerability consists of three key components: 1) *sensitivity* of a system to climate changes; 2) *exposure* of a system to climate changes; and 3) *adaptive capacity* to respond to those changes (IPCC 2007, as cited by Stein et al. 2011). Sensitivity is a measure of the degree to which a system is affected, either adversely or beneficially, by a given change in climate. Exposure is a measure of the amount of climatic and environmental change that a species or system is likely to experience. Adaptive capacity is the ability of a species or system to accommodate or cope with climatic and environmental change impacts with minimal disruption. Figure 89 illustrates the theoretical relationship among the three components and how they interact to determine overall vulnerability.

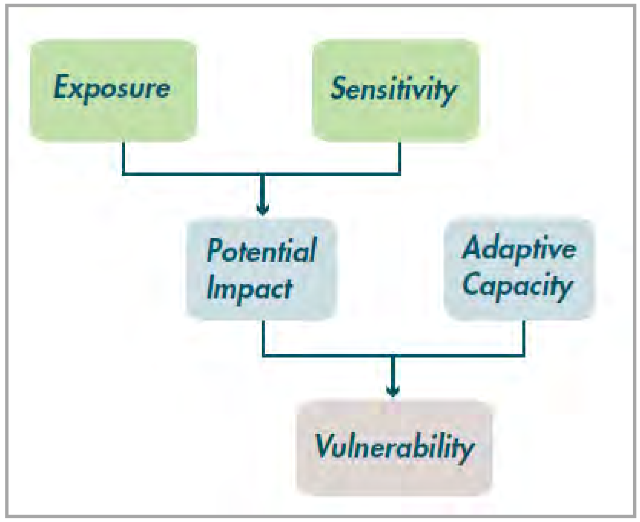

Figure 89. Key components of vulnerability, illustrating the relationship between exposure, sensitivity, and adaptive capacity (Source: Stein et al. 2011).

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Appendix B. Pinyon-juniper woodland/savanna community composition by association/alliances and growth habitat based on vegetation mapping project classification descriptions (Von Loh et al. 2007).

Key to coded columns- A: Two-needle pinyon-(one-seed juniper, Utah juniper) / needle-and-thread woodland, B: Two-needle pinyon-Utah juniper/Utah serviceberry woodland, C: Two-needle pinyon-Utah juniper/Bigelow’s sagebrush woodland, D: Two-needle pinyon-Utah juniper/black sagebrush woodland, E: Two-needle pinyon-Utah juniper/littleleaf mountain-mahogany woodland, F: Two-needle pinyon-Utah juniper/mixed shrubs talus woodland, G: Two-needle pinyon-Utah juniper/grassy rock-goldenrod woodland, H: Two-needle pinyon-Utah juniper/sparse understory woodland, I: Two-needle pinyon-Utah juniper/Wyoming big sagebrush woodlands, J: Two-needle pinyon-juniper species/mountain-mahogany-mixed shrub woodland, K: Two-needle pinyon-juniper species/saline wildrye grass woodland, and L: Blue spruce-two-needle pinyon-Utah juniper/Gambel’s oak woodland.

Species Type	Scientific Name	Common Name	A	B	C	D	E	F	G	H	I	J	K	L
Tree Species	*Fraxinus anomala*	singleleaf ash		X	X	X	X	X		X		X		
	Juniperus osteosperma	Utah juniper	X	X	X	X	X	X	X	X	X	X	X	X
	Picea pungens	blue spruce												X
	Pinus edulis	two-needle pinyon pine	X	X	X	X	X	X	X	X	X	X	X	X
	Pinus ponderosa	ponderosa pine										X		
	Quercus gambelii	Gambel’s oak										X		X
Shub Species	*Amelanchier utahensis*	Utah serviceberry		X		X		X		X		X		X
	Artemisia bigelovii	Bigelow's sagebrush			X		X	X			X	X		
	Artemisia nova	black sagebrush				X						X	X	
	Artemisia tridentata ssp. *tridentata*	basin big sagebrush								X		X		
	Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush			X	X				X	X	X		
	Atriplex canescens	fourwing saltbush			X						X			
	Atriplex confertifolia	shadscale										X	X	
	Berberis repens	Oregon grape										X		
	Brickellia microphylla var. *scabra*	rough brickellbush			X			X				X		
	Cercocarpus ledifolius var. *intricatus*	littleleaf mountain-mahogany			X		X							
	Cercocarpus montanus	true mountain-mahogany		X	X	X		X		X		X		X

*Indicates a non-native species.

Species Type	Scientific Name	Common Name	A	B	C	D	E	F	G	H	I	J	K	L
Shub Species (continued)	*Chrysothamnus depressus*	dwarf rabbitbrush											X	
	Chrysothamnus viscidiflorus ssp. *viscidiflorus*	slenderleaf rabbitbrush		X	X	X		X		X	X	X	X	
	Echinocereus triglochidiatus	claretcup			X	X		X	X	X	X	X		
	Ephedra viridis	Mormom tea	X	X	X	X	X	X	X	X	X	X	X	
	Ericameria nauseosa	rubber rabbitbrush					X			X				
	Ericameria parryi	Parry's rabbitbrush										X		
	Eriogonum corymbosum	crispleaf buckwheat			X			X				X		
	Eriogonum microthecum var. laxiflorum	slender wild buckwheat				X				X	X			
	Fendlera rupicola	fendlerbush		X	X			X						
	Grayia spinosa	spiny hopsage			X	X								
	Holodiscus discolor var. dumosus	oceanspray										X		
	Krascheninnikovia lanata	winterfat									X			
	Opuntia fragilis	brittle pricklypear				X			X	X	X			
	Opuntia phaeacantha	berry pricklypear			X			X		X	X		X	
	Opuntia polyacantha	plains pricklypear			X	X	X	X		X			X	
	Opuntia polyacantha var. erinacea	grizzlybear pricklypear			X	X	X	X	X	X	X		X	
	Opuntia spp.	pricklypear species										X		
	Purshia Mexicana var. *stansburyana*	cliffrose			X							X		
	Rhus aromatica var. *pilosissima*	skunkbush sumac		X			X	X				X		X
	Sclerocactus whipplei	Whipple's fishhook cactus				X	X			X	X	X		
	Yucca harrimaniae	Harriman's yucca		X	X	X	X	X	X	X	X	X		
Graminoid Species	*Achnatherum hymenoides*	Indian ricegrass	X	X	X	X	X	X	X	X	X	X	X	
	*Agropyron cristatum**	crested wheatgrass									X			
	Aristida purpurea	purple three-awn			X		X	X				X		
	Bouteloua gracilis	blue grama						X		X	X			
	*Bromus tectorum**	cheatgrass		X	X	X	X	X	X	X	X	X		
	Elymus elymoides	squirreltail			X	X	X	X	X	X	X	X		

*Indicates a non-native species.

Species Type	Scientific Name	Common Name	A	B	C	D	E	F	G	H	I	J	K	L
Graminoid Species (continued)	*Hesperostipa comata*	needle and thread	X		X	X	X	X			X	X		
	Hilaria jamesii	James' galleta	X		X	X	X	X		X	X	X	X	
	Leymus salina	saline wildrye		X		X		X				X	X	
	Pascopyrum smithii	western wheatgrass								X				
	Poa fendleriana	mutton grass		X	X	X	X	X	X	X	X	X	X	
	Poa secunda	Sandberg's bluegrass								X				
	Pseudoroegneria spicata	bluebunch wheatgrass						X				X		
	Sporobolus cryptandrus	sand dropseed									X			
	Vulpia octoflora	six weeks fescue			X	X	X	X	X	X	X	X	X	
Forb Species	*Aliciella stenothyrsa*	Uinta gilia					X							
	Allium acuminatum	tapertip onion									X			
	Allium textile	textile onion				X							X	
	Arabis pulchra	beautiful rockcress											X	
	Arabis spp.	rockcress				X								
	Arenaria fendleri	Fendler's sandwort			X			X	X	X			X	
	Arenaria spp.	sandwort										X		
	Artemisia ludoviciana	Louisiana wormwood						X						
	Astragalus mollissimus	woolly locoweed									X			
	Calochortus gunnisonii	Gunnison's mariposa										X	X	
	Calochortus nuttallii	sego lily				X								
	Ceratocephala testiculata	curveseed butterwort								X			X	
	Chaenactis douglasii	hoary dusty-maiden					X				X			
	*Chenopodium album**	lambsquarters								X	X			
	Cirsium undulatum var. undulatum	wavy-leaf thistle								X				
	Cryptantha flavoculata	yellow-eye cryptantha				X								
	Cryptantha spp.	cryptantha						X		X	X	X		
	Cymopterus bulbosus	onion springparsley				X							X	
	Cymopterus glomeratus	Fendler's springparsley									X			

*Indicates a non-native species.

