National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Vital Signs at Rocky Mountain National Park

Natural Resource Report NPS/ROMO/NRR—2015/946

PHOTO CREDITS
On the cover: elk, Ann Schonlau; limber pine, white-tailed ptarmigan, and Fern Lake fire, National Park Service. Where not otherwise indicated, photos in this report are courtesy of the National Park Service.

NPS 121/128364, April 2015

Natural Resource Vital Signs at Rocky Mountain National Park

Natural Resource Report NPS/ROMO/NRR—2015/946

Mary Ann Franke, Therese Johnson*, Isabel Ashton, and Ben Bobowski

National Park Service
Rocky Mountain National Park
1000 Highway 36
Estes Park, CO 80517-8397

*Corresponding author: therese_johnson@nps.gov

April 2015

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

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

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

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

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 was peer-reviewed by two monitoring and ecological assessment experts. The breadth of this report is necessarily broad, covering all RMNP natural resources. Peer-reviewers therefore focused on whether interpretation of data and presentation of the information was objective and representative.

Please cite this publication as:

Franke, M. A., T. L. Johnson, I. W. Ashton, and B. Bobowski. 2015. Natural resource vital signs at Rocky Mountain National Park. Natural Resource Report NPS/ROMO/NRR—2015/946. National Park Service, Fort Collins, Colorado.

Contents

Figures

Page

Foreword

Rocky Mountain National Park (RMNP) is a spectacular mountain wilderness where scientists and managers have been researching the natural resources for more than 100 years. In recent decades, resource stewardship has strived to document the status and trends in resource conditions and integrate science into decision-making using an adaptive management framework. Although tracking every resource in the park is not possible, a selection of "vital signs" can provide an assessment of the park's natural resources. In this report, we provide information on the current status of 24 natural resource vital signs in four categories: physical environment, native wildlife, vegetation communities, and challenges.

This report is one of three efforts to synthesize the status of the park's resources. The other two are vital signs summaries produced by our Rocky Mountain Inventory and Monitoring Network and a RMNP "State of the Park" report to be produced in collaboration with the NPS Natural Resource Stewardship and Science Directorate . As these complimentary syntheses converge over time, we expect them to provide all of us with a more complete picture of the resources of RMNP.

Additionally, we have begun to summarize the status of our cultural resources in a way similar to the natural resources described within this report. It will take some time, but this is an important step forward to better integrate our understanding of human history on this amazing landscape and how both culture and nature interact to provide the experiences we have today.

This report is the first in what we hope will be a continued conversation in best addressing how to summarize, synthesize, and integrate a diversity of perspectives of resource stewardship at RMNP. As with any aspect of science, this is a process. It is incumbent upon each of us to assist this effort and to use this genesis as a springboard of discussion, of learning, and growth in support of this special place we care for, Rocky Mountain National Park.

Ben Bobowski
Chief of Resource Stewardship
Rocky Mountain National Park

Acknowledgements

In support of the work done by Rocky Mountain National Park staff, the following agencies and organizations provided data and/or analysis that was used in preparing this report:

- Colorado State University
- National Park Service Biological Resource Management Division
- National Park Service Air Resources Division
- Rocky Mountain Inventory and Monitoring Network
- Rocky Mountain National Park Air Quality Initiative (a partnership of the Colorado Department of Public Health and the Environment, the U.S. Environmental Protection Agency Region 8, and the National Park Service)
- U.S. Fish and Wildlife Service
- USDA Forest Service
- U.S. Geological Survey

We especially want to acknowledge the contributions to the text made by individuals in some of their areas of expertise: Mary Kay Watry (amphibians, bears, bighorn sheep, fish, and aquatic nuisance species) and Scott Esser (subalpine forest), both of Rocky Mountain National Park, and Billy Schweiger (wetlands) of the Rocky Mountain Inventory and Monitoring Network.

Scientists at other government agencies and organizations who have shared their knowledge and data include N. Thompson Hobbs, Colorado State University (elk); Christopher Kennedy, U.S. Fish and Wildlife Service (lakes and fish); and Erin Muths, U.S. Geological Survey (amphibians).

Scientists in other National Park Service divisions whose research was used to prepare this report include: Colleen Flanagan Pritz, Air Resources Division (pesticides and mercury contamination); Patrick Gonzales, NPS Climate Change Scientist; Ryan Monello, Biological Resource Management Division (elk); and Mike Britten, Rocky Mountain Inventory and Monitoring Network (wetlands).

Other RMNP staff who contributed to the content of this report include Jim Cheatham (vegetation), Dave Pettebone (wilderness), Barry Sweet (visitor use), Brian Verhulst (bark beetles), and Nate Williamson (fire). This report was also improved by overall reviews and suggestions from Scott Esser, Karina Puikkonen, Paul McLaughlin, Holly Nickels, and Michele Bratschun.

Alpine tundra in Rocky Mountain National Park. Photo: FHWA

Introduction

Established by Congress on January 26, 1915, Rocky Mountain National Park (RMNP) encompasses 265,761 acres in north-central Colorado. The park's purpose is to preserve the high-elevation ecosystems and wilderness character of the southern Rocky Mountains within its borders and to provide recreational use of and access to the park's scenic landscapes, wildlife, natural features and processes, and cultural objects (NPS 2013). The alpine tundra that covers one-third of the park is one of the largest protected examples of this ecosystem type in the contiguous United States. The glaciers and flowing water that carved the park's landscape are the source of several rivers, including the Colorado River and the South Platte.

The elevation range within the park spans from 7,630 to 14,259 feet and straddles the Continental Divide. It allows for diverse plant and animal communities in three interconnected ecological zones: montane, subalpine, and alpine. Ninety-five percent of the park is designated wilderness. As one of North America's premier wildlife watching destinations, it provides habitat for about 60 mammal species, more than 280 recorded bird species, 4 amphibian species, 2 reptile species, 4 native fish species, and many insect species, including a large number of butterflies. The park is designated as a United Nations Educational, Scientific and Cultural (UNESCO) international biosphere reserve and globally important bird area.

The park's proximity to Denver, the largest urban area in the Rocky Mountain region, makes it readily accessible to a large constituency of visitors, but also contributes to a variety of resource issues. At the current time, the most significant natural resource issues are visitor congestion and climate change. Other concerns include air and water pollution, a legacy of water diversions, the spread of exotic species and diseases, the consequences of previous ungulate overpopulation and adjacent land development.

Vital Signs

Scientifically credible information on the current status and long-term trends of natural resources is critical to park and wilderness management, especially in the context of current and future changes in climate and land use. Providing a synthesis and interpretation of research and data for decision makers is a key component of adaptive management because this information helps determine the preferred alternative actions. In cases where Park Service intervention is occurring (e.g., management of exotic plants and the impact of elk on vegetation), monitoring data can be used to evaluate its effectiveness and actions can be refined as necessary. Moreover, monitoring data often reveal early warning signs of declines in ecosystem health which can prompt management intervention.

While monitoring every species, ecosystem, and process in the park is not feasible, we can focus on certain "vital signs" that, when assessed together, provide a good indication of the ecological integrity of the park and wilderness area. In the National Park Service (NPS), vital signs are defined as physical, chemical, and biological elements and processes that have a key influence on the ecosystems within and around a park, are especially vulnerable to change as a result of current or potential stressors, or are of particular importance to park visitors or other stakeholders.

We focus here on the natural resource vital signs, but our hope is to incorporate cultural resource vital signs in future reports. For the purpose of this report, the park's vital signs are grouped into four categories:

- Physical Environment
- Native Wildlife
- Vegetation Communities
- Challenges

Understanding the current condition of park resources within the context of broad spatial and temporal scales is important. The large landscapes that make up the park affect physical and biological resources such as air, water, migratory animals, and plant communities that do not stop at its boundary. These resources may be connected regionally, continentally, or globally across management jurisdictions. Ecological conditions also occur along a continuum over time, linking natural and anthropogenic changes since the last ice age to the present.

The vital signs presented in this report are monitored by park staff, regional or national NPS offices, other federal and state agencies, and university scientists. Data for each indicator are based on monitoring and research done in the park, as well as external data that provide a broader context. Some information is based on single or periodic surveys intended to provide a snapshot of conditions at a point in time, while other indicators are tracked annually or on other defined schedules.

For most of the park's vital signs, we have only a limited set of data gleaned from past surveys (e.g., exotic plants and fish populations) or the data represent the first few years of long-term and continuing projects (e.g. wetlands, alpine vegetation). In other cases, the information comes from studies where the original intent was specific research questions (e.g. bears, montane vegetation, soundscape) not general monitoring. While there are limitations to these datasets, we find management utility in them as they increase our understanding of resource conditions in the park. Where funding allows, we recommend that we continue research and monitoring efforts for these vital signs and look for ways to adjust protocols, as necessary, to better meet reporting needs.

Some vital signs are the focus of interagency or park management plans to restore and maintain a natural range of variability in conditions (2007 Elk and Vegetation Management Plan), control unwanted impacts (2003 Invasive Exotic Plant Management Plan, 2005 Bark Beetle Management Plan, 2012 Wildland Fire Management Plan), or contribute to the recovery of threatened and endangered species (1998 Greenback Trout Recovery Plan, 2001 Boreal Toad Conservation Plan).

While drawing on other synthesis efforts, including the Rocky Mountain Network Vital Signs Monitoring Plan (Britten et al. 2007), the RMNP Natural Resource Condition Assessment (Theobald et al. 2010a), the Park Analysis of Landscapes and Monitoring Support project (Theobald et al. 2010b), and the State of the Alpine Report for RMNP (Ashton et al. 2013), this report provides the first comprehensive examination of park conditions through 2014. Our hope is that it can be repeated in subsequent years so that short current summaries of resource conditions will be more accessible to park managers and the public.

Moreover, the RMNP Vital Signs Report provides a first step toward the preparation of a more comprehensive "State of the Park Report," an NPS effort to evaluate conditions in individual park units. When written, RMNP's State of the Park Report will broaden the vital signs monitoring by including facilities management, cultural resources, museums and archives, interpretive and educational activities, and wilderness character.

Comparison to Reference Conditions

The following table summarizes the current status of selected resources. In most cases, a reference condition is indicated for comparison purposes. Sometimes the reference condition is based on "historical" evidence, meaning information that was reported before or in the first years after the park was established in 1915. Because conditions may fluctuate widely over time in response to natural factors, the reference condition is not considered the "desired" condition unless it is one that has been specified by government regulation or a management plan. In other cases, the reference condition simply provides a measure for understanding the current condition, e.g., a historical range or scientific opinion as to the level needed to maintain biological viability.


JOHN MARINO, NPS

Vital Signs Summary

Condition Indicators	Current Data 2013 (or latest available)	Reference Condition	Assessment
Physical Environment			
Climate		Annual average, 1981–2010	Climate change is one of the most significant factors causing changes in the park's natural resources. While year-to-year variations occur, temperatures have increased on average during the last century and this trend is expected to continue. There has been no significant long-term change in precipitation, but snowpack has generally been below average since 2000.
• Park-wide average temperature (based on PRISM modeling)	33.7°F	33.0°F	
• Grand Lake average monthly minimum and maximum temperatures	20.4°, 50.9°	22.0°, 53.8°	
• Grand Lake annual precipitation	20.9 inches	19.9 inches	
• Bear Lake April 1 snow water equivalent	10.3 inches	16.5 inches	
• Lake Irene April 1 snow water equivalent	16.3 inches	24.3 inches	
Hydrology			The volume of water flowing in the park's rivers shows large year-to-year fluctuations without indicating any long-term change, but the timing of peak flow has become more variable and earlier in the spring.
(Big Thompson River,Colorado River)		Average for period of record	
• Annual average daily discharge (cubic feet per second)	71.4 cfs, 114.1 cfs (2014)	56.8 cfs, 64.8 cfs	
• Date of peak flow	May 31, May 31 (2014)	June 23, June 8	
Fire			Most areas of the park are within their natural range of variability for fire frequency and severity. However, effective fire suppression has reduced the size of fires in the park's east side montane forests.
• Area burned per year	1 acre (2014)	0–3,500 (1944–2014 range)	
• Area receiving fuel treatment	1,406 acres (2012)	593–1,719 (2008–2012 range)	
Air Quality			Evidence indicates that high levels of nitrogen deposition are affecting park ecosystems. Based on NPS benchmarks, nitrogen deposition and ozone in the park are of significant concern and sulfur deposition and visibility warrant moderate concern. Nitrogen and sulfur deposition declined during 2003–2012, but there was a large increase in nitrogen deposition in 2013.
(5-year averages)			
• Nitrogen deposition	3.2 kg/ha/yr	1.5 kg/ha/yr (critical load)	
• Sulfur deposition	1.3 kg/ha/yr (2012)	< 1 kg/ha/yr (NPS standard)	
• Visibility (deciviews)	3.0 dv (2012)	< 2 dv (NPS standard)	
• Ozone (parts per billion)	73.9 ppb (2012)	≤ 60 ppb (NPS standard)	
Snowpack Chemistry			The concentrations of airborne pollutants in snow shows substantial year-to-year-fluctuations, but no substantial improvement since monitoring began.
(average at 3 sites)		Annual Average	
• Sulfate (microequivalents per liter)	6.1 ± 0.7 µeq/L	6.8 ± 0.30 µeq/L (1993–2009)	
• Calcium (microequivalents per liter)	9.1 ± 0.7 µeq/L	8.9 ± 0.79 µeq/L (1993–2009	
• Mercury (nanograms per liter)	3.1 ± 1.2 ng/L	2.9 ± 0.3 ng/L (2001–2009)	
Lakes and Streams		Minimally Disturbed Condition	Introduced fish have altered the nutrient dynamics and food webs in many of the park's lakes. Nitrogen deposition has affected many of the lakes east of the Continental Divide, with an increase in nitrate concentrations and reduced acid-neutralizing capacity that could cause episodic acidification and lethal or sublethal effects on fish and aquatic invertebrates..
• Lakes that have fish	50 lakes	No lakes	
In 25 lakes on the east side of the park:			
• Average nitrate concentration (milligrams per liter)	0.57 ± 0.033 mg/L (1997–2007)	≤ 0.1 mg/L	
• Average acid neutralizing capacity (microequivalents per liter))	49.7 ± 21.2 ueq/ L (1997–2007)	80–100 ueq/L	

Condition Indicators	Current Data 2013 (or latest available)	Reference Condition	Assessment
Native Wildlife			
Amphibians • Boreal toad occupied/breeding sites	8/5 of 11 surveyed (2014)	14/7 of 21 surveyed (1988–1994))	Boreal toad populations have declined since the late 1990s, though recent reintroduction efforts may establish a new population.
Beaver • Estimated number in Moraine Park	6 beaver	315 beaver (1939–1940)	Beaver abundance and distribution are far below historical levels. Beaver are absent from or occur in low densities in many places in the park with suitable habitats.
Bighorn Sheep • Population estimate	360 bighorn sheep (2004)	1,000 bighorn sheep (1915)	Bighorn sheep numbers and distribution have declined substantially since the park was established, but recent data are not available to assess current status.
Black Bears • Population estimate • Times bears obtained human food, caused property damage or human injury, or behaved aggressively	20–24 bears (2003–2006) 35 times (2014)	20–25 bears (1984–1991) 44 times (2007–2011 average)	The park's bear population appeared stable from the mid-1980s through 2006; however, more recent data are not available to assess the current status. Visitor and staff education, bear-proof storage facilities, and attention to trash management are being used to prevent incidents involving bears.
Cutthroat Trout • Presence on east side of park • Presence on west side of park	None 4 streams	8 streams (historical) 6 streams (historical)	Based on the most recent genetic analysis, no populations of the cutthroat trout native to the east side of the park remain. Four relatively pure (<20% hybridized) populations of the cutthroat trout native to the west side of the park are still present.
Elk • Median winter population on the east side of the park	185 elk, BCI = 146–225 (2014)	200–800 (modeled historical range) 600–800 (management objective)	The park's winter elk population has dropped substantially since 2009 at least partly because of an eastward shift in the areas used by the elk.
Pika • Percentage of surveyed sites that were occupied	54% (2010-2011 average)	54% (2010–2011 baseline)	More data about pika populations are needed to understand annual occupancy fluctuations and distinguish between short-term and long-term change.
Ptarmigan • Population density in surveyed sites that were occupied	5.2 ptarmigan per km^2	4.5–13.5 (1966–1994 range)	The ptarmigan population appears stable, though densities in recent years have been relatively low and some evidence suggests warmer summers may be contributing to lower reproduction.
Vegetation Communities			
Wetlands Percentage in reference condition: • Fens • Riparian • Wet meadow	(2007–2009) 69 ± 20% 58–84 ± 16% 51 ± 31%	100% 100% 100%	Wetlands are the park's biodiversity hotspots, but many show evidence of human disturbance. Wetlands are assessed using multimetric indices based on vegetation community structure and thresholds that measure the affect of invasive species, trails, water diversions, dams, fences, and other human activity.
Montane Forest • Average density, live mature trees	350 ± 137 trees/ha (2014)	472 ± 57 (1998–2014 average)	Montane forest tree density has increased since park establishment. The recent bark beetle infestation has increased tree mortality,
Bark Beetles • Affected acres	55,255 acres (2011)	1,600–85,400 (2001–2011 range)	Beetle infestations are a natural part of forest succession, but the most recent outbreak of bark beetles has caused unusually extensive tree mortality.

Condition Indicators	Current Data 2013 (or latest available)	Reference Condition	Assessment
Subalpine Forest • Average density, live mature limber pine • Incidence of white pine blister rust	 114 trees/ha Not present	 104 trees/ha (1972) Not present	The subalpine forests are changing in response to disturbances such as mountain pine beetle outbreaks, forest pathogens, and climate. Limber pine stands are at particular risk of mortality from bark beetles and the nonnative white pine blister rust.
Alpine Vegetation • Average native species in 1m^2 plots • Nonnative species on 4 peaks	 18 species ± 1 (2009)) 1 species (2009	 18 species ± 1 (2009) Not present	Alpine vegetation monitoring began in 2009 is underway to monitor possible impacts on native plant diversity as a result of warmer temperatures, increased visitor use, and air pollution.
Challenges			
Biodiversity (number of native species) • Mammal • Bird • Amphibian • Reptile • Fish • Crab/Lobster/Shrimp • Slug/Snail • Insect • Spider/Scorpion • Protozoa • Chromista • Other Non-Vertebrate • Fungi • Bacteria • Vascular Plant • Non-Vascular Plant	Recorded in the Park 67 267 4 4 3 22 7 514 23 2 135 21 263 102 1,007 360	Estimated Total 67–71 267–281 4–5 4–5 3–4 > 200 > 70 > 1,000 > 200 > 3 > 1,000 > 2,000 > 1,000 > 10,000 ≈ 1,100 > 1,000	Documenting the park's biodiversity before species become extinct presents a major challenge. Especially in more remote places, there are areas of the park that have never been inventoried for species, and the areas that have been surveyed have not included all taxa. Only a small portion of the park has been surveyed for non-vascular plants, bacteria, fungi, and invertebrates. Information about what species were present before the park was established, how many of these species are still present, and which of the currently observed species are native to the park area is also incomplete. The "estimated total" for each taxa is the number of species likely to be in the park based on a professional judgement of how many species have already been documented relative to the size of the area that has been surveyed for that taxa and the expected number of species likely to be found in habitats similar to those found in the park.
Nonindigenous Aquatic Species • Habitat occupied by nonnative fish • Quagga and zebra mussels • New Zealand mudsnails	 > 50% of park waters Not present Not present	 No park waters Not present Not present	Nonnative trout in the park have diminished native fish populations and altered food webs. The threat of New Zealand mudsnail or nonnative mussel introduction is considered high because of their proximity to the park and high visitor use of park waters.
Invasive Plants • Number of nonnative plant species • Extent of invasive terrestrial plants	 90 species 1.7% of 1,279 plots; 5.85% of plots > 9500′	 None 0% historically; 4.6% of 571 plots outside park	Despite efforts to control invasive plants, the number of species and area covered has increased over time along with efforts to survey additional areas of the park.
Mercury in Wildlife • Average concentration in fish at 21 sites (nanograms per gram of wet weight)	 19.8–121.2 ng/g (range)	 90 ng/g (threshold for impairment to birds)	Mercury concentrations in fish were below the threshold for toxicity to fish and the EPA limit for human health at most tested sites, but above the threshold for fish-eating birds at many sites.
Direct Human Impacts • Annual park visitation • Backcountry permits • Soundscape • Housing units, Estes Park and Grand Lake	 3.4 million visitors (2014) 34,321 (2014) TBD 5,112 units (2012)	 2.9 million (2004–2013 average) 33,264 (2004–2013 average) TBD 1,400–4,800 (1970–2010 range)	The extent and character of human presence within, around, and above the park affect the visitor experience as well as park resources such as native plant and animals species. As the human footprint continues to grow, so will its impact.