Species Type	Scientific Name	Common Name	A	B	C	D	E	F	G	H	I	J	K	L
Forb Species (continued)	*Cymopterus purpureus*	Colorado Plateau springparsley								X				
	Delphinium nuttallianum	Nuttall's larkspur				X								
	Descurainia pinnata ssp. *halictorum*	western tansymustard			X	X	X	X	X	X	X	X	X	
	Draba reptans	dwarf draba			X		X	X		X	X			
	Eremogone hookeri var. *hookeri*	Hooker's sandwort				X								
	Eriogonum alatum	winged buckwheat										X		
	Eriogonum ovalifolium var. ovalifolium	cushion buckwheat		X										
	*Erodium cicutarium**	stork's bill			X		X							
	Erysimum capitatum	western wallflower									X			
	Euphorbia glyptosperma	ridge-seeded spurge						X		X				
	Galium coloradoense	Colorado bedstraw						X				X		
	Gutierrezia sarothrae	broom snakeweed		X	X	X	X	X	X	X	X	X	X	
	Heterotheca villosa	hairy false goldenaster			X	X	X	X		X	X	X		
	Hymenoxys richardsonii	Colorado rubber-plant	X											
	Lappula occidentalis var. occidentalis	western stickseed			X	X				X	X	X	X	
	Lepidium montanum	mountain pepperwort		X	X	X	X	X	X	X	X	X	X	
	Linanthus pungens	prickly phlox				X		X					X	
	Mirabilis multiflora	Colorado four o'clock	X											
	Oenothera pallida ssp. *trichocalyx*	pale evening primrose								X	X		X	
	Penstemon caespitosus	mat penstemon				X						X		
	Petradoria pumila	grassy rockgoldenrod			X	X	X		X	X		X	X	
	Phlox austromontana	desert phlox											X	
	Phlox longifolia	longleaf phlox				X				X	X	X		
	Physaria acutifolia	sharpleaf twinpod		X	X	X		X		X				
	Selaginella densa	dense spikemoss			X			X						

*Indicates a non-native species.

Species Type	Scientific Name	Common Name	A	B	C	D	E	F	G	H	I	J	K	L
Forb Species (continued)	*Senecio integerrimus*	western groundsel				X	X			X	X	X		
	Silene antirrhina	sleepy catchfly			X	X	X	X	X	X	X	X	X	
	Sphaeralcea coccinea ssp. *coccinea*	scarlet globemallow								X	X		X	
	Stanleya pinnata	desert princesplume										X		
	Stenotus armerioides	thrift goldenweed								X				
	Streptanthella longirostris	longbeak fiddle mustard		X		X	X	X	X	X	X	X	X	
	Streptanthus cordatus	heartleaf jewelflower			X			X	X	X				
	Tetraneuris acaulis	Arizona hymenoxys			X	X			X			X		
	Tetraneuris ivesiana	Canyonlands hymenoxys							X					
	Townsendia incana	hoary townsendia									X			
	Valeriana edulis	tobacco root					X	X	X					

*Indicates a non-native species.

Appendix C. Pinyon-juniper woodland community climate vulnerability scoring worksheet

1. Location in geographical range/distributi of community	Close to (<200 kms) southern limit of community distribution	5		High	3		Pinyon pine is at northern end
	More distant from southern limit of community distribution	1		Medium	2		of geograhic range, while Utah
				Low	1		juniper is more centrally
		Score	**4**	**Score**	**2**	**3**	located
2. Sensitivity to extreme climatic events (e.g., drought, floods, windstorms, icestorm	Highly vulnerable to extreme climatic events	5		High	3		Both are somewhat sensitive
	Less vulnerable to extreme climatic events	3		Medium	2		to drought, however the pinyon
	Not vulnerable to extreme climatic events	1		Low	1		pine has higher sensitivity
		Score	**3**	**Score**	**3**		
5. Dependence on specific hydrologic cond	community is dependent on specific hydrologic conditions	5		High	3		Niether is dependent on a
	community is less dependent on specific hydrologic conditio	1		Medium	2		hydrologic regime
				Low	1		
		Score	**1**	**Score**	**3**		
4. Intrinsic adaptive capacity	Unlikely to be significant (low adaptive capacity)	5		High	3		Previously pinyon-juniper has
	Likely to be significant (high adaptive capacity)	1		Medium	2		been successful expaning into
				Low	1		other areas in the Southwest
		Score	**3**	**Score**	**3**		under similar warmer arid condition
6. Vulnerability of Foundation/Keystone spe to climate change	Foundation/keystone spp. likely to be particularly vulnerable	5		High	3		The pinyon pine is more
	Foundation/keystone spp. unlikely to be vulnerable to climate	1		Medium	2		vulnerable to the changing
				Low	1		climate conditions than the
		Score	**3**	**Score**	**2**	**4**	Utah juniper. Juniper could become dominant
7. Potential for climate change to exacerbate of non-climate stressors	Potential for large increase in stressor impacts	5		High	3		Potential change in invasive
	Potential low	1		Medium	2		composition, increased wildfire
				Low	1		regime. Insect and disease outbreaks
		Score	**3**	**Score**	**2**	**4**	
		Totals	17		15	16-19	

	Total score	Vulnerability category	Confidence scores	
Range of 7-35	7 to 16	Less Vulnerable	7 to 11	Low
	17 to 23	Vulnerable	12 to 16	Moderate
	24 to 30	Highly Vulnerable	17 to 21	High
	31 to 35	Critically Vulnerable		

Appendix D. Sagebrush shrubland/shrub steppe community composition and growth habitat based on Hogan et al. (2009) comprehensive list of plant species.