Climate

Climate change will be a major factor in the future of the park's natural resources. Since 1900, the park has experienced a statistically and biologically significant increase in temperature (fig. 1) but no significant change in precipitation (Gonzalez 2012).

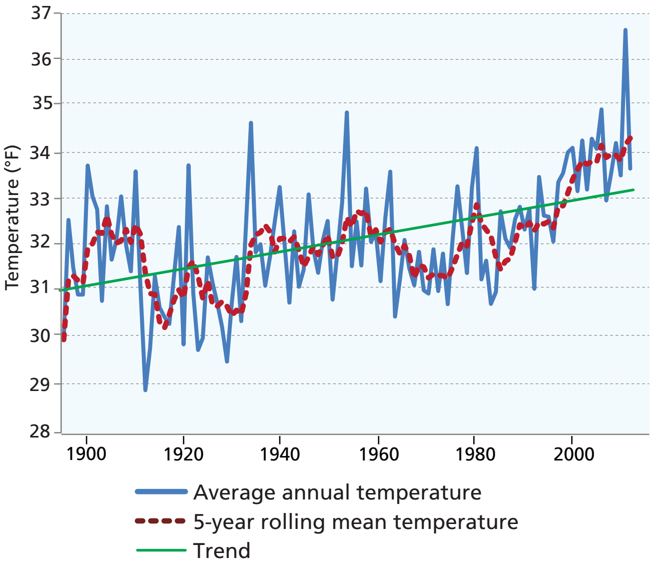


Figure 1. Average annual mean temperature, 5-year rolling average, and trend in Rocky Mountain National Park, 1895-2013. Based on 800-m scale PRISM data from within the park. (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created Oct. 2014.)

Many physical and ecological changes detected in the western U.S. during the second half of the 20th century have been attributed to climate change. The physical changes include higher winter temperatures (Bonfils et al. 2008), decreased snowpack (Barnett et al. 2008), decreased ratio of snow to rain (Pierce et al. 2008), and earlier spring warmth (Ault et al. 2011) and streamflow (Barnett et al. 2008). The ecological changes include a poleward shift in the winter ranges of numerous bird species (La Sorte and Thompson 2007), increased conifer tree background mortality (van Mantgem et al. 2009), and increased wildfire (Westerling et al. 2006) and beetle outbreaks (Raffa et al. 2008).

The weather station at Grand Lake (1NW) provides one of the longest and most complete climate records in Colorado. Data from the Grand Lake and other park stations show that climate trends in the park are generally consistent with those for the state of Colorado (fig. 2), in which annual average temperatures have increased by 2.0°F over the past 30 years and 2.5°F over the past 50 years (Lukas et al. 2014). Although the park's large elevation gradient and complex topography likely result in different rates of warming in different areas of the park, documenting this variation is difficult because of the limited number of weather stations, particularly at the highest elevations (Dobrowski 2011).

While no long-term trend in annual precipitation is evident, snowpack has generally been below average in Colorado river basins since 2000 (Lukas 2014). Since the 1970s, the April 1 snow water equivalent at stations near the park has declined 0.5–1.1 inches per decade (Clow 2010). Future precipitation trends are difficult to predict, but most models indicate that the snowpack decline is likely to continue and extreme precipitation events will occur more often (Lukas 2014). The heavy precipitation that fell in September 2013 caused flooding and debris flows across much of the eastern portion of the park.

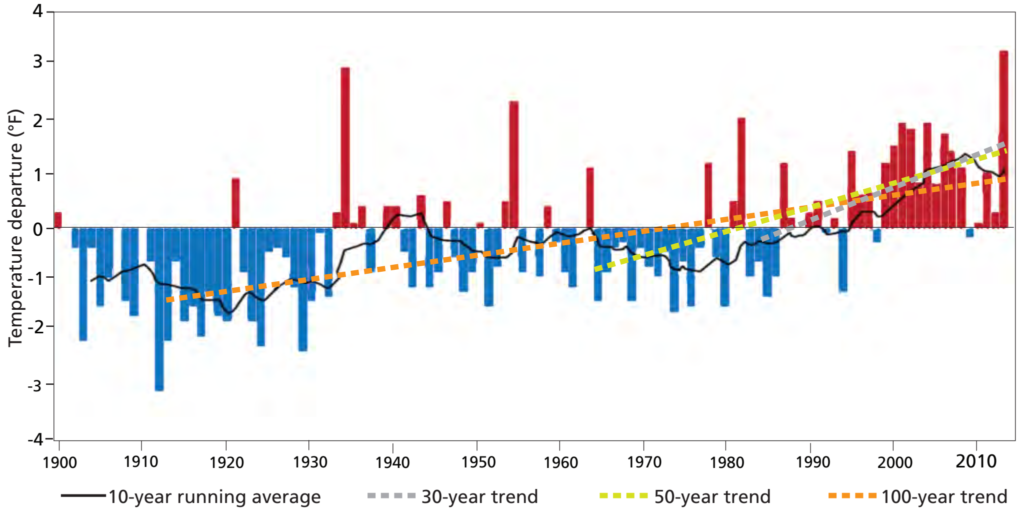


Figure 2. Departure in Colorado statewide annual average temperatures, 1900–2012, from the average temperature during 1971–2000. The 30-year, 50-year, and 100-year warming trends are statistically significant. (Graph from Lukas et al. 2014; data from NOAA NCDC.)

PHYSICAL ENVIRONMENT

Fire

Fire has been one of the most significant and frequent agents of change in the Rocky Mountains since the last glaciation. Periodic fires recycle nutrients into the soil, release seeds for growth, and contribute to the diversity of habitats in the park. Fire regimes in the park generally follow an elevational gradient, with the ponderosa pine and mixed conifer forests characterized by a mixed-severity fire regime that includes stand replacing and surface fire (Sherriff and Veblen 2007). The lodgepole pine forests are characterized by a stand-replacement regime with fire return intervals from 50 to 200 years; the subalpine forests are characterized by stand replacing fires every 400 to 800 years (Sibold et al. 2006).

Most of the vegetation communities in the park are thought to be within or close to their natural range of variability with respect to fire occurrence (Sibold et al. 2006; Sheriff and Veblen 2007). However, while fire frequency has remained similar, effective fire suppression has reduced the size of fires in the park's east side montane stands (Ehle and Baker 2003). Although human-caused fires in the park are suppressed as soon as possible, since 1971 some lightning-ignited fires have been allowed to burn when they have not presented a threat to human safety or property. The number of lightning ignitions in the park is typically about three to seven per year, but most go out quickly because of insufficient combustible fuel. The park's Fire Management Plan seeks to maintain natural fire regimes to the greatest extent possible, allowing fire to function as an ecological process in the park.

More fires have occurred in the park in the last 10 years than in the preceding 100 years (fig. 3) The high winds and steep terrain of the Fern Lake Fire, which started from an illegal campfire in October 2012, made suppression efforts difficult and dangerous. At nearly 3,500 acres, it became the largest fire since the park was established, but it was not unprecedented for subalpine forests (Sibold et al. 2006). The Big Meadows Fire (653 acres in 2013) and the Tonahutu Fire (1 acre in 2014) were both suppressed.

To reduce the risk of serious wildfire and protect people, their property, infrastructure, and natural and cultural resources, the park's fire management program reduces hazardous fuel loads using prescribed fires when and where conditions permit, and manual and mechanical forest thinning in areas adjacent to park structures and private land. More than 6,100 acres were treated in fuels projects from 2008 to 2012.

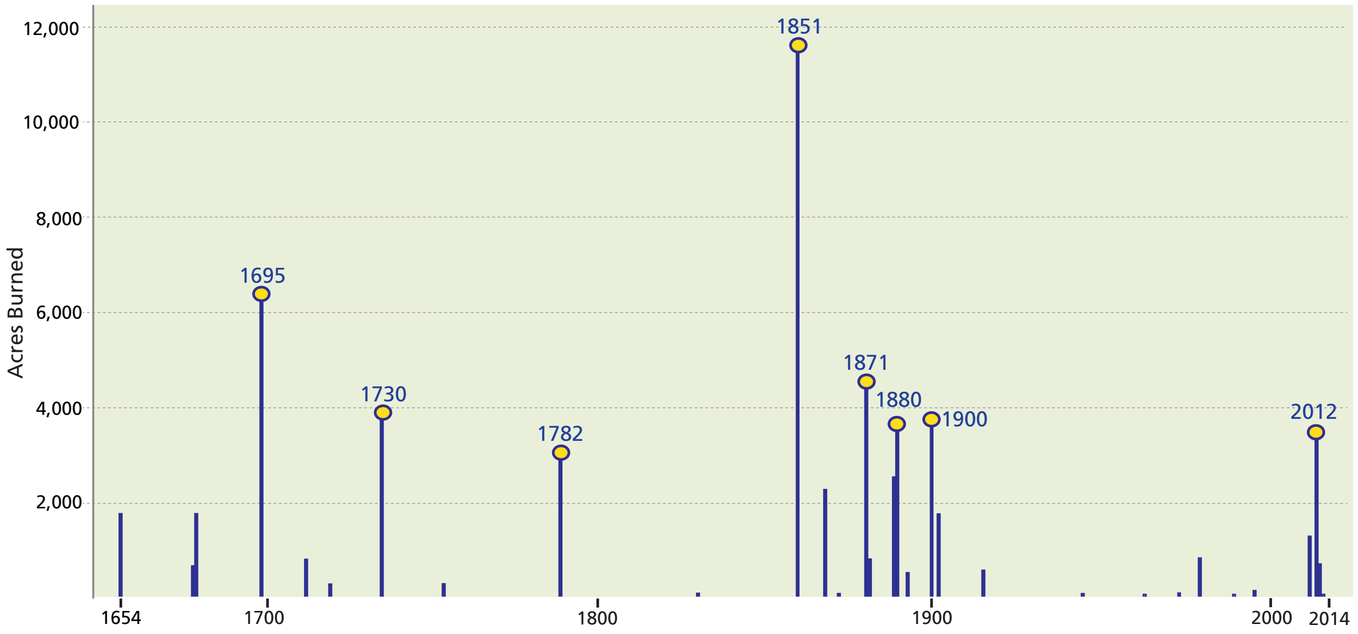


Figure 3. Estimated annual acreage burned in Rocky Mountain National Park, 1650–2014. Yellow circles indicate years in which more than 3,000 acres burned. Data from 1650 to 1978 are from Sibold et al. 2006.

Hydrology

The headwaters of four major river basins originate in Rocky Mountain National Park: the Colorado River on the west side, and the Big Thompson, the North Fork of the St. Vrain, and the Cache la Poudre on the east. The Continental Divide runs the length of the park, dividing it hydrologically; water flowing west drains into the Colorado River and water flowing east becomes part of the Missouri and Mississippi River drainages. As in many areas in the Rocky Mountains, the annual streamflow in the park is usually dominated by a snowmelt peak during late spring or early summer. Fluctuations in mean annual discharge (fig. 4A) therefore reflect annual variations in total snow deposition.

Recent analyses indicate a shift toward earlier spring runoff and peak flows in Colorado (Clow 2010, Lukas et al. 2014), similar to those seen across the rest of the western US (Stewart et al. 2005). The date of peak flow in the Colorado and Big Thompson Rivers has fluctuated between early May and late June in most years during the period of record (fig. 4B). However, the recent increase in the variable timing and quantity of flow is consistent with state-wide trends.

Many climate models predict that these types of extreme events will become more common in the future. Torrential rainfall in mid-September 2013 swelled streams across the Front Range. The event's high peak flow transformed stream corridors on the park's east side, washing out the road into Endovalley with mud, rocks, and other debris, rerouting the Roaring River, and causing numerous landslides, including a massive one on the northwest flank of Twin Sisters.

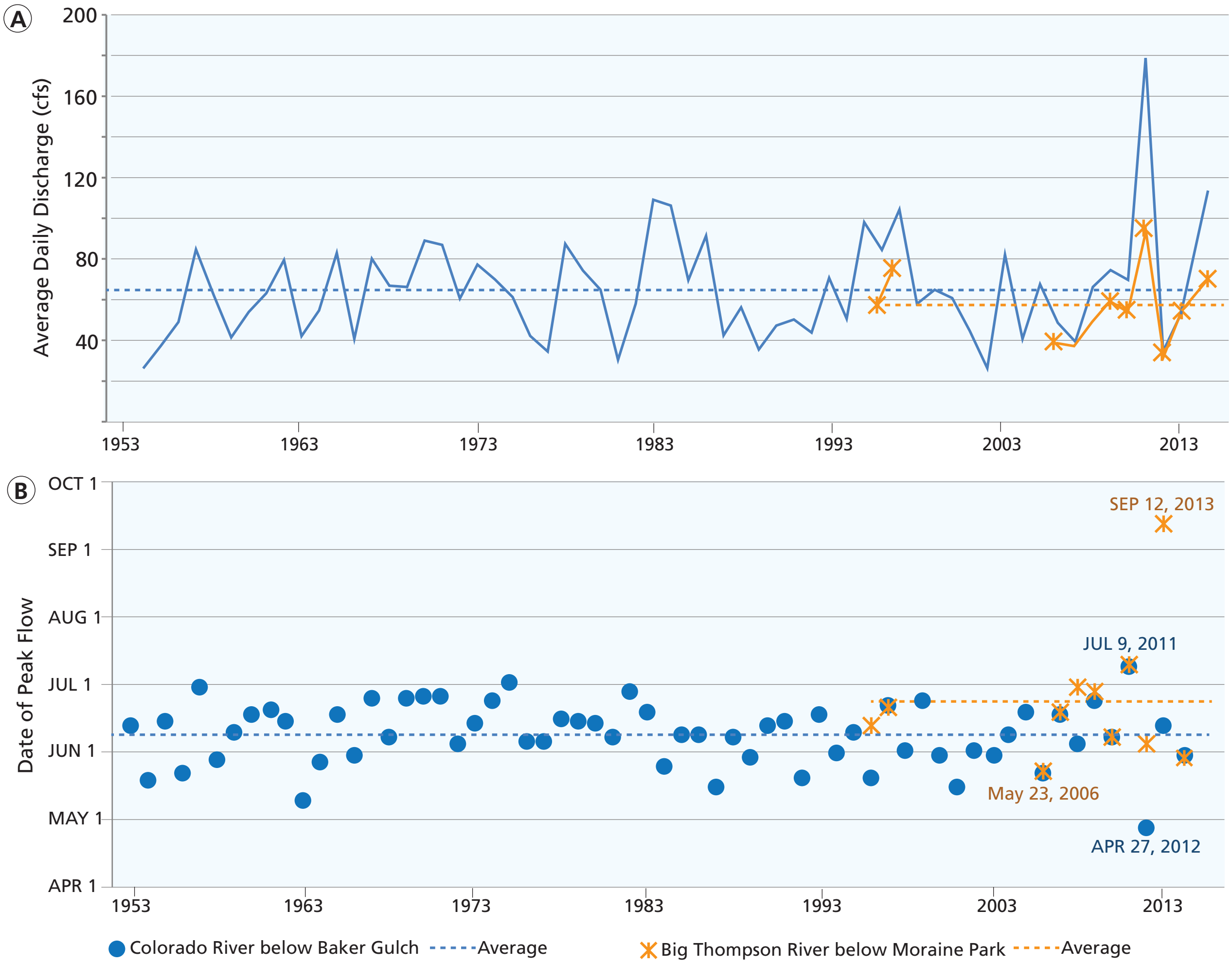


Figure 4. On the Colorado River below Baker Gulch, 1953–2013, and the Big Thompson River below Moraine Park (incomplete data set): (A) the annual average daily discharge (cubic feet per second); and (B) the annual date of peak flow; the earliest and latest dates during the period of record are noted. (Data from http://waterdata.usgs.gov/nwis.)

Air Quality

As a Class I Airshed designated under the Clean Air Act, RMNP is required to meet high standards for air quality. However, atmospheric deposition, regional haze, and ozone formation are affecting park resources.

Nitrogen Deposition

Current nitrogen deposition is 15 times greater than the natural background rate, affecting soil, water, and plants (Morris et al. 2014). Three-quarters of the park is above 9,000 feet in elevation, where ecosystems are especially susceptible to excess nitrogen because they have evolved under and are adapted to an estimated annual natural deposition rate of only 0.2 kg per hectare (Morris et al. 2014). Elevated nitrogen levels may reduce forest health, induce a shift from forbs to graminoids, and contribute to the spread of nonnative plants.

Wet nitrogen deposition has been monitored at Loch Vale and Beaver Meadows on the east side of the park since the early 1980s. As of 2006, the five-year annual average at Loch Vale (10,364') was 3.1 kg per hectare (Morris et al. 2014). In 2007, a multi-agency Nitrogen Deposition Reduction Plan (NDRP) established 1.5 kg N/ha as the science-based threshold for the "critical load" that can be absorbed annually by sensitive ecosystems in the park before detrimental changes occur (Morris et al. 2014). The actual deposition rate has been higher than that since the late 1950s. The long-term NDRP goal is to reduce wet nitrogen deposition at Loch Vale to the 1.5 kg threshold by 2032. As of 2013, the five-year annual average was 3.2, which is above the glidepath goal (fig 5).

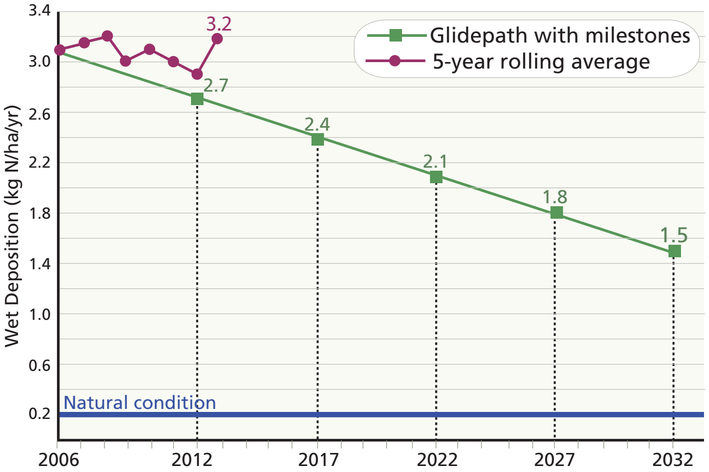


Figure 5. Wet nitrogen deposition at Loch Vale, 2006–2013, and NDRP glidepath for reduction to 1.5 kg N/ha/yr by 2032 (Data from NADP.).

Ozone

Ground level ozone can be harmful to vegetation and human health. The NPS Air Resources Division estimates ozone condition based on the average 4th-highest 8-hour concentration for the last five years. The 2008–2012 average measurement near Longs Peak was 73.9 parts per billion (fig. 6). Although this is below the Environmental Protection Agency threshold of 75 ppb for human health, the NPS considers it to warrant significant concern because part of the park lies within a county (Larimer) that the EPA has designated as "nonattainment" for exceeding the 75 ppb threshold. Ozone-sensitive plants in the park include spreading dogbane (*Apocynum androsaemifolium*) and quaking aspen (*Populus tremuloides*).

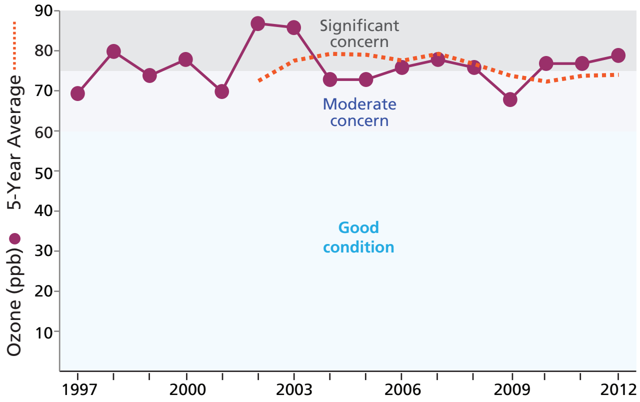


Figure 6. Annual ozone measurements near Longs Peak, 1997–2012, and the rolling 5-year average.

Air Quality (cont.)

Visibility

Air pollution can reduce visibility by causing haze, which is measured in deciviews. The deciview scale starts at 0 for a pristine atmosphere and increases as visibility degrades. The NPS visibility standard is based on a rolling 5-year annual average measurement of deciviews above the estimated natural background conditions. As of 2012, the average measurement near Longs Peak was 3 dv (fig. 7), which “warrants moderate concern” (NPS Air Resources Division 2013). For the visibility to be considered in “good condition,” the measurement must be less than 2 dv. The 2003–2012 data showed a declining trend in deciviews on the 20 clearest days, indicating an improvement in visibility on those days, but no significant change on the 20% haziest days.

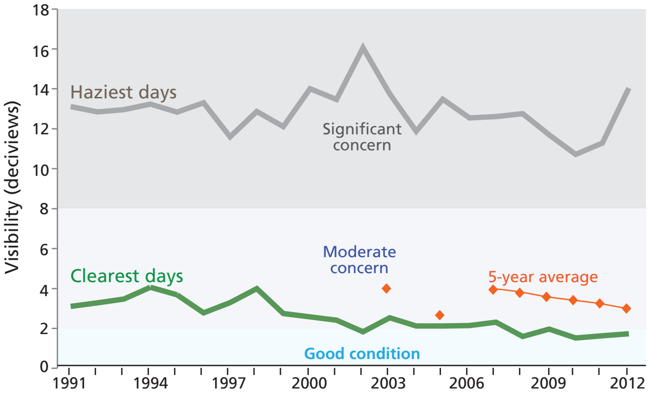


Figure 7. Average visibility near Longs Peak on the 20 haziest and 20 clearest days, 1991–2012, and the rolling 5-year average visibility for available years.

Snowpack Chemistry

Monitoring snow chemistry is another method to better understand air quality. As snowpack accumulates in the park each year, typically starting in October, it stores chemicals deposited from the atmosphere until the snow melts in the spring. The U.S. Geological Survey collects full-depth snow samples at three high-elevation sites in the park at the time of maximum snowpack each spring.

Sulfur dioxide is a major contributor to acid rain. While snowpack records in the West have shown a decrease in sulfate deposition since 1994 (Ingersoll et al. 2008), which is consistent with the lower sulfur emissions reported for the region, there has been no significant trend in the park. The increased frequency of dust events has increased calcium concentrations in snow across the West (Brahney et al 2013). Snow samples from the park have shown large annual fluctuations in calcium, but no long-term trend (fig. 8).

Mercury levels, which have been monitored in the park since 2001, have also fluctuated from year to year. As the snow melts and the mercury enters waterways, it can fatally contaminate fish and the wildlife that eats them (see Mercury in Wildlife, page 28).

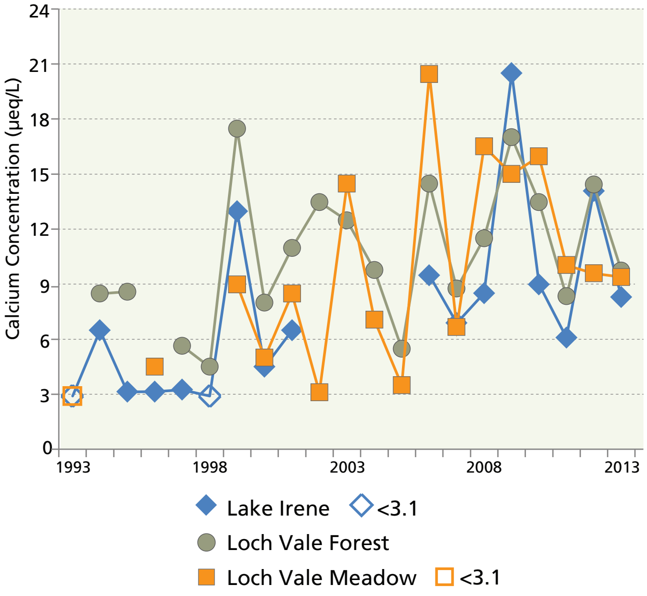
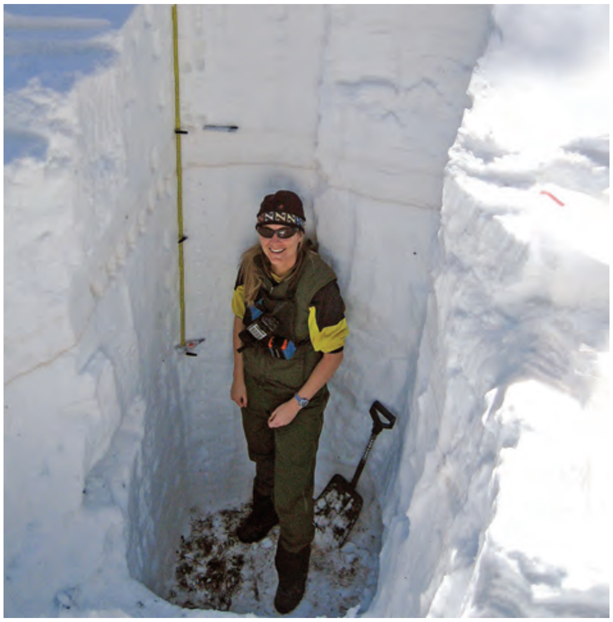


Figure 8. Calcium levels in snowpack measured at three sites in Rocky Mountain National Park, 1993–2013 (data from the USGS).



Collecting snow samples. Photo: G. Ingersoll, USGS

Lakes and Streams

Most of the 147 lakes in Rocky Mountain National Park are small, high-elevation lakes with low temperatures and low nutrient concentrations. In addition to their hydrologic functions of water storage and buffering, these lakes and their shorelines provide important habitat for a diverse assemblage of aquatic invertebrates and other wildlife. Lakes are also one of the most popular destinations for park visitors.

All of these lakes are assumed to have been fishless in the past because of waterfalls and other migration barriers downstream. As a result of fish introductions that began in the 1880s and continued until the 1960s, fish are present in approximately one-third of the lakes in the park (see Nonindigenous Aquatic Species, page 26). When introduced to a lake or stream, fish can alter nutrient dynamics and food webs. For instance, in Wild Basin, trout introductions have changed the composition and abundance of zooplankton and benthic invertebrates (Detmer 2014).

Another stressor to lakes and streams is the deposition of nutrients and pollutants. Weather stations and stream gauges have been collecting data in the Loch Vale watershed, a 660-hectare (1,630 acre) alpine and subalpine catchment, since 1983 (Baron 1992). Studies in Loch Vale and comparisons to other areas of the park have shown that soils, water, vegetation, and diatom communities have been altered by increased nitrogen availability (Baron et al. 2000, Wolfe et al. 2003, Baron 2006). Nitrogen deposition has affected many of the lakes in the park east of the Continental Divide, with a measurable increase in nitrate concentrations and reduced acid-neutralizing, or buffering, capacity (Baron et al. 2010). Historical and currently-used pesticides are also polluting waters in the park.

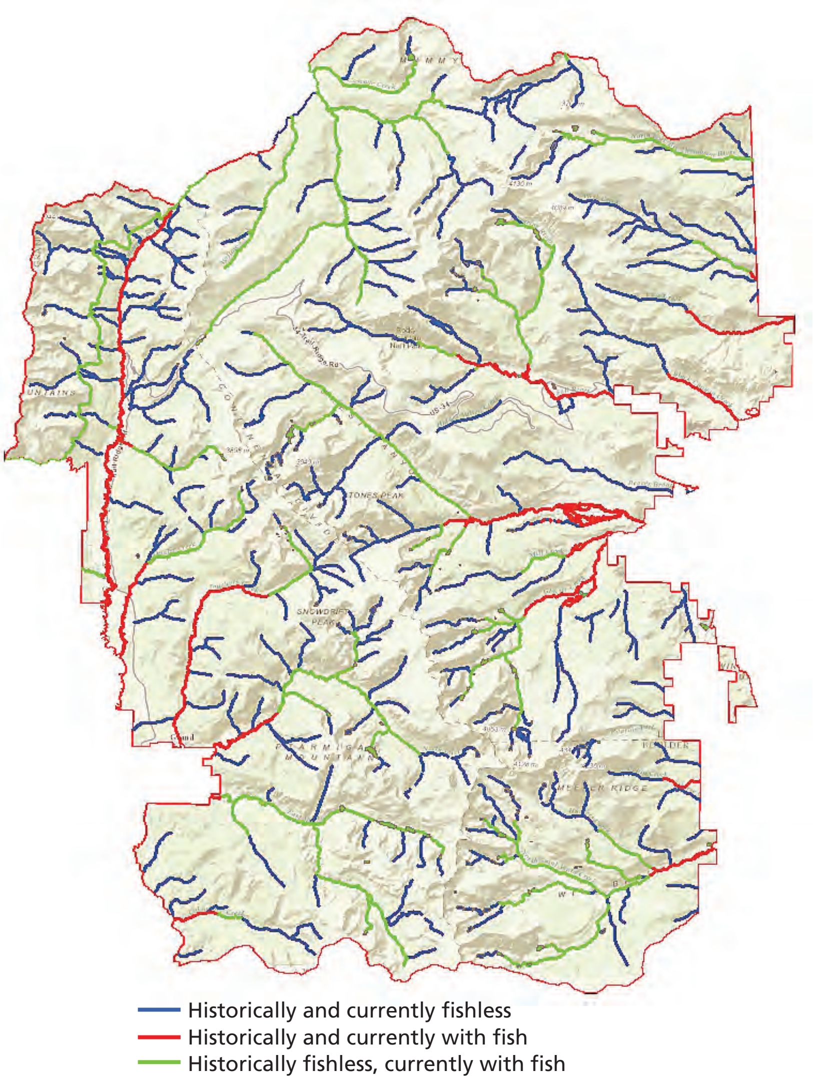


Figure 9. Historical and current status of lakes and streams in the park in regard to the presence of fish. (Map by Christopher Kennedy, USFWS; data from Kennedy 2014)

A recent study detected p,p’–DDT (the active ingredient in commercial dichlorodiphenylethene) in some fish in the park at concentrations that exceed the guidelines for human health and wildlife consumption (Flanagan Pritz et al. 2014).

Amphibians

Declines in amphibian populations have been documented throughout the world, including protected areas in the Rocky Mountains. All five species that inhabit the mountains of northern Colorado occurred in the park historically: tiger salamander (*Ambystoma tigrinum*), boreal chorus frog (*Pseudacris maculate*), wood frog (*Rana sylvatica*), boreal toad (*Bufo boreas*), and northern leopard frog (*Lithobates pipiens*) (Hammerson 1999). Four of these species are still present, but the northern leopard frog has not been observed in the park since the 1970s (Corn et al. 1989, P. S. Corn pers. com.).

In 1988–1990 and 1994 Corn et al. (1997) surveyed 116 locations in the park that had historical records of amphibians or appropriate physical habitat characteristics. Of these sites, 48 (41%) were occupied by amphibians. When the same sites were surveyed in 2000, 26 (22%) were occupied, suggesting an overall decline in amphibian presence in the park (Muths unpublished report 2000). Occupancy by site varied, with amphibians absent from 29 of the previously occupied sites and present at 7 sites where they had been absent previously.

The boreal toad, which has experienced a severe decline in the southern Rocky Mountains (Carey 1993), is listed as an endangered species in the state of Colorado, and a determination on federal listing is to be made by September 30, 2017. Boreal toads are found in a variety of park habitats, from beaver ponds to high elevation glacial lakes, but their distribution is patchy and sparse. Over the years, they have only been documented at 24 sites in the park (unpublished park records) and occupancy of those sites has declined.

Corn et al. (1997) found boreal toads present at 14 of 21 (66%) known sites during surveys conducted in 1988-94, including 7 with breeding populations. Populations in the North Fork drainage were the largest known in the southern Rocky Mountains until amphibian chytrid fungus Batrachochytrium dendrobatidis (Bd), an invasive pathogen thought to have originated in Africa, caused a precipitous decline in the late 1990s (Scherer et al. 2005). Although three additional sites with breeding populations have been discovered since 2000, this is likely due to increased survey effort rather than new colonization. Monitoring in 2014 found that 7 of the 11 surveyed sites (5 sites had only limited surveys) were occupied, including 5 with breeding activity, but only one site had more than a few adults and egg masses. Boreal toads continue to be threatened by Bd, which has been found in many known sites (Muths et al. 2003), including all of the most recent breeding sites.

Boreal toad; photo by E. Muths, USGS.

The park is a member of the interagency Boreal Toad Recovery Team and Translocation Working Group. In 1995, the park began contributing toad stock to the captive breeding program at the Colorado Parks and Wildlife Native Aquatic Species Restoration Facility to prepare for restoration activities, a measure that could be essential to ensure the long-term regional sustainability of the species. In 2007, a project to reintroduce boreal toads to a site on Red Mountain began. Annual monitoring indicates that individuals of multiple age classes have been found at the site since 2009; however, since then Bd was found in the population and resulted in the death of the only adult toad known to have returned to the site.

NATIVE WILDLIFE

Beaver

Beaver *(Castor canadensis)* are a keystone species that has profound effects on landscapes over broad spatial scales. Beaver dams affect stream structure and function by slowing stream current, reducing turbidity, and elevating water tables. Beaver activities also modify nutrient cycling and influence plant and animal diversity (Naiman et al. 1988, Baker 2003, Collen and Gibson 2004, Westbrook et al. 2006).

Once abundant in the park, beaver declined dramatically beginning in the 1940s as a result of trapping, and continued to decline for various reasons even after trapping ceased. In areas used by elk, intense elk browsing reduced the abundance of tall willow that beaver rely on (Baker et al. 2004). Tularemia, a zoonotic, bacterial infection usually transmitted by insects, has been detected in beaver on both the west and east sides of the park, but the prevalence of this potentially fatal disease is not known.

Periodic surveys from 1939 to 2000 monitored trends in beaver activity and abundance in specific drainages. For example, the population on the lower Big Thompson River declined from an estimated 315 in 1939–40 (Packard 1947) to 102 in 1964, 12 in 1980, and six in 1999 (NPS data). After a number of years without any documented beaver activity, occupied areas were observed east of "the Pool" on the Big Thompson River in 2013.

The Natural Resource Condition Assessment (NRCA) mapped beaver survey data collected in 1939–1940 (Packard 1947) and 1999–2000 (Mitchell et al. 1999) and concluded that beaver abundance and distribution in the park were far below historical levels (Theobald et al. 2010a; fig. 10). Density estimates were also much lower than in similar habitats in other areas (Baker and Hill 2003).

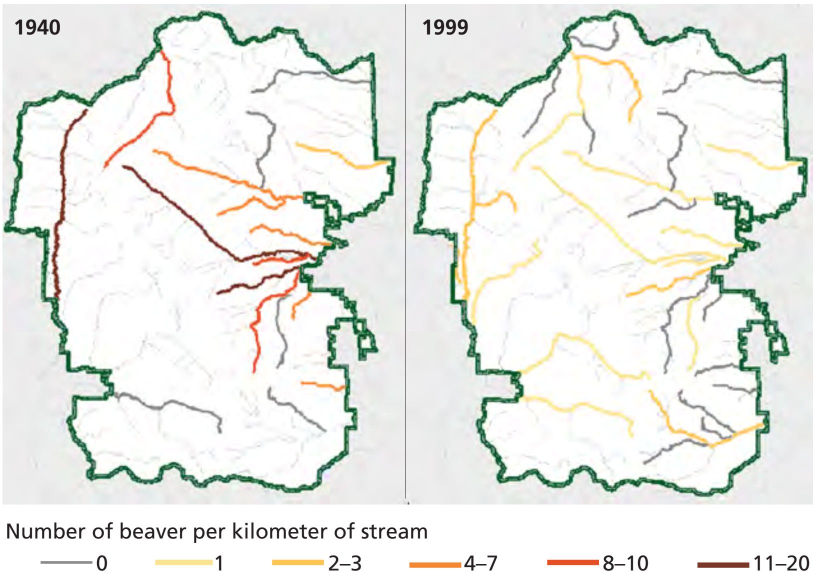


Figure 10. A comparison of beaver density and distribution based on data collected in 1939–1940 and 1999–2000 as part of the park's Natural Resource Condition Assessment (Theobald et al. 2010a).

In 2009–2010, citizen scientists helped park staff collect occupancy data from plots across a range of habitats to assess park-wide beaver status. Results suggested that beaver occupy only 10% of the most suitable streamside habitat in the park (Scherer et al. 2011). Evidence of current beaver presence was detected in too few locations to statistically analyze the data or rigorously evaluate the NRCA map of potential habitat; however, results suggested that the map has some predictive power.

Bighorn Sheep

The bighorn sheep (*Ovis canadensis*) is the symbol of Rocky Mountain National Park as well as the state animal of Colorado, which has more bighorn sheep than any other state. The greatest threat facing the remaining bighorn populations in North America for the last century has been pneumonia, introduced by domestic sheep and goats, which can quickly kill off more than half a herd of bighorn sheep (McClintock and White 2007).

One researcher estimated that as many as 4,000 bighorn may have been present in the area at some point, and the number had dropped to 1,000 by 1915 when the park was established (Packard 1946). More robust estimates based on survey data were not done until the 1970s, when the park population was estimated at about 200 sheep. The low number was attributed to insufficient low-elevation winter habitat within the park and the grazing of domestic sheep along the park boundary. The population rebounded to nearly 700, allowing the transplanting of 142 sheep from the park to the Big Thompson and other herds from 1979 to 1989 (George and Anderson 2009). But then the park herds collapsed again, at least partly because of a pneumonia epidemic.