Species Type	Scientific Name	Common name	Nativity	Park status
Tree Species	*Celtis reticulata*	netleaf hackberry	Native	Present
	Elaeagnus angustifolia	Russian olive	Non-native	Present
	Ulmus pumila	Siberian elm	Non-native	Present
Shrub Species	*Amelanchier utahensis*	Utah serviceberry	Native	Present
	Artemisia bigelovii	Bigelow's sagebrush	Native	Present
	Artemisia frigida	fringed sagebrush	Native	Present
	Artemisia nova	black sagebrush	Native	Present
	Artemisia tridentata ssp. *tridentata*	basin big sagebrush	Native	Present
	Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush	Native	Probably present
	Atriplex canescens	fourwing saltbush	Native	Present
	Atriplex confertifolia	shadscale	Native	Present
	Atriplex corrugata	mat saltbush	Native	Present
	Atriplex gardneri	Garnder's saltbush	Native	Probably present
	Berberis fremontii	Fremont's berberis	Native	Present
	Brickellia californica	California brickellbush	Native	Present
	Brickellia microphylla var. *scabra*	rough brickellbush	Native	Present
	Brickellia oblongifolia	Mohave brickellbush	Native	Present
	Cercocarpus montanus	alderleaf mountain-mahogany	Native	Present
	Chrysothamnus depressus	dwarf rabbitbrush	Native	Present
	Chrysothamnus vaseyi	Vasey's rabbitbrush	Native	Probably present
	Chrysothamnus viscidiflorus	yellow rabbitbrush	Native	Present
	Ephedra torreyana	Torrey's Mormon tea	Native	Present
	Ephedra viridis	Mormons tea	Native	Present
	Ericameria nauseosa	rubber rabbitbrush	Native	Present
	Eriogonum corymbosum var. orbiculatum	rimrock wild buckwheat	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Shrub Species (continued)	*Eriogonum lonchophyllum*	longleaf wild buckwheat	Native	Present
	Eriogonum microthecum var. *simpsonii*	Simpson's buckwheat	Native	Present
	Glossopetalon spinescens	spiny greasebush	Native	Present
	Grayia brandegeei	Brandegee's siltbush	Native	Present
	Grayia spinosa	spiny hopsage	Native	Present
	Gutierrezia sarothrae	broom snakeweed	Native	Present
	Holodiscus discolor var. dumosus	oceanspray	Native	Present
	Krascheninnikovia lanata	winterfat	Native	Present
	Linanthus pungens	prickly phlox	Native	Present
	Picrothamnus desertorum	bud sagebrush	Native	Probably present
	Rhus aromatica var. *pilosissima*	skunkbush sumac	Native	Present
	Ribes leptanthum	trumpet gooseberry	Native	Present
	Sarcobatus vermiculatus	black greasewood	Native	Present
	Symphoricarpos longiflorus	longleaf snowberry	Native	Probably present
	Symphoricarpos rotundifolius	mountain snowberry	Native	Present
	Tetradymia canescens	spineless horsebrush	Native	Present
	Tetradymia spinosa	shortspine horsebrush	Native	Present
	Yucca harrimaniae	Harriman's yucca	Native	Present
Perennial Forb Species	*Abronia elliptica*	fragrant sand-verbena	Native	Present
	Ageratina herbacea	white thoroughwort	Native	Present
	Aliciella stenothyrsa	Uinta gilia	Native	Probably present
	Allionia incarnata	trailing four o'clock	Native	Present
	Allium acuminatum	tapertip onion	Native	Present
	Allium textile	textile onion	Native	Present
	Ambrosia psilostachya	western ragweed	Native	Present
	Androstephium breviflorum	pink funnel-lily	Native	Present
	Artemisia biennis	biennial wormwood	Non-native	Present
	Artemisia ludoviciana ssp. *albula*	white sagebrush	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Perennial Forb Species (continued)	*Asclepias asperula* ssp. *asperula*	spider milkweed	Native	Present
	Asclepias cryptoceras	pallid milkweed	Native	Present
	Asclepias subverticillata	whorled milkweed	Native	Present
	Aster spp.	hybrid aster	Native	Present
	Astragalus amphioxys var. *vespertinus*	Sheldon's milkvetch	Native	Present
	Astragalus chamaeleuce	cicada milkvetch	Native	Present
	Astragalus convallarius	lesser rushy milkvetch	Native	Present
	Astragalus eastwoodiae	Eastwood's milkvetch	Native	Present
	Astragalus flavus	yellow milkvetch	Native	Present
	Astragalus lentiginosus var. *palans*	straggling milkvetch	Native	Present
	Astragalus mollissimus var. *thompsoniae*	woolly milkvetch	Native	Present
	Astragalus multiflorus	pulse milkvetch	Native	Present
	Astragalus wingatanus	Fort Wingate milkvetch	Native	Present
	Boechera formosa	desert rockcress	Native	Present
	Calochortus gunnisonii	Gunnison's mariposa lily	Native	Probably present
	Calochortus nuttallii	sego-lily	Native	Present
	Castilleja angustifolia	northwestern paintbrush	Native	Present
	Castilleja linariifolia	Wyoming paintbrush	Native	Present
	Castilleja scabrida	Eastwood's paintbrush	Native	Present
	Chaetopappa ericoides	rose-heath	Native	Present
	Cichorium intybus	chicory	Non-native	Present
	Cirsium neomexicanum	New Mexico thistle	Native	Present
	Cirsium tracyi	Tracy's thistle	Native	Present
	Comandra umbellata	bastard toadflax	Native	Present
	Convolvulus arvensis	field bindweed	Non-native	Present
	Cryptantha flava	plateau yellow cryptanth	Native	Present
	Cryptantha flavoculata	yellow-eye crypantha	Native	Present
	Cryptantha humilis	dwarf cryptanth	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Perennial Forb Species (continued)	*Cymopterus bulbosus*	bulbous spring parsley	Native	Present
	Cymopterus purpureus	Colorado Plateau springparsley	Native	Present
	Delphinium nuttallianum	Nuttall's larkspur	Native	Present
	Dieteria canescens	hoary-aster	Native	Present
	Dracocephalum parviflorum	smallflower dragonhead	Native	Probably present
	Echinocereus triglochidiatus	claretcup	Native	Present
	Eremogone hookeri var. *hookeri*	Hooker's sandwort	Native	Probably present
	Eremogone kingii	basin sandwort	Native	Present
	Erigeron aphanactis	hairy aster	Native	Present
	Erigeron divergens	spreading daisy	Native	Present
	Erigeron engelmannii	Engelmann's daisy	Native	Present
	Erigeron flagellaris	trailing daisy	Native	Present
	Eriogonum alatum	winged buckwheat	Native	Present
	Eriogonum inflatum	desert trumpet	Native	Present
	Eriogonum ovalifolium var. *ovalifolium*	cushion buckwheat	Native	Present
	Eriogonum umbellatum	sulfur wild buckwheat	Native	Probably present
	Erysimum capitatum	western wallflower	Native	Present
	Euphorbia brachycera	shorthorn spurge	Native	Present
	Euphorbia fendleri	Fendler's spurge	Native	Present
	Gaillardia pinnatifida	red dome blanketflower	Native	Present
	Gilia ophthalmoides	eyed gilia	Native	Present
	Grindelia hirsutula	hairy gumweed	Native	Present
	Grindelia squarrosa	curlycup gumweed	Native	Present
	Hedysarum boreale	northern sweetvetch	Native	Present
	Heterotheca villosa	hairy false goldenaster	Native	Present
	Hymenopappus filifolius	common hyalineherb s	Native	Present
	Hymenoxys richardsonii	Colorado rubber-plant	Native	Probably present
	Ipomopsis aggregata ssp. aggregata	scarlet gilia	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Perennial Forb Species Continued)	*Ipomopsis roseata*	San Rafael gilia	Native	Present
	Lepidium draba	whitetop	Non-native	Unconfirmed
	Lepidium montanum	mountain pepperweed	Native	Present
	Linanthus watsonii	Watson's prickly-phlox	Native	Present
	Linaria vulgaris	butter -and-eggs	Non-native	Present
	Linum lewisii	blue flax	Native	Present
	Lithospermum incisum	showy stoneseed	Native	Present
	Lomatium eastwoodiae	Eastwood's tall pepperwort	Native	Present
	Lomatium grayi	Milfoil lomatium	Native	Probably present
	Lupinus argenteus	silvery lupine	Native	Present
	Lygodesmia grandiflora	showy rush-pink	Native	Present
	Maianthemum stellatum	starry false Solomon's-seal	Native	Present
	Medicago sativa	alfalfa	Non-native	Present
	Melilotus officinalis	yellow sweetclover	Non-native	Present
	Mirabilis linearis	narrow-leaf four-o'clock	Native	Present
	Mirabilis multiflora	Colorado four o'clock	Native	Present
	Oenothera cespitosa ssp. *marginata*	long-tube evening-primrose	Native	Present
	Oenothera lavandulifolia	lavender-leaf sundrops	Native	Present
	Oenothera pallida ssp. *trichocalyx*	pale evening primrose	Native	Present
	Opuntia fragilis	brittle pricklypear	Native	Present
	Opuntia phaeacantha	berry pricklypear	Native	Present
	Opuntia polyacantha	plains pricklypear	Native	Present
	Opuntia polyacantha var. *erinacea*	grizzlybear pricklypear	Native	Probably present
	Orobanche fasciculata	clustered broomrape	Native	Present
	Orobanche ludoviciana	Cooper's broomrape	Native	Present
	Packera multilobata	basin groundsel	Native	Present
	Pediocactus simpsonii	Simpson's hedgehog cactus	Native	Present
	Pediomelum aromaticum	aromatic breadroot	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Perennial Forb Species (continued)	*Pediomelum megalanthum*	large-flowered breadroot	Native	Present
	Penstemon caespitosus	mat penstemon	Native	Present
	Penstemon comarrhenus	dusty penstemon	Native	Present
	Penstemon cyanocaulis	bluestem penstemon	Native	Present
	Penstemon moffatii	Moffatt penstemon	Native	Present
	Petradoria pumila	grassy rockgoldenrod	Native	Present
	Phlox austromontana	desert phlox	Native	Probably present
	Phlox hoodii	Hood's phlox	Native	Present
	Phlox longifolia	longleaf phlox	Native	Present
	Physalis virginiana	Virginia ground-cherry	Native	Present
	Physaria acutifolia	sharpleaf twinpod	Native	Present
	Physaria ludoviciana	silver bladderpod	Native	Present
	Physaria rectipes	Colorado Plateau bladderpod	Native	Probably present
	Plantago lanceolata	English plantain	Non-native	Present
	Plantago major	common plantain	Non-native	Present
	Platyschkuhria integrifolia	oblongleaf basindaisy	Native	Present
	Psilostrophe bakeri	Baker's paperflower	Native	Present
	Rhinotropis subspinosa	cushion milkwort	Native	Present
	Rumex hymenosepalus	canaigre dock	Native	Present
	Rumex triangulivalvis	willow dock	Native	Present
	Sclerocactus whipplei	Whipple's fishhook cactus	Native	Present
	Sedum lanceolatum	lance-leaved stonecrop	Native	Present
	Senecio integerrimus	western groundsel	Native	Probably present
	Sisymbrium linifolium	flax-leaved plainsmustard	Native	Present
	Solidago velutina	three-nerve goldenrod	Native	Present
	Sphaeralcea coccinea ssp. *coccinea*	scarlet globemallow	Native	Present
	Sphaeralcea parvifolia	small-leaf globemallow	Native	Present
	Stanleya pinnata	desert princesplume	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Perennial Forb Species (continued)	*Stenotus acaulis*	stemless goldenweed	Native	Probably present
	Stenotus armerioides	thrift goldenweed	Native	Present
	Stephanomeria pauciflora	brownplume wirelettuce	Native	Probably present
	Streptanthus cordatus	heartleaf jewelflower	Native	Present
	Symphyotrichum ascendens	Pacific aster	Native	Present
	Taraxacum officinale	common dandelion	Non-native	Present
	Tetraneuris acaulis	Arizona hymenoxys	Native	Probably present
	Tetraneuris ivesiana	Canyonlands hymenoxys	Native	Present
	Thelypodiopsis elegans	Westwater tumblemustard	Native	Present
	Thelypodium integrifolium	elegant thelypody	Native	Present
	Townsendia incana	hoary townsendia	Native	Present
	Toxicoscordion paniculatum	foothills death camas	Native	Present
	Toxicoscordion venenosum	meadow deathcamas	Native	Present
	Tragopogon dubius	yellow salsify	Non-native	Present
	Valeriana edulis	tobacco root	Native	Probably present
	Verbascum thapsus	woolly mullein	Non-native	Present
	Verbena bracteata	prostrate vervain	Native	Present
	Vicia americana	American vetch	Native	Probably present
	Xanthisma grindelioides	gumweed aster	Native	Present
Annual Forb Species	*Alyssum simplex*	alyssum	Non-native	Probably present
	Amaranthus albus	tumble pigweed	Non-native	Present
	Ambrosia acanthicarpa	bur ragweed	Native	Present
	Androsace occidentalis	western rock-jasmine	Native	Present
	Androsace septentrionalis	pygmy-flower rock-jasmine	Native	Present
	Astragalus nuttallianus	smallflower milkvetch	Native	Present
	Atriplex rosea	tumbling orache	Non-native	Present
	Camelina microcarpa	little-pod false flax	Non-native	Probably present
	Chaenactis stevioides	Stevia dusty-maiden	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Annual Forb Species (continued)	*Chenopodium album**	lambsquarters	Non-native	Probably present
	Chenopodium fremontii	Fremont's goosefoot	Native	Present
	Chenopodium leptophyllum	narrow-leaf goosefoot	Native	Present
	Chorispora tenella	blue mustard	Non-native	Present
	Cryptantha fendleri	sand dune cryptanth	Native	Probably present
	Cryptantha gracilis	slender cryptanth	Native	Present
	Cryptantha pterocarya	wing-nut cryptanth	Native	Present
	Cuscuta indecora	large-seed dodder	Native	Present
	Descurainia pinnata ssp. *halictorum*	western tansymustard	Native	Present
	Descurainia sophia	flixweed	Non-native	Present
	Draba reptans	dwarf draba	Native	Probably present
	Eriogonum cernuum	nodding wild buckwheat	Native	Present
	Eriogonum hookeri	Hooker's wild buckwheat	Native	Present
	Erodium cicutarium	stork’s bill	Non-native	Probably present
	Euphorbia glyptosperma	ridge-seeded spurge	Native	Present
	Gilia sinuata	shy gilia	Native	Present
	Helianthus annuus	common sunflower	Native	Present
	Kochia scoparia	summer-cypress	Non-native	Present
	Lactuca serriola	prickly lettuce	Non-native	Present
	Lappula marginata	cupseed stickseed	Native	Present
	Lappula occidentalis var. *occidentalis*	western stickseed	Native	Present
	Lepidium densiflorum	prairie pepperwort	Native	Present
	Lepidium lasiocarpum	hairy-pod pepperwort	Native	Present
	Lepidium perfoliatum	clasping pepperwort	Non-native	Present
	Medicago lupulina	black medick	Non-native	Present
	Melilotus albus	white sweetclover	Non-native	Present
	Mentzelia albicaulis	white-stem blazingstar	Native	Present
	Mimulus rubellus	reddish monkeyflower	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Annual Forb Species (continued)	*Peritoma lutea*	yellow beeplant	Native	Present
	Peritoma serrulata	Rocky Mountain beeplant	Native	Present
	Phacelia crenulata	crenulate phacelia	Native	Present
	Phacelia ivesiana	Ives' phacelia	Native	Present
	Plantago patagonica	woolly plantain	Native	Present
	Polanisia dodecandra	clammy-weed	Native	Present
	Portulaca oleracea	common purslane	Non-native	Present
	Ranunculus testiculatus	sagebrush buttercup	Non-native	Present
	Salsola australis	Russian thistle	Non-native	Present
	Silene antirrhina	sleepy catchfly	Native	Present
	Sisymbrium altissimum	tumble mustard	Non-native	Present
	Solanum rostratum	buffalobur	Native	Present
	Stephanomeria exigua	white-plume wire-lettuce	Native	Present
	Strigosella africana	African mustard	Non-native	Present
	Tribulus terrestris	puncture vine	Non-native	Present
Perennial Graminoid Species	*Achnatherum aridum*	Mormon needlegrass	Native	Present
	Achnatherum hymenoides	Indian ricegrass	Native	Present
	Agropyron desertorum	desert wheatgrass	Non-native	Present
	Aristida purpurea	purple three-awn	Native	Present
	Bouteloua curtipendula	sideoats grama	Native	Present
	Bouteloua gracilis	blue grama	Native	Probably present
	Bromus inermis	smooth brome	Non-native	Present
	Dactylis glomerata	orchard grass	Non-native	Present
	Elymus elymoides	squirreltail	Native	Probably present
	Elymus elymoides ssp. *elymoides**	bottlebrush squirreltail	Native	Probably present
	Elymus repens	quackgrass	Non-native	Present
	Elymus trachycaulus	slender wheatgrass	Native	Present
	Erioneuron pilosum	hairy tridens	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Perennial Graminoid Species (continued)	*Hesperostipa comata*	needle and thread	Native	Present
	Hesperostipa neomexicana	New Mexico feathergrass	Native	Present
	Hilaria jamesii	James'galleta	Native	Present
	Hordeum jubatum	foxtail barley	Native	Present
	Koeleria macrantha	junegrass	Native	Present
	Leymus salina	saline wildrye	Native	Present
	Muhlenbergia richardsonis	mat muhly	Native	Probably present
	Muhlenbergia thurberi	Thurber's muhly	Native	Present
	Panicum virgatum	switchgrass	Native	Present
	Pascopyrum smithii	western wheatgrass	Native	Present
	Poa bulbosa	bulbous bluegrass	Non-native	Present
	Poa fendleriana	muttongrass	Native	Present
	Poa pratensis	Kentucky bluegrass	Non-native	Present
	Poa pratensis ssp. *angustifolia**	Agassiz's bluegrass	Non-native	Present
	Poa secunda	Sandberg's bluegrass	Native	Present
	Pseudoroegneria spicata	bluebunch wheatgrass	Native	Probably present
	Puccinellia nuttalliana	Nuttall's alkaligrass	Native	Present
	Sporobolus airoides	alkali sacaton	Native	Present
	Sporobolus contractus	spike dropseed	Native	Present
	Sporobolus cryptandrus	sand dropseed	Native	Present
	Sporobolus flexuosus	mesa dropseed	Native	Present
	Thinopyrum intermedium ssp. *intermedium*	intermediate wheatgrass	Non-native	Present
Annual Graminoid Species	*Bromus diandrus*	ripgut brome	Non-native	Present
	Bromus japonicus	Japanese brome	Non-native	Probably present
	Bromus tectorum	cheatgrass	Non-native	Present
	Cenchrus longispinus	field sandbur	Native	Present
	Echinochloa crus-galli	barnyard grass	Non-native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Species Type	Scientific Name	Common name	Nativity	Park status
Annual Graminoid Species (continued)	*Eragrostis barrelieri*	Mediterranean lovegrass	Non-native	Present
	Hordeum pusillum	little barley	Native	Present
	Muhlenbergia depauperata	sixweeks muhly	Native	Present
	Muhlenbergia minutissima	annual muhly	Native	Present
	Munroa squarrosa	false buffalograss	Native	Present
	Panicum capillare	witchgrass	Native	Present
	Setaria viridis	green bristlegrass	Non-native	Present
	Triticum aestivum	wheat	Non-native	Probably present
	Vulpia octoflora	six weeks fescue	Native	Present
Fern Species	*Cheilanthes feei*	slender lip fern	Native	Present