JOHN MARINO, NPS

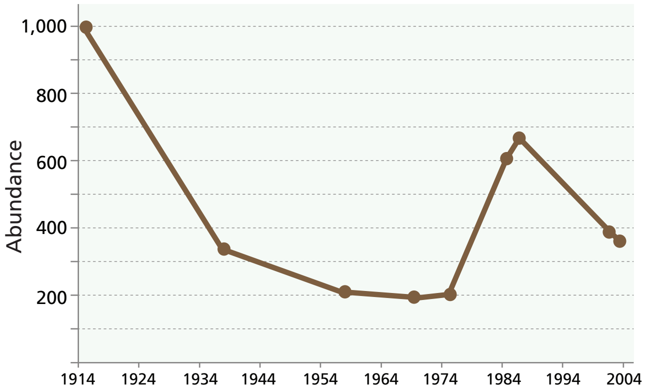


Figure 11. Bighorn sheep population estimates for Rocky Mountain National Park, 1915–2004. (Based on McClintock and White 2007.)

In 2004, the last peer-reviewed, published survey estimated that 366 bighorn sheep were using the Never Summer, Continental Divide, Mummy Range, and Cow Creek areas of the park, with only 24% of the lambs surviving at least one year (McClintock and White 2007; fig. 11). Biologists are currently developing a non-invasive population estimation technique using fecal DNA because accurate estimates using radio collars and aerial surveys are expensive and risky for both the sheep and researchers.

Genetic sampling of the four herds whose ranges currently include land within the park plus the herd that occupies an area east of the park along the Big Thompson River, found that all five herds had reasonable and comparable levels of genetic variation (Driscoll et al. 2012; fig. 12). This is most likely a result of gene flow due primarily to migration of rams among the herds. Even the Mummy Range herd, which is the smallest, showed no evidence of inbreeding.

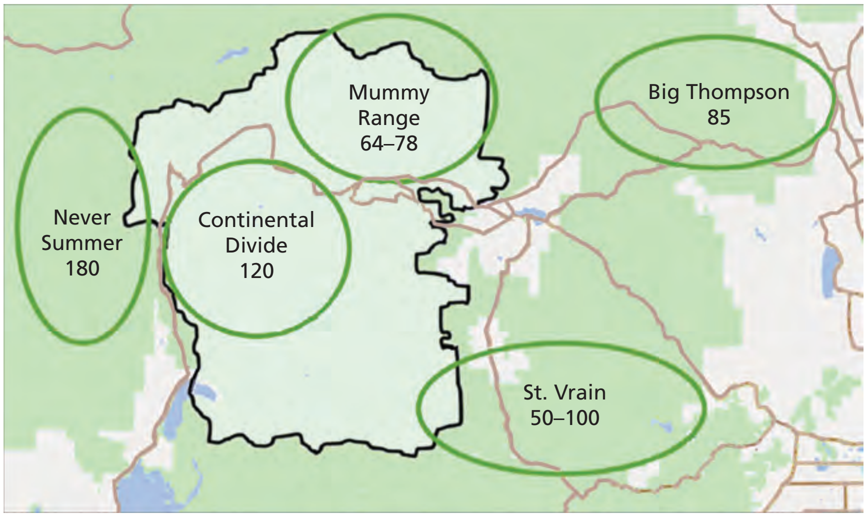


Figure 12. Geographic ranges and population estimates for the five bighorn sheep herds in and around Rocky Mountain National Park. (Adapted from Driscoll et al. 2012).

Black Bears

Visitors value the sighting of a black bear (*Ursus americanus*) in the park, especially since the population is relatively small. Data collected from 1984 to 1991 indicated a population of approximately 20 to 25 park bears, one of the lowest population densities with some of the lightest black bear weights on record in North America (Zeigenfuss 2001). The low population density is likely due to a short growing season and limited natural food sources (Baldwin and Bender 2009). The most recent research in the park (2003–2006, summarized in Baldwin and Bender 2012) found that

- The bear population appeared to be stable to increasing, with an estimated minimum known population of 20 to 24 bears and median density of 1.35 bears per 100 km^2 (90% CI = 1.23–1.48).
- Annual survival was high for adults and sub-adults.
- The bears denned closer to areas characterized by higher human presence and overall bear distribution had shifted toward human-use areas (70% of bear locations compared to 51% in the 1984–1991 data).
- The bears appeared to be habituating to humans, a trend likely associated with access to human food.
- Compared to the 1984–1991 data, the female bears had higher body condition index and body weight, earlier age of first reproduction, higher cub survival and recruitment, more reproductive years, and higher lifetime reproductive output per female, resulting in reproductive rates similar to those of other western U.S. black bear populations.

Monitoring population trends in low-density populations is important to assess long-term population viability, but the research required to estimate the minimum population is difficult and expensive. Although park staff do not have the capacity to study bear population size and structure on an annual basis, they closely monitor the occurrence of negative incidents involving bears and humans or human property.

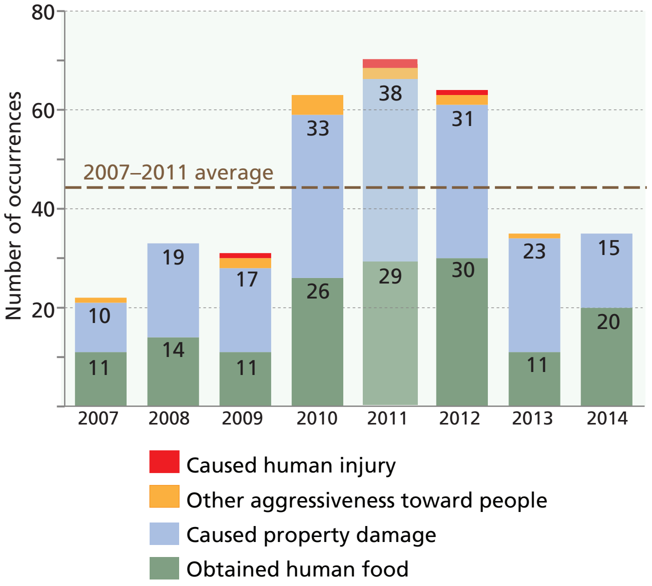


Figure 13. The number of negative human-bear encounters, 2007–2014, compared to the average annual total during 2007–2011.

From 2007 to 2014, bears most often obtained human food at backcountry campsites (29% of the occurrences), frontcountry campsites (21%), and from dumpsters or trash cans (19%). The most frequent forms of property damage were to camping gear (64 occurrences) and vehicles (51).

In 2012, park staff initiated a long-term effort to reduce the number of negative events below the 2007–2011 annual average of 44 by increasing visitor and staff education, providing more bear-proof storage facilities, improving compliance with food storage rules, and increasing attention to trash management. In 2014, bears were known to have obtained human food or caused property damage a total of 35 times (fig. 13). Since 2007 there have been three reported incidents that resulted in human injury and 12 others that involved aggressive behavior toward people.

Cutthroat Trout

Of the six lineages of cutthroat trout (Oncorhynchus clarkii) known to be native to Colorado, two occurred in the park before the area was settled: the greenback cutthroat that was native to the South Platte drainage on the east side of the continental divide, and a subspecies currently referred to as the green lineage) on the west side. While the historical records are incomplete, it is probable that because of the cold water and physical barriers to fish migration, cutthroat and other native fish in the park were present only in lower-elevation streams and lakes prior to European settlement (see map in Lakes and Streams, page 11).

The introduction of nonnative trout to enhance opportunities for recreational fishing in Colorado led to a serious decline in native cutthroat trout populations and limited their distributions primarily to isolated headwater streams and lakes. From 1886 to1968, brook, brown, rainbow and various cutthroat trout subspecies were stocked in what became or were park waters (see “Nonindigenous Aquatic Species,” page 26). Through competition and interbreeding, these nonnative trout have reduced the size and genetic purity of native cutthroat populations. Cutthroat trout are also threatened by whirling disease (Myxobolus cerebilis), an invasive pathogen from Europe that has spread throughout the country. The pathogen is present in the park but no clinical signs of whirling disease have been observed (Kennedy 2014).

The classification of native cutthroats is an area of active research and debate. Traditionally cutthroat trout were classified by subspecies based on geography and quantitative characteristics, such as the number of scales. Recent research and more advanced techniques for assessing genetics have revealed that many cutthroat populations, including most of those in the park, are not the subspecies they were thought to be. The U.S. Fish and Wildlife Service is conducting a status review to consider needs for any change in subspecies listings under the Endangered Species Act.

Park staff are working with researchers to evaluate the current number and genetic assignment of RMNP cutthroat populations. Based on the most recent analysis, no populations of the cutthroat trout native to the east side of the park remain, but four, relatively pure (<20% mixed heritage) populations of the cutthroat trout native to the west side of the park are still present (Stowell et al. in review).

Cutthroat trout

Fishing in Lily Lake

NATIVE WILDLIFE

Elk

Elk (*Cervus elaphus*) are a major attraction at the park, with some of the highest visitation occurring during autumn to observe elk mating behavior. The elk that use the park are part of a regional, migratory population (fig. 14).

After commercial hunting extirpated elk from the region in the late 1800s, they were reintroduced in 1913 and 1914. By then, wolves had been eliminated from the area and the elk population grew quickly until park managers began limiting it in 1945. After population control ended in 1968, the number of elk wintering on low-elevation winter range on the east side of the park increased at an annual rate of 6.5% and then gradually stabilized, fluctuating around 1,000 from the mid-1980s through the 1990s. Studies showed that the large population and high concentrations resulted in significant adverse impacts on aspen and willow communities which support high biological diversity. Ecosystem modeling predicted that if the suite of native predators was intact, the number of elk wintering in the park would fluctuate between 200 and 800, allowing willow and aspen to persist.

To restore a more natural range of variability in the elk population and vegetation communities, the 2007 Elk and Vegetation Management Plan (NPS 2007) set a winter population objective of 600 to 800 elk in the park and 1,000 to 1,300 in the Estes Valley. To maintain the park population at the low end of that range, 130 female elk were culled from 2009 to 2011. In addition, 20 female elk in a 2008 research project received a contraceptive to test its efficacy in preventing pregnancy; 19 of the cows were infertile the following year.

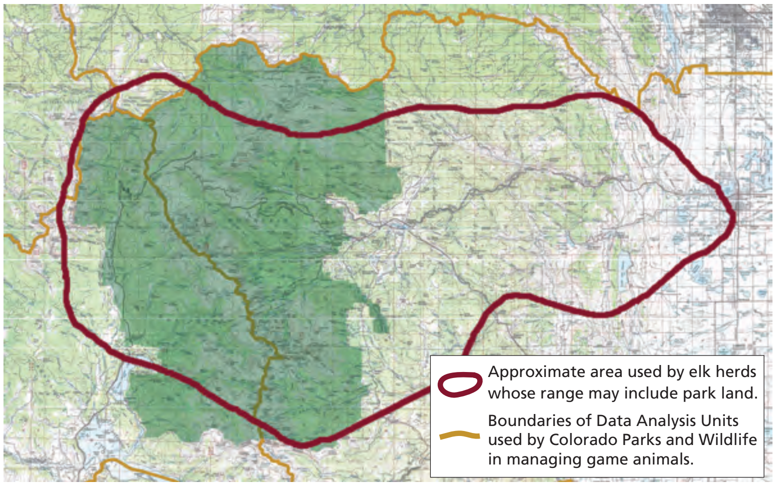


Figure 14. Range used by elk in and around Rocky Mountain National Park. (Based on unpublished data compiled by the National Park Service and Colorado Parks and Wildlife.)

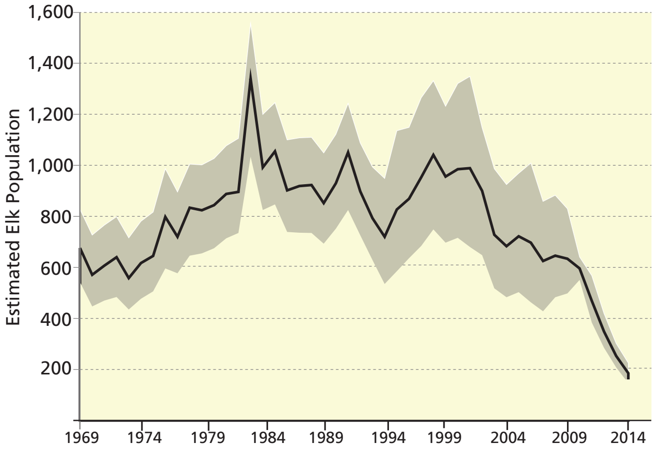


Figure 15. Model estimates (solid line) of the number of elk on winter range in Rocky Mountain National Park from 1969 to 2014. Shaded area indicates 95% Bayesian credible intervals. (Unpublished data from N. Thompson Hobbs).

The frequent movements of elk across the RMNP boundary hinder efforts to quantify their use of winter range in the park. However, an eastward shift in the elk herd's range that began in 2002 became more apparent in the winter of 2011–2012, when groups of more than 100 elk were observed in and around the Loveland area while fewer elk wintered in RMNP and Estes Park (fig. 14). This decline has continued; in the winter of 2013–2014, the estimated median winter elk population was 185 in RMNP (95% Bayesian credible interval = 146–225) (fig. 15) and 330 in Estes Park (BCI = 250–420). These estimates are based on preliminary ground survey and modeling methods that are being developed to better quantify the use of winter range (Hobbs 2014).

The leading cause of cow elk mortality from 2008 to 2014 was chronic wasting disease, with the estimated percentage of infected cows fluctuating between 6% and 13% (Monello et al. 2014). Ongoing research will enable us to better quantify the proportion of time that elk spend in the park, cow elk survival rates, and causes of mortality.

Pika

The American pika (*Ochotona princeps*), a charismatic and conspicuous inhabitant of many western mountains landscapes, is considered a sentinel species for detecting ecological effects of climate change. Temperature and precipitation, the major determinants of geographic range in most species, appear to be the cause of the pika's recent range shifts.

Data collected in 2010 during the first comprehensive pika survey in the park provide a baseline for subsequent monitoring. Of the 58 potential sites surveyed then, 39 (67%) were considered occupied, 7 contained only old sign, and 12 lacked any evidence of pika activity (Jeffress et al. 2010; fig. 16). The percentage of occupied sites dropped to 43% in 2011, when pikas or fresh sign were found at 29 of the 68 potential sites that were surveyed (Jeffress et al. 2013, fig. 16). Of the 20 sites surveyed in both years, 7 of those considered occupied in 2010 had no pika sign in 2011. At the seven other national parks that were surveyed both years, the occupancy percentage increased at three and decreased at four.

Turnover in site occupancy is high in pikas (Peacock and Smith 1997). A longer time series of data is needed to understand annual occupancy fluctuations and distinguish between short-term and long-term change.

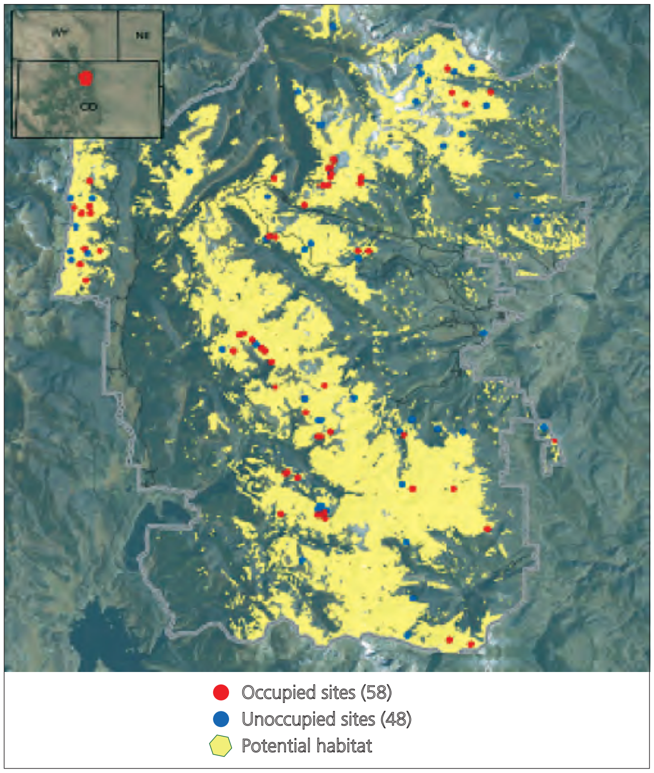


Figure 16. Results of survey for pika at 106 potential sites in the park in 2010 and 2011 (Map from Jeffress et al. 2013).

Ptarmigan

As one of the few North American species that lives its entire life near or above treeline, the white-tailed ptarmigan (*Lagopus leucurus*) is an important indicator of alpine ecosystem health. During monitoring from 1968 to 1994 by the Colorado Division of Parks and Wildlife, the park's ptarmigan population appeared stable, but breeding activities were correlated with climate, suggesting that ptarmigan could be negatively impacted by rapid climate change(Wang et al. 2002). After a 15-year hiatus, annual monitoring began again in 2010.

Ptarmigan density was monitored in three areas along Trail Ridge Road from 2010 to 2014. The Toll Memorial area near the top of the road typically has the highest density, followed by the Fall River area and the Tombstone Ridge-Sundance area (Braun et al. 2010). The estimated density of the combined areas was 6.9, 7.8, 5.6, and 5.2 birds per km^2 in 2010, 2011, 2012, and 2013, respectively. The last two surveys were both within but on the low end of the range of 4.5–13.5 birds observed during research conducted from 1966 to 1994 (Braun et al. 2010). In 2013, the 10 hens monitored through the breeding season had 60% nest success.

Along with climate changes, the degradation of alpine willows from elk browse may be contributing to population declines (Braun et al. 1991). Current research is focused on continued monitoring of density and reproduction success and better elucidating the causes of recent population declines..

Native Species of Concern

The flora and fauna of the park are protected within its boundaries from hunting, trapping, and collecting. However, several native species were extirpated from the area before the park was established in 1915.

Wolves (*Canis lupis*) and bison (*Bos bison*) were present in the late 1800s, but largely gone by 1915 (Armstrong 1987). Grizzly bears (*Ursus arctos*) were apparently more resilient; a few were seen in the area of the park as late as the 1920s (Armstrong 1987). Lynx (*Lynx canadensis*) and wolverines (***Gulo gulo***) were also destroyed as predators. Some of the bird species that were present historically are no longer seen in the park. For example, the yellow-billed cuckoo (*Coccyzus americanus*), which is dependent on dense riparian woodlands, has declined throughout the West (Carter 1998).

River otter.

As of 2015, the park provides habitat for only a few federally-listed threatened and endangered species. Greenback cutthroat trout (see page 16) and lynx are threatened species. Lynx, which were reintroduced in Colorado from 1999 to 2006 using more than 200 animals relocated from Canada and Alaska, are rare in the park. Lynx sightings are difficult to confirm because their appearance is similar to that of bobcats. Changes in snow cover and vegetation driven by warmer temperatures are expected to likely cause a significant decrease in suitable habitat for lynx in the coming century (Gonzalez et al. 2007).

Lynx. Photo: USDA Forest Service.

Several species in the park are considered threatened and endangered in the state of Colorado, including wolverines, river otters (*Lontra canadensis*), bald eagles (*Haliaeetus leucocephalus*) and boreal toads (see Amphibians, page 12).

Species of management concern within the park include relatively common wildlife such as elk, pika, and ptarmigan (covered earlier in this report), and moose. After they were introduced in North Park in the 1970s, moose (*Alces alces*) became common throughout RMNP. Historical records indicate that moose were occasional visitors to the area before the 1970s, but it is unlikely that there were reproducing populations (Armstrong 1987). The large increase in moose populations may be having a negative impact on willows and riparian communities.

With the encouragement of the Estes Park Game and Fish Commission, park staff launched a program in 1922 to eliminate predators of game animals. This reduced the park's populations of bobcats, wolves, foxes, lynx, coyotes, and mountain lions, the carcasses of which appear in this photograph.

Wetlands

Rocky Mountain National Park has a diverse array of wetlands that provide important ecological functions for a broad suite of species. Along with the alpine, wetlands are probably the most recognizable habitat type in the park. The topology, soils, historical climate patterns, and geologic age of the park's landscape have been conducive to the formation and maintenance of fens, wet meadows, and riparian wetlands. However, research suggests that wetlands are threatened by local and large-scale stressors, especially shifts in climate. Wetlands in the park have also been impacted by wildlife use, water diversions, and the loss of beaver.

At 154 wetland sites in the park that have been sampled since 2007, the Rocky Mountain Inventory and Monitoring Network (ROMN) has recorded 465 vascular and 73 non-vascular plant taxa. This represents more than 30% of the park's flora in only 4–5% of its area. About 48% of the park's avian and 20% of its mammal species are also commonly found in these wetland areas. ROMN crews have documented many other characteristics of these sites, including vegetation cover, ground water hydrology, woody stem density, damage to woody stems by beaver and ungulates, and other anthropogenic and natural stressors that influence wetland condition (Schweiger et al. draft report).

Using the data collected at wetlands in the park, the ROMN and their collaborators created multimetric indices (MMI) to provide estimates of wetland conditions based on vegetation community structure (Schoolmaster et al. 2013). They also established thresholds to assess the extent to which the wetlands have been affected by invasive species, trails, water diversions, dams, fences, and other human activity. Data collected from 2007 to 2009 suggest that 31% to 49% (depending on type) of the park's wetlands was in a human-disturbed or non-reference condition (fig. 17).

Many wetland sites, especially at higher elevations, were in reference condition with intact vegetation communities (high native species richness, high cover of wetland obligates, etc.). In contrast, the Kawuneeche Valley sentinel site is an example of a wetland where, although native forb cover was above the reference threshold from 2008 to 2013, invasive species richness was in a non-reference condition, pushing the overall MMI below the reference threshold for all six years. Ongoing work will examine the wetland data to look for causal links among ungulates, beaver, hydrology, and vegetation response.

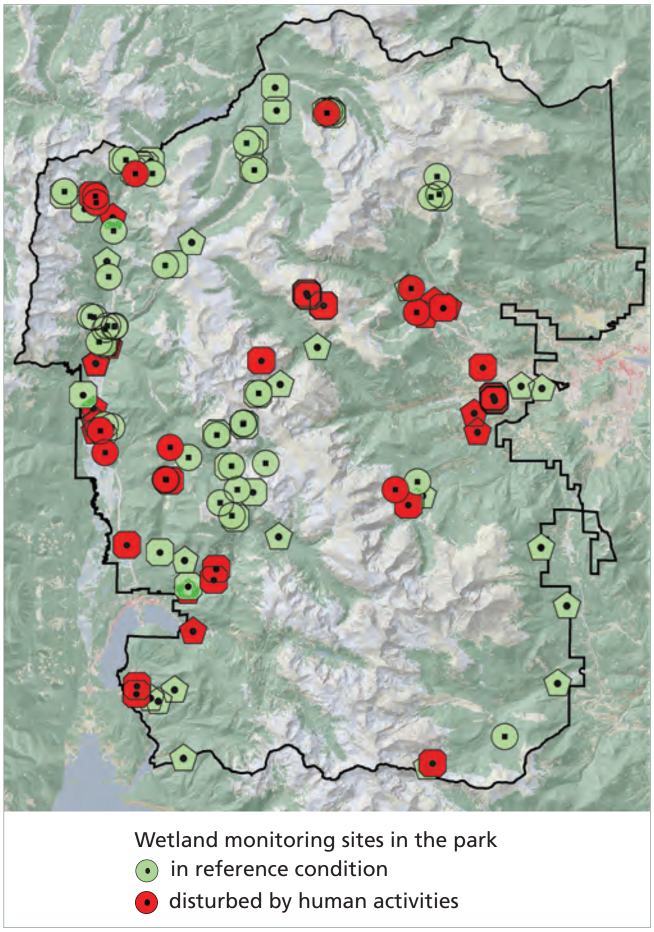


Figure 17. Wetland monitoring sites determined to be in reference or non-reference condition, 2007–2009.

VEGETATION COMMUNITIES

Montane

The montane ecosystem occurs at elevations from approximately 5,600 to 9,500 feet. Dry, south-facing slopes of the montane zone often have open stands of large ponderosa pine (*Pinus ponderosa*). Grasses, other forbs, and shrubs may grow between the widely spaced trees on dry slopes. In areas with more moisture and on north-facing slopes, aspen (*Populus tremuloides*), lodgepole pine (*Pinus contorta*), and Douglas fir (*Pseudotsuga menziesi*i var. *menziesii*) are found interspersed with ponderosa pine.

During the last century, altered fire regimes, beetle outbreaks, park development, invasive plants, and intense wildlife use have changed the montane ecosystem. For example, nonnative cheatgrass (*Bromus tectorum*), which outcompetes native plants and increases fire danger, is now found throughout the montane zone (NPS 2014; see invasive species section).

Forest structure, fuel loads, and understory plant composition in the montane zone have been monitored by the RMNP Fire Effects Program since 1998 (Williamson 2013). The most abundant of the more than 245 understory species documented in those plots, are native graminoids including Parry's oatgrass (*Danthonia parryi*), sedges (*Carex* spp.), and mountain muhly (*Muhlenbergia montana*).

Of the nine tree species in the plots, the most common are ponderosa pine (54 plots), lodgepole pine (27 plots), and Douglas fir (27 plots). The average density of live mature trees (> 2.5 cm in diameter) from 1998 to 2013 was 472 stems per hectare. Logging, homesteading, and frequent fires in the late 1800s contributed to low forest cover when the park was first established (see the Fire section, page 6). Over the past century, tree density in the montane forest has increased (Veblen and Lorenz 1991; fig. 18).

Park staff use prescribed fire, mechanical thinning, and invasive plant control to manage and improve ecological conditions and reduce fire risk in the montane zone.

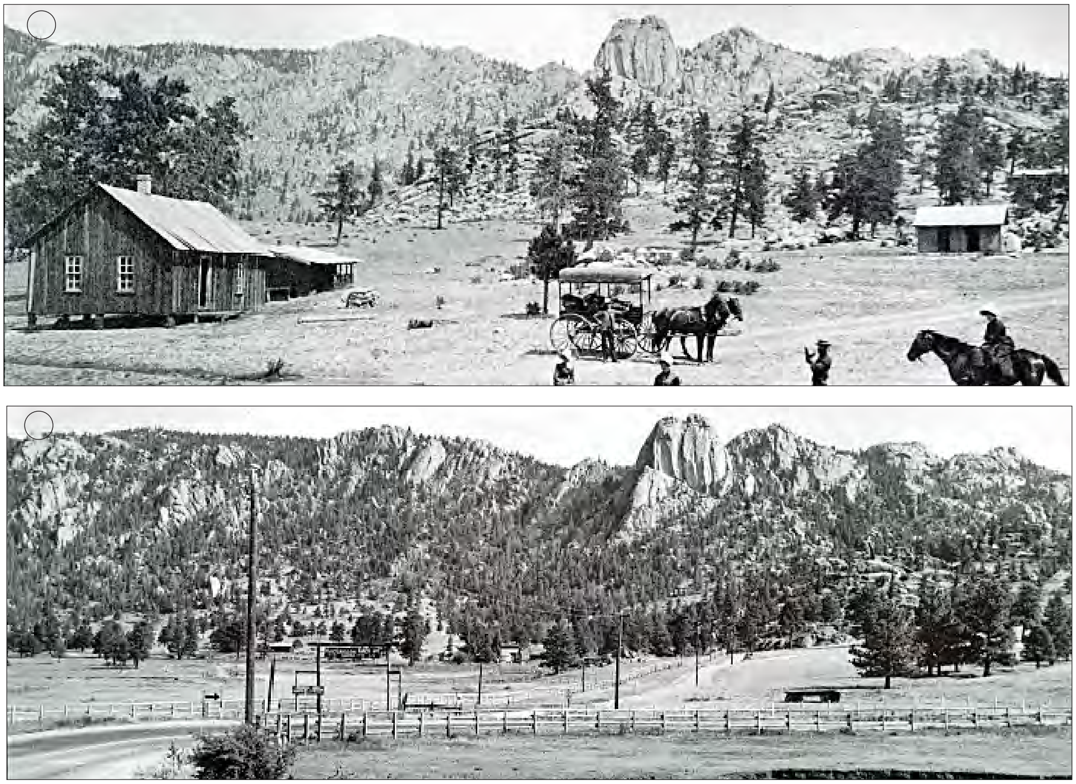


Figure 18. View north of the Twin Owls and Lumpy Ridge. In photo A (c. 1900, photographer unknown, Denver Public Library), the rocky slopes are sparsely covered with ponderosa pine and Douglas fir. Photo B (1986, T. Veblen and D. C. Lorenz) shows a large increase in stand density, with the crowns of Douglas fir recently defoliated by spruce budworm in the background. (Photos cropped from images in Veblen and Lorenz 1991.)

Bark Beetles

Bark beetles are native insects that have shaped the forests of North America for thousands of years. Like other dead trees, those resulting from beetle outbreaks contribute to the diversity of forest habitats for cavity-nesting birds and other species. With winters too mild to kill off the beetles and dense forests stressed by drought, the mountain pine bark beetle (*Dendroctonus ponderosae*) outbreak that began in 2002 became the most severe in the park's recorded history.

Along the Continental Divide National Scenic Trail

A tree's vulnerability to beetle infestation depends partly on the age and structure of the stand, the tree's health and proximity to an existing infestation. Bark beetle populations typically diminish as the most susceptible trees are killed. U.S. Forest Service surveys indicate that more than 100,000 acres, or about 90% of the park's forested areas, have been affected, killing hundreds of thousands of lodgepole pine, ponderosa pine, Douglas-fir, limber pine (*Pinus flexilis)*, Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and Colorado blue spruce *(Picea pungens)*. The infested areas in the park declined from a high of approximately 85,000 acres in 2009 to 55,000 acres in 2011 (data from USDA Forest Service, Forest Health Protection and its partners).

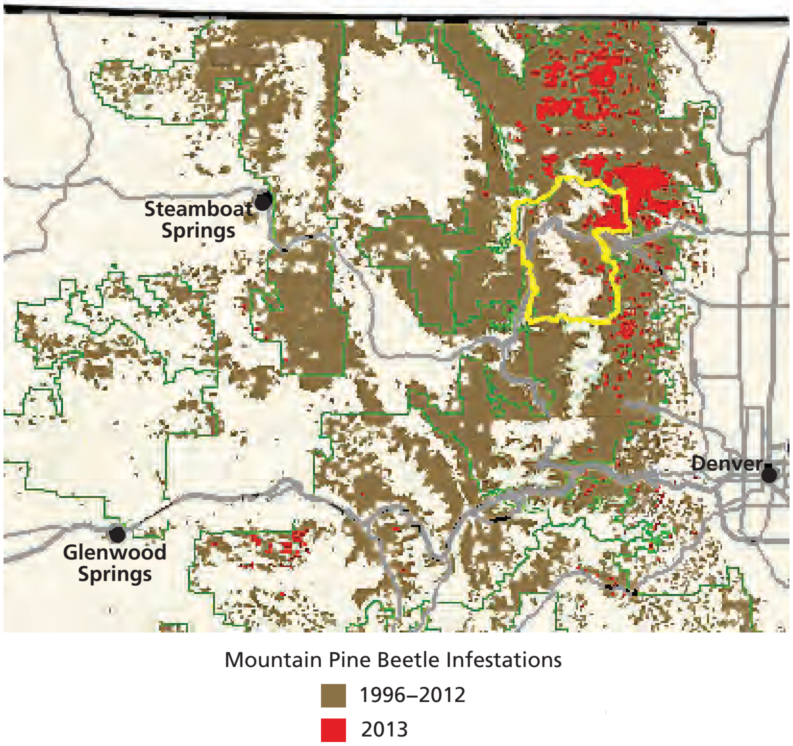


Figure 19. Areas of mountain pine beetle infestation in north-central Colorado during 1996 to 2012 and in 2013. (From map by USDA Forest Service.)

In Colorado, areas of active mountain pine beetle infestation have decreased since 2008. Areas of significant beetle impact include 85,000 acres in Larimer County, representing 87% of all mountain pine beetle activity in the state in 2013 (Colorado State Forest Service 2014)(fig. 19). However, along the Front Range south of the park to the I-70 corridor, a substantial population of host trees, suitable for attack and brood development, remains.

The eventual collapse of standing dead trees makes them a hazard to human life and property. Park staff have made a concerted effort to remove standing dead trees in backcountry and frontcountry campsites and other highly visited areas. They have also sprayed thousands of tree trunks in the frontcountry with insecticide to help prevent beetle infestations. As 95 % of the park is designated wilderness, bark beetle populations are allowed to fluctuate under natural processes in most of the backcountry.

Subalpine

The subalpine life zone, which lies from approximately 9,000 to 11,400 feet in elevation, is the most heavily forested of the park's three primary vegetation communities. The dominant tree species are Engelmann spruce, subalpine fir, lodgepole pine, Douglas fir, aspen, and limber pine. The forest tends to be dense, with only minimal light reaching the forest floor, and contains a wealth of diversity. Subalpine growing seasons are relatively short and snow blankets the forest for much of the year.

Similar to many other areas of the western U.S. , the park experienced an epidemic outbreak of mountain pine beetles beginning in the early 2000s that resulted in extensive mortality of lodgepole pine and limber pine (see Bark Beetles, 22). Limber pine, which provide valuable wildlife food and habitat, are a particular concern due to mortality from mountain pine beetles and a nonnative pathogen, white pine blister rust (*Cronartium ribicola*), which is causing large-scale mortality outside the park. Blister rust was first confirmed in the park in 2010, in the limber pine at Rainbow Curve, but it is not currently evident (Schoettle et al. 2013).

Shifts in subalpine forest structure and composition from changing climate, altered disturbance regimes, and altered land use are occurring and expected to increase in the coming decades. Recent studies have documented changes in forest structure and species migration over the past 40 years (Peet 1981, Esser 2014). The forest response to these changes has varied by species, topographic position (northern vs. southern aspect), and by the presence of disturbances such as fire and mountain pine beetles (Esser 2014). While the stem density of limber pines has shown relatively no change, shade-tolerant species such as Douglas-fir and subalpine fir have increased their abundance (fig. 20).

Models predict and observational data suggest that as temperatures increase, subalpine trees, such as limber pine, will move upslope (Monahan et al. 2013, Esser 2014) but disturbances such as fire, beetles and white pine blister rust will be the primary drivers of patterns of forest distribution.

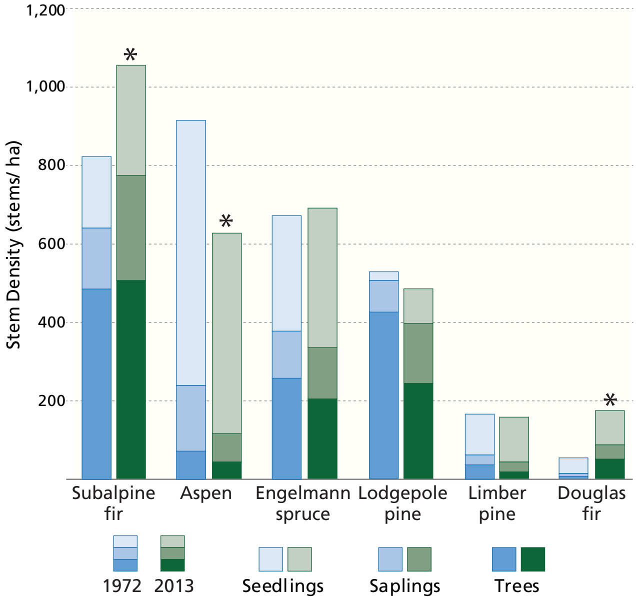


Figure 20. Stem density of six tree species measured on monitoring plots in the park in 1972 and 2013. The asterisks (*) indicate species in which a significant change in density occurred during this period. (Data from Esser 2014).

Limber pine

VEGETATION COMMUNITIES

Alpine

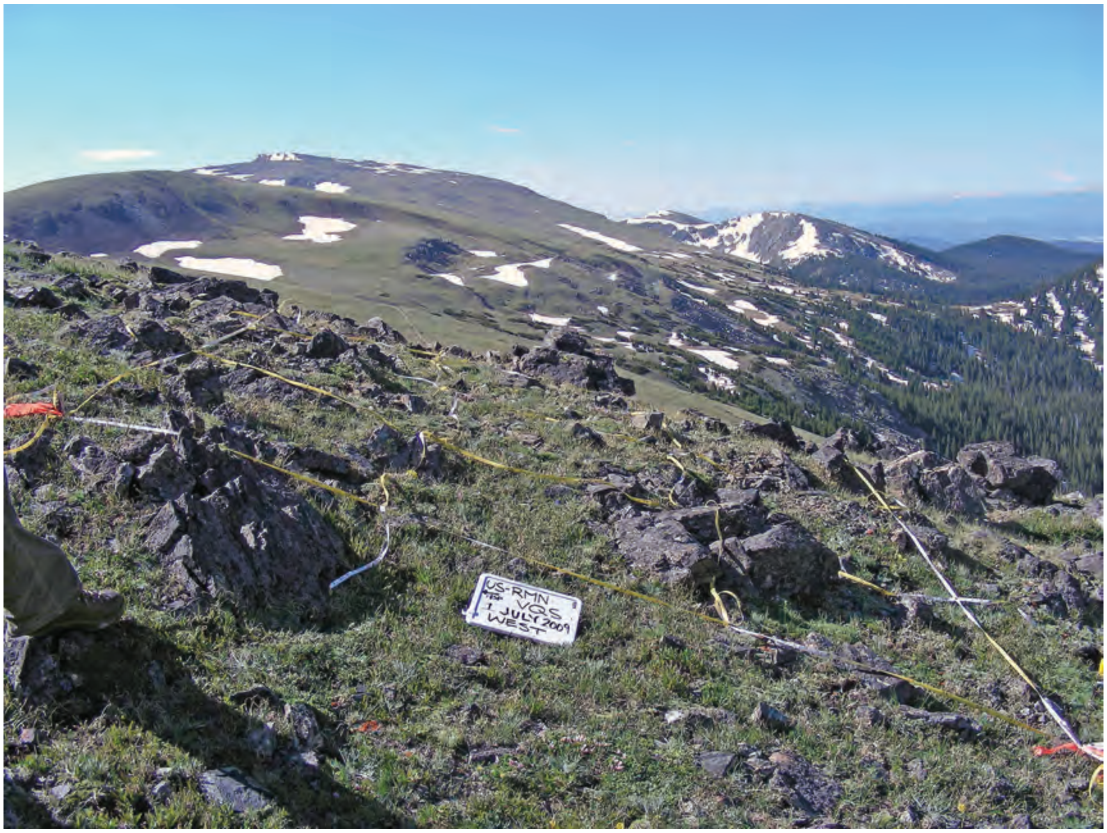
With about one-third of the park above an elevation where trees can thrive, visitor access to the alpine tundra is one of the park's most distinctive features. Alpine vegetation occurs above approximately 11,400 feet of elevation where the vegetation is primarily grasses, sedges, wildflowers, and low-growing shrubs. For most alpine plant species, growth and reproduction are strongly limited by environmental conditions and nutrient availability.