*Nativity and park status are assumed to be the same as the species level for these subspecies.

Appendix E. Riparian habitat/large dry wash community dominant species composition by growth habitat based on vegetation mapping project classification descriptions (Von Loh et al. 2007).

Key to coded columns- A: Cottonwood/coyote willow woodland, B: Coyote willow/mesic graminoids shrubland, C: Quaking aspen/water birch forest, D: Rubber rabbitbrush desert wash shrubland, E: Baltic rush herbaceous vegetation, F: Box elder/disturbed understory woodland, G: Quaking aspen western chokecherry forest, H: Singleleaf ash woodland, I: Skunkbush intermittently flooded shrubland, J: Smooth horsetail herbaceous vegetation, and K: Water birch/starry false Solomon's-seal shrubland.

Species Type	Scientific Name	Common Name	A	B	C	D	E	F	G	H	I	J	K
Tree Species	*Acer glabrum*	Rocky Mountain maple						X					
	Acer negundo	boxelder						X					
	Betula occidentalis	water birch			X								X
	Celtis reticulata	netleaf hackberry	X										
	Fraxinus anomala	singleleaf ash	X							X			
	Juniperus osteosperma	Utah juniper	X							X		X	X
	Populus angustifolia	narrow-leaved cottonwood	X										
	Populus deltoides ssp. wislizeni	Rio Grande cottonwood	X		X		X					X	
	Populus tremuloides	quaking aspen			X								X
	Quercus gambelii	Gambel's oak		X									
Shrub Species	*Amelanchier utahensis*	Utah serviceberry								X	X		
	Artemisia bigelovii	Bigelow's sagebrush								X			
	Artemisia tridentata ssp. *tridentata*	basin big sagebrush	X										
	Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush									X		
	*Elaeagnus angustifolia**	Russian olive	X										
	Ericameria nauseosa	rubber rabbitbrush	X	X		X		X					
	Prunus virginiana	western chokecherry		X									
	Rhus aromatica	skunkbush	X								X		
	Rosa woodsii	Woods' rose		X									X
	Salix exigua	coyote willow	X	X	X								

*Indicates a non-native species.

Species Type	Scientific Name	Common Name	A	B	C	D	E	F	G	H	I	J	K
Shrub Species (continued)	*Salix fragilis**	crack willow	X										X
	Salix lucida	whiplash willow	X										
	Salix monticola	mountain willow	X										X
	Sarcobatus vermiculatus	black greasewood					X						
	*Tamarix ramosissima**	saltcedar	X										
Graminoid Species	*Achnatherum hymenoides*	Indian ricegrass								X			
	*Agrostis gigantea**	redtop	X				X					X	
	*Bromus japonicus**	Japanese chess	X	X			X			X			
	*Bromus tectorum**	cheatgrass	X	X		X	X	X		X			
	*Dactylis glomerata**	orchard grass	X										
	Distichlis spicata	desert saltgrass	X	X		X						X	
	Hesperostipa comata	needle and thread								X			
	Hordeum jubatum	foxtail barley					X						
	Juncus balticus	Baltic rush	X	X			X					X	X
	Muhlenbergia asperifolia	scratchgrass					X						
	Pascopyrum smithii	western wheatgrass					X						
	Phragmites australis	common reed	X	X									
	*Poa pratensis**	Kentucky bluegrass	X	X	X		X						
	Sporobolus airoides	alkali sacaton	X										
Forb Species	*Artemisia ludoviciana* ssp. *albula*	white sagebrush								X			
	Cirsium undulatum var. *undulatum*	wavy-leaf thistle	X										
	Clematis ligusticifolia	white virgin's bower	X	X									X
	Equisetum arvense	field horsetail	X										
	Equisetum laevigatum	smooth horsetail	X	X								X	X
	Glycyrrhiza lepidota	Nuttall's licorace	X										
	Heterotheca villosa	hairy false goldenaster	X										
	Iva axillaris	povertyweed					X						
	Maianthemum stellatum	starry false Solomon's-seal	X										X

*Indicates a non-native species.

Species Type	Scientific Name	Common Name	A	B	C	D	E	F	G	H	I	J	K
Forb Species (continued)	*Melilotus officinalis**	yellow sweetclover	X	X									
	Ranunculus cymbalaria	marsh buttercup											X
	Typha latifolia	broad-leaved cattail	X										

*Indicates a non-native species.