Paleoenvironmental records reveal that precipitation and temperature regimes changed after the local glaciers retreated 17,000–12,000 years before present. During that period, large shifts in treeline and vegetation zones occurred from tundra to forest and forest to shrubland (McWethy et al. 2010).

Although the stressors have been smaller in magnitude and the alpine tundra has generally been less affected by human activities than the park's other vegetation zones because of its relative inaccessibility and harsh climate, the alpine tundra is more sensitive to human impacts than other areas. Visitor trampling, increased nitrogen deposition, and previous livestock and current wildlife grazing have altered the landscape. Experimental and monitoring data along with paleoenvironmental records suggest that grasses and shrubs will be become more dominant over time and other plant species will begin to migrate upslope if nitrogen deposition and temperatures continue to increase.

Rocky Mountain National Park is part of the Global Observation Research Initiative in Alpine Environments, an international network established in 2001 to assess and predict biodiversity changes in alpine communities (Pauli et al. 2004). The ROMN established eight long-term plots on four summits in the park in 2009 to monitor trends in vascular plants and soil temperature. In 2009, the plots had an average of 18 species per square meter. Common dandelion (*Taraxacum officinale*), which was found in low abundance on the lowest peak, was the only nonnative species found.

The 2009 data will provide a baseline for monitoring at five-year intervals. Data from the 2014 sampling of all sites are currently being analyzed for indications of how the alpine vegetation and soil temperatures are changing over time.



Monitoring plots on the alpine tundra.

CHALLENGES

Biodiversity

Biodiversity is the variety of genes, species, and ecosystems in a region. Preserving and protecting biodiversity is increasingly recognized as a vital component of resource stewardship because it has a critical role in maintaining ecological integrity and resilience.

Biodiversity is threatened on global and local scales. Current extinction rates are estimated to be 1,000 times higher than in the past (De Vos et al. 2014). One major challenge is that our knowledge of species diversity is incomplete and species may be lost without prior knowledge of their existence. Of the estimated 9 million species on Earth, only 14% of the terrestrial species have been catalogued (Mora et al. 2011).

To increase our knowledge of the park's biodiversity, the National Park Service has partnered with the National Geographic Society to conduct ten 24-hour species inventories, called BioBlitzes, in national parks. The sixth BioBlitz, which took place in RMNP in 2012, documented several species in the park for the first time. Park staff have also promoted biodiversity awareness through workshops and partnerships with the E.O. Wilson Foundation, and by hosting biodiversity interns and students.

Approximately 3,182 species have been documented in the park. The Rocky Mountain Inventory & Monitoring Network added most of these records during a large effort to inventory vascular plants and vertebrates. The species lists they generated from museum collections, field surveys, and the published literature were all verified by taxonomic experts.

Similar efforts need to be made for invertebrates, nonvascular plants, and bacteria, all of which are poorly represented in NPSpecies even though they represent a large portion of the park's biodiversity. For example, of the estimated 6,000-8,000 arthropod species in the park (B. Kondratieff, pers. comm.), only 627—perhaps less than 10%—have been documented.

Pale swallowtail (Papilio eurymedon). *Photo by K. Daugherty*

Students participated in the 2012 BioBlitz. Photo by D. Biddle.

Thanks to a team of citizen scientists who have monitored butterfly populations since 1995, they are the most studied arthropods in the park.

The most complete list of RMNP species is maintained in the National Park Species database (https://irma.nps.gov/NPSpecies/) which can be accessed by the public.

Three of the park's documented arthropod species: grasshopper (photo by C. Bolt), wolf spider (K Aigner), and isopod (C. Bolt).

Nonindigenous Aquatic Species

Nonindigenous aquatic species can threaten the diversity and abundance of native species or the ecological stability of the waters into which they are introduced. For instance, whirling disease and chytrid fungus, both nonnative aquatic pathogens, are present in the park (see Cutthroat Trout, page 16, and Amphibians, page 12).

Fish

The 147 lakes in the park were fishless until trout were introduced to many of them beginning in the 1880s. This altered the food webs and phytoplankton, zooplankton, and benthic invertebrate communities in these lakes. Through hybridization and competition for food, these nonnative trout also diminished native fish populations in the few streams that had them. Eastern brook trout (*Salvelinus fontinalis)*, rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), and Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) were stocked for recreational fishing until the 1960s, and 50 lakes still contain remnants of those populations.

Mussels

Zebra and quagga mussels (*Dreissena polymorpha* and *D. rostriformis bugensis*) are small freshwater shellfish native to Eurasia. Both species were discovered in the Great Lakes in the late 1980s, when they were discharged in ballast water of ocean-going ships. They spread to other waters in the United States on boats, trailers, and other equipment. Once the mussels are established in an area, they can grow in large numbers, out-compete native species, remove substantial amount of phytoplankton from the water column, and alter aquatic food webs.

In 2008, zebra and/or quagga mussel larvae were found outside the park's southwest boundary in Grand Lake, Lake Granby, Shadow Mountain Lake, and Willow Creek reservoir (fig. 21). The State of Colorado initiated mandatory boat inspections and, when necessary, boat decontamination, and no mussels have been detected in those waters since 2008.

Snails

The New Zealand mudsnail (NZMS), *Potamopyrgus antipodarum*, was first documented in the United States in 1987 and in Colorado in 2004. It has spread to waterways throughout the U.S. West (fig. 21) and in the Great Lakes, where it can reach densities of over 300,000 snails per square meter. In high densities, these snails can affect native species richness, alter nutrient dynamics, and may adversely affect trout populations.

NZMS are very small and may not be detected until they have been present in a body of water for a long time. Although they have not been found in the park, there is a chance they are already here. The threat of introduction is considered high because of the proximity of NZMS populations in Boulder, Larimer, and Jackson counties, and high park visitation. Properly cleaning and disinfecting clothing and equipment before entering the water is one of the best ways to prevent the spread of this and other nonindigenous aquatic species.

Zebra mussel. Photo: California Fish & Game

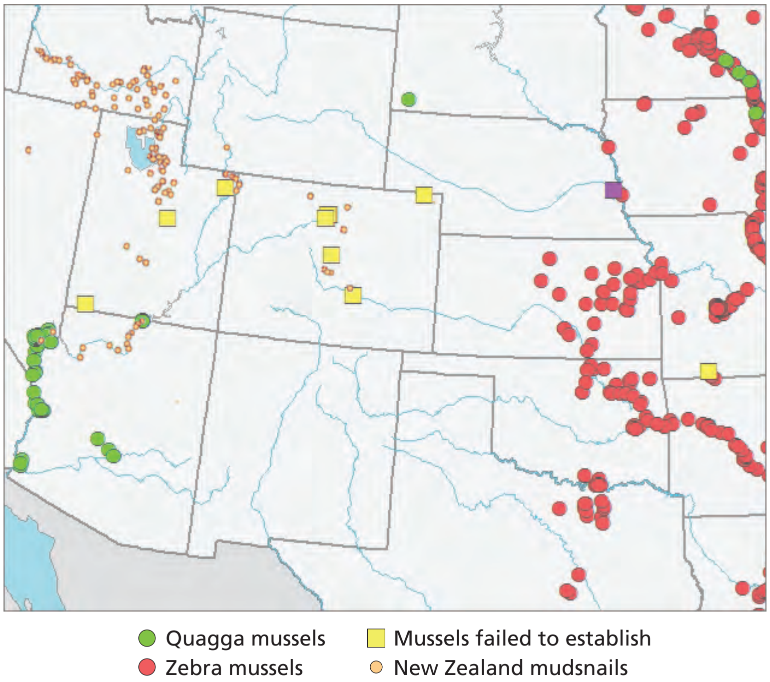


Figure 21. Reported sightings of quagga and zebra mussels and New Zealand mudsnails, 2014. (Based on U.S. Geological Survey maps.)

Invasive Plants

Of the 1,000 known vascular plant species in the park, more than 100 are exotic, including 42 that are considered invasive. These species are of concern because they displace native vegetation, degrade wildlife habitat, and reduce biological diversity. Despite efforts to prevent the spread of invasive species, their number, distribution,and abundance is growing. Invasive plants such as cheatgrass and Canada thistle (*Cirsium arvense*) can spread rapidly even in wilderness areas, and once they have become established, eradicating them is expensive and extremely difficult.

In RMNP, nonnative plants species are generally more abundant near streams and rivers, in flat areas, and at lower elevations (Kumar et al. 2006). Using data from vegetation maps developed through field sampling and remote sensing (Salas et al. 2005), the park's Natural Resource Condition Assessment (Theobald et al. 2010a) estimated that nonnative plants were present on 1.7% of the plots located within the park compared to 4.6% of the plots outside the park (fig. 22). Nonnative plants were more abundant east of the Continental Divide than to the west, and the highest percentages were found on plots in the lower montane (5.2% average cover) and riparian (4.6%) ecosystems, but nonnative plants were also found above 10,500' (1.7%). Canada thistle, yellow toadflax (*Linaria vulgaris*), spotted knapweed (*Centaurea maculosa*), and curly dock (*Rumex crispus*) can be seen along Trail Ridge Road at and above the tree line.

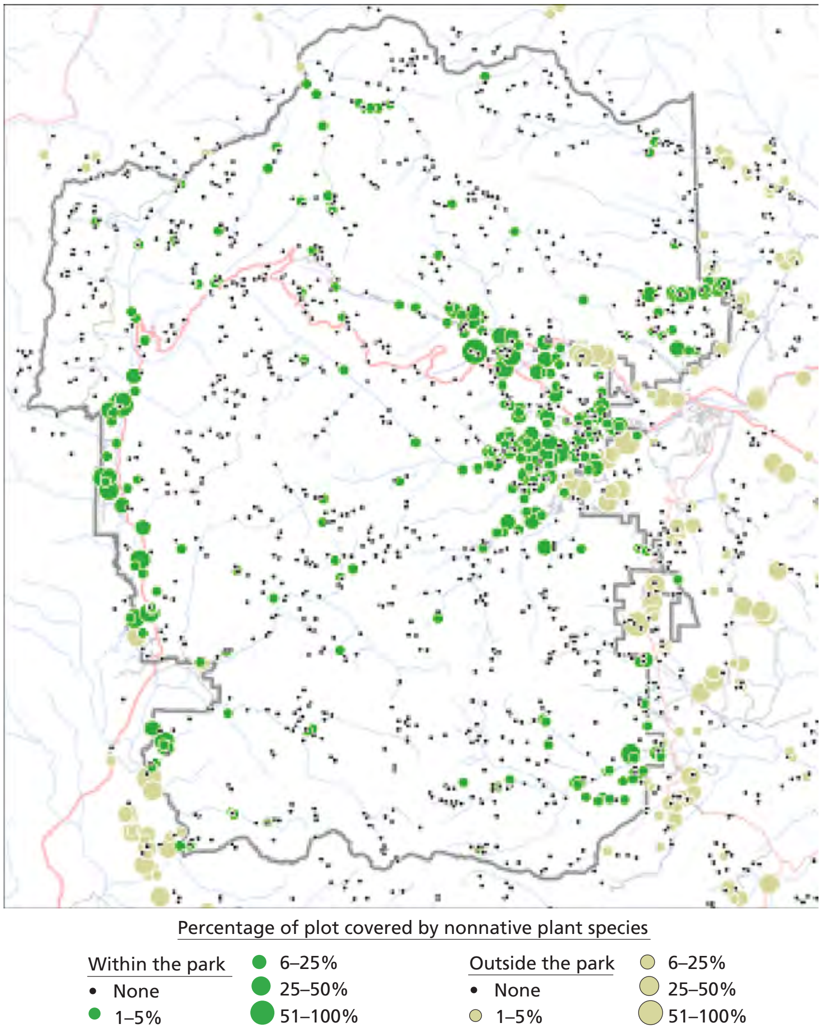


Figure 22. Percentage of nonnative plants in vegetation plots in or near Rocky Mountain National Park based on conditions in 2001 (Theobald et al. 2010a).

Within the plots monitored as part of the RMNP Fire Effects Program from 1998 to 2013, the most frequently found nonnative plant species were cheatgrass, Canada thistle , smooth brome (*Bromus inermis*), timothy grass (*Phleum pratense*), and dandelion (*Taraxacum officinale*). Cheatgrass had the highest average percent cover per plot, 5.6%. In 2014, it was found in two of the six plots surveyed, at 4% and 9% cover. These data are consistent with the general trend of increasing frequency and cover of cheatgrass in the park since the 1990s (Bromberg et. al 2011).

Control of invasive plants in the park began in 1960 using synthetic herbicides on Canada thistle and leafy spurge (*Euphorbia esula*). Using herbicides and manual removal, park staff and contractors treated 19 species on over 2,600 acres and up to elevations exceeding 10,000' in 2013. Treatment priorities are based on ecological impact, difficulty of control, the location and invasiveness of the species, and consideration of state and federal priorities (NPS 2003).

For a complete list of nonnative plant species in the park and treatment priorities, see the Appendix, page 38.

Mercury in Food Webs

Bioaccumulation of mercury in wildlife is becoming a greater concern because of the park's proximity to major metropolitan areas. After settling to the ground in dust particles or precipitation, some airborne mercury pollution is transformed into a more toxic form, methylmercury, that can accumulate in organisms. It becomes more concentrated as it travels up food chains, posing a risk to wildlife and human health. Park staff have been monitoring mercury levels in snowpack, dragonflies, and fish (see Snowpack Chemistry, page 10). Although there are natural sources of mercury, most of the mercury in national parks comes from coal-burning power plants that may be hundreds of miles away (Nelson and Pritz 2014).

Working with the U.S. Geological Survey and the U.S. Fish & Wildlife Service, the National Park Service monitored mercury levels in fish from 2008 to 2012 at 21 sites in the park. The average concentration (66.1 ng/g wet weight) was slightly lower at the RMNP sites than at 21 other national parks (Eagles-Smith et al. 2014). However, Mirror Lake (121.2 ng/g), was more than double the national park average and more than 6.5 times higher than lowest RMNP site, Lake Haiyaha (19.8 ng/g, fig. 23). Although concentrations in fish at most of the sites were below the threshold for toxicity to fish (200 ng/g), and the EPA limit for human health (300 ng/g), many sites were above the threshold for impairment to fish-eating birds (90 ng/g,). Brook trout from Mirror Lake and suckers from the Colorado and Fall Rivers longer than 50 mm (2 inches) are likely to exceed the EPA limit for human health. .

To complement the research on mercury concentrations in fish, youth citizen scientists have been sampling dragonflies in Lily Lake and the ponds near Holzwarth Ranch since 2012. Dragonflies build up higher levels of mercury than other water-dwelling insects because they prey on many smaller insects and they have a relatively long life span during which to accumulate the toxin. Mercury levels in the park's dragonfly larvae have been fairly high compared to those in other national parks (Nelson and Pritz 2014). Continued monitoring will provide evidence of any trends in mercury deposition and increase our understanding of the consequences for wildlife and visitors.

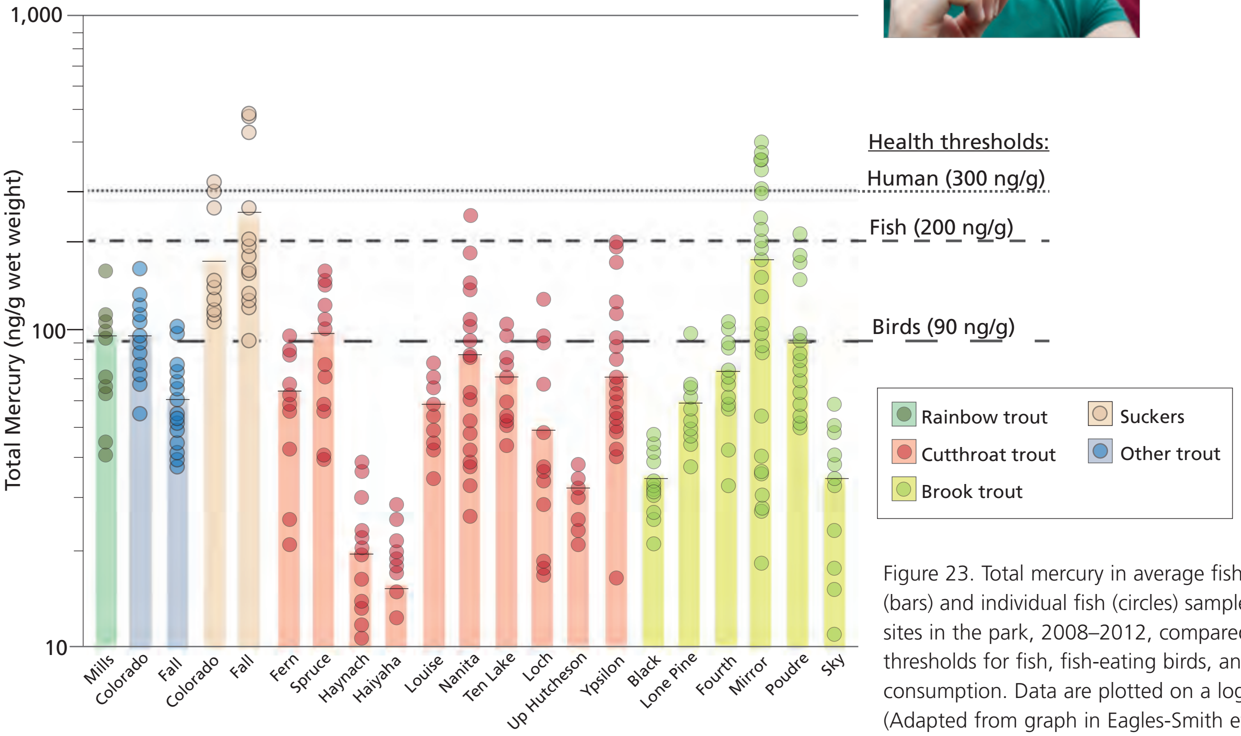


Figure 23. Total mercury in average fish tissue (bars) and individual fish (circles) sampled at 21 sites in the park, 2008–2012, compared to health thresholds for fish, fish-eating birds, and human consumption. Data are plotted on a $\log_{10}$ scale. (Adapted from graph in Eagles-Smith et al. 2014.)

CHALLENGES

Visitor Use

Rocky Mountain National Park was established in 1915 in part to provide people with access to its scenery. Unfortunately, increased visitation can degrade the park's resources and crowding can detract from visitor experience. Alpine vegetation, the spread of nonnative plants and aquatic organisms, wildlife distribution and habituation, soundscapes, and water quality are particularly susceptible to visitor impacts.

Park visitation has fluctuated since exceeding 3 million for the first time in 1998 (fig. 24). Factors that may affect the visitation count include weather, economic conditions, fee increases, fire events, and major construction projects. Visitation dropped just below 3 million in 2013 because of road closures east of the park after the September flooding and the government shutdown in October. In 2014, an estimated 3.4 million visitors came to the park, exceeding the previous record set in 2012. Typically 70% of park visitation occurs from June through September. July, which is usually the busiest month, averaged more than 22,000 visitors a day in 2014. About 96% of the visitors are from the U.S., and 28% from Colorado. (Papadogiannaki et al. 2011, Blotkamp et al. 2011).

Less than 1% of visitors spend one or more nights in the park's backcountry. Similar to trends at other western parks, overnight backcountry use in RMNP peaked in 1980 at more than 57,000 backcountry overnights (the total number of nights that campers spent in the backcountry (fig. 24). The fee that campers began paying for backcountry permits in 1995 increased in 1997 and 2004. Questionnaires completed by 682 backcountry users in the summer of 2002 indicated that 20% had hiked off designated trails (Wallace et al. 2004). Those who had camped in the backcountry spent an average of two nights there.

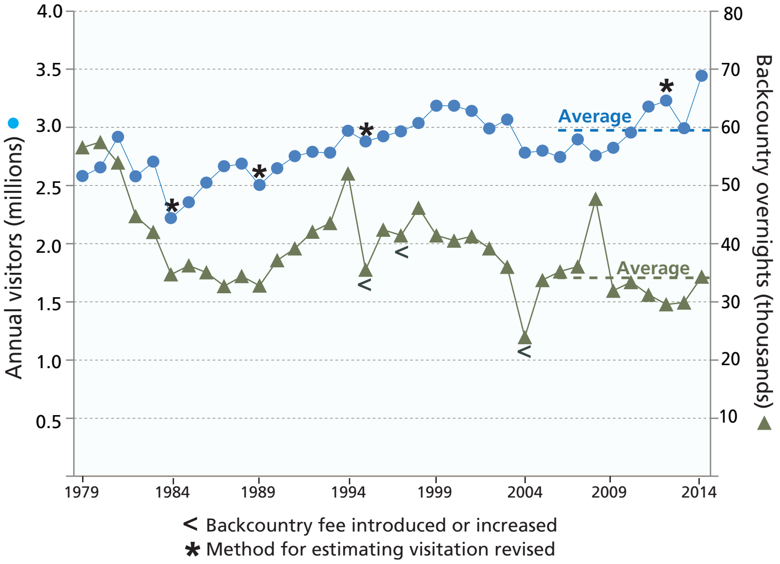


Figure 24. Estimated park visitors and backcountry overnights, 1979–2014, and annual averages for 2005–2014. Estimates for years in which the estimation method was revised are not directly comparable to prior years.

Unauthorized trail created at Sandbeach Lake.

Because nearly all park visitors are only present during the day, most visitor impacts are a result of day use. Managing day use is therefore a priority in order to protect park resources and maintain the quality of visitors' experiences. In one study, 78% of people indicated some level of crowding during their visit (Newman and Monz 2010). Current and emerging concerns include crowding withiin the Bear Lake Corridor, the impact of climbers, and the increasing use of areas such as Longs Peak and Wild Basin.

CHALLENGES

Land Use

The size and character of the human footprint within and around the park affects park resources such as vegetation, wildlife, wildland fire, and soundscape. Of the 415 square mile in the park, approximately 2.9% is developed. This includes the park headquarters, residences, visitor centers, and parking lots at trailheads and campgrounds. Nearly 95% of the park area is designated wilderness. Many dams, lodges, and other non-historic structures have been removed so that these areas can be restored to native vegetation. This includes the former Hidden Valley Ski Area and Moraine Park Golf Course. However, designated wilderness does include evidence of human use such as trails and backcountry campsites, and cabins that concentrate visitor use, disturb wildlife, and require management such as the removal of hazard trees and fire suppression.

The park is surrounded by federal, state, and private lands, and the towns of Estes Park, Allenspark, Glen Haven, Meeker Park, and Grand Lake. About 62% of the park boundary is adjacent to national forest, of which 70% is designated wilderness. In the surrounding area (9,450 km^2), 24% of the land was privately owned and 89% of the private land was developed as of 2000, with an average 0.323 homes per km^2, more than four times as many as in 1940 (Theobald et al. 2010b). The number of housing units has continued to grow since then, reaching more than 4,000 in the town of Estes Park, and twice that many in the entire Estes Valley (fig. 25).

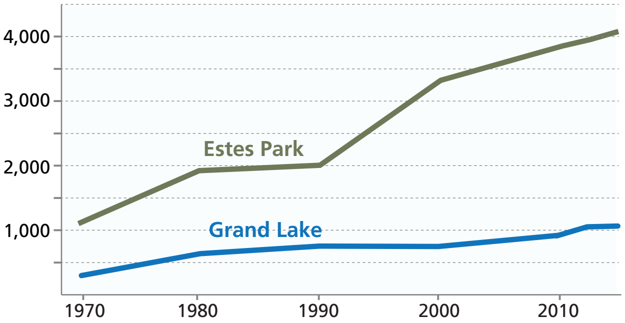


Figure 25. The number of housing units in the towns of Estes Park and Grand Lake, 1970–2012, based on U.S. Census data.

FEDERAL HIGHWAYS ADMINISTRATION

Soundscape

The ability of many wildlife species to find optimal habitat and mates, pursue prey or avoid predators, protect their young, and defend their territories depends at least in part on the acoustical environment. Human-caused sounds such as people's voices and footsteps, road traffic, and aircraft can mask the sounds that animals are making or listening for, resulting in changes in behavior, distribution, or survival.

Sound levels in Rocky Mountain National Park may exceed 80 dB on a busy road or drop below 25 dB in the backcountry but also vary widely depending on factors such as wind in the trees and the proximity of rushing water. Decibels are a logarithmic scale; an increase of 10 dB results in a doubling of perceived loudness. For example, while the sound of one vacuum cleaner might measure 70 dB, 10 of those vacuum cleaners would generate 80 dB. An increase of 5 dB in background sound level could reduce the distance at which a prey species could hear a predator approaching by 45% (Barber et al. 2009).

Although the effect of anthropogenic sounds on wildlife has not been studied in the park, some research projects have been designed to delineate its soundscape. For example, noise modeling based on data collected in the Bear Lake road corridor in 2008 was used to estimate that vehicular noise was audible to visitors until they had walked an average of more than a half mile from the trailheads (Park et al. 2010).

Commercial air tours over the park are prohibited, but other commercial, military, and private aircraft are allowed to fly over above a specified altitude. Acoustical monitoring stations were set up in the park for two months beginning November 19, 2012 to collect data on aircraft noise before the Federal Aviation Administration revised the flight routes for the approximately 600 daily flights into and out of Denver International Airport that are routed over the park (NPS Natural Sounds and Night Skies Division 2013a; fig. 26). The changes included a reduction in flights over the park's backcountry by channeling more flights into the corridor over Trail Ridge Road, an area already impacted by anthropogenic noise, and require pilots to use a glide-path that keeps their engine throttles idle all the way to the runway (Magill 2013).

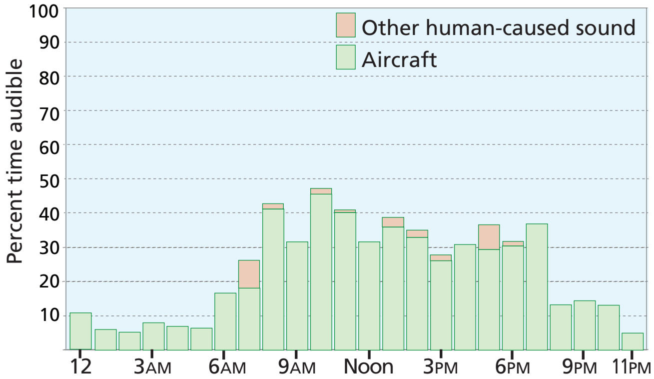


Figure 26. The average estimated percentage of time that aircraft and other human activities were audible at a backcountry site near Sandbeach Lake Trail during three days in June 2012. Other human-caused sounds may also have been present when aircraft were audible (NPS Natural Sounds and Night Skies Division 2013b).

Alberta Falls

OPPORTUNITIES

In the middle of difficulty lies opportunity.
— Albert Einstein

This vital signs report illustrates that some significant progress has been made and some of the challenges that lie ahead. The way forward, particularly in the face of climate change, can seem unclear and overwhelming at times. However, there is a way forward.

As we reflect upon the diversity of vital signs presented in this report, we know that our knowledge of the resources in Rocky Mountain National Park represents just the tip of the iceberg. And yet, those scientists who actually study icebergs can tell you much about the ice and environment that lies out of sight, beneath the waves of the ocean. So too do we know much more about the park's resources than is expressed with these vital signs.

Opportunities are abundant—from the diversity of research projects in our future to actions that we know can make a difference today; from engaging youth as citizen scientists to benefiting from those more seasoned; from understanding our local environment to exploring the landscape and global interactions that influence what we experience; and from engaging those with stories to tell of this land from hundreds and thousands of years ago to the people of all cultures who come to the park today to recreate, or to re-create themselves, among the peaks, alpine flowers and majestic skylines.

The way forward has been and will continue to be with people —to tell our collective stories, to enhance the value of science, to invest in science and relationships. Through relationships we will build understanding and coalitions of support so that future generations may enjoy this special place in the years to come.

Ben Bobowski
Chief of Resource Stewardship
Rocky Mountain National Park

DIRK O'NEILL

Literature Cited

Armstrong, D. M. 1987. Rocky Mountain mammals: A handbook of mammals of Rocky Mountain National Park and vicinity. Colorado Associated University Press. Boulder, Colorado.

Ashton, I. W. , J. Visty, E. W. Schweiger, J. R. Janke, and B. Bobowski (editor). 2013. State of the alpine report for Rocky Mountain National Park: 2010 Summary Report. Natural Resource Data Series NPS/ROMN/NRDS—2013/535. National Park Service, Fort Collins, Colorado.

Ault, T. R., A. K. Macalady, G. T. Pederson, J. L. Betancourt, and M. D. Schwartz. 2011. Northern Hemisphere modes of variability and the timing of spring in western North America. *Journal of Climate* 24: 4003-4014.

Baker, B. W., D. C. S. Mitchell, H. C. Ducharme, T. R. Stanley, and H. R. Peinetti. 2004. Why aren't there more beaver in Rocky Mountain National Park?. Pages 85–90 *in* Wildlife and Riparian Areas. Proceedings of the Colorado Riparian Association 17th Annual Conference, October 13–15, 2004, Estes Park, Colorado.

Baker, B., and E. Hill. 2003. Beaver *(Castor canadensis)*. Pages 288–310 *in* G. Fledhamer, B. Thompson, and J. Chapman, editors. Wild mammals of North America: Biology, management, and conservation. 2nd edition. Baltimore Maryland: The Johns Hopkins University Press.

Baldwin, R. A., and L. C. Bender. 2012. Estimating population size and density of a low-density population of black bears in Rocky Mountain National Park, Colorado. *European Journal of Wildlife Research* 58:557–566.

Barber, J. R., K. M. Fristrup, C. L. Brown, A. R. Hardy, L. M. Angeloni, and K. R. Crooks. 2009. Conserving the wild life therein: Protecting park fauna from anthropogenic noise. *Park Science* 26(3):26–31.

Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D. R. Cayan, and M. D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. *Science* 319: 1080–1083.

Baron, J. S. 2006. Hindcasting nitrogen deposition to determine an ecological critical load. *Ecological Applications* 16:433-439.

Baron, J. S., editor. 1992. Biogeochemistry of a subalpine ecosystem: Loch Vale Watershed. Springer-Verlag, New York.

Baron, J. S., K. E. Williams, and M. Hartman. 2010. Condition of alpine lakes and atmospheric deposition. In: A Natural Resource Condition Assessment for Rocky Mountain National Park. Natural Resource Report NPS/NRPC/WRD/NRR—2010/228. National Park Service, Fort Collins, Colorado.

Baron, J. S., H. M. Rueth, A. M. Wolfe, K. R. Nydick, E. J. Allstott, J. T. Minear, and B. Moraska. 2000. Ecosystem responses to nitrogen deposition in the Colorado Front Range. *Ecosystems* 3:352–368.

Baron, J. S., T. M. Schmidt, and M. D. Hartman. 2009. Climate-induced changes in high elevation stream nitrate dynamics. *Global Change Biology* 15: 1777-1789.

Blotkamp, A., W. Boyd, D. Eury, and , S. J. Hollenhorst. 2011. Rocky Mountain National park visitor study: Summer 2010. Natural Resource Report NPS/NRSS/SSD/NRR-2011/121/107587. National Park Service, Fort Collins, Colorado.

Bonfils, C., B. D. Santer, D. W. Pierce, H. G. Hidalgo, G. Bala, T. Das, T. P. Barnett, D. R. Cayan, C. Doutriaux, A. W. Wood, A. Mirin, and T. Nozawa. 2008. Detection and attribution of temperature changes in the mountainous western United States. J*ournal of Climate* 21: 6404-6424.

Bragg, A. N. 1960. Population fluctuation in the amphibian fauna of Cleveland County, Oklahoma, during the past 25 years. *Southwestern Naturalist* 5:165–169.

Brahney, J., A. P. Ballantyne, C. Sievers, and J. C. Neff. 2013. Increasing Ca2+ deposition in the western US: The role of mineral aerosols. *Aeolian Research* 10:77-87.

Braun, C. E., C. Stricker, S. Oyler-McCance, G. Wann, N. Y. Hobb, and C. Aldridge. 2010. Investigator's annual report: The impacts of climate and elk on population viability of white-tailed ptarmigan on Trail Ridge, Rocky Mountain National Park.

Braun, C. E., D. R. Stevens, K. M. Giesen, and C. P. Melcher. 1991. Elk, white-tailed ptarmigan and willow relationships: A management dilemma in Rocky Mountain National Park. *Transactions of the North American Wildlife Conference* 56:74-85

Britten, M., E. W. Schweiger, B. Frakes, D. Manier, and D. Pillmore. 2007. Rocky Mountain Network vital signs monitoring plan. Natural Resource Report. NPS/ROMN/NRR–2007/010. National Park Service, Fort Collins, Colorado.

Bromberg, J. E., S. Kumar, C. S. Brown, and T. J. Stohlgren. 2011. Distributional changes and range predictions of downy brome (*Bromus tectorum*) in Rocky Mountain National Park. *Invasive Plant Science and Management* 4:173–182.

Carey, C. 1993. Hypothesis concerning the causes of the disappearance of boreal toads from the mountains of Colorado. *Conservation Biology* 7:355-362.

Carter, M. F. 1998. Yellow-billed cuckoo (*Coccyzus americanus*). *In* Colorado Breeding Bird Atlas, H.E. Kingery, ed. Colorado Wildlife Heritage Foundation, Denver, Colorado.

Clow, D. W. 2010. Changes in the timing of snowmelt and streamflow in Colorado: A response to recent warming. *Journal of Climate* 23:2293–2306.

Collen, P., and R. J. Gibson. 2004. The general ecology of beavers as related to their influence on stream ecosystems and riparian habitats, and the subsequent effect on fish. *Reviews in Fish Biology and Fisheries* 10:439–461.

Colorado State Forest Service. 2014. Caring for Colorado's forests: Today's challenges, tomorrow's opportunities. 2013 Colorado Forest Health Report.

Corn, P. S., W. Stolzenburg, and R. B. Bury. 1989. Acid precipitation studies in Colorado and Wyoming: Interim report of surveys of montane amphibians and water chemistry. U.S. Fish and Wildlife Service. Biological Report 80 (40.26).

Corn, P. S., M. L. Jennings, E. Muths. 1997. Survey and assessment of amphibian populations in Rocky Mountain National Park. *Northwestern Naturalist* 78:34–55.

De Vos, J. M., L. N. Joppa, J. L. Gittleman, P. R. Stephens, and S. L. Pimm. 2014. Estimating the normal background rate of species extinction. *Conservation Biology.* doi: 10.1111/cobi.12380.

Detmer, T. M. 2014. Effects of fish on aquatic food webs at high elevation. Ph.D. dissertation, University of Colorado Boulder.

Dobrowski, S. Z. 2011. A climatic basis for microrefugia: The influence of terrain on climate. *Global Change Biology* 17(2):1022–1035.

Driscoll, C., C. Hazekamp, and J. B. Mitton. 2012. Population genetic analyses of Rocky Mountain bighorn sheep (*Ovis canadensis*) herds in and around Estes Park, Colorado. Draft report submitted to Rocky Mountain National Park, Estes Park, Colorado.

Eagles-Smith, C. A., J. J. Willacker, J. J., and C. M. Flanagan Pritz. 2014. Mercury in fishes from 21 national parks in the Western United States. U.S. Geological Survey Open-File Report 2014-1051.

Ehle, D. S. and W. L. Baker. 2003. Disturbance and stand dynamics in ponderosa pine forests in Rocky Mountain National Park, USA. *Ecological Monographs* 73:543-566.

Esser, S. M. 2014. Topography, disturbance and climate: Subalpine forest change 1972–2014, Rocky Mountain National Park. Colorado State University. Fort Collins, Colorado.

Flanagan Pritz, C.M., J. Schrlau, S. Massey Simonich, and T. Blett. 2014. Contaminants of emerging concern in fish from western U.S. and Alaskan national parks: Spatial distribution and health thresholds. *Journal of the American Water Resources Association* 50(2):309-323.

Gonzalez, P. 2012. Climate change trends and impacts for planning at Rocky Mountain National Park. Unpublished report to the National Park Service, June 11, 2012.

Gonzalez, P., R. Neilson, K. S. McKelvey, J. Lenihan, and R. Drapek. 2007. Potential impacts of climate change on habitat and conservation priority areas for *Lynx canadensis*. http://www.rmrs.nau.edu/publications/Gonzalezetal/Gonzalezetal.pdf. The Nature Conservancy, Arlington, Virginia.

Hammerson, G. A. 1999. Amphibians and reptiles in Colorado, 2nd edition. University Press of Colorado and Colorado Division of Wildlife, Boulder, Colorado.

Hessl, A. E. and W. L. Baker. 1997. Spruce and fir regeneration and climate in the forest-tundra ecotone of Rocky Mountain National Park, Colorado. *Arctic and Alpine Research* 29: 173-183.

Hobbs, N. T. 2013. Annual Report: Modeling in Support 1 of Adaptive Management of the Rocky Mountain National Park Elk Population. Unpublished report submitted to Rocky Mountain National Park.

Hoffman, M. J., A. G. Fountain, and J. M. Achuff. 2007. 20th-century variations in area of cirque glaciers and glacierets, Rocky Mountain National Park, Colorado, USA. *Annals of Glaciology* 46: 349-354.

Ingersoll, G. P., M. A. Mast, D. H. Campbell, D. W. Clow, L. Nanus, and J. T. Turk. 2008. Trends in snowpack chemistry and comparison to National Atmospheric Deposition Program results for the Rocky Mountains, US, 1993-2004. Atmospheric Environment 42:6098-6113.

Janke, J. R. 2005. Modeling past and future alpine permafrost distribution in the Colorado Front Range. *Earth Surface Processes and Landforms* 30: 1495-1508.

Jeffress, M. R., L. K. Garrett, M. Britten, C. Ray, C. W. Epps, and S. Wolff. 2010. Pikas in peril: Multi-regional vulnerability assessment of a climate-sensitive sentinel species. Project accomplishment report. National Park Service.

Jeffress, M. R., T. J. Rodhouse, C. Ray, S. Wolff, and C. W. Epps. 2013. The idiosyncrasies of place: Geographic variation in the climate-distribution relationships of the American pika. *Ecological Applications* 23(4):864–878.

Kennedy, C. 2014. Rocky Mountain National Park Fisheries and Aquatic Management, 2012. U.S. Fish & Wildlife Service Report. Lakewood, Colorado.

Knowles, N., M. D. Dettinger, and D. R. Cayan. 2006. Trends in snowfall versus rainfall in the western United States. *Journal of Climate* 19: 4545-4559.

Kumar, S., T. Stohlgren, and G. Chong. 2006. Spatial heterogeneity influences native and nonnative plant species richness. *Ecology* 87(12): 3186–3199.