Appendix F. Seeps and springs community composition at No Thoroughfare and Lower Echo Canyon springs inventoried by Springer et al. (2006).

Scientific name	Common Name	NTC	LEC
-	algae	X	
-	moss	X	
*Agrostis stolonifera**	creeping bentgrass		X
Aquilegia desertorum	Chiricahua Mountain columbine		X
Artemisia spp.	sagebrush	X	X
Asclepias speciosa	showy milkweed		X
*Asparagus officinalis**	garden asparagus		X
Astragalus spp.	milkvetch		X
Betula occidentalis	water birch	X	
Brickellia microphylla	littleleaf brickellbush		X
*Bromus tectorum**	cheatgrass	X	
Carex spp.	sedge	X	
Castilleja linariifolia	Wyoming paintbrush		X
Cirsium neomexicanum	New Mexico thistle		X
Cirsium undulatum var. *undulatum*	wavy-leaf thistle	X	
Clematis ligusticifolia	white virgin's bower	X	X
*Dactylis glomerata**	orchardgrass	X	
Eleocharis spp.	spikerush		X
Elymus canadensis	Canada wildrye		X
Epilobium ciliatum	fringed willowherb	X	
Epilobium spp.	willowherb	X	
Epipactis gigantea	giant helleborine		X
Equisetum laevigatum	smooth horsetail		X
Equisetum variegatum	northern scouring-rush	X	
Ericameria spp.	rabbitbrush		X
Euthamia occidentalis	western goldenrod	X	
Fendlerella utahensis	Utah fendlerella	X	
Grindelia fastigiata	erect gumweed		X
Heterotheca villosa	hairy false goldenaster		X
Hordeum spp.	barley	X	
Ipomopsis aggregata	scarlet gilia	X	
Juncus arcticus	Arctic rush	X	X
*Lactuca serriola**	prickly lettuce	X	
Lactuca spp.	lettuce		X
Maianthemum stellatum	starry false Solomon's-seal	X	
*Medicago sativa**	alfalfa		X

*Indicates a non-native species.

Scientific name	Common Name	NTC	LEC
*Melilotus officinalis**	yellow sweetclover		X
Muhlenbergia andina	foxtail muhly		X
Muhlenbergia asperifolia	scratchgrass		X
Oenothera spp.	evening primrose		X
Perityle congesta	Grand Canyon rockdaisy		X
*Plantago lanceolata**	English plantain		X
Populus angustifolia	narrow-leaved cottonwood		X
Populus fremontii	Fremont cottonwood		X
Pseudotsuga menziesii	Douglas-fir		X
Rhus aromatica var. *pilosissima*	skunkbush sumac		X
Salix bebbiana	Bebb's willow		X
Salix eriocephala	Missouri River willow		X
Salix exigua	coyote willow	X	X
Salix laevigata	red willow		X
Salix spp.	willow	X	
Schoenoplectus pungens	three-square bulrush		X
*Sisymbrium altissimum**	tumblemustard	X	
Stephanomeria spp.	wirelettuce		X
Symphyotrichum lanceolatum	Siskiyou aster		X
*Taraxacum officinale**	common dandelion	X	X
Toxicodendron rydbergii	western poison ivy		X
*Tragopogon dubius**	yellow salsify		X
Typha domingensis	southern cattail		X
	Totals†	**21**	**41**

*Indicates a non-native species.

†Totals do not include the first five table rows, since these organisms are described broadly rather than to species or genus.

Appendix G. Seeps and springs community composition by canyon, as documented by Lamm et al. (2014).

Unidentified species (e.g., “unknown highly serrated plant”) were excluded. Numbers in parentheses indicate the number of sites visited in each canyon.

		Site**						
Scientific Name	**Common Name**	**EC (1)**	**UC (5)**	**MC (13)**	**NTC (10)**	**WC (2)**	**RC (1)**	**CC (2)**
-	Algae (green, blue)	X	X	X	X			X
-	Biological Soil Crust			X				
-	Black algae			X				
-	Moss			X	X	X		X
-	Red algae				X			
Acer glabrum	Rocky Mountain maple							X
Achnatherum hymenoides	Indian ricegrass		X	X	X	X		
*Agropyron desertorum**	desert wheatgrass		X					
*Agrostis gigantea**	redtop			X	X			
*Alyssum simplex**	allysum		X	X				
Amelanchier utahensis	Utah serviceberry	X	X	X	X	X		X
Apocynum cannabinum	common dogbane			X				
Arctium minus	burdock				X			
Artemisia ludoviciana ssp. *incompta*	Columbia River wormwood	X						
Artemisia tridentata	big sagebrush	X	X	X	X	X		X
Asclepias speciosa	showy milkweed			X				X
Astragalus desperatus	rimrock milkvetch		X					
Astragalus lentiginosus var. *palans*	straggling milkvetch			X				
Betula occidentalis	water birch		X		X			

*Indicates a non-native species.

** EC = Echo Canyon, UC = Ute Canyon, MC = Monument Canyon, NTC = No Thoroughfare Canyon, WC = Wedding Canyon, RC = Red Canyon, CC = Columbus Canyon.

Scientific Name	Common Name	Site**						
		EC (1)	UC (5)	MC (13)	NTC (10)	WC (2)	RC (1)	CC (2)
Brickellia microphylla var. *scabra*	rough brickellbush	X			X			
*Bromus inermis**	smooth brome				X			
*Bromus tectorum**	cheatgrass	X	X	X	X	X		X
Carex microptera	small-wing sedge				X			
Castilleja angustifolia var. *dubia*	desert paintbrush			X				
Castilleja linariifolia	Wyoming paintbrush				X			
Castilleja minor ssp. *minor*	annual paintbrush				X			
Cirsium spp.	thistle	X	X	X	X	X		X
*Cirsium vulgare**	bull thistle				X			
Clematis ligusticifolia	white virgin's bower	X	X	X	X		X	X
Comandra umbellata	bastard toadflax		X					
*Conium maculatum**	poison-hemlock				X			
Conyza canadensis	Canadian horseweed			X	X			
*Dactylis glomerata**	orchard grass		X	X	X			
Descurainia pinnata ssp. *halictorum*	western tansymustard		X		X			
Distichilis spicata	desert saltgrass	X	X	X	X	X	X	X
Elymus trachycaulus	slender wheatgrass	X	X	X	X	X		X
Epipactis gigantea	giant helleborine	X						
Equisetum laevigatum	smooth horsetail	X	X	X	X	X		
Ericameria nauseosa	rubber rabbitbrush	X	X	X	X			X
Erigeron divergens	spreading daisy		X					
Erigeron utahensis	Utah daisy			X		X		
Fendlera rupicola	fendlerbush				X			

*Indicates a non-native species.

** EC = Echo Canyon, UC = Ute Canyon, MC = Monument Canyon, NTC = No Thoroughfare Canyon, WC = Wedding Canyon, RC = Red Canyon, CC = Columbus Canyon.

Scientific Name	Common Name	Site**						
		EC (1)	UC (5)	MC (13)	NTC (10)	WC (2)	RC (1)	CC (2)
Fraxinus anomala	singleleaf ash	X	X	X	X	X		X
Grindelia squarrosa	curlycup gumweed			X				
Gutierrezia sarothrae	broom snakeweed			X				X
Hesperostipa comata	needle and thread			X				
Heterotheca villosa	hairy false goldenaster	X	X	X	X	X		X
Hilaria jamesii	James' galleta		X		X			
Hordeum jubatum	foxtail barley			X	X	X		X
Hymenopappus filifolius	common hyalineherb				X			
Ipomopsis aggregata ssp. *aggregata*	scarlet gilia		X					
Ipomopsis roseata	San Rafael gilia			X				
Juncus arcticus	Arctic rush		X	X	X	X		X
Juniperus osteosperma	Utah juniper		X	X		X		X
Koeleria macrantha	junegrass				X			
*Lactuca serriola**	prickly lettuce			X	X			X
Lepidium montanum	mountain pepperweed	X	X	X		X		
Leymus salina	saline wildrye							X
Lomatium eastwoodiae	Eastwood's tall pepperwort	X	X	X	X			X
Maianthemum stellatum	starry false Solomon's-seal		X		X			
*Melilotus officinalis**	yellow sweetclover	X	X	X	X			X
Oenothera pallida ssp. *trichocalyx*	pale evening primrose							
Opuntia spp.	pricklypear		X					
Packera multilobata	basin groundsel		X		X			
Panicum capillare	witchgrass			X				

*Indicates a non-native species.

** EC = Echo Canyon, UC = Ute Canyon, MC = Monument Canyon, NTC = No Thoroughfare Canyon, WC = Wedding Canyon, RC = Red Canyon, CC = Columbus Canyon.

Scientific Name	Common Name	Site** EC (1)	UC (5)	MC (13)	NTC (10)	WC (2)	RC (1)	CC (2)
Penstemon cyanocaulis	bluestem penstemon				X			
Phalaris arundinacea	reed canary grass		X					
Phragmites australis	common reed							X
Physaria acutifolia	sharpleaf twinpod							X
Pinus edulis	two-needle pinyon pine		X	X	X	X		X
*Plantago lanceolata**	English plantain		X					
*Poa pratensis**	Kentucky bluegrass		X	X	X			
Populus angustifolia	narrow-leaved cottonwood	X	X	X	X		X	
Populus fremontii	Fremont cottonwood	X	X	X	X	X	X	X
Quercus gambelii	Gambel's oak		X		X			
Rhus aromatica var. *pilosissima*	skunkbush sumac	X		X	X			X
Rosa woodsii	Woods' rose		X		X			
Salix spp.	willow	X	X	X	X	X	X	X
Sarcobatus vermiculatus	black greasewood			X				
Silene antirrhina	sleepy catchfly			X				
*Sisymbrium altissimum**	tumble mustard			X				
Solidago velutina	three-nerve goldenrod			X				
Sporobolus cryptandrus	sand dropseed			X				
Stephanomeria tenuifolia	slender wirelettuce	X						X
*Tamarix ramosissima**	saltcedar	X		X	X			
*Taraxacum officinale**	common dandelion				X			
Tetraneuris ivesiana	Canyonlands hymenoxys		X					
Thelypodiopsis elegans	elegant thelypody							X

*Indicates a non-native species.

** EC = Echo Canyon, UC = Ute Canyon, MC = Monument Canyon, NTC = No Thoroughfare Canyon, WC = Wedding Canyon, RC = Red Canyon, CC = Columbus Canyon.

Scientific Name	Common Name	Site EC (1)	UC (5)	MC (13)	NTC (10)	WC (2)	RC (1)	CC (2)
*Tragopogon dubius**	yellow salsify		X	X	X	X		
Typha latifolia	broad-leaved cattail		X	X	X			
*Verbascum thapsus**	woolly mullein				X			
Veronica anagallis-aquatica	water speedwell				X			
Vicia americana	American vetch	X		X				
Yucca harrimaniae	Harriman's yucca			X				
Zannichellia palustris	horned pondweed						X	
	Totals†	**24**	**42**	**49**	**51**	**19**	**6**	**28**

*Indicates a non-native species.

** EC = Echo Canyon, UC = Ute Canyon, MC = Monument Canyon, NTC = No Thoroughfare Canyon, WC = Wedding Canyon, RC = Red Canyon, CC = Columbus Canyon.

†Totals do not include the first five table rows, since these organisms are described broadly rather than to species or genus.

Appendix H. Seep, spring, tinaja habitats climate vulnerability scoring worksheet.

		Vulnerability Score		Confidence Score		Alternative Score	Notes:
1. Location in geographical range/distribution	Close to (<200 kms) southern limit of community distribution	5		High	3		COLM is located at the northern
of community	More distant from southern limit of community distribution	1		Medium	2		and eastern margin of geographic
				Low	1		range of Mancos columbine and
		Score	**4**	**Score**	**3**	**3**	Rio Grande cottonwood
2. Sensitivity to extreme climatic events	Highly vulnerable to extreme climatic events	5		High	3		Increased frequency and intensity
(e.g., drought, floods, windstorms, icestorms)	Less vulnerable to extreme climatic events	3		Medium	2		of extreme weather events can be
	Not vulnerable to extreme climatic events	1		Low	1		detrimental to seep, spring, and
		Score	**4**	**Score**	**3**		tijana habitas. Extremely drought sensitive
5. Dependence on specific hydrologic conditions	community is dependent on specific hydrologic conditions	5		High	3		Rely on availability of precipitation,
	community is less dependent on specific hydrologic conditions	1		Medium	2		both rain and snow for recharge
				Low	1		Reduced winter snowpack and
		Score	**4**	**Score**	**3**		seasonal rains
4. Intrinsic adaptive capacity	Unlikely to be significant (low adaptive capacity)	5		High	3		Require a degree of soil moisture
	Likely to be significant (high adaptive capacity)	1		Medium	2		in order to survive. Very little
				Low	1		adaptability to a hotter, drier
		Score	**4**	**Score**	**3**	**5**	climate for Mancos columbine
6. Vulnerability of Foundation/Keystone species	Foundation/keystone spp. likely to be particularly vulnerable to climate cha	5		High	3		Mancos columbine is niche species
to climate change	Foundation/keystone spp. unlikely to be vulnerable to climate change	1		Medium	2		Smooth horsetail, Rio Grande
				Low	1		cottonwood and coyote willow
		Score	**4**	**Score**	**3**	**3**	more tolerant of projected conditions
7. Potential for climate change to exacerbate impac	Potential for large increase in stressor impacts	5		High	3		Potential change in invasive
of non-climate stressors	Potential low	1		Medium	2		composition, increased wildfire
				Low	1		regime. Potential for increased
		Score	**4**	**Score**	**3**	**5**	water demand for urban & ag needs
		Totals	24		18	22-26	

	Total score	Vulnerability category	Confidence scores	
Range of 7-35	7 to 16	Less Vulnerable	7 to 11	Low
	17 to 23	Vulnerable	12 to 16	Moderate
	24 to 30	Highly Vulnerable	17 to 21	High
	31 to 35	Critically Vulnerable		

Appendix I. Montane shrubland and growth habitat based on Hogan et al. (2009) comprehensive list of plant species.

Species Type	Species name	Common name	Nativity	Park status
Tree Species	*Celtis reticulata*	netleaf hackberry	Native	Present
	Juniperus osteosperma	Utah juniper	Native	Present
	Pinus ponderosa	ponderosa pine	Native	Present
	Populus tremuloides	quaking aspen	Native	Present
	Pseudotsuga menziesii	Douglas-fir	Native	Present
	Quercus gambelii	Gambel's oak	Native	Present
Shrub Species	*Acer glabrum*	Rocky Mountain maple	Native	Present
	Amelanchier utahensis	Utah serviceberry	Native	Present
	Arctostaphylos patula	greenleaf manzanita	Native	Present
	Artemisia tridentata ssp. *tridentata*	basin big sagebrush	Native	Present
	Berberis repens	Oregon grape	Native	Present
	Cercocarpus ledifolius	curl-leaf mountain mahogany	Native	Present
	Cercocarpus montanus	true mountain-mahogany	Native	Present
	Chrysothamnus depressus	dwarf rabbitbrush	Native	Present
	Ephedra viridis	Mormon tea	Native	Present
	Ericameria nauseosa	rubber rabbitbrush	Native	Present
	Eriogonum microthecum var. *laxiflorum*	slender wild buckwheat	Native	Present
	Eriogonum microthecum var. *simpsonii*	Simpson's buckwheat	Native	Present
	Fraxinus anomala	singleleaf ash	Native	Present
	Gutierrezia sarothrae	broom snakeweed	Native	Present
	Holodiscus discolor var. *dumosus*	oceanspray	Native	Present
	Juniperus communis	common juniper	Native	Probably present
	Linanthus pungens	prickly phlox	Native	Present
	Paxistima myrsinites	mountain-lover	Native	Present
	Philadelphus microphyllus	littleleaf mock-orange	Native	Present
	Prunus virginiana	western chokecherry	Native	Present
	Purshia mexicana var. *stansburyana*	cliffrose	Native	Present
	Quercus X *undulata*	few-lobe oak	Native	Present

Species Type	Species name	Common name	Nativity	Park status
Shrub Species (continued)	*Ribes inerme*	whitestem gooseberry	Native	Probably present
	Rosa woodsii	Woods' rose	Native	Present
	Symphoricarpos rotundifolius	mountain snowberry	Native	Present
Perennial Forb Species	*Ageratina herbacea*	white thoroughwort	Native	Present
	Allium textile	textile onion	Native	Present
	Antennaria marginata	sandstone pussytoes	Native	Present
	Artemisia dracunculus	tarragon	Native	Present
	Artemisia ludoviciana ssp. *incompta*	Columbia River wormwood	Native	Present
	Astragalus desperatus	rimrock milkvetch	Native	Present
	Astragalus eastwoodiae	Eastwood's milkvetch	Native	Present
	Astragalus flavus	yellow milkvetch	Native	Present
	Astragalus mollissimus var. *thompsoniae*	woolly milkvetch	Native	Present
	Astragalus multiflorus	pulse milkvetch	Native	Present
	Astragalus wingatanus	Fort Wingate milkvetch	Native	Present
	Brickellia grandiflora	tassel-flower brickellbush	Native	Present
	Calochortus gunnisonii	Gunnison's mariposa	Native	Probably present
	Calochortus nuttallii	sego-lily	Native	Present
	Castilleja angustifolia	northwestern paintbrush	Native	Present
	Castilleja linariifolia	Wyoming paintbrush	Native	Present
	Castilleja scabrida	Eastwood's paintbrush	Native	Present
	Chaenactis douglasii	hoary dusty-maiden	Native	Present
	Comandra umbellata	bastard toadflax	Native	Present
	Corallorhiza maculata	spotted coral-root	Native	Present
	Cryptantha flavoculata	yellow-eye crypantha	Native	Present
	Delphinium nuttallianum	Nuttall's larkspur	Native	Present
	Dieteria canescens	hoary aster	Native	Present
	Dracocephalum parviflorum	smallflower dragonhead	Native	Probably present
	Eremogone fendleri	Fendler's sandwort	Native	Probably present
	Erigeron aphanactis	hairy daisy	Native	Present

Species Type	Species name	Common name	Nativity	Park status
Perennial Forb Species (continued)	*Erigeron utahensis*	Utah daisy	Native	Present
	Eriogonum alatum	winged buckwheat	Native	Present
	Eriogonum umbellatum	sulfur wild buckwheat	Native	Probably present
	Euphorbia brachycera	shorthorn spurge	Native	Present
	Galium coloradoense	Colorado bedstraw	Native	Present
	Hedysarum boreale	northern sweetvetch	Native	Present
	Heterotheca villosa	hairy false goldenaster	Native	Present
	Heuchera parvifolia	littleleaf alumroot	Native	Present
	Ipomopsis aggregata ssp. *aggregata*	scarlet gilia	Native	Present
	Ipomopsis roseata	San Rafael gilia	Native	Present
	Lathyrus lanszwertii var. *leucanthus*	whiteflower sweetpea	Native	Present
	Linum lewisii	blue flax	Native	Present
	Lupinus argenteus	silvery lupine	Native	Present
	Maianthemum stellatum	starry false Solomon's-seal	Native	Present
	Mirabilis linearis	narrowleaf four-o'clock	Native	Present
	Mirabilis oxybaphoides	spreading four-o'clock	Native	Present
	Oenothera cespitosa ssp. *marginata*	long-tube evening-primrose	Native	Present
	Oenothera pallida ssp. *trichocalyx*	pale evening primrose	Native	Present
	Opuntia fragilis	brittle pricklypear	Native	Present
	Opuntia phaeacantha	berry pricklypear	Native	Present
	Opuntia polyacantha	plains pricklypear	Native	Present
	Packera multilobata	basin groundsel	Native	Present
	Penstemon comarrhenus	dusty penstemon	Native	Present
	Penstemon cyanocaulis	bluestem beardtongue	Native	Present
	Petradoria pumila	grassy rockgoldenrod	Native	Present
	Phlox austromontana	desert phlox	Native	Probably present
	Phlox hoodii	Hood's phlox	Native	Present
	Phlox longifolia	longleaf phlox	Native	Present
	Physaria ludoviciana	silver bladderpod	Native	Present

Species Type	Species name	Common name	Nativity	Park status
Perennial Forb Species (continued)	*Sedum lanceolatum*	lance-leaved stonecrop	Native	Present
	Senecio integerrimus	western groundsel	Native	Probably present
	Sisymbrium linifolium	flax-leaved plainsmustard	Native	Present
	Solidago velutina	three-nerve goldenrod	Native	Present
	Sphaeralcea coccinea ssp. coccinea	scarlet globemallow	Native	Present
	Sphaeralcea parvifolia	small-leaf globemallow	Native	Present
	Stanleya pinnata	desert princesplume	Native	Present
	Stenotus acaulis	stemless goldenweed	Native	Probably present
	Stephanomeria tenuifolia	slender wirelettuce	Native	Present
	Streptanthus cordatus	heartleaf jewelflower	Native	Present
	Symphyotrichum ascendens	Pacific aster	Native	Present
	Taraxacum officinale	common dandelion	Non-native	Present
	Thelypodium laxiflorum	slate thelypody	Native	Probably present
	Verbascum thapsus	woolly mullein	Non-native	Present
	Vicia americana	American vetch	Native	Probably present
Annual Forb Species	*Alyssum simplex*	alyssum	Non-native	Probably present
	Androsace occidentalis	western rock-jasmine	Native	Present
	Androsace septentrionalis	pygmy-flower rock-jasmine	Native	Present
	Chenopodium foliosum	leafy goosefoot	Native	Present
	Chenopodium fremontii	Fremont's goosefoot	Native	Present
	Cryptantha fendleri	sand dune cryptanth	Native	Probably present
	Cryptantha gracilis	slender cryptanth	Native	Present
	Descurainia pinnata ssp. *halictorum*	western tansymustard	Native	Present
	Gilia sinuata	shy gilia	Native	Present
	Lactuca serriola	prickly lettuce	Non-native	Present
	Lappula marginata	cupseed stickseed	Native	Present
	Lappula occidentalis var. *occidentalis*	western stickseed	Native	Present
	Phacelia ivesiana	Ives' phacelia	Native	Present
	Salsola australis	Russian thistle	Non-native	Present

Species Type	Species name	Common name	Nativity	Park status
Perennial Graminoid Species	*Achnatherum hymenoides*	Indian ricegrass	Native	Present
	Aristida purpurea	purple three-awn	Native	Present
	Carex rossii	Ross' sedge	Native	Present
	Elymus elymoides	squirreltail	Native	Probably present
	Elymus trachycaulus	slender wheatgrass	Native	Present
	Hesperostipa comata	needle and thread	Native	Present
	Koeleria macrantha	junegrass	Native	Present
	Muhlenbergia richardsonis	mat muhly	Native	Probably present
	Panicum virgatum	switchgrass	Native	Present
	Pascopyrum smithii	western wheatgrass	Native	Present
	Piptatherum micranthum	littleseed ricegrass	Native	Present
	Poa fendleriana	muttongrass	Native	Present
	Poa pratensis	Kentucky bluegrass	Non-native	Present
	Poa secunda	Sandberg's bluegrass	Native	Present
	Pseudoroegneria spicata	bluebunch wheatgrass	Native	Probably present
Annual Graminoid Species	*Bromus japonicus*	Japanese chess	Non-native	Probably present
	Panicum capillare	witchgrass	Native	Present
Ferns and Allies Species	*Argyrochosma fendleri*	Fendler's false cloak fern	Native	Present
	Cheilanthes feei	slender lip-fern	Native	Present
	Cystopteris fragilis	brittle bladder fern	Native	Present
	Pellaea atropurpurea	purple cliffbrake	Native	Present

Appendix J. Bird species observed in COLM during monitoring and survey efforts.

Species	NPS (2015)*	CBC*	Giroir (2001)*	RMBO Monitoring*
American Coot		B		
American Crow	R	R		R
American Dipper		R		
American Goldfinch	R	R		R
American Kestrel	R	R	R	R
American Pipit	M	M		
American Robin	R	R		R
American Tree Sparrow	M	M		
American White Pelican		M		
American Wigeon		M		
Anna's Hummingbird		V		
Ash-throated Flycatcher	R		R	R
Bald Eagle	M	M		
Band-tailed Pigeon	B			
Bank Swallow	B			
Barn Owl	R	R		
Barn Swallow	R			
Barrow's Goldeneye		M		
Belted Kingfisher	M	M		
Bewick's Wren	R	R	R	R
Black Phoebe		V		
Black Rosy-Finch	M	M		
Black-and-white Warbler	V			
Black-billed Magpie	R	R	R	
Black-capped Chickadee	R	R	R	
Black-chinned Hummingbird	R		R	R
Black-chinned Sparrow	M			
Black-crowned Night-Heron		B		
Black-headed Grosbeak	R		R	R
Black-throated Blue Warbler		V		
Black-throated Gray Warbler	R		R	R
Black-throated Sparrow	B	B	B	B
Blue Grosbeak	M			M
Blue Grouse	M			
Blue Jay		R		
Blue-gray Gnatcatcher	R	R	R	R
Blue-winged Teal		B		
Bohemian Waxwing	M	M		

*R = resident species, B = breeding species, M = migratory species, V = vagrant species.

Species	NPS (2015)*	CBC*	Giroir (2001)*	RMBO Monitoring*
Brewer's Blackbird	R	R		R
Brewer's Sparrow	R		R	R
Broad-tailed Hummingbird	R		R	R
Brown Creeper	M	M		
Brown-capped Rosy-Finch	M	M		
Brown-headed Cowbird	R	R	R	R
Bufflehead		M		
Bullock's Oriole	R	R	R	
Burrowing Owl	B			
Bushtit	B	B	B	B
Cackling Goose		M		
California Gull		M		
California Quail		R		
Canada Goose		R		
Canvasback		M		
Canyon Wren	R	R	R	R
Cassin's Finch	M	M		M
Cassin's Vireo	M			
Cedar Waxwing	M	M		
Chipping Sparrow	R	R	R	R
Chukar	R	R		R
Clark's Nutcracker	R	R	R	R
Cliff Swallow	R		R	R
Common Goldeneye		M		
Common Grackle		B		
Common Loon		M		
Common Merganser		B		
Common Nighthawk	B			B
Common Poorwill	B			
Common Raven	R	R	R	R
Common Redpoll		M		
Common Yellowthroat	M	M		
Cooper's Hawk	B	B		B
Cordilleran Flycatcher	R			
Dark-eyed Junco	R	R	R	R
Double-crested Cormorant		M		
Downy Woodpecker	R	R		
Dunlin		M		
Dusky Flycatcher	R		R	R

*R = resident species, B = breeding species, M = migratory species, V = vagrant species.

Species	NPS (2015)*	CBC*	Giroir (2001)*	RMBO Monitoring*
Eared Grebe		B		
Eastern Bluebird	V	V		
Eastern Kingbird	R			
Eastern Phoebe		V		
Eurasian Collared-Dove	R	R		R
European Starling	R	R		
Evening Grosbeak	R	R		
Ferruginous Hawk	B	B		
Fox Sparrow		M		
Gadwall		B		
Gambel's Quail	B	B	B	B
Golden Eagle	B	B	B	B
Golden-crowned Kinglet	R	R		
Golden-crowned Sparrow		V		
Grace's Warbler	B			B
Gray Catbird	B			
Gray Flycatcher	R		R	R
Gray Jay		R		
Gray Vireo	B		B	B
Gray-crowned Rosy-Finch	M	M		
Great Blue Heron	M	M		
Great Egret		M		
Great Horned Owl	B	B		
Great-tailed Grackle		R		
Greater Scaup		M		
Greater White-fronted Goose		V		
Greater Yellowlegs		M		
Green Heron		M		
Green-tailed Towhee	R	R	R	R
Green-winged Teal		R		
Gunnison Sage-Grouse	R			
Hairy Woodpecker	R	R		R
Hammond's Flycatcher	M			
Harris's Sparrow		M		
Hermit Thrush	R	R	R	R
Hooded Merganser		M		
Horned Grebe		M		
Horned Lark	R	R		
House Finch	R	R	R	R

*R = resident species, B = breeding species, M = migratory species, V = vagrant species.

Species	NPS (2015)*	CBC*	Giroir (2001)*	RMBO Monitoring*
House Sparrow	R	R		
House Wren	R	R	R	R
Juniper Titmouse	R	R	R	R
Killdeer	R	R		
Lapland Longspur		M		
Lark Bunting		M		
Lark Sparrow	R	R	R	
Lazuli Bunting	R		R	R
Least Sandpiper		M		
Lesser Goldfinch	R	R	R	R
Lesser Scaup		M		
Lesser Yellowlegs		M		
Lewis's Woodpecker	R	R		
Lincoln's Sparrow	B	B		B
Loggerhead Shrike	R	R		
Long-eared Owl	M	M		
MacGillivray's Warbler	M			M
Magnificent Hummingbird	V			
Mallard	M	M		
Marsh Wren		R		
Merlin	M	M		
Mountain Bluebird	R	R	R	R
Mountain Chickadee	R	R	R	R
Mountain Quail		V		
Mourning Dove	B	B	B	B
Mute Swan		V		
Northern Flicker	R	R	R	R
Northern Goshawk	M	M		
Northern Harrier	M	M		
Northern Mockingbird	R	R		
Northern Pintail		R		
Northern Pygmy-Owl	R	R	R	
Northern Rough-winged Swallow	B			B
Northern Saw-whet Owl	M	M		
Northern Shoveler		B		
Northern Shrike	R	R		
Oak Titmouse		V		
Olive-sided Flycatcher	B			B
Orange-crowned Warbler	M	M		

*R = resident species, B = breeding species, M = migratory species, V = vagrant species.

Species	NPS (2015)*	CBC*	Giroir (2001)*	RMBO Monitoring*
Osprey	M			M
Peregrine Falcon	B	B	B	B
Pied-billed Grebe		R		
Pine Grosbeak	R	R		
Pine Siskin	R	R	R	R
Pinyon Jay	R	R	R	R
Plumbeous Vireo	B		B	B
Prairie Falcon	B	B	B	
Pygmy Nuthatch		R		
Red Crossbill	R	R		
Red-bellied Woodpecker		V		
Red-breasted Merganser		M		
Red-breasted Nuthatch	M	M		M
Red-naped Sapsucker	M	M		
Red-shouldered Hawk		V		
Red-tailed Hawk	R	R		R
Red-winged Blackbird	M	M		
Redhead		B		
Ring-billed Gull		M		
Ring-necked Duck		M		
Ring-necked Pheasant	R	R		
Ringed Turtle-Dove		V		
Rock Dove	R	R	R	R
Rock Wren	B	B	B	B
Rose-breasted Grosbeak	M			
Ross's Goose		M		
Rough-legged Hawk	M	M		
Ruby-crowned Kinglet	M	M		M
Ruddy Duck		B		
Rufous Hummingbird	M			
Rufous-crowned Sparrow		R		
Rusty Blackbird		M		
Sage Sparrow	M	M		
Sage Thrasher	M	M		
Sandhill Crane		M		
Savannah Sparrow	M			
Say's Phoebe	R	R	R	R
Sedge Wren		V		
Scott's Oriole	B			

*R = resident species, B = breeding species, M = migratory species, V = vagrant species.

Species	NPS (2015)*	CBC*	Giroir (2001)*	RMBO Monitoring*
Semipalmated Sandpiper		M		
Sharp-shinned Hawk	R	R	R	
Snow Goose		M		
Song Sparrow	R	R		R
Sora		B		
Spotted Sandpiper		B		
Spotted Towhee	R	R	R	R
Steller's Jay	R	R		
Swainson's Hawk	B	B		
Swamp Sparrow		M		
Townsend's Solitaire	R	R		
Townsend's Warbler	M			
Tree Swallow	M	M		M
Trumpeter Swan		V		
Tundra Swan		M		
Turkey Vulture	R	R	R	R
Varied Thrush		V		
Vaux's Swift	M			
Vermilion Flycatcher	V			
Vesper Sparrow	R	R	R	
Violet-green Swallow	R		R	R
Virginia Rail		B		
Virginia's Warbler	R		R	R
Warbling Vireo	R		R	R
Western Bluebird	R	R	R	R
Western Grebe		B		
Western Kingbird	R	R		
Western Meadowlark	R	R	R	
Western Screech-owl	M	R		
Western Scrub-Jay	R	R	R	R
Western Tanager	R		R	R
Western Wood-Pewee	R			R
White-breasted Nuthatch	R	R	R	R
White-crowned Sparrow	R	R		
White-throated Sparrow		M		
White-throated Swift	R		R	R
White-winged Dove		B		
White-winged Scoter		V		
Wild Turkey	R	R		

*R = resident species, B = breeding species, M = migratory species, V = vagrant species.

Species	NPS (2015)*	CBC*	Giroir (2001)*	RMBO Monitoring*
Williamson's Sapsucker	B			
Willow Flycatcher	M			M
Wilson's Snipe		B		
Wilson's Warbler	M			
Wood Duck		M		
Yellow Warbler	M			M
Yellow-bellied Sapsucker		V		
Yellow-breasted Chat	M			
Yellow-headed Blackbird		B		
Yellow-rumped Warbler	M	M		M
Zone-tailed Hawk	V			
# of Resident Species	**84**	**77**	**50**	**52**
# of Migratory Species	**46**	**66**	**0**	**10**
# of Breeding Species	**26**	**30**	**10**	**15**
# of Vagrant Species	**5**	**18**	**0**	**0**
Total Species	**161**	**191**	**60**	**77**

*R = resident species, B = breeding species, M = migratory species, V = vagrant species.

Appendix K. Annotated list of species-related name changes and adjustments made by SMUMN GSS to the Grand Junction CBC data.

- Observations that were not specific to a bird species (e.g., *vireo* sp., *Buteo* sp.) were omitted from analysis.
- Records of the American eared grebe were merged with records of the eared grebe, as these are both accepted common names of *Podiceps nigricollis*.
- Records of the American green-winged teal were merged with records of the green-winged teal, as these are both accepted common names of *Anas crecca*.
- Records of the American magpie were merged with records of the black-billed magpie, as both are common names of *Pica hudsonia*.
- Records of the American merganser were merged with records of the common merganser, as both are common names of *Mergus merganser*.
- Records of the American raven were combined with records of the common raven, as both are common names of *Corvus corax*.
- Records of the Batchelder's woodpecker were treated as observations of the downy woodpecker; both species share the Latin name *Picoides pubescens*.
- Records of the common barn owl were merged with records of the barn owl, as both are common names of *Tito alba*.
- Records of the common crow were merged with records of the American crow, as both are common names of *Corvus brachyrhynchos*.
- Dark-eyed junco, gray-headed dark-eyed junco, dark-eyed junco (Oregon race), pink-sided dark-eyed junco, Shuteldt's junco, and slate-sided dark-eyed junco observations were treated as one species (*Junco hyemalis*) (Sibley and Ahlquist 1983).
- Records of the English sparrow were merged with records of the house sparrow, as both are common names of *Passer domesticus*.
- Records of Gambel's partridge were merged with records of Gambel's quail, as both are common names for *Callipepla gambelii*.
- Records of Gambel's sparrow were merged with records of white-crowned sparrow, as both are common names for *Zonotrichia leucophrys*.
- Records of Harlan's hawk were merged with records of red-tailed hawks, as there is uncertainty regarding speciation of the Harlan's hawk. Both records were treated using the Latin name *Buteo jamaicensis*.
- Records of the marsh hawk were merged with records of the northern harrier, as both are common names for *Circus cyanus*.
- Records of mockingbird were merged with records of the northern mockingbirds, as both refer to the species *Mimus polyglottos*.

- Records of the mountain song sparrow were merged with records of the song sparrow, as both are common names of *Melospiza melodia*.
- Observations for northern flicker, red-shafted northern flicker, and yellow-shafted northern flicker were merged and renamed to *Colaptes auratus*. Yellow- and red-shafted flickers were previously believed to be separate species, but genetic analysis has classified them as one species (Sibley and Ahlquist 1983).
- Records of the pale goldfinch were merged with records of the American goldfinch, as both are/were common names of *Spinus tristis*.
- Records of the pigeon hawk were merged with records of the merlin, as both common names referred to *Falco columbarius*.
- Records of plain titmouse were merged with records of oak titmouse, as both are common names for *Baeolophus inornatus*.
- Records of the robin were merged with records of the American robin, as both are common names of *Turdus migratorius*.
- Records of the rock pigeon were merged with records of the rock dove, as both are accepted common names of *Columba livia*.
- Records of the rufous-sided towhee were treated as records of the spotted towhee, as spotted towhee is the preferred common name for *Pipilo maculatus*. The rufous-sided towhee was previously the accepted common name for this species before the eastern towhee and the spotted towhee were identified as separate species.
- All forms of the snow goose (e.g., blue-form) were treated as a single species, *Chen caerulescens*.
- Records of the sparrow hawk were merged with records of the American kestrel, as both represent common names of *Falco sparverius*.
- Records of 'starling' and 'common starling' were treated as records for the European starling, *Sturnus vulgaris*.
- Observations of American pipit and water pipit were merged as these are both accepted common names for *Anthus rubescens.*
- Records of the common snipe and Wilson's snipe were merged, as these are both common names of *Gallinago delicate.*
- Records of the tree sparrow and the American tree sparrow were merged, as these are both common names of *Spizella arborea*.
- Records of the green-backed heron were merged with records of the green heron, as both are /were common names of *Butorides virescens*.
- Records of the gray shrike were merged with records of the northern shrike, as both refer to *Lanius excubitor*.

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

Literature Cited

Hunt, P. D., and D. J. Flaspohler. 1998. Yellow-rumped warbler (*Setophaga coronata*), *in* The Birds of North America Online (A. Poole, Ed.). Cornell Lab of Ornithology, Ithaca, New York.

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