La Sorte, F. A. and F. R. Thompson. 2007. Poleward shifts in winter ranges of North American birds. *Ecology* 88: 1803-1812.

Lubow, B. C., F. J. Singer, T. L. Johnson, and D. C. Bowden. 2002. Dynamics of interacting elk populations within and adjacent to Rocky Mountain National Park. J*ournal of Wildlife Management* 66:757-775.

Lukas, J., J. Barsugli, N. Doesken, L. Rangwala, and K. Wolter 2014. Climate change in Colorado: A synthesis to support water resources management and adaptation. Western Water Assessment, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder.

Mast, M. A., D. H. Campbell, D. P. Krabbenhoft, and H. E. Taylor. 2005. Mercury transport in a high-elevation watershed in Rocky Mountain National Park, Colorado. *Water, Air, and Soil Pollution* 161:21–42.

McClintock, B. T., and G. C. White. 2007. Bighorn sheep abundance following a suspected pneumonia epidemic in Rocky Mountain National Park. *Journal of Wildlife Management* 71:183-189.

McWethy, D. B., S. T. Gray, P. E. Higuera, J. S. Littell, G. T. Pederson, A. J. Ray, and C. Whitlock. 2010. Climate and terrestrial ecosystem change in the U.S. Rocky Mountains and Upper Columbia Basin: Historic and future perspectives for resource management. Natural Resource Report NPS/GRYN/NRR-2010/260. National Park Service, Fort Collins, Colorado.

Metcalf, J. L., S. L. Stowell, C. M. Kennedy, K. B. Rogers, D. Mcdonald, J. Epp, K. Keepers, A. Cooper, J. J. Austin, and A. P. Martin. 2012. Historical stocking data and 19th century DNA reveal human-induced changes to native diversity and distribution of cutthroat trout. *Molecular Ecology* 21:5194–5207.

Mitchell, D., J. Tjornehoj, and B. W. Baker. 1999. Beaver populations and possiblelimiting factors in Rocky Mountain National Park. Unpublished report submitted to Rocky Mountain National Park. U.S. Geological Survey, Midcontinent Ecological Science Center, Fort Collins, Colorado.

Monahan, W. B., T. Cook, F. Melton, J. Connor, and B. Bobowski. 2013. Forecasting distributional responses of limber pine to climate change at management-relevant scales in Rocky Mountain National Park. *PLoS One* 8:e83163.

Monello, R. J., Powers, J. G., Hobbs, N. T., Spraker, T. R., Watry, M. K. and Wild, M. A. 2014. Survival and population growth of a free-ranging elk population with a long history of exposure to chronic wasting disease. *Journal of Wildlife Management* 78: 214–223. doi: 10.1002/jwmg.665.

Mora, C., D. P. Tittensor, S. Adl, A. G. B. Simpson, and B. Worm. 2011. How Many Species Are There on Earth and in the Ocean? *PLoS Bio*l 9(8): doi:10.1371/journal.pbio.1001127

Morris, K., A. Mast, D. Clow, G. Wetherbee, J. Baron, C. Taipale, T. Blett, D. Gay, and J. Heath. 2014. 2012 monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: January 2014. Natural Resource Report NPS/NRSS/ARD/NRR—2014/757. National Park Service, Denver, Colorado

Muths, E., D. S. Pilliod, and L. J. Livo. 2008. Distribution and environmental limitations of an amphibian pathogen in the Rocky Mountains. *Biological Conservation* 14(6):1484–1492.

Muths, E., P. S. Corn, A. P. Pessier, and D. E. Green. 2003. Evidence for disease-related amphibian decline in Colorado. *Biological Conservation* 110:357–365.

Naiman, R., C. Johnston, and J. Kelley. 1988. Alteration of North American streams by beaver. *Bioscience* 38:753–762.

National Park Service. 2003. Invasive Exotic Plant Management Plan and Environmental Assessment for Rocky Mountain National Park.

National Park Service. 2007. Final Elk and Vegetation Management Plan/Environmental Impact Statement for Rocky Mountain National Park.

National Park Service. 2014. Climate change in Rocky Mountain National Park: Frequently asked questions. http://www.nps.gov/romo/naturescience/upload/Climate_Change_RMNP_FAQ.pdf

National Park Service Natural Sounds and Night Skies Division. 2013a (draft). Area Navigation (RNAV) report.

National Park Service Natural Sounds and Night Skies Division. 2013b. Investigator's Annual Report.

Newman, P., S. Lawson, C. Monz. 2010. Integrated approach to transportation and visitor use management at Rocky Mountain National Park. Report submitted to the National Park Service.

Packard, F. M. 1946. An ecological study of the bighorn sheep in Rocky Mountain National Park, Colorado. *Journal of Mammalogy* 27: 3–28.

Packard, F. M. 1947. A survey of the beaver population of Rocky Mountain National Park, Colorado. *Joumal of Mammalogy* 28: 2I9–227.

Papadogiannaki, E., Y Le, and S. J. Hollenhorst. 2011. Rocky Mountain National Park visitor study: Winter 2011. National Park Service, Fort Collins, Colorado.

Park, L., S. Lawson, K. Kaliski, P. Newman, and A. Gibson. 2010. Modeling and mapping hikers' exposure to transportation noise in Rocky Mountain National Park. *Park Science* 26(3):59–64.

Pauli, H., M. Gottfried, D. Hohenwallner, K. Reiter, R. Casale, G. Casale, and G. Grabherr (eds). 2004. The GLORIA field manual: The multi-summit approach. Luxembourg: European Commission DG Research, EUR 21213, Office for Official Publications of the European Communities.

Peacock, M. M., and A. T. Smith. 1997. The effect of habitat fragmentation on dispersal patterns, mating behavior, and genetic variation in a pika metapopulation. *Oecologia* 112:524–533.

Peet, R. K. 1981. Forest vegetation of the Colorado Front Range. *Vegetatio* 45:3-75.

Pierce, D. W., T. P., Barnett, H. G. Hidalgo. T. Das, C. Bonfils, B. D. Santer, G. Bala, M. D. Dettinger, D. R. Cayan, A. Mirin, A. W. Wood, and T. Nozawa. 2008. Attribution of declining western U.S. snowpack to human effects. *Journal of Climate* 21: 6425-6444.

Raffa, K. F., B. H. Aukema, B. J. Bentz, A. L. Carroll, J. A. Hicke, M. G. Turner, and W. H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. *BioScience* 58: 501-517.

Salas, D. E., J. Stevens, and K. Schulz. 2005. Rocky Mountain National Park 2001–2005 vegetation classification and mapping. Technical Memorandum 8260-05-02 Remote Sensing and GIS Group. Technical Service Center, Bureau of Reclamation.

Scherer, R. D., E. Muths, B. R. Noon, and P. S. Corn. 2005. An evaluation of weather and disease as causes of decline in two populations of boreal toads. *Ecological Applications* 15(6):2150–2160.

Scherer, R. D., B. Baldwin, J. Connor, and B. R. Noon. 2011. Occupancy of beaver (*Castor canadensis*) in Rocky Mountain National Park: The second field season. Unpublished report to Rocky Mountain National Park.

Schoettle, A. W., J. Connor, J. Mack, P. Pineda Bovin, J. Beck, G. M. Baker, R. A. Sniezko, and K. S. Burns. 2014. Establishing the science foundation to sustain high-elevation, five-needle pine forests threatened by novel interacting stresses in four western national parks. *George Wright Forum* 30:3(302–312).

Schoolmaster Jr, D. R., J. B. Grace, E. W. Schweiger, G. R. Guntenspergen, B. R. Mitchell, K. M. Miller, and A. M. Little. 2013. An algorithmic and information-theoretic approach to multimetric index construction. Ecological Indicators 26:14-23.

Schweiger, E. W., J. B. Grace, K. M. Driver, D. R. Schoolmaster, Jr., D. Cooper, G. R. Gutenspergen, D. Shorrock, I. Ashton, J. Burke, L. O'Gan, and M. Britten. Draft report.Wetland Ecological Integrity at Rocky Mountain National Park Rocky Mountain Inventory & Monitoring Network 2007–2009 Protocol Development Pilot, Version 1.1. Natural Resource Technical Report. National Park Service, Fort Collins, Colorado.

Sherriff, R. L., and T. T. Veblen. 2007. A spatially-explicit reconstruction of historical fire occurrence in the ponderosa pine zone of the Colorado Front Range. *Ecosystems* 10:311-323.

Sibold, J. S., T. T. Veblen, and M. E. González. 2006. Spatial and temporal variation in historic fire regimes in subalpine forests across the Colorado Front Range. *Journal of Biogeography* 33: 631-647.

Singer, F. J. and L. C. Zeigenfuss, eds. 2002. Ecological evaluation of the abundance and effects of elk herbivory in Rocky Mountain National Park, Colorado, 1994-1999. Colorado State University and U.S. Geological Survey, Fort Collins, Colorado.

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

Stowell, S. L., C. M. Kennedy, S. C. Beals, J. L. Metcalf, and A. P. Martin. *In review.* The genetic legacy of more than a century of stocking trout: A case study in Rocky Mountain National Park, Colorado. University of Colorado–Boulder.

Theobald, D. M., J. S. Baron, P. Newman, B. Noon, J. B. Norman III, I. Leinwand, S. E. Linn, R. Sherer, K. E. Williams, and M. Hartman. 2010a. A natural resource condition assessment for Rocky Mountain National Park. Natural Resource Report. NPS/NRPC/WRD/NRR–2010/228. Report to National Park Service, Fort Collins, Colorado.

Theobald, D. M., S. Goetz, J. Gross, A. Hansen, N. Piekielek, F. Melton, and S. Hiatt. 2010b. Landscape conditions and trends in and around Rocky Mountain National Park: Summary results. Report to National Park Service, Fort Collins, Colorado.

van Mantgem, P. J., N. L. Stephenson, J. C. Byrne, L. D. Daniels, J. F. Franklin, P. Z. Fule, M. E. Harmon, A. J. Larson, J. M. Smith, A. H. Taylor, and T. T. Veblen. 2009. Widespread increase of tree mortality rates in the western United States. *Science* 323: 521–524.

Veblen, T. T., and D. C. Lorenz. 1991. The Colorado Front Range: A century of ecological change. University of Utah Press, Salt Lake City.

Wallace, G. N., J. J. Brooks, and M. L. Bates. 2004. A survey of day and overnight backcountry/wilderness visitors in Rocky Mountain National Park. Final Project Report for the National Park Service. Fort Collins: Colorado State University, Department of Natural Resource Recreation and Tourism.

Wang, G. M., N. T. Hobbs, F. J. Singer, D. S. Ojima, and B. C. Lubow. 2002. Impacts of climate changes on elk population dynamics in Rocky Mountain National Park, Colorado. *Climatic Change* 54: 205-223.

Westbrook, C. J., D. J. Cooper, and B. W. Baker. 2006. Beaver dams and overbank floods influence groundwater-surface water interactions of a RockyMountain riparian area. *Water Resources Research* 42:4560.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313:940–943.

Williamson, N. 2013. Rocky Mountain National Park FFI Fire Effects Monitoring Data. Rocky Mountain National Park, Colorado. Generic Dataset-2193449. https://irma.nps.gov/App/Reference/Profile/2193449.

Wolfe, A. P., A. C. Van Gorp, and J. S. Baron. 2003. Recent ecological and biogeochemical changes in alpine lakes of Rocky Mountain National Park (Colorado, USA): A response to anthropogenic nitrogen deposition. *Geobiology* 1:153-168.

Appendix: Nonnative Animals and Plants

For the purposes of this list, “nonnative” species whose presence in the park is understood to be a direct or indirect result of human activity. As indicated in the second column, this list includes species whose presence in the park has been reported but not officially confirmed. Other nonnative species are also likely present in the park but they have not been detected.

For nonnative vascular plants, the list notes which species are priorities for herbicidal (*) and/or manual (¤) control.

Nonnative Species Name	**Occurrence**
Mammals	
domestic cattle *(Bos taurus)*	Non-residents that occasionally wander into the park
fox squirrel *(Sciurus niger)*	Rare
mountain goat *(Oreamnos americanus)*	Non-residents that occasionally wander into the park
Birds	
European starling *(Sturnus vulgaris)*	Uncommon breeder
house sparrow (Passer domesticus)	Uncommon breeder
rock pigeon, rock dove (Columba livia)	Uncommon
wild turkey *(Meleagris gallopavo)*	Rare resident
Fish	
blue lineage cutthroat trout (*Oncorhynchus clarkii pleuriticus*)	Common
brook trout *(Salvelinus fontinalis)*	Common
brown trout *(Salmo trutta)*	Uncommon
rainbow trout *(Oncorhynchus mykiss)*	Uncommon
Yellowstone cutthroat trout *(Oncorhynchus clarkii bouvieri)*	Uncommon
Vascular Plants	
alsike clover *(Trifolium hybridum)*	Unknown abundance
amaranth *(Amaranthus retroflexus)*	Common
annual bluegrass *(Poa annua)*	Unknown abundance
asparagus *(Asparagus officinalis)*	Rare
baby’s breath *(Gypsophila paniculata)*	Rare
Bermuda grass *(Cynodon dactylon)*	Uncommon
big chickweed *(Cerastium fontanum ssp. Vulgare)*	Uncommon
bindweed *(Convolvulus arvensis)*	Rare
black bindweed *(Polygonum convolvulus var. convolvulus)*	Common
black medic *(Medicago lupulina)*	Common
bluebuttons, field scabiosa *(Knautia arvensis)*	Uncommon
bouncingbet *(Saponaria officinalis)*	Not currently observed; present historically
bulbous bluegrass *(Poa bulbosa)*	Unconfirmed
bull thistle *(Cirsium vulgare)*¤	Rare
burdock *(Arctium minus)*	Uncommon
butter-and-eggs, yellow toadflax (*Linaria vulgaris)* *	Abundant
Canada bluegrass *(Poa compressa)*	Uncommon
Canada thistle *(Cirsium arvense)**	Common

Nonnative Species Name	**Occurrence**
caraway *(Carum carvi)*	Common
cheatgrass *(Bromus tectorum)**¤	Common
clasping peppergrass *(Lepidium perfoliatum)*	Not currently observed; present historically
Colorado wild rye **(Leymus cinereus)**	Rare
cream-anther field pepperwort, field pepperweed *(Lepidium campestre)*	Unknown abundance
crested wheatgrass *(Agropyron cristatum)*	Unknown abundance
curly dock (*Rumex crispus)* ¤	Common
cutleaf nightshade *(Solanum triflorum)*	Unknown abundance
dalmation toadflax *(Linaria dalmatica ssp. dalmatica)* *	Common
dame's rocket *(Hesperis matronalis)*	Not currently observed; present historically
dandelion *(Taraxacum officinale)*	Abundant
deptford pink *(Dianthus armeria)*	Rare
diffuse knapweed *(Centaurea diffusa)* *¤	Uncommon
fanweed *(Thlaspi arvense)*	Unknown abundance
fiddleneck *(Amsinckia menziesii)*	Common
ground-cherry nightshade *(Solanum physalifolium)*	Rare
hare's ear mustard *(Conringia orientalis)*	Uncommon
hoary alyssum *(Berteroa incana)* ¤	Common
horehound *(Marrubium vulgare)*	Uncommon
horseweed *(Iva xanthifolia)*	Unconfirmed
horseweed *(Conyza canadensis)*	Common
houndstongue *(Cynoglossum officinale)**¤	Common
Japanese brome, Japanese bromegrass, Japanese chess *(Bromus japonicus)*	Uncommon
jim hill mustard *(Sisymbrium altissimum)*	Common
Kentucky bluegrass *(Poa pratensis)*	Common
leafy spurge, russian leafy spurge, spurge, wolf's milk *(Euphorbia esula var. uralensis)* *	Uncommon
maiden's tears *(Silene vulgaris)*	Uncommon
marsh sowthistle, swamp sowthistle *(Sonchus arvensis ssp. uliginosus)*	Uncommon
mayweed chamomile *(Anthemis cotula)*	Common
meadow foxtail *(Alopecurus pratensis)*	Unknown abundance
mountain brome, rescue grass *(Bromus carinatus)*	Common
musk thistle (*Carduus nutans ssp. macrolepis)*¤	Abundant
Norway cinquefoil *(Potentilla norvegica)*	Unknown abundance
orange hawkweed *(Hieracium aurantiacum)**	Rare
orchard grass *(Dactylis glomerata)*	Uncommon
ox-eye daisy ***(Leucanthemum vulgare)****	Common
pale alyssum ***(Alyssum alyssoides)***	Common
peppergrass (*Lepidium densiflorum)*	Not currently observed; present historically
perennial sweet pea (*Lathyrus latifolius)*	Probably present

Nonnative Species Name	**Occurrence**
poison hemlock *(Conium maculatum)*	Uncommon
rag-weed, skeletonleaf bursage *(Ambrosia tomentosa)*	Uncommon
red catchfly (*Silene latifolia ssp. alba)*	Uncommon
red clover *(Trifolium pratense)*	Common
redstem filaree *(Erodium cicutarium)* ¤	Unknown abundance
redtop *(Agrostis gigantea)*	Uncommon
Russian olive *(Elaeagnus angustifolia)*	Not currently observed; present historically
Russian thistle *(Salsola tragus)* ¤	Common
Russian thistle, tumbleweed *(Salsola collin)* ¤	Common
Russian wild-rye *(Psathyrostachys juncea)*	Uncommon
ryegrass *(Lolium perenne)*	Unknown abundance
ryegrass *(Lolium pratense)*	Uncommon
salsify *(Tragopogon dubius)*	Uncommon
sand spurry *(Spergularia rubra)*	Unknown abundance
scentless chamomile *(Tripleurospermum perforata)* ¤	Unknown abundance
scotch thistle *(Onopordum tauricum)*	Rare
sheep fescue *(Festuca ovina)*	Uncommon
sheep sorrel *(Rumex acetosella)*	Common
shepherd's purse (*Capsella bursa-pastoris)*	Common
Sierran tansymustard *(Descurainia californica)*	Uncommon
smallseed falseflax *(Camelina microcarpa)*	Common
smooth brome *(Bromus inermis* var. *inermis)*	Common
spearmint *(Mentha spicata)*	Unconfirmed
spotted knapweed *(Centaurea biebersteinii)* *¤	Uncommon
St. John's wort *(Hypericum perforatum)*	Not currently observed; present historically
sulphur cinquefoil *(Potentilla recta)*	Uncommon
sweet william *(Dianthus barbatus)*	Occasional
tansy mustard *(Descurainia sophia)*	Common
thyme-leaf spurge *(Chamaesyce serpyllifolia* ssp. *serpyllifolia)*	Unconfirmed
timothy *(Phleum pratense)*	Common
tower rockcress (*Arabis glabra)*	Unknown abundance
treacle mustard *(Erysimum cheiranthoides)*	Unconfirmed
twitch, couchgrass, creeping quackgrass, quackgrass, quickgrass, quitch, scutch *(Elymus repens)*	Uncommon
vervain *(Verbena bracteata)*	Unknown abundance
wheat *(Triticum aestivum)*	Unconfirmed
white Dutch clover *(Trifolium repens)*	Common
white sweet-clover *(Melilotus alba)* ¤	Common
woolly mullein *(Verbascum thapsus)* ¤	Common
yellow rocket *(Barbarea vulgaris)*	Uncommon
yellow sweet-clover *(Melilotus officinalis)* ¤	Common
yellow whitlowort *(Draba nemorosa)*	Common

NPS 121/128364, April 2015

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov