National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Dinosaur National Monument

Natural Resource Report NPS/DINO/NRR—2021/2245

The production of this document cost $101,532, including costs associated with data collection, processing, analysis, and subsequent authoring, editing, and publication.

ON THE COVER
View upstream from Echo Park boat ramp.
Photo by Dave Jones, Colorado State University

Natural Resource Condition Assessment

Dinosaur National Monument

Natural Resource Report NPS/DINO/NRR—2021/2245

David S. Jones[1], Roy Cook[1], John Sovell[2], Matt Ley[1], Jill Handwerk[2], Hannah Shepler[1], John Kemper[3], David Weinzimmer[1], Carlos Linares[4] and B. Maynard[1].

[1] Colorado State University
CEMML – Department 1490
Warner College of Natural Resources
Fort Collins, CO 80523-1490

[2] Colorado State University
Colorado Natural Heritage Program
Department of Fish, Wildlife and Conservation Biology
Warner College of Natural Resources
Fort Collins, CO 80523

[3] Colorado State University
Department of Geosciences
Warner College of Natural Resources
Fort Collins, CO 80523

[4] Colorado State University
Department of Human Dimensions of Natural Resources
Warner College of Natural Resources
Fort Collins, CO 80523

April 2021

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.

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

This report received informal peer review, which was provided by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. The level and extent of peer review was based on the importance of report content or its potentially controversial or precedent-setting nature.

This report is available in digital format from the Natural Resource Condition Assessment Program website and the Natural Resource Publications Management website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Jones, D. S., R. Cook, J. Sovell, M. Ley, J. Handwerk, H. Shepler, J. Kemper, D. Weinzimmer, C. Linares and B. Maynard. 2021. Natural resource condition assessment: Dinosaur National Monument. Natural Resource Report NPS/DINO/NRR—2021/2245. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2285165.

NPS 122/175193, April 2021

Contents

Contents (continued)

Page

Contents (continued)

Contents (continued)

Page

Contents (continued)

Page

Contents (continued)

Page

Contents (continued)

Page

Figures

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Tables

Page

Tables (continued)

Page

Tables (continued)

Page

Tables (continued)

Page

Tables (continued)

Page

Tables (continued)

Page

Tables (continued)

Page

Executive Summary

The National Park Service (NPS) Natural Resource Condition Assessment (NRCA) Program administered by the NPS Water Resources Division evaluates current conditions for important natural resources and resource indicators using primarily existing information and data. NRCAs also report on trends in resource condition when possible, identify critical data gaps, and characterize a general level of confidence for study findings. This NRCA complements historic resource assessments, is multi-disciplinary in scope, employs a hierarchical indicator framework, identifies and develops reference conditions/values for comparison against current conditions, and emphasizes spatial evaluation and display of conditions.

Dinosaur National Monument (DINO) was established by Presidential Proclamation in 1915 as a 32-hectare (80-acre) monument to preserve the outstanding fossil resources at the dinosaur quarry north of Jensen, Utah. In 1938, the monument was enlarged to 82,510 hectares (203,885 acres) as an area to be administered for purposes of preservation of natural resources and public use. A major focus of expansion of the land base was protection of river corridors and adjacent viewsheds for the major canyons of the Green and Yampa Rivers. In 1960, Congress passed legislation enlarging the monument to 85,447 hectares (211,142 acres). The purpose of the monument is to protect, study, and provide access to extraordinary fossil deposits of dinosaurs and other life, a record of thousands of years of human occupation and use, and the wild and ecologically diverse landscape shaped by the Green and Yampa Rivers. Proposals have been submitted to Congress for designation of wild and scenic rivers and for wilderness, but neither proposed designation has been approved. In the meantime, most of the monument continues to be managed to protect wilderness values.

The NRCA for DINO began in 2015, employing a scoping process involving Colorado State University, monument and NPS staff to discuss the NRCA framework, identify important preserve resources, and gather existing information and data. Indicators and measures for each resource were then identified and evaluated. Data and information were analyzed and synthesized to provide summaries and address condition, trend and confidence using a standardized but flexible NPS framework that compared current condition to a reference condition.

A total of 15 focal resources were examined: five addressing landscape context – system and human dimensions, three addressing chemical and physical attributes, and seven addressing biological attributes. Landscape context – system and human dimensions included land cover and land use, dark night skies, natural sounds, visual resources, and climate change. Climate change and land cover/land use were not assigned a condition or trend – they provide important context to the monument and many natural resources, and can be a source of stress and management concern. Some of the land cover and land use-related stressors at DINO and in the larger region are related to historical land uses, grazing and the expansion of gas and oil exploration and production in the region. Nationwide modeling of anthropogenic sound level impacts indicates that modern noise intrusions are moderately increasing the existing ambient sound level above the natural ambient sound level near DINO. Dark night skies are high quality. Indications are that the climate in this region is already becoming hotter, possibly wetter, and is potentially more prone to more frequent and extreme weather events. Trends

in the indicators are projected to continue or accelerate by the end of the century. There are opportunities to mitigate the effects of local landscape context stressors through planning, management and mitigation. Stressors driven by more distant factors such as haze from population centers hundreds of miles away, or the effects of Flaming Gorge Reservoir on water quality and river function are more difficult to mitigate. Collectively, this context supports resource planning and management within the monument, and provides a foundation for collaborative conservation with other landowners in the surrounding area.

The supporting chemical and physical environment at the monument include its air quality, water quality and stream hydrology/geomorphology. The condition of these resources can affect human dimensions of the monument such as visibility and scenery as well as biological components such as stream biota. Air quality warranted moderate concern. Regional air quality is in decline due to increased oil and gas production in the Uintah Basin of northeastern Utah. Oil and gas operations increase deposition through increased regional N emissions, decrease visibility due to the release of haze-causing agents such as NOx and fugitive dust, and contribute to increased ozone levels. Other regional and local pollution sources that cause haze and contribute to visibility impairment throughout the region include automobiles, coal- and oil-fired power plants, smelters, wildfires, and urban emissions

Water quality was in good, although declining, condition. The largest single stressor to water quality at DINO is the effect of Flaming Gorge Reservoir on the upper (and to a lesser extent the lower) Green River. In addition, human population growth, transmountain diversions, in-basin depletions and impoundments, increasing nonpoint pollution sources, and competing water interests threaten both the Yampa and Green Rivers. Increase in mean annual temperature and drought, dust on snow, and other climate change effects can and have altered timing, magnitude, and duration of snowmelt, with significant implications for river ecosystem health and function. Some agricultural land uses in the Yampa and Green River Basins likely contribute a portion of the nutrient issues within the large river systems of DINO.

Physical structure and processes for three different segments of the Yampa and Green River system were examined. The primary driver of change in the large river systems at DINO is the creation and ongoing operations of the Flaming Gorge Reservoir and Dam on the Green River upstream of the monument in southwestern Wyoming. The effects of the reservoir on the Green River provide an interesting case study for the effects of upstream impoundments on rivers when compared to the relatively free-flowing Yampa River. As expected, our analysis of these river segments showed the Yampa River to be in good condition, the Upper Green River segment to be in poor condition, while the Lower Green River was in moderate condition as this segment represents the combined state of the Upper Green and its confluence with the Yampa.

The floral biological components examined included vegetation and plant species of special concern. Threats to vegetation communities at DINO include the spread of invasive exotic plant species, excessive disturbance by native and nonnative grazers and livestock, altered fire regimes, climate change, and altered hydrology within river riparian zones. Localized threats to particular locations can include recreational impacts and human land uses such as development and agriculture.

Livestock grazing is considered a stressor on numerous monument resources and natural processes. The condition of rare plant species at the monument was found to be good overall. The Uinta Basin is renowned for a high number of substrate-specific endemic plant taxa, with several dozen plant taxa of special concern known to occur in DINO. Impacts to rare plants at DINO include altered plant community composition, increase of exotic species such as cheatgrass (*Bromus tectorum*), soil erosion, and altered hydrology. Current grazing practices in some areas of the monument have also resulted in excessive browsing and trampling of several populations of rare plant taxa.

The faunal biological components examined included fish, greater sage-grouse, bats, birds and bighorn sheep. All but bats were found to be in moderate condition, with bats earning a good condition rating. Fish and birds have been impacted primarily by flow modification and landscape development. Impacts to greater sage-grouse and bighorn sheep populations have been linked to effects of climate change. Climate change effects on sage-grouse that could occur or are already taking place in the region include: increased susceptibility and exposure to infectious agents, increased fire frequency, and spread of invasive plants that effect habitat and food sources. Greater sage-grouse declines have also come from landscape fragmentation and development. Stressors affecting habitat quality and continuity, as well as climate change, are a common thread for the animal species examined.

The identification of data gaps during the course of the assessment is an important outcome of the NRCA. In some cases, significant data gaps contributed to low confidence in the condition or trend assigned to a resource. Primary data gaps and uncertainties encountered were lack of recent survey data; availability of consistent, long-term data; and incomplete understanding of the ecology of rare resources. Additional data gaps realized during the scoping phase eliminated some resources of concern from our analysis. These included surveys of abiotic and biotic characteristics of seeps and springs, inventory and characterization of hanging garden plant communities, vegetation/rangeland condition and livestock stocking data related to grazing management, and the condition of vegetation and soil resources impacted by native ungulates, primarily elk and deer.

Dinosaur National Monument is a place where visitors can experience solitude, high-quality and expansive scenery, dark night skies and wild rivers. While the majority of monument lands are remote and untouched by modern visitors, historical and continuing land uses within the monument such as livestock grazing, coupled with dynamic stressors related to biotic (e.g., invasive exotic plants) and abiotic (e.g., air quality/visibility and changing climate) conditions degrade numerous focal resources and most importantly stress numerous species, communities and ecosystems within the monument. The links between increasing cheatgrass, altered fire regimes, changing climate and habitat degradation for species within the monument appear clear, as these drylands are especially susceptible to current and future effects of co-occurring climate change and land uses.

Regional and preserve-specific mitigation and adaptation strategies are needed to maintain or improve the condition of some resources over time. Success will require acknowledging a "dynamic change context" that manages widespread and volatile problems while confronting uncertainties, managing natural and cultural resources simultaneously and interdependently, developing broad

disciplinary and interdisciplinary knowledge, and establishing connectivity across broad landscapes beyond monument borders.

Chapter 1. NRCA Background Information

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

NRCAs Strive to Provide…

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

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

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

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

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

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

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

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

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

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

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

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

Important NRCA Success Factors

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

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management

targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

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

NRCA Reporting Products…

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

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

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

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

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

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

Chapter 2. Introduction and Resource Setting

2.1. Introduction

2.1.1. Enabling Legislation/Presidential Proclamation[1]

Dinosaur National Monument (DINO) was established by Presidential Proclamation 1313 on October 4, 1915 (39 Stat. 1752), as an 80-acre monument to preserve the outstanding fossil resources at the dinosaur quarry north of Jensen, Utah. In 1938, Presidential Proclamation 2290 enlarged the monument to 82,510 hectares (203,885 acres) (53 Stat. 2454). This proclamation cited the Act of August 25, 1916, that established the NPS (16 U.S.C. 1a-7), thereby specifically identifying DINO as an area to be administered for purposes of preservation of natural resources and public use. A major focus of expansion of land base was protection of river corridors and adjacent viewsheds for the major canyons of the Green and Yampa Rivers. On September 8, 1960, Congress passed Public Law 86-729, 74 Stat. 857. This key piece of legislation enlarged the monument to 85,447 hectares (211,141.69 acres). P.L. 86-729 also established procedures directed toward the eventual elimination of grazing from the monument.

2.1.2. Monument History[2]

Dinosaur National Monument's geologic history reaches back to over 1 billion years ago with the oldest rocks in the monument, part of the Uinta Mountain Group. A more recent layer of rock is what fascinates most visitors for it contains the remains of dinosaurs and other life that roamed this area approximately 149 million years ago. Paleontologist Earl Douglass made the dinosaur quarry here famous with his excavations of numerous specimens for display at the Carnegie Museum in Pittsburgh, Pennsylvania. Earl Douglass also proposed protecting a portion of the quarry as a scientific and educational display as a national monument.

Dinosaur National Monument's human history dates to at least 10,000 years before present (BP) evidenced by Paleoindian artifacts in several locations. The Uinta Basin and Dinosaur National Monument show low occupation rates through the Early (8000–5000 BP) and Middle (5000–3000BP) Archaic periods. Occupation began to rise during the Late Archaic (3500–2000 BP) period and increased in intensity with the introduction of maize ca. 1800–1700 BP. An intensification of biscuit root harvesting set the stage for the introduction and cultivation of maize agriculture.

The Fremont culture is the predominant culture represented in the archaeological record and increased in population from 7500–1050 AD (approximately 1200–1000 years BP) and declined from 1050–1300 AD (800–1000 years BP). Recent research has indicated that the Fremont archaeology within the monument is significant globally, as it indicates human response to climatic shifts from primarily hunting and foraging to maize agriculture and returning to foraging when necessitated by climate shifts. The archaeological record suggests the apex for human occupation in the monument is the Fremont cultural period from 300–1300 AD (700–1700 years BP), with an intensification of Fremont pithouse villages from AD 750–1050. The monument contains the earliest

[1] Adapted from NPS (2018a)

[2] Adapted from Coles et al. (2008) and Manni and Le (2014)

evidence for maize agriculture in the northern Uintah Basin at AD 250, as well as some very late dates (1400s). Rock art sites dating to the Fremont period are prolific throughout the monument, and rock shelters along the river corridor have produced some of the most diverse and compelling material culture (artifacts) related to the Fremont culture to date. The Castle Park Archaeological District includes several of these rockshelters, which were excavated from the 1940s–1960s. The collections from several of these sites are now housed at University of Colorado, Boulder.

Dinosaur National Monument has 36 traditionally associated tribes and was within the homelands for the Yamparika Band of the Ute Tribe. Ute rock art is present at several locations throughout the monument and indicates heavy land use. The protohistoric/historic use of the landscape by traditionally associated tribes for hunting, trading, and gathering will be better informed by future ethnographic studies and tribal consultation.

The monument's historic archaeological record is also extensive, indicating 19th century use of the lands by ranchers, sheep herders, homesteaders, outlaws, and miners. The monument retains much of this record in historic cabins and homesteads, corrals, historic mines, trails, roads, and historic artifacts. The monument's archaeology program is developing; at this time approximately 14% of the monument has been surveyed for archaeological and historic resources and additional research is planned for a deeper understanding of the continual use of the landscape.

Proposed Wild and Scenic Rivers

An NPS wild and scenic river proposal report for the Yampa River and the Green River in Colorado and Utah (within the monument boundaries) was transmitted to Congress on November 14, 1983. The river was determined eligible, but the Secretary of the Interior did not include a recommendation for designation. This proposal has not been revisited since that time.

Designated and Proposed Wilderness

On December 4, 1974, President Gerald Ford recommended to Congress that 165,341 acres of DINO be designated as wilderness, with an additional 10,274 acres of potential wilderness addition (mostly road corridors associated with inholdings and grazing units to be added to designated wilderness by decision of the Secretary of Interior once these potential wilderness additions met the definition of wilderness under the Wilderness Act of 1964). On May 11, 1978, a revision of the 1974 proposal was recommended to Congress, which increased the proposed wilderness acreage to 205,672 acres with an additional 5,055 acres of potential wilderness. The increase in total proposed wilderness acreage was the result of the purchase of inholdings, the retirement of grazing privileges (on previous potential wilderness addition lands that were now considered eligible for wilderness), the closure of a few grazing-related roads, and the decision to no longer withhold certain areas from wilderness status for future development purposes (NPS 2015b). The 1978 recommendation was never approved nor rejected by Congress and has not been superseded by any subsequent DINO draft wilderness proposal revisions. National Park Service policy is to continue to fully protect the wilderness values and resources of any area deemed suitable for further wilderness study until it is formally eliminated from eligibility (Crump 2012).

The recommended wilderness in DINO is divided into two distinct sections by the Echo Park and Yampa Bench roads, which are designated as non-wilderness areas by the recommendation. The majority of the monument is recommended wilderness and the wilderness boundary generally follows the monument boundary. Exceptions to wilderness include developed areas in the southwest region of the monument along Utah Hwy 149, including the Quarry Exhibit Hall and Quarry Visitor Center, the staff housing and maintenance facilities, Split Mountain campground and boat launch, Green River campground, the Fossil Discovery Trail, the Sound of Silence Trail, the Desert Voices Trail, and the Josie Basset Morris Home site. Other areas labeled as non-wilderness include roads leading to Rainbow Park and Island Park, the Rainbow Park campground and boat launch, Harpers Corner Road, Echo Park Road, Yampa Bench Road, the Gates of Lodore campground and boat launch, and the most northern section of the Green River. A number of relatively small non-wilderness parcels largely representing potential developments or service and access roads that have long-since been closed are also included in the 1978 proposal (Crump 2012).

2.1.3. Geographic Setting

Straddling the Colorado/Utah border, the majority of DINO is located in Moffat County, Colorado, a mostly rural county with 13,795 residents (2010 U.S. Census) (Figure 2.1-1). The portion of the monument residing within Utah is located in Uintah County, Utah, and has 32,588 residents (2010 U.S. Census). Dinosaur National Monument is in the easternmost extension of the Uinta Mountain anticline at the northern edge of the Colorado Plateau. The monument is shaped somewhat like an inverted T; at its widest and longest dimensions it is 35 kilometers (22 miles) north to south and 71 kilometers (44 miles) east to west. Portions are approximately 32 highway kilometers (20 miles) east of Vernal, Utah; 80 kilometers (50 miles) west of Craig, Colorado; and about 193 kilometers (120 miles) north of Grand Junction, Colorado. Elevations range from under 1,448 meters (4,750 feet) near the quarry to over 2,743 meters (9,000 feet) at Zenobia Peak.

Dinosaur National Monument includes canyons of the lower Yampa River and of the upper Green River below Browns Park. Using the confluence of the Green and Yampa Rivers in Echo Park as a central point, the monument extends upstream on the Yampa some 46 river miles, upstream on the Green about 20 river miles, and downstream on the Green another 25 river miles. The land base extends as far as five miles lateral distance from the river courses. The rivers flow through deep canyons with high velocity/high gradient stream reaches interspersed with more open parks with lower stream gradients.

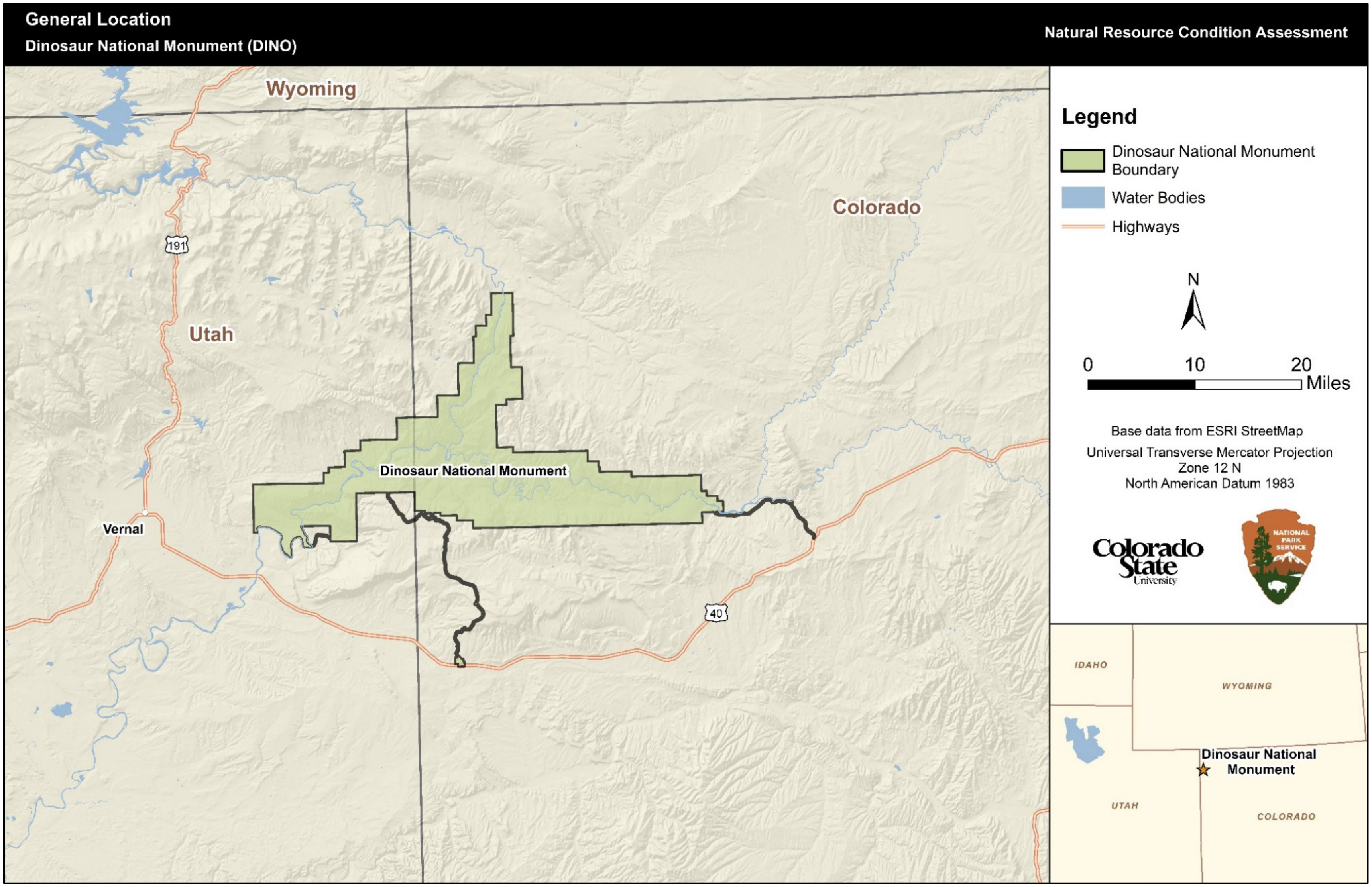


Figure 2.1-1. General location of Dinosaur National Monument (base data from ESRI StreetMap).

2.1.4. Monument Significance

The monument's *Foundation Document* (NPS 2015a) describes the significance of the monument:

- The world-famous Carnegie Dinosaur Quarry provides a remarkable window onto the Late Jurassic world of dinosaurs. There the National Park Service pioneered the *in situ* (in place) preservation of fossils, with 1,500 dinosaur bones available for viewing, touching, and study.

- Dinosaur National Monument displays the most complete geological record of any national park unit. The 23 rock formations and their fossils reveal vast environmental and biological changes over 1.1 billion years of Earth history, spanning the Pre-Cambrian to Cenozoic eras. Powerful geologic forces have uplifted, eroded, and exposed these layers in spectacular faults, folds, and canyons that prompt inquiry by general visitors as well as researchers.

- The exceptionally diverse communities of plants and animals within DINO result from its geographic location at the hub of five major biophysical regions, as well as the strikingly large number of geologic substrates and varied topography, ranging from river bottoms to montane peaks.

- Over 90% of DINO retains substantial wilderness character, which provides opportunities for visitors to experience solitude, natural sounds, dark night skies, wilderness whitewater recreation, wildlife viewing, and inspirational scenic vistas.

- Dinosaur National Monument contains the lower 46 miles of the Yampa River, which is the last remaining large, free-flowing river in the entire Colorado River system. The Yampa's natural snowmelt-driven flow provides a unique whitewater rafting experience and important habitat for native and endangered Colorado River Basin fish.

- The Yampa and Green Rivers within DINO provide outstanding opportunities to observe and study a wild river (Yampa), a flow-regulated river (Green above the confluence), and a hybrid river (Green below the confluence) within the Colorado River Basin. Comparing the three river reaches informs management for long-term river ecosystem health and function in the face of climate change and human impacts.

- The proposal to dam the Green River below Echo Park in the 1950s galvanized the nation's fledgling conservation organizations into a potent political power that defended the national park idea. The resolution of this controversy empowered the conservation movement and played a role in the Wilderness Act and establishment of the National Wilderness Preservation System.

- Explorer John Wesley Powell set the stage for whitewater boating on the wild rivers within DINO—a unique, high-quality, non-motorized boating experience. Many historic innovations in whitewater craft design and technique were developed specifically to run the Yampa and Green Rivers in what is today DINO.

- Dinosaur National Monument is unique in preserving and protecting a complete chronology of the prehistoric Fremont Indian culture, providing excellent opportunities for research and education. This record includes over 400 documented sites, such as seasonal gathering sites, hunting sites, villages, rock art, and other associated artifacts.

The monument's *Foundation Document* describes the purpose of the monument:

"Dinosaur National Monument protects, studies, and provides access to extraordinary fossil deposits of dinosaurs and other life, a record of thousands of years of human occupation and use, and the wild and ecologically diverse landscape shaped by the Green and Yampa Rivers." (NPS 2015a).

2.1.5. Visitation Statistics

Monument visitors are a mixture of recreation and non-recreation travelers and local residents. Annual monument recreation visitation has dropped considerably since the early 1990's, but has been increasing since a low of 197,812 visitors in 2010 (Figure 2.1-2). Mean annual visitation for the five-year period ending 2017 was 287,391 recreation visitors. Monthly visitation is highest from May to September (NPS 2018b) (Figure 2.1-3).

Of the 315,859 people who visited DINO in 2017, approximately 43% of the visitation (137,041 visitors) was concentrated in the Quarry Visitor Center area on the Utah side of the monument. River running is the second most popular activity, with 9,045 commercial and private boaters rafting the Green and Yampa Rivers in 2017 (NPS 2018b). Other recreation within the monument includes hiking, fishing, biking on established roads, automobile tours, camping, and limited amounts of horse packing and backpacking.

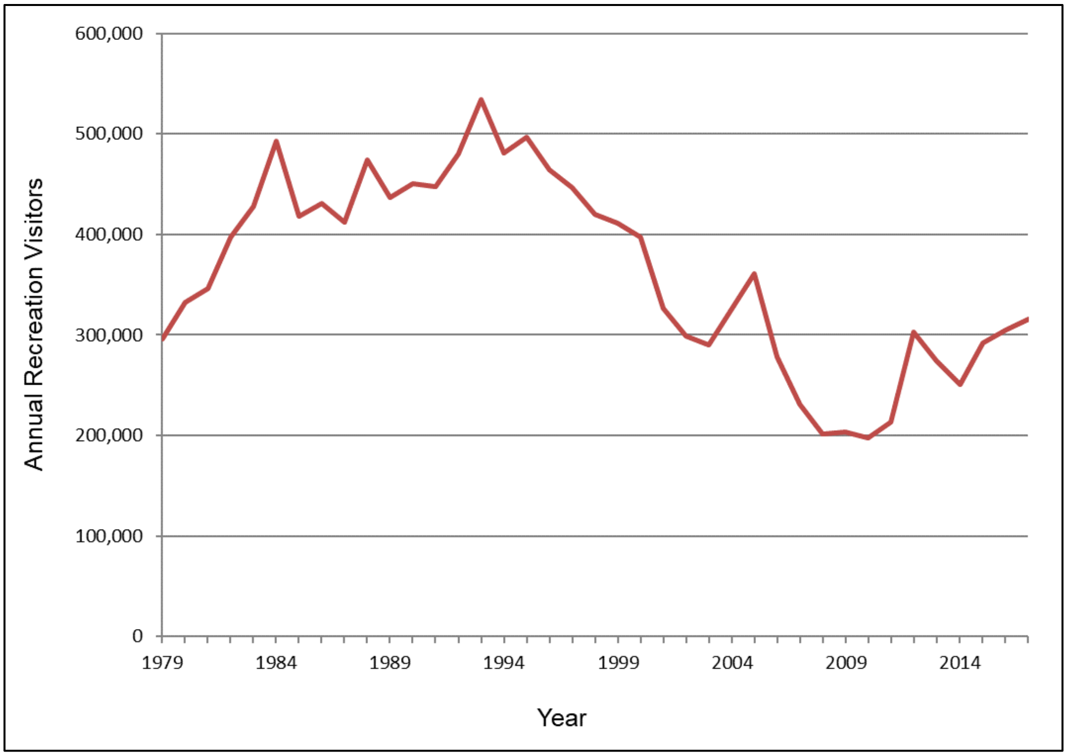


Figure 2.1-2. Annual DINO recreation visitation for 1979–2017 (NPS 2018b).

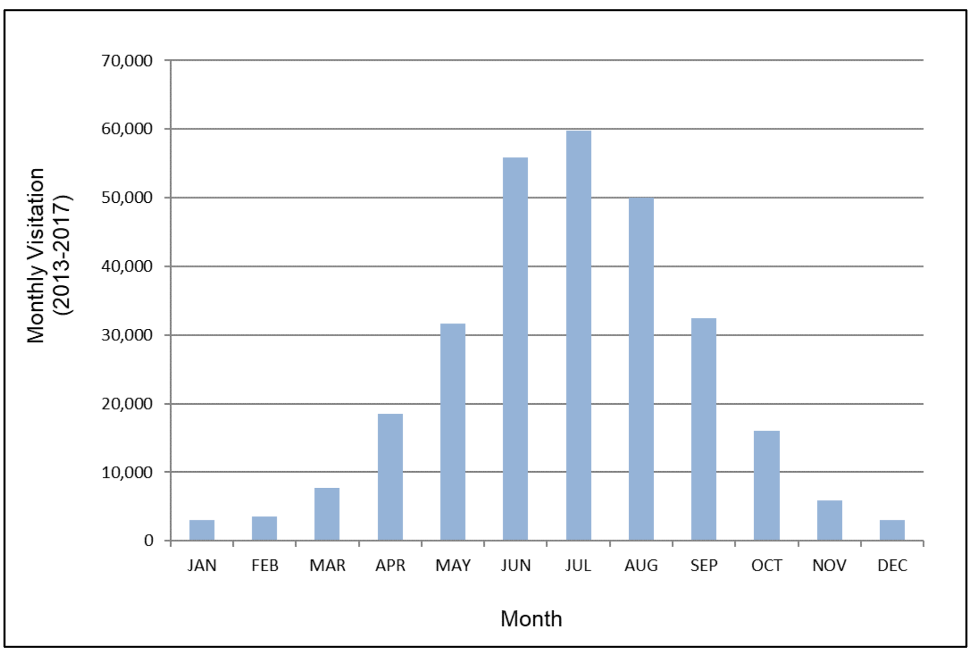


Figure 2.1-3. Mean monthly recreation visitation for DINO for 2013–2017 (NPS 2018b).

2.2. Natural Resources

2.2.1. Ecological Units

The majority of northwestern Colorado and northeastern Utah fall within the Colorado Plateau Level III ecoregion (20c). This ecoregion is further divided into Level IV ecoregions based primarily on dominant landforms and geology. Dinosaur National Monument lies mostly within the Semiarid Benchlands and Canyonlands Level IV ecoregion. This region is characterized by broad benches and mesas covered in grasslands, shrublands, and woodlands. Slickrock and fin bedrock exposures are common. The deep eolian soils are composed of fine sand and support sagebrush (*Artemisia* spp.), saltbush (*Atriplex* spp.), Mormon tea (*Ephedra* spp.), winterfat (*Krascheninnikovia lanata*), and warm-season grasses. Pinyon-juniper woodlands occur on shallower and stonier soils (Woods et al. 2001, Chapman et al. 2006).

Small portions of the north end of DINO, where the Green River enters the monument, lie within the Rolling Sagebrush Steppe (18a) and Salt Desert Shrub Basins (18e) of the Wyoming Basin Level III ecoregion. Other parts of the monument are also within the Shale Deserts and Sedimentary Basins (20b, along the Yampa River corridor at the very east end of the monument boundary) and Uinta Basin Floor (20f, at the southwestern boundary of the monument near Jensen, Utah) Level IV ecoregions (Omernik 1987).

At the habitat level, a vegetation inventory and mapping project at DINO (Coles et al. 2008) mapped 174 vegetation associations, alliances, or park special vegetation types. These associations are broadly organized into Ecological Systems (ES) developed by NatureServe (Comer et al. 2003, NatureServe 2003). Twenty-four ES units are known to occur within the DINO vegetation mapping project area. Of these 24, the most dominant or ecologically important systems are: Colorado Plateau Pinyon-Juniper Woodlands (49,511 ha, 58% of the monument's area), Sagebrush/Rabbitbrush Shrublands (11,565 ha or 14%), Native Grassland Herbaceous Vegetation (6,064 ha or 8%), and Riparian Woodlands and Shrublands (420 ha or <1%). Although covering a very small percentage of land at DINO, riparian systems are extremely important to the ecological function of not only the monument but the Colorado Plateau region as a whole.

2.2.2. Resource Descriptions

Climate[3]

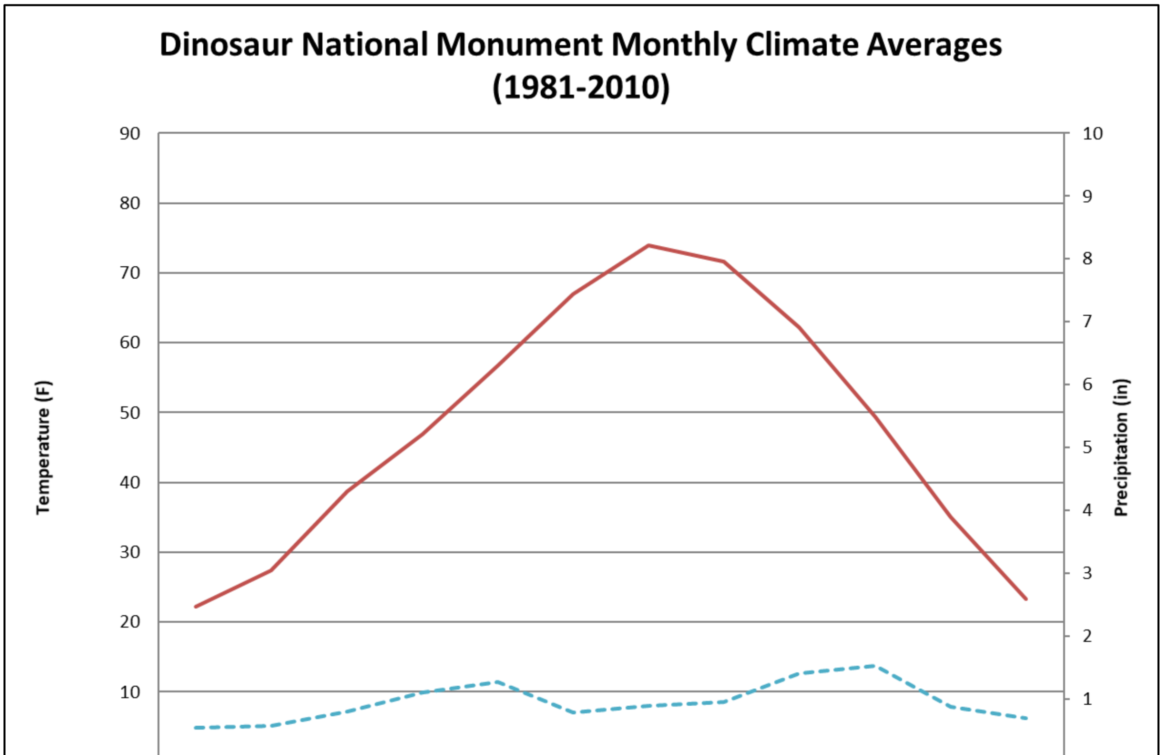
Records of climatic conditions have been maintained continuously at the DINO visitor center since 1965. DINO is characterized by a semiarid climate, averaging 29.5 cm (11.6 inches) of annual precipitation. Precipitation is roughly evenly distributed throughout the year with minor peaks during the spring and fall (Figure 2.2-1). Total annual snowfall averages approximately 101.6 cm (40 inches) with December and January being the snowiest months.

Conditions within the monument are typical of high-elevation plateaus in the continental interior. Summers are long with hot days averaging 32.6 °C (90.6 °F) and warm nights averaging 13.8 °C (56.8 °F) in July. Hot days typically approach 38 °C (100 °F) and the hottest day on record is 39 °C

[3] Adapted from Coles et al. (2008)

(103 °F). Winters are cold, with an average maximum temperature of 0.4 °C (32.8 °F) and an average minimum temperature of −11.8 °C (10.7 °F) occurring in January. On the coldest day on record the thermometer fell to −34 °C (−29 °F). The sun shines 78% of the time during the summer and 60% of the time during winter. Prevailing winds are from the west and average wind speed is at its highest (approximately 16 km per hour [10 mph]) between April and July.

Weather conditions at the monument can change significantly within a single day, as well. Summer thunderstorms associated with cold fronts can lower temperatures several tens of degrees while dropping more than an inch of rain or hail in less than half an hour. Climate change projections for DINO are summarized by Gonzalez (2014), and described in further detail in Chapter 4.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp	22.2	27.4	38.7	46.9	56.7	67	74	71.7	62.2	49.4	35	23.3
Precip	0.54	0.57	0.8	1.1	1.27	0.79	0.89	0.95	1.4	1.52	0.87	0.7

Figure 2.2-1. Walter climate diagram of DINO 30-year temperature and precipitation averages (1981–2010) (data from NCDC 2018).

Geology and Soils[4]

Dinosaur National Monument contains one of the most complete stratigraphic columns exposed within any NPS unit; geologic processes created the strata and structures visible within DINO over nearly one billion years. Over the last 270 million years, the rocks have been eroded and buried, tilted and folded, then exhumed and eroded again into the current plateau and canyon landscape.

[4] Adapted from Coles et al. (2008)

Almost all of the rocks exposed in DINO are sedimentary in origin, ranging in age from late Precambrian Uinta Mountain Group quartzite (800 to 750 million years before present) to Miocene Browns Park Formation conglomerate (5 to 15 million years before present [MYBP]). The lone igneous rock within DINO is an Ordovician dike exposed near Pot Creek. In some parts of the monument, the bedrock is obscured by unconsolidated surficial deposits laid down in the past few millennia by wind, water, or gravity. With the exception of the Silurian and Devonian, rocks representing all of the major periods of the geologic time scale are visible within DINO.

Eighty soil series or soil complexes are known to occur in the monument, varying widely in erodibility and productivity depending on topographic position, parent material, hydrology, slope, and other factors (NRCS 2007). Most of the soils in the monument are likely to form a surface crust. Precipitation is the main controlling factor for soil productivity. Relatively low precipitation typical of the monument produces limited vegetative cover and consequently limited soil organic matter. Soil susceptibility to water erosion is generally slight to moderate, but can be severe in areas with low permeability. Runoff potential is generally moderate.

Hydrology

Rivers and Streams[5]

Although most of the monument consists of xeric uplands, it also contains diverse water resources in the form of rivers, perennial and intermittent streams, seeps, and springs. The Green and Yampa Rivers form the core of management interest within DINO; the Green River flows into the monument from the north at the Gates of Lodore and the Yampa River flows into the monument from the east at Deerlodge Park. The confluence of the Yampa and Green rivers occurs at Echo Park near the center of the monument. The rivers alternate between narrow, bedrock-controlled canyons and broad valleys with well-developed floodplains where the geology consists of softer marine shales.

The Green River hydrograph was significantly modified by the closure of Flaming Gorge Dam upstream from DINO in 1962 (NRCS 2007). The timing and magnitude of flows, water quality, sediment loads, and river habitats through the monument have been markedly altered by dam operation. In many areas, the lack of peak floods and overbank sediment deposition have caused the Green River to become entrenched. Many terraces are no longer connected to the water table, and the communities they support are transitioning to upland vegetation.

The Yampa River is essentially free-flowing, affected minimally by a few small headwater impoundments and some agricultural diversions. Average annual flows on the Yampa River range from peaks of 13,700 cfs in May–June to lows of 350 cfs (USGS 2008) in the late summer and mid-winter. The unaltered runoff pattern in the Yampa River mitigates some of the effects of Flaming Gorge Dam below the confluence with the Green River (NRCS 2007). The Yampa River is the only remaining large tributary in the Colorado River system that retains its free-flowing character, making the river the single most important area in the Colorado River watershed for survival of four federally listed endangered fish species: humpback chub (*Gila cypha*), bonytail chub (*Gila elegans*), Colorado

---

[5] Adapted from Coles et al. (2008)

pikeminnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*), as well as roundtail chub (*Gila robusta*), currently considered a sensitive species (USFWS 1994).

Perennial tributary streams within the monument include Rippling Brook, Pool Creek, Alcove Brook, Cub Creek, and Jones Hole Creek. Only Pool and Jones Hole creeks contribute significant base flows; however, flash flooding and debris flows are possible from early spring through fall in any tributary. The monument also contains limited water resources in the form of intermittent streams, plunge pools, intermittently filled bedrock potholes (tinajas), seeps, and springs. Intermittent streams in side canyons may support stands of riparian and wetland vegetation, especially below pour-offs where plunge-pools form. Tinajas develop in solution pits formed in level exposures of sandstone and limestone; the geology at DINO is such that few potholes hold more than a few hundred gallons of water.

Seeps and Springs

Seeps and springs with flow rates of only a few gallons per minute provide sufficient water for localized surface flows in canyon heads and moist to saturated soils where they emerge from bedding planes and joints in sandstone cliffs. Because of the scarcity of water on the Colorado Plateau and their disproportionately high use by flora and fauna, springs and seeps are considered an ecosystem of concern for park units on the Colorado Plateau (O'Dell et al. 2005). Although not identified as a high priority by DINO during the development of the Northern Colorado Plateau Inventory and Monitoring Network (NCPN) vital signs process, these areas are indeed important as upland water sources and diversity hotspots, and are key to the existence and sustainment of hanging garden communities (see Vegetation below in this chapter for a brief discussion of hanging gardens). The distribution of documented seeps and springs at DINO is shown in Figure 2.2-2. Seeps and springs are found throughout the monument in both upland and lowland locations. For reference, stock pond locations, nearly all of which are in upland locations, and livestock grazing allotments are also shown in Figure 2.2-2. There are 27 known seeps (33% within current livestock grazing allotments) and 87 springs (54% within current livestock grazing allotments) mapped by the monument. Seeps and springs at DINO for the most part have not been characterized and their condition is generally unknown. Some seeps and springs have been field verified. Livestock grazing is believed to be a significant source of degradation for seeps and springs at DINO (pers. comm., Tamara Naumann, 2017). The NCPN has begun monitoring springs, seeps and hanging gardens in some NCPN NPS units. The three indicators selected for springs and seeps monitoring are: (1) water quantity, (2) water chemistry, and (3) vegetation species composition, with an emphasis on rare plants at hanging gardens (Weissinger and Moran 2013).

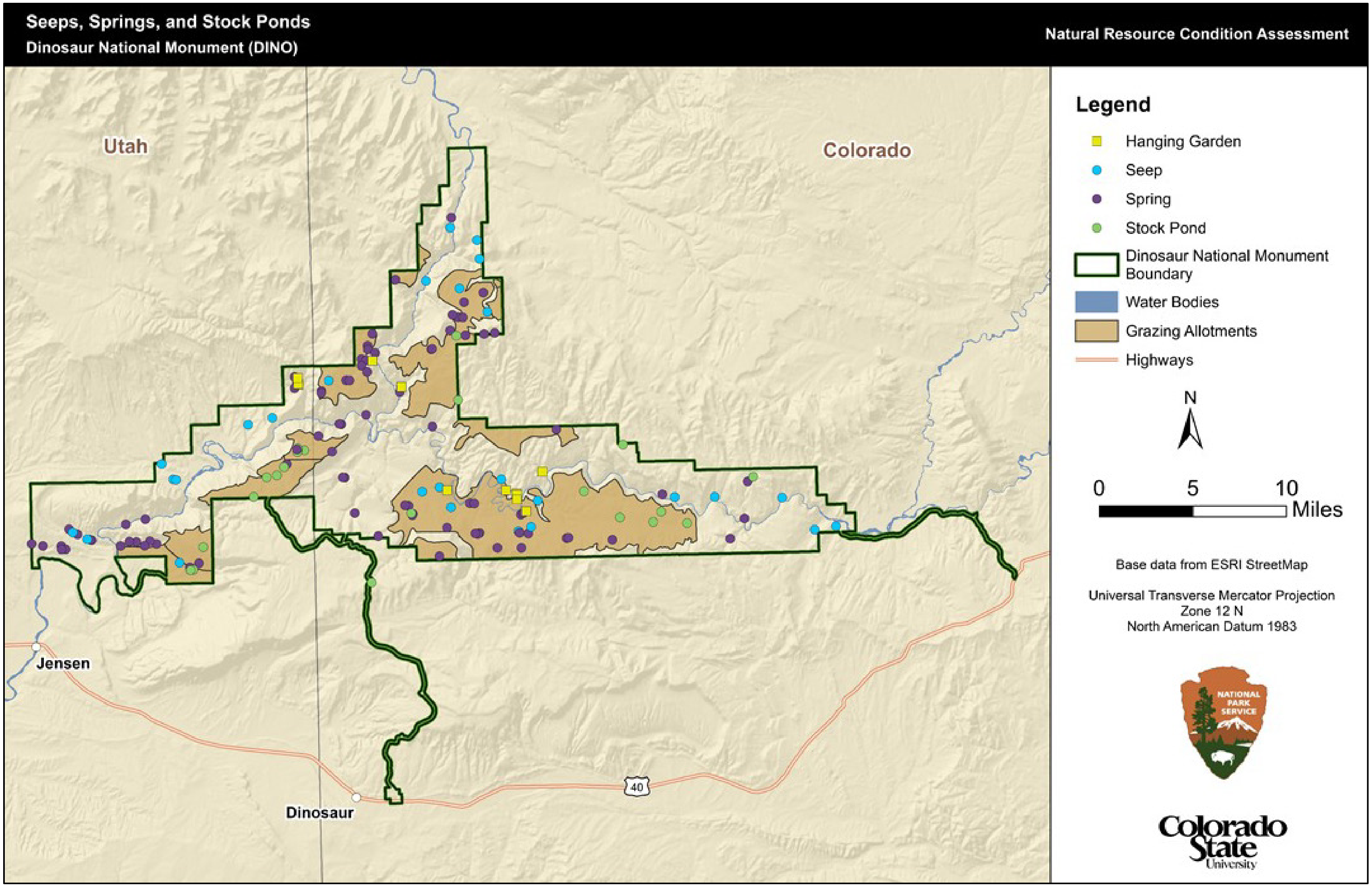


Figure 2.2-2. Seeps, springs, stock ponds and hanging gardens at DINO (Data provided by Dinosaur National Monument 2017).

Air Quality

Dinosaur National Monument is designated as a Class II airshed. Visibility is a major concern at DINO due to the vistas viewed from within and looking into and out of the monument (Sullivan 2016). Regional sources of air pollution that cause haze and contribute to poor visibility include coal- and oil-fired power plants, wildfires, urban emissions that drift into the region via prevailing winds, and more recently oil and gas development (Peterson et al. 1998, Sullivan and McDonnell 2014). Indicators of air quality, including ozone, visibility, particulate matter, and wet and dry deposition are now considered vital signs of park health and condition by the Northern Colorado Plateau Inventory and Monitoring Network (NCPN 2018).

Land Use[6]

Human activities within the DINO landscape over the past 150 years have resulted in changes in the distribution and abundance of native vegetation and have contributed to invasions of non-native plant species. Early settlers to the area arrived in the mid-1800s and established homesteads and ranches,introducing some of the first non-native plants to the area for livestock forage. In particular, livestock grazing and fire suppression allowed big sagebrush, two-needle pinyon pine, and Utah juniper to increase while decreasing the abundance of native grasses. Much of DINO has been grazed for more than a century; ranching began on a large scale in the 1880s and the area was heavily used by both cattle and sheep through the 1920s. The combination of fire suppression and repeated spring and summer grazing pressure has converted much of the sagebrush/ perennial grass shrub-steppe to monotypic, decadent Wyoming big sagebrush stands with invasive annual understories. Seeps and springs were also heavily impacted by human use and livestock grazing.

More recently, development of roads, campgrounds, trails, boat ramps, picnic areas, and buildings to accommodate increased visitation within the monument has contributed to the establishment of non-native species and have also impacted other resource values related to wilderness character. Oil and gas exploration and development within the region threatens a number of resource values important to the monument. These include air and water quality, wildlife habitat quality and fragmentation, and visual resources, natural soundscape, and dark night skies.

Wildlife[7]

Over 200 bird species, 16 reptile species, 6 amphibian species, about 50 fish species, and nearly 70 mammalian species reside within DINO. Large ungulates include elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), bighorn sheep (*Ovis canadensis*) and moose (*Alces alces*); bison (*Bison bison*) have been extirpated. Large mammalian predators include mountain lion (*Puma concolor*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), and black bear (*Ursus americanus*); grizzly bear (*Ursus arctos horribilis*) have been extirpated. Wolf (*Canis lupus*) are rare but not extripated (pers. comm., Morgan Wehtje, December 2020). Nearly the entire Colorado bat fauna is represented in DINO (approximately 15 species). Raptors include peregrine (*Falco peregrinus*) and other falcons, Mexican spotted owl (*Strix occidentalis lucida*), bald (*Haliaeetus leucocephalus*) and golden (*Aquila*

---

[6] Adapted from Coles et al. (2008) and Manni and Le (2014)

[7] Adapted from NPS (2018a)

chrysaetos) eagles, osprey (*Pandion haliaetus*), accipiters, harriers, hawks and other owls. Non-native species are a notable problem only within the fish component where multiple non-native species prey on or compete with various life stages of endangered fishes.

Listed species in or near the monument include the Colorado pikeminnow, humpback chub, razorback sucker, bonytail chub, Mexican spotted owl, and bald eagle. Species proposed for protection by the Endangered Species Act include spotted bat (*Euderma maculatum*), roundtail chub, flannelmouth sucker (*Catostomus latipinnis*), greater sage-grouse (*Centrocercus urophasianus*), northern goshawk (*Accipiter gentilis*), and ferruginous hawk (*Buteo regalis*). Black-footed ferrets (*Mustela nigripes*) have been reintroduced in the region, and could eventually occupy the monument. Peregrine falcons, though recently delisted, remain of special concern and the focus of long-term monitoring. Also of management concern for a variety of reasons are bighorn sheep, elk, bats, and amphibians.

<u>Vegetation</u>
Great diversity of geologic substrates combines with extreme topographic variation within DINO to produce plant communities that are nearly all ecotonal (transitional) to some degree. A diverse landscape supports plant communities reminiscent of several ecoregional provinces described by Bailey (1995), including Intermountain semi-desert and desert, Utah mountains semi-desert-coniferous forest, Southern Rocky Mountain steppe-open woodland coniferous forest, and Colorado Plateau semi-desert. Most of DINO vegetation falls within montane or submontane/cold temperate lowland zones (Colorado Plateau province). Classification of plant communities is challenging because of variation within the physical environment and the need for additional classification effort in the region.

More than 600 plant species have been documented, and approximately 200 more are expected. Dinosaur National Monument's cold desert flora is particularly rich in localized endemic species. Invasive non-native plants threaten native plant communities in a variety of habitats, especially within the river corridors. Prescribed fire has been used extensively in an effort to restore native grassland communities degraded by livestock grazing and fire suppression (NPS 2018a).

Dinosaur National Monument provides habitat for approximately 40 rare plant species. Only one species, the Ute ladies'-tresses orchid (*Spiranthes diluvialis*), is listed as federally threatened. According to information provided by the monument maintained in databases by the Utah and Colorado Natural Heritage Programs, four plant taxa have a NatureServe Global Conservation Status Rank of G1. These taxa are considered critically imperiled—at very high risk of extinction or elimination due to very restricted range, very few populations or occurrences, very steep declines, very severe threats, or other factors (NatureServe 2018). Seven plant taxa are ranked G2. These taxa are considered imperiled—at high risk of extinction or elimination due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors. Approximately 15 plant taxa are endemic to the Uinta Basin.

Hanging gardens are isolated mesophytic communities physically and biologically distinct from surrounding xerophytic or riparian communities. Geologic and hydrologic parameters control the

existence, distribution and physical attributes of hanging-garden habitat. Hanging gardens are distributed within the drainage system of the Colorado Plateau from the Zion National Park area at the southwest to the canyons of the Green and Yampa rivers in the northeast (May et al. 1993). Hanging gardens in the Colorado Plateau region are surrounded by an arid environment and associated with canyon country. These highly localized environments include canyonlands with perennial water sources (seeps) forming pocketed wetlands and draping vegetation across wet cliff faces. Three main garden types exist: alcove, terrace, or windowblind. They tend to occur at all exposures of the canyon walls, but they are always shaded for much to most of each day. Temperature and humidity are relatively stable compared to the surrounding environment. Most hanging gardens are dominated by herbaceous plants, and a number of these are endemic to this region. Common species include *Adiantum capillus-veneris, Adiantum pedatum, Mimulus eastwoodiae, Mimulus guttatus, Sullivantia hapemanii, Cirsium rydbergii*, and several species of *Aquilegia* (NatureServe 2019). In DINO, the Weber Sandstone in the Yampa River Canyon has numerous small hanging gardens, and other hanging gardens are located in Humbug Sandstone (Fowler 1995). A survey of hanging gardens by Fowler et al. (1995) in NPS units on the Colorado Plateau found most to be less than 100 m^2 in size, with occasional larger hanging gardens over 1000 m^2.

Coles et al. (2008) identified and mapped 13 hanging garden sites representing two distinct plant communities (Figure 2.2-2). The communities fall within the Colorado Plateau Hanging Garden ecological system – CES304.764 (Comer et al. 2003): *Calamagrostis scopulorum* Hanging Garden Herbaceous Vegetation CEGL002751, and *Aquilegia micrantha – Calamagrostis scopulorum* Herbaceous Vegetation CEGL002751 (NatureServe 2019). Nearly all examples of this map class occur on vertical cliff faces or inside alcoves. They are therefore invisible on the aerial photography and were not mapped. Instead, known locations have been recorded as point data. Most examples occur in tributary canyons of the Green and Yampa rivers, or in alcoves set back from the stream bank. The substrate is nearly always Weber sandstone. Water quantity and chemistry controls the species that are present in a garden, but the species assemblages characterized by the two associations are fairly consistent across all hanging gardens at DINO. The mapped points represent a small fraction of the total number of hanging gardens present in the monument (Coles et al. 2008). Some plant taxa found in hanging gardens on the Colorado Plateau are endemic to the Colorado Plateau and some of these are endemic to hanging garden habitats (Fowler 1995).

Diversion of the seep supply and erosion of colluvial soil by human foot traffic and livestock use negatively affect garden ecology (May et al. 1993). Management recommendations for some hanging gardens found at DINO are described in Fowler et al. (1995). Although this report is somewhat dated, the general recommendations may still be valuable for management. Exotic plant species cover was higher at several DINO hanging gardens than the other sites surveyed on the Colorado Plateau. Buzz and Redrock hanging gardens had relatively high levels of cheatgrass (*Bromus tectorum*), redtop (*Agrostis stolonifera*) and giant whitetop (*Lepidium latifolium*). Fowler et al. (1995) also described impacts to vegetation and soils from livestock grazing and loafing at Rimrock and Redrock (a.k.a. Barn Cave) hanging gardens in DINO. Livestock was described as the probable vector for cheatgrass invasion at Redrock hanging garden. A comparison of two hanging gardens in Blind Canyon found

that Rimrock hanging garden (heavy livestock use) had higher levels of bare soil and lower native plant species richness, and markedly less plant foliage compared to Bench hanging garden (no livestock use). Snow and Limestone hanging gardens were noted as having a high potential for disturbance of vegetation or wet/colluvial soils by human foot traffic (Fowler et al. 1995).

2.2.3. Resource Issues Overview

Regional Colorado Plateau ecosystem stressors that can impact monument resources and their management include altered disturbance regimes such as fire and flooding, conversion and fragmentation of natural habitats, spread of invasive exotic plants and animal species that threaten regional biological diversity, loss of native pollinators, altered hydrology and channel degradation of streams, sedimentation and pollution of streams (NPS 2015a, O'Dell et al. 2005). Management concerns highlighted in the monument's *Foundation Document* (NPS 2015a) and discussed with monument staff during the scoping process consist of natural resource issues as well as stressors from outside the monument. Primary resource management concerns are briefly described below.

<u>Long-Term Protection of Upland Ecosystem Health and Function</u>

The diverse upland ecosystems within DINO face constant change from several human-induced threats as well as ongoing natural processes. Climate change, nearby oil and gas development, water development projects, and grazing are just a few examples of human-induced threats to the monument's ecosystem. Systemic changes attributable to these threats are increasing wildfire frequency and intensity, reductions in snowpack and rainfall (and thus stream/river flows), degradation of air and water quality, spread of invasive non-native plants, incursion of artificial light sources and noise, and alterations in plant and animal communities and populations that are beyond the range of natural variability. The complexity and widespread nature of several of these ecological pressures further supports the importance of working with other land management partners, private landowners, and other monument stakeholders to increase the effectiveness and breadth of ecological management efforts.

<u>Long-Term Protection of River Ecosystem Health</u>

The Yampa and Green River System is also facing significant change from human-induced threats, including climate change, altered flow regulation, water withdrawals, and declining water quality. The impacts of these changes are many and complex. For example, in addition to altering precipitation patterns in the region (altering the snowmelt quantity and timing that regulate the Yampa's natural hydrograph), climate change could also increase wildfire frequency, with subsequent alterations of local vegetation cover that could influence upland water runoff quantity and quality. Water diversion and dam-regulated water flows have equally complex impacts on sediment transport and river channel dynamics. Given these threats, further scientific understanding of the river system and the flows are required to ensure long-term protection of river ecosystem health.

<u>Building and Maintaining Relationships with Key Partners, Stakeholders, and Traditionally Associated Tribes, and Improving Coordination with Inholding and External Development Interests</u>

Due to the complex and widespread nature of the monument's many resource and value management issues, proactive collaboration and cooperation with partners, stakeholders and traditionally associated tribes are essential to maximize the effectiveness and extent of management efforts.

Education and outreach efforts in local communities are also important components tied to this issue. Likewise, because many of the internal and external development threats to monument resources and values result from the management actions and decisions of other entities, it is critical that the National Park Service improve its engagement and collaboration with these other entities. This could include engagement with inholding and adjacent property owners, oil and gas development companies, and local and state government agencies, to name a few.

Livestock Grazing

Livestock grazing is considered a stressor on numerous monument resources and natural processes (NPS 2015a). There are 10 grazing allotments on approximately 32,375 hectares (80,000 acres) with a total maximum grazing preference of about 2,300 animal unit months or AUMs. Most livestock grazing is related to inholdings and continues as per the enabling legislation. Grazing pressure varies by allotment with some livestock use having minimal impacts and some allotments exhibiting significant adverse impacts (pers. comm., Tamara Naumann, December 2017). The relative or combined impacts of domestic livestock vs. deer and elk are unknown or anecdotal. Special regulations for the administration and termination of grazing are found in 36 CFR 7.63. Grazing associated with private inholdings shall continue until inholdings are purchased (NPS 2015a). Little documentation of rangeland condition or stocking levels exists. The NPS has begun developing a Livestock Management Plan to help promote sustainable use of livestock grazing within the monument while minimizing impacts to other resource values. Livestock grazing history and allotments are discussed in Chapter 4.

Recreational Use

Dinosaur National Monument receives about 300,000–500,000 visitors annually; the vast majority visits only the quarry. However, nearly half of total visitor hours are associated with river use. Although the River Management Plan limits whitewater river use (number of launches, group size), impacts of human use in the river canyons appear to be increasing. Among other things, social trails in and near campsites are proliferating; monitoring indicates an increase in bare ground area and in occurrence of human fecal matter. Recreational use impacts are increasing in side canyons and other areas adjacent to the river because of increasing use from travel originating from the river corridor as well as upland access points. Mountain bike use, though nominally confined to existing roads, is increasing along with subsequent adverse impacts to monument resources such as biological soil crusts, trails, and soil resources.

Land Use Impacts

There are more than 3,400 acres (17 parcels) in private ownership within the monument. Grazing leases and other agricultural activities are associated with these parcels. Activities on adjacent federal and private lands have potential to adversely impact resources and resource values. Various land uses, existing and proposed water depletions, and operation of Flaming Gorge Dam significantly and adversely impact resources. There has been an apparent significant rise in pH on the Yampa River—to the point of potential fish kills. Ongoing research is designed to determine whether the pH rise is real or an artifact of sampling methodologies. If the increase is real, then research will attempt to identify sources of change. Pursuant to a jeopardy Biological Opinion and flow recommendations for

endangered fish, the process is underway to modify operations of Flaming Gorge Dam to benefit listed species (the 4 endangered fish species and the threatened Ute ladies'-tresses orchid).

Endemic and Special Concern Plant Species

The Green River District contains a number of important developed facilities (e.g., campgrounds, boat ramp, picnic area, fossil quarry and visitor center, housing area, maintenance yard, fire cache, hiking trails, etc.). The frequency and density of sensitive plants in the Green River District require frequent clearances for surface-disturbing maintenance and construction activities. Inadequate map and inventory information makes clearance time-consuming, resulting in occasional work delays and/or substandard clearance work.

Known threats to rare plants include unauthorized off-road vehicle use, recreational social trailing, increased use by horses associated with commercial trail rides, changes in livestock grazing use patterns, and invasive species encroachment. No evidence of plant poaching or intentional damage to sensitive plant species has been documented. Another potential threat arises from road improvements that may lead to increased backcountry use.

Invasive Exotic Plant Species

Sixty-six non-native plant species have been identified in DINO. Twenty-five of these are listed by the NCPN as invasive exotic plants (Washuta et al. 2018). Flaming Gorge dam operations, livestock grazing, and external vectors have contributed to invasive plant establishment and spread. NPS (internal) fire management operations, new construction, roadside vegetation management and facility maintenance operations have also contributed. Invasive plant management and native plant restoration efforts appear to be under-supported relative to identified needs.

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

Each unit in the National Park System is required by the National Park Service Organic Act of 1916 to "conserve the scenery and natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations." The General Authorities Act in 1970 (as amended) reiterated the provisions of the Organic Act and emphasized that "these areas, though distinct in character, are united through their inter-related purposes and resources into one national park system as cumulative expressions of a single national heritage." The Act also re-emphasized the importance of "unimpaired" NPS resources for future generations. The enabling legislation establishes park purposes and legislatively authorized uses within a context of cultural and natural resources. The National Park Service Management Policies (NPS 2006) provides Service-wide guidance for Park System planning, land protection, natural and cultural resources management, wilderness preservation and management, interpretation and education, use of the parks, park facilities and commercial visitor services. All management and planning documents developed for the monument must adhere to these overarching documents and other laws, Executive Orders and Director's Orders.

In addition to these NPS-level documents, a number of important documents guide the management of natural resources in the monument. The monument's *Resource Management Plan* (NPS 1995),

Foundation Document (NPS 2015a) and *Superintendent's Compendium* (NPS 2015b) articulate a management philosophy and provide broad direction and vision for future management decisions at the monument, based on the monument's enabling legislation and threats and stressors to the monument's resources.

2.3.2. Status of Supporting Science

Available data and reports varied significantly depending upon the resource topic. Much of the supporting baseline survey and monitoring data was collected through the ongoing NCPN initiated in the early 2000s. The NCPN also supported requests for geospatial data. Landscape context information and aspects of human dimensions were greatly supported by national program staff such as the Natural Sounds and Night Skies Division (NSNSD), the national NPS Air Quality program, and the NPScape Project within the Inventory and Monitoring Program. Additional information and data were provided by the monument, published and unpublished reports and articles, and other outside experts noted in the individual resource sections.

2.4. Literature Cited

Bailey, R.G. 1995. Ecoregions: The ecosystem geography of the oceans and continents, second edition. Springer, New York, New York.

Chapman, S.S., G.E. Griffith, J.M. Omernik, A.B. Price, J. Freeouf, and D.L. Schrupp. 2006. Ecoregions of Colorado (color poster with map, descriptive text, summary tables, and photographs; map scale 1:1,200,000). U.S. Geological Survey, Reston, Virginia.

Coles, J., D. Cogan, D. Salas, A. Wight, G. Wakefield, J. Von Loh, and A. Evenden. 2008. Vegetation classification and mapping project report, Dinosaur National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2008/112. National Park Service, Fort Collins, Colorado.

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow, and J. Teague. 2003. Ecological systems of the United States: a working classification of U.S. terrestrial systems. NatureServe, Arlington, Virginia.

Crump, S.V. 2012. Dinosaur recommended wilderness: building blocks for wilderness character. Dinosaur National Monument, National Park Service Unpublished Report, Dinosaur, Colorado.

Fowler, J.F. 1995. Biogeography of hanging gardens on the Colorado Plateau. Thesis. Department of Zoology and Physiology, University of Wyoming, Laramie, Wyoming.

Fowler, J.F., N.L. Stanton, and S.W. Buskirk. 1995. Management recommendations for hanging gardens in Arches National Park, Canyonlands National Park, Dinosaur National Monument, Glen Canyon National Recreation Area, Natural Bridges National Monument, and Zion National Park. University of Wyoming, Laramie, Wyoming.

Gonzalez, P. 2014. Climate change summary, Dinosaur National Monument in Colorado and Utah. National Park Service Climate Change Response Program Unpublished Report. Natural Resources Stewardship and Science, National Park Service, Washington, D.C.

Manni, M.F., and Y. Le. 2014. Dinosaur National Monument visitor study: Summer 2013. Natural Resource Report NPS/NRSS/EQD/NRR—2014/786. National Park Service, Fort Collins, Colorado.

May, C.L., J. Fowler, and N. Stanton. 1993. Geomorphology of the hanging gardens of the Colorado Plateau. In Charles Van Riper, editor, Proceedings of the 2nd Biennial Conference on Research in Colorado Plateau National Parks, October 25–28, 1993, National Park Service Transactions and Proceedings Series NPS/NRNAU/NRTP-95/11.

National Climatic Data Center (NCDC). 2018. Climate Data Online website. Available at: http://www.ncdc.noaa.gov/cdo-web/ (accessed 19 February 2018).

National Park Service (NPS). 1995. Dinosaur National Monument resource management plan. National Park Service, Dinosaur, Colorado.

NPS. 2006. Management policies 2006: the guide to managing the National Park System. National Park Service, Washington, D.C.

NPS. 2015a. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

NPS. 2015b. 2015 Dinosaur National Monument: Superintendent's compendium. National Park Service, Dinosaur, Colorado.

NPS. 2018a. Northern Colorado Plateau Inventory & Monitoring Network: biophysical description of Dinosaur National Monument webpage. Available at: https://www.nps.gov/im/ncpn/bpd-dino.htm (accessed 15 November 2018).

NPS. 2018b. National Park Service visitor use statistics webpage. Available at: https://irma.nps.gov/Stats/ (accessed 15 November 2018).

Natural Resources Conservation Service (NRCS). 2007. Soil survey of Dinosaur National Monument, Colorado and Utah. In cooperation with Colorado State University, Colorado Agricultural Experiment Station, Utah State University, Utah Agricultural Experiment Station, and USDI-NPS.

NatureServe. 2003. International ecological classification standard: terrestrial ecological systems of the United States. Natural Heritage Central Databases. NatureServe. Arlington, VA. Available at: http://www.natureserve.org/explorer (accessed 10 July 2017).

NatureServe. 2018. Conservation status assessment web page. Available at: http://www.natureserve.org/conservation-tools/conservation-status-assessment (accessed 15 December 2018).

NatureServe. 2019. NatureServe Explorer: An online encyclopedia of life. Available at: http://explorer.natureserve.org/ (accessed March 2018).

Northern Colorado Plateau Inventory and Monitoring Network (NCPN). 2018. NCPN air quality program.

O'Dell, T., S. Garman, A. Evenden, M. Beer, E. Nance, D. Perry, R. DenBleyker, et al. 2005. Northern Colorado Plateau Inventory and Monitoring Network, Vital Signs Monitoring Plan. National Park Service, Inventory and Monitoring Network, Moab, Utah.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Map (scale 1:7,500,000). Annals of the Association of American Geographers 77(1):118–125.

Peterson, D.L., T.J. Sullivan, J.M. Eilers, S. Brace, D. Horner, K. Savig, and D. Morse. 1998. Assessment of air quality and air pollutant impacts in national parks of the Rocky Mountains and Northern Great Plains. Regional Air Quality Reviews. Technical Report NPS D-657. National Park Service-Air Resources Division, Denver, Colorado.

Sullivan, T.J. 2016. Air quality related values (AQRVs) for Northern Colorado Plateau Network (NCPN) parks: Effects from ozone; visibility reducing particles; and atmospheric deposition of acids, nutrients and toxics. Natural Resource Report NPS/NCPN/NRR—2016/1169. National Park Service, Fort Collins, Colorado.

Sullivan, T.J., and T.C. McDonnell. 2014. Mapping of nutrient-nitrogen critical loads for selected national parks in the Intermountain West and Great Lakes Regions. Natural Resource Technical Report NPS/ARD/NRTR—2014/895. National Park Service, Fort Collins, Colorado.

U.S. Census Bureau. 2010. 2010 Census – Urban and Rural Classification. Available at: https://www2.census.gov/geo/tiger/TIGER2010/UA/2010/ (accessed 21 June 2018).

U.S. Fish and Wildlife Service (USFWS). 1994. Endangered and threatened wildlife and plants; determination of critical habitat for the Colorado River endangered fishes: razorback sucker, Colorado squawfish, humpback chub, and bonytail chub. Final rule. Federal Register, Vol. 59, #54, Monday, March 21, 1994.

U.S. Geological Survey (USGS). 2008. National water information system: streamflow gauge data from the Yampa River at Deerlodge Park, Colorado website. Available at http://nwis.waterdata.usgs.gov/nwis/uv?09260050 (accessed 13 March 2018).

Washuta, A., D.W. Perkins, and L. Gommermann. 2018. Invasive exotic plant monitoring at Dinosaur National Monument: Yampa River and the Echo Park and Mitten Park extra area, 2017

field season. Natural Resource Report NPS/NCPN/NRR—2018/1729. National Park Service, Fort Collins, Colorado.

Weissinger, R., and M. Moran. 2013. Proposed sampling design for springs, seeps, and hanging gardens monitoring in the Northern Colorado Plateau Network. Natural Resource Report NPS/NCPN/NRR—2013/618. National Park Service, Fort Collins, Colorado.

Woods, A.J., D.A. Lammers, S.A. Bryce, J.M. Omernik, R.L. Denton, M. Domeier, and J.A. Comstock. 2001. Ecoregions of Utah (color poster with map, descriptive text, summary tables, and photographs; map scale 1:1,175,000). U.S. Geological Survey, Reston, Virginia.

Chapter 3. Study Scoping and Design

3.1. Scoping

The initial phase of the study consisted of communications between Colorado State University (CSU) and National Park Service (NPS) staff, including Dinosaur National Monument (DINO) staff, the Intermountain Regional NPS Office (IMRO), the Northern Colorado Plateau Inventory and Monitoring Network (NCPN), Water Resources Division (NRCA program lead), and National Resource Stewardship and Science programs. Project scoping was initially coordinated among CSU, DINO staff and Donna Shorrock (then NPS Intermountain Region NRCA Coordinator). A phone meeting with Lisa Baldwin, Chief of DINO Resource Stewardship and Science, Donna Shorrock, and Dave Jones was held on November 18, 2015, to discuss the NRCA process, discuss schedule and scoping meeting dates, and other project needs. We agreed that the best approach would be to push the on-site scoping forward to spring 2016 to combine the meetings with field tours of the monument.

Pre-scoping preparation consisted of reviewing available published information and reports in order to understand the management and resource context for the monument. Priorities identified through the NCPN Vital Signs Inventory and Monitoring Program (O'Dell et al. 2005, NCPN 2015), the DINO *Foundation Document* (NPS 2015), and other sources of information formed the basis for a preliminary list of focal resources to support initial NRCA discussions with monument staff and others invited to participate. CSU prepared the NRCA briefing and agenda for two days on site and a preliminary list of focal resources to discuss. The preliminary list of resources was sent to Lisa Baldwin for review/feedback prior to the meetings. CSU also summarized NPScape and other land cover and land use data for the region surrounding the monument to support scoping discussions. In the months leading up to the meetings, CSU continued to gather and assemble available data, information, reports, and literature to support the project. A site visit and initial meetings took place April 12–14, 2016, at DINO Headquarters. The attendee list is shown in Table 3.1-1. The purpose of the preliminary scoping meetings was to:

- establish contact and begin dialogue with key staff members;
- identify points of contact;
- provide an overview of NRCA purpose and process (for DINO staff);
- provide an overview of DINO context, administrative history and management concerns (for cooperators);
- discuss analysis framework, reporting scales/units, and rating system;
- identify and discuss priority/focal resources in support of framework development;
- discuss key NRCA concepts including indicators and measures, threats and stressors, and reference conditions;

- identify and gather available data and information;
- identify sources of expertise inside and outside the NPS;
- define project expectations, constraints, and the need to balance depth vs. breadth; and
- review the assessment timeline.

Table 3.1-1. List of scoping participants and their affiliations.

Name	Title	Affiliation
Mark Foust	Superintendent	DINO
Lisa Baldwin	Chief, Resource Stewardship and Science (RSS)	DINO
Anita Dore	Administration Officer	DINO
Michael Hodgkinson	Chief, Facility Management	DINO
Dan Johnson	Chief, Interpretation, Education, and Visitor Services	DINO
Dan Chure	Paleontologist	DINO RSS
Andy Bundshun	Fire Management Officer	DINO RSS
Tamara Naumann	Ecologist/Botanist	DINO RSS
Emily Spencer	Natural Resource Specialist	DINO RSS
Lee Buschkowsky	Chief Ranger, Visitor and Resource Protection	DINO
Jeff Albright	Coordinator, NRCA Program	NPS Water Resources Division
Rebecca Weissinger	Ecologist	NPS NCPN
Dana Witwicki	Ecologist	NPS NCPN
Roy Cook	Natural Resources Specialist	CSU-Warner College of Natural Resources
David Jones	Ecologist and Principal Investigator	CSU-Warner College of Natural Resources
John Sovell	Zoologist	CSU-Warner College of Natural Resources
Bernadette Kuhn	Botanist	CSU-Warner College of Natural Resources

Key constraints placed on the scope of NRCA include the following:

- the assessment provides a snapshot of a subset of monument resources, as determined through the scoping process;
- some lower priority resources or those having little supporting data may not be fully examined to allow a more comprehensive analysis of higher-priority resources;
- the assessment will use existing information/data and not modeled or projected data, although limited analysis and data development may be undertaken where feasible (e.g., data to support visual resources assessment) – future modeled data is only used in the climate change section; and

- assignment of condition ratings may be constrained by insufficient information or inadequately defined reference conditions.

In the fall of 2016, Phyllis Bovin took over as IMRO NRCA Coordinator and assumed the role of NPS Agreement Technical Representative (ATR).

3.2. Study Design

3.2.1. Indicator Framework, Focal Resources and Indicators

The NRCA framework used for DINO is adapted from The Heinz Center (2008) (Table 3.2-1). The Heinz structure was identified in the NRCA guidance documents as a relevant framework that organizes indicators under each focal resource within broad groupings of ecosystem attributes related to: landscape context including system and human dimensions; chemical and physical components; biological components; and integrated systems. Although threats and stressors are described for each focal resource, the *Land Cover and Land Use* and *Climate Change* sections were added to address broad ecosystem-level processes and stressors affecting multiple resources. Some resources identified as important to the monument and desirable to include in the NRCA during the scoping phase were either not included as focal resources or were addressed in a brief fashion due to lack of information or data, poor understanding of their ecological role and significance in the landscape, their absence at the monument, or lack of justification to include them as a focal resource. The latter case for eliminating resources considered to have a lower priority for inclusion also reflected realities related to balancing cooperator budget, breadth of the assessment across many resources, and depth of analysis. A total of 18 resources were examined and included here: five addressing system and human dimensions, three addressing chemical and physical attributes, and seven addressing biological attributes.

Table 3.2-1. Dinosaur National Monument natural resource condition assessment framework.

Ecosystem Attribute	Focal Resource	Reporting Unit	Indicators and Measures
Landscape Context – System and Human Dimensions	Land Cover and Land Use	Monument and surrounding buffers: 3 km, 30 km, and 160 km	Land cover/land use metrics Human population and housing Conservation/protection status Energy exploration, extraction and distribution
	Dark Night Skies	Monument and surrounding region	Anthropogenic Light Ratio (ALR) Bortle Night Sky Brightness
	Natural Sounds	Monument and surrounding area	Anthropogenic sources of noise Traffic volume on CO-64 and US-40 – vehicle counts Percent time above specified level of 52 dBA Exceedance levels – dBA level of L_{50} Sounds levels by frequency Percent time audible natural and anthropogenic sound sources Anthropogenic sound level impacts (modeled) – median and maximum impacts in dBA

Table 3.2-1 (continued). Dinosaur National Monument natural resource condition assessment framework.

Ecosystem Attribute	Focal Resource	Reporting Unit	Indicators and Measures
Landscape Context – System and Human Dimensions (cont.)	Climate Change	Monument and surrounding area	Temperature and precipitation metrics Palmer Drought Severity Index Observed and projected changes in frost-free period
	Visual Resources	Monument-wide: views from key viewpoints	Scenic Inventory Value – Scenic quality and view importance
Chemical and Physical/Envtl Quality	Air Quality	Monument and surrounding area	Level of ozone – human and vegetation risk levels Atmospheric wet deposition: total nitrogen and sulfur Visibility haze index
	Water Quality	By major stream reach within monument (Yampa, Green above confluence, Green below confluence)	Water temperature pH Dissolved oxygen Turbidity/Total Dissolved Solids Chloride Sulfate Iron E. coli Nitrogen Phosphorus Aquatic macroinvertebrates
	Yampa and Green River System	By major stream reach within monument (Yampa, Green above confluence, Green below confluence)	Stream flows Sediment loads/dynamics Geomorphology
Biological – Plants	Vegetation	Monument-wide by: pinyon-juniper woodlands, sagebrush shrublands, grasslands, and riparian	Community composition (% native species) Floristic quality – mean Coefficient of Conservatism Invasive exotic plant (IEP) species cover Dominance of cheatgrass in the herbaceous layer Priority IEP species cover and occurrence size in native riparian vegetation communities (Severity rank) Fire regime metrics
	Plant species of special concern	Monument-wide	Abundance measures over time Distribution and extent of each species NatureServe element occurrence rankings Other metrics of condition

Table 3.2-1 (continued). Dinosaur National Monument natural resource condition assessment framework.

Ecosystem Attribute	Focal Resource	Reporting Unit	Indicators and Measures
Biological – Animals	Fish	Monument-wide; large rivers	Native species richness Fish index of biotic integrity Status/trends in fish species of conservation concern
	Greater sage-grouse	Monument-wide	Percent of sagebrush habitat modeled as suitable within the monument Disturbance index associated with modeled suitable habitat Regional vulnerability of greater sage-grouse to climate change Regional male lek attendance
	Bats	Monument-wide	Abundance of native bat species Native bat species richness Occurrence of bat species of conservation concern
	Landbirds	Upland, Riparian	Native species richness (S) Bird index of biotic integrity (IBI) Occurrence of bird species of conservation concern
	Bighorn sheep	Monument-wide	Population size and viability Proximity of suitable habitat to domestic livestock grazing allotments Landscape condition Regional vulnerability to climate change

Existing data for some resources and indicators were lacking or incomplete. The following resources were discussed and eliminated from full or partial treatment for various reasons, including management priority, value of the resource as a Fundamental Resource Value, lack of data, and budgetary constraints:

- Wilderness Character. Over 90% of DINO is recommended wilderness and managed as such. Wilderness character has not been evaluated at DINO using standard NPS protocols and evaluation protocols. The NPS will likely do a formal evaluation of wilderness character sometime in the future.

- Paleontological Resources. Although paleontology is the primary reason for the monument's existence, this topic was discussed and it was decided that ancient ecosystems preserved in the fossil record are best addressed/characterized in existing plans. The monument decided not to include this topic in the NRCA. Paleontological resources are often not addressed in NRCAs.

- Peregrine Falcon. This species is iconic and considered a success story in the history of the monument and national conservation. As a top predator, the peregrine falcon was seriously endangered world-wide in the mid-20th century because of the effects of DDT and other

persistent pesticides, which caused thin-shelled eggs prone to breaking during incubation. The species was listed as federally endangered in 1973. The peregrine falcon was removed from the U.S. Endangered Species list in 1999 following policies to reduce DDT in the environment and a host of other nationwide recovery and reintroduction efforts. The species is found within DINO and considered stable. A formal monitoring program ended in 2012. It was decided that this species will be briefly referenced in the bird section.

- Deer and Elk. Deer and elk populations can significantly impact vegetation and soil resources at DINO. Unnaturally large populations may be due to the absence of most natural predators (pers. comm., Tamara Naumann, April 2016). There is little information or data available to characterize the problem in detail or guide management. This management issue is considered a "potential emerging problem", and is a sensitive topic because it involves game management and greatly interests the public. A grazing management plan for DINO, which could have implications for deer and elk populations, is currently in development.

- Seeps, Springs and Hanging Gardens. These resources and features were noted as important and possibly at risk during the scoping period (pers. comm., Tamara Naumann, 2016). The regional literature on this topic is sparse and the data for park seeps, springs and hanging gardens is very limited. The extent of seep and spring data is a point feature class data layer with location data for 27 seeps and 87 springs. According to the data layer, a minority of the locations have been field verified. No other data were found for these resources. For hanging gardens, aside from various surveys from the 1990s and more recent characterization and classification of hanging garden plant communities (Coles et al. 2008), little documentation of hanging gardens at the monument exists. These unique communities often harbor rare and endangered plant species and endemic plant species.

These topics are mentioned briefly in Chapter 2 and may also be discussed in focal resource sections in Chapter 4.

3.2.2. Reporting Areas

The reporting area for all resources varies by resource but is often the entire area within the monument boundary. In some cases, indicators were analyzed using subsets based on geographic or ecological strata within the monument, e.g., upland birds and riparian birds. The results for each subset was then combined into single monument-wide condition and trend ratings for the resource. For several resources such as those capturing landscape context, the extent of the analysis extends outside monument boundaries in a fixed or variable way.

3.2.3. General Approach and Methods

General Approach

This study employed a scoping process involving Colorado State University, DINO and other NPS staffs to discuss the NRCA framework, identify important monument resources, and gather existing literature and data for each of the focal resources. Indicators and measures to be used for each resource were then identified and evaluated. All available data and information were analyzed and synthesized to provide summaries and address condition, trend and confidence. Condition ratings

compared the current condition at the monument to the reference condition when possible. In some cases, due to interrelationships, a focal resource was used to help determine condition and/or trend for another focal resource. For example, changes in land cover/land use and impervious surfaces within the watershed are used to support trend determination for stream hydrology.

Sources of Information and Data

Non-spatial data, published literature, unpublished reports and other grey literature related to conditions both inside and outside the monument were obtained from myriad sources. The primary sources for monument-specific resource data were monument staff, NCPN staff, and the public access side of the IRMA (Integrated Resource Management Applications) web portal, which is intended as a "one-stop shop" for data and information on monument-related resources. Monument and NCPN staff were a valuable source of knowledge regarding resources, stressors, and management history and activities. State and federal agency reports and data were downloaded using the web or obtained from the monument or other agency staff. Spatial data were provided by the monument, the NCPN, the NPS IMRO and other sources. GIS data developed to support analyses or maps were documented using NPS metadata standards. The NPS Inventory and Monitoring (I&M) program and Night Skies and Natural Sounds Division (NSNSD) also provided data to support the assessment. Primary data sources are described in each focal resource section. In some cases, existing data were reworked in order to make them more useful for analysis.

Subject Matter Experts

A number of subject matter experts were consulted while developing this assessment. Expert involvement included in-person and telephone meetings, correspondence, and reviews of preliminary resource drafts. The experts consulted for each focal resource are listed in the resource sections in Chapter 4.

Data Analysis and NRCA Development

Data analysis and development of technical sections followed NRCA guidance and recommendations provided by the NPS. Data analyses were tailored to individual resources, and methods for individual analyses are described within each section of Chapter 4. As one of the tenets of the NRCA framework, geospatial analysis and presentation of results are used where possible throughout the assessment. Periodic contact between the authors, monument and other NPS staff and subject matter experts took place as needed to obtain additional data and information or collaborate on an analysis framework or approach or on the interpretation of results.

Final Assessments

Final drafts followed a process of preliminary draft review and comment by monument staff and other reviewers. Reviewer comments were incorporated and addressed to improve the analysis and technical synthesis within the limits of the NRCA scope, schedule and budget.

3.2.4. Rating Condition, Trend and Confidence

For each focal resource, a reference condition for each indicator is established and a condition rating framework is presented. The condition rating framework forms the basis for assigning a current condition to each indicator. In some cases, current condition and trend may be based on data or

information that is several or more years old. Condition may be based on qualitative, semi-quantitative or quantitative data. Trend is assigned where data exist for at least two time periods separated by an ecologically significant span or may be based on qualitative assessments using historical information, photographs, anecdotal evidence or professional opinion. It is not uncommon for there to be some correlation among indicators for a particular focal resource. In a few cases, the trend assigned to an indicator may be influenced by the data for a correlated indicator. For example, vehicle traffic trend data may influence the trend rating for anthropogenic noise levels.

The level of confidence assigned to each assessed indicator integrates the comfort level associated with the condition and/or trend rating assigned. A lower confidence (i.e., higher uncertainty) may be assigned where data have considerable uncertainty or numerous assumptions, where changes may be small and no quantitative data are available, where statistical inference is poor (e.g., as is often the case where sample sizes are inadequate), where interannual or seasonal variability is very high or unknown, where detectability is difficult when monitoring (e.g., some plants and birds), where only several closely spaced data points are available for trend determination (e.g., invasive exotic plant sampling only several years apart and only two periods available), or where a very small proportion of the reference frame or population of interest is sampled (in time or space), which influences the representativeness of the sample (e.g., the timing and length of attended listening data for natural sounds analysis). Lack of information/data may result in an unknown condition rating, which is often associated with unknown trend and low confidence.

3.2.5. Symbology and Scoring[8]

This NRCA uses a standardized set of symbols to represent condition status, trend and confidence (Table 3.2-2, Table 3.2-3). This standardized symbology provides some consistency with other NPS initiatives and reporting programs.

The overall assessment of the condition for a focal resource may be based on a combination of the status and trend of multiple indicators and specific measures of condition. A set of rules was developed for summarizing the overall status and trend of a particular resource when ratings are assigned for two or more indicators or measures of condition. To determine the combined condition, each red symbol is assigned zero points, each yellow symbol is assigned 50 points, and each green symbol is assigned 100 points. Open (uncolored) circles are omitted from the calculation. Average scores of 0 to 33 warrant significant concern, average scores of 34 to 66 warrant moderate concern, and average scores of 67 to 100 indicate the resource is in good condition. In some cases, certain indicators may be assigned larger weights than others when combining multiple metrics into a condition score. In those cases, the authors provide an explanation for the weights applied.

To determine the overall trend, the total number of down arrows is subtracted from the total number of up arrows. If the result is 3 or greater, the overall trend is improving. If the result is −3 or lower, the overall trend is deteriorating. If the result is between 2 and −2, the overall trend is unchanged. Sideways trend arrows and cases where trend is unknown are omitted from this calculation.

[8] Adapted from NPS-NRCA Guidance (NPS 2017).

Table 3.2-2. Standardized condition status, trend and confidence symbology used in this NRCA.

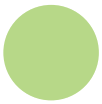
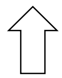
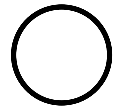
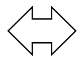
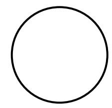
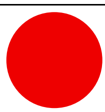
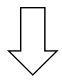
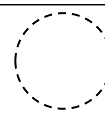
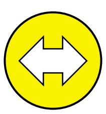
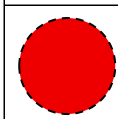
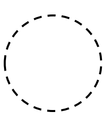
Condition Status		Trend in Condition		Confidence in Assessment	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition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

Table 3.2-3. Examples of how condition symbols should be interpreted.

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

3.2.6. Reporting Structure for Focal Resource Sections

The results for each focal resource section in Chapter 4 are presented using the following structure.

Background and Importance

This section provides information regarding the relevance of the resource to the monument and the broader ecological or geographic context. This section explains the characteristics of the resource to

help the reader understand subsequent sections of the document. Relevant stressors of the resource and the indicators/measures selected are listed or discussed.

Data and Methods

This section describes the source and type of data used for evaluating the indicators/measures, data management and analysis (including qualitative) methods used for processing or evaluating the data, and outputs supporting the assessment.

Reference Conditions

This section describes the reference conditions applied to each indicator and how the reference conditions are cross-walked to a condition status rating for each indicator. NRCAs must use logical and clearly documented forms of reference conditions and values. Reference condition concepts and guidance are briefly described in Chapter 1. A reference condition is “a quantifiable or otherwise objective value or range of values for an indicator or specific measure of condition that is intended to provide context for comparison with the current condition values. The reference condition is intended to represent an acceptable resource condition, with appropriate information and scientific or scholarly consensus” (NPS 2017). An important characteristic of a reference condition is that it may be revisited and refined over time. The nature of the reference condition prescribed for a particular resource can vary with the status of the resource relative to historic conditions and anticipated future conditions (Figure 3.2-1).

For example, substantial overlap might exist for pinon-juniper vegetation communities, moderate overlap might exist for birds and river flows, and little to no overlap might exist for some native fish species. Reference conditions can be particularly difficult to define where pre-settlement conditions or range of variability are unknown, and/or where little inventory and monitoring data exist.

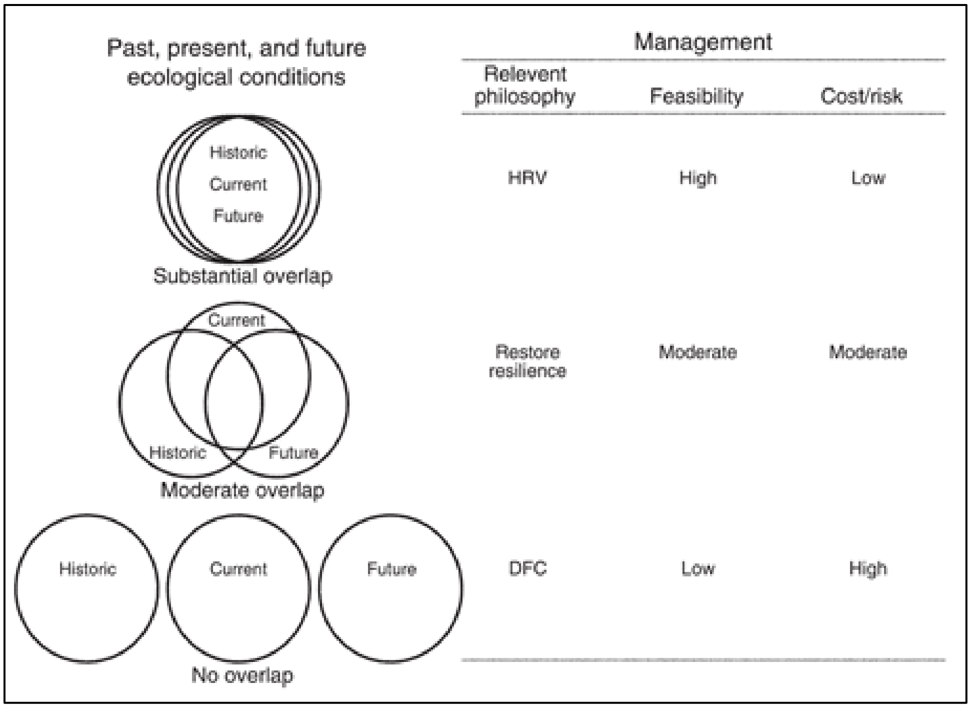


Figure 3.2-1. Illustration of three possible cases of the extent to which current ecosystem conditions in a place differ from historic conditions and from projected future conditions. Circles denote the range of variability for each time period. Also shown are the expected management criteria for each case. Abbreviations are HRV, historic range of variability and DFC, desired future conditions (Hansen et al. 2014).

Condition and Trend

This section provides a summary of the condition for each indicator/measure based on available literature, data, and expert opinions. A condition status, trend and confidence designation for each indicator/measure is assigned and accompanying rationale is provided. Where multiple indicators or metrics are used, a single rating is consolidated for each resource using the condition rating scoring framework described earlier in this chapter. Lack of information/data may result in an unknown condition rating, which is often associated with unknown trend and low confidence.

Uncertainty and Data Gaps

This section briefly highlights information and data gaps and uncertainties related to assessment of the resource. Low confidence can be associated with a combination of data that are not current, insufficient data, unrepresentative data, poorly documented data, or data having poor precision and/or accuracy.

Sources of Expertise

Individuals who were consulted, provided data or provided preliminary reviews for the focal resource are listed in this section.

Literature Cited

This section lists all of the referenced sources for the section. Including sources here allows each focal resource section to stand alone as a brief technical document complete with references.

3.3. Literature Cited

Coles, J., D. Cogan, D. Salas, A. Wight, G. Wakefield, J. Von Loh, and A. Evenden. 2008. Vegetation classification and mapping project report, Dinosaur National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2008/112. National Park Service, Fort Collins, Colorado.

Hansen, A.J., N. Piekielek, C. Davis, J. Hass, D.M. Theobald, J.E. Gross, W.B. Monahan, T. Olliff, and S.W. Running. 2014. Exposure of U.S. National Parks to land use and climate change 1900–2100. Ecological Applications 24(3):484–502.

National Park Service (NPS). 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

NPS. 2017. Natural resource condition assessment guidance documents and useful resources. NPS Water Resources Division. Available at: https://www.nps.gov/orgs/1439/nrca.htm (accessed 24 February 2018)

Northern Colorado Plateau Inventory and Monitoring Network (NCPN). 2015. NCPN website. Available at https://www.nps.gov/im/ncpn/index.htm (accessed 17 October 2017).

O'Dell, T., S. Garman, A. Evenden, M. Beer, E. Nance, D. Perry, R. DenBleyker, et al. 2005. Northern Colorado Plateau Inventory and Monitoring Network Vital Signs Monitoring Plan. National Park Service, Inventory and Monitoring Network, Moab, Utah.

The H. John Heinz III Center for Science, Economics and the Environment (The Heinz Center). 2008. The state of the nation's ecosystems 2008: measuring the lands, waters, and living resources of the United States. Island Press, Washington, D.C.

Chapter 4. Natural Resource Conditions

Each focal resource used to assess the ecosystem attributes for Dinosaur National Park will be presented and discussed as noted in Table 4-1.

Table 4-1. List of sections contained in Chapter 4.

Ecosystem Attributes	Focal Resource	Section Number
Landscape Content – System and Human Dimensions	Land Cover and Land Use	4.1
	Dark Night Skies	4.2
	Natural Sounds	4.3
	Climate Change	4.4
	Visual Resources	4.5
Chemical and Physical/Environmental Quality	Air Quality	4.6
	Water Quality	4.7
	Yampa and Green River System	4.8
Biological – Plants	Vegetation	4.9
	Plant Species of Special Concern	4.10
Biological – Animals	Fish	4.11
	Greater Sage-Grouse	4.12
	Bats	4.13
	Landbirds	4.14
	Bighorn Sheep	4.15

4.1. Land Cover and Land Use

4.1.1. Background and Importance

This section places monument resources and management concerns within a local and regional context of land cover and land use and examines implications related to human population and resource conservation. Using several metrics, it characterizes conditions and dynamics of the surrounding areas, highlights the potential effects of related landscape-scale stressors on monument resources, and underscores the conservation value of the monument to the surrounding region. The synthesis of national data uses a series of straightforward spatial analyses for areas within and surrounding the monument. Condition and trend ratings are not assigned to these landscape context metrics. In some cases, long-term data are not available and for the most part the monument has little influence over activities occurring outside monument boundaries. Longer-term data and future projections are available for some population and housing metrics.

Threats and Stressors

Land use is intensifying around many protected areas including parks and monuments (Wittemyer et al. 2008, Wade and Theobald 2010, Davis and Hansen 2011, Hansen et al. 2014). Many parks in the region are concerned with the ecological consequences of habitat loss associated with land development, conversion of surrounding areas to non-natural uses (especially oil and gas exploration), as well as the effects of climate change on natural communities (Hansen and Gryskiewicz 2003). The growth of housing adjacent to protected areas can create a patchwork of land use that degrades the conservation impact of high-value protected areas on adjacent parcels and within the region (Radeloff et al. 2010). Protected areas are most effective when they conserve habitat within their boundaries and are connected with other protected areas via intact corridors (Radeloff et al. 2010). According to the Radeloff et al. study, the main threat to protected areas in the United States is housing density, which is highly correlated with population density. The adverse effects of development also impact the quality of the natural environment and visitor experience related to dark night skies, natural soundscapes and viewscapes/scenery.

Energy Exploration, Extraction, and Distribution

Like many other National Park units across the western United States, Dinosaur National Monument (DINO) has experienced an increase in oil and gas development near the monument boundary. According to the U.S. Geological Survey, oil and gas activity in the Upper Colorado River Basin and around DINO has greatly increased since 2000 with a majority of this activity occurring within the Uinta Basin of northeast Utah. The Uinta Basin lies south of DINO and is estimated to have 21 trillion ft^3 of gas, 60 million barrels of oil and 43 million barrels of natural gas liquids (Buto et al. 2010). The Bureau of Land Management (BLM) manages the majority of the land surrounding DINO and administers the development of oil and gas on these federal lands.

Beginning in 2019, the BLM is expected to lease new areas for oil and gas development near the border of DINO. Some of the new lease sites may be visible from the monument's main Visitor Center (NPCA 2017). This evaluation incorporates data on energy extraction activities and their distribution around DINO using multiple data sources. This information can be compared with future conditions to help document energy development trends and potential impacts.

While oil and gas development are not occurring within the monument boundary, impacts from energy development still have potential to affect the natural resources at DINO. Dinosaur National Monument is a "split estate" unit of the NPS, meaning that while the federal government owns the land surface, mineral rights (including oil and gas) may belong to private companies that could exercise their right to extraction in the future (NPS 1995). Land disturbance associated with oil and gas resource development is caused by activities related to constructing drill pads to contain drilling and well maintenance equipment and roads to access the drill pad. Roads and disturbance associated with drill pads can accelerate soil erosion, degrade streams, fragment and alter habitat and increase public use of an area (BLM 2007). Arid-land soils such as those in many parts of DINO are often stabilized by chemical and biological crusts. Even minimal disturbance of these crusts can lead to active erosion of a previously stable surface (Wilshire et al. 1996). A study in southern Wyoming found roadway and well density at the landscape-scale significantly impacted the large-scale occupancy of some sagebrush-obligate songbirds (Mutter et al. 2015). New oil, gas and other types of development may increase sound and light pollution, decrease view quality, increase traffic, increase habitat fragmentation near the monument, impact wildlife, and possibly reduce air and water quality (Buto et al. 2010, Mutter et al. 2015, NPCA 2017).

Indicators and Measures

Indicators of landscape context applied here include a variety of metrics for land cover and land use, population and housing, and land conservation status.

- Land cover and use
  - Extent of Anderson Level II classes
  - Extent of natural vs. converted land cover
  - Extent of impervious surface area
- Energy exploration, extraction and distribution
  - Number, type and distribution of well sites
  - Transmission corridors in relation to DINO and areas of potential conflict
- Human population and housing
  - Housing density
  - Historic population: total and density
  - Population: current and projected total and density
- Conservation status
  - Protected area (ownership) extent
  - Biodiversity conservation status (level of protection)

4.1.2. Data and Methods

Spatial data for land cover, population, and housing used for condition and trend analysis were provided by the NPS NPScape Program and follow protocols described in Monahan et al. (2012). Sources of other data are noted below.

Defining Areas of Interest

Landscape context elements were examined within several areas of interest because landscape attributes important to monument resources often vary with scale or spatial extent. Relevant scales or areas of analysis (AOAs) consist of the area within the monument boundary, the "boundary" area immediately adjacent to the monument (extending 3 km from the administrative boundary), the local area surrounding the monument (i.e., within 30 km of the monument boundary), the watershed area(s) upstream from the monument contributing to streams within the monument, and nearby counties. Areas of analysis and metrics used here are based on recommendations from Monahan et al. (2012) (Table 4.1-1). The contributing upstream watershed is included because it significantly influences water quality and watershed/hydrologic characteristics (Monahan and Gross 2012).

Land Cover

United States Geological Survey (USGS) National Land Cover Dataset (NLCD) data for 2011 was used to characterize current/recent conditions (NLCD 2018). NLCD data products are derived from Landsat Thematic Mapper (TM) imagery with a 30 m pixel resolution. NLCD summaries employ a well-documented, consistent procedure that is highly repeatable over time. Although NLCD data date back to 1992, differences in classification and analysis methods do not favor comparison of the 1992 data with 2011 data (Monahan et al. 2012). Procedures for the summarization of data for the following indicators are from NPS (2014a).

- **Anderson land cover/land use classes**: NLCD data were interpreted and classified using Anderson Level II land cover classes (Table 4.1-2) for the areas of analysis listed in Table 4.1-1.

- **Acreage of natural vs. converted land cover**: The NLCD Anderson Level I "developed" and "agriculture" classes were reclassified as "converted" (Table 4.1-2) and analyzed using the areas of analysis listed in Table 4.1-1. Other classes were classified as "natural".

- **Impervious surface area**: The NLCD Anderson Level I "developed" classes are reclassified as "impervious" and all other land cover classes were classified as "pervious" and analyzed using the areas of analysis listed in Table 4.1-1. Areas that are more impervious reduce the amount of water infiltration into the soil and local water tables, and contribute to altered hydrographs and flashier runoff characteristics.

Table 4.1-1. Areas of analysis used for land cover and land use measures (from recommendations in Monahan et al. 2012).

Indicators	Measures	Areas of Analysis			
		Park + 3 km buffer around park	**Park + 30 km buffer**	**Contributing upstream watershed**	**Counties overlapping park + 30 km buffer**
Land cover and use	Anderson Level I Classes	X	X	X	–
	Natural vs. converted land cover	X	X	X	–
	Impervious surfaces	–	–	X	–
Human Population and Housing	Population total and density by census block group (historic and projected)	–	X	–	–
	Historic population totals by county	–	–	–	X
	Housing density 1970–2010	–	X	X	–
Conservation status	Protected areas (ownership) and biodiversity conservation status	–	X	X	–

Table 4.1-2. Anderson land cover/land use classes (Anderson et al. 1976) and rules for reclassifying energy exploration, extraction and disturbance.

Anderson Level I	Anderson Level II	Classification
Open Water	–	Natural
Developed	–	Converted
Barren/Quarries/Transitional	–	Natural
Forest	–	Natural
Shrub/Scrub	–	Natural
Grassland/Herbaceous	–	Natural
Agriculture	pasture/hay vs. cultivated agriculture	Converted
Wetlands	–	Natural

Energy Exploration, Extraction and Distribution

Oil and gas well site information for Utah, Colorado and Wyoming was obtained from the Utah Department of Natural Resources, Colorado Oil and Gas Conservation Commission (COGCC), and Wyoming Oil and Gas Conservation Commission (WOGCC). The state databases were not standardized, so Colorado State University created a consolidated geospatial database in ArcGIS by reclassifying each well status into four categories: Currently Active (producing, injecting, or other activity at location), Future Activity (location in development with permit/application), Non-Active

(future activity planned), and Non-Active or Abandoned (no future activity planned). Reclassification of these data in a consolidated database enabled comparisons among the three datasets.

Oil and gas lease data were downloaded from the BLM Landscape Approach Data Portal (BLM 2018). The database is updated quarterly (last update prior to our download – July 2, 2018) and shows all current and active leases on BLM land. The database does not show the locations of the projected leases near the monument boundary and the database does not include lease data for the State of Wyoming.

To examine energy transmission corridors in relation to DINO and "Areas of Potential Conflict", data were examined using the Section 368 Energy Corridor Mapping tool from The West-wide Energy Corridor Information Center (2018). The West-wide Energy Corridor Information Center is a joint collaboration between the BLM, U.S. Forest Service, and the Department of Energy. The Section 368 Mapping Tool was developed as a public information and involvement tool for the West-wide Energy Corridor. This tool can be used to track development of energy corridors in the future and evaluate potential impacts within areas of potential conflict near DINO lands. It facilitates public participation in the decision making process of energy development in the west and the new energy transmission corridors that are either undergoing construction or are being proposed. Areas of potential conflict were designated using a combination of factors, including but not limited to land ownership, species protected by the Endangered Species Act, specific land designations and protections, and visual resource ratings (West-wide Energy Corridor 2018).

<u>Human Population and Housing</u>

Housing Density

Change from 1970 to 2010 and projected changes to 2050 were examined. The NPScape housing density metrics used here are based on the Spatially Explicit Regional Growth Model (SERGoM v3) (Theobald 2005). Housing density data are categorized into 11 non-uniform development classes and then reclassified as described by Theobald (2005): rural (0–0.0618 units/ha), exurban (0.0618–1.47 units/ha), suburban (1.47–10.0 unit/ha), and urban (> 10.0 units/ha). The non-uniform ranges permit a much finer delineation of areas of low-density housing than is common for non-ecological studies (Monahan et al. 2012).

Total Population and Population Density

Historical data were derived from county-level population totals for all counties overlapping with the 30 km park buffer. Population density was derived from U.S Census Bureau block data from 1990, 2000 and 2010. Population density (number of people per square kilometer) classes follow NPS guidance (NPS 2014b).

<u>Conservation Status</u>

The two primary sources of protected area data were the Protected Areas Database-US (PAD-US) Version 2 (CBI 2013) and the National Conservation Easement Database (NCED). The two databases are designed to be used together to show comprehensive protection status for areas of interest while using compatible database attributes such as ownership type and agency.

Ownership

Land ownership greatly influences the level of conservation protection. The PAD-US (CBI Edition) Version 2 is a national database of protected fee lands in the United States. It portrays the United States protected fee lands with a standardized spatial geometry with their associated land ownership, management designations, and conservation status (using national GAP coding systems). The National Conservation Easement Database (NCED) Version III (July 2013) is a voluntary national geospatial database of conservation easement information that compiles records from land trusts and public agencies throughout the United States. It allows for the identification of all lands under conservation easements regardless of ownership. It is a collaborative partnership by the Conservation Biology Institute, Defenders of Wildlife, Ducks Unlimited, NatureServe, and the Trust for Public Land (NCED 2013). As of December 2017, the acreage of publicly-held easements is considered to be 25% complete for Colorado and 44% complete for Utah; the accounting of the acreage of non-governmental organization (NGO)-held easements in Colorado is currently estimated at approximately 73% complete, while Utah is 71% complete.

Level of Protection

The USGS Gap Analysis Program (GAP) uses a scale of 1 to 4 to categorize the degree of biodiversity protection for each distinct land unit (Scott et al. 1993). A status of "I" denotes the highest, most permanent level of maintenance, and "IV" represents no biodiversity protection or areas of unknown status. The PAD-US (CBI Version 2) database includes the coded GAP biodiversity protection status of each parcel. The NCED database is designed to accommodate the GAP protection status field but most parcels have not been assigned a GAP conservation value. The four status categories are described below.

- **Status I:** These areas have permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, and intensity) are allowed to proceed without interference or are mimicked through management. Most national parks, Nature Conservancy preserves, some wilderness areas, Audubon Society preserves, some USFWS National Wildlife Refuges and USFS Research Natural Areas are included in this class.

- **Status II:** These areas have permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive use or management practices that degrade the quality of existing natural communities. Some national park units, most wilderness areas, USFWS National Wildlife Refuges managed for recreational uses, and BLM Areas of Critical Environmental Concern are included in this class.

- **Status III:** These areas have permanent protection from conversion of natural land cover for the majority of the area, but may be subject to extractive uses of either a broad, low-intensity type or localized intense type. This class also confers protection to federally-listed endangered and threatened species throughout the area. Most non-designated public lands, including USFS, BLM and state park land are included in this class.

- **Status IV:** These areas lack irrevocable easement or mandate to prevent conversion of natural habitat types to anthropogenic habitat types. This class allows for intensive use throughout the tract, and includes those tracts for which the existence of such restrictions or sufficient information to establish a higher status is unknown. Most private lands fall into this category by default.

Protected areas data from the two databases were examined by owner type and by easement protection status within a 30 km buffer of the monument boundary. GAP biodiversity protection values were summarized for NCED and PAD-US parcels by ownership type within the 30 km buffer areas of interest. There is some spatial overlap between the PAD-US and NCED databases due to the existence of easements on some lands owned by federal, state and local agencies. Where easements existed on these public (i.e., protected) lands, the acreages were reported by owner only to avoid double counting in the number of protected acres.

4.1.3. Landscape Context Findings

Land Cover and Use

Extent of Anderson Level II Classes 2011

In the immediate vicinity of DINO (3 km buffer) over 60% of land acreage is scrub/shrub cover, and nearly 34% is evergreen forest (Table 4.1-3, Figure 4.1-1). Less than 0.5% of the land area within 3 km of DINO is developed. Within the 30 km buffer, over 72% of the acreage is scrub/shrub and 20% is evergreen forest. Land cover of the contributing upstream watershed of the monument is over 70% shrub/scrub, 16% forested, a mixture of other vegetated classes, and less than 1% developed classes (Figure 4.1-2).

Table 4.1-3. Anderson Level II land cover classes within 3 km and 30 km of the monument boundary, and within the contributing upstream watershed of the monument (summaries derived from data provided by the NPS NPScape Program).

	3 km Buffer		Park + 30 km Buffer		Contributing Upstream Watershed	
Anderson Level 2 Classes	**Acres**	**% of Area**	**Acres**	**% of Area**	**Acres**	**% of Area**
Barren Land	14,171	3.11%	57,219	2.08%	199,101	1.22%
Cultivated Crops	363	0.08%	1,308	0.05%	14,763	0.09%
Deciduous Forest	2,954	0.65%	34,437	1.25%	847,774	5.19%
Developed, High Intensity	0	0.00%	269	0.01%	1,452	0.01%
Developed, Low Intensity	355	0.08%	7,562	0.27%	30,703	0.19%
Developed, Medium Intensity	1	0.00%	1,252	0.05%	8,784	0.05%
Developed, Open Space	1,589	0.35%	15,298	0.56%	80,589	0.49%
Emergent Herbaceous Wetlands	33	0.01%	1,604	0.06%	152,451	0.93%
Evergreen Forest	150,741	33.13%	544,015	19.75%	1,877,288	11.49%
Hay/Pasture	4,118	0.91%	53,609	1.95%	425,537	2.60%
Herbaceous	510	0.11%	13,710	0.50%	942,911	5.77%

Table 4.1-3 (continued). Anderson Level II land cover classes within 3 km and 30 km of the monument boundary, and within the contributing upstream watershed of the monument (summaries derived from data provided by the NPS NPScape Program).

	3 km Buffer		Park + 30 km Buffer		Contributing Upstream Watershed	
Anderson Level 2 Classes	**Acres**	**% of Area**	**Acres**	**% of Area**	**Acres**	**% of Area**
Mixed Forest	0	0.00%	1,434	0.05%	83,571	0.51%
Open Water	3,059	0.67%	10,395	0.38%	99,568	0.61%
Perennial Snow/Ice	0	0.00%	0	0.00%	2,421	0.01%
Shrub/Scrub	274,325	60.29%	1,997,521	72.51%	11,449,110	70.05%
Unclassified	0	0.00%	0	0.00%	0	0.00%
Woody Wetlands	2,788	0.61%	15,361	0.56%	128,921	0.79%
Total	**455,007**	**–**	**2,754,994**	**–**	**16,344,944**	**–**

Land cover data from the NLCD 2011 can be used to demonstrate both status and changes in land cover and associated land uses/disturbances over time. It can effectively estimate the areas that have been converted from a natural setting to a developed one. This includes the effects of oil and gas exploration and production around DINO, as localized areas that experience such physical disturbance are considered "developed" (Figure 4.1-2). While this data source provides a general idea of the patterns and magnitude of landscape disturbance, there are limitations to using this national-level spatial database. Many oil and gas roads, drilling pads and other associated infrastructure are below the minimum mapping unit for the NLCD and, during the imagery classification process, are merged with the predominant surrounding land cover type.

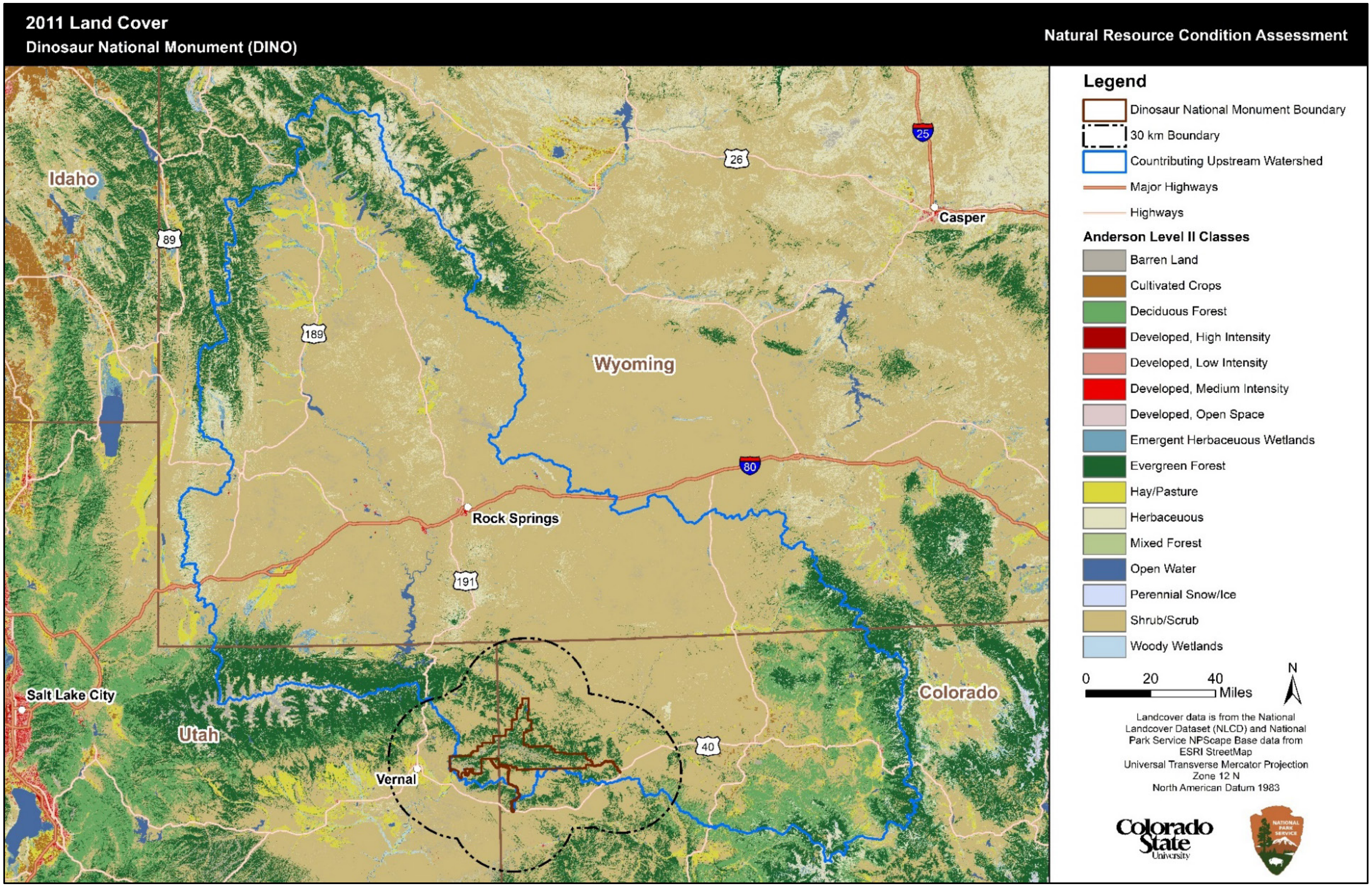


Figure 4.1-1. Anderson Level II land cover classes within 3 km and 30 km of the monument boundary, and within the contributing upstream watershed of the monument. National Land Cover Dataset data provided by NPS NPScape Program.

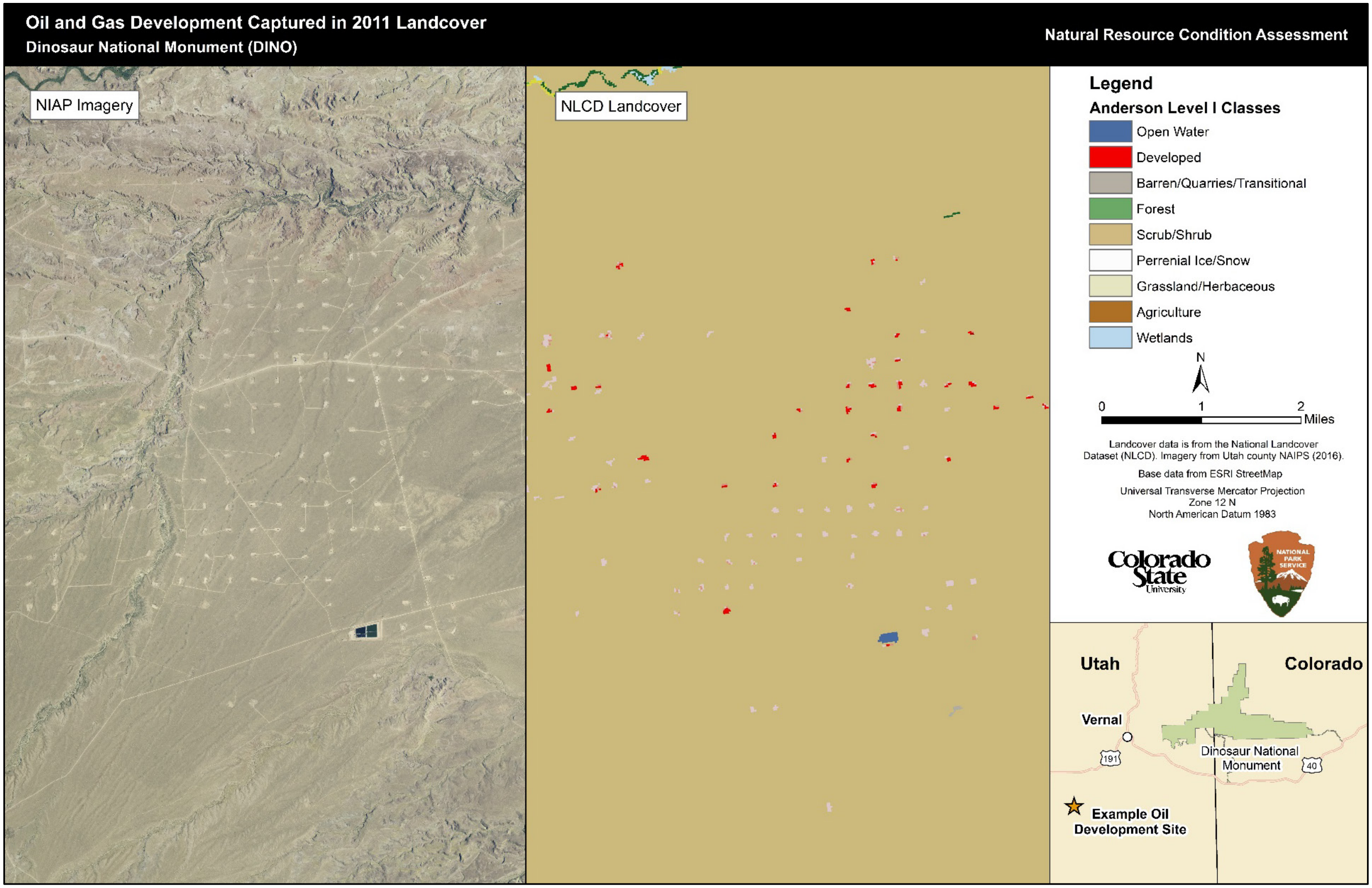


Figure 4.1-2. National Agricultural Insurance Program (NAIP) imagery (1m pixel resolution) from 2011 (left) compared to classified NLCD land cover from 2011 (right), illustrating limitations of the NLCD data. Example is from an area in the Uinta Basin southwest of Vernal, Utah.

Most roads are too narrow to be captured by the relatively coarse resolution imagery used by the national level analyses. In our cursory examination of several localities in the Uintah Basin, we found only 5–10% of the well pads were classified by the NLCD as “developed”, and the vast majority of primary and secondary access roads to the well pads are missed entirely and are classified as shrub/scrub. Approximately 25% of the well pads were classified as grassland/herbaceous within a larger matrix of scrub/shrub habitat.

Our cursory examination of a few randomly-selected areas having obvious oil and gas disturbance appears to confirm similar findings presented by Buto et al. (2010) for the Upper Colorado River Basin. Therefore, care should be taken when using NLCD data to examine or characterize disturbance associated with oil and gas activities using relatively small well pads and narrow access roads. Moreover, the total acreage associated with such disturbance is very small on the landscape scale but has more extensive impacts with respect to wildlife behavior, habitat fragmentation, watershed and hydrologic response, and spread of non-native plant species.

Natural vs. Converted Land Cover

Change in natural land cover is possibly the most basic indication of habitat condition (O’Neill et al. 1997). Knowing the proportions of natural and converted land cover areas provides a general indication of overall landscape condition, offering insight into potential threats and opportunities for future conservation.

The proportion of converted acreage surrounding DINO is low due to the rural nature of the region (Table 4.1-4, Figure 4.1-3). Within 30 km of the monument boundary, less than 3% of the area is classified as converted, and approximately 3.5% of the contributing upstream watershed is classified as converted (Figure 4.1-3).

Table 4.1-4. Natural vs. converted acreage within 3 km and 30 km of the monument boundary, and within the contributing upstream watershed of the monument (summaries derived from data provided by the NPS NPScape Program).

	Natural		Converted	
AOA	**Acres**	**% of Area**	**Acres**	**% of Area**
3 km	448,580	98.57%	6,426	1.43%
monument + 30 km Buffer	2,675,696	97.12%	79,298	2.88%
Contributing Upstream Watershed	15,783,120	96.56%	561,824	3.44%

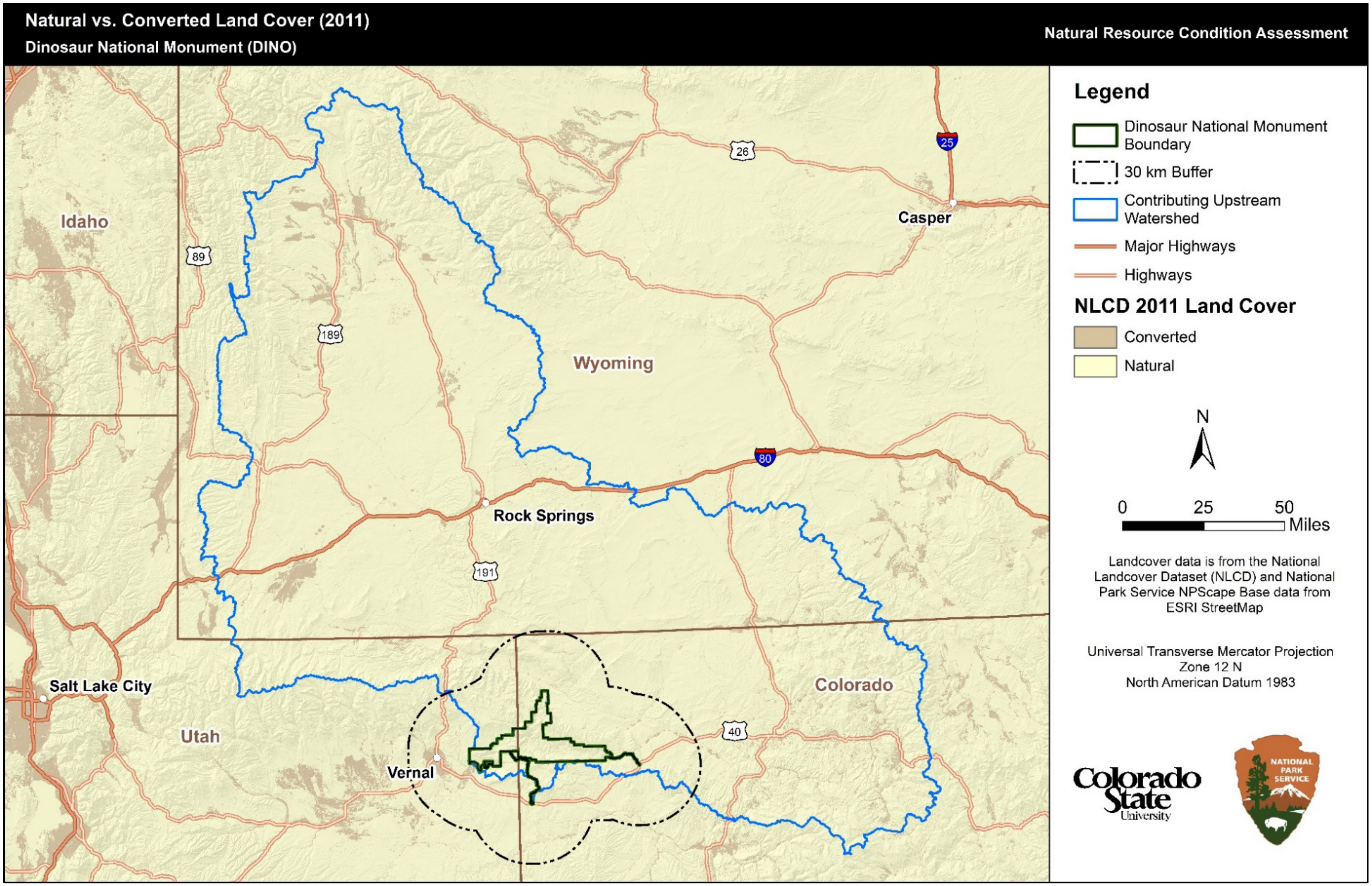


Figure 4.1-3. Natural vs. converted land cover classes within 3 km and 30 km of the monument boundary, and within the contributing upstream watershed of the monument. 2006 National Land Cover Dataset data provided by NPS NPScape Program.

Impervious Surface Area

Impervious surfaces include bare rock, paved roads, and areas covered with concrete/cement. These surfaces prevent infiltration of precipitation into the ground. This reduced infiltration can cause significant hydrological effects including quicker runoff into streams and rivers resulting in flooding, more rapid rising and dropping of streamflow after precipitation events, reduced local evapotranspiration, and reduced recharge of local aquifers. Imperviousness can also increase aquatic pollution as contaminant transport is increased by water flowing directly to a stream or other water body without the opportunity for uptake or decomposition by plants and soil organisms.

Most of DINO's contributing upstream watershed is in the lowest imperviousness class (0–2% impervious surfaces) (Table 4.1-5). As a benchmark for future analysis, approximately 0.35% of the contributing upstream watershed of the monument was classified as having >25% impervious surfaces (Table 4.1-5), the majority of which is concentrated near the towns of Rock Springs, Wyoming and Craig, Colorado.

Table 4.1-5. Percent impervious surfaces acreage based on Anderson land cover classes within the contributing upstream watershed of the monument (summaries derived from data provided by the NPS NPScape Program).

Percent Impervious Surface	Acres	% of Area
0%–2%	15,944,131	97.55%
2%–4%	54,406	0.33%
4%–6%	48,914	0.30%
6%–8%	50,160	0.31%
8%–10%	44,306	0.27%
10%–15%	77,308	0.47%
15%–25%	68,610	0.42%
25%–50%	41,414	0.25%
50%–100%	15,695	0.10%
Total	**16,344,944**	**–**

<u>Energy Exploration, Extraction and Distribution</u>

Well Numbers and Distribution

The highest density of oil and gas wells in the greater DINO area is located southwest of the monument in Utah, mostly occurring on BLM and Bureau of Indian Affairs (BIA) lands. This dense cluster of oil and gas wells extends east into Colorado, and is dominated by activity in the Uinta Basin. In addition, oil and gas wells are scattered across nearby areas in Colorado in lower densities (Figure 4.1-4). Out of the 4,920 wells within 30 km of the monument boundary, 24.1% are currently active, 3% are in development with permits and applications, and 8.3% are not currently active but have some future activity planned (Table 4.1-6). It is difficult to forecast future exploration, well development activity and leasing. However, the current leases and well activity indicate a high

potential for continued disturbance in many areas in the near future. With the increased number of oil and gas wells and the number of wells under development, monument managers are worried that the increase in activity might have a negative impact on natural resources (pers. comm., Tamara Naumann, April 2017).

The well and lease data illustrate that there are numerous active wells in the region (currently active wells), there is a high potential for oil and gas development in the future (future activity wells and leases as well as non-active wells with future activity planned), and oil and gas disturbance/development may occur closer to the monument boundary with potential new leases (e.g., southeast of the monument and the areas surrounding the western end).

Table 4.1-6. The status of wells within a 30 km buffer of DINO, including Colorado, Wyoming and Utah. Data were obtained in June 2018 from the Utah Department of Natural Resources, Colorado Oil & Gas Conservation Commission, and the Wyoming Oil & Gas Conservation Commission.

	Number of Wells within 30 km of Dinosaur National Monument, by State			
Well Status	**Colorado**	**Wyoming**	**Utah**	**Total**
Currently Active (Producing, injecting, or other activity at location)	821	1	364	**1186**
Future Activity (Location in Development with Permit/Application)	6	0	144	**150**
Non-Active (Future Activity Planned)	237	0	171	**408**
Non-Active or Abandoned (No Future Activity)	1914	0	1262	**3176**
Total	**2978**	**1**	**1941**	**4920**

Transmission Corridors and Areas of Potential Conflict

These areas are evaluated as low, medium or high potential conflict (Figure 4.1-5). Dinosaur National Monument, surrounding wilderness study areas, and other lands within several kilometers of the boundary have a high potential for conflict attributed to a combination of the presence of BLM Class I and II Visual Resource Management Areas, the presence of lands inventoried and managed for wilderness characteristics and wilderness study areas (BLM), and the occurrence of greater sage-grouse priority or general habitat management areas. There are also large areas around the monument that have medium potential corridor conflicts attributed to a combination of the presence of BLM Class II Visual Resource Management Areas, the presence of lands inventoried and managed for wilderness characteristics, and the occurrence of greater sage-grouse priority or general habitat management areas.

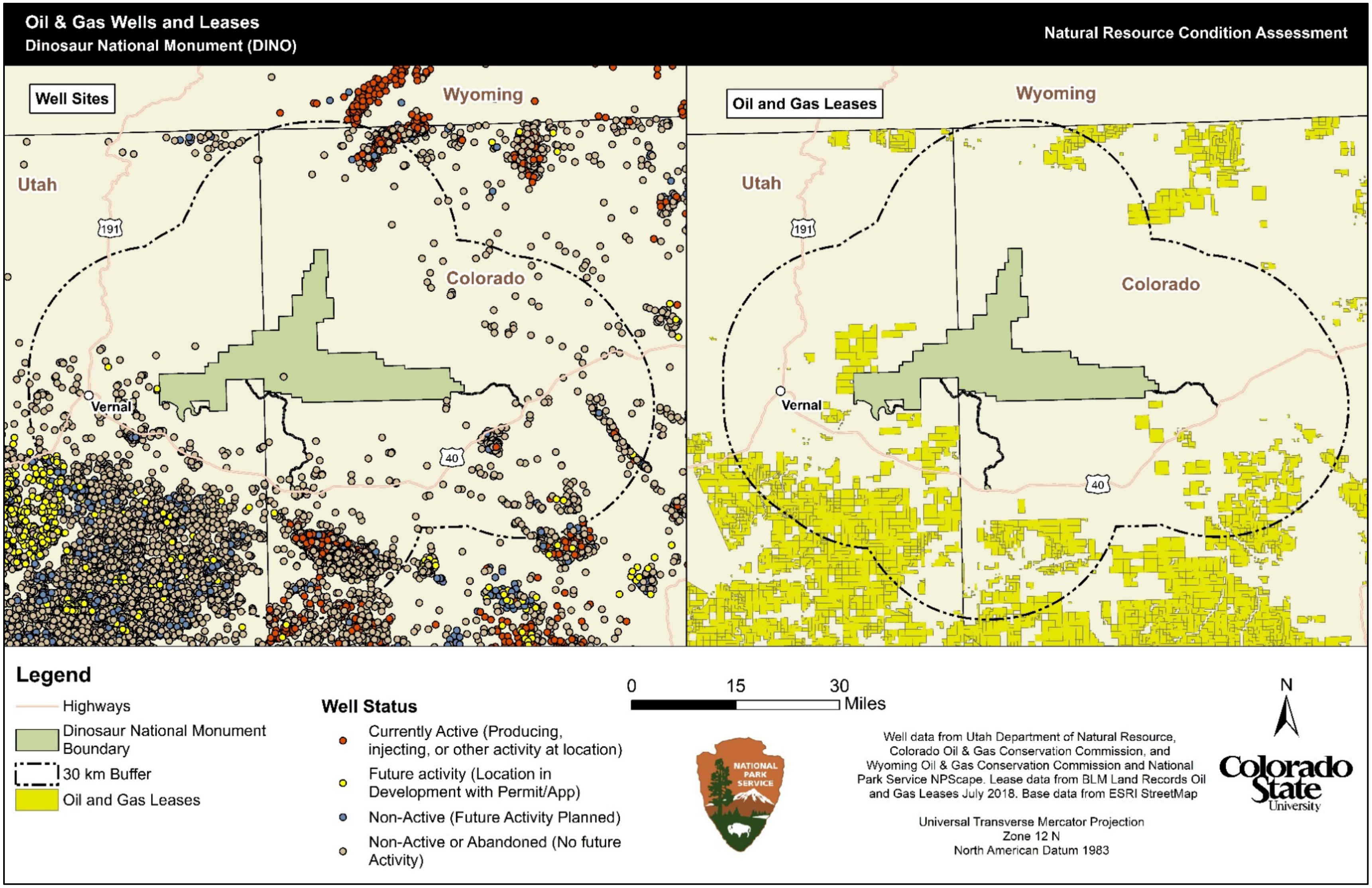


Figure 4.1-4. Location of wells and their status (left) and BLM oil and gas leases (right) within 30 km of the monument boundary.

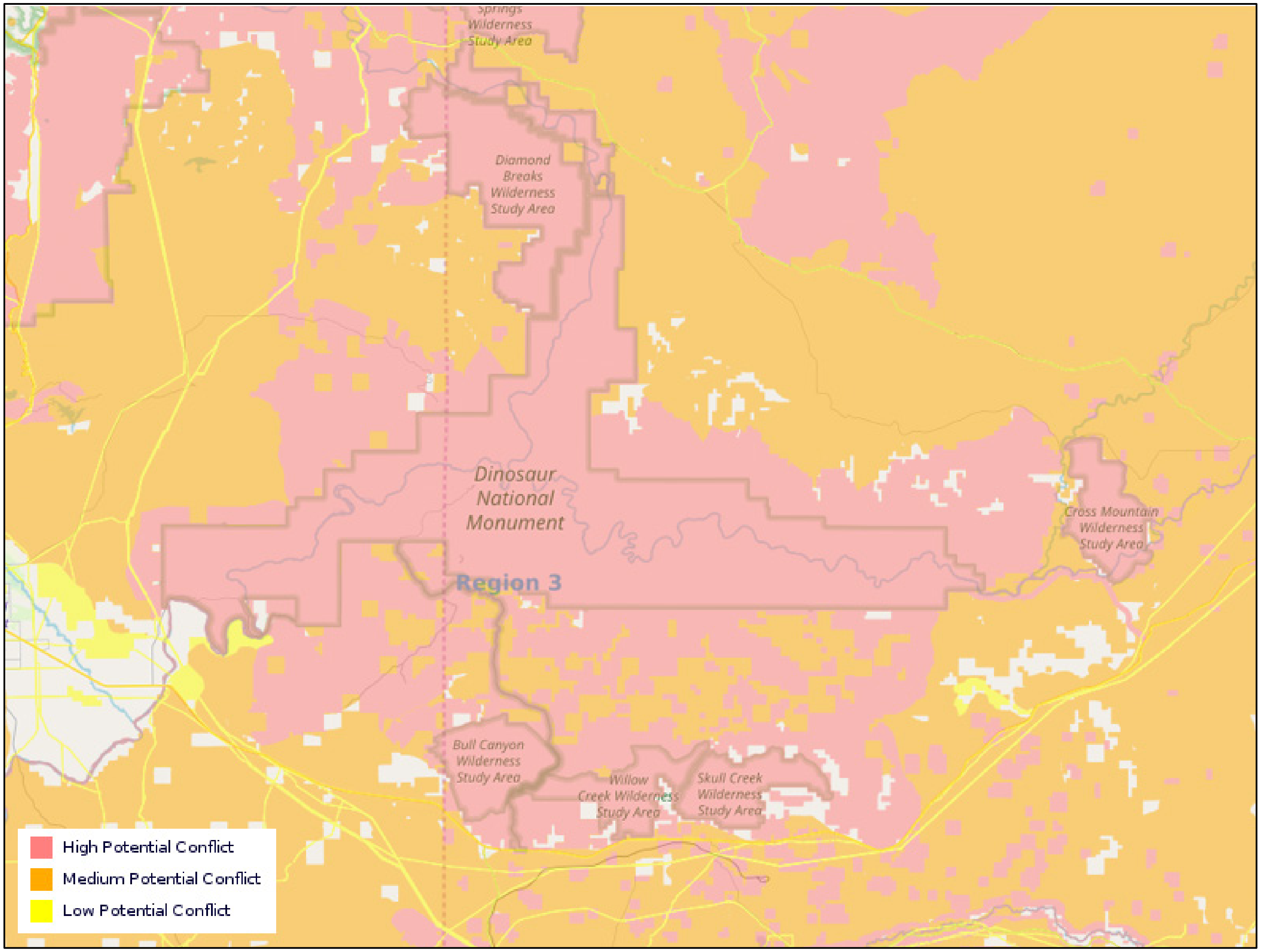


Figure 4.1-5. Areas of Potential Conflict in relation to designated Section 368 energy transmission corridors (yellow lines). Graphic generated from by the Section 368 Energy Corridor Mapping Tool (West-wide Energy Corridor 2018).

Population and Housing

Historic and Projected Population

High human population density has been shown to adversely affect the persistence of habitats and species (Kerr and Currie 1995, Woodroffe 2000, Parks and Harcourt 2002, Luck 2007). Conversion of natural landscapes to agriculture, suburban, and urban landscapes is generally permanent, and this loss of habitat is a primary cause of biodiversity declines (Wilcove et al. 1998). Human conversion of landscapes can alter ecosystems and reduce biodiversity by replacing habitat with non-habitable cover types and structures, fragmenting habitat, reducing availability of food and water, increasing disturbance by people and their animals, altering vegetation communities, and increasing light, noise, and pollution.

Population density within 30 km of the monument's boundary is low, with most of the area within this 30 km radius having a density of 1–20 people/km^2 (Table 4.1-7, Figure 4.1-6). Historically, population has increased in the region, with an accelerated increase since the 1970s (Figure 4.1-7).

There is a slight increasing trend in population density. This increase is taking place in medium density classes, primarily the 301 to 750 people/km^2 category. Overall population density is low due to the overwhelmingly natural condition of the surrounding area.

Table 4.1-7. Population density classes and acreage for 1990, 2000, and 2010 by census block group for the monument and surrounding 30 km buffer. U.S. Census data provided by NPS NPScape Program.

Population Density (#/km^2)	1990		2000		2010	
	Acres	% of Area	Acres	% of Area	Acres	% of Area
1–20	2,729,410	99.07%	2,729,276	99.07%	2,733,785	99.23%
21–75	5,794	0.21%	0	0.00%	0	0.00%
76–150	9,770	0.35%	16,960	0.62%	10,697	0.39%
151–300	8,804	0.32%	5,656	0.21%	6,241	0.23%
301–750	778	0.03%	2,289	0.08%	3,722	0.14%
751–1200	223	0.01%	480	0.02%	0	0.00%
1201–1500	215	0.01%	333	0.01%	549	0.02%
1501–2000	0	0.00%	0	0.00%	0	0.00%
2001–3000	0	0.00%	0	0.00%	0	0.00%
>3000	0	0.00%	0	0.00%	0	0.00%

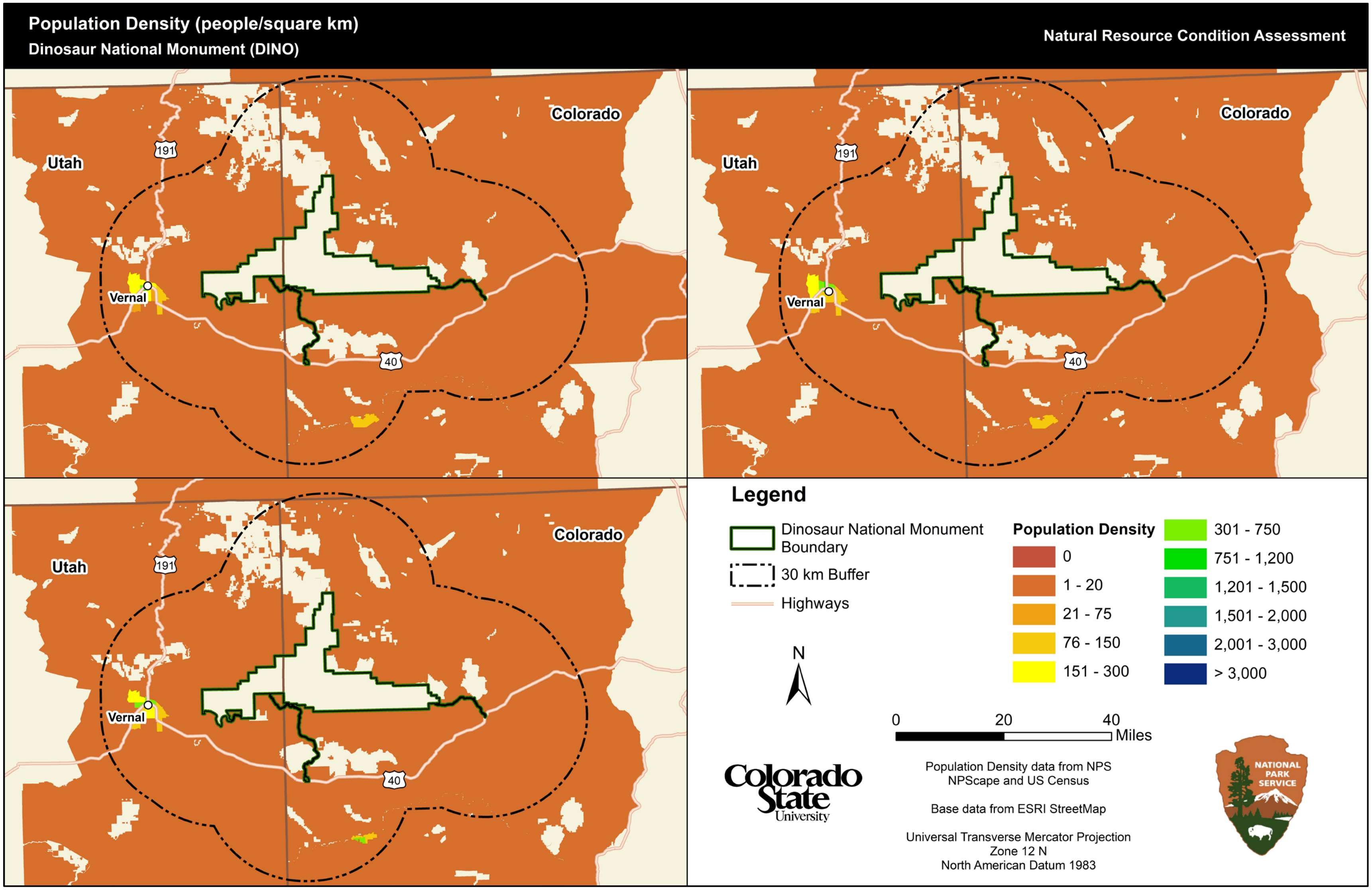


Figure 4.1-6. Population density for 1990 (upper left), 2000 (upper right), and 2010 (lower left) by census block group for the monument and surrounding 30 km buffer. U.S. Census data provided by NPS NPScape Program.

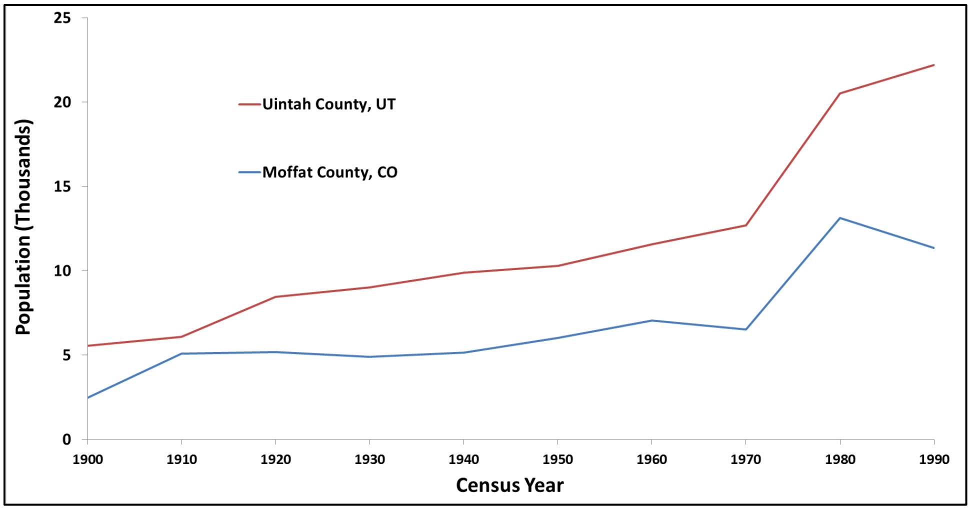


Figure 4.1-7. Historic population by decade for counties within 30 km of DINO (2010 U.S. Census data provided by NPS NPScape Program).

Housing Density

Housing density in the region surrounding the monument shows an increase in exurban development and corresponding decrease in rural development between 1970 and 2010 (Table 4.1-8, Figure 4.1-8). Although the acreages of these changes are substantial (from 16,500–18,000 acres for each), the percent change compared to the total AOA is small. Areas shown in white in Figure 4.1-8 are primarily BLM and NPS land. These areas are considered "no data" but are included in the calculation for percentage of area for each housing density class. The total area of these lands equals 2,214,320 acres. Only a small proportion of the monument's 30 km buffer is inhabited (about 20%).

Table 4.1-8. Historic and projected housing density classes by decade for 1970–2050 for the monument and surrounding 30 km buffer (2010 U.S. Census data provided by NPS NPScape Program).

Census Year	Rural (0–0.0618 units/ha)		Exurban (0.0618–1.47 units/ha)		Suburban (1.47–10.0 units/ha)	
	Acres*	% of Area*	Acres	% of Area	Acres	% of Area
1970	531,434	19.29%	4,549	0.17%	573	0.02%
1980	527,769	19.16%	7,739	0.28%	1,043	0.04%
1990	520,186	18.88%	14,891	0.54%	1,458	0.04%
2000	517,230	18.77%	16,887	0.61%	1,601	0.06%
2010	513,603	18.64%	20,994	0.76%	1,658	0.06%
2020	513,556	18.64%	21,036	0.76%	1,663	0.06%
2030	513,514	18.64%	21,078	0.77%	1,663	0.06%
2040	513,494	18.64%	21,093	0.77%	1,668	0.06%
2050	513,494	18.64%	21,093	0.77%	1,668	0.06%

* Rural acreage and percentages do not include protected lands.

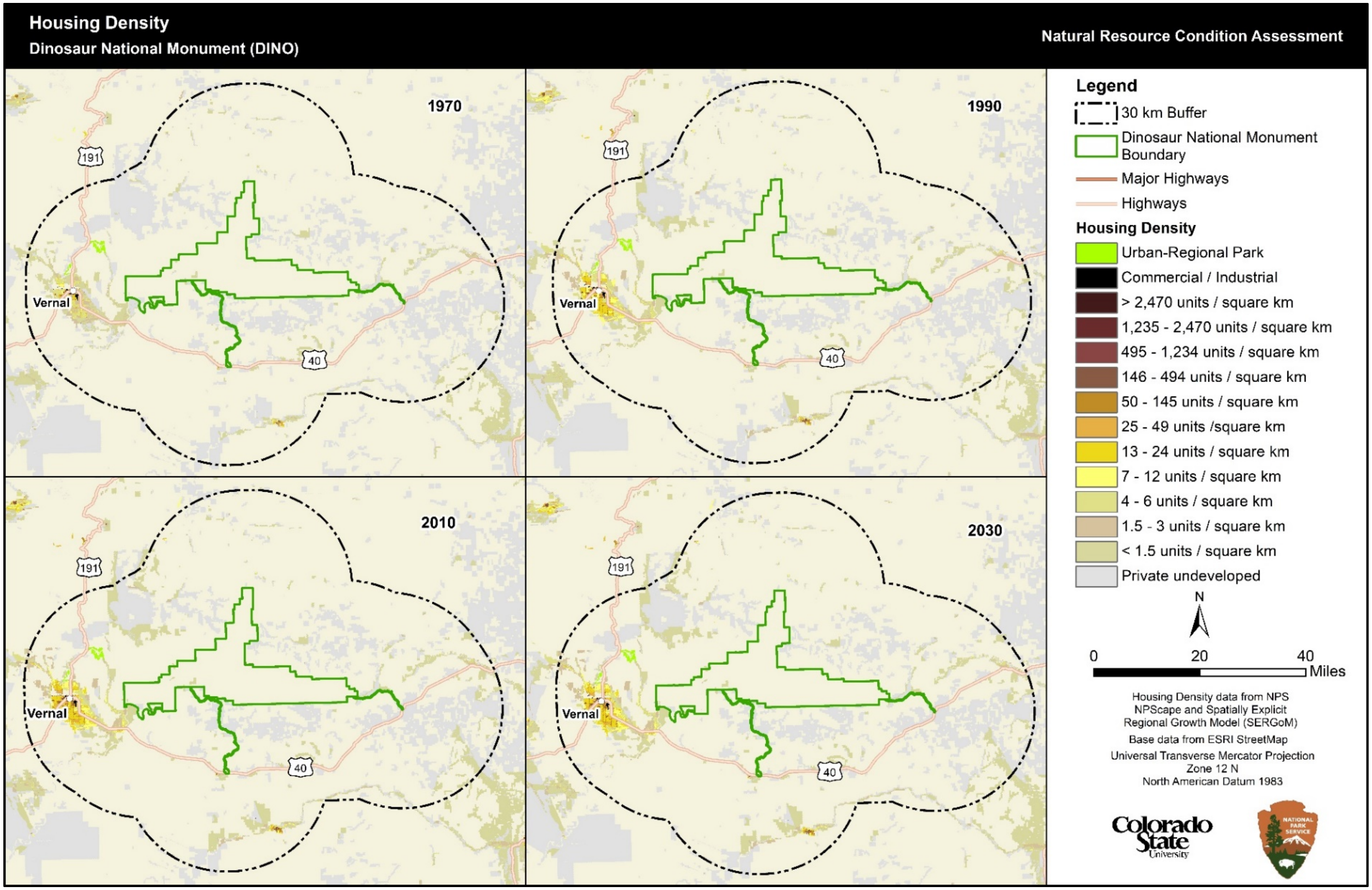


Figure 4.1-8. Historic and projected housing density for 1970, 1990, 2010 and 2030 for the monument and surrounding 30 km buffer. SERGOM data provided by NPS NPScape Program. Areas of no data represent protected lands (especially publicly-owned, but including some private lands with conservation easements) (NPS 2013).

Conservation Status

Spatial data from the Protected Areas Database-US (PAD-US) Version 2 (CBI 2013) and the National Conservation Easement Database (NCED) were consolidated to show comprehensive protection status for areas of interest while using compatible database attributes such as ownership type and agency (Figure 4.1-9). The analysis illustrates the high percentage of protected areas near the monument and in the larger region compared to the Midwest and eastern United States.

Protected Area Extent (Ownership)

Within the 30 km monument buffer most protected land is federally owned. Within the contributing upstream watershed, approximately one-third of the area is federally owned, and one-third is under joint or unknown ownership (Table 4.1-9).

Table 4.1-9. Acreage of lands by ownership within 30 km of the boundary of DINO, and within the contributing upstream watershed of the monument (data from the Protected Areas Database-US (PAD-US) Version 2 (CBI 2013) and the National Conservation Easement Database (NCED)). Percentages are the proportion of total AOA.

	Monument + 30 km Buffer		**Contributing Upstream Watershed**	
Ownership	**Acres***	**% of Area***	**Acres***	**% of Area***
Federal	2,005,091	72.78%	5,226,303	31.98%
Native American	842	0.03%	0	0.00%
State	211,324	7.67%	323,843	1.98%
City and County	0	0.00%	904	<0.01%
Private Conservation	14,390	0.52%	238,900	1.46%
Joint Ownership/Unknown	3,066	0.11%	5,692,488	34.83%
Other Conservation Easement	0	0.00%	73	<0.01%
Total	**2,234,713**	**81.11%**	**11,482,511**	**70.25%**

* The remaining acreage within the area of analysis is comprised of private lands with no known conservation protection.

Level of Protection

Most protected land area in the region is owned by federal and state entities (Table 4.1-9). The GAP status makeup is similar within each of the AOAs. Within 30 km of the monument and in the contributing upstream watershed, most protected land is in Status II or III, with a significant amount also in Status IV (Table 4.1-10). At least 84% of land area in each of the AOA's is not protected (or status unknown), which highlights the importance of DINO and other parcels providing biodiversity protection in the region. Moreover, in protected areas such as DINO natural processes and disturbance regimes are more likely to occur and support a greater degree of biodiversity, as well as provide critical linkages to the surrounding natural landscape.

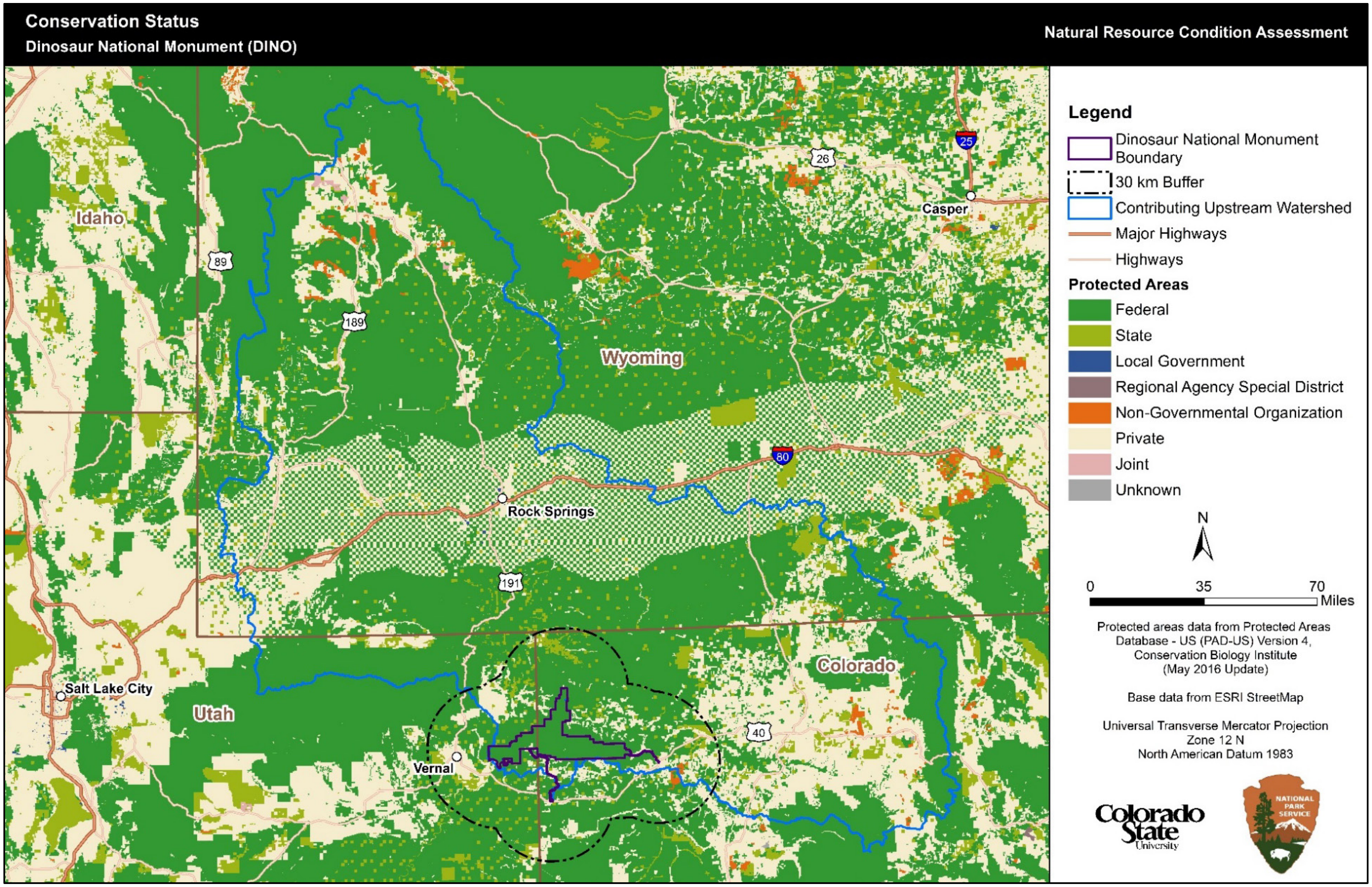


Figure 4.1-9. Conservation status of lands within 30 km of the DINO boundary and within its contributing upstream watershed (data from the Protected Areas Database-US (PAD-US) Version 2 (CBI 2013) and the National Conservation Easement Database (NCED) and ESRI Streetmap). Light tan areas are lands without conservation easement status. Checkerboard ownership (state or private within federal matrix) is most evident along Interstate 80 (data from the Protected Areas Database-US (PAD-US) Version 2 (CBI 2013) and the National Conservation Easement Database (NCED) and ESRI Streetmap).

Table 4.1-10. Biodiversity protection status of lands within 30 km of DINO, and within the contributing upstream watershed of the monument (PAD-US and NCED data). Percentages are the proportion of total AOA area.

	Monument + 30 km Buffer		Contributing Upstream Watershed	
Protection Level	**Acres[1]**	**% of Area[1]**	**Acres[1]**	**% of Area[1]**
I (highest)	0	0.00%	118,262	0.72%
II	475,981[2]	17.23%	1,386,791	8.48%
III	1,653,777	60.03%	9,842,515	60.22%
IV (lowest/status unknown)	104,955	3.81%	134,942	0.83%
Total	**2,234,713**	**81.11%**	**11,482,511**	**70.25%**

[1] The remaining acreage within the area of analysis is comprised of private lands with no known conservation protection.

[2] Land area within Dinosaur National Monument is Level II.

Land Cover and Land Use Summary

Landscape context indicator summaries are provided in Table 4.1-11. Overall, the area surrounding the monument is mostly natural with some agricultural and rural land use. Population densities in the area are low and there has been a gradual increase in exurban vs. rural settlement, although the percent change is very small. Most of the stressors to the landscape surrounding DINO are related to historic land uses, grazing, and the expansion of gas and oil exploration and production. Development, land uses, and energy-related disturbances concern DINO managers, as the links between these activities and impacts to vegetation communities, wildlife habitats and species, natural soundscape, dark night skies, air quality, and water quality are well-documented. Although these changes may appear minimal at site scales, collectively, these elements may compound the effects of other resource stressors.

Although a large percentage of land is protected, unlike in the Midwest and eastern U.S. where the small percentage of public lands are truly protected by various public and private entities (such as the USFWS, NPS, and NGO's like The Nature Conservancy), public land in the west is not necessarily protected to a great degree simply by virtue of ownership. In the arid west, where the vast majority of public lands are managed by the BLM, numerous land uses that can degrade resource values and condition are often permitted or occur with inadequate regulation or enforcement. Also, where ownership is a checkerboard of state, federal, and private (e.g., originally railroad grants), the patterns of ownership create barriers to access and effective management, likely devaluing the conservation protection status of public lands. For these reasons, we encourage careful interpretation of summaries, for example the need to examine patterns and locations of lands as well as their extent on the landscape to avoid misleading or inaccurate conclusions.

Table 4.1-11. Summary for land cover and land use indicators, Dinosaur National Monument.

Land Cover/Use	Indicator	Summary Notes Integrating Results for 3 km, Contributing Upstream Watershed and 30 km Areas of Interest
Land Cover	Extent of Anderson Level II classes	Most of the acreage surrounding DINO is shrub/scrub, regardless of AOA. The next most prevalent land cover is evergreen forest, mostly occurring at higher elevations.
	Extent of impervious surface area	There is a low degree of imperviousness at DINO. This is due to the fact that most of the surrounding acreage is natural/undeveloped.
	Extent of natural vs. converted land cover	The proportion of converted acreage surrounding DINO is very low.
Energy Exploration, Extraction and Distribution (this AOA needs to be larger to include oil and gas activities to the west including Uinta basin)	Oil and gas wells	There are numerous active wells in the region (currently active wells), there is a high potential for oil and gas development in the future (future activity wells and leases as well as non-active wells with future activity planned), and future oil and gas disturbance/development may occur closer to the monument boundary with potential new leases (e.g., southeast of the monument and the areas surrounding the western end).
	Transmission corridor areas of potential conflict	DINO, surrounding BLM wilderness study areas, and other lands immediately outside the boundary have a high potential for conflict. Other surrounding areas have a medium potential for conflict. Conflict is mainly attributed to BLM Visual Resources Management priorities, lands managed for wilderness characteristics and wilderness study areas, and greater sage-grouse habitat management areas.
Population and Housing	Historic and projected population total and density	Population density within 30 km of the monument's boundary is low, with most of the area within this 30 km radius having a density of 1–20 people/km^2. The low population density of the area is attributable to the prevalence of natural cover surrounding DINO. Historically, county populations in the surrounding area have been rising steadily since the early 20th century.
	Housing density	Within a 30 km radius of the monument, the most notable trend is a slight increase in exurban areas and a corresponding decrease in rural acreage, although the percentage change is very small. Most of this change is occurring in the Vernal, Utah, urban area.
Conservation Status	Protected area extent and biodiversity protection status	A large portion of the acreage in the region surrounding the monument is protected through ownership or conservation easements. Although a large percentage of land is protected, public land in the west is not necessarily protected to a great degree simply by virtue of ownership. This portion of the land cover/land use summary should not be interpreted as stating a high level of environmental protection for the region. Even protected land (mostly BLM) can allow detrimental land uses.

4.1.4. Uncertainty and Data Gaps

The primary source of uncertainty is associated with assumptions regarding the relationships between land ownership and conservation status. Although information about ownership and protection status can be useful, the degree to which biodiversity is represented within the existing network of protected areas is largely unknown (Pressey at al. 2002). Protection status and extent must be combined with assessments of conservation effectiveness (e.g., location, design, and progress toward conservation objectives) to achieve more meaningful results (Chape et al. 2005).

Disturbances associated with oil and gas activities surrounding the monument and their effects on natural resources are poorly documented, both individually and collectively. At the local scale, disturbance and potential impacts might be characterized and estimated, but larger landscape-scale disturbances and impacts to flora, fauna and other resources are poorly characterized and understood. At the broadest scales, habitat fragmentation is especially concerning.

4.1.5. Sources of Expertise

- Bill Monahan, Ph.D., NPS Inventory and Monitoring Division, Fort Collins, Colorado. Dr. Monahan provided NPScape data summaries, consulted on the selection and use of various metrics, and provided helpful manuscript reviews.

- Joe Neubauer, NPS Intermountain Region, Environmental Quality Division, Energy and Compliance Specialist. Mr. Neubauer provided guidance and recommendations for data sources and regional implications of oil and gas activities and transmission corridors on natural resources.

4.1.6. Literature Cited

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. USDI Geological Survey Professional Paper 964. A revision of the land use classification system as presented in U.S. Geological Survey Circular 671, United States Department of the Interior, Washington, D.C.

Bureau of Land Management (BLM). 2007. Surface operating standards and guidelines for oil and gas exploration and development, fourth edition. BLM/WO/ST-06/021+3071/REV 07. Bureau of Land Management, Denver, Colorado.

BLM. 2018. Landscape Approach Data Portal, National Data website. Available at: https://landscape.blm.gov/geoportal/catalog/BLMNational/BLM National.page (accessed 11 July 2018).

Buto, S.G., T.A. Kenney, and S.J. Gerner. 2010. Land disturbance associated with oil and gas development and effects of development-related land disturbance on dissolved-solids loads in streams in the Upper Colorado River Basin, 1991, 2007, 2025. Scientific Investigations Report 2010/5064. U.S. Geological Survey, Reston, Virginia.

Chape, S., J. Harrison, M. Spalding, and I. Lysenko. 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philosophical Transactions of the Royal Society Biological Sciences 360:443–455.

Conservation Biology Institute (CBI). 2013. Conservation Biology Institute protected areas database – US (PAD-US) Version 2 download website. Available at: http://consbio.org/products/projects/pad-us-cbi-edition (accessed 23 September 2013).

Davis, C.R., and A.J. Hansen. 2011. Trajectories in land-use change around U.S. National Parks and their challenges and opportunities for management. Ecological Applications 21:3299–3316.

Hansen, A.J., and D. Gryskiewicz. 2003. Interactions between Heartland National Parks and surrounding land use change: development of conceptual models and indicators for monitoring. Prepared for the National Park Service Heartland Network by Montana State University.

Hansen, A.J., N. Piekielek, C. Davis, J. Hass, D.M. Theobald, J.E. Gross, W.B. Monahan, T. Olliff, and S.W. Running. 2014. Exposure of U.S. National Parks to land use and climate change 1900–2100. Ecological Applications 24(3):484–502.

Kerr, J.T., and D.J. Currie. 1995. Effects of human activity on global extinction risk. Conservation Biology 9:1528–1538.

Luck, G.W. 2007. A review of the relationships between human population density and biodiversity. Biological Reviews 82:607–645.

Monahan, W.B., and J.E. Gross. 2012. Upstream landscape dynamics of US national parks with implications for water quality and watershed management. Pages 27–50 *in* Abiud Kaswamila, editor. Sustainable natural resources management. InTech, Rijeka, Croatia.

Monahan, W.B., J.E. Gross, L.K. Svancara, and T. Philippi. 2012. A guide to interpreting NPScape data and analyses. Natural Resource Technical Report NPS/NRSS/NRTR—2012/578. National Park Service, Fort Collins, Colorado.

Mutter, M., D. Pavlacky, N. Van Lanen, and R. Grenyer. 2015. Evaluating the impact of gas extraction infrastructure on the occupancy of sagebrush-obligate songbirds. Ecological Applications 25(5):1175–1186.

National Conservation Easement Database (NCED). 2013. National Conservation Easement Database website. Available at: https://www.conservationeasement.us/ (accessed 22 January 2016).

National Land Cover Database (NLCD). 2018. Multi-Resolution Land Characteristics Consortium (MRLC) website. Available at: https://www.conservationeasement.us/ (accessed 16 July 2018).

National Parks Conservation Association (NPCA). 2017. Out of balance. National Parks and the threat of oil and gas development. National Parks Conservation Association, Salt Lake City, Utah.

National Park Service (NPS). 1995. Dinosaur National Monument resource management plan. National Park Service, Dinosaur, Colorado.

NPS. 2013. NPScape standard operating procedure: Housing measure – current and projected housing density. Version 2014-04-09. National Park Service, Natural Resource Stewardship and Science, Fort Collins, Colorado.

NPS. 2014a. NPScape standard operating procedure: land cover measure – area per category, impervious surface, change index, and natural vs. converted. Version 2014-05-01. National Park Service, Natural Resource Stewardship and Science, Fort Collins, Colorado.

NPS. 2014b. NPScape standard operating procedure: population measure – current density and total. Version 2014-05-01. National Park Service, Natural Resource Stewardship and Science, Fort Collins, Colorado.

O'Neill, R.V., C.T. Hunsaker, K.B. Jones, K.H. Riitters, J.D. Wickham, P.M. Schwartz, I.A. Goodman, B.L. Jackson, and W.S. Baillargeon. 1997. Monitoring environmental quality at the landscape scale. BioScience 47:513–519.

Parks, S.A., and A.H. Harcourt. 2002. Reserve size, local human density, and mammalian extinctions in US protected areas. Conservation Biology 16:800–808.

Pressey, R.L., G.L. Whish, T.W. Barrett, and M.E. Watts. 2002. Effectiveness of protected areas in north-eastern New South Wales: recent trends in six measures. Biological Conservation 106:57–69.

Radeloff, V.C., S.I. Stewart, T.J. Hawbaker, U. Gimmi, A.M. Pidgeon, C.H. Flather, R.B. Hammer, and D.P. Helmers. 2010. Housing growth in and near United States protected areas limits their conservation value. Proceedings of the National Academy of Sciences of the United States of America 107:940–945.

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards, Jr., J. Ulliman, and R.G. Wright. 1993. Gap analysis: a geographic approach to protection of biological diversity. Wildlife Monographs 123:3–41.

Theobald, D.M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1):32.

Wade, A., and D. Theobald. 2010. Residential development encroachment on U.S. protected areas. Conservation Biology 24:151–161.

West-wide Energy Corridor. 2018. Section 368 Energy Corridor Mapping Tool Portal. Available at: http://corridoreis.anl.gov/maps/ (accessed 16 July 2018).

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48:607–615.

Wilshire, H.G., K.A. Howard, C.M. Wentworth, and H. Gibbons. 1996. Geologic processes at the land surface: U.S. Geological Survey Bulletin 2149. United States Government Printing Office, Washington, D.C.

Wittemyer, G., P. Elsen, W.T. Bean, A. Coleman, O. Burton, and J.S. Brashares. 2008. Accelerated human population growth at protected area edges. Science 321:123–126.

Woodroffe, R. 2000. Predators and people: using human densities to interpret declines of large carnivores. Animal Conservation 3:165–173.

4.2. Night Skies

4.2.1. Background and Importance

National Park Service (NPS) units are known for preserving natural resources and ecosystem integrity, but they also function as refuges for the less evident resources like natural darkness and starry night skies. An NPS study found that dark night skies are rated as "extremely" or "very" important by 57% of visitor groups (Kulesza et al. 2013). The NPS recognizes the significance of naturally dark night skies to humans and wildlife species and is bound to protect the natural night skies just like any other natural resource. For humans, there is cultural, scientific, economic, and recreational value associated with high-quality night skies. *NPS Management Policies* states that the NPS will "…preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light" (NPS 2006). *NPS Management Policies* also provides specific actions that the NPS will take to prevent the loss of dark conditions and natural night skies: restricting the use of artificial lighting where safety and resource requirements allow, utilizing minimal-impact lighting techniques, and providing shielding for artificial lighting (NPS 2006).

The Milky Way galaxy fills the night sky above Mitten Park and the Green River. Photo by Dan Duriscoe, NPS.

The National Park Service defines a natural lightscape as the resources and values that exist in the absence of human-caused light at night. Natural lightscapes are critical for nighttime scenery and nocturnal habitat. There are many species that depend on natural patterns of light and dark for navigation, predation and other natural processes (Van Doren et al. 2017). Nearly half of all animal species are nocturnal and require naturally dark habitats; the presence of excessive artificial light can cause significant impacts to these species (Rich and Longcore 2005). Light pollution is the introduction of artificial light either directly or indirectly into the natural environment (Cinzano et al.

2000). Nearly all of Dinosaur National Monument (DINO) is recommended (i.e., proposed) wilderness and is managed to preserve wilderness character. Wilderness is characterized by natural night skies unmarred by human light, contributing to a sense of solitude for visitors. Light pollution can reduce the enjoyment of park visitors by degrading the view of the night sky and reducing the contrast between faint extraterrestrial objects and the background of the luminous atmosphere. Some examples of light pollution are sky glow, sometimes referred to as artificial sky glow, light domes or fugitive light, which is the brightening of the night sky from human-caused light scattered into the atmosphere, and glare, which is the direct shining of light.

It is important to document excessive artificial light pollution in NPS units by establishing baseline conditions and monitoring changes in conditions over time to support planning and management actions (Moore et al. 2013). Poor air quality in combination with light pollution can dim the stars and other celestial objects, reducing the ability to see starry skies. Poor air quality also "scatters" artificial light, resulting in parks near cities and other significant light sources having a greater sky glow than if pollution were not present (Kulesza et al. 2013). The NPS has clearly declared its commitment to protecting night skies for the benefit of natural ecosystems and the enjoyment of current and future generations of park visitors (Peel 2000; NPS 2006).

On April 22, 2019, Dinosaur National Monument announced its designation as an International Dark Sky Park, a distinction that recognizes an exceptional quality of natural night sky darkness and the monument's commitment to the enjoyment and protection of dark skies for future generations. Because there is little light pollution here, you can see the stars of the Milky Way galaxy with startling clarity. At DINO, there are numerous prime places to view the night sky with either the naked eye or through the use of telescopes and binoculars. The number of stars visible to the naked eye at DINO is many times greater than what can be seen from major western cities (Figure 4.2-1). The monument regularly holds night sky programs near the Split Mountain Campground.

Threats and Stressors

Dinosaur National Monument is surrounded mainly by BLM-owned land, with some private lands supporting rural development and agricultural activities concentrated near the western entrance. Much of the oil and gas activity occurs on leased BLM land. Light originating from night operations of oil and gas drilling on the west side of the monument and extending into the Uinta Basin presents a distinct threat to the monument's natural lightscape and to the quality of visitor experiences (pers. comm., Lisa Baldwin, February 24, 2016; NPS 2015). Anthropogenic light can be perceived many miles away from its source (Falchi et al. 2016). Available light pollution data (Falchi et al. 2016, Duriscoe et al. 2018) indicate that the nearby towns of Vernal, Utah, and Rangely, Colorado, are significant sources of light pollution, as are several unnamed oil and gas storage and processing facilities in unpopulated areas north and south of the monument.

A comprehensive examination of landscape context related to land cover/land use, population and housing, all of which are correlated with light pollution, was performed for the area surrounding the monument and is presented in Section 4.1 *Land Cover and Land Use*. Section 4.1 also describes and summarizes patterns of oil and gas wells and leases in the tri-state region surrounding DINO.

Landscape context parameters can be highly correlated with ambient light levels. Therefore, changes in these factors can have significant impacts on the night sky of the park.

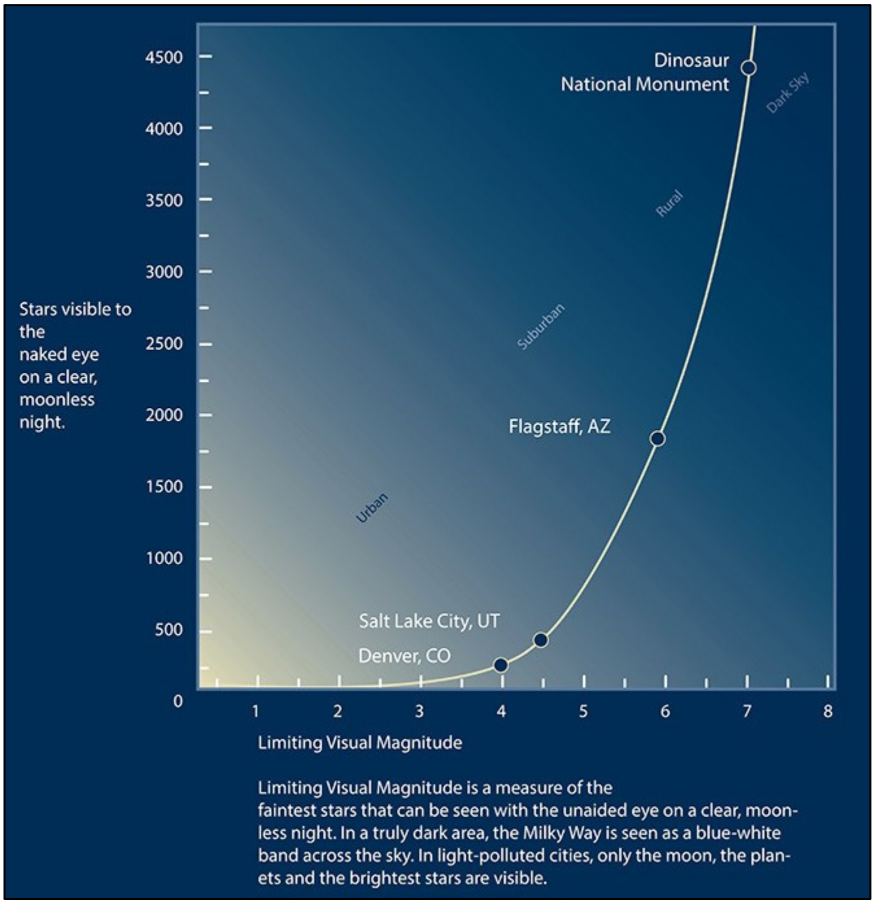


Figure 4.2-1. Night sky quality at DINO relative to some western U.S. cities (NPS 2019).

Indicators and Measures

- Anthropogenic Light Ratio (ALR)
- Bortle night sky brightness

4.2.2. Data and Methods

The NPS Natural Sounds and Night Skies Division (NSNSD) conducted on-site night sky assessments in DINO at three field sites in July 2009 (Green River Campground, Serviceberry Ridge, and Split Mountain group site) and an additional site in June 2012 (Harpers Corner Road). Data collected included ALR readings and Bortle scale ratings. A specialized digital camera was used to photograph a series of images of the night sky over DINO, and various photometric indicators were obtained at each site. Figures 4.2-2 (modeled natural sky background brightness), 4.2-3 (estimated artificial sky glow), and 4.2.4 (full resolution mosaic) are examples of images collected at the Green River Campground site.

The NSNSD recommends ALR as a metric to assess the condition of the night skies at NPS units (Moore et al. 2013). The NSNSD characterizes park unit photic environment by measuring both anthropogenic and natural light. In contrast to nightscapes or natural night skies, photic environments are a broader concept that encompasses the totality of the pattern of light at night at all wavelengths. The ALR is a relatively coarse measure using the ratio of anthropogenic to natural light. An ALR value of zero indicates natural light, while an ALR value of one indicates that anthropogenic light is 100% brighter than natural light from night skies (Moore et al. 2013). Researchers in collaboration with NPS developed models that calculate ALR values and applied them to all NPS units, including DINO and the surrounding area (Duriscoe et al. 2018).

In addition, a geospatial data layer showing Artificial Sky Brightness for the region surrounding DINO (Falchi et al. 2016) was helpful in identifying sources of artificial light threatening natural night skies at DINO. Although Falchi et al.'s (2016) brightness values are not directly comparable with ALR values, they are a related index used to confirm sources of anthropogenic light around DINO.

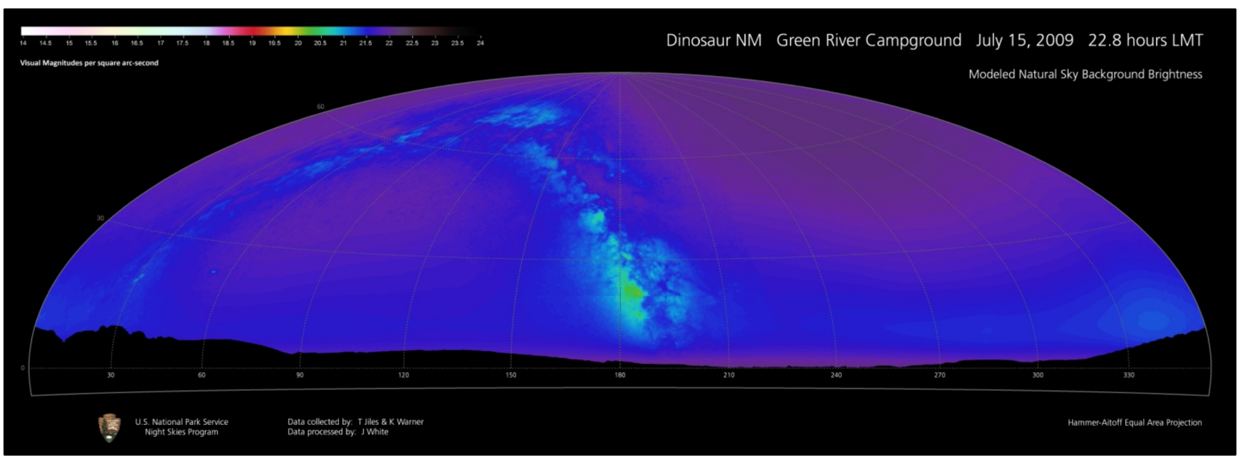


Figure 4.2-2. Modeled 360-degree natural sky background brightness, Green River Campground site (image provided by NPS NSNSD).

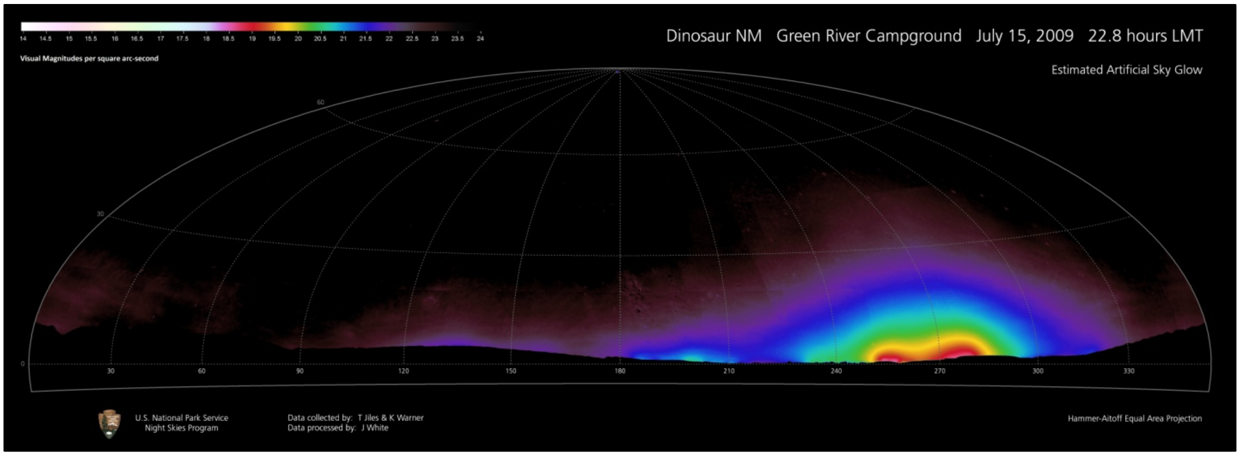


Figure 4.2-3. Estimated 360-degree artificial sky glow, Green River Campground site (image provided by NPS NSNSD).

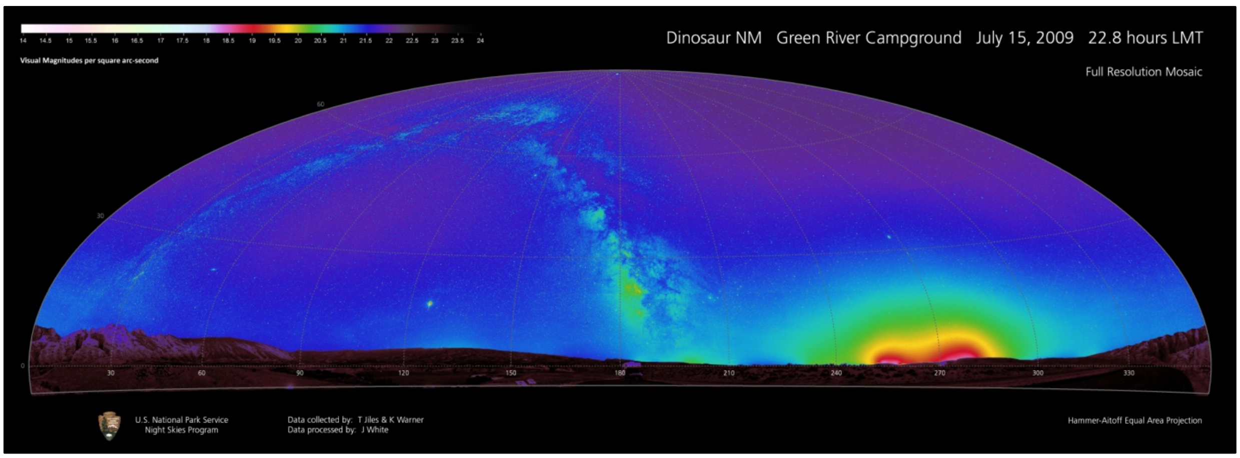


Figure 4.2-4. Full resolution 360-degree mosaic of all-sky brightness depicted in false colors, showing nearby light domes and other sources of anthropogenic light, Green River Campground site (image provided by NPS NSNSD).

4.2.3. Reference Conditions

The reference condition for the night sky in Dinosaur National Monument is one in which the intrusion of artificial light into the night scene is minimized. Natural sources of light (such as moonlight, starlight, and the Milky Way) will be more visible from the monument than anthropogenic sources. As little outdoor lighting as is necessary to maintain a safe environment for monument visitors and employees will be used. To help the monument achieve its cultural mission, it is important that the night sky of the site retains its pre-industrial-era character.

Impact thresholds have been developed for non-urban (Level 1) and urban (Level 2) park night sky resources (Moore et al. 2013). Parks outside of designated urban areas are considered more sensitive to the impact of anthropogenic light and are assessed using lower thresholds of impact. Parks within urban areas, as designated by the U.S. Census Bureau, are considered less sensitive to the impact of anthropogenic light and are assessed using higher thresholds of impact. According to the U.S. Census

Bureau (2010), DINO is categorized as non-urban area (U.S. Census Bureau 2010), thus the Level 1 condition thresholds are applied (Table 4.2-1).

Table 4.2-1. Reference condition rating framework for night sky indicators at DINO (Moore et al. 2013).

Indicator	Good Condition	Warrants Moderate Concern	Warrants Significant Concern
Mean Anthropogenic Light Ratio (ALR)	ALR < 0.33	ALR = 0.33–2.0	ALR > 2.0
Bortle Night Sky Brightness	Bortle Class 1–3	Bortle Class 4	Bortle Class 5–9

4.2.4. Condition and Trend

Values of ALR and Bortle night sky brightness collected at four DINO sites were used to assess the condition of the dark sky (Table 4.2-2). The Green River Campground site was the most degraded from anthropogenic light based on the Mean ALR values and the Bortle class rating.

Table 4.2-2. Photometric indicator results for four sites in DINO (data provided by NSNSD).

	Light Pollution Ratio (Artificial/Natural)			
Indicator	Green River Campground (7/15/09)	Serviceberry Ridge (7/16/09)	Split Mountain Group Site (7/17/09)	Harpers Corner Road (6/13/12)
Mean ALR	0.32	0.17	0.17	0.19
Bortle Night Sky Brightness	4	3	3	3

Values of ALR modeled by NSNSD at DINO and the surrounding region are displayed in Figure 4.2-5. The ALR values in the monument range from 0.04–0.32, indicating natural night skies with little influence of anthropogenic light and considered good condition (Table 4.2-1). Figure 4.2-5 shows the locations of primary sources of anthropogenic light influencing natural night skies at DINO. Notable nearby sources include the towns of Vernal, Utah, to the west and Rangely, Colorado, south of DINO. The next closest locations having ALR values above 0.64 are two oil and gas storage/processing facilities roughly 50–100 acres each in size. They are in unpopulated areas having high densities of active oil and gas well pads (Figure 4.2-5). One is in Uinta County, Wyoming, approximately 60 miles northeast of Vernal and the second is in Rio Blanco County, Colorado, approximately 35 miles east-southeast of the town of Rangely. Artificial night sky brightness spatial data developed by Falchi et al. (2016) show a similar pattern and sources of degradation.

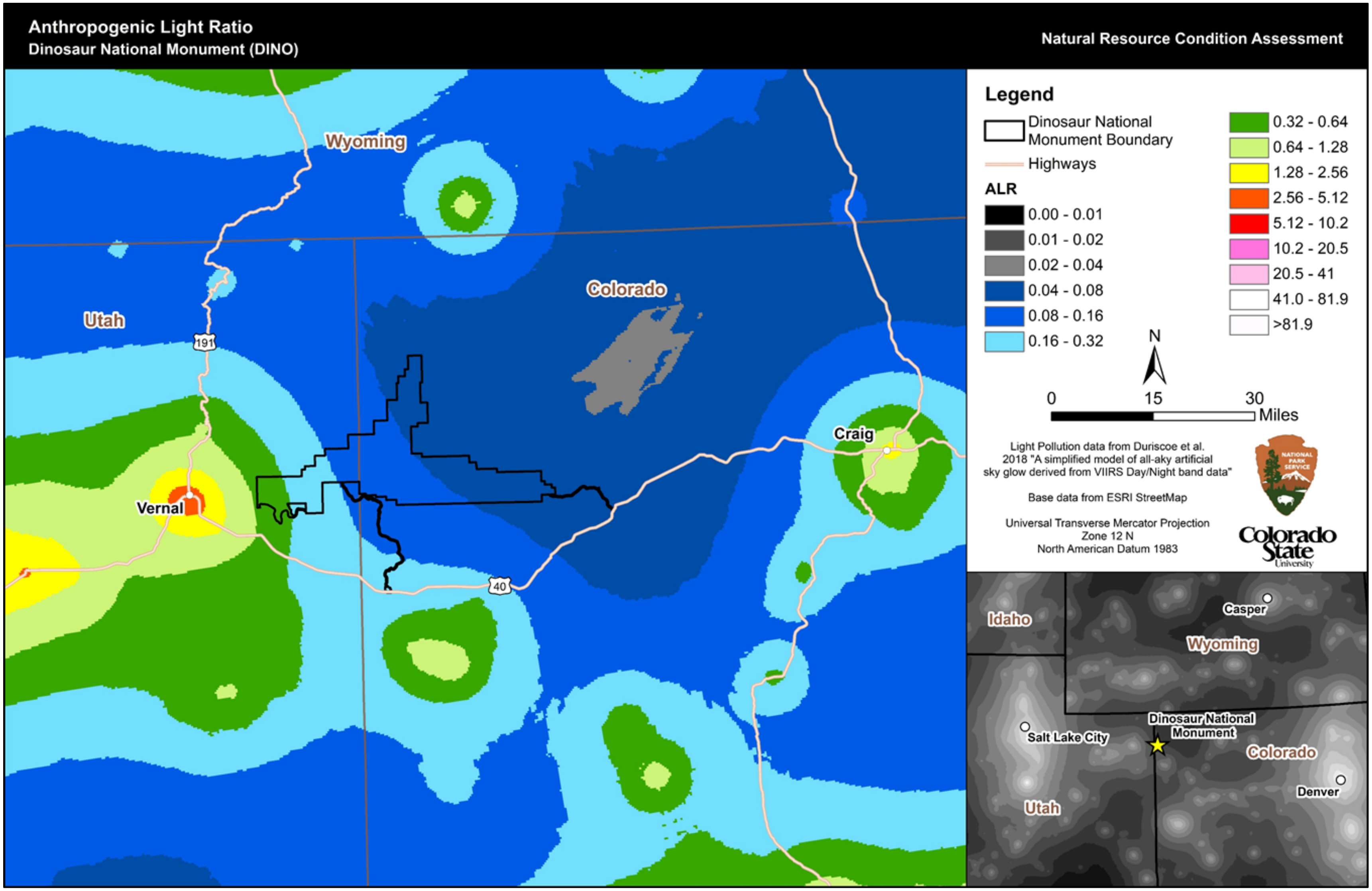


Figure 4.2-5. Anthropogenic Light Ratio (ALR) values in DINO and the surrounding region (Duriscoe et al. 2018).

The mean anthropogenic light ratio was less than 0.33 at all four sites studied. Bortle class ratings indicated a good condition for the night sky for three of the four sites (with the fourth site indicating moderate concern). Based on the results for ALR and Bortle night sky brightness, night skies at DINO appear to be in good condition. No trend data are available. Recent residential and oil and gas development have impacted DINO's night skies over the past several decades. This is evident in the light pollution ratios documented for areas with little to no housing or population but showing ample evidence of drilling pads and petroleum product storage and processing facilities. A summary of night sky indicators is shown in Table 4.2-3. The confidence associated with these ratings is high due to the on-site measurements and use of quantitative metrics.

Table 4.2-3. Condition and trend summary for night skies at Dinosaur National Monument.

Indicator	Condition Status/Trend	Rationale
Mean Anthropogenic Light Ratio (ALR)	Good condition (green circle)	Anthropogenic Light Ratio (ALR) is a measure of light pollution calculated as the ratio of median Anthropogenic Sky Glow to average Natural Sky Luminance. ALR for DINO varied from 0.17 to 0.32 across the 4 sites, which is considered good condition.
Bortle Night Sky Brightness	Good condition (green circle)	Three out of four sites had a Bortle Class of 3, which is considered good condition. The fourth site, Green River Campground, had a Bortle Class of 4, which warrants moderate concern.
Night Skies overall	Good condition (green circle)	**Night skies are in good condition with an unknown trend. Confidence in the assessment is high.**

4.2.5. Uncertainty and Data Gaps

There is a high level of certainty in the assessment due to the range of qualitative and quantitative data available from the NSNSD site visits and reports. No trend data are available. Due to the concern regarding the impact of nearby and regional development and oil and gas activities, there is some likelihood that the night skies have been degraded within the past several decades.

4.2.6. Sources of Expertise

- Jeremy White, Colorado State University.
- Lisa Baldwin, Chief of Research and Resource Management, Dinosaur National Monument.
- Sharolyn Anderson, NPS Natural Sounds and Night Skies Division.
- Randy Stanley, Intermountain Region Office, Natural Resources Division, reviewed the draft manuscript and provided helpful comments.

4.2.7. Literature Cited

Cinzano, P., F. Falchi, C.D. Elvidge, and K.E. Baugh. 2000. The artificial night sky brightness mapped from DMSP satellite Operational Linescan System measurements. Monthly Notices of the Royal Astronomical Society 318:641–657.

Duriscoe, D.M., S.J. Anderson, C.B. Luginbuhl, and K.E. Baugh. 2018. A simplified model of all-sky artificial sky glow derived from VIIRS Day/Night band data. Journal of Quantitative Spectroscopy and Radiative Transfer 214:133–145.

Falchi, F., P. Cinzano, D. Duriscoe, C. Kyba, C. Elvidge, K. Baugh, B.A. Portnov, N.A. Rybnikova, and R. Furgoni. 2016. The new world atlas of artificial night sky brightness. Science Advances 2:e1600377.

Kulesza, C., Y. Le, M. Littlejohn, and S.J. Hollenhorst. 2013. National Park Service visitor values and perceptions of clean air, scenic views & dark night skies; 1988–2011. Page 70. Natural Resource Report NPS/NRSS/ARD/NRR–2013/632. National Park Service, Fort Collins, Colorado.

Moore, C., F. Turina, and J. White. 2013. Recommended indicators and thresholds of night sky quality for NPS State of the Park reports. NPS Natural Sounds and Night Skies Division. Available from https://irma.nps.gov/DataStore/Reference/Profile/2198592 (accessed 30 July 2018).

National Park Service (NPS). 2006. Management policies 2006: the guide to managing the National Park System. National Park Service, Washington, D.C.

NPS. 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

NPS. 2019. Stargazing, Dinosaur National Park website. Available at: https://home.nps.gov/dino/planyourvisit/stargazing.htm (accessed March 2019).

Peel, K.A. 2000, May 23. Director's Order #47: Soundscape Preservation and Noise Management. Available at: https://www.nps.gov/policy/DOrders/DOrder47.html (accessed 25June 2018).

Rich, C., and T. Longcore. 2005. Ecological consequences of artificial night lighting. Island Press, Washington, D.C.

U.S. Census Bureau. 2010. 2010 Census – Urban and Rural Classification. Available at: https://www2.census.gov/geo/tiger/TIGER2010/UA/2010/ (accessed 21 June 2018).

Van Doren, B.M., K.G. Horton, A.M. Dokter, H. Klinck, S.B. Elbin, and A. Farnsworth. 2017. High-intensity urban light installation dramatically alters nocturnal bird migration. Proceedings of the National Academy of Sciences 114:11175–11180.

4.3. Natural Sounds

4.3.1. Background and Importance

The acoustic environment includes all sounds present in the environment, and not just those that can be heard by humans. All the natural sounds that occur within the boundaries of the National Park System units and the physical capacity for transmitting those natural sounds and their interrelationships with other sounds comprise the natural acoustic environment of a park (NPS 2006). Visitors to national parks are often highly motivated to experience natural tranquility, sounds of nature, and solitude (McDonald et al. 1995, Krog et al. 2010, Mace et al. 2013). However, anthropogenic noise increasingly degrades, disturbs, and reduces visitor enjoyment (Rapoza et al. 2015). Most visitors prefer to hear sounds intrinsic to the natural and cultural settings of the park units they are visiting. Sounds are important because they can have a strong effect on people's perception and enjoyment of a landscape (Benfield et al. 2010). A growing body of research also documents the biological and behavioral impacts of unnatural and unusual noise on a variety of wildlife (Barber et al. 2009, Shannon et al. 2016). Many species depend on natural soundscape conditions—free from anthropogenic noise intrusions—to successfully reproduce and survive (Rabin et al. 2006, Habib et al. 2007). In 2000 the NPS issued the *Director's Order #47: Soundscape Preservation and Noise Management* "to articulate National Park Service operational policies that will require, to the fullest extent practicable, the protection, maintenance, or restoration of the natural soundscape resource in a condition unimpaired by inappropriate or excessive noise sources" (Peel 2000). The order established guidelines for monitoring and planning to preserve park soundscapes.

New NPS management policies introduced in 2006 included several directives related to soundscapes, including the affirmation that "The Service will preserve, to the greatest extent possible, the natural soundscapes of parks. The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise), and will protect the acoustic environment from unacceptable impacts" (NPS 2006). Excessive noise in NPS units threatens to adversely impact natural and cultural resources and the quality of visitor experiences. The NPS has clearly declared its commitment to protect intrinsic soundscapes for the enjoyment of current and future generations of park visitors.

Dinosaur National Monument's *Foundation Document* identifies natural sounds as a key component of the monument's significance as part of its extensive wilderness character (NPS 2015). Over 90% of DINO is recommended wilderness, providing the opportunity for visitors and wildlife to experience dark night skies and natural sounds. Natural sounds are also described as a "Fundamental Resources Value" (NPS 2015).

<u>Threats and Stressors</u>

Primary threats to the natural soundscape include noise originating from modern transportation (automobiles and aircraft), development, and oil and gas drilling on nearby lands. The most active areas of traffic and potential development are to the west and south of the monument (See Section 4.1 *Land Cover and Land Use* for more details). Aircraft noise is typically one of the most pervasive threats to natural sounds in NPS units and is a notable source of anthropogenic noise at DINO. Although the monument is located far from any major airports, overflights could still be a significant

source of anthropogenic noise at the monument (FlightAware 2018; Flightradar24 2018). Government reports indicate air and vehicle traffic are projected to significantly increase at regional and national scales (U.S. Department of Transportation 2015). There is little noise associated with park management activities outside of developed facilities and campgrounds at the monument's western entrance. Noise from transportation and development associated with the oil and gas industry is a distinct threat to the natural soundscape of DINO and the quality of visitor experiences (Jones et al. 2015).

The NSNSD has used acoustic modeling to estimate the anthropogenic impact to the ambient sound level in DINO, which is the existing sound level minus the estimated natural sound level (Mennitt et al. 2013). Mean impact thus provides a measure of how much anthropogenic noise is increasing the existing sound level above the natural sound level, on average, in the monument. For reference, for human visitors and resident wildlife, an increase in background sound level of 3 dB produces an approximate decrease in listening area of 50%. In other words, raising the sound level by 3 dB reduces the ability of listeners to hear the sounds around them by half. Furthermore, an increase of 7 dB leads to an approximate decrease in listening area of 80%, and an increase of 10 dB decreases listening area by approximately 90%.

A comprehensive examination of landscape context related to land cover/land use and population and housing, all of which can degrade natural and historic soundscapes, was performed for the area surrounding the monument and is presented in Section 4.1. These parameters can be highly correlated with ambient sound levels. Therefore, changes in these factors can have significant impacts on the soundscape of the monument.

Indicators and Measures

- Anthropogenic sources of noise – presence/absence and relative noise level
- Road traffic volume on CO-64 and US-40 – vehicle counts
- Percent time above specified level of 52 dB ($LA_{eq,\ 1s}$)
- Percentile levels –$LA_{90,\ 12\ hr}$, $LA_{50,\ 12\ hr}$, $LA_{10,\ 12\ hr}$
- Sounds levels by frequency
- Time audible natural and anthropogenic sound sources (attended listening)
- Noise impacts (modeled) – median and maximum impact in dBA

4.3.2. Data and Methods

The condition of the soundscape at DINO was evaluated using input from monument documents and staff, and data provided by the NPS Natural Sounds and Night Skies Division (NSNSD). The NSNSD conducted acoustical monitoring at 4 sites in DINO in summer 2010 (Figure 4.3-1) (Warner 2013). Sites were representative of the monument's dominant vegetation zones. Each monitoring period lasted approximately 25 days. Various metrics of soundscape condition were collected during

these monitoring periods and are described below. In addition, the NSNSD provided results from nation-wide modeling of ambient sound levels (Mennitt et al. 2013). Modeling was applied to all NPS units, including the entire area of DINO and the surrounding region. This analysis permitted estimation of the impact of anthropogenic noise on natural sound levels in the monument. NSNSD also conducted seven hours of attended listening at DINO in summer 2010 (two hours each at DINO001, DINO003, and DINO004; one hour at DINO002; Figure 4.3-1). Attended listening consists of a trained observer recording all sounds—natural and anthropogenic—that are audible from a specific site during a fixed time interval (Warner 2013). Observations and opinions from DINO staff are also incorporated in this assessment with respect to desired soundscape conditions as well as sources of anthropogenic noise intrinsic and extrinsic to the monument.

A recent publication examined noise pollution in protected areas across the continental United States (Buxton et al. 2017). Researchers used a metric termed "noise exceedance" to quantify the difference between the predicted A-weighted (defined below) sound levels and predicted sound levels minimizing the influence of anthropogenic noise. In other words, noise exceedance quantifies how much anthropogenic noise raises sound above natural levels. Estimated levels of noise exceedance were also calculated for DINO.

Vehicle count data from the Colorado Department of Transportation were used to assess road traffic volume (CDOT 2018).

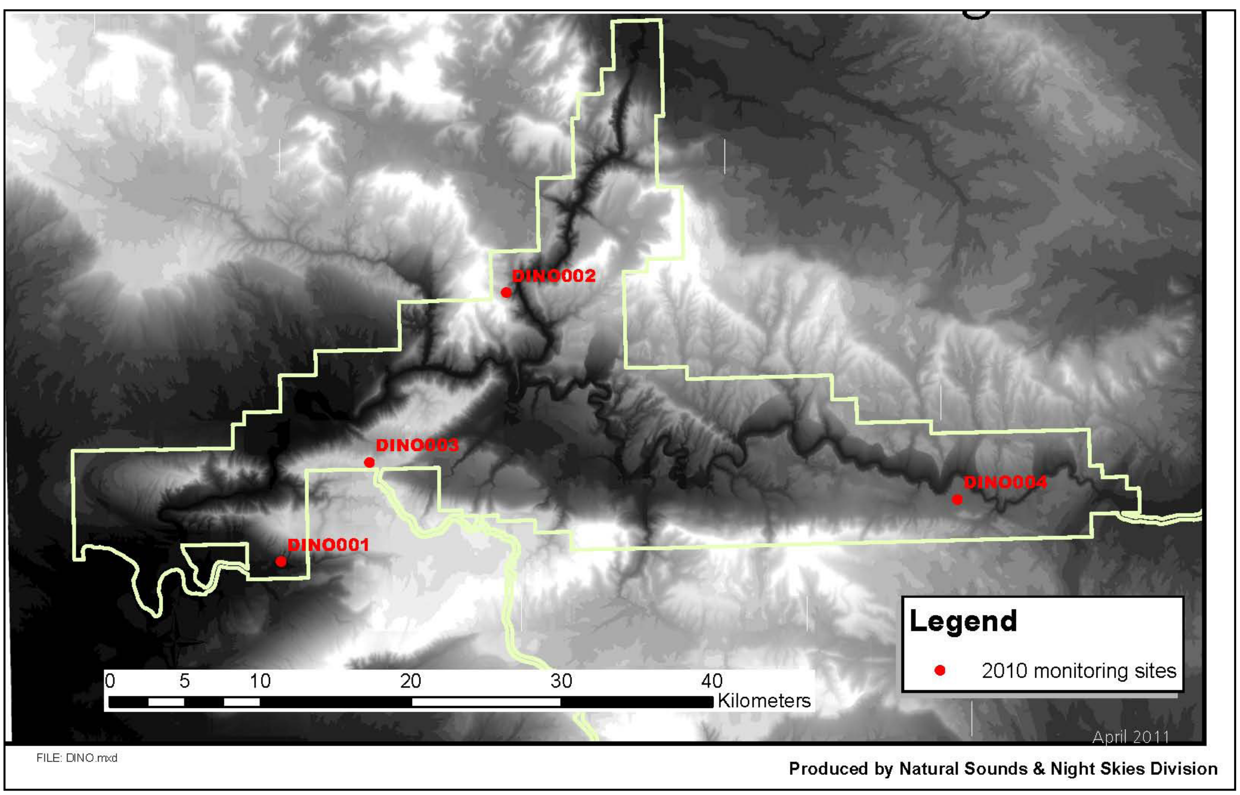


Figure 4.3-1. Location of acoustical monitoring sites at DINO (Warner 2013).

Decibel Scale

Sound pressure levels are often represented in the logarithmic decibel (dB) scale. In this scale, 0 dB is equivalent to the lower threshold of human hearing at a frequency of 1 kHz. This scale can be adjusted to account for human sensitivity to different frequencies of sound, a correction known as A-weighting. Examples of common sound sources (both within and outside of park unit environments) and their approximate sound levels are shown in Table 4.3-1 (Lynch 2009).

Table 4.3-1. Sound pressure level examples from NPS and other settings (Lynch 2009).

Park Sound Sources	Common Sound Sources	Sound Level (dBA*)
Volcano crater (Haleakala National Park)	Human breathing at 3m	10
Leaves rustling (Canyonlands National Park)	Whispering	20
Crickets at 5m (Zion National Park)	Residential area at night	40
Conversation at 5m (Whitman Mission National Historic Site)	Busy restaurant	60
Snowcoach at 30m (Yellowstone National Park)	Curbside of busy street	80
Thunder (Arches National Park)	Jackhammer at 2m	100
Military jet at 100m AGL (Yukon-Charley Rivers National Preserve)	Train horn at 1m	120

* dB re 20 µPa A-weighted broadband (12.5 Hz—20 kHz) sound level over varied measurement durations and at the distances indicated

4.3.3. Reference Conditions

Park managers have not yet identified specific reference conditions for the soundscape in DINO (pers. comm., Lisa Baldwin, February 24, 2016). The reference condition for the soundscape in DINO is dominated by natural and cultural sounds that are intrinsic to the monument. Natural sounds could include birds, wind, rain, running water, and insects. A condition rating system for the soundscape indicators was developed through using widely-used thresholds and communications with NSNSD and is presented in Table 4.3-2.

Table 4.3-2. Reference condition rating framework for soundscape indicators at DINO.

Indicator	Good Condition	Warrants Moderate Concern	Warrants Significant Concern
Anthropogenic Sources of Noise	Infrequent, low, or inaudible levels of anthropogenic noise. Annoyance level of visitors low. Natural sounds heard continuously.	Moderately frequent and audible anthropogenic noise. Annoyance level of visitors moderate.	Frequent and highly audible anthropogenic noise. Annoyance level of visitors high.
Road Traffic Volume	Not exceeding 2017 baseline of traffic volume on CO-64 (near US-40 and the town of Dinosaur) of 1,814 vehicles per day; no increase in the proportion of heavy commercial trucks using the roads.	5–10% increase in total traffic volume from 2017 baseline; higher proportion of heavy commercial trucks.	>10% increase in total traffic volume from 2017 baseline; higher proportion of heavy commercial trucks.

Table 4.3-2 (continued). Reference condition rating framework for soundscape indicators at DINO.

Indicator	Good Condition	Warrants Moderate Concern	Warrants Significant Concern
Time Above Specified Levels	Time above 52 dB (level of speech interference for interpretive programs) ≤10%.	Time above 52 dB (level of speech interference for interpretive programs) is >10%-<25%.	Time above 52 dB (level of speech interference for interpretive programs) ≥25%.
Median Sound Level*	L_{50} ≤ 35 dB (sound level exceeded 50% of the time is less than or equal to 35 dB)	35 dB < L_{50} < 45 dB (sound level exceeded 50% of the time is between 35 and 45 dB)	L_{50} ≥ 45 dB (sound level exceeded 50% of the time is greater than or equal to 45 dB)
Attended Listening	Natural sounds heard continuously; anthropogenic (except appropriate cultural) sounds heard rarely.	Natural sounds heard some of the time; anthropogenic sounds heard frequently but not continuously.	Natural sounds heard rarely; anthropogenic sounds heard continuously.
Anthropogenic Sound Level Impacts	Median impact ≤ 3 dBA Maximum impact ≤ 7.5 dBA	3 dBA < Median impact < 5 dBA 7.5 dBA < Maximum impact < 10 dBA	Median impact ≥ 5 dBA Maximum impact ≥ 10 dBA

* A-weighted broadband (12.5 Hz — 20 kHz) derived from one-second averaged noise level ($L_{Aeq,\ 1s}$).

4.3.4. Condition and Trend

Anthropogenic Sources of Noise

The following primary or common sources of anthropogenic noise were identified by staff members at DINO (pers. comm., Lisa Baldwin, February 24, 2016): vehicle traffic and road noise, including traffic and noise from oil and gas drilling on land (predominantly Bureau of Land Management) adjacent to the monument. Most anthropogenic noise originates outside the monument. Information from the Colorado Department of Transportation (CDOT) indicates an increasing trend in traffic volume, which may result in higher levels of anthropogenic noise in the future (Table 4.3-3). Commercial jet overflights were the most common source of noise during the 2010 acoustic inventory. Based on input from the monument and other anecdotal evidence, the condition of this indicator warrants moderate concern, with an unknown trend and a medium level of confidence due to lack of visitor survey data.

Table 4.3-3. Annual average daily traffic volume, measured as vehicle counts, near Dinosaur, Colorado (CDOT 2018).

Road Segment	1991	1995	Annual Average Daily Traffic Volume (vehicle counts)					Change 1991–2017
			2000	2010	2015	2017	Projected 2020	
CO-64 (near US-40)	1,425	1,469	1,520	1,955	1,874	1,814	1,870	21.44%

Traffic Volume

We examined annual traffic volumes available for main roads and highways in and near DINO. According to the Colorado Department of Transportation's (CDOT) Online Transportation Information System, the intersection of CO-64 and US-40 near the town of Dinosaur, Colorado, had an annual average daily traffic volume of 1,814 vehicles in 2017 (Table 4.3-3). The percentage of traffic consisting of heavy commercial trucks was 11.4% in 2014 and 17.2% in 2017 (CDOT 2018). The annual average daily volume is projected to increase to 1,870 by 2020. The condition of this indicator warrants moderate concern with a deteriorating trend and a medium confidence level.

Time above Specified Sound Levels

The NSNSD conducted acoustical monitoring at 4 sites in DINO during 2010 (Figure 4.3-1) (Warner 2013). Time above specific sound pressure (decibel) levels was determined for the full frequency range (12.5–20,000 Hz) and was reported in percent of a 24-hour day. Sound pressure levels measured in the monument were compared to levels that are known to produce functional effects in humans, including blood pressure and heart rate increases in sleeping humans at 35 dB (Haralabidis et al. 2008), the World Health Organization's recommended maximum noise level inside bedrooms at 45 dB (Berglund et al. 1999), speech interference for interpretive programs at 52 dB (EPA 1974), and speech interruption for normal conversation at 60 dB (EPA 1974). Table 4.3-4 summarizes the percent time above these four levels at each of the 4 sites for both daytime and nighttime periods.

Results varied widely by monitoring location. For DINO003 and DINO004, one-second averaged sound level ($LA_{eq, 1s}$) exceeded 35 dB less than 30% of the time (and less than 7% of the time for DINO003 at night). By contrast, sound pressure levels exceeded 35 dB as much as 89% and 100% of the time for DINO001 and DINO002, respectively. Despite this variability by site, sound pressure levels exceeded 52 dB less than 6% of the time at all sites for both time periods (day and night). Therefore, this indicator is in good condition, with an unknown trend and a high confidence level.

Table 4.3-4. Time above various sound pressure levels and exceedance levels for various percentages of time for the full frequency range (12.5–20,000 Hz) (Warner 2013).

Site #	Time of Day*	Time Above (% of 24-hour day)				Exceedance Levels (dBA)		
		35 dB	45 dB	52 dB	60 dB	$LA_{90, 12 hr}$	$LA_{50, 12 hr}$	$LA_{10, 12 hr}$
DINO001	Day	88.99	35.40	5.29	0.19	36.4	42.7	48.9
	Night	57.96	14.82	0.95	0.06	31.0	36.8	43.0
DINO002	Day	100.0	8.12	1.84	0.12	37.2	38.1	39.5
	Night	100.0	0.23	0.00	0.00	37.5	38.0	38.7
DINO003	Day	13.04	0.99	0.20	0.01	21.8	27.3	35.3
	Night	6.97	0.83	0.17	0.01	16.8	19.7	28.8
DINO004	Day	28.07	6.82	2.24	0.91	n/a	n/a	n/a
	Night	13.54	2.73	1.14	0.48	n/a	n/a	n/a

* Day period is 0700h–1900h; Night period is 1900h–0700h. Frequency range 12.5 Hz–20 kHz.

Exceedance Levels

The NSNSD also calculated the sound pressure levels that exceeded a certain percentage of the time during the monitoring period (i.e., L_{50} is the sound level that is exceeded 50% of the stated time period) (Warner 2013). Analysis was performed for the full frequency range (12.5–20,000 Hz) for both daytime and nighttime hours. Table 4.3-4 presents the exceedance levels for 3 of the sites (exceedance levels were not calculated for DINO004 because the system was destroyed by cattle two days after deployment). The sound level exceeded 50% of the time is between 35 and 45 dB for DINO001 and DINO002 and considerably less than 35 dB for DINO003. The condition of this indicator warrants moderate concern, with an unknown trend and a high confidence level.

Sound Levels by Frequency

The full frequency spectrum derived from acoustic monitoring can be divided into 33 smaller frequency bands (each representing a single one-third octave range). The NSNSD created plots of the daytime and nighttime sound pressure levels for each frequency band to demonstrate the distribution of lower- and higher-frequency sounds occurring in DINO throughout the day for each sampling period. An example of plotted sound levels by frequency for DINO001 is shown in Figure 4.3-2 (Warner 2013). Although these plots can be informative when combined with other metrics, they are not useful indicators of soundscape quality on their own. Furthermore, it is challenging to select a reference condition for this indicator. Sound levels by frequency are included here for reference and may be used in future assessments; a condition rating is not assigned.

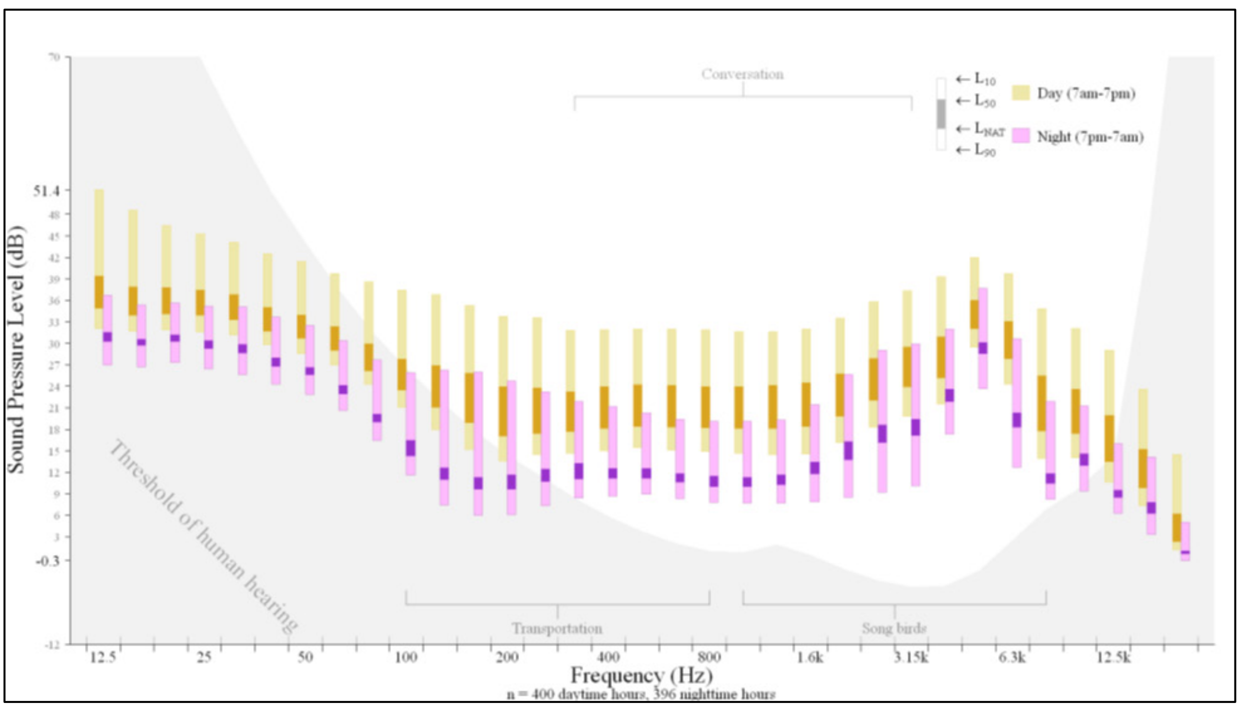


Figure 4.3-2. Daytime and nighttime sound pressure levels for 33 one-third octave frequency bands (DINO001) (Warner 2013).

Percent Time Audible Natural and Anthropogenic Sounds (Attended Listening)
The NSNSD conducted seven hours of attended listening at four sites in DINO in summer 2010 (Warner 2013). The data from NSNSD's attended listening sessions in 2010, summarized in Table 4.3-5, provide an estimate of how often different sound sources are audible in DINO.

Table 4.3-5. Time audible percentages for various sound sources in DINO from attended listening sessions (Warner 2013).

	Time Audible (Average % of hour-long session)			
Sound Source	***DINO001*** **(2 hours of listening)**	***DINO002*** **(1 hour of listening)**	***DINO003*** **(2 hours of listening)**	***DINO004*** **(2 hours of listening)**
Aircraft	8.2	28.0	27.0	14.5
Park maintenance	23.0	–	–	–
Vehicle	6.0	–	–	–
Wind	100.0	9.0	99.0	97.0
Bird	80.0	53.0	90.0	99.0
Insect	46.0	3.0	11.0	10.0
Water	–	94.0	–	–
Mammal	–	–	9.0	–

Although the individual listening sessions only represent a small snapshot in time and place, the results are potentially informative in determining the balance between natural, cultural, and other anthropogenic sounds that may typically be audible to DINO visitors. For example, aircraft were audible at all four sites, ranging from 8.2% of the time at DINO001 to 28.0% of the time at DINO002. Park maintenance activities (23%) and vehicles (6%) were only audible at DINO001. In terms of natural sounds, wind and birds were heard nearly constantly at all sites except DINO002, where flowing water was audible 94% of the time during the listening session. The condition of this indicator warrants moderate concern with an unknown trend and a high confidence level.

Anthropogenic Impacts on Ambient Sound Level (Modeled)
In DINO, the mean impact was 1.9 dB. Additional metrics describing a range of impacts across the landscape of the monument were also obtained. Minimum impact (minimum sound level impact in the monument) was 0.3 dB, 1st quartile impact (25% of points in the monument have this level or impact or less) was 1.3 dB, median impact (50% of the monument has this impact or less) was 1.7 dB, 3rd quartile impact (75% of the monument has this impact or less) was 2.3 dB, and maximum impact (maximum impact value inside monument boundaries) was 10.6 dB. Modeled mean impacts in the area immediately surrounding DINO are shown in Figure 4.3-3. The areas within DINO with the lowest anthropogenic sound level impacts are the south-central and south-eastern boundaries. The area with the highest impacts is the far western portion near the town of Jensen, Utah. The condition of this indicator warrants moderate concern with a high confidence level. No trend data are available.

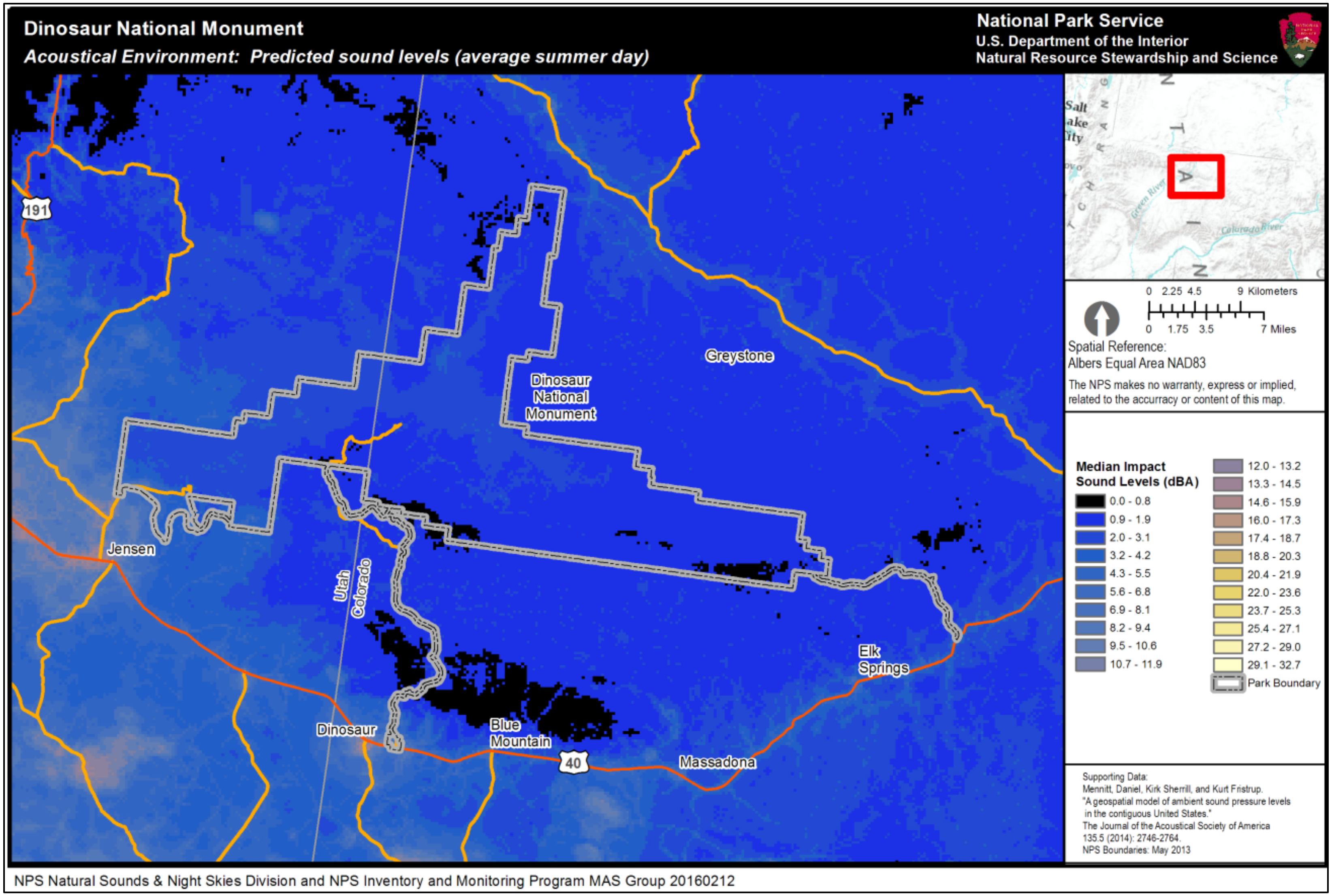
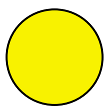
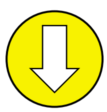
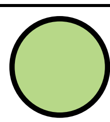
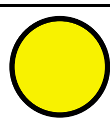
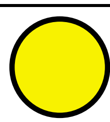
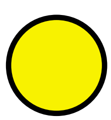
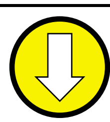


Figure 4.3-3. Modeled sound level impacts for DINO and the surrounding area (Warner 2013).

Overall Condition

Results suggest that the condition of the soundscape at DINO warrants moderate concern with a deteriorating trend. A summary of soundscape indicators is shown in Table 4.3-6. State transportation projections indicate that traffic volumes on CO-64 near the monument will increase by 2020. Noise from aircraft was also audible from 8% to 28% of the time during the listening sessions; natural sounds were frequently heard. Nationwide modeling of anthropogenic sound level impacts indicates that modern noise intrusions are moderately increasing the existing ambient sound level above the natural ambient sound level of the monument (mean impact = 1.9 dB; maximum impact = 10.6 dB). Noise exceedance levels are >10dB, indicating a severe reduction of the listening area. If active oil and gas development remains pervasive near the monument, the condition of the soundscape will likely continue to deteriorate. The confidence associated with these ratings is high due to the wide range of measures available, including quantitative metrics.

Table 4.3-6. Condition and trend summary for natural sounds at Dinosaur National Monument.

Indicator	Condition Status/Trend	Rationale
Anthropogenic Sources of Noise		Vehicles, aircraft traffic and noise from oil and gas drilling on nearby BLM land particularly threatens DINO's natural soundscape.
CO-64 and US-40 Traffic Volumes		Local traffic volumes on CO-64 near DINO have increased and are projected to continue increasing. If that happens, the natural sound environment will be further negatively impacted.
Percent Time Above Specified Levels		Sound pressure levels exceeded 52 dB less than 10% of the time at all sites during both daytime and nighttime.
Exceedance Levels		The sound level exceeded 50% of the time was between 35 and 45 dB for two sites but considerably less than 35 dB for the third site, warranting moderate concern overall for this indicator.
Attended Listening		Natural sounds like birdsong, wind, and flowing water were frequently audible at all sites. Aircraft could be heard 8% to 28% of the time, depending on site.
Anthropogenic Impacts to Ambient Sound Level		Anthropogenic noise is moderately increasing the existing ambient sound level above the natural ambient sound level of DINO (median impact < 3.0 dBA but maximum impact > 10.0 dB). Ground and air traffic are generally projected to increase over time, which may contribute to a deteriorating trend.
Natural Sounds overall		**Condition warrants moderate concern with an anticipated deteriorating trend. Confidence in the assessment is high.**

4.3.5. Uncertainty and Data Gaps

No evaluative research to determine the social impacts of existing soundscape conditions on visitor experiences has been collected on-site in DINO.

4.3.6. Sources of Expertise

- Emma Brown, Acoustical Resource Specialist, NPS Night Skies and Natural Sounds Division, provided data and helpful reviews.
- Lisa Baldwin, Chief of Research and Resource Management, Dinosaur National Monument.

4.3.7. Literature Cited

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. ParkScience 26(3):26–31. Available at: https://irma.nps.gov/DataStore/ (accessed 27 June 2018).

Benfield, J.A., P.A. Bell, L.J. Troup, and N.C. Soderstrom. 2010. Aesthetic and affective effects of vocal and traffic noise on natural landscape assessment. Journal of Environmental Psychology 30:103–111.

Berglund, B., L. Thomas, and H.S. Dietrich. 1999. Guidelines for community noise. World Health Organization, Geneva, Switzerland.

Buxton, R.T., M.F. McKenna, D. Mennitt, K. Fristrup, K. Crooks, L. Angeloni, and G. Wittemyer. 2017. Noise pollution is pervasive in U.S. protected areas. Science 356:531–533.

Colorado Department of Transportation (CDOT). 2018. Online Transportation Information System website. Available at: http://dtdapps.coloradodot.info/otis/TrafficData#ui/2/1/2/station/000208/criteria/000208/.

Environmental Protection Agency (EPA). 1974. Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety. Report No. 550/9-74-004. EPA Office of Noise Abatement and Control, Arlington, Virginia. Available at: https://nepis.epa.gov (accessed 23 October 2018).

FlightAware. 2018. Live Flight Tracking website. Available at: http://flightaware.com/live/ (accessed 27 June 2018).

Flightradar24. 2018. Live air traffic website. Available at: https://www.flightradar24.com/41.24,-95.97/7 (accessed 30 June 2018).

Habib, L., E.M. Bayne, and S. Boutin. 2007. Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*. Journal of Applied Ecology 44:176–184.

Haralabidis, A.S., K. Dimakopoulou, F. Vigna-Taglianti, M. Giampaolo, A. Borgini, M. Dudley, G. Pershagen, G. Bluhm, D. Houthuijs, W. Babisch, M. Velonakis, K. Katsouyanni, and L. Jarup. 2008. Acute effects of night-time noise exposure on blood pressure in populations living near airports. European Heart Journal 29:658–664.

Jones, N.F., L. Pejchar, and J.M. Kiesecker. 2015. The energy footprint: how oil, natural gas, and wind energy affect land for biodiversity and the flow of ecosystem services. BioScience 65:290–301.

Krog, N.H., B. Engdahl, and K. Tambs. 2010. Effects of changed aircraft noise exposure on the use of outdoor recreational areas. International Journal of Environmental Research and Public Health 7:3890–3915.

Lynch, E. 2009. San Antonio Missions National Historical Park acoustical monitoring report 2009. Natural Resource Report NPS/NRPC/NRTR 2009/001. National Park Service, Fort Collins, Colorado.

Mace, B.L., G.C. Corser, L. Zitting, and J. Denison. 2013. Effects of overflights on the national park experience. Journal of Environmental Psychology 35:30–39.

McDonald, C.D., R.M. Baumgartner, and R. Iachan. 1995. National Park Service aircraft management studies: visitors survey. NPOA Report No. 94-2. Available at: https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB95196002.xhtml (accessed 30 June 2018).

Mennitt, D., K. Fristrup, K. Sherrill, and L. Nelson. 2013. Mapping sound pressure levels on continental scales using a geospatial sound model. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, Innsbruck, Austria.

National Park Service (NPS). 2006. Management policies 2006: the guide to managing the National Park System. National Park Service, Washington, D.C.

NPS. 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

Peel, K.A. 2000, May 23. Director's Order #47: Soundscape Preservation and Noise Management. Available at: https://www.nps.gov/policy/DOrders/DOrder47.html (accessed 25 June 2018).

Rabin, L.A., R.G. Coss, and D.H. Owings. 2006. The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). Biological Conservation 131:410–420.

Rapoza, A., E. Sudderth, and K. Lewis. 2015. The relationship between aircraft noise exposure and day-use visitor survey responses in backcountry areas of national parks. The Journal of the Acoustical Society of America 138:2090–2105.

Shannon, G., M.F. McKenna, L.M. Angeloni, K.R. Crooks, K.M. Fristrup, E. Brown, K.A. Warner, M.D. Nelson, C. White, J. Briggs, S. McFarland, and G. Wittemyer. 2016. A synthesis of two decades of research documenting the effects of noise on wildlife. Biological Reviews 91:982–1005.

U.S. Department of Transportation. 2015. State transportation by the numbers: a compendium of state summaries. U.S. Department of Transportation Bureau of Transportation Studies.

Warner, K. 2013. Dinosaur National Monument: acoustical monitoring report. Natural Resources Technical Report NPS/NRSS/NRTR—2013/722. NPS Natural Sounds and Night Skies Division, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2194105 (accessed 23 October 2018).

4.4. Climate Change

4.4.1. Background and Importance

Climate change is increasingly recognized as a major stressor of biological taxa, communities and ecological systems. Understanding the magnitude and effects of changing climate is essential within the NPS to "manage for change while confronting uncertainty" while developing new management and adaptation strategies (National Park System Advisory Board Science Committee 2012) and is a significant scientific component of the NPS *Climate Change Response Strategy* (NPS 2010). Resources found to be especially vulnerable to climate change at Dinosaur National Monument (DINO) include the bluebunch wheatgrass (*Pseudoroegneria spicata*) herbaceous vegetation community (NCPIMP 2010). General effects of climate change at DINO could include a 25% increase in fire frequency by 2100, reduced snowpack leading to lower summer streamflow and water supply, and upslope shifts of vulnerable ecosystems, communities, and species (Gonzalez 2014).

The primary drivers of ecosystems in the Colorado Plateau are climate and topography (NCPIMP 2010, Davey et al. 2006). Arid ecosystems, like those found throughout the NCPN, are sensitive to climatic variability and both short- and long-term changes in temperature and water availability because organisms in these ecosystems are often already living near their physiological limits (Loehman 2010). The climate suitable for coniferous woodlands in the region (such as the monument's pinyon-juniper woodlands) is expected to be reduced by as much as 40% by 2090, with much of this area transitioning to hotter and drier montane scrub and desert scrub habitat (Rehfeldt et al. 2012). Drought-induced reductions in pinyon-juniper woodlands are likely to be long-lasting due to the slow growth of pinon pines and altered stand dynamics and other community-level interactions that could prevent a return to pre-drought conditions (Loehman 2010).

An NPS Climate Change Resource Brief (NPS 2014) based upon research from Monahan and Fisichelli (2014) maintains that the local climate near DINO is already getting hotter, especially in the summer. Climate change may also affect visitation patterns at DINO (NPS 2015). An overall increase in visitation (15–45% annually) as well as an increase in both peak season (10–31%, defined as the three busiest contiguous months) and shoulder season visitation (27–67%, defined as two months prior and two months following peak season) may require park management to alter planning schedules. An expansion in the visitation season of 12–40 days could also lead to staffing shortages and altered seasonal worker rotations (NPS 2015).

Overall climate change vulnerability for a particular resource considers a combination of exposure, sensitivity and adaptive capacity (Glick et al. 2011). The synopsis of potential changes to the monument's climate presented here characterizes the "exposure" component of resource vulnerability. We characterize climate here using modeled future climate scenarios, but potential resource vulnerability and management implications are based on the relative amounts and directions of changes rather than specific magnitudes or thresholds of change. Although the monument can do its part to mitigate greenhouse gas emissions and optimize the efficiency of operations vis-a-vis greenhouse gases, climate change and its associated effects on park resources are largely out of the control of park managers. The impacts of climate change are already evident and will require an

evaluation of the vulnerability of park resources. Moreover, specific and diverse adaptation measures for some park resources may be necessary to mitigate effects of climate change and transition to future climatic conditions.

Threats and Stressors
Increases in atmospheric greenhouse gases are resulting in changes in global, regional and local climates. Changes in the amounts and patterns of temperature and precipitation have numerous direct and indirect effects on environmental conditions and biota. An increase in the frequency of extreme weather is likely under climate change.

Indicators and Measures

- Temperature changes from baseline – mean annual, mean annual maximum, mean annual minimum
- Precipitation changes from baseline – total annual, very heavy events, total annual snowfall
- Palmer Drought Severity Index (PDSI) – historical period of record
- Observed and projected changes in frost-free period

4.4.2. Data and Methods

We apply a variety of data and analysis approaches to characterize the climate during the historical period of record and examine possible changes in climate for the monument. A combination of site-specific and regional results is presented. Historical climate and modeled future climate change were examined within DINO, or for the monument plus the area extending approximately 30 km from its boundary. The monument is relatively large and has considerable elevation change within its boundaries. Therefore, climatic variation within the monument is substantial and care should be taken not to extrapolate these general summaries to myriad habitats, elevations and geographic locations at DINO. Consolidation of future modeled climates and comparisons with historical baseline and graphic representation of results were completed by Monahan and Fisichelli (2014) and Gonzalez (2014). Witwicki (2013) provided historical data for two climate stations within the monument.

The Palmer Drought Severity Index (PDSI) uses temperature and precipitation data to calculate water supply and demand, incorporates soil moisture, and is considered most effective for unirrigated cropland (Palmer 1965, USDA 2014). Long-term drought is cumulative, so the intensity of drought during a point in time is dependent on the current weather patterns plus the cumulative patterns of the previous period. The PDSI is used widely by the U.S. Department of Agriculture and other agencies. PDSI values range between −4.00 or less (extreme drought) and +4.00 or greater (extreme moisture). The index uses a value of 0 as "normal". Values below −1.5 are considered drought conditions. The Palmer Index is most effective in determining long-term drought (i.e., lasting at least several months). Monthly PDSI values were obtained from the National Climatic Data Center (NCDC 2019). Assumptions of the PDSI regarding the relationship between temperature and evaporation may give biased (i.e., overestimated evaporation) results in the context of climate change (Sheffield et al.

2012). However, examination of historical PDSI does appear to corroborate known drought periods and the PDSI approach is not used to model future drought.

The length of the frost-free period, which corresponds with the area's growing season, is an important determinant of which plants will grow and flourish in a particular region (Walsh et al. 2014a). These observed climate changes are correlated with increases in satellite-derived estimates of the length of the growing season (Jeong et al. 2011). The frost-free season length, defined as the period between the last occurrence of 32°F in the spring and the first occurrence of 32°F in the fall, has been gradually increasing since the 1980s (EPA 2012). The length of the frost-free period can alter plant phenology. Increases in temperature are responsible for plants flowering earlier in the spring and the delayed onset of dormancy in autumn. This affects not only synchrony among plants, pollinators and complex evolutionary adaptation, but can shorten (or lengthen) a plant's growing season. Phenology also plays an important role in the amount of water released to the atmosphere via evapotranspiration, sequestration of carbon in new growth, and the amount of nitrogen utilized from the soil (Ibanez et al. 2010).

4.4.3. Reference Conditions

For most indices, the reference condition for this assessment is the period from the early 20th century, when meteorological data were first systematically collected, to approximately the first decade of the 21st century (2000 for Gonzalez (2014), 2011 for Witwicki (2013) and 2012 for Monahan and Fisichelli (2014)). Modeled future changes were not available for Witwicki (2013). Although there may have been some changes occurring during this period, the long reference period avoids bias associated with wet, dry, warm and cold periods or extreme events such as prolonged or severe drought. For frost-free season length, the baseline period was 1901–1960. For aridity, the period analyzed was 1895–2017, with no future modeled changes available.

4.4.4. Historical Conditions, Range of Variability and Modeled Changes

<u>Temperature</u>

Historical Trends

Monahan and Fisichelli (2014) updated the climate inventories for 289 units of the NPS, including DINO. The area of analysis included DINO and a 30-km buffer surrounding the monument. Twenty-five biologically relevant climate variables were assessed to evaluate climate change exposure of the monument. Values exceeding 95% of the historical range of conditions were defined as "extreme," noting significant exposure. Annual mean temperature (°C) from 1901 to 2012 is shown in Figure 4.4-1. The results for seven of the most relevant temperature variables at DINO are shown in Figure 4.4-2. Mean temperature of the warmest quarter was the only temperature variable considered extreme, although several others are close to the extreme threshold.

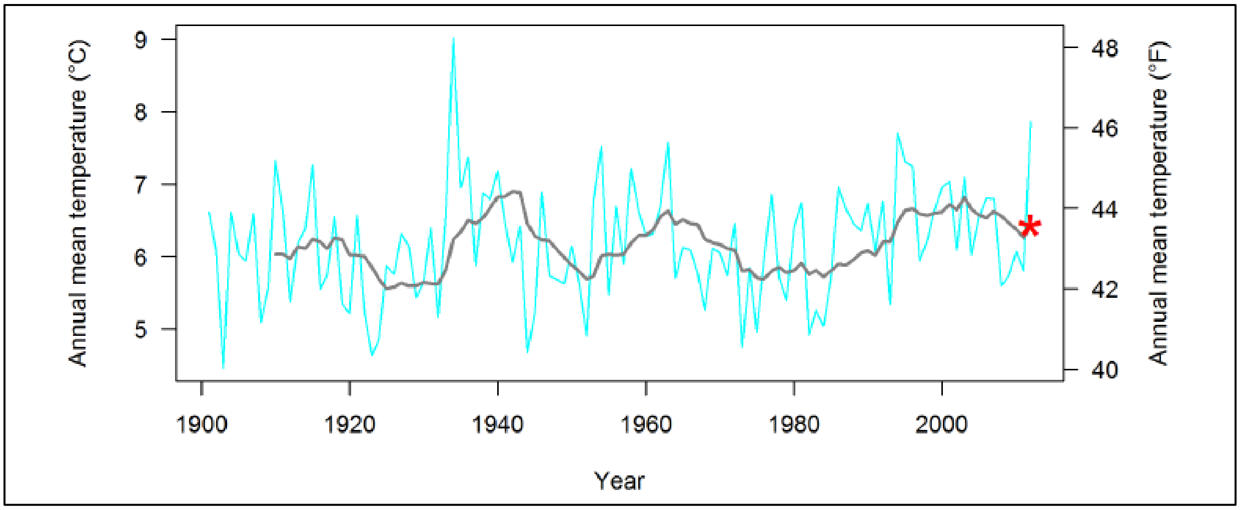


Figure 4.4-1. Annual mean temperature at Dinosaur National Monument (including areas within 30 km of the monument boundary). The blue line shows temperature for each year, the gray line shows temperature averaged over progressive 10-year moving windows, and the red asterisk is the average temperature of the most recent 10-year moving window as of 2012 (NPS 2014).

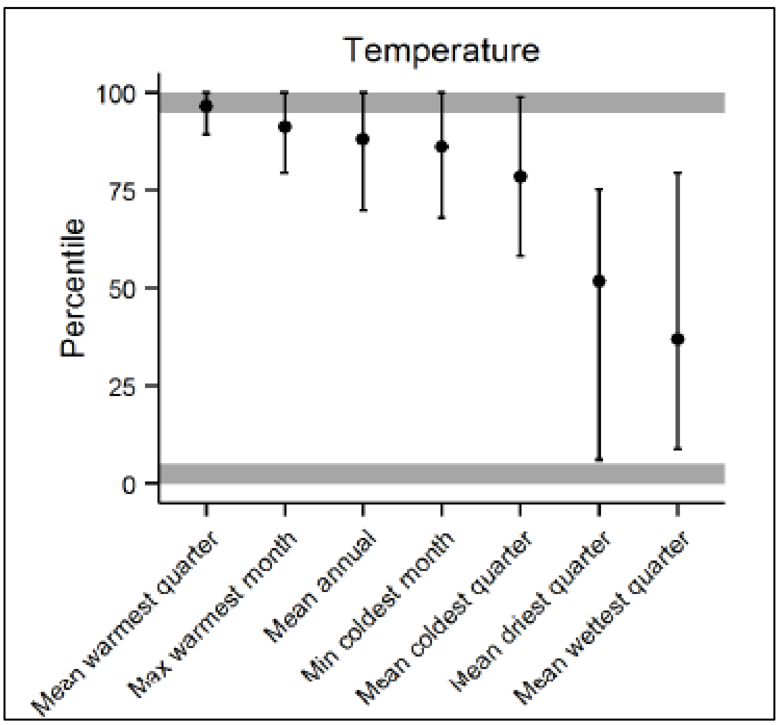


Figure 4.4-2. Results for seven temperature variables (1901–2012) analyzed by Monahan and Fisichelli (2014) at DINO. Results are considered "extreme" if the mean percentiles are <5th percentile or >95th percentile of the historical range of conditions (if the mean is within the upper or lower gray area). Black bars indicate the range of recent percentiles across multiple-year moving windows (larger bars indicate higher sensitivity to moving window size). (NPS 2014).

The climate change summary for DINO by Gonzalez (2014) using data from Daly et al. (2008) shows a statistically significant increase in mean annual temperature from 1950 to 2010 ($p<0.01$, Figure 4.4-3). An NCPN climate monitoring summary (Witwicki 2013) shows statistically significant positive trends in both maximum and minimum temperatures over time from two climate stations within the monument (Table 4.4-1).

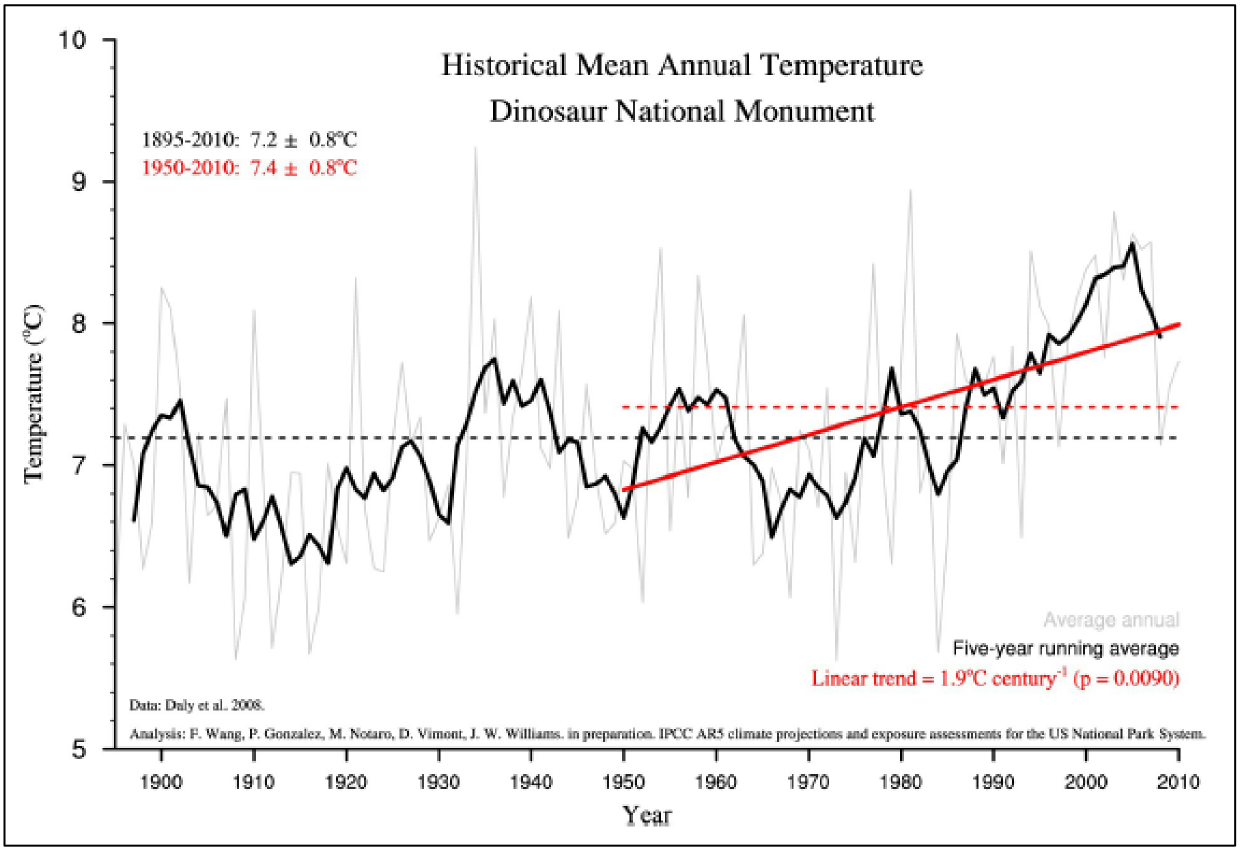


Figure 4.4-3. Historical mean annual temperature for DINO from 1901–2010 (Gonzalez 2014). The red line shows the trend from 1950 to 2010.

Table 4.4-1. Results of trend analyses for temperature variables based on a least-squares regression of the moving mean over time (Witwicki 2013). df = degrees of freedom; $AdjR^2$ = coefficient of determination.

		Maximum Temperature (°F)				Minimum Temperature (°F)			
Station	**Period of record**	**df**	**p-value**	**$AdjR^2$**	**Slope**	**df**	**p-value**	**$AdjR^2$**	**Slope**
DINO/NM	06/1965–12/2011	40	<0.001	0.30	0.053	40	<0.001	0.72	0.110
DINO/Quarry	12/1915–12/2011	42	<0.001	0.25	0.055	44	<0.001	0.23	0.051

Modeled Future Changes

Climate models summarized by Gonzalez (2014) indicate that temperatures at the monument will rise substantially under climate change (Table 4.4-2, Figure 4.4-4). Mean annual temperatures are

expected to increase by approximately 2.4–3.1°C (4.3–5.6 °F) by 2050, and by approximately 3.2–5.6°C (5.8–10.1°F) by 2100, depending on the emissions scenario.

Table 4.4-2. Projected changes in average temperature for three emissions scenarios and two time periods (Gonzalez 2014). IPCC RCP = Intergovernmental Panel on Climate Change Representative Concentration Pathway.

	Projected Change in Temperature (compared to 1971–2000 baseline)	
Emission Scenario	**2000–2050**	**2000–2100**
Low Emissions (IPCC RCP 4.5)	+2.4ºC (+4.3ºF)	+3.2ºC (+5.8ºF)
High Emissions (IPCC RCP 6.0)	+2.1ºC (+3.8ºF)	+3.7ºC (+6.7ºF)
Highest Emissions (IPCC RCP 8.5)	+3.1ºC (+5.6ºF)	+5.6ºC (+10.1ºF)

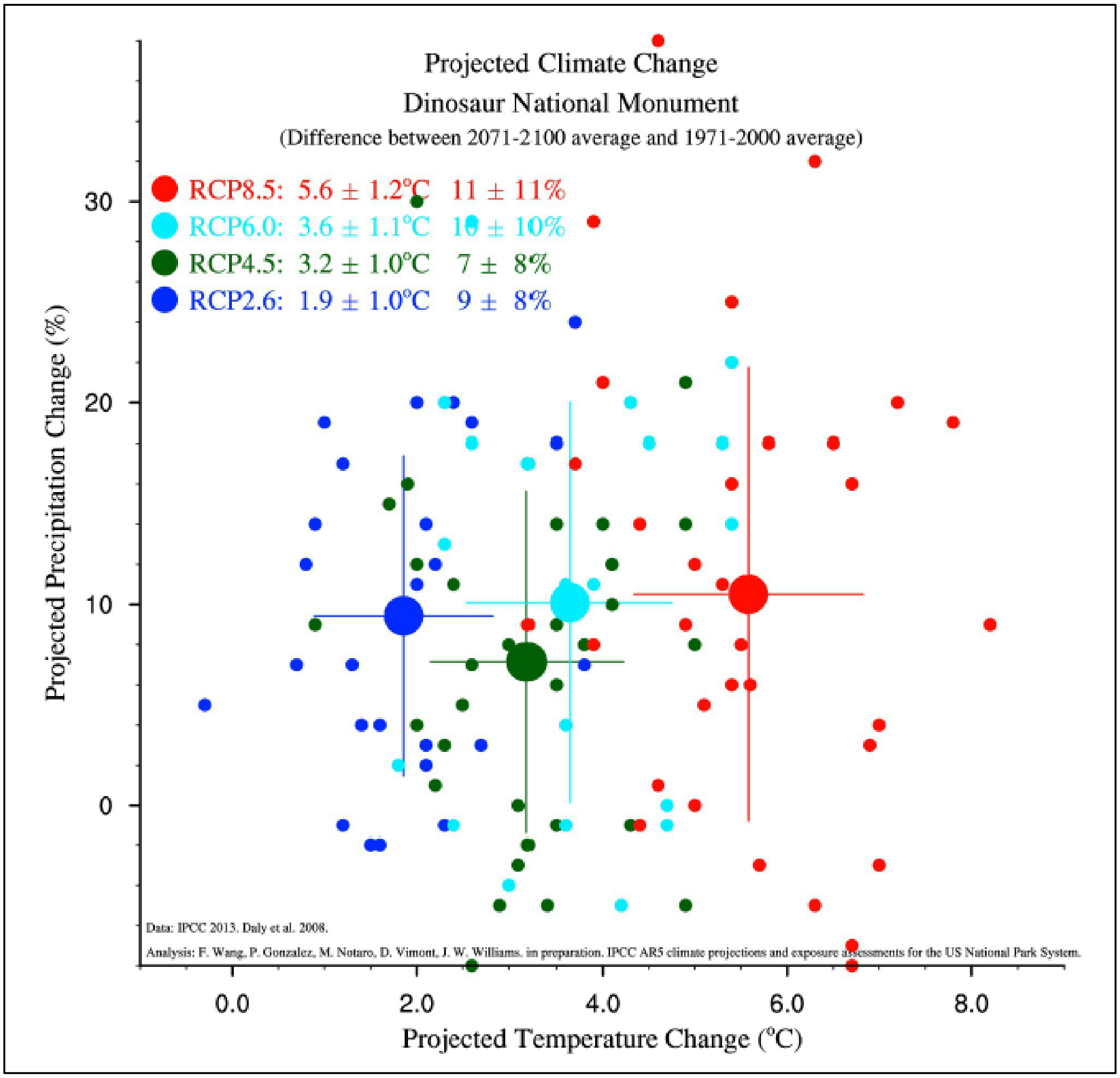


Figure 4.4-4. Projections of future climate for DINO. Small dots are the output of a single climate model. The large dots are the average values for four IPCC emissions scenarios. The lines from the average values are standard deviations (Gonzalez 2014).

<u>Precipitation</u>

Historical Trends

Monahan and Fisichelli (2014) analyzed historical data for seven of the most relevant precipitation variables at DINO (Figure 4.4-5). None of the precipitation variables were considered extreme, although coldest quarter, driest month, and driest quarter precipitation levels were just under the upper limit for extreme conditions and may be considered extreme in the future.

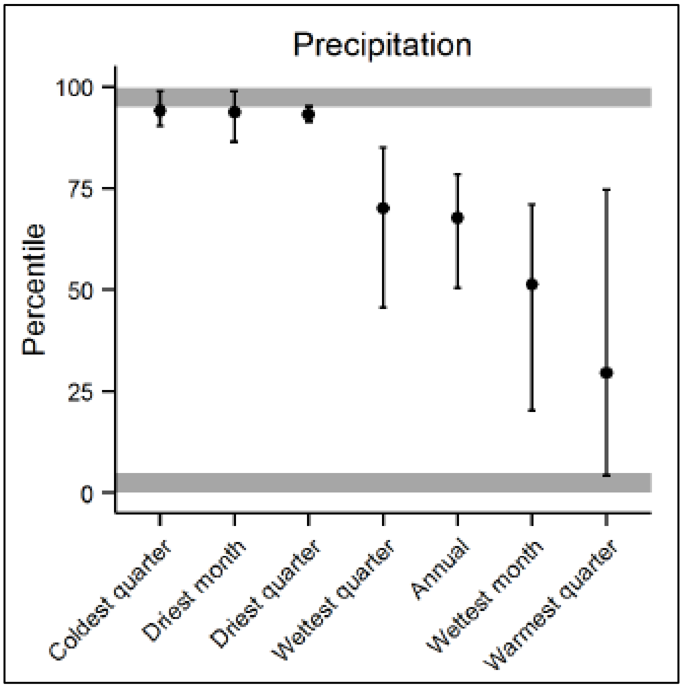


Figure 4.4-5. Results for seven precipitation variables (1901–2012) analyzed by Monahan and Fisichelli (2014) at DINO. Results are considered "extreme" if the mean percentiles are <5th percentile or >95th percentile of the historical range of conditions (if the mean is within the upper or lower gray area).

The climate change summary for DINO by Gonzalez (2014) using data from Daly et al. (2008) shows an increase in annual total precipitation from 1950 to 2010, but the trend is not statistically significant (p=0.09, Figure 4.4-6). An NCPN climate monitoring summary for 2011 (Witwicki 2013) shows no significant trend in precipitation over time from two climate stations within the monument (p=0.50 for "DINO/NM" station, and p=0.23 for "DINO/Quarry" station).

In recent decades, there have been increases nationally in the annual amount of precipitation falling in very heavy events, defined as the heaviest 1% of all daily events from 1901 to 2012. The largest regional increases have been in the Midwest and Northeast when compared to the 1901–1960 average (Walsh et al. 2014a). Regional results for the Southwest region including DINO indicate an increase of approximately 5% in the annual amount of precipitation falling in very heavy events over the past few decades (Figure 4.4-7). This is the lowest increase in the continental United States over this period.

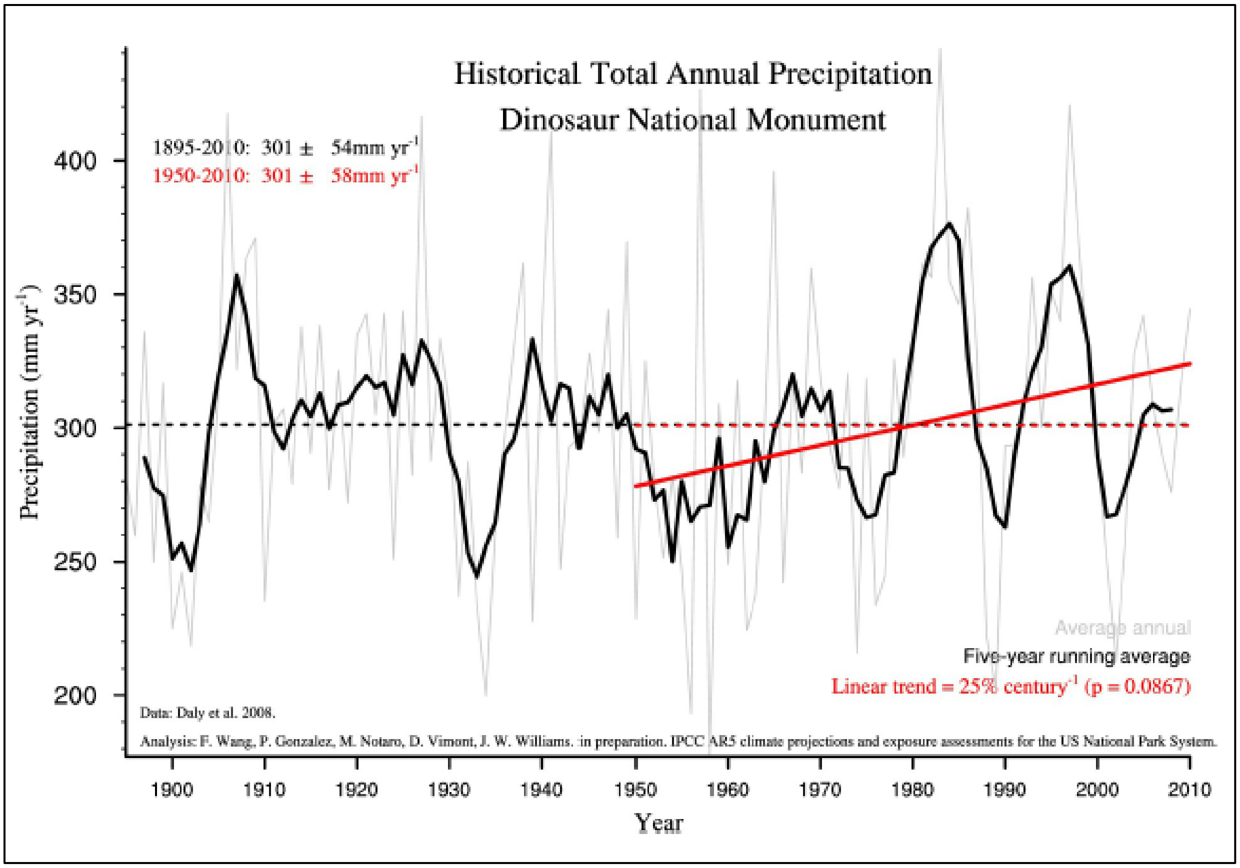


Figure 4.4-6. Historical mean annual total precipitation for DINO from 1901–2010 (Gonzalez 2014). The red line shows the trend from 1950 to 2010.

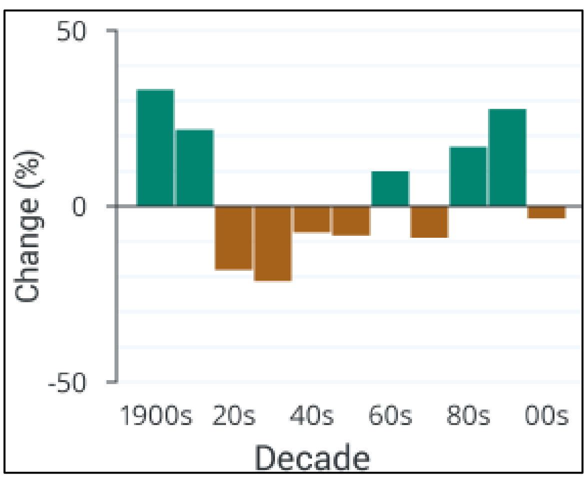


Figure 4.4-7. Percent change in the annual amount of precipitation falling in very heavy events by decade compared to the 1901–1960 average for the Southwest region. A very heavy event is defined as the heaviest 1% of all daily events from 1901 to 2012. The far right bar is for 2001–2012 (Walsh et al. 2014a).

An NCPN climate monitoring summary (Witwicki 2013) shows a significant reduction in total annual snowfall from two climate stations within the monument (Table 4.4-3).

Table 4.4-3. Results of trend analyses of annual snowfall totals based on a least-squares regression of the moving mean over time (Witwicki 2013). df = degrees of freedom; AdjR2 = coefficient of determination.

		Total Snowfall (in)			
Station	**Period of record**	**df**	**p-value**	**AdjR^2**	**Slope**
DINO/NM	06/1965–12/2011	40	<0.001	0.70	−1.05
DINO/Quarry	12/1915–12/2011	41	<0.001	0.35	−0.03

Modeled Future Changes

Models used in Gonzalez (2014) indicate that precipitation at the monument will rise under climate change (Table 4.4-4, Figure 4.4-4). Total annual precipitation is expected to increase by approximately 5–7% by 2050 and by approximately 7–10% by 2100, depending on the emissions scenario. Walsh et al. (2014b) also suggest similar trends in the region, with most of the increase in precipitation coming in the winter and spring seasons.

Table 4.4-4. Projected changes in total annual precipitation for three emissions scenarios and two periods (Gonzalez 2014).

	Projected Change in Precipitation (compared to 1971–2000 baseline)	
Emission Scenario	**2000–2050**	**2000–2100**
Low Emissions (IPCC RCP 4.5)	+5%	+7%
High Emissions (IPCC RCP 6.0)	+6%	+10%
Highest Emissions (IPCC RCP 8.5)	+7%	+10%

Aridity

Aridity and moisture availability are examined using the Palmer Drought Severity Index (Palmer 1965) for the 1895–2017 period. No modeled future events are considered for aridity due to a lack of well-supported tools to examine this indicator's potential for change.

Historical Trends

Palmer Drought Severity Index (PDSI) values were calculated for the period from 1895 to 2017 (Figure 4.4-8, Figure 4.4-9). For the period of record, DINO PDSI data show periodic moderate to severe drought lasting 2–5 years occurring approximately every 10–13 years since about 1962. PDSI values of −3.00 or less seem to be more frequent during 1962–2017 than they were from 1895–1961. Large negative values for the Uintah Basin climate division of Utah (Figure 4.4-9) seem to be more frequent although less severe than those of the Colorado Drainage climate division of Colorado (Figure 4.4-8). The Colorado Drainage climate division includes the entire western third of Colorado, so conditions in the immediate vicinity of DINO may differ slightly (ESRL 2019).

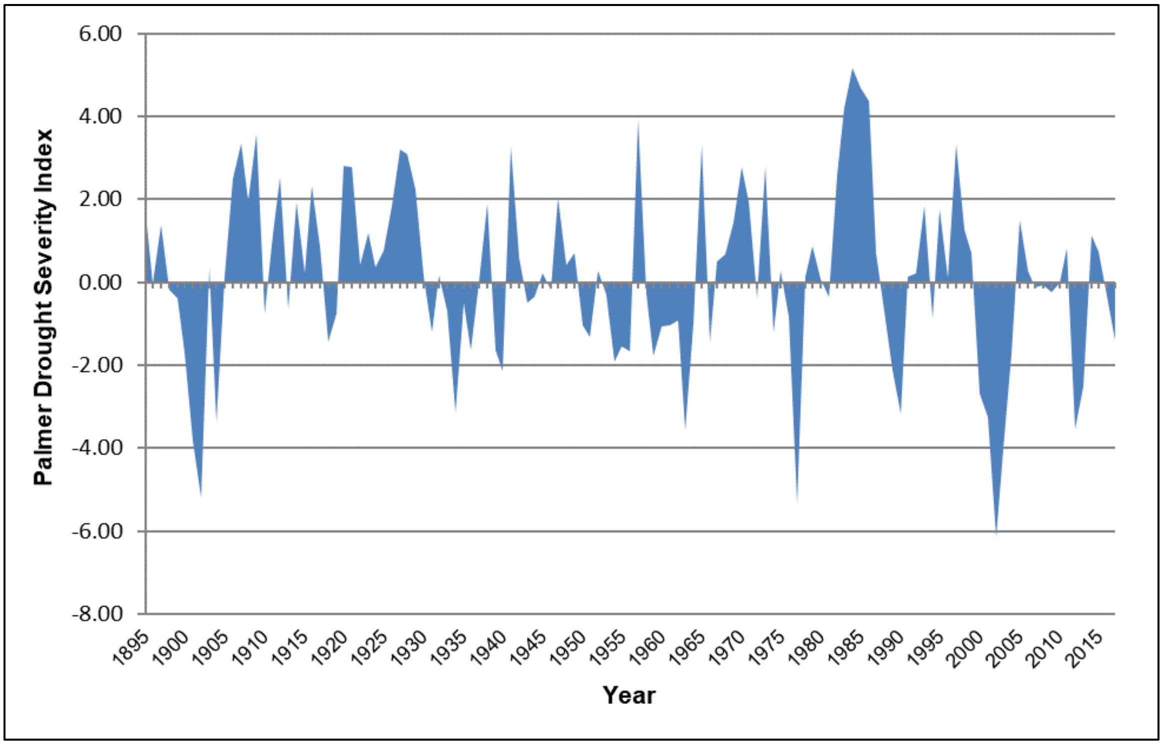


Figure 4.4-8. Palmer Drought Severity Index from 1895 –2017 for Dinosaur National Monument (Colorado Drainage climate division, Colorado; division code: 0502). Negative values represent dry conditions and positive values represent moist conditions (NCDC 2019).

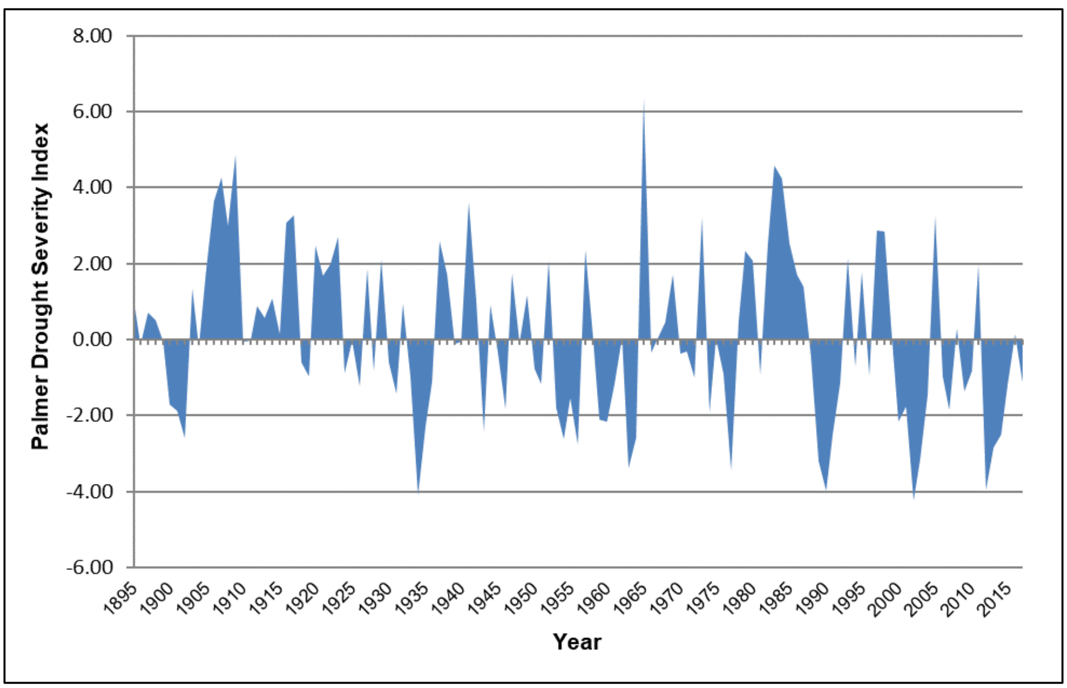


Figure 4.4-9. Palmer Drought Severity Index from 1895 –2017 for Dinosaur National Monument (Uinta Basin climate division, Utah; division code: 4206). Negative values represent dry conditions and positive values represent moist conditions (NCDC 2019).

Frost-Free Period

Historical Trends

The last frost in the spring has been occurring earlier in the year, and the first frost in the fall has been happening later. In the Southwest region, the average frost-free season for 1991–2011 was about 19 days longer than during 1901–1960 (Walsh et al. 2014a). A longer growing season can increase carbon sequestration in plants (Peñuelas et al. 2009) and increase the growth of both desirable and undesirable plants.

Modeled Future Changes

By the 2070–2099 period, the frost-free season for the area surrounding DINO is projected to lengthen significantly as heat-trapping gas emissions continue to grow, increasing by 20–30 days under the low emissions scenario and 40–50 days under the higher emissions scenario compared to the 1971–2000 baseline period (Walsh et al. 2014a).

Overall Assessment

Indications are that the climate in this region is already becoming hotter, possibly wetter, and is potentially more prone to more frequent and extreme weather events. Trends in the indicators are projected to continue or accelerate by the end of the century. Reductions in total snowfall and projected increases in winter and spring precipitation totals indicate that DINO will experience a transition from a snowmelt-driven to a rainfall-driven system.

Because these changes in the environment are beyond the control of park managers and climate is not a conventional resource to be managed, climate change is not evaluated using the condition status and trend framework applied in this condition assessment. Research and monitoring related to climate change, the anticipated vulnerability of specific resources vis-a-vis climate change, and its associated effects on resources and interaction with other ecological processes can be informed by this broad overview of the magnitude of climate change in the region.

4.4.5. Management and Ecological Implications

Changing climate is anticipated to impact the Colorado Plateau in a number of ways and is likely to compound the effects of existing stressors and increase the vulnerability of forests and shrublands to pests, invasive species, altered fire regimes, and loss of native species (NFWPCAP 2012). Species ranges and ecological dynamics are already responding to recent climate shifts, and current natural areas including NPS units will likely be unable to support all species, communities and ecosystems currently present (Heller and Zavaleta 2009), some of which form the core of their NPS mission. Some of the key anticipated ecological impacts and potential management implications of climate change in the northern Colorado Plateau region and at DINO include:

- Extreme streamflow events are expected to increase, with a shift toward higher flows in the winter and spring, and lower flows in summer and fall. Impacts will be exacerbated by a transition from a snowmelt-driven to a rain-driven hydrological system, which can change runoff patterns and river flow rates, disrupting the timing of ecological events, complicating water allocation schedules, and increasing competition from non-native species (Loehman 2010).

- Disruption of runoff timing may cause shifts in grassland communities by favoring either warm-season (C_4) or cool-season (C_3) grasses, depending on local microenvironments (Witwicki et al. 2016).

- Increasing temperatures will cause an increase in evaporation, potentially increasing the vulnerability of organisms in the region to drought and alteration of other ecosystem dynamics (Loehman 2010).

- Warmer temperatures may increase the negative effects of ozone pollution on forest growth and health and increase vulnerability to disease (USDA 2001).

- An interruption in the timing of lifecycles between predators and prey may significantly impact wildlife (Parmesan 2006).

- An increase in the transmission of zoonotic diseases to humans including hantavirus pulmonary syndrome, plague, and West Nile virus is possible (Epstein 2001, Confalonieri et al. 2007).

- Increases in invasive exotic plants is possible (NFWPCAP 2012).

- Higher temperatures could affect phenological events such as flowering, fruit set, and seed production (Loehman 2010).

- Staffing needs may change as the monument is expected to have an increase in annual visitation, with the largest increase coming in shoulder season visitation (April–May and September–October; NPS 2015).

- More frequent extreme events such as heat waves and heavy rains are possible (Karl et al. 2009, Walsh et al. 2014a).

- Climate change is likely to exacerbate existing stressors related to anthropogenic disturbances at landscape scales, including energy development and agriculture that fragment the landscape and hinder species adaptation (Bagne et al. 2013, Shafer et al. 2014).

It is increasingly clear that, given significant shifts in climatic variables, adaptation efforts will need to emphasize managing for inevitable ecological changes and concurrently adjusting some management objectives or targets (Stein et al. 2013). In a review of articles examining biodiversity conservation recommendations in response to climate change, Heller and Zavaleta (2009) synthesized conservation recommendations with regard to regional planning, site-scale management, and modification of existing conservation plans. They found that most recommendations offer general principles for climate change adaptation but lack the specificity needed for implementation. Specific adaptation tools and approaches will undoubtedly help park managers with these challenges. Adaptation approaches need to be intentional, context-specific and based on a deliberative process, rather than selected from a generic menu of options (Stein et al. 2014).

While climate change cannot be controlled by the monument, managers can take steps to minimize the severity of exposure to these changes and help conserve sensitive resources as the transition continues. Existing condition analyses and data sets developed by this NRCA will be useful for subsequent park-level climate change studies and planning efforts.

4.4.6. Uncertainty and Data Gaps

Climate change projections have inherently high uncertainty. Confidence is higher in modeled temperature dynamics and lower for modeled precipitation totals and seasonal patterns. The largest uncertainty in projecting climate change beyond the next few decades is the level of heat-trapping gas emissions (Walsh et al. 2014b). Information gaps needing to be addressed to help manage resources and understand the repercussions of climate change to the monument include: 1) more specific, applied examples of adaptation principles that are consistent with uncertainty about the future; 2) a practical adaptation planning process to guide selection and integration of recommendations into existing policies and programs; and 3) greater integration of social science and extension of adaptation approaches beyond park boundaries (Heller and Zavaleta 2009).

4.4.7. Sources of Expertise

- John Gross, Climate Change Ecologist, NPS Inventory and Monitoring Program National Office, provided expertise regarding modeled climate and metrics and discussing appropriate metrics to include in NRCAs.

4.4.8. Literature Cited

Bagne, K., P. Ford, and M. Reeves. 2013. Grasslands. USDA Forest Service, Climate Change Resource Center. Available at: https://www.fs.usda.gov/ccrc/topics/biomes/grasslands (accessed 21 October 2013).

Confalonieri, U., B. Menne, R. Akhtar, K.L. Ebi, M. Hauengue, R.S. Kovats, B. Revich, and A. Woodward. 2007. Human health. Pages 391–431 *in* M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson, editors. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Daly, C., M. Halbleib, J.I. Smith, W. P. Gibson, M.K. Doggett, G.H. Taylor, J. Curtis, and P.P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. International Journal of Climatology 28:2031–2064.

Davey, C.A., K.T. Redmond, and D.B. Simeral. 2006. Weather and climate inventory, National Park Service, Northern Colorado Plateau Network. Natural Resource Technical Report NPS/NCPN/NRTR—2006/002. National Park Service, Fort Collins, Colorado.

Earth System Research Laboratory (ESRL). 2019. Location of US Climate Divisions. Available at: https://www.esrl.noaa.gov/psd/data/usclimdivs/data/map.html (accessed 28 January 2019).

Epstein, P.R. 2001. Climate change and emerging infectious diseases. Microbes and Infection 3:747–754.

Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

Gonzalez, P. 2014. Climate change summary, Dinosaur National Monument in Colorado and Utah. National Park Service Climate Change Response Program Unpublished Report, Washington D.C.

Heller, N.E., and E.S. Zavaleta. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation 142:14–32.

Ibanez, I., R.B. Primack, A.J. Miller-Rushing, E. Ellwood, H. Higuchi, S.D. Lee, H. Kobori, and J.A. Silander. 2010. Forecasting phenology under global warming. Philosophical Transactions of the Royal Society B: Biological Sciences 365:3247–3260.

Jeong, S.J., C.H. Ho, H.J. Gim, and M.E. Brown. 2011. Phenology shifts at start vs. end of growing season in temperate vegetation over the Northern Hemisphere for the period 1982–2008. Global Change Biology 17:2385–2399.

Karl, T.R., J.M. Melillo, and T.C. Peterson, editors. 2009. Global climate change impacts in the United States. Cambridge University Press, Cambridge, UK.

Loehman, R. 2010. Understanding the science of climate change: talking points – impacts to Arid Lands. Natural Resource Report NPS/NRPC/NRR—2010/209. National Park Service, Fort Collins, Colorado.

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

National Climatic Data Center (NCDC). 2019. Archive of monthly PDSI estimates. Available at: https://www.ncdc.noaa.gov/temp-and-precip/drought/ (accessed 28 January 2019).

National Fish, Wildlife and Plants Climate Adaptation Partnership (NFWPCAP). 2012. National fish, wildlife and plants climate adaptation strategy. Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service, Washington, D.C.

National Park Service (NPS). 2010. National Park Service climate change response strategy. NPS Climate Change Response Program, Fort Collins, Colorado.

NPS. 2014. Climate change resource brief: Recent climate change exposure of Dinosaur National Monument. National Park Service, Fort Collins, Colorado.

NPS. 2015. Park visitation and climate change: park-specific brief. Dinosaur National Monument: how might future warming alter visitation? National Park Service, Fort Collins, Colorado.

National Park System Advisory Board Science Committee. 2012. Revisiting Leopold: resource stewardship in the National Parks. National Park Service, Washington, D.C.

Northern Colorado Plateau Inventory and Monitoring Program (NCPIMP). 2010. Northern Colorado Plateau Network information brief: Climate change in the Northern Colorado Plateau Network: current findings and how future monitoring will detect it. National Park Service, Moab, Utah.

Palmer, W.C. 1965. Meteorological drought. Research Paper No. 45. U.S. Weather Bureau, Washington, D.C.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 37:637–669.

Peñuelas, J., T. Rutishauser, and I. Filella. 2009. Phenology feedbacks on climate change. Science 324:887–888.

Rehfeldt, G.E., N.L. Crookston, C. Sáenz-Romero, and E.M. Campbell. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. Ecological Applications 22:119–141.

Shafer, M., D. Ojima, J.M. Antle, D. Kluck, R.A. McPherson, S. Petersen, B. Scanlon, and K. Sherman. 2014. Chapter 19: Great Plains. Pages 441–461 in J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, editors. Climate change impacts in the United States: the third national climate assessment. U.S. Global Change Research Program, Washington, D.C. doi:10.7930/J0D798BC.

Sheffield, J., E.F. Wood, and M.L. Roderick. 2012. Little change in global drought over the past 60 years. Nature 491:435–438.

Stein, B.A., A. Staudt, M.S. Cross, N.S. Dobson, C. Enquist, R. Griffis, L.J. Hansen, J.J. Hellman, J.J. Lawler, E.J. Nelson, and A. Pairis. 2013. Preparing for and managing change: climate adaptation for biodiversity and ecosystems. Frontiers in Ecology and the Environment 11(9):502–510.

Stein, B.A., P. Glick, N. Edelson, and A. Staudt, editors. 2014. Climate-smart conservation: putting adaptation principles into practice. National Wildlife Federation, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 2012. Climate change indicators in the United States, 2012, second edition. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Department of Agriculture (USDA). 2001. Forests: the potential consequences of climate variability and change. A report of the National Forest assessment for the US Global Change Research Program. Cambridge University Press, Cambridge, UK.

USDA. 2014. U.S. Drought Portal, National Integrated Drought Information System. Available at: http://www.drought.gov/drought/content/products-current-drought-and-monitoring-drought-indicators/palmer-drought-severity-index (accessed 15 March 2014).

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014a. Chapter 2: Our changing climate. Pages 19–67 *in* J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, editors. Climate change impacts in the United States: The third national climate assessment. U.S. Global Change Research Program, Washington, D.C.

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014b. Appendix 3: Climate science supplement. Pages 735–789 *in* J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, editors. Climate change impacts in the United States: The third national climate assessment. U.S. Global Change Research Program, Washington, D.C.

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

Witwicki, D.L., S.M. Munson, and D.P. Thoma. 2016. Effects of climate and water balance across grasslands of varying C_3 and C_4 grass cover. Ecosphere 7(11):e01577. 10.1002/ecs2.1577.

4.5. Visual Resources

4.5.1. Background and Importance

Visual resources have important value in terms of historic and cultural context, aesthetics, and tourism and health. Scenery encompasses the visible physical features on a landscape including the land, water, vegetation, structures, animals and other features, and is linked to air quality-related values and natural night skies. The National Park Service Organic Act of 1916 specifies that the NPS shall "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." Protection and conservation of scenic resources is also required under other legislation and policies such as the National Environmental Policy Act, Federal Land Policy and Management Act, National Historic Preservation Act, the Clean Air Act and NPS guidance. Current NPS management policies (NPS 2006) do not provide guidance regarding service-wide policies or practices for scenery conservation.

Dinosaur National Monument (DINO) has unique and valuable scenic vistas, including large canyons, mountains, rolling hills, plains and rivers. The monument contains the confluence of the Green and Yampa rivers, including 46 miles of the lower Yampa River, which is the last large free-flowing river in the Colorado River system (NPS 2015). More than 90% of the monument retains wilderness character, which allows visitors to experience a virtually untouched landscape throughout the park (NPS 2015). In surveys conducted throughout the national park system, 94% of NPS visitors responded that scenic views are extremely important or very important (Kulesza et al. 2013). Views at DINO present visitors with the rare opportunity to connect with a prehistoric landscape and the ability to understand how cultures and time have the ability to shape an area.

According to the DINO *Foundation Document* (NPS 2015), along the Point of Pines Road the NPS holds title to 64 acres of right-of-way easements (2 tracts) and 251 acres of scenic easements (3 tracts) external to the monument. Planning and management provisions provided by Public Law 86-729, which revised the monument's boundaries in 1960, added 47 tracts totaling approximately 2,654 acres in scenic easements that are managed as part of the monument (NPS 2015). Of the 47 tracts, 45 are Bureau of Land Management (BLM) scenic easements, one is a private scenic easement, and one is a State of Utah scenic easement (NPS 2015).

Some of the most popular views at DINO include scenic overlooks on Harpers Corner Road and Yampa Bench Road, and the magnificent overlooks associated with the Green and Yampa river canyons at the terminus of the Harpers Corner Trail. Many views at DINO extend beyond the monument's boundaries, but still contribute to the scenic quality of the viewshed. Therefore, it is important for managers to be aware of incompatible development or land uses outside of the boundaries and the potential for impacting visual resources.

<u>Threats and Stressors</u>

- Poor air quality from a variety of sources, including emissions associated with oil and gas production within the Uinta Basin that would affect clarity, vividness and distance of views.

For additional discussion of nearby and regional lands uses, see *Land Cover and Land Use* (Section 4.1) and *Air Quality* (Section 4.6).

- Development and land uses inside and outside the monument (e.g., agriculture, oil and gas infrastructure, and park facilities and roads) that impact scenic views. Regional land-use patterns are described and mapped in Section 4.1, *Land Cover and Land Use*.

Indicators and Measures

- Scenic inventory value for assessed viewpoints, incorporating scenic quality and importance ratings

4.5.2. Data and Methods

No previous inventory of visual resources has been completed at DINO. Scenery evaluation and incorporation of results in the NRCA follows unpublished guidance provided by the NPS Air Resources Division (Meyer et al. 2018, NPS ARD 2018). Important views were identified based on the DINO website, DINO park map and other maps, and from park staff input. In collaboration with park staff, twenty representative views for a cross section of park visitor experiences were selected for the inventory (Figure 4.5-1). These twenty views included nearly all of the views considered highly important by the park. The primary access corridors for the views are the western entrance road between the Quarry Visitor Center/Quarry Exhibit Hall and Josie Morris Cabin, Island Park Road, Harpers Corner Road, and Yampa Bench Road. Several points identified as high priority but not inventoried are Jones Hole, accessible by trail in Whirlpool Canyon, and the Gates of Lodore river access area and campground. Detailed analysis of viewpoints can be generated by the "Enjoy the View Database": https://irma.nps.gov/ETV/Report/SSRS/ETV_ParkViewBrief.

The views represent a range of landscape types, levels of visitation, and types of visitation/access (e.g., campground, hiking trails, river access points, and road pullouts/overlooks). Most views assessed were accessible by car with or without a short walk, or were associated with a hiking trail. Several were associated with the Quarry Exhibit Hall/Quarry Visitor Center or historic cultural resources. Field data were collected for both the viewpoint (where the observer is located) and the viewed landscape seen by the observer. Key characteristics for each point and view included the GPS location, right and left limits of the view, the type of view, weather, observer position, photography and associated records, and the landscape description, which included landscape character type, extent of distance zones and landscape elements, and landscape design elements.

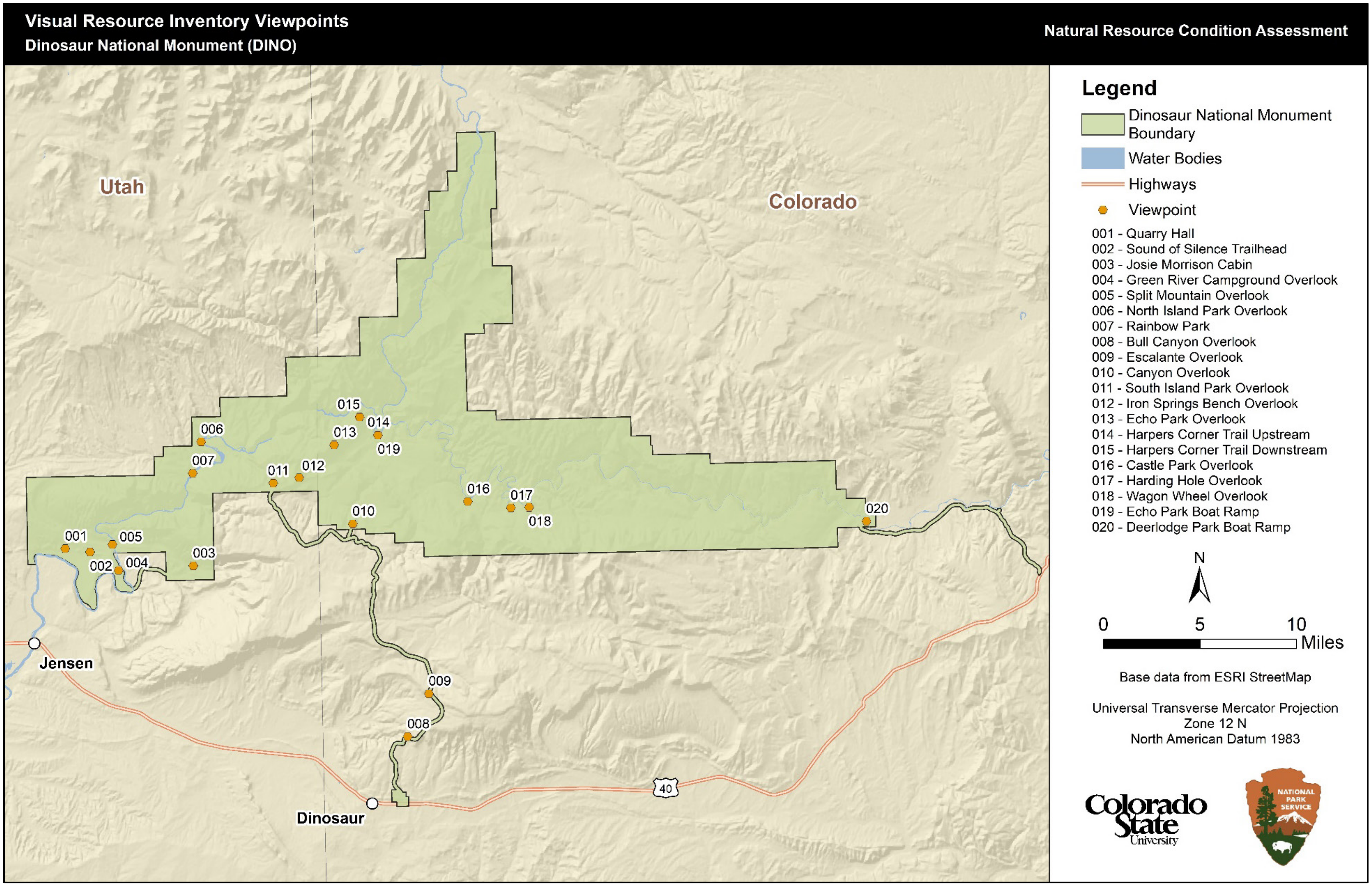


Figure 4.5-1. Locations of viewpoints assessed during July 2018 at Dinosaur National Monument (CSU viewpoint data; base data from ESRI StreetMap).

The scenic quality ratings were collected by CSU in July 2018 using NPS guidance and methods developed specifically for visual resource inventory (Meyer et al. 2018). Twenty pre-identified points were inventoried throughout the park (Figure 4.5-1). Although it is optimal for NPS staff from the monument to participate in the evaluations, no staff were available to participate during the survey period. Each observer rated the scenic quality based on landscape character integrity, vividness, and visual harmony. Two landscape character types occurred within the park: a natural/natural appearing landscape and an agricultural landscape. Each landscape character type has a list of features that are expected to be observed in each type (below). These features are specific to DINO and vary by location. Observers recorded individual ratings and then the group discussed and assigned a single scenic quality rating to each view on a scale of A (highest scenic quality) to E (lowest scenic quality).

Natural/Natural Appearing Landscape. This landscape character type is dominated by natural features. There may be evidence of human changes to the landscape, but they are minimal and do not detract from the natural landscape character. Typical elements include:

- River
- Cliffs and canyons
- Mountains and valleys
- Folding, uplifting, rock fins, hogbacks or similar features
- Sandstone features and slickrock
- Eroded hills
- Buttes and mesas
- Gullies, gulches, dry washes
- Shrublands and woodlands
- Riparian vegetation corridors

Agricultural Landscape. This landscape character type can include planted fields of row crops, orchards, and livestock pasture or confined feeding operations. The topography is typically flat to rolling, and generally does not occur on steep terrain. These landscapes sometimes have clustered farm buildings and structures. Typical elements include:

- Farm/ranch houses
- Outbuildings, barns, etc.
- Windmills, water development/irrigation
- Livestock fencing

- Small unpaved or paved roads
- Crop fields
- Hay and pastures
- Rural electric distribution

At each point, observation data and panoramic photos of the view being evaluated were collected. View importance was evaluated in the office environment using the following categories: viewpoint importance, viewed landscape importance, and viewer concern. Importance was rated on a scale of 1 (highest) to 5 (lowest). Historic, cultural, and landscape designations contribute to the importance of a view and are critical to consider when rating a viewpoint, but are not accounted for within the scenic quality evaluation. The view importance section allows important designations to be considered while rating a view.

The overall scenic inventory value (SIV) for a view is based on a combination of the scenic quality and the view importance scores (Table 4.5-1). Possible SIVs are: very high (VH), high (H), medium (M), low (L), or very low (VL). Final visual resource inventory data are entered into the Enjoy the View (ETV) web-enabled database: https://irma.nps.gov/ETV/ (accessible when connected to a DOI network). This database can produce summary inventory reports on a view-by-view basis, summarizing scenic quality and view importance, location and extent of the view, the overall scenic inventory value, and any additional field notes. The DINO summary inventory reports are included following the panoramic view photos.

Table 4.5-1. Scenic Inventory Value (SIV) rating matrix (Meyer et al. 2018).

Scenic Quality	View Importance Rating				
	1	2	3	4	5
A	VH	VH	VH	H	M
B	VH	VH	H	M	L
C	H	H	M	L	L
D	H	M	L	VL	VL
E	M	L	VL	VL	VL

4.5.3. Reference Conditions/Values

Dinosaur National Monument was established in 1915 and then expanded in 1938 to its current size (NPS 2015). The remote and rugged landscape protected within the monument is largely an untouched and undeveloped landscape for visitors to experience. The natural geology and supported ecosystems have developed and persisted over time with little to no management (NPS 2015). The area that is now DINO was home to the pre-historic Fremont Indians, early explorers and homesteaders; evidence of human use and occupation can be found throughout the monument. The reference condition for the scenic quality rating consists of a mostly natural landscape with some

Fremont Indian culture and homestead sites present. Elements considered outside of the reference condition vary for the landscape character types, but generally include paved roads, agricultural development, telecommunication and energy transmission structures, and modern buildings and structures. Within DINO's boundaries there are a number of private agricultural inholdings and operations where visual elements such as crops, equipment, and machinery are inconsistent elements.

The condition rating framework for visual resources follows guidance in NPS ARD (2018), and is based on scenic inventory values combining scenic quality and view importance ratings. The ARD guidance using five categories (very good, good, fair, poor and very poor) was consolidated to fit into three categories to be consistent with the NRCA program guidance (Table 4.5-2).

Table 4.5-2. Condition rating framework for scenic inventory value (NPS ARD 2018).

Category	Criteria
Good Condition	75% or more views have a Scenic Inventory Value (SIV) of very high or high
Moderate Concern	50% to 74% of views have a SIV of very high or high
Significant Concern	51% to 75% or more have a SIV of moderate, low, or very low

4.5.4. Condition and Trend

Scenic inventory values (SIV) were generally high to very high (Table 4.5-3). Eighteen out of 20 views (90%) had scenic inventory values rated high or very high, and only two had a medium rating. Scenic quality ratings were rated as either an A (eight views) or a B (twelve views). View importance had three viewpoints with a rating of 1, five with a rating of 2, and six views in both the 3 and 4 categories (Table 4.5-3). Park staff knowledgeable of historic, cultural and landscape designations should be involved in assigning importance, but were not available to support this project at the time (see Section 4.5.6, *Uncertainty and Data Gaps*), so the view importance portion of the inventory is considered incomplete or having low certainty. Overall, visual resources at DINO are in good condition. This assessment is a baseline inventory for DINO. Panoramic photos collected during the inventory are presented in Figures 4.5-2 to 4.5-22 (all photos by Colorado State University).

The scenery opportunities within the monument are exceptional and numerous, and are coupled with qualities associated with solitude and wilderness character. The level of confidence for the scenic inventory value is high because nearly all of the views identified as important by the monument staff were inventoried, the views inventoried represent most of the monument, and view assessments were done in the field (NPS ARD 2018). Because most views rated as high are within the park or dominated by protected landscapes, recent or anticipated changes to the views appear to be minimal. The primary threat to visual resources appears to be periodic poor air quality (haze) (see *Air Quality*, Section 4.6). In addition to occasional development or inconsistent view elements associated with agriculture or monument infrastructure, there are some telecommunication towers in the background of some views, but they are not highly visible.

Table 4.5-3. Scenic quality, view importance and scenic inventory values for viewpoints/landscape views assessed at Dinosaur National Monument.

Viewpoint Number	Viewpoint/View Name	Scenic Quality	View Importance	Scenic Inventory Value
001	Quarry Hall	B	4	M
002	South of Silence Trailhead	B	4	M
003	Josie Morris Cabin	B	1	VH
004	Green River Camp Ground Overlook	B	3	H
005	Split Mountain Overlook	B	3	H
006	North Island Park Overlook	A	4	H
007	Rainbow Park	B	3	H
008	Bull Canyon Overlook	B	2	VH
009	Escalante Overlook	B	3	H
010	Canyon Overlook	A	3	VH
011	South Island Park Overlook	B	2	VH
012	Iron Spring Bench Overlook	B	2	VH
013	Echo Park Overlook	B	2	VH
014	Harpers Corner Trail Overlook Upstream	A	1	VH
015	Harpers Corner Trail Overlook Downstream	A	1	VH
016	Castle Park Overlook	A	4	H
017	Harding Hole Overlook	A	4	H
018	Wagon Wheel Overlook	A	4	H
019	Echo Park Boat Ramps	A	2	VH
020	Deer Lodge Park Boat Ramp	B	3	H

Figure 4.5-2. Viewpoint 1: Quarry Hall.

Figure 4.5-3. Viewpoint 2: Sound of Silence Trail.

Figure 4.5-4. Viewpoint 3a: Josie Morris Cabin, view facing the cabin.

Figure 4.5-5. Viewpoint 3b: Josie Morris Cabin, view facing opposite of the cabin towards the picnic tables.

Figure 4.5-6. Viewpoint 4: Green River Campground Overlook.

Figure 4.5-7. Viewpoint 5: Split Mountain Overlook.

Figure 4.5-8. Viewpoint 6: North Island Park Overlook.

Figure 4.5-9. Viewpoint 7: Rainbow Park Boat Ramp.

Figure 4.5-10. Viewpoint 8: Bull Canyon Overlook.

Figure 4.5-11. Viewpoint 9: Escalante Overlook.

Figure 4.5-12. Viewpoint 10: Canyon Overlook.

Figure 4.5-13. Viewpoint 11: South Island Park Overlook.

Figure 4.5-14. Viewpoint 12: Iron Springs Bench Overlook.

Figure 4.5-15. Viewpoint 13: Echo Park Overlook.

Figure 4.5-16. Viewpoint 14: Harpers Corner Trail looking upstream.

Figure 4.5-17. Viewpoint 15: Harpers Corner Trail looking downstream.

Figure 4.5-18. Viewpoint 16: Castle Park Overlook.

Figure 4.5-19. Viewpoint 17: Harding Hole Overlook.

Figure 4.5-20. Viewpoint 18: Wagon Wheel Overlook.

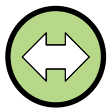
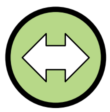
Figure 4.5-21. Viewpoint 19: Echo Park Boat Ramp.

Figure 4.5-22. Viewpoint 20: Deerlodge Boat Ramp.

4.5.5. Condition Summary

Visual resources at DINO are in good condition. A condition summary is presented in Table 4.5-4.

Table 4.5-4. Condition and trend summary for visual resources at Dinosaur National Monument.

Indicator	Condition Status	Rationale
Scenic Inventory Value		Views predominantly have SIVs of high or very high; two views rated medium and none rated lower than medium. Scenic quality ratings were very good and only consisted of A and B ratings. Eight of the views were rated as an A and the remaining twelve were rated as a B. View importance is high enough to support excellent SIV ratings. For some views, information gaps reduced the confidence of the importance rating to low. An unchanging trend is assigned since nearly all views consist of views within the park boundary where development is not expected. Confidence in the assessment is high because nearly all of the views considered important were inventoried and there is good representation of landscape types and levels of visitation.
Visual Resources overall		**Condition is good with an unchanging trend. Confidence in the assessment is high.**

4.5.6. Uncertainty and Data Gaps

The level of confidence in the assessment is high. However, for the view importance assessment, the assessment team lacked information or local expertise to complete some of the fields for viewpoint and viewed landscape importance. Input from monument staff regarding cultural, historic, or regulatory importance of the area associated with each viewpoint and viewed landscape was not available but could easily be added to the assessment to improve accuracy and completeness. While many of the important viewpoints have been assessed, some additional viewpoints that were identified but not inventoried (e.g., the river camp sites on the Green and Yampa Rivers) could be completed to provide a more comprehensive inventory.

4.5.7. Sources of Expertise

- Mark Meyer, Visual Resources Specialist, National Park Service Air Resources Division.

4.5.8. Literature Cited

Kulesza, C., Y. Le, and S.J. Hollenhorst. 2013. National Park Service visitor perceptions & values of clean air, scenic views, & dark night skies, 1988–2011. Natural Resource Report NPS/NRSS/ARD/NRR–2013/632. National Park Service, Fort Collins, Colorado.

Meyer, M., M. Peters, Ksienya Taylor, and R. Sullivan. 2018. Visual Resources Inventory Training Manual – Draft (April 2018). NPS Natural Resource Stewardship and Science and Argonne National Laboratory.

National Park Service (NPS). 2006. Management policies 2006: the guide to managing the National Park System. National Park Service, Washington, D. C.

NPS. 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

National Park Service Air Resources Division (NPS ARD). 2018. Guidance for evaluating visual resources in Natural Resource Conditions Assessments (August 2018 Version). Unpublished Report. U.S. National Park Service, Air Resources Division.

4.6. Air Quality

4.6.1. Background and Importance

The NPS Organic Act, Air Quality Management Policy 4.7.1 (NPS 2006) and the Clean Air Act (CAA) of 1977 and its subsequent amendments protect and regulate the air quality of the National Parks within the United States. Among the purposes of the CAA, one is "to preserve, protect, and enhance the air quality in national parks... and other areas of special national or regional natural, recreational, scenic, or historic value." The CAA includes special programs to prevent significant air quality deterioration in clean air areas and to protect visibility in national parks and wilderness areas (NPS ARD 2019a).

The NPS is responsible for protecting air quality and related issues and resources that may be impacted by air pollution. Two categories of air quality areas have been established through the authority of the CAA: Class I and II. The air quality classes are allowed different levels of permissible air pollution increases, with Class I areas receiving the most stringent protection. While Dinosaur National Monument (DINO) is designated as a Class II area, the NPS Organic Act and NPS management policies direct that all units of the National Park System be managed so as to protect resources unimpaired for the benefit of current and future generations. This includes protecting air resources in all park units, Class I and Class II alike. Direction in the CAA, as well as mandates under the NPS Organic Act and associated management policies, gives the NPS a responsibility and an opportunity to participate in the decision making processes of regulatory agencies that might affect air quality in these national federally protected areas (NPS 2006).

For example, scenic vistas require good visibility and low haze. Human-made pollution can harm ecological resources, including water quality, plants and animals. Air pollution can also cause or intensify respiratory symptoms for NPS visitors and employees. Because of these many links, poor and/or declining air quality can impact park visitation. A synthesis of 19 visitor studies conducted in the NPS Intermountain Region found that clean air was ranked as extremely important or very important by 97% of visitor groups (Kulesza et al. 2013).

Air quality can have a significant impact on the vegetation and ecology of an area. Nitrogen (ammonia – NH^4) and sulfur (sulfate – SO^3) deposition can cause acidification of water bodies, while excess nitrate (NO^3) can lead to nutrient effects on biodiversity. The NPS Air Resources Division describes ground-level ozone (along riparian corridors) and atmospheric nitrogen deposition (invasive grass response) as having the largest risk to ecosystem processes (Rao and Allen 2010, Kohut 2017). Nitrogen emissions from oil and gas development have been increasing since 2008 (Sullivan 2016). Oil and gas-related ozone concentrations in the Uintah Basin of northeastern Utah have been increasing in recent years, which could eventually lead to health risks for visitors and monument staff (Sullivan 2016). Decreased visibility from haze does not affect the ecology of an area so much as it affects the human element through decreased viewing opportunities of the NPS lands, other protected lands and surrounding areas. As of November 2018, DINO, in partnership with NPS Air Resource Division, is an IMPROVE network special study site and hosts a webcam to better understand and monitor visibility conditions on the Utah side of the monument.

Threats and Stressors

Oil and Gas

DINO is located within the north central portion of the Uinta-Piceance basin, an oil and gas-rich region that straddles northwestern Colorado and northeastern Utah. The Uinta is located on the Utah side of the boarder, and the Piceance is located on the Colorado side. Both basins are older, more developed plays, with the first natural gas production established the Uinta in 1925 and the first oil production established in the Uinta in 1949. As of April 2019, there were approximately 33,097 active oil and gas wells within the Uinta-Piceance Basins (NGISD 2019a). The highest concentrations of active wells begin just 10–20 miles west and south of the monument and extend over 100 miles into the northwestern corner of Colorado and northeastern corner of Utah. However, some newer wells on the Utah side are encroaching on the monument and are located less than a mile from the DINO's western boundary.

The Piceance Basin, a tight sands formation which produces primarily liquids-rich natural gas, saw increased growth in the early 2000's, but the rate of production growth began declining in 2009 due to lower natural gas prices; 2013 was the first year since 2000 that annual natural gas production decreased from the prior year (NGI 2016). The majority of current production in the Piceance is focused in the Williams Fork formation. However, interest is growing in deeper formations including the Mancos shale, which has greater oil potential, and the Niobrara formation, which includes oil-rich, liquids-rich natural gas and dry natural gas zones. Development of these formations using horizontal drilling and hydraulic fracturing techniques is in the early stages, but speculation over production potential is high (NGISD 2019b).

The Uinta Basin produces both oil and natural gas from conventional and unconventional tight sands and shale formations. Oil production began increasing in the Uinta in 2004–2005 and has grown at a rate of 12% per year through 2014 (NGISD 2019a). Historically, wells have been developed with vertical drilling, and vertical drilling activity continues, but the number of horizontally drilled wells has increased in recent years. In fact, the development of long lateral horizontal wells is thought to be one reason production continues to increase in spite of recent decreases in drilling activity (Pétron et al. 2012). Growth in the basin has been dampened by a lack of take-away capacity (e.g., pipelines) and the fact that the basin produces waxy crude, which is more costly to transport and refine relative to other producing regions. Waxy crude must be heated in order to flow in a pipeline, increasing the need for costly truck transport, and requires additional refining near the source. However, the industry is developing ways to overcome these technical and market-driven challenges, making development of the basin much more attractive in recent years (UDEQ 2019a).

Oil and gas operations emit significant quantities of air pollutants in basins with large-scale development, such as the Uinta-Piceance. Pollutants emitted from oil and gas operations include hydrocarbons such as methane (CH4) and a mixture of non-methane hydrocarbons, referred to as volatile organic compounds (VOCs), including alkanes (e.g., C_2-C_5 alkanes), cycloalkanes, aromatic BTEX compounds (benzene, toluene, xylene and ethylbenzene), and formaldehyde. Non-hydrocarbon criteria pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), particulate matter (PM) and sulfur dioxide (SO2) are also emitted from oil and gas

operations (Pétron et al. 2012). Methane and VOC emissions are primarily emitted from venting and leakage from connections, piping, gathering lines, pipelines, pneumatic devices, tanks and other storage units, heaters, separators, dehydrators, blow down events and well completions. The criteria pollutants NOx, CO, CO2, and SO2 are emitted from combustion sources used in oil and gas operations such as drill rig and fracturing pump engines, compressor engines, flares and combustors, artificial lift and other miscellaneous engines, heaters, separators and transportation sources such as tanker trucks and drilling traffic.

The emissions from oil and gas activity in these basins are substantial. The most recent comprehensive oil and gas emissions inventory for the Uinta and Piceance basins is available through the Intermountain West Data Warehouse (CIRA 2019). This inventory was developed for the year 2011 (an oil and gas inventory update for year 2014 is underway, but has not been completed). Table 4.6-1 reports the 2011 emissions for oil and gas point and area sources for the eight counties in Colorado and Utah that contain the majority of oil and gas development in these basins (CIRA 2019).

Table 4.6-1. Some oil and gas emission components for the Uinta and Piceance Basins for 2011 (CIRA 2019).

Component	Emissions (tons/year)
Methane	926,360
NO_x	39,446
$PM_{2.5}$	1,783
SO_2	525
VOC	191,760

The increased oil and gas activity and production in the Uintah and Piceance basins and the associated pollutant emissions have contributed to the degradation of air quality within and surrounding DINO (UDEQ 2016, Sullivan 2016).

Oil and gas emissions contribute to nitrogen deposition through increased regional NOx emissions, and decrease visibility due to the release of haze-causing agents such as NO_x, elemental carbon, secondary organic aerosols and fine particulate matter from fugitive dust. Oil and gas NOx and VOC emissions are precursors to photochemical ozone formation and oil and gas sources are causing high ozone episodes in the basin, which is an increasing problem in the region (Sullivan 2016, UDEQ 2016).

Ozone Issues in the Uinta Basin

The United States Environmental Protection Agency (EPA) established a National Ambient Air Quality Standard (NAAQS) for ozone of 70 parts per billion (ppb) over an 8-hour period. This standard was established to protect human health, as ozone can cause difficulty breathing, chest pain, coughing, inflamed airways, and increased susceptibility to infection (EPA 2012). As of November 2018, all land in the Uintah Basin (which includes Duchesne and Uintah Counties) below an

elevation of 6,250 ft was listed by the EPA as an area of marginal-nonattainment for ozone (EPA 2018). This means areas below this elevation in the Utah section of the monument are in nonattainment status for ozone.

Many of the ozone exceedances are occurring in the peak of winter, outside of the traditional "ozone season." Photochemical ozone production near the Earth's surface was historically considered an urban summertime phenomenon because the reactions between precursor pollutants require sunlight. While summertime exceedances of the standard do still occur in the region, for nearly a decade increases in wintertime ozone in and near the monument have been observed. Many episodes lead to ozone levels that are far above the ozone NAAQS of 70 ppb, sometimes exceeding 100 to 120 ppb, and are a result of the photochemical processing of emissions from oil and gas development in the Uinta Basin (UDEQ 2019b, Edwards et al 2014, Ahmadov et al. 2015). Ozone levels in DINO, particularly during these episodes, could pose a health risk to visitors and park staff.

Studies have determined that winter ozone episodes require both extensive snow cover, which provides for ample photolysis to drive ozone-forming photochemical reactions, and strong and persistent temperature inversions, which decrease atmospheric mixing and trap emissions from significant NOx and VOC emissions sources located within the basin. The unique combination of emissions sources, meteorology and topography in the basin allow ozone to accumulate near ground level (UDEQ 2012). These conditions may not be present or the same every year and thus ozone levels as measured at ground level will likely fluctuate from year to year.

Preliminary results from a special in-park air quality study (2018 to 2019) at DINO confirm that gradually increasing wintertime ozone in January and February corresponds to solar radiation, generally low wind speeds, and persistent snow cover. Results of this study show that during high ozone, air comes from west and south of the park (pers. comm., Anthony Prenni, April 29, 2019).

Studies have also found that during the inversion events, the ozone levels in the basin are not influenced by transport of ozone or its precursors from outside the basin or from the nearby Bonanza Power Plant (Lyman and Shorthill 2013). Opportunities exist to work with the UTDEQ on planning efforts to reduce emissions and bring the region back into attainment with the ozone NAAQS.

Air Quality Related Value Impacts in the Region

Regional haze events occur mainly during the summer and fall, but are now also observed in the wintertime. Initial analyses from a special in-park air quality study suggest that wintertime haze events observed in January and February at DINO can be attributed to air masses that originate from south and west of the park, areas that include oil and gas development (pers. comm., Anthony Prenni, April 29, 2019). Ongoing work aims to determine the sources of these haze events and to assess the need for additional air quality monitoring at DINO.

Other regional and local pollution sources that cause haze and contribute to visibility impairment throughout the region include automobiles, coal- and oil-fired power plants, smelters, wildfires, and urban emissions (Peterson et al. 1998). Power generation plants in Hayden and Craig, Colorado, are

occasional sources of pollution affecting the monument (pers. comm., Tamara Naumann, April 2016).

Nitrogen deposition (N) in DINO is exceeding levels known to affect natural diversity of herbaceous plant and lichen communities (Pardo et al. 2011, NPS-ARD 2019a). Atmospheric N deposition within DINO peaks at 3.4 kg ha^{-1} yr^{-1} (NPS ARD 2019a). Ecosystem sensitivity is ranked as "very high" due to a risk of increased growth of invasive plant species (Sullivan et al. 2011a). While the monument has previously been described as being at low overall risk from N enrichment (Sullivan et al. 2011a), increasing deposition due to nearby development is increasing the likelihood of ecosystem change. Many of the counties around DINO emitted more than 1 ton/mi^2/yr of NO_x from oil and gas development (Sullivan and McDonnell 2014). Potential future increases in local N emissions from oil and gas development is cause for concern (Sullivan and McDonnell 2014).

The monument also has "low" exposure to acidic deposition from sulfur (S) and N emissions and has been described as being moderately at risk from acidic deposition (Sullivan et al. 2011b). There are 6 plant species identified within DINO that are sensitive to acidification: box elder (*Acer negundo*), Utah juniper (*Juniperus osteosperma*), quaking aspen (*Populus tremuloides*), two-needle pinyon (*Pinus edulis*), ponderosa pine (*Pinus ponderosa var. scopulorum*) and douglas-fir (*Pseudotsuga menziesii var. glauca*) (NPS ARD 2019b).

Ozone also poses a risk for sensitive vegetation. There are 11 plant species identified within DINO that are sensitive to ozone: box elder (*Acer negundo*), saskatoon serviceberry (*Amelanchier alnifolia*), Utah serviceberry (*Amelanchier utahensis*), common dogbane (*Apocynum cannabinum*), swamp milkweed (*Asclepias incarnate*), singleleaf ash (*Fraxinus anomala*), white-stem blazingstar (*Mentzelia albicaulis*), western evening-primrose (*Oenothera elata*), quaking aspen (*Populus tremuloides*), Scouler's willow (*Salix scouleriana*), and late goldenrod (*Solidago gigantean*) (NPS ARD 2017). Ozone enters leaves through stomata and causes chlorosis and necrosis of leaves (Figure 4.6-1), among other problems. Soil moisture plays a big role in the uptake of ambient ozone, as moist soils allow plants to transpire and increase stomatal conductance which, in turn, increases ozone uptake (NPS 2019). A risk assessment concluded that plants in DINO were at low risk for ozone damage (Kohut 2007, Kohut 2004). In terms of plant damage from ozone, plants in riparian areas, which are abundant along the Yampa and Green rivers within the monument, may be at greater risk because their uptake of ozone is less likely to be limited by dry soil conditions (Sullivan 2016).

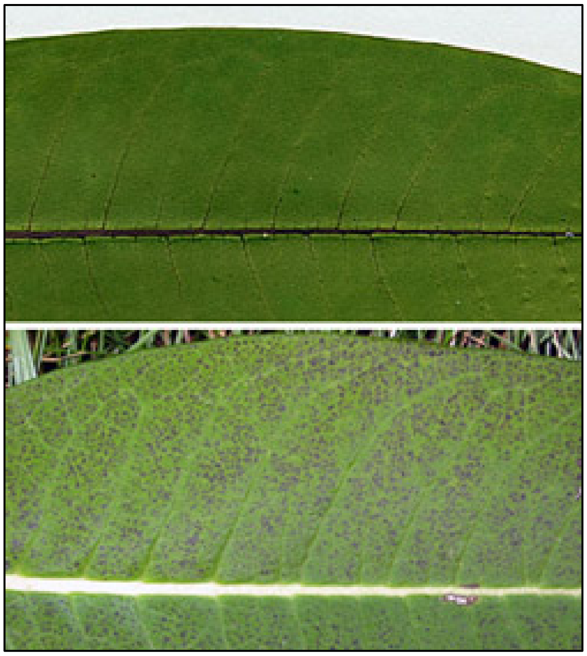


Figure 4.6-1. Example of ozone damage to plant leaf. *Asclepias syriaca* normal leaf (top) and ozone-injured leaf (bottom). Photo: NPS ARD.

Indicators and Measures

- Ozone: human health risk
- Ozone: vegetation health risk
- Atmospheric wet deposition of nitrogen
- Atmospheric wet deposition of sulfur
- Visibility haze index

4.6.2. Data and Methods

The condition of air quality within DINO was assessed using methodology developed by the NPS ARD for use in Natural Resource Condition Assessments (NRCAs) (Taylor 2017). For condition assessments, the NPS ARD uses all available data from NPS, the EPA, state, and/or tribal monitoring stations to interpolate air quality values, with a specific value assigned to the maximum value within each park. This method is used to estimate 5-year average (2012–2016) values. Even though the data are derived from all available monitors, data from the closest stations are more heavily weighted.

Trends are computed from data collected over a 10-year period (2007–2016) at on-site or nearby representative monitors. Trends are calculated for sites that have at least six years of annual data and an annual value for the end year of the reporting period. There is an ozone monitoring station within the monument's western boundary. There is a representative visibility monitor (IMPROVE site ID: FLTO1) located about 50 miles southeast of DINO in the Flat Tops Wilderness Area. However, there are not enough data to calculate 10-year trends as the monitor started operating in 2012. In 2018, a

special visibility study was launched in DINO to better understand wintertime pollution events at DINO and to determine if a closer, more representative monitor is necessary to capture the inversion events that cause wintertime haze. There are no representative monitoring stations for wet deposition located in or near DINO suitable for assessing 10-year trends. The nearest wet deposition monitoring station is in Moffat County, Colorado, just west of Craig, approximately 45 miles east of DINO.

4.6.3. Reference Conditions

Reference conditions are based on regulatory standards, best available scientific knowledge, or NPS ARD recommendations and guidance (Taylor 2017). A summary of reference conditions and condition class rating for air quality indicators is shown in Table 4.6-2.

Table 4.6-2. Reference condition framework for air quality indicators (Taylor 2017). ppm-hrs = parts per million-hours; dv = deciviews.

Air Quality Indicator	Specific Measure	Good Condition	Moderate Condition/Warrants Moderate Concern	Poor Condition/Warrants Significant Concern
Ozone	Human Health: Annual 4th-highest 8hr concentration	≤ 54 ppb	55–70 ppb	≥ 71 ppb
	Vegetation Health: 3-month maximum 12hr W126	< 7 ppm-hrs*	7–13 ppm-hrs	> 13 ppm-hrs
Visibility	Haze Index	< 2 dv*	2–8 dv	> 8 dv
Nitrogen	Wet Deposition	<1 kg/ha/yr	1–3 kg/ha/yr	> 3 kg/ha/yr
Sulfur	Wet Deposition	<1 kg/ha/yr	1–3 kg/ha/yr	> 3 kg/ha/yr

Ozone: Human Health Risk

The primary National Ambient Air Quality Standard (NAAQS) for ground-level ozone is set by the EPA and is based on human health effects. The current 2015 ozone standard is an 8-hour average ozone concentration of 70 parts per billion (ppb). The NPS ARD benchmarks for the human health risk from ozone status are based on the EPA's Air Quality Index (AQI) breakpoints. The status for human health risk from ozone is based on the estimated 5-year average of the 4th-highest daily maximum 8-hour average ozone concentration compared to benchmarks. Ozone concentrations greater than or equal to 71 ppb are assigned to the "Warrants Significant Concern" category. Ozone concentrations from 55–70 ppb are assigned to the "Warrants Moderate Concern" category. A resource in the Good Condition category is identified when ozone concentrations are less than or equal to 54 ppb (Table 4.6-2) (Taylor 2017).

Ozone: Vegetation Health Risk

The W126 metric is a biologically relevant measure that focuses on plant response to ozone exposure. The W126 metric equation preferentially weights the higher ozone concentrations that are more likely to cause plant damage. It sums all of the weighted concentrations during daylight hours when the majority of gas exchange occurs between the plant and the atmosphere. The highest 3-month period that occurs during the growing season is reported in parts per million-hours (ppm-hrs).

The status for vegetation health risk from ozone is based on the estimated 5-year average of the 3-month 12-hour W126 index compared to benchmarks. For the NRCA, W126 values greater than 13 ppm-hrs are considered to “warrant significant concern,” W126 values from 7–13 ppm-hrs are considered to “warrant moderate concern,” and W126 values less than 7 ppm-hrs indicate “good condition” (Table 4.6-2) (Taylor 2017).

Visibility

Visibility is measured using the Haze Index in deciviews (dv). Visibility conditions are the difference between the mid-range day visibility and estimated average natural visibility (2.5 dv at DINO), where the mid-range days natural visibility is the mean between the 40th and 60th percentiles (Taylor 2017). Five-year interpolated averages are used in the contiguous United States. Visibility is considered to be in “good condition” if visibility is less than 2 dv, “warrants moderate concern” if between 2–8 dv, and “warrants significant concern” if greater than 8 dv (Table 4.6-2) (Taylor 2017).

Wet Nitrogen Deposition

The NPS ARD (Taylor 2017) considers parks that receive less than 1 kg/ha/yr of nitrogen as being in “good condition”. Parks receiving between 1–3 kg/ha/yr are ranked as “warrants moderate concern”. Those parks that receive greater than 3 kg/ha/yr are ranked as “warrants significant concern” (Table 4.6-2) (Taylor 2017).

Wet Sulfur Deposition

The NPS ARD (Taylor 2017) considers parks that receive less than 1 kg/ha/yr of sulfur as being in “good condition.” Parks receiving between 1–3 kg/ha/yr are ranked as “warrants moderate concern.” Those parks that receive greater than 3 kg/ha/yr are ranked as “Poor Condition” (Table 4.6-2) (Taylor 2017).

4.6.4. Condition and Trend

Ozone: Human Health Risk

From 2011–2016 the estimated 4th highest daily maximum 8-hr ozone average concentration was 82.0 ppb (NPS ARD 2019c)(Figure 4.6-2). For 2007–2016 the trend in ozone concentration at DINO remained relatively unchanged (no statistically significant trend) (NPS ARD 2019c). Available data indicate a warrants significant concern condition for ozone levels with an unchanging trend and high confidence due to an on-site ozone monitor (NPS ARD 2019c).

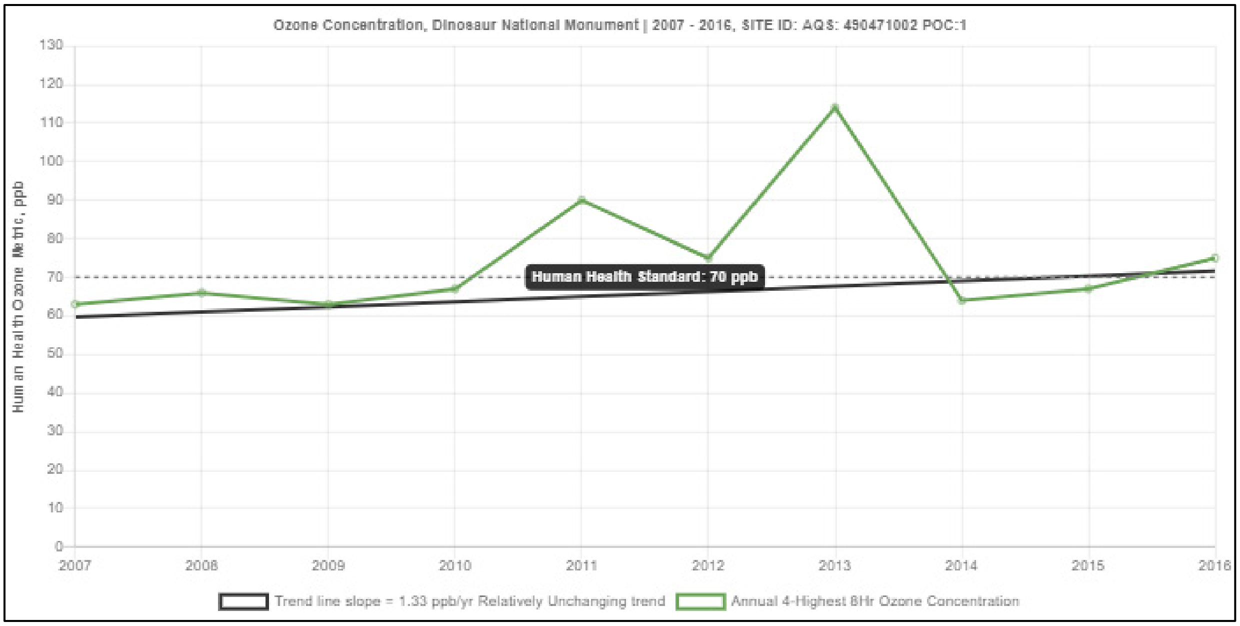


Figure 4.6-2. Annual 4th highest daily maximum 8-hr ozone concentration for DINO (NPS ARD 2019c). The human health standard of 70ppb is noted by the dashed line.

Ozone: Vegetation Health Risk

The 2011–2016 estimated W126 metric is 11.6 ppm-hrs. This value indicates moderate concern for the impact of ozone on vegetation (NPS ARD 2019c). For 2007–2016, the trend in ozone concentration at DINO remained relatively unchanged (no statistically significant trend)(Figure 4.6-3)(NPS ARD 2019c). Overall, the vegetation health risk from ground-level ozone is in moderate condition with an unchanging trend and high confidence due to an on-site ozone monitor (NPS ARD 2019c).

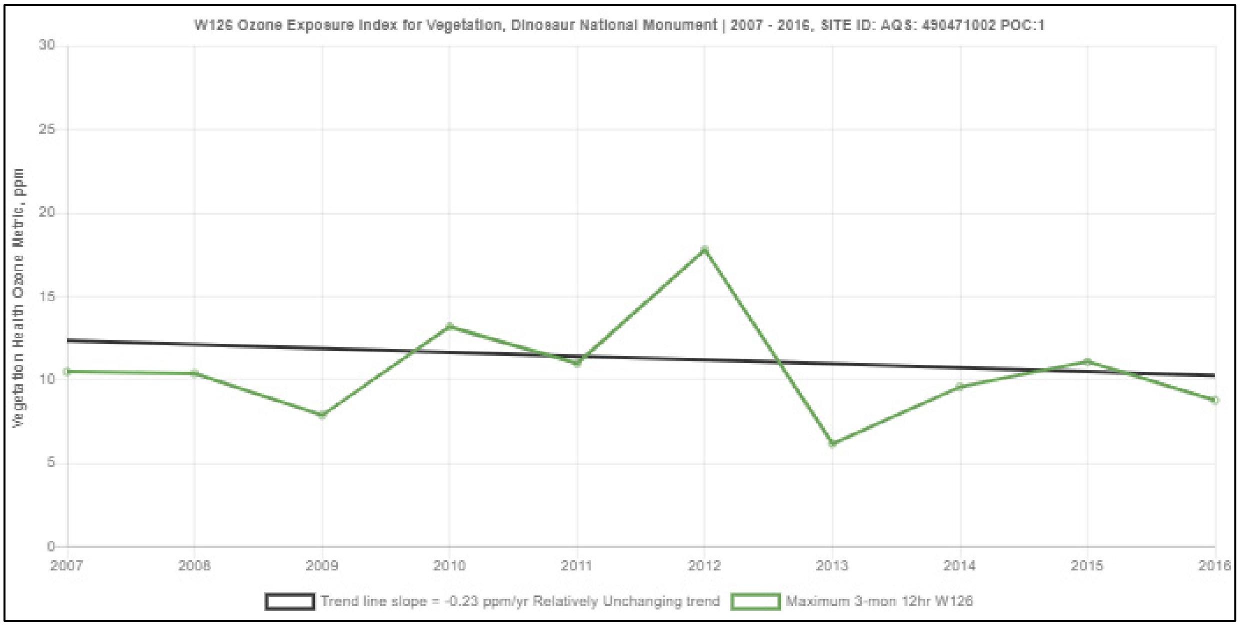


Figure 4.6-3. W126 ozone concentration for DINO (NPS ARD 2019c).

Visibility

Based on the 2012–2016 estimated visibility on mid-range days of 2.3 dv above estimated natural condition of 2.5 dv, the visibility condition falls in the moderate condition category with high confidence due to data being highly influenced by a representative monitor. The trend is unknown because there are not sufficient nearby visibility monitoring data to calculate a 10-year trend (NPS ARD 2019c). Visibility impairment primarily results from small particles in the atmosphere that include natural particles from dust and wildfires and anthropogenic sources from organic compounds, NO_x, and sulfur dioxide (SO_2). The contributions made by different classes of particles to haze vary by region but often include ammonium sulfate, coarse mass, and organic carbon. Ammonium sulfate originates mainly from coal-fired power plants and smelters, and organic carbon originates primarily from combustion of fossil fuels and vegetation. Sources of coarse mass include dust from roads, agriculture, construction sites, mining operations, and other similar activities. Data from the Flat Tops visibility monitor that is considered representative of air quality in DINO indicates that on the haziest days, organic carbon is one of the main contributors to visibility impairment followed by ammonium sulfate and coarse mass (Figure 4.6-4).

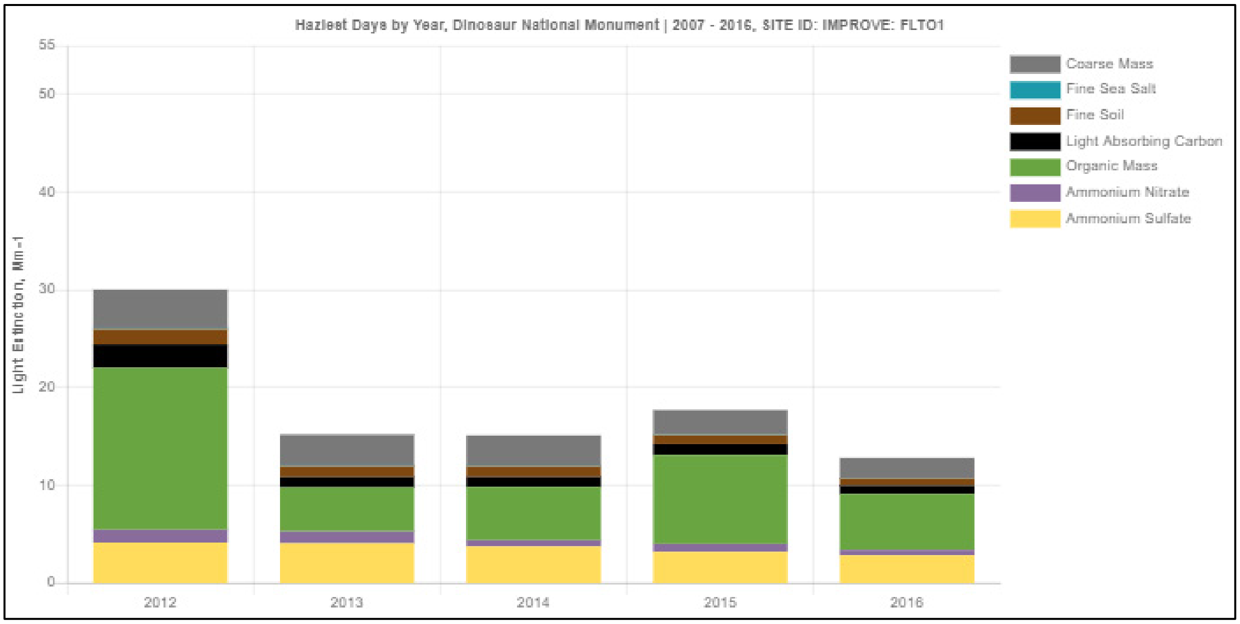


Figure 4.6-4. Sources of haze-producing pollutants at DINO (from Ksienya Taylor, NPS ARD).

Wet Nitrogen Deposition

Based on the 2012–2016 estimated wet nitrogen deposition of 1.4 kg/ha/yr, wet nitrogen deposition warrants significant concern with medium confidence due to the regional and modeled nature of the data. This level of wet nitrogen deposition would normally warrant moderate concern; however, the status for DINO has been elevated to significant concern by NPS ARD due to ecosystems at the monument being very highly sensitive to the effects of nitrogen enrichment relative to other parks. No trend information is available because there are not sufficient on-site or nearby deposition monitoring data (NPS ARD 2019c).

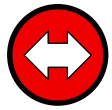
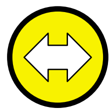
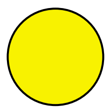
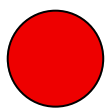
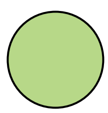
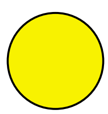
Wet Sulfur Deposition

Based on the 2012–2016 estimated wet sulfur deposition of 0.5 kg/ha/yr, wet sulfur deposition is in the good condition category with medium confidence due to the regional and modeled nature of the data. The trend is unknown because there are insufficient on-site or nearby deposition monitoring data (NPS ARD 2019c).

Overall Condition

Based on the evaluation of ozone, nitrogen and sulfur wet deposition, and visibility, air quality condition in DINO warrants moderate concern with an unchanging trend (Table 4.6-3). Confidence in the assessment is medium.

Table 4.6-3. Condition and trend summary for air quality at Dinosaur National Monument.

Indicator	Measure	Condition Status/Trend	Rationale
Ozone	Human Health: Annual 4th-highest 8hr concentration		Human health risk from ground-level ozone warrants significant concern at DINO. Condition is based on NPS Air Resources Division benchmarks and the 2011–2015 estimated ozone of 82.0 ppb. The degree of confidence at DINO is high because there is an on-site or nearby ozone monitor.
	Vegetation Health: 3-month maximum 12hr W126		Condition is based on NPS Air Resources Division benchmarks and the 2011–2015 estimated W126 metric of 11.6 parts per million-hours (ppm-hrs) and warrants moderate concern. The W126 metric relates plant response to ozone exposure. A risk assessment concluded that plants at DINO were at low risk for ozone damage (Kohut 2007). The degree of confidence at DINO is high because there is an on-site or nearby ozone monitor.
Visibility	Haze Index		Visibility warrants moderate concern at DINO. Condition is based on NPS Air Resources Division benchmarks and the 2011–2015 estimated visibility on mid-range days of 2.3 deciviews (dv) above estimated natural conditions.
Nitrogen	Wet Deposition		Wet nitrogen deposition warrants significant concern based on NPS Air Resources Division benchmarks and the 2011–2015 estimated wet nitrogen deposition of 1.4 kg/ha/yr. Nitrogen deposition may disrupt soil nutrient cycling and affect biodiversity of some plant communities, including grasslands and wetlands.
Sulfur	Wet Deposition		Wet sulfur deposition is in good condition based on NPS Air Resources Division benchmarks and the 2011–2015 estimated wet sulfur deposition of 0.5 kg/ha/yr.
Air Quality overall	–		**Overall, air quality condition warrants moderate concern with an undetermined trend due to insufficient on-site or nearby monitoring stations. Confidence in the assessment is medium because most estimates are based on interpolated data from more distant monitoring stations.**

Ozone levels are expected to increase in the region with a projected increase in oil and gas development. Risk to human health is already likely with long-term exposure at current levels of ozone, and could be exacerbated with further increases in 4th-highest daily maximum 8hr average ozone concentrations.

Scenic vistas have been identified by DINO staff as well as other stakeholders as a fundamental resource and value for the monument (NPS 2015). The “moderate concern” condition rating for visibility threatens the enjoyment of visual resources at DINO.

4.6.5. Uncertainty and Data Gaps

Monitoring stations for wet deposition and visibility are needed at DINO to better understand the specific air quality conditions used in this analysis. Estimated air quality values derived using the

Inverse Distance Weighting interpolation method are adequate, but can misrepresent park conditions due to modeling errors, especially in mountainous regions or areas with distinct airsheds, such as those in the vicinity of DINO. Monitoring of all air quality parameters within DINO or nearby would eliminate uncertainty from the interpolations.

4.6.6. Sources of Expertise

- The NPS ARD manages the national air resource management program for the NPS. They, along with NPS regional offices and park staff, provide air quality analysis and expertise relevant to air quality topics.

- Andrea Stacy and Ksienya Taylor (NPS ARD) reviewed this section, provided recent air quality information for the Uintah Basin, and provided graphics that were not yet publicly available as of the completion of this report.

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

4.6.7. Literature Cited

Ahmadov, R., S. McKeen, M. Trainer, R. Banta, A. Brewer, S. Brown, P. M. Edwards, J. A. de Gouw, G. J. Frost, J. Gilman, D. Helmig, B. Johnson, A. Karion, A. Koss, A. Langford, B. Lerner, J. Olson, S. Oltmans, J. Peischl, G. Pétron, Y. Pichugina, J. M. Roberts, T. Ryerson, R. Schnell, C. Senff, C. Sweeney, C. Thompson, P.R. Veres, C. Warneke, R. Wild, E.J. Williams, B. Yuan, and R. Zamora. 2015. Understanding high wintertime ozone pollution events in an oil- and natural gas-producing region of the western US. *Atmospheric Chemistry and Physics* 15:411–429. doi:10.5194/acp-15-411-2015.

Colorado State University Cooperative Institute for Research in the Atmosphere (CIRA). 2019. Intermountain West data warehouse. Available at: https://views.cira.colostate.edu/iwdw/Emissions/ReviewTool.aspx (accessed 23 May 2019).

Edwards, P.M., S.S. Brown, J.M. Roberts, R. Ahmadov, R.M. Banta, J.A. deGouw, W.P. Dube´, R.A. Field, J.H. Flynn, J.B. Gilman, M. Graus, D. Helmig, A. Koss, A.O. Langford, B.L. Lefer, B.M. Lerner, R. Li, S.-M. Li, S.A. McKeen, S.M. Murphy, D.D. Parrish, C.J. Senff, J. Soltis, J. Stutz, C. Sweeney, C.R. Thompson, M.K. Trainer, C. Tsai, P.R. Veres, R.A. Washenfelder, C. Warneke, R.J.Wild, C.J. Young, B. Yuan, and R. Zamora. 2014. High winter ozone pollution from carbonyl photolysis in an oil and gas basin. *Nature* 514: 351–354. doi:10.1038/nature13767.

Environmental Protection Agency (EPA). 2012. Health effects – ground level ozone. Available at: www.epa.gov/ozone-pollution (accessed 15 August 2013).

EPA. 2018. The Green Book nonattainment areas for criteria pollutants. Available at: https://www.epa.gov/green-book (accessed 15 November 2018).

Kohut, R.J. 2004. Northern Colorado Plateau Network Ozone Risk Assessment. National Park Service. Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2181489

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

Kohut, R. 2017. Field surveys to assess foliar ozone injury on plants in national parks and monuments on the Colorado Plateau. Cornell University, Ithaca, NY. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2240635

Kulesza, C., Y. Le, and S.J. Hollenhorst. 2013. National Park Service visitor perceptions & values of clean air, scenic views, & dark night skies: 1988–2011. Natural Resource Report NPS/NRSS/ARD/NRR–2013/632. National Park Service, Fort Collins, Colorado.

Lyman, S., and Shorthill, H. 2013. Final Report: 2012 Uintah Basin winter ozone and air quality study. Doc. No. CRD13-320.32. Commercialization and Regional Development, Utah State University.

National Park Service (NPS). 2006. Management policies 2006: the guide to managing the National Park System. National Park Service, Washington, D.C.

NPS. 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

NPS. 2019. Air: ozone effects on plants. Available at: https://www.nps.gov/subjects/air/nature-ozone.htm (accessed 23 May 2019).

NPS ARD. 2017. Ozone sensitive species. Available at: https://irma.nps.gov/NPSpecies/Reports/Systemwide/Ozone Sensitive%20Species%20in%20a%20Park (accessed 04 August 2017).

NPS ARD. 2019a. Nitrogen critical loads and estimated exceedances in NPS areas (2015–2017). Natural Resource Stewardship and Science Directorate, Air Resources Division, Denver, Colorado.

NPS ARD. 2019b. Acid sensitive species. Available at: https://irma.nps.gov/NPSpecies/Reports/Systemwide/Acid-sensitive%20Species%20in%20a%20Park (accessed 25 April 2019).

NPS ARD. 2019c. Air quality conditions & trends by park. Available at: https://www.nps.gov/subjects/air/park-conditions-trends.htm (accessed 23 May 2019).

Natural Gas Intelligence (NGI). 2016. North American shale & resource plays 2016 fact book. Sterling, Virginia. Available at: https://www.desmogblog.com/sites/beta.desmogblog.com/files/2016-Shale-Factbook_0.pdf

Natural Gas Intelligence's Shale Daily (NGISD). 2019a. Information on the Uinta Basin. Available at: https://www.naturalgasintel.com/uintainfo (accessed 23 May 2019).

Natural Gas Intelligence's Shale Daily (NGISD). 2019b. Information on the Piceance Basin. Available at: https://www.naturalgasintel.com/uintainfo (accessed 23 May 2019).

Pardo, L.D., M.J. Robin-Abbott, and C.T. Driscoll, editors. 2011. Assessment of nitrogen deposition effects and empirical critical loads of nitrogen for ecoregions of the United States. General Technical Report NRS-80. U.S. Forest Service, Northern Research Station, Newtown Square, PA.

Peterson, D.L., T.J. Sullivan, J.M. Eilers, S. Brace, D. Horner, K. Savig, and D. Morse. 1998. Assessment of air quality and air pollutant impacts in national parks of the Rocky Mountains and Northern Great Plains. Regional Air Quality Reviews. Technical Report NPS D-657. National Park Service – Air Resources Division, Denver, Colorado.

Pétron, G., G. Frost, B.R. Miller, A.I. Hirsch, S.A. Montzka, A. Karion, M. Trianer, C. Sweeney, A.E. Andrews, L. Miller, J. Kofler, A. Bar-Ilan, E.J. Dlugokencky, L. Patrick, C.T. Moore Jr., T.B. Ryserson, C. Siso, W. Kolodzey, P.M. Lang, T. Conway, P. Novelli, K. Masarie, B. Hall, D. Guenther, D. Kitzis, J. Miller, D. Welsh, D. Wolfe, W. Neff, and P. Tans. 2012. Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study. Journal of Geophysical Research 117(D4), D04304, doi:10.1029/2011JD016360.

Rao, L., and E. Allen. 2010. Combined effects of precipitation and nitrogen deposition on native and invasive winter annual production in California deserts. Oecologia 162:1035–1046.

Sullivan, T.J. 2016. Air quality related values (AQRVs) for Northern Colorado Plateau Network (NCPN) parks: Effects from ozone; visibility reducing particles; and atmospheric deposition of acids, nutrients and toxics. Natural Resource Report NPS/NCPN/NRR—2016/1169. National Park Service, Fort Collins, Colorado.

Sullivan, T.J., and T.C. McDonnell. 2014. Mapping of nutrient-nitrogen critical loads for selected national parks in the intermountain west and great lakes regions. Natural Resource Technical Report NPS/ARD/NRTR—2014/895. National Park Service, Fort Collins, Colorado.

Sullivan, T.J., T.C. McDonnell, G.T. McPherson, S.D. Mackey, and D. Moore. 2011a. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: Heartland Network (HTLN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/311. National Park Service, Denver, Colorado.

Sullivan, T.J., G.T. McPherson, T.C. McDonnell, S.D. Mackey, and D. Moore. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from

atmospheric sulfur and nitrogen deposition: Heartland Network (HTLN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/359. National Park Service, Denver, Colorado.

Taylor, K.A. 2017. National Park Service air quality analysis methods: August 2017. Natural Resource Report NPS/NRSS/ARD/NRR—2017/1490. National Park Service, Fort Collins, Colorado.

Utah Department of Environmental Quality (UDEQ). 2012. Final report: 2012 Uinta Basin winter ozone and air quality study. Utah Division of Air Quality, Salt Lake City, Utah.

UDEQ. 2016. 2016 annual report. Utah Division of Air Quality, Salt Lake City, Utah.

UDEQ. 2019a. Black and yellow wax. Available at: https://deq.utah.gov/general/petroleum (accessed 23 May 2019).

UDEQ. 2019b. Uinta Basin Ozone Studies (UBOS). Availale at: https://deq.utah.gov/air-quality/uinta-basin-ozone-studies-ubos.

4.7. Water Quality

4.7.1. Background and Importance

Dinosaur National Monument (DINO) includes three distinct river canyons that have been carved by eons of snowmelt-driven river flows from the Green and Yampa Rivers. DINO contains 46 miles of the lower Yampa River, the last largely free-flowing, large river in the entire Colorado River system. The Yampa's natural flow provides a unique whitewater rafting experience and important habitat for native and endangered Colorado River Basin fish.

In contrast, 47 miles upstream of the monument, the Green River is dammed and regulated at Flaming Gorge Reservoir. Thus, below the confluence of the Green and Yampa Rivers, a "hybrid" river exists, consisting of input from the free-flowing Yampa and the flow-regulated Green. This living laboratory of a natural and modified river system in one park unit provides a rare opportunity for inquiry and study of river sciences, including the impact of flow regulation on water quality. Comparing the three river reaches informs management for long-term river ecosystem health and function in the face of climate change and human population growth.

The main source of flow in these two rivers is snowmelt from mountain ranges along the Continental Divide in Wyoming and Colorado, as summer rainstorms do not significantly add to overall flows (Harza 2001). The highest flows typically occur in May. Perennial tributaries that flow into the Green River within the monument include Jones Hole Creek, Zenobia Creek, Garden Creek, and Pool Creek. Cub Creek joins the Green River outside the monument boundaries (Sumsion 1976). In addition to the major rivers and tributaries, there are also numerous springs and ephemeral drainages in the area (Miller 2002).

A detailed examination of river flows, sedimentation and geomorphology for the Yampa River above the confluence with the Green, the Green River above the confluence with the Yampa, and the Green River below the confluence with the Yampa is presented in Section 4.8, *Yampa and Green River System*.

<u>Yampa River</u>

The Yampa River extends for nearly 250 miles from its source in the Park Range in Routt County, Colorado, to its confluence with the Green River. The upper watershed is predominantly forested and the lower watershed also includes agricultural uses in and above the Yampa River Valley. The water quality of the Yampa River is generally good, especially in the upper reaches in the high mountains. Portions of the headwaters have been designated as "Outstanding Waters" for their high-quality trout habitat (Harza 2001). However, accelerated sedimentation, elevated pH levels, naturally occurring salts, and more recently emerging contaminants have become a concern within some lower elevation tributaries (Harza 2001, NPS 2015). The Yampa River enters the monument at Deerlodge Park, in the eastern section of the monument. From there, it flows in a generally westward direction for 46 miles through the Yampa Canyon and joins the Green River at Echo Park.

In the entire Colorado River System, the Yampa is the only major tributary that is mostly free of major instream impoundments (NPS 1995). The largest impoundments include Stagecoach and Catamount Reservoirs upstream from Steamboat Springs, Steamboat Lake on the upper Elk River,

and Elkhead Reservoir on Elkhead Creek. The largest water diversion in the Yampa is the Maybell Canal, dating back to 1899 (Colorado River District 2019). Despite these impoundments and one notable diversion canal, the Yampa is commonly referred to as being largely unregulated.

Green River

The Green River originates in the Wind River Mountains of Wyoming and enters the monument in the northern section at Browns Park, Colorado. It then flows for 19 miles south through the gorge of the Canyon of Lodore where it meets the Yampa River in Echo Park. From Echo Park the river leaves the monument 26 miles further downstream through Split Mountain Canyon in the southwest portion at 4,730 feet, the lowest elevation in the monument. Water quality of surrounding areas is generally good although water flows and sediment levels have been altered by human activities, such as damming and diversion of water for agricultural purposes. The Green River above the confluence with the Yampa River has been impacted by Flaming Gorge Dam operations, while water quality below the confluence with the Yampa River is in good to fair condition, although up–to-date water quality data are somewhat lacking (NPS 2015).

Groundwater and Upland Water Resources

Aquifers within the monument are mainly sandstone and limestone formations that are drained from higher areas (Sumsion 1976). Inflow of groundwater to rivers is believed to occur in a few locations within the monument, predominantly in the Weber Sandstone and Morgan Formation (Foster et al. 2000). Through the monument, there are many areas with seeps or springs, especially in canyons where water seeps out through the rock. The quality of these water sources varies depending upon the type and level of utilization. Some spring locations have been used or developed as permanent water sources for livestock, homesteads, or farming. Little data or information exist for the few perennial streams and numerous ephemeral streams. These resources and groundwater dynamics are not examined in this report. Seeps and springs are examined briefly in Section 4.8.

Threats and Stressors

Human population growth, transmountain diversions, in-basin depletions and impoundments, increasing nonpoint pollution sources, and competing water interests threaten both the Yampa and Green Rivers. Increase in mean annual temperature and drought, dust on snow, and other climate change effects can and have altered timing, magnitude, and duration of snowmelt, with significant implications for river ecosystem health and function (NPS 2015).

Exceedance of water quality standards for nitrogen and phosphate have been noted at DINO, with phosphates regularly being found in high concentrations in both the Yampa and Green Rivers (Brown and Thoma 2012). Agricultural land uses (which are primarily rangeland and hay production, as shown in Section 4.1) in the Yampa and Green River Basins are a likely contributor to at least a portion of these nutrients being introduced into surface waters.

Although mercury is a concern at some Northern Colorado Plateau Network (NCPN) locations, no samples for this toxic metal have been taken inside the monument since 2011 (Thoma et al. 2007, EPA 2018b). Samples from outside of the monument (from the Yampa River upstream of DINO, and

the Green River downstream of the monument) have shown elevated levels of mercury (Hinck et al. 2007).

Contaminants of emerging concern (CECs), such as pharmaceuticals and pesticides, have been found throughout the Northern Colorado Plateau in varying concentrations (Weissinger et al. 2016). Concentrations of CECs at DINO are generally low and below available thresholds for aquatic life and human health, although the effects of many CECs are poorly understood (Weissinger et al. 2016).

Indicators and Measures

Three core parameters are examined for every water quality sample: temperature, pH, and dissolved oxygen (NPS 2016). (Data for specific conductance and flow have also been collected in DINO, but those parameters are not assessed for this analysis, as explained below.) These core parameters, in addition to other field and laboratory measurements chosen depending on local water-quality concerns, are compared to state water quality standards to determine whether current concentrations are within these limits and to detect changes over time that may lead to a parameter going beyond its acceptable limit (NPS 2016). In addition to the core parameters, seven additional measures (total dissolved solids, chloride, sulfate, iron, *Escherichia coli*, nitrogen, and phosphorus) were added to this analysis due to their usefulness in determining potential degradation with respect to drinking water supply, recreational contact, or the health of aquatic organisms. Commonly used indicators and measures that were not included in this analysis (turbidity, aquatic macroinvertebrates and pharmaceuticals) are mentioned at the end of this section with the rationale for not including them.

Specific Conductance

Specific conductance is a measure of a sample of water's ability to pass electrical current, and is largely affected by the presence of inorganic dissolved solids. Conductance in natural bodies of water is primarily due to the geology of the surrounding area. However, certain human-induced impacts can alter conductivity, such as a sewage leak (raises conductivity) or an oil spill (lowers conductivity) (EPA 2012b). This measure was not included in this analysis because there is no standard for the State of Colorado, State of Utah, or the EPA.

Flow

Flow rate is the volume of water per unit time. Flow rates are important to aquatic and terrestrial fauna as well as to water quality (EPA 2013c). Larger flow rates can ameliorate pollutants in a water body faster than smaller flow rates. Organisms are influenced by water body flow rates as well; some aquatic fauna require fast flowing waters while others require calm pools or springs (EPA 2013c). The flow rates for each river segment are covered extensively in Section 4.8, *Yampa and Green River System*.

Temperature

Water temperature has a major influence on water chemistry, biological activity, and the species of organisms that can survive in a body of water. Higher water temperatures generally increase the rate of chemical reactions, which can lead to more dissolved minerals and metals. More importantly, in terms of the Green and Yampa River systems, water temperature is the primary determinant of

dissolved oxygen levels in surface waters, with colder water able to hold more dissolved oxygen. Species that are adapted to higher levels of dissolved oxygen may not be able to survive in a body of water with lower levels. Changes in water temperature can be caused by runoff from impervious surfaces, seasonal changes, loss of riparian vegetation, impoundments such as dams, and climate change (USGS 2016). Large dams, such as Flaming Gorge Reservoir on the Green River, can change natural seasonal patterns of water temperature, leading to altered timing of biological events for aquatic organisms such as spawning, mating, migration, and insect hatches (Caissie 2006).

pH

Measured on a scale of 0 (pure acid) to 14 (pure base), pH is a measure of how acidic or basic a water sample is. Aquatic life forms are adapted to the pH range found in the body of water in which they evolved. Even small to moderate changes can have large effects on fish, amphibians, and aquatic insects. Some of these effects include reduced hatching success and irritation of gills and other membranes. Like temperature, changes in pH can also alter chemical reactions that take place in a water body, making certain compounds more toxic (like ammonia), and promoting leaching of metals from surrounding bank and bed materials (like aluminum). Atmospheric deposition of acidic compounds from past and present industrial processes and point source pollution, especially from mining, can alter the pH of surface waters (Mesner and Geiger 2005).

Dissolved oxygen

Dissolved oxygen (DO) in water bodies is critical for aquatic fauna. Oxygen enters water bodies from the atmosphere as well as via ground water discharge (USGS 2013a). The amount of DO in a water body is also related to the temperature of the water body; cold water is able to hold more oxygen than warm water (USGS 2013a). All forms of aquatic life use DO and therefore, DO is used to measure the “health” of lakes and streams. Depletion of DO from water bodies can have negative effects on the development of larval and juvenile fish (Doudoroff and Shumway 1970).

Total dissolved solids

Total dissolved solids (TDS) is a measure of the total concentration of dissolved substances in water (SDWF 2013). TDS may consist of inorganic minerals or salts in ionic and organic material. TDS for a sample of water is measured by passing the sample through a 0.45 micron filter to remove suspended solids; the remaining water is evaporated and the remaining residue represents the TDS concentration in milligrams per liter (mg/L) (SDWF 2013). Common sources of TDS include mineral springs, urban runoff, sewage, fertilizers, and soil erosion. TDS concentrations can impact the water balance of cells within aquatic organisms by causing the cells to swell when TDS is too low and to shrink when TDS is too high (EPA 2013a). Reservoirs can both lower and raise TDS depending on their location and type of bank material.

Chloride

Chloride forms inorganic salts that may be deposited into surface waters from a variety of sources such as road salting, oil and gas wells, and agricultural runoff (McDaniel 2013). High levels of chloride can be toxic to freshwater fish and macroinvertebrates. The toxicity of chloride is increased when mixed with potassium or magnesium, as it is with certain road salts (NHDES undated). When these metals are released from chloride, dissolved oxygen levels are reduced, which causes additional

stress to aquatic life (NHDES undated). Additionally, high chloride levels can facilitate some fast-growing invasive plants, such as Eurasian water milfoil, which can out-compete native fauna (Evans and Frick 2001).

Sulfate

Sulfate is a constituent of TDS and may form salts with sodium, potassium, calcium, magnesium, and other cations. Sulfate can occur naturally in surface waters but anthropogenic sources such as reverse osmosis-reject water, waste from pyrite oxidation, atmospheric deposition of sulfate from the combustion of fossil fuels, and coal preparation wastewater may lead to elevated levels of sulfate. Elevated levels of sulfate may be toxic to some macroinvertebrates while fish are more tolerant of excess sulfate (IDNR 2013).

Iron

Iron is an abundant metal, making up about 5% of the earth's crust. Iron is most commonly found in nature combined with oxygen- and sulfur-containing compounds in the form of oxides, hydroxides, sulfates and carbonates (WHO 1996). An essential element in human nutrition, iron consumption, even at high levels, is unlikely to cause adverse effects. The taste and appearance of drinking water can be affected by high levels of iron, and high levels of the metal are primarily a concern in terms of drinking water standards dealing with aesthetic properties for human consumption.

Naturally occurring mineralization of iron is common in the area, thus elevated iron concentrations are not abnormal for the region (Roehm 2004, Harza 2002, Thoma et al. 2007). High iron concentrations can also be the result of mining operations. Iron concentrations at Deerlodge Park, Colorado, are regularly higher than levels observed near Craig, Colorado, indicating that a source of the metal exists between these two locations along the Yampa River (Hackbarth and Weissinger 2016).

Escherichia coli

Escherichia coli (*E. coli*) bacteria are measured via a laboratory test examining the number of bacteria colonies that grow on a prepared medium (USGS 2013b). *E. coli* are coliform bacteria found in the intestinal tract of warm-blooded animals. *E. coli* can cause a variety of illnesses and have been used to establish microbial water quality criteria (USGS 2013b). Levels of this bacterium are a concern at DINO due to the possibility of ingesting water while boating or swimming; all river segments at the monument are listed as primary contact recreational waters by their respective states because of the popularity of these activities.

Nitrogen (as Nitrate and Nitrite)

Nitrate and Nitrite as N is a measure of the inorganic forms of nitrogen. Excessive nitrogen in a water body can lead to increased plant production and toxic conditions for aquatic life as well as humans (EPA 2013b).

Total Phosphorus

Total phosphorus is a measure of all forms of phosphorus found in a water sample. Like nitrogen, phosphorus can be found in a variety of forms. Excessive phosphorus in a water body can also lead to

greatly increased plant production which can, in turn, lead to eutrophication of water bodies. Large growths of plants or algae along waterways can lead to fish illness and mortality (EPA 2013b).

Turbidity

One of the many ecological effects of the Flaming Gorge Reservoir has been a decrease in turbidity of the Green River below the dam, as naturally suspended sediment upstream of the reservoir is able to settle out in the relatively slow-moving currents of the reservoir. Fishes endemic to the region have evolved with naturally high turbidity, as is still mostly present in the Yampa River (NPS 2005). However, decreases in sediment input from the Little Snake River (the Yampa River's primary sediment source) since at least 1960 are already having an effect on the Yampa River as evidenced by altered channel structure and riparian vegetation (Scott and Friedman 2018). Low turbidity levels can increase predation of juvenile native fishes such as humpback chub (*Gila cypha*) and flannelmouth sucker (*Catostomus latipinnis*) by introduced fishes such as rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) (Karp and Tyus 1990, Yard et al. 2011).

No water-quality standards exist for turbidity for the Green or Yampa Rivers, so turbidity will not be examined further or given a condition rating.

Aquatic macroinvertebrates

Aquatic macroinvertebrates live in the water for all or part of their lives and are dependent on water quality. Aquatic macroinvertebrates are an essential part of the food chain in aquatic environments. They are sensitive to chemical, physical, and biological water conditions and are a good indicator of water quality (EPA 2013d). Some aquatic macroinvertebrates, such as stonefly nymphs, are more sensitive to water quality than others. For example, stonefly nymphs cannot survive low DO levels and their absence may indicate the impaired "health" of a water body (EPA 2013d).

Miller et al. (2012) listed mean taxa richness for samples taken throughout DINO in all three river segments as ranging from approximately 13 taxa (near Gates of Lodore in 2011) to approximately 22 taxa (in the Yampa River in 2010), indicating that aquatic macroinvertebrates at DINO may be in poor condition. A recent Master's Thesis by Metcalfe (2018) employed a citizen science approach to examine species and genetic-level diversity of the net-spinning caddisflies (*Hydropsyche* spp.). However, the Metcalfe data and results do not support examination of benthic assemblages, diversity, or abundances. The reference condition for taxa richness for DINO is unknown due to a lack of available datasets and technical reports regarding aquatic macroinvertebrate assemblages in or near the park. Therefore, aquatic macroinvertebrates will not be analyzed further or given a condition rating.

Pharmaceuticals and other Organic Contaminants

Beginning in 2015, in conjunction with the EPA Region 8 office, surface waters at 18 locations in the NCPN were periodically sampled for pharmaceuticals and drugs, personal care products, pesticides, hormones and phytosterols, as well as other indicators of wastewater pollution. These wastewater indicators, commonly referred to as contaminants of emerging concern (CECs), are trace organic compounds not commonly tested for in routine water quality monitoring and can have adverse effects on organisms even at very low concentrations (Battaglin and Kolok 2014, Weissinger et al. 2016).

Locations sampled at DINO were the Yampa River at Deerlodge Park, Colorado, and the Green River at Jensen, Utah. To date, there have been no exceedances associated with sampling locations at DINO for any of the CECs monitored by the NCPN (Weissinger et al. 2016). An in-depth study of CECs is beyond the scope of this report; condition and trend for CECs will not be included.

4.7.2. Data and Methods

The NPS (2003a) had previously compiled surface water quality data for DINO using six of the EPA's national databases: Storage and Retrieval (STORET) water quality database management system, River Reach File (RF3), Industrial Facilities Discharge (IFD), Drink Water Supplies (DRINKS), Flow Gages (GAGES), and Water Impoundments (DAMS). In addition to retrieving data from within DINO's boundary, stations from 3 miles upstream and 1 mile downstream were included. The retrieval resulted in 54,040 observations at 259 different monitoring stations, with an overall record from 1959 to 2018. For this analysis, three USGS monitoring stations (the Yampa River at Deerlodge Park, CO (USGS-09260050), the Green River above Gates of Lodore, CO (USGS-404417108524900), and the Green River near Jensen, UT (USGS-09261000)) were chosen due to their length of recordkeeping for water quality parameters of interest as well as their usefulness in rating the condition of the three major watersheds located within the park (Figure 4.7-1). A new search of the National Water Quality Monitoring Council water quality portal (NWQMC 2018, a repository that retrieves data from all six of the aforementioned databases) was completed on December 3, 2018, to obtain any new monitoring data since the NPS (2003a) study.

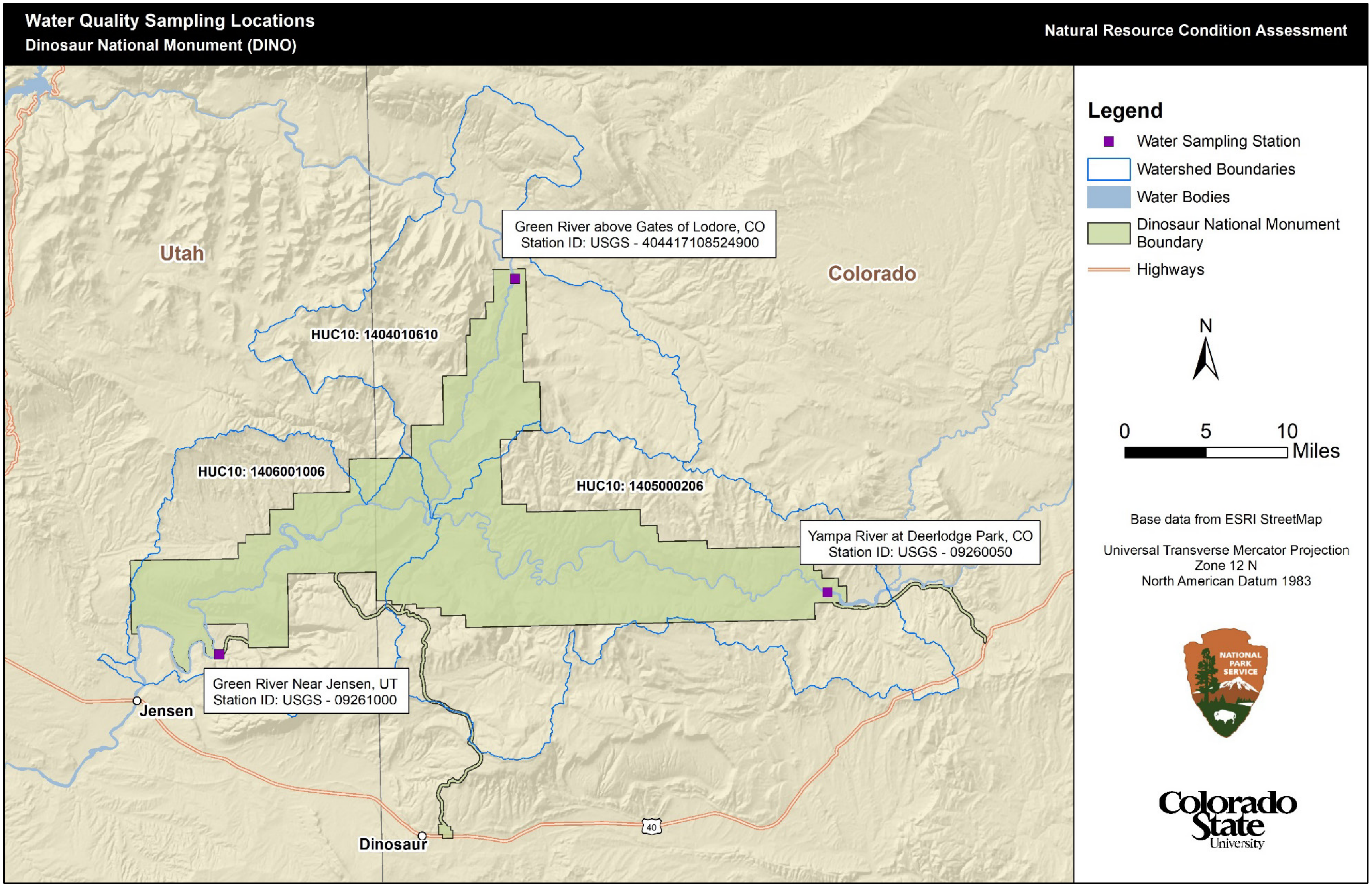


Figure 4.7-1. Water quality study area and sampling station locations for DINO (NWQMC (2018) and ESRI StreetMap).

Condition Rating Methodology

Data were sorted by water-quality parameter, and descriptive statistics and charts showing time-series measurements were created. The condition of water-quality parameters within each watershed were assessed using a methodology developed by the USGS for a summary completed on the Yampa River for water years 2016 and 2017 (USGS 2018). This summary used a three-tiered concern level system similar to that of the NRCA condition rating system described in Chapter 3 of this document. Cutoffs for these three condition levels follow the methodology used by the State of Colorado to assess whether water quality standards for streams are being met (CDPHE 2017). For most water-quality parameters, the 85th percentile of the data for that stream segment was used to determine the concern level. If the 85th percentile was higher than the state standard, the parameter was given a "high concern level," corresponding to the "warrants significant concern" or poor condition category for this analysis. In Appendix B of CDPHE (2017), the State of Colorado suggests that if the 85th percentile of an assessed value exceeds the standard, then there is a high degree of confidence (95%) that the actual concentration is significantly higher than the standard. If the 85th percentile was higher than one-half of the state standard, the parameter was given a "medium concern level," corresponding to the "warrants moderate concern" or moderate condition category for this analysis. Those segments with the 85th percentile less than one-half of the state standard were considered to be in good condition. Closely following USGS (2018), which uses measurements for the last two water years as "current" observations, measurements from the beginning of water year 2017 to present (October 1st, 2016 to present) were used as "current data" and their 85th percentile calculated to determine the condition rating for that parameter and river segment. All parameters apply the above condition rating system except as follows:

Dissolved Oxygen – Per CDPHE (2017), the 15th percentile for DO was used to determine the condition rating. If the 15th percentile for current data is above the standard, the river segment will be considered to be in good condition. If the 15th percentile for current data are below the standard, the river segment will be considered to be in poor condition or "warrants significant concern."

E. coli – The geometric mean for *E. coli* will be used to determine the condition rating. The geometric mean is used in place of an arithmetic mean due to the geometric mean's ability to dampen the effects of very high or low values, which can be helpful when bacteria concentrations often vary by several degrees of magnitude over a specified sampling period (EPA 2012a). If the geometric mean for current data is below the standard, the river segment will be considered to be in good condition. If the geometric mean for current data is above the standard, the river segment will be considered to be in poor condition or "warrants significant concern."

pH – Per CDPHE (2017), the 15th and 85th percentiles for current data will be used to determine the condition rating. If either percentile is outside of the pH range of 6.5–9.0, the river segment will be considered to be in poor condition or "warrants significant concern."

Water Temperature – Water temperature standards for the Yampa and Green Rivers in Colorado are seasonal, with the "warm" and "cool" seasons for each river segment dependent on the reach's classification as a warmwater or coldwater stream. State water temperature standards are based on either the maximum weekly average temperature (MWAT) or the daily mean (DM) standard. Neither

of these is calculable from periodic water samples; therefore, the 85th percentile will be used in this analysis as a comparison to the DM temperature standard for each river segment (USGS 2018). Only warm season water temperature is examined, since exceeding water temperature limits during the winter is not a concern. The State of Utah does not have a temperature standard based on season (27°C for warmwater rivers and streams all year). However, the water temperature data for the Green River near Jensen, Utah segment are sorted using the warm season for the Yampa River (March through November) for a more useful comparison between segments. The 85th percentile for water temperature will be used to determine the condition rating. If the 85th percentile for current data is below the standard, the river segment will be considered to be in good condition. If the 85th percentile for current data is above the standard, the river segment will be considered to be in poor condition or "warrants significant concern."

To determine the condition of each watershed in regard to water quality, each parameter will be scored using the methodology explained in section 3.2.5 (*Symbology and Scoring*), with the combined condition rating depending on the average score of the individual condition ratings. To determine the overall condition of the resource for the monument, the three watershed rating scores will be combined and averaged using the same method.

Trend and Level of Confidence

Data for water years 2016 and earlier (from September 30th, 2016, to the beginning of records for each parameter and station) were used as historical data to determine trends in the condition of each river segment. Trends were determined using a Seasonal Mann-Kendall non-parametric trend test (with LOWESS) run in a DOS-based program developed by the USGS for Mann-Kendall trend tests (Helsel et al. 2006). A nonparametric test was chosen because nonparametric tests have higher statistical power in cases of nonnormality and large data gaps, and are robust against outliers. This particular statistical test accounts for seasonal patterns in data that may lead to inaccurate trend determinations. The Seasonal Mann-Kendall test performs a Mann-Kendall calculation for each season, then combines the results for each season into a single statistic (τ). This trend test is robust and fairly powerful, making it an often-used method for water quality trend determinations (Meals et al. 2011). In addition, differences in parameter concentrations due to the variance in streamflow throughout the year were accounted for by using streamflow as a covariate via a LOWESS (Locally Weighted Scatterplot Smoothing) algorithm. LOWESS is analogous to regression without requiring a straight line as the output. For more information on seasonality, covariance and LOWESS, see Meals et al. (2011). Parameter samples that that did not have a corresponding streamflow measurement on the same day were not used in the trend analysis (the number of samples used is noted in each trend test summary table in the following parameter sections). A significance level of $\alpha = 0.05$ was used for all tests.

To determine the trend of each watershed in regard to water quality, each parameter trend will be scored using the methodology explained in section 3.2.5 (*Symbology and Scoring*), with the combined trend depending on the sum of the individual trends. To determine the overall trend of the resource for the monument, the three watershed trends will be combined using the same method.

For parameters with current data and at least 50 observations, the rating was given high confidence in the assessment. For those parameters and segments without current data, a condition rating was still given using historical data, with the assessment given a low confidence rating and no trend was determined.

4.7.3. Reference Conditions

The reference conditions for DINO water quality are the State of Colorado (from the Colorado Department of Public Health and Environment, CDPHE) and State of Utah water quality standards for surface waters, which provide limits for the health of freshwater organisms, agricultural use, primary contact recreation (e.g., swimming and boating), and drinking water standards (Table 4.7-1, Table 4.7-2). EPA standards are also listed for reference purposes and are used when state standards for the parameter do not exist.

Table 4.7-1. Use designations for river segments applicable to the Green and Yampa Rivers within DINO (CDPHE 2018a, UOAR 2018, NPS 2003b).

Station	River Segment Identifier	Use Designation Codes	Use Designation Description
Yampa River at Deerlodge Park, CO	YR-D	AG ALWW1 RecE DWS	Agricultural use Aquatic-life warmwater class 1 Existing primary-contact recreation Drinking-water supply
Green River above Gates of Lodore, CO	GR-GoL	AG ALCW1 RecE DWS	Agricultural use Aquatic-life coldwater class 1 Existing primary-contact recreation Drinking-water supply
Green River near Jensen, UT	GR-J	1C 2A 3B 4	Drinking-water supply Primary-contact recreation Aquatic-life warmwater species Agricultural use

Table 4.7-2. Colorado, Utah, and EPA standards for surface-water quality (CDPHE 2018a, 2018b, 2018c, EPA 2018a, 2018c, UOAR 2018). Standards are for warmwater aquatic life criteria for rivers and streams unless otherwise noted.

Parameter	Colorado Standard	Utah Standard	EPA Standard
Temperature, water	Mar–Nov: 28.6 °C[1] Dec-Feb: 14.3 °C[1] Apr–Oct: 23.9 °C[2] Nov–Mar: 13.0 °C[2]	27 °C	Location and species dependent
pH	6.5–9.0	6.5–9.0	6.5–9.0
Dissolved oxygen	≥ 5.0 mg/L[1] ≥ 6.0 mg/L[2]	≥ 5.0 mg/L[1]	≥ 5.0 mg/L
Total dissolved solids	none	1,200 mg/L[3]	none[j]
Chloride	n/a[4]	n/a	≤ 860 mg/L[5]
Sulfate	≤ 250 mg/L[5]	≤ 250 mg/L[5]	≤ 250 mg/L[5]
Iron	1000 µg/L	1000 µg/L	1000 µg/L
Coliform bacteria	126 CFU/100ml[6]	126 CFU/100ml[6]	≤ 200 CFU/100mL[6]
Nitrogen	≤ 2 mg/L	≤ 4 mg/L	0.38 mg/L[7]
Phosphorous	170 µg/L[1] 110 µg/L[2]	0.05 mg/L	21.88 µg/L[7]

[1] warmwater stream temperature tier two (WS-II) standard (applicable to Yampa River at Deerlodge Park, Colorado)

[2] coldwater stream temperature tier two (CS-II) standard (applicable to Green River at Gates of Lodore, Colorado)

[3] agricultural use standard

[4] no acute standard, chronic standard is 250 mg/L

[5] standard for drinking water

[6] primary contact recreation standard

[7] based on Aggregate Ecoregion III (Xeric West) nutrient criteria for rivers and streams (EPA 2000)

4.7.4. Condition and Trend

Temperature

For warmwater streams in Colorado, the "warm season" standard (28.6°C) applies from March through November, while the "cool season" (14.3°C) is from December through February. For coldwater streams, the CDPHE warm season standard (23.9°C) applies from April through October, and the cool season standard (13.0°C) from November through March. The State of Utah has a single year-long warmwater standard of 27°C.

All three segments had 85th percentiles that were substantially less than the parameter standard, indicating these segments are currently in good condition for warm season water temperature (Table 4.7-3). It should be noted that water temperature in both segments of the Green River is heavily influenced by releases from the Flaming Gorge dam (Bestgen 2018, Closs et al. 2015), and that lower water temperatures are not always indicative of a "healthier" system, especially in regard to native

warmwater fishes (Clarkson and Childs 2000). Seasonal Mann-Kendall trend tests for all segments show unchanging trends for all three (Table 4.7-4). Measurements for each of the three sampling stations are shown in Figure 4.7-2. Confidence in the condition ratings for all segments is high due to the age and length of data records (Figure 4.7-3).

Table 4.7-3. Warm season water temperature measurements from stations Yampa River at Deerlodge Park, Colorado, Green River above Gates of Lodore, Colorado, and Green River near Jensen, Utah (˚C) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard.

Station	Period of record	n	# exc	Min	Max	Mean (SD)	Historic 85th Percentile	Current 85th Percentile
Yampa River at Deerlodge Park, CO	08/75–10/18	360	2	0.0	32.5	15.3(6.7)	23.1	19.1
Green River above Gates of Lodore, CO	05/99–10/18	97	1	1.1	25.0	11.8(4.0)	15.9	14.8
Green River near Jensen, UT	10/59–10/18	708	0	0.0	26.0	13.0(5.5)	19.5	21.4

Table 4.7-4. Seasonal Mann-Kendall trend test (τ) results for warm season water temperature. Bold values note significance at α=0.05. n = number of observations that met criteria; τ = Mann-Kendall trend statistic.

Station	n	τ	p-value	Trend
Yampa River at Deerlodge Park, CO	248	−0.01	0.84	Unchanging
Green River above Gates of Lodore, CO	71	−0.11	0.39	Unchanging
Green River near Jensen, UT	413	0.08	0.14	Unchanging

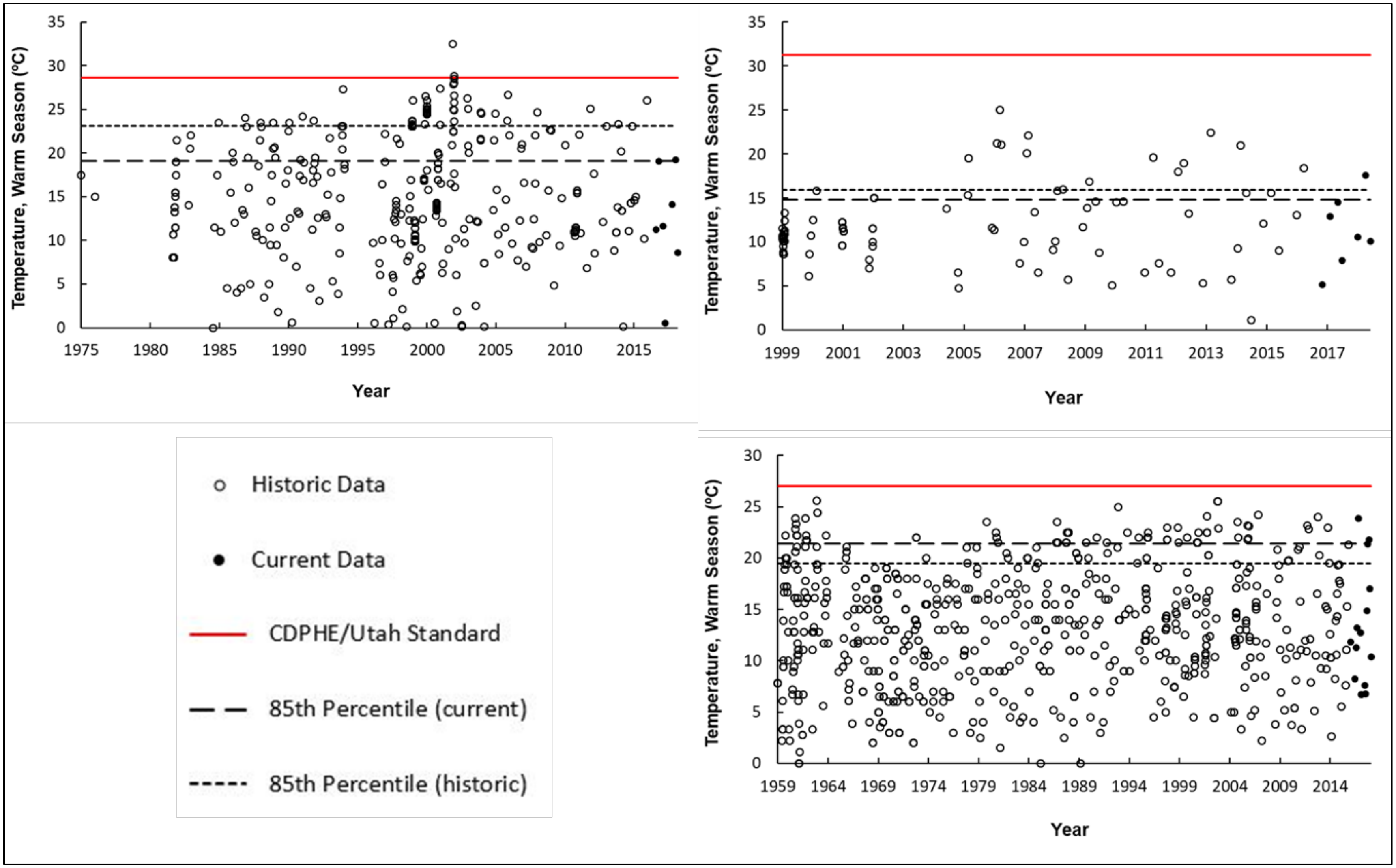


Figure 4.7-2. Warm season water temperature measurements for Yampa River at Deerlodge Park, CO (USGS-09260050, top left), Green River above Gates of Lodore, CO (USGS-404417108524900, top right), and Green River near Jensen, UT (USGS-09261000, bottom right).

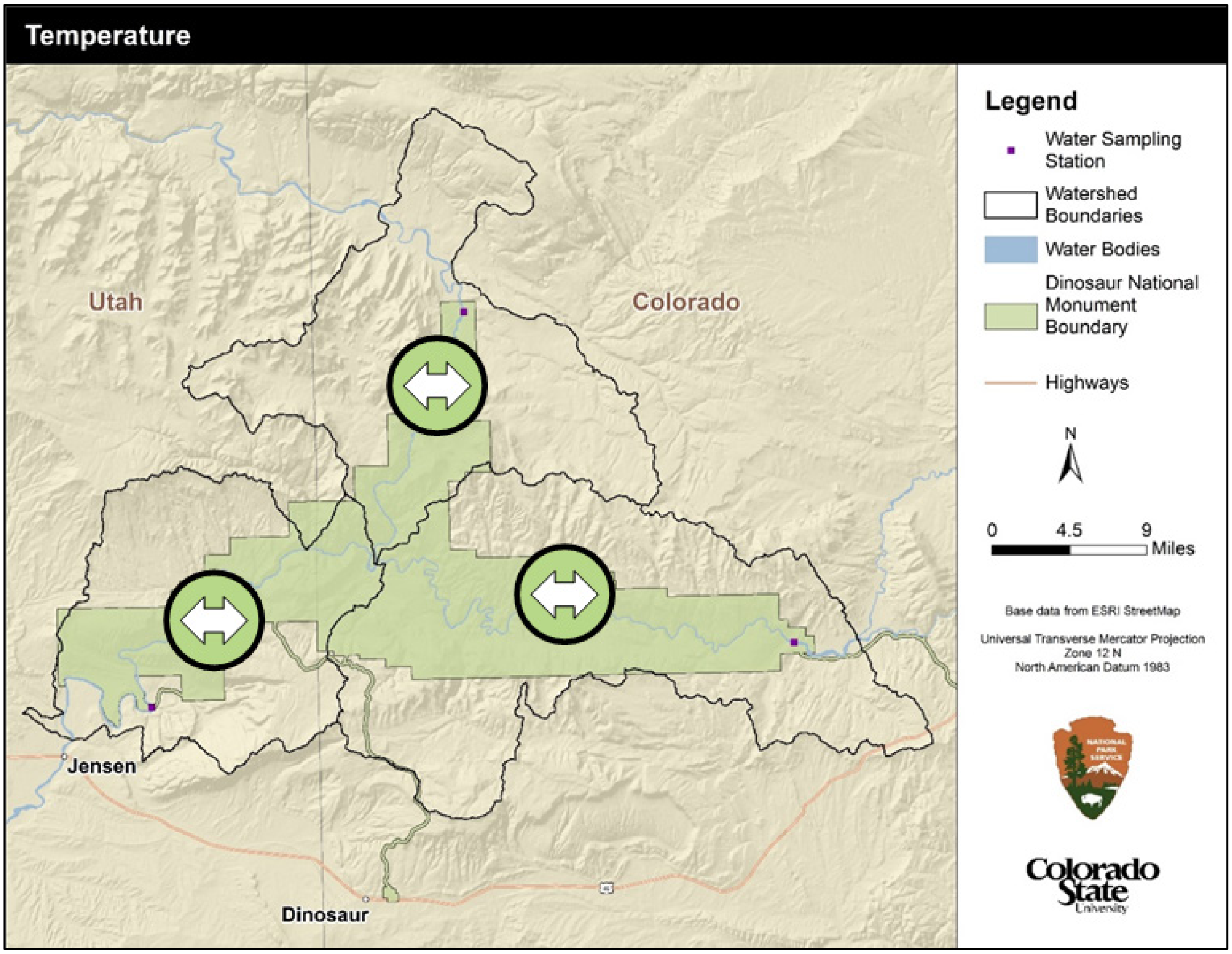


Figure 4.7-3. Warm season water temperature ratings of each of the three watersheds used in this analysis. Green River above confluence (upper), Yampa River (right) and Lower Green River (left). Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

pH

EPA, CDPHE and State of Utah standards for pH are 6.5 to 9.0. The YR-D and GR-GoL segments had 15th and 85th percentiles that were within the standard range, indicating these segments are currently in good condition for pH (Table 4.7-5). GR-J does not have any current data, but data as late as 2012 indicate this segment is also in good condition for pH. Seasonal Mann-Kendall trend tests for the YR-D and GR-GoL segments show unchanging trends for both (Table 4.7-6). Measurements for each of the three study area sampling stations are shown in Figure 4.7-4. Confidence in the condition ratings for the YR-D and GR-GoL segments are high due to the age and length of data records. Due to the age of data for GR-J, this segment was given low confidence in the assessment (Figure 4.7-5).

Table 4.7-5. pH measurements from stations Yampa River at Deerlodge Park, CO, Green River above Gates of Lodore, CO, and Green River near Jensen, Utah (standard units) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard.

Station	Period of record	n	# exc	Min	Max	Mean (SD)	Historic $15^{th}/85^{th}$ Percentile	Current $15^{th}/85^{th}$ Percentile
Yampa River at Deerlodge Park, CO	08/75–10/18	174	0	7.0	8.7	8.3(0.3)	8.1/8.5	8.0/8.4
Green River above Gates of Lodore, CO	02/06–10/18	61	0	8.0	8.8	8.5(0.1)	8.4/8.6	8.4/8.7
Green River near Jensen, UT	04/62–10/12	673	0	6.6	8.8	8.0(0.4)	7.6/8.4	N/A

Table 4.7-6. Seasonal Mann-Kendall trend test (τ) results for pH. Bold values note significance at α=0.05. n = number of observations that met criteria; τ = Mann-Kendall trend statistic.

Station	n	τ	p-value	Trend
Yampa River at Deerlodge Park, CO	117	−0.02	0.86	Unchanging
Green River above Gates of Lodore, CO	54	−0.11	0.39	Unchanging
Green River near Jensen, UT	No current data	No current data	No current data	No current data

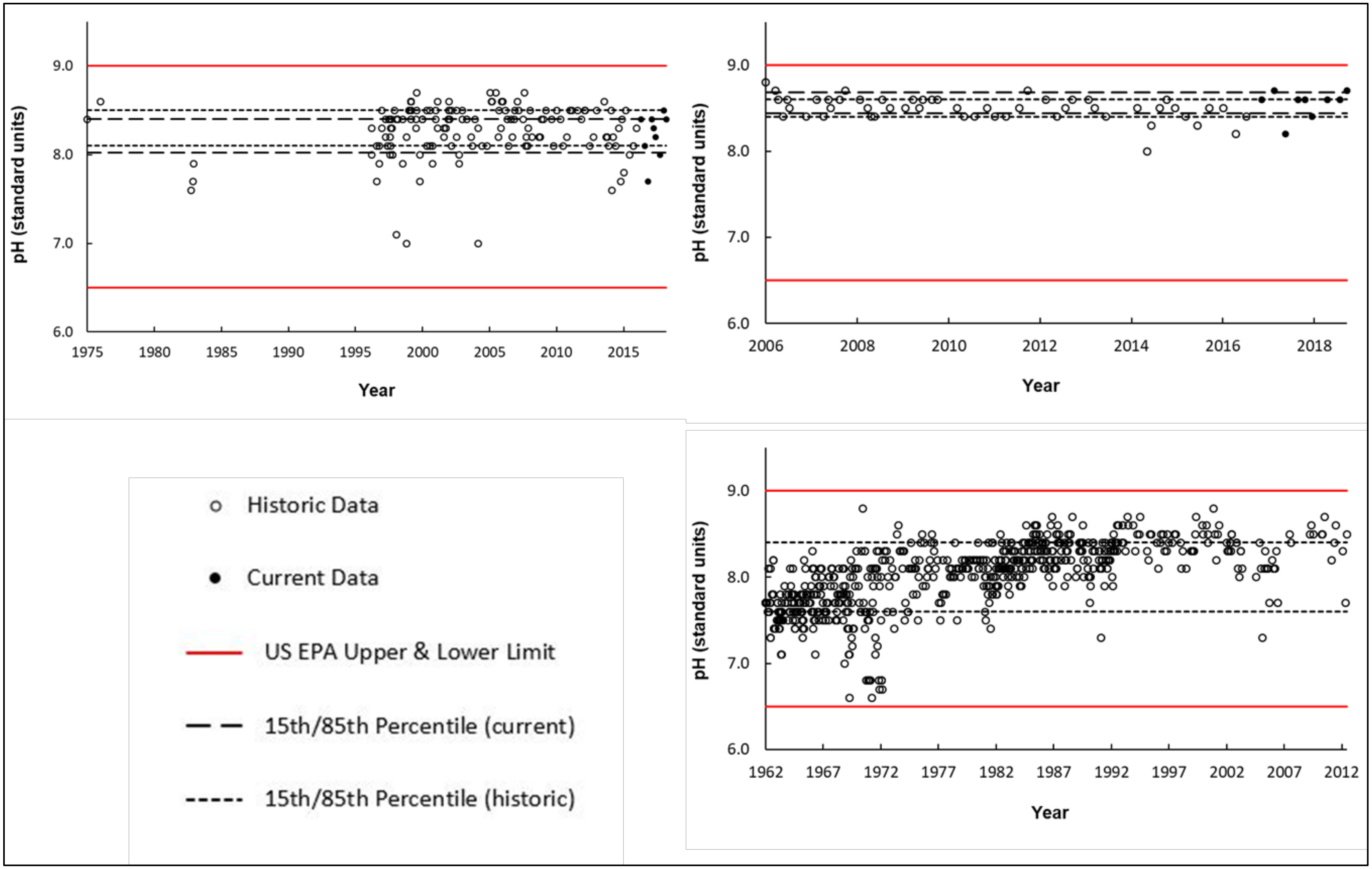


Figure 4.7-4. pH measurements for the Yampa River at Deerlodge Park, Colorado (USGS-09260050, top left), the Green River above Gates of Lodore, Colorado (USGS-404417108524900, top right), and the Green River near Jensen, Utah (USGS-09261000, bottom right).

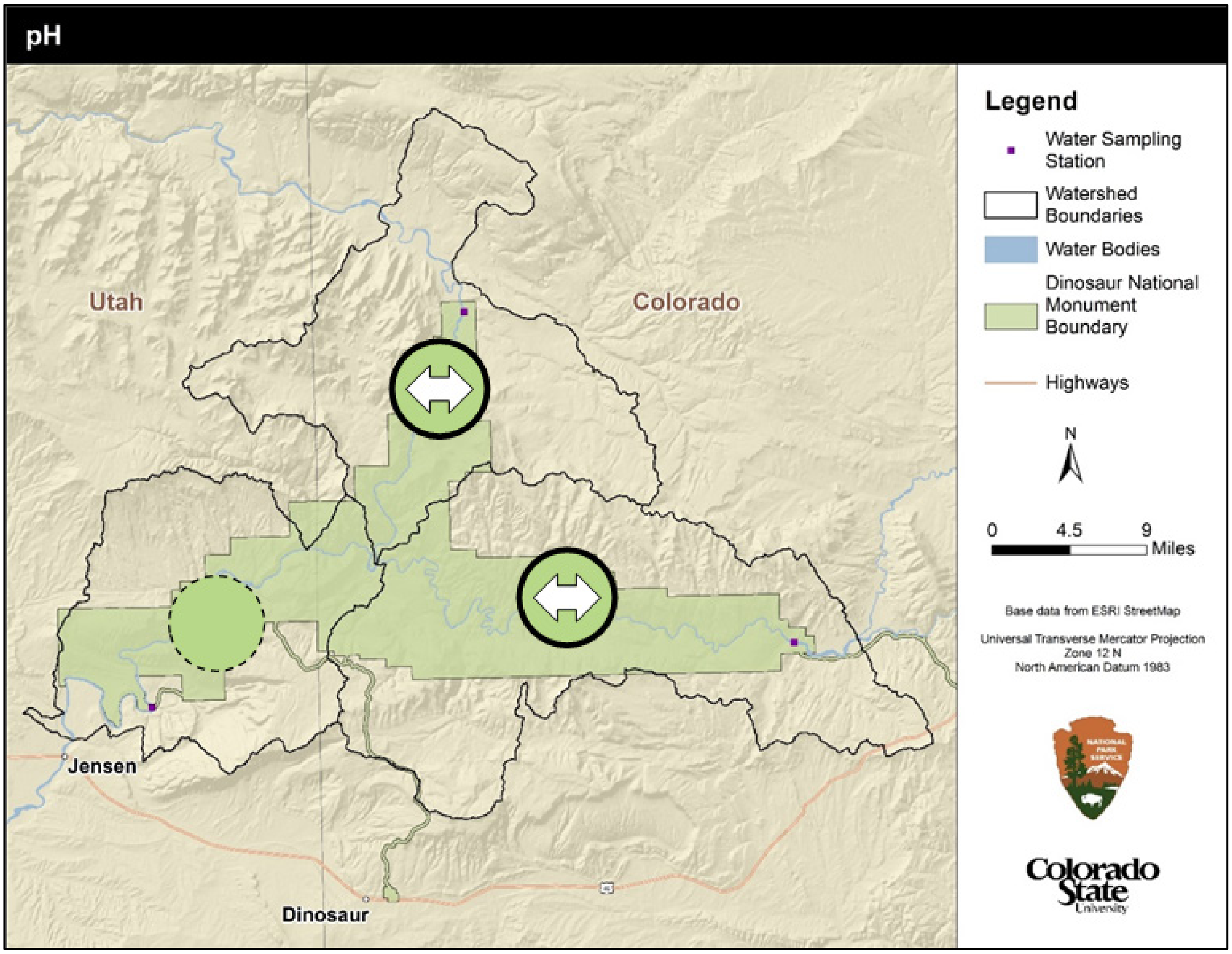


Figure 4.7-5. pH ratings for each river segment. Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

<u>Dissolved oxygen</u>

EPA, Utah, and CDPHE warmwater standards state that DO concentrations must be greater than 5.0 mg/L (for YR-D), while the Colorado standard for coldwater streams (for GR-GoL) is 6.0 mg/L (EPA 1986, CDPHE 2018a, UOAR 2018). The YR-D and GR-GoL segments had 15th percentiles that were greater than their respective standards, indicating these segments are currently in good condition for DO (Table 4.7-7). GR-J does not have any current data, but data as late as 2012 indicate this segment is also in good condition for DO. Seasonal Mann-Kendall trend tests for the YR-D and GR-GoL segments show unchanging trends for both (Table 4.7-8). Measurements for each of the three sampling stations are shown in Figure 4.7-6. Confidence in the condition ratings for the YR-D and GR-GoL segments are high due to the age and length of data records. Due to the age of data for GR-J, this segment was given low confidence in the assessment (Figure 4.7-7).

Table 4.7-7. Dissolved oxygen measurements from stations Yampa River at Deerlodge Park, Colorado, Green River above Gates of Lodore, Colorado, and Green River near Jensen, Utah (mg/L) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard.

Station	Period of record	n	# exc	Min	Max	Mean (SD)	Historic 15th Percentile	Current 15th Percentile
Yampa River at Deerlodge Park, CO	8/75–10/18	129	0	6.4	12.7	9.1(1.6)	7.2	7.6
Green River above Gates of Lodore, CO	2/06–10/18	60	0	7.0	13.6	9.2	7.6	8.2
Green River near Jensen, UT	10/69–10/12	246	0	6.0	14.0	10.0	8.1	N/A

Table 4.7-8. Seasonal Mann-Kendall trend test (τ) results for dissolved oxygen. Bold values note significance at α=0.05. n = number of observations that met criteria; τ = Mann-Kendall trend statistic.

Station	n	τ	p-value	Trend
Yampa River at Deerlodge Park, CO	105	−0.04	0.71	Unchanging
Green River above Gates of Lodore, CO	53	0.10	0.52	Unchanging
Green River near Jensen, UT	No current data	No current data	No current data	No current data

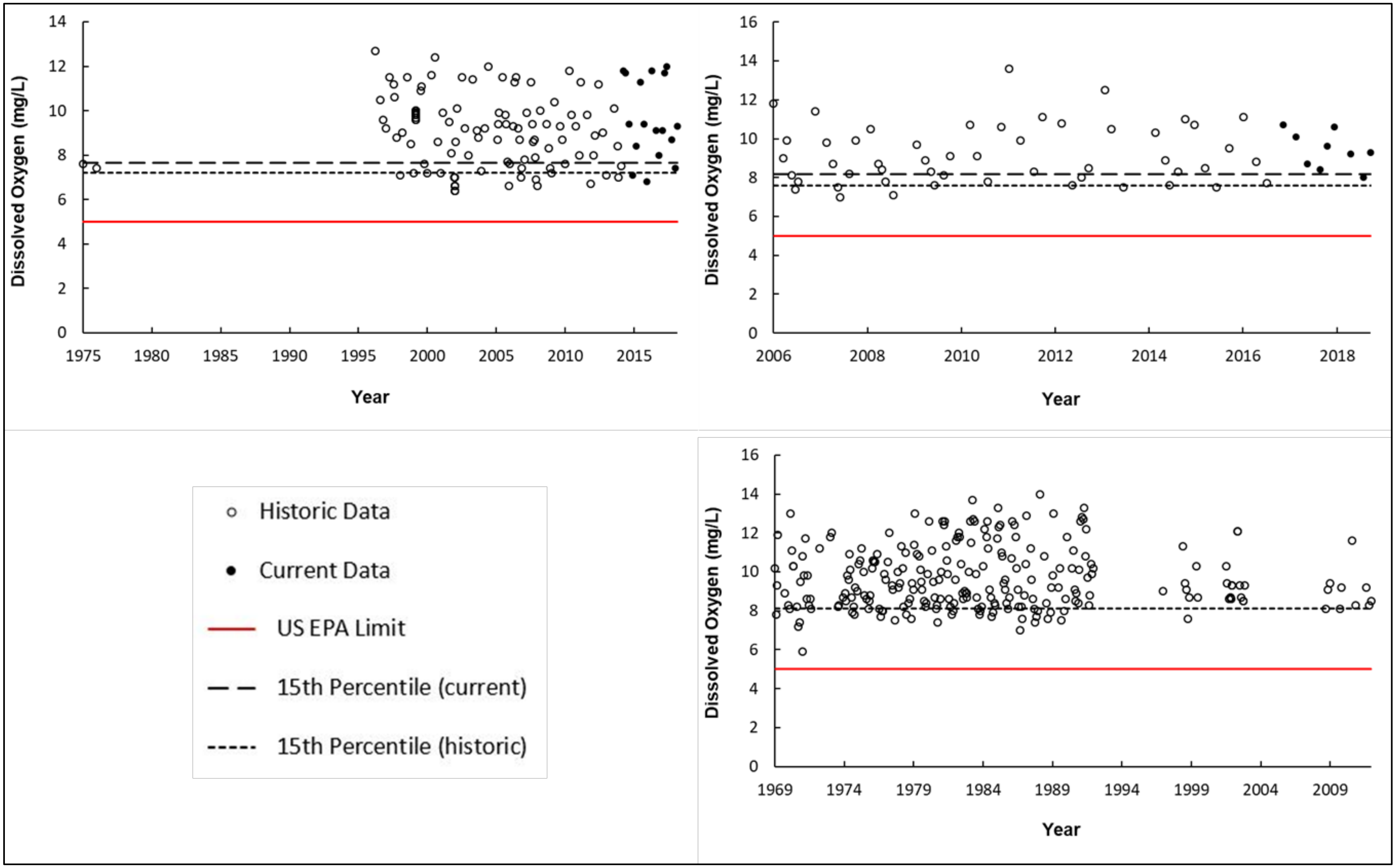


Figure 4.7-6. Dissolved oxygen measurements for the Yampa River at Deerlodge Park, Colorado (USGS-09260050, top left), the Green River above Gates of Lodore, Colorado (USGS-404417108524900, top right), and the Green River near Jensen, Utah (USGS-09261000, bottom right).

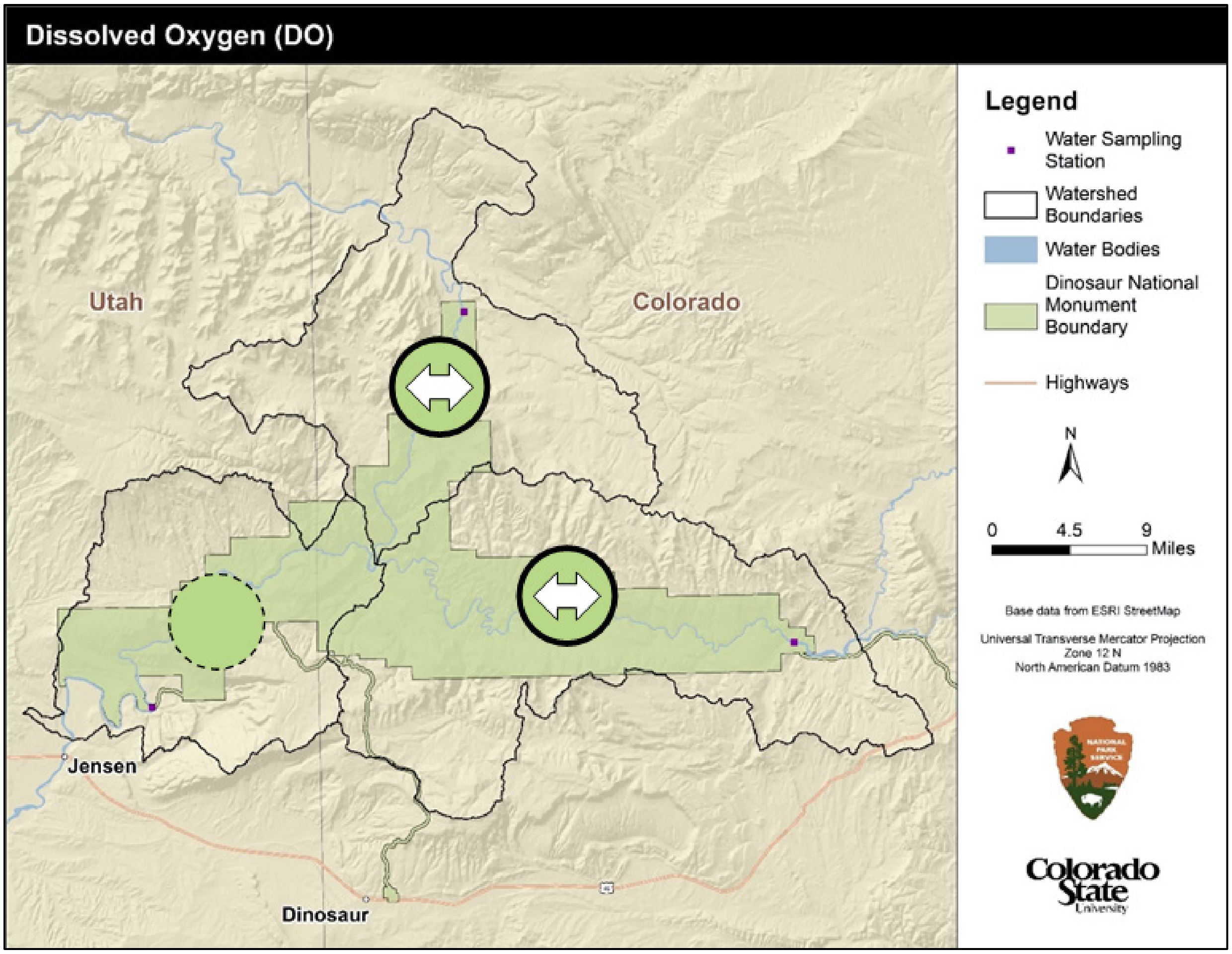


Figure 4.7-7. Dissolved oxygen ratings for each river segment. Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

Total Dissolved Solids

The EPA standard for total dissolved solids in drinking water is less than or equal to 500 mg/L. However, this is an unenforceable secondary standard to be used as a guideline for public drinking water systems for aesthetic consideration (taste and smell) and is not useful for the monitoring of natural bodies of water. The State of Utah has set a standard of 1,200 mg/L for agricultural use. The State of Colorado uses an equation-based standard for irrigation water use with several variables and is beyond the scope of this general assessment; therefore, the Utah standard is used for all stations.

The YR-D and GR-GoL segments had 85th percentiles that were less than one-half of the parameter standard, indicating these segments are currently in good condition for TDS (Table 4.7-9). GR-J does not have any current data, but data as late as 2012 indicate this segment is also in good condition for TDS. Seasonal Mann-Kendall trend tests for the YR-D and GR-GoL segments show unchanging trends for both (Table 4.7-10). Measurements for each of the three sampling stations are shown in Figure 4.7-8. Confidence in the condition ratings for the YR-D and GR-GoL segments are high due to the age and length of data records. Due to the age of data for GR-J, this segment was given low confidence in the assessment (Figure 4.7-9).

Table 4.7-9. Total dissolved solids measurements from stations Yampa River at Deerlodge Park, Colorado, Green River above Gates of Lodore, Colorado, and Green River near Jensen, Utah (mg/L) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard.

Station	Period of record	n	# exc	Min	Max	Mean (SD)	Historic 85th Percentile	Current 85th Percentile
Yampa River at Deerlodge Park, CO	08/83–10/18	115	1	<1	1450	278(180)	405	396
Green River above Gates of Lodore, CO	02/06–08/18	60	0	328	443	389(27)	416	374
Green River near Jensen, UT	06/66–10/12	648	1	90	1220	396(115)	495	N/A

Table 4.7-10. Seasonal Mann-Kendall trend test (τ) results for total dissolved solids. Bold values note significance at α=0.05. n = number of observations that met criteria; τ = Mann-Kendall trend statistic.

Station	n	τ	p-value	Trend
Yampa River at Deerlodge Park, CO	105	−0.17	0.12	Unchanging
Green River above Gates of Lodore, CO	54	−0.40	0.06	Unchanging
Green River near Jensen, UT	No current data	No current data	No current data	No current data

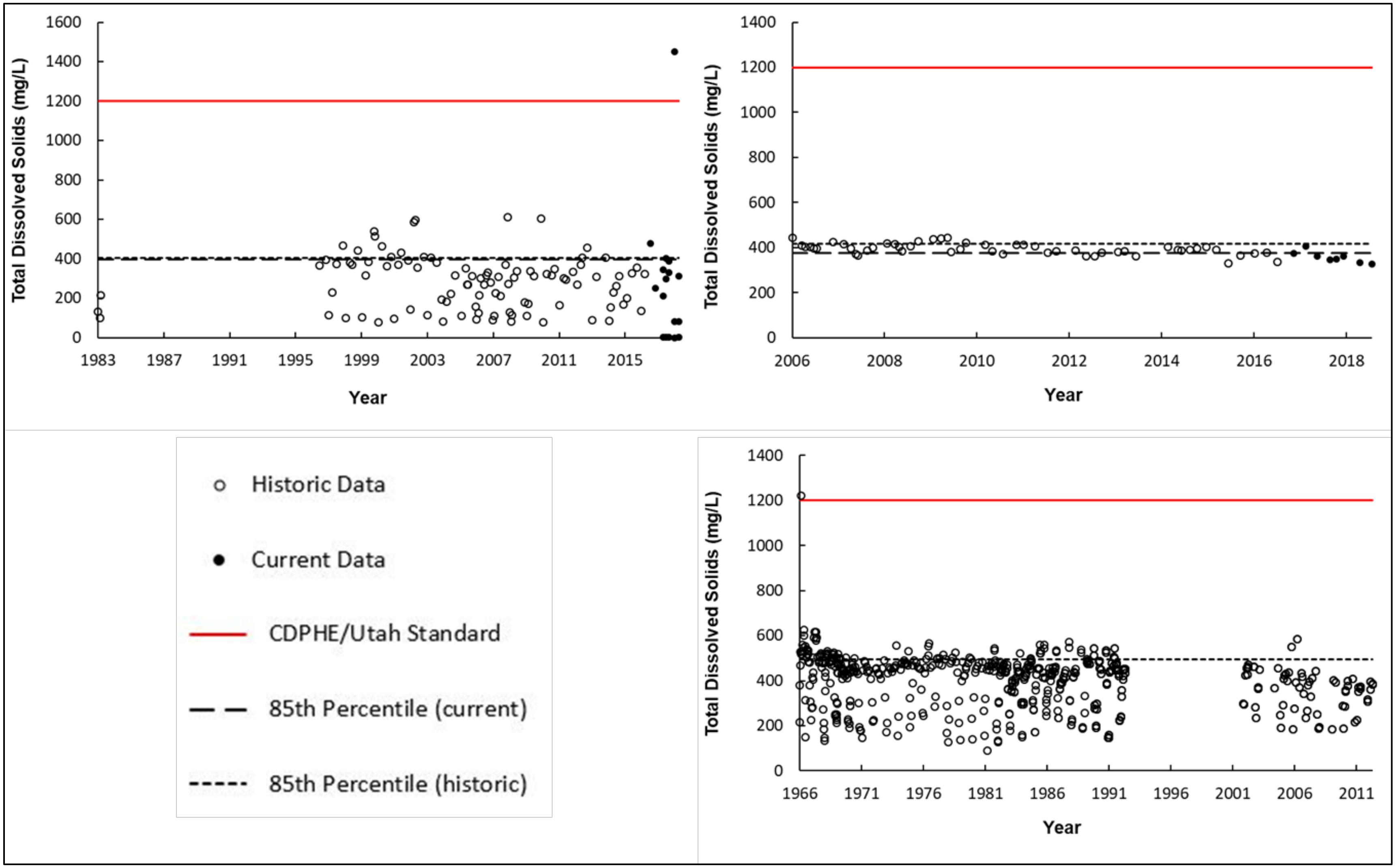


Figure 4.7-8. Total dissolved solids measurements for the Yampa River at Deerlodge Park, Colorado (USGS-09260050, top left), the Green River above Gates of Lodore, Colorado (USGS-404417108524900, top right), and the Green River near Jensen, Utah (USGS-09261000, bottom right). One extreme value for Deerlodge was omitted to improve the scale of the graph.

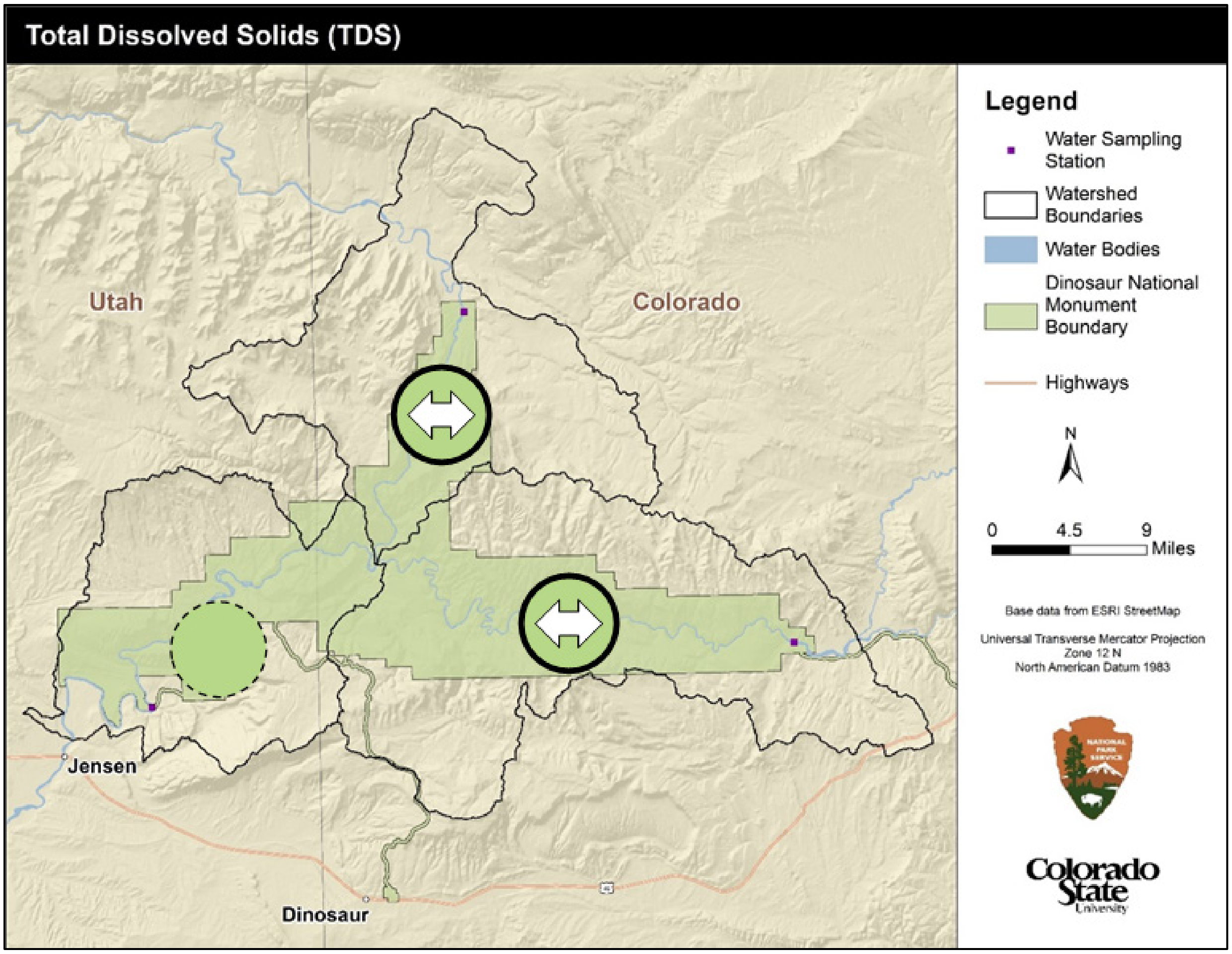


Figure 4.7-9. Total dissolved solids ratings for each river segment. Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

<u>Chloride</u>

The EPA standard for chloride in surface waters is less than or equal to 860 mg/L. Neither state has an acute standard for chlorides; Colorado does have a chronic standard of 250 mg/L. The YR-D and GR-GoL segments had 85th percentiles that were less than one-half of the parameter standard, indicating these segments are currently in good condition for chloride (Table 4.7-11). GR-J does not have any current data, but data as late as 2012 indicate this segment is also in good condition for chloride. Measurements for each of the three sampling stations are shown in Figure 4.7-10. Seasonal Mann-Kendall trend tests for the YR-D and GR-GoL segments show unchanging trends for both (Table 4.7-12). Confidence in the condition ratings for the YR-D and GR-GoL segments are high due to the age and length of data records. Due to the age of data for GR-J, this segment was given low confidence in the assessment (Figure 4.7-11).

Table 4.7-11. Chloride measurements from stations Yampa River at Deerlodge Park, Colorado, Green River above Gates of Lodore, Colorado, and Green River near Jensen, Utah (mg/L) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard.

Station	Period of record	n	# exc	Min	Max	Mean (SD)	Historic 85th Percentile	Current 85th Percentile
Yampa River at Deerlodge Park, CO	05/83–08/18	105	0	1	75	14(12)	23	24
Green River above Gates of Lodore, CO	02/06–08/18	60	0	14	20	17(1)	18	17
Green River near Jensen, UT	04/62–10/12	448	0	3	87	21(11)	28	N/A

Table 4.7-12. Seasonal Mann-Kendall trend test (τ) results for chloride. Bold values note significance at α=0.05. n = number of observations that met criteria ; τ = Mann-Kendall trend statistic.

Station	n	τ	p-value	Trend
Yampa River at Deerlodge Park, CO	105	−0.17	0.09	Unchanging
Green River above Gates of Lodore, CO	54	−0.30	0.14	Unchanging
Green River near Jensen, UT	No current data	No current data	No current data	No current data

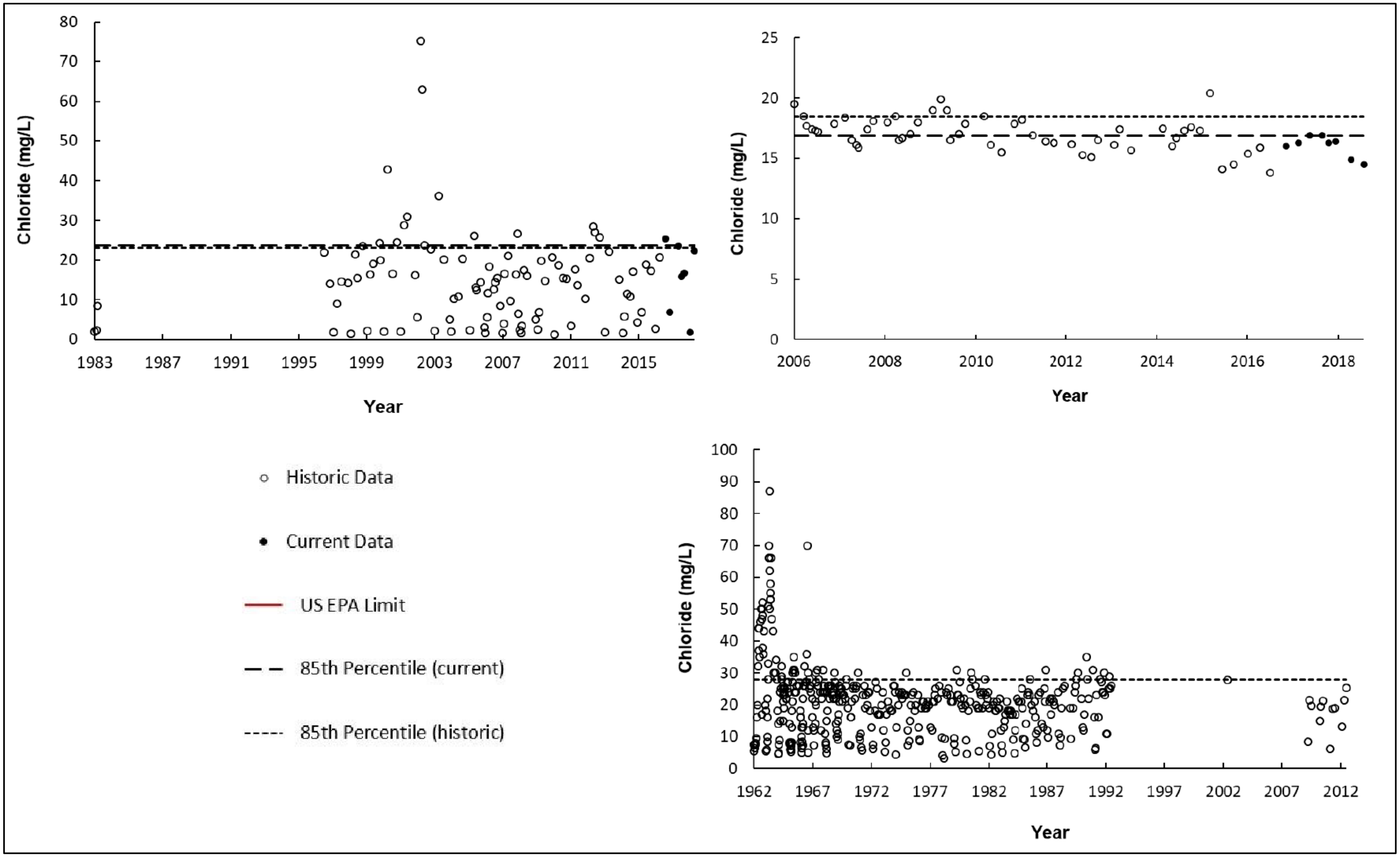


Figure 4.7-10. Chloride measurements for the Yampa River at Deerlodge Park, Colorado (USGS-09260050, top left), the Green River above Gates of Lodore, Colorado (USGS-404417108524900, top right), and the Green River near Jensen, Utah (USGS-09261000, bottom right). The line showing the US EPA limit of 860 mg/L was removed to improve the scale of the graphs.

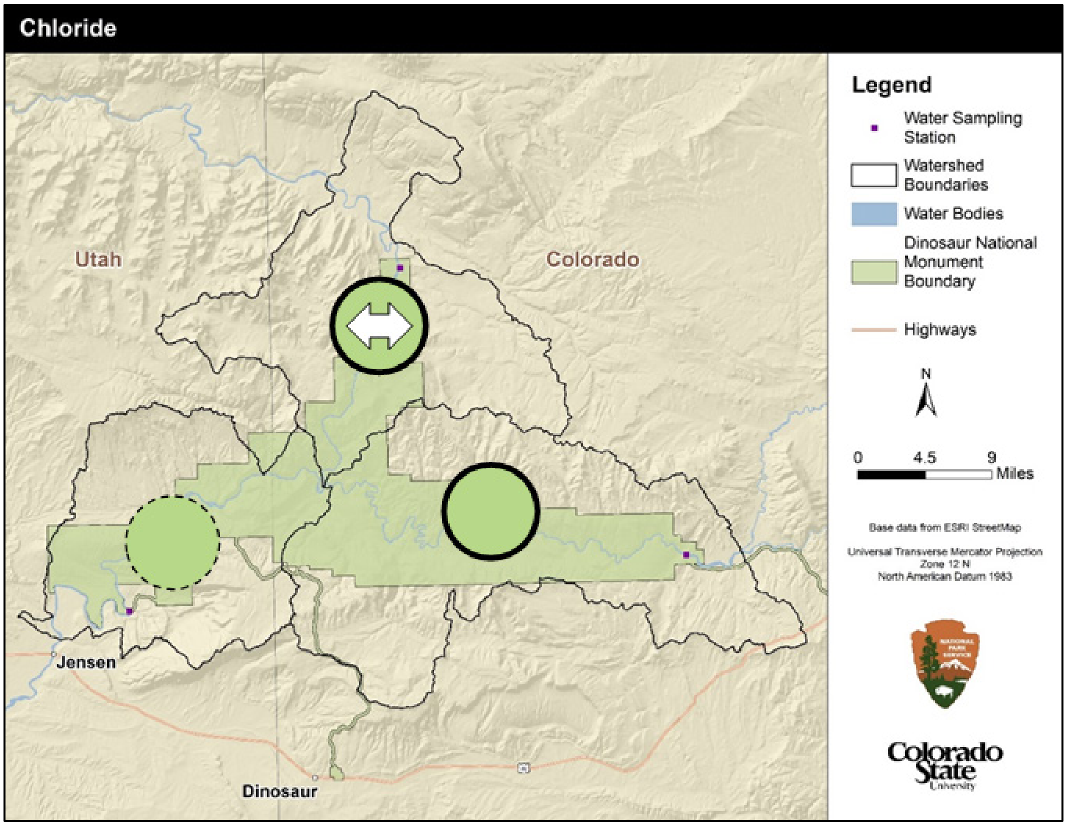


Figure 4.7-11. Chloride ratings for each river segment. Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

<u>Sulfate</u>

The EPA and CDPHE standards for sulfate are less than or equal to 250 mg/L, while Utah has a standard of 1000 mg/L. The YR-D and GR-GoL segments had 85th percentiles that were greater than one-half of the parameter standard, indicating these segments are currently in moderate condition for sulfate (Table 4.7-13). GR-J does not have any current data, but data as late as 2012 indicate this segment is also in moderate condition for sulfate. Seasonal Mann-Kendall trend tests for the YR-D and GR-GoL segments show an improving trend for GR-GoL and an unchanging trend for YR-D (Table 4.7-14). Measurements for each of the three sampling stations are shown in Figure 4.7-12. Confidence in the condition ratings for the YR-D and GR-GoL segments are high due to the age and length of data records. Due to the age of data for GR-J, this segment was given low confidence in the assessment (Figure 4.7-13).

Table 4.7-13. Sulfate measurements from stations Yampa River at Deerlodge Park, Colorado, Green River above Gates of Lodore, Colorado, and Green River near Jensen, Utah (mg/L) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard.

Station	Period of record	n	# exc	Min	Max	Mean (SD)	Historic 85th Percentile	Current 85th Percentile
Yampa River at Deerlodge Park, CO	05/83–08/18	105	2	13	293	92.5(58)	109	145
Green River above Gates of Lodore, CO	02/06–08/18	60	0	111	200	153(19)	171	137
Green River near Jensen, UT	04/62–10/12	449	2	20	1290	163(99)	217	N/A

Table 4.7-14. Seasonal Mann-Kendall trend test (τ) results for sulfate. n = number of observations that met criteria; τ = Mann-Kendall trend statistic.

Station	N	T	p-value	Trend
Yampa River at Deerlodge Park, CO	105	−0.20	0.08	Unchanging
Green River above Gates of Lodore, CO	54	−0.51*	**0.02***	**Improving***
Green River near Jensen, UT	No current data	No current data	No current data	No current data

* Values note significance at α=0.05 (also in bold).

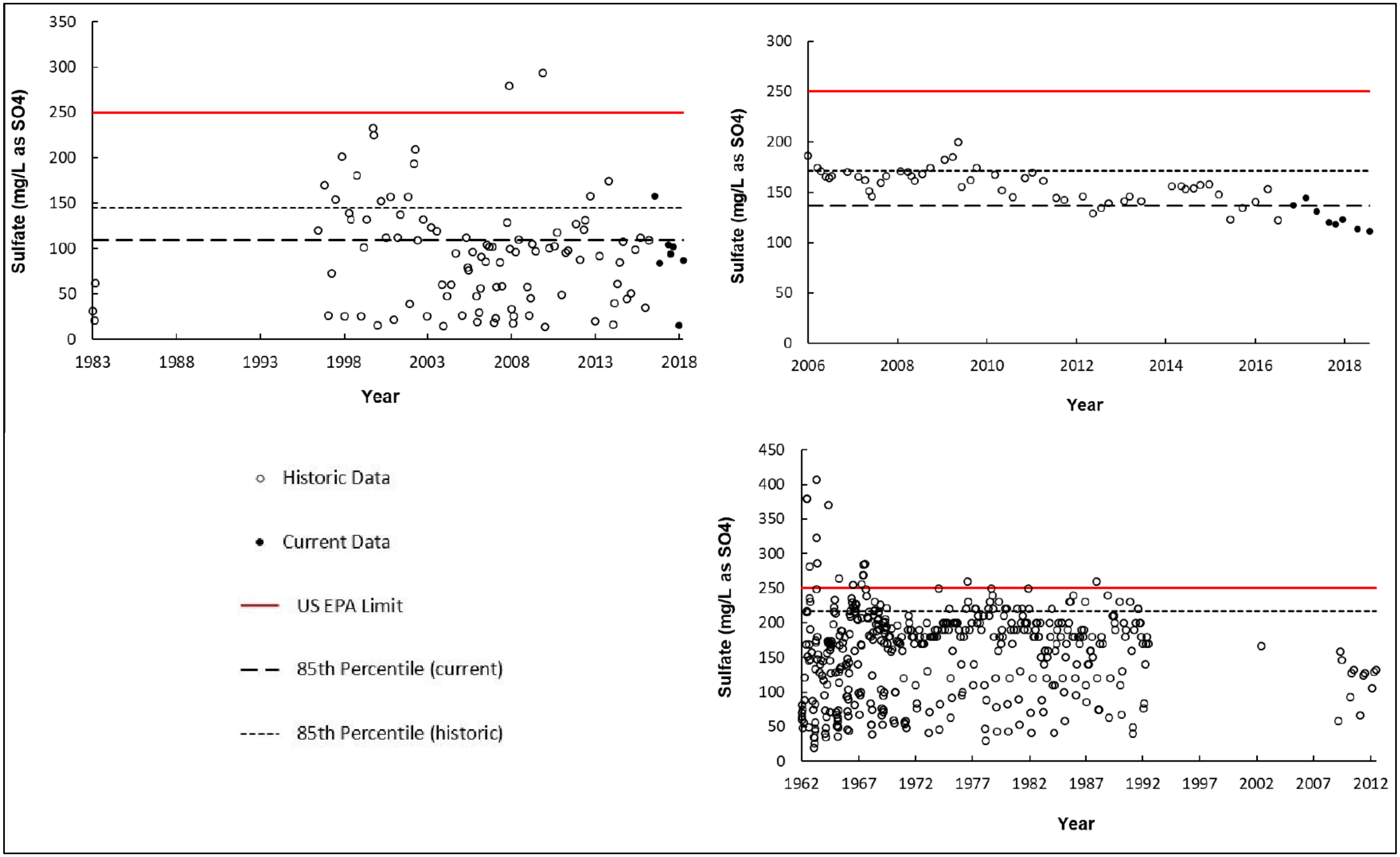


Figure 4.7-12. Sulfate measurements for the Yampa River at Deerlodge Park, Colorado (USGS-09260050, top left), the Green River above Gates of Lodore, Colorado (USGS-404417108524900, top right), and the Green River near Jensen, Utah (USGS-09261000, bottom right). Some extreme samples were omitted from Deerlodge to improve the scale of the graph.

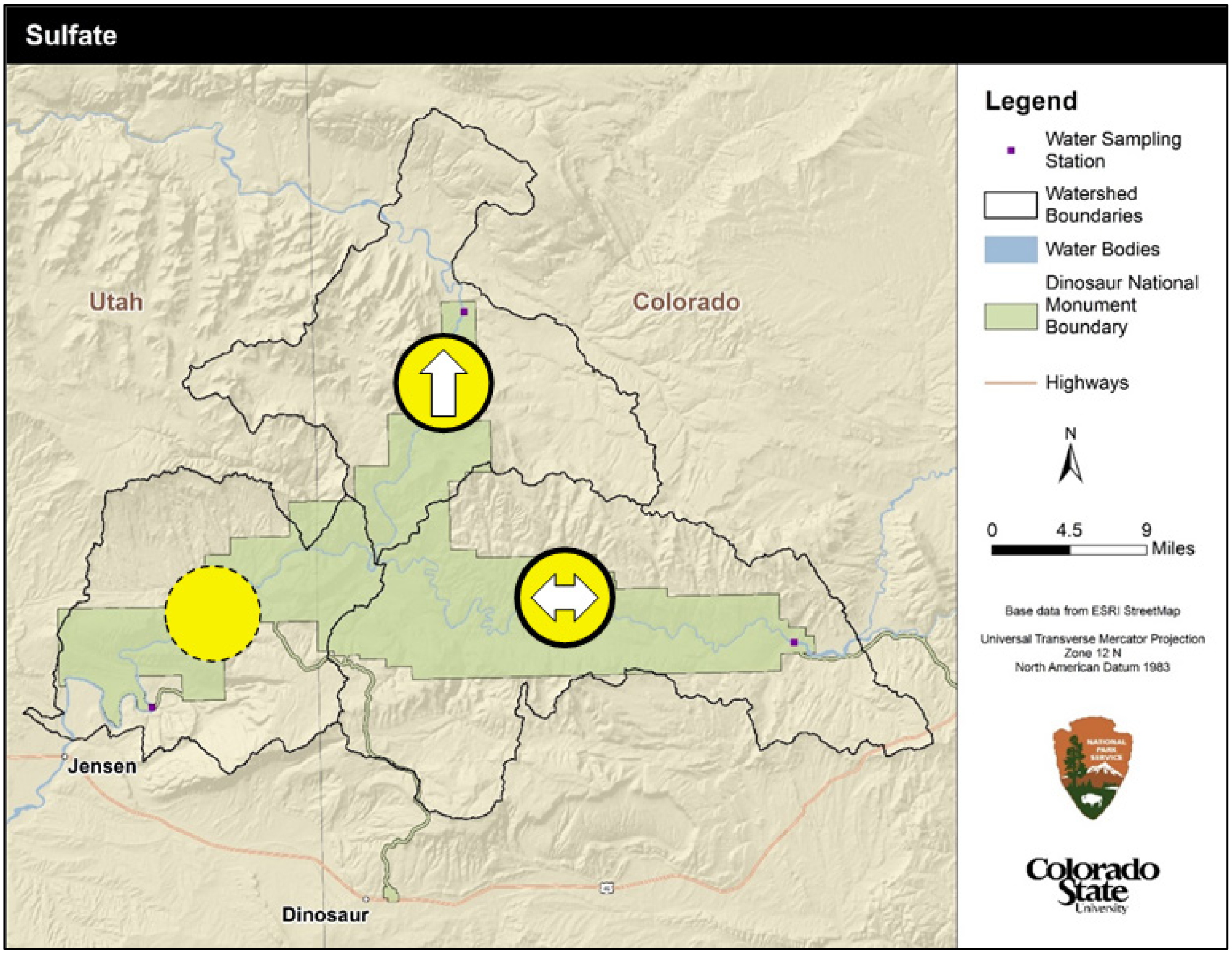


Figure 4.7-13. Sulfate ratings for each river segment. Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

<u>Iron</u>

EPA, Utah, and CDPHE standards state that iron levels may not exceed 1000 µg/L. The YR-D and GR-GoL segments had 85th percentiles that were much greater than the standard, indicating these segments are currently in poor condition for iron (Table 4.7-15). GR-J does not have any current data, and there were only 13 iron samples taken in a 50-year period ending in 2012 for this segment, therefore no condition will be given. Seasonal Mann-Kendall trend tests for the YR-D and GR-GoL segments show an unchanging trend for YR-D and a deteriorating trend for GR-GoL (Table 4.7-16). Measurements for each of the three sampling stations are shown in Figure 4.7-14. Confidence in the condition ratings for the GR-GoL segment is medium due to having fewer than 50 data records. Due to the age of data for GR-J, this segment was not rated (Figure 4.7-15).

Table 4.7-15. Iron measurements from stations Yampa River at Deerlodge Park, Colorado, Green River above Gates of Lodore, Colorado, and Green River near Jensen, Utah (µg/L) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard.

Station	Period of record	n	# exc	Min	Max	Mean (SD)	Historic 85th Percentile	Current 85th Percentile
Yampa River at Deerlodge Park, CO	08/75–08/18	83	40	90	38,600	3493(6820)	6421	2278
Green River above Gates of Lodore, CO	12/10–08/18	32	5	85	4270	624(865)	584	1149
Green River near Jensen, UT	04/62–08/12	13	0	3	340	68(105)	142	N/A

Table 4.7-16. Seasonal Mann-Kendall trend test (τ) results for iron. n = number of observations that met criteria; τ = Mann-Kendall trend statistic.

Station	n	τ	p-value	Trend
Yampa River at Deerlodge Park, CO	81	0.07	0.47	Unchanging
Green River above Gates of Lodore, CO	26	**0.68***	**0.01***	**Deteriorating***
Green River near Jensen, UT	No current data	No current data	No current data	No current data

* Values note significance at α=0.05 (also in bold).

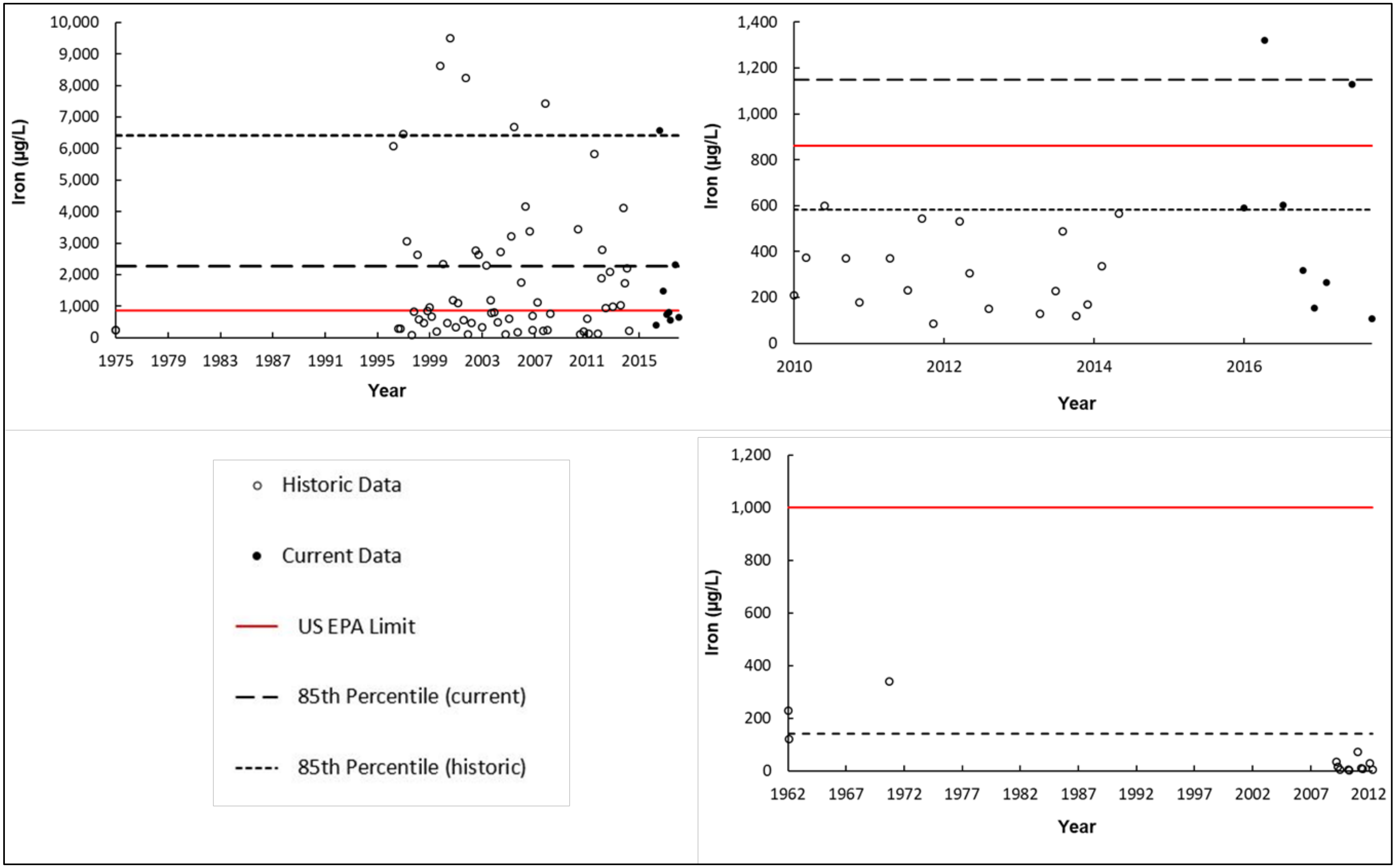


Figure 4.7-14. Iron measurements for the Yampa River at Deerlodge Park, Colorado (USGS-09260050, top left), the Green River above Gates of Lodore, Colorado (USGS-404417108524900, top right), and the Green River near Jensen, Utah (USGS-09261000, bottom right). Some extreme samples were omitted from Deerlodge and Gates of Lodore to improve the scale of the graph.

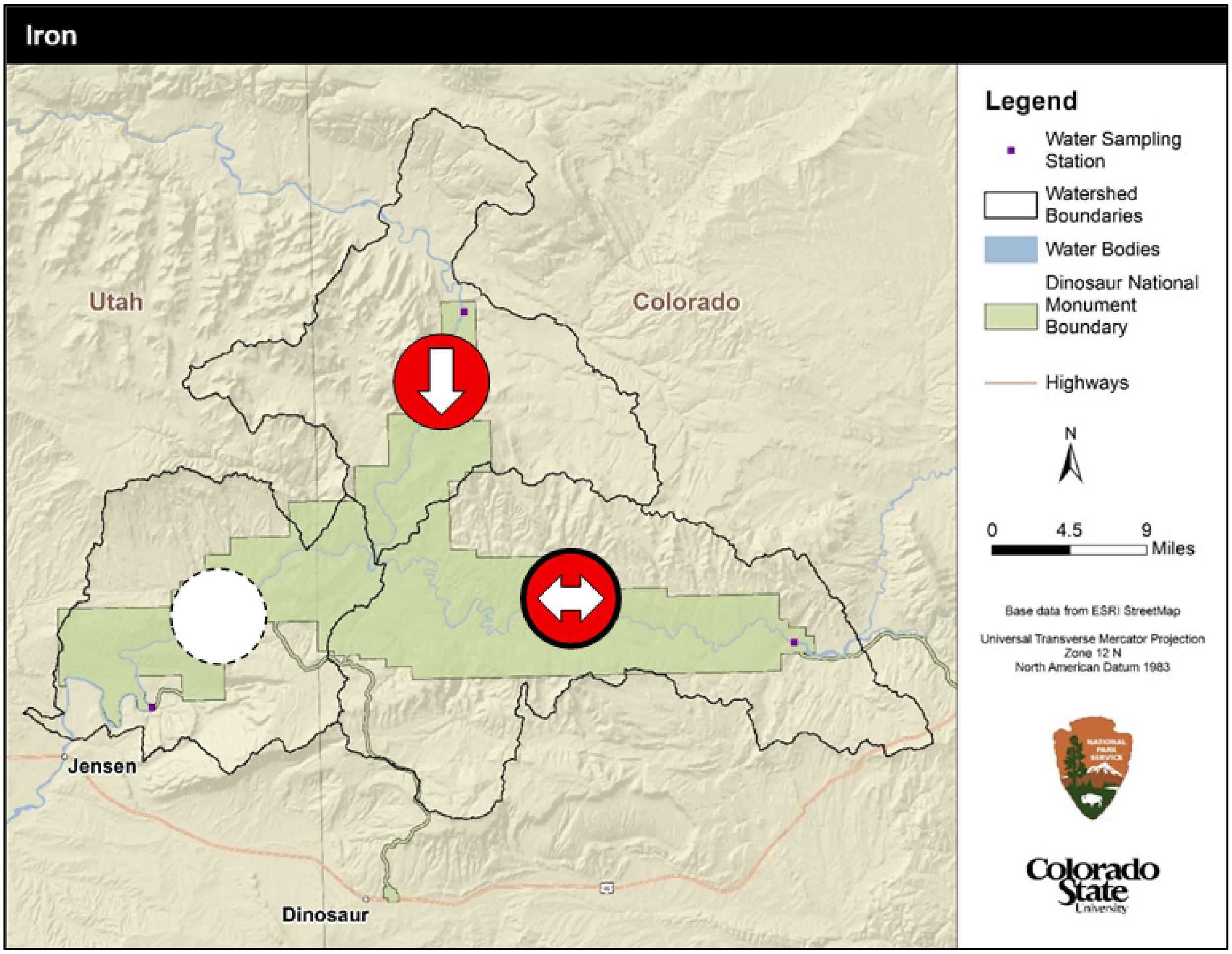


Figure 4.7-15. Iron ratings for each river segment. Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

<u>Escherichia coli</u>

The EPA standard for *E. coli* bacteria in surface waters is less than or equal to 200 CFU/100ml. Colorado and Utah use a different approach based on the recreational water use type. All three river segments are listed for use as primary contact recreational waters by their respective states. The YR-D segment has recorded maximum CFU concentrations that are well above the standard established by CDPHE but the geometric mean values indicate that most concentrations are well below this standard. For the Green River, the GR-GoL segment has not had an *E. coli* exceedance since records began in 2006, and the GR-J segment has no current or historical records for this parameter (Table 4.7-17). Seasonal Mann-Kendall trend tests for the YR-D and GR-GoL segments show an unchanging trend for each (Table 4.7-18). Measurements for the YR-D and GR-GoL sampling stations are shown in Figure 4.7-16 and Figure 4.7-17. Confidence in the condition rating for the GR-GoL segment is medium due to having fewer than 50 data records (Figure 4.7-18).

Table 4.7-17. *Escherichia coli* measurements from stations Yampa River at Deerlodge Park, Colorado, Green River above Gates of Lodore, Colorado, and Green River near Jensen, Utah (CFU/100ml) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard; GSD = geometric standard deviation.

Station	Period of record	n	# exc	Min	Max	Geometric Mean (GSD)	Historic Geometric Mean	Current Geometric Mean
Yampa River at Deerlodge Park, CO	03/97–10/18	98	4	1	660	21(4)	21	16
Green River above Gates of Lodore, CO	04/06–08/18	46	0	1	73	6(4)	6	6
Green River near Jensen, UT	None	–	–	–	–	–	–	–

Table 4.7-18. Seasonal Mann-Kendall trend test (τ) results for *E. coli*. Bold values note significance at α=0.05. n = number of observations that met criteria; τ = Mann-Kendall trend statistic.

Station	n	τ	p-value	Trend
Yampa River at Deerlodge Park, CO	97	0.09	0.28	Unchanging
Green River above Gates of Lodore, CO	42	0.05	0.79	Unchanging
Green River near Jensen, UT	No current data	No current data	No current data	No current data

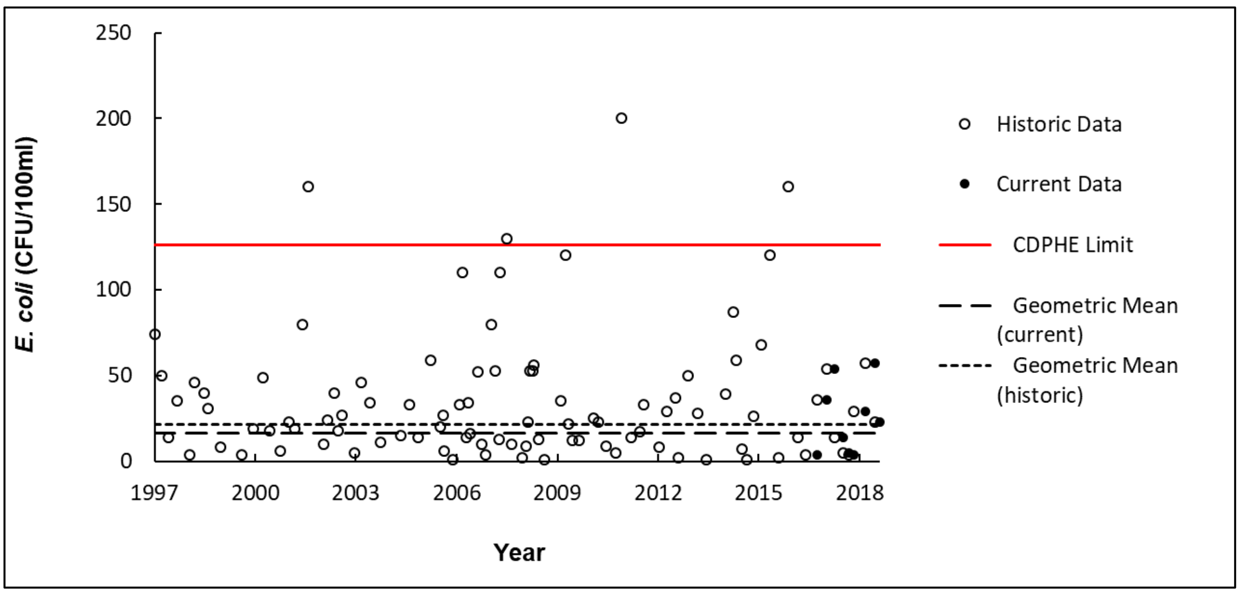


Figure 4.7-16. *E. coli* measurements from 1997–2018 at the Yampa River at Deerlodge Park, Colorado station (USGS-09260050).

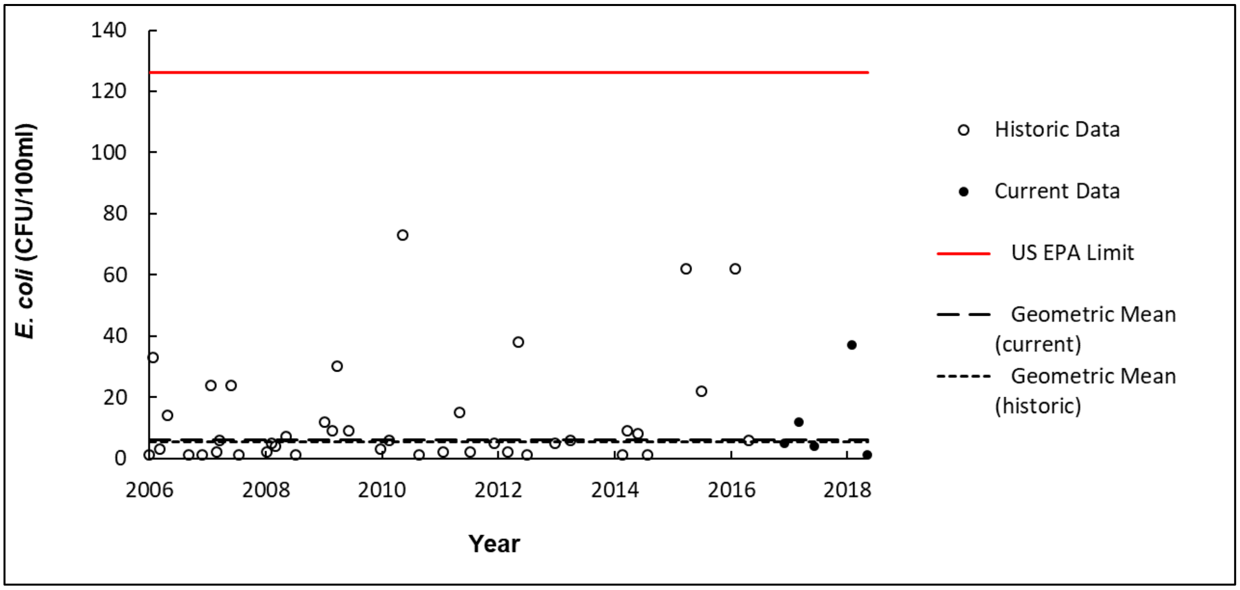


Figure 4.7-17. *E. coli* measurements from 2006–2018 at the Green River above Gates of Lodore, Colorado station (USGS-404417108524900).

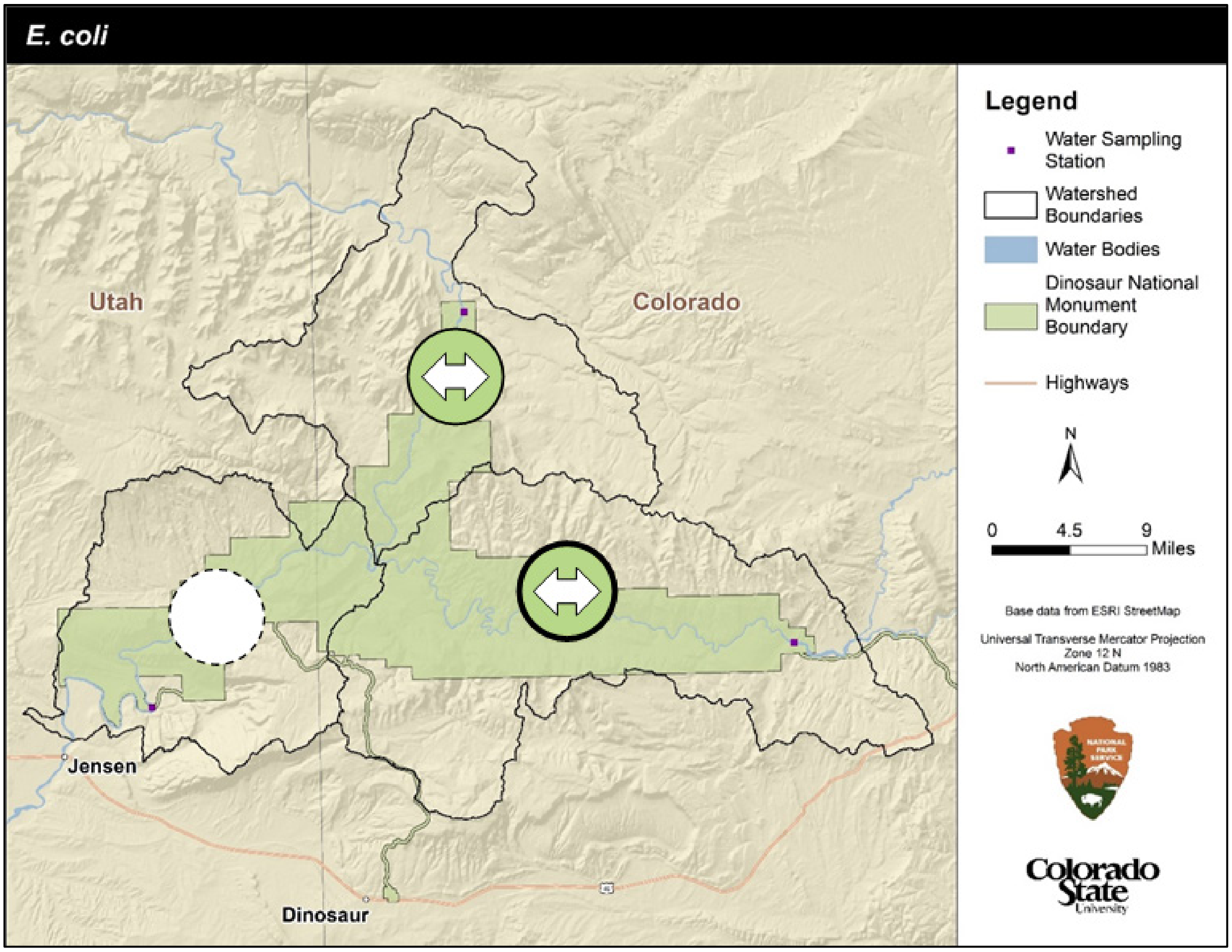


Figure 4.7-18. *E. coli* ratings for each river segment. Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

Nitrogen

The EPA standard for total nitrogen in rivers and streams in Aggregate Ecoregion III (Xeric West) is 0.38 mg/L. This standard is not a regulatory compliance threshold, but is guidance for states and tribes to use as a starting point to determine their own water quality standards (EPA 2000). The Colorado and Utah standards for nitrogen are ≤ 2 mg/L and ≤ 4 mg/L, respectively. There were many nitrogen values that were below the detectable limit of the analysis and were removed from the analysis, thus overestimating nitrogen levels. The YR-D and GR-GoL segments had 85th percentiles that were less than one-half of the parameter standard, indicating these segments are currently in good condition for nitrogen (Table 4.7-19). GR-J does not have any current data, but data as late as 2012 indicate this segment is also in good condition for nitrogen. Seasonal Mann-Kendall trend tests for the YR-D and GR-GoL segments show an unchanging trend for each (Table 4.7-20). Measurements for each of the three sampling stations are shown in Figure 4.7-19. GR-GoL and GR-J were given medium and low confidence ratings, respectively, due to GR-GoL having fewer than 50 records (and only four current measurements) and GR-J having just four (Figure 4.7-20). Although all segments were in good condition for nitrogen, all segments are above the EPA guideline of 0.38

mg/L for the ecoregion. The monument should closely monitor nitrogen levels to prevent them from drifting even further away from the EPA-issued guideline.

Table 4.7-19. Total nitrogen measurements from stations Yampa River at Deerlodge Park, Colorado, Green River above Gates of Lodore, Colorado, and Green River near Jensen, Utah (mg/L) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard.

Station	Period of record	n	# exc	Min	Max	Mean (SD)	Historic 85th Percentile	Current 85th Percentile
Yampa River at Deerlodge Park, CO	08/75–05/18	61	1	0.20	2.70	0.78(0.49)	1.20	0.86
Green River above Gates of Lodore, CO	08/06–01/18	17	0	0.26	0.52	0.34(0.07)	0.40	0.31
Green River near Jensen, UT	05/14–09/15	4	0	0.20	0.68	0.43(0.24)	0.67	N/A

Table 4.7-20. Seasonal Mann-Kendall trend test (τ) results for total nitrogen. Bold values note significance at α=0.05. n = number of observations that met criteria; τ = Mann-Kendall trend statistic.

Station	n	τ	p-value	Trend
Yampa River at Deerlodge Park, CO	57	−0.02	0.87	Unchanging
Green River above Gates of Lodore, CO	14	0.11	1.00	Unchanging
Green River near Jensen, UT	No current data	No current data	No current data	No current data

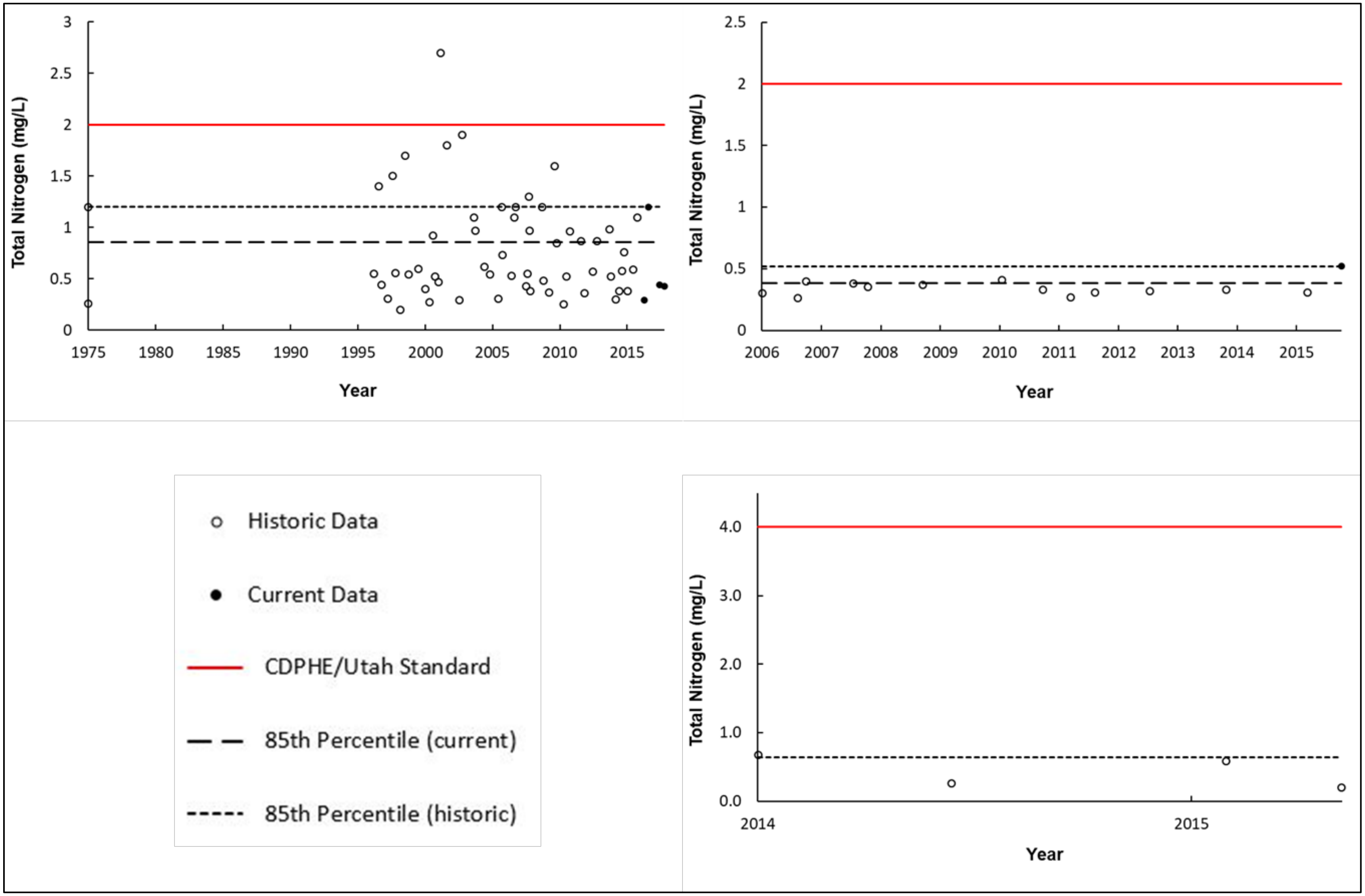


Figure 4.7-19. Total nitrogen measurements for the Yampa River at Deerlodge Park, Colorado (USGS-09260050, top left), the Green River above Gates of Lodore, Colorado (USGS-404417108524900, top right), and the Green River near Jensen, Utah (USGS-09261000, bottom right).

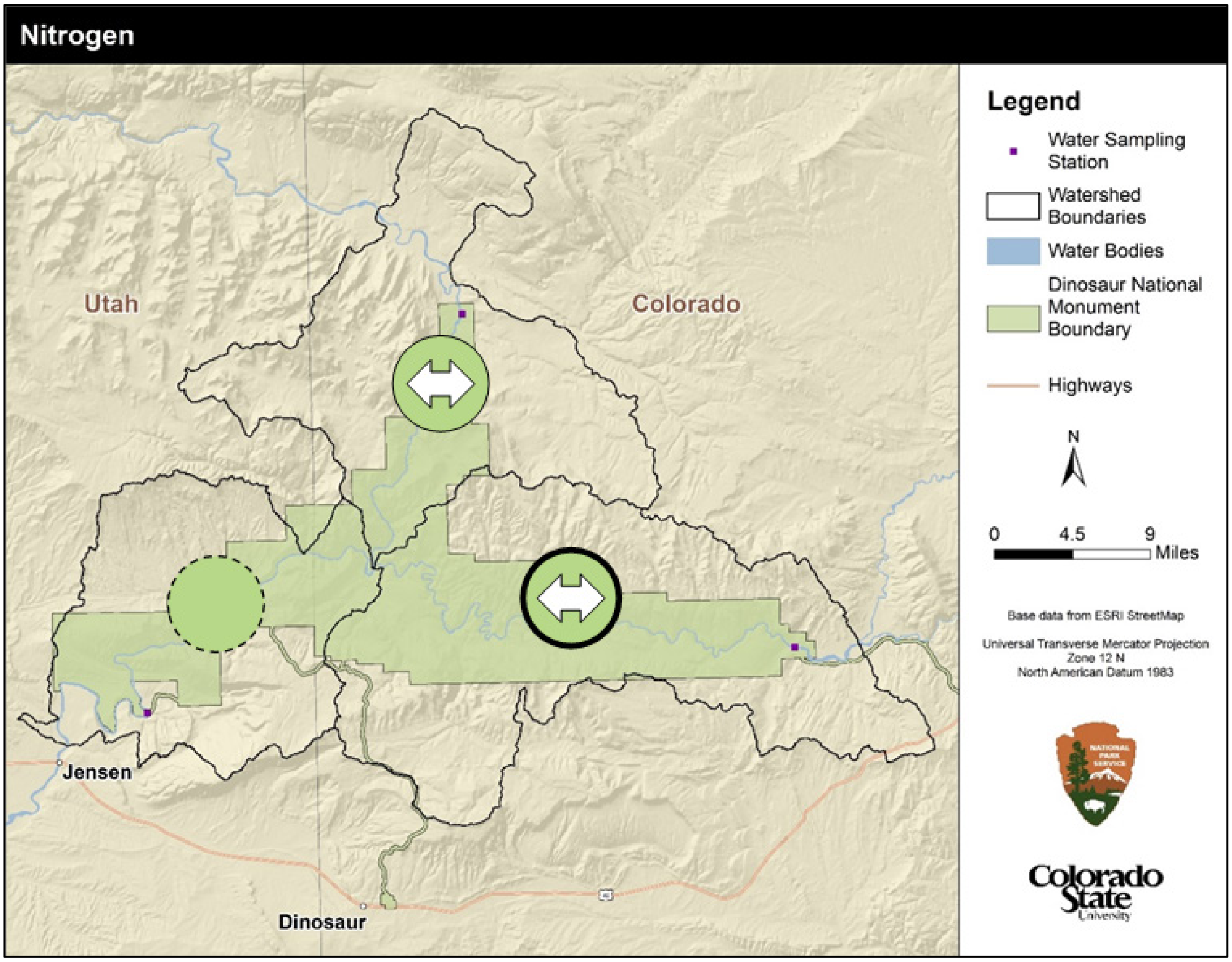


Figure 4.7-20. Total nitrogen ratings for each river segment. Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

<u>Phosphorus</u>

The EPA standard for total phosphorus in rivers and streams in Aggregate Ecoregion III (Xeric West) is 21.88 µg/L (0.02188 mg/L). This standard is not considered a law or regulation, but as guidance for states and tribes to use as a starting point to determine their own water-quality standards (EPA 2000). The Colorado warmwater stream, Colorado coldwater stream, and Utah standards for phosphorus are ≤ 0.017 mg/L, ≤ 0.011 mg/L, and 0.05 mg/L respectively. There were several phosphorus values that were below the detectable limit of the analysis and were removed. Historic 85th percentile for the GR-J segment and current 85th percentile for the YR-D segment were both above their respective state standards, while measurements for GR-GoL were greater than one half of the Colorado coldwater stream standard (Table 4.7-21). Seasonal Mann-Kendall trend tests show an unchanging trend for the YR-D segment and a degrading (increasing) trend for the GR-GoL segment (Table 4.7-22). Measurements for each of the three sampling stations are shown in Figure 4.7-21. GR-J and YR-D segment measurements indicate they are in poor condition for phosphorus, while GR-J is in moderate condition. GR-J was given a low confidence rating due to having no current

measurements, with the other two segments receiving a high confidence rating due to length and age of data records (Figure 4.7-22).

Table 4.7-21. Total phosphorus measurements from stations Yampa River at Deerlodge Park, Colorado, Green River above Gates of Lodore, Colorado, and Green River near Jensen, Utah (mg/L) (NWQMC 2018). n = number of observations; # exc = number of readings exceeding parameter standard.

Station	Period of record	n	# exc	Min	Max	Mean (SD)	Historic 85th Percentile	Current 85th Percentile
Yampa River at Deerlodge Park, CO	08/75–10/18	105	32	0.01	3.22	0.78(0.49)	0.37	0.20
Green River above Gates of Lodore, CO	02/06–10/18	60	2	<0.01	0.37	0.04(0.05)	0.05	0.08
Green River near Jensen, UT	10/79–09/15	32	5	<0.01	0.26	0.04(0.06)	0.06	N/A

Table 4.7-22. Seasonal Mann-Kendall trend test (τ) results for total phosphorus. n = number of observations that met criteria; τ = Mann-Kendall trend statistic.

Station	n	τ	p-value	Trend
Yampa River at Deerlodge Park, CO	102	0.10	0.30	Unchanging
Green River above Gates of Lodore, CO	54	**0.42***	**<0.01***	**Deteriorating***
Green River near Jensen, UT	No current data	No current data	No current data	No current data

* Values note significance at α=0.1 (also in bold).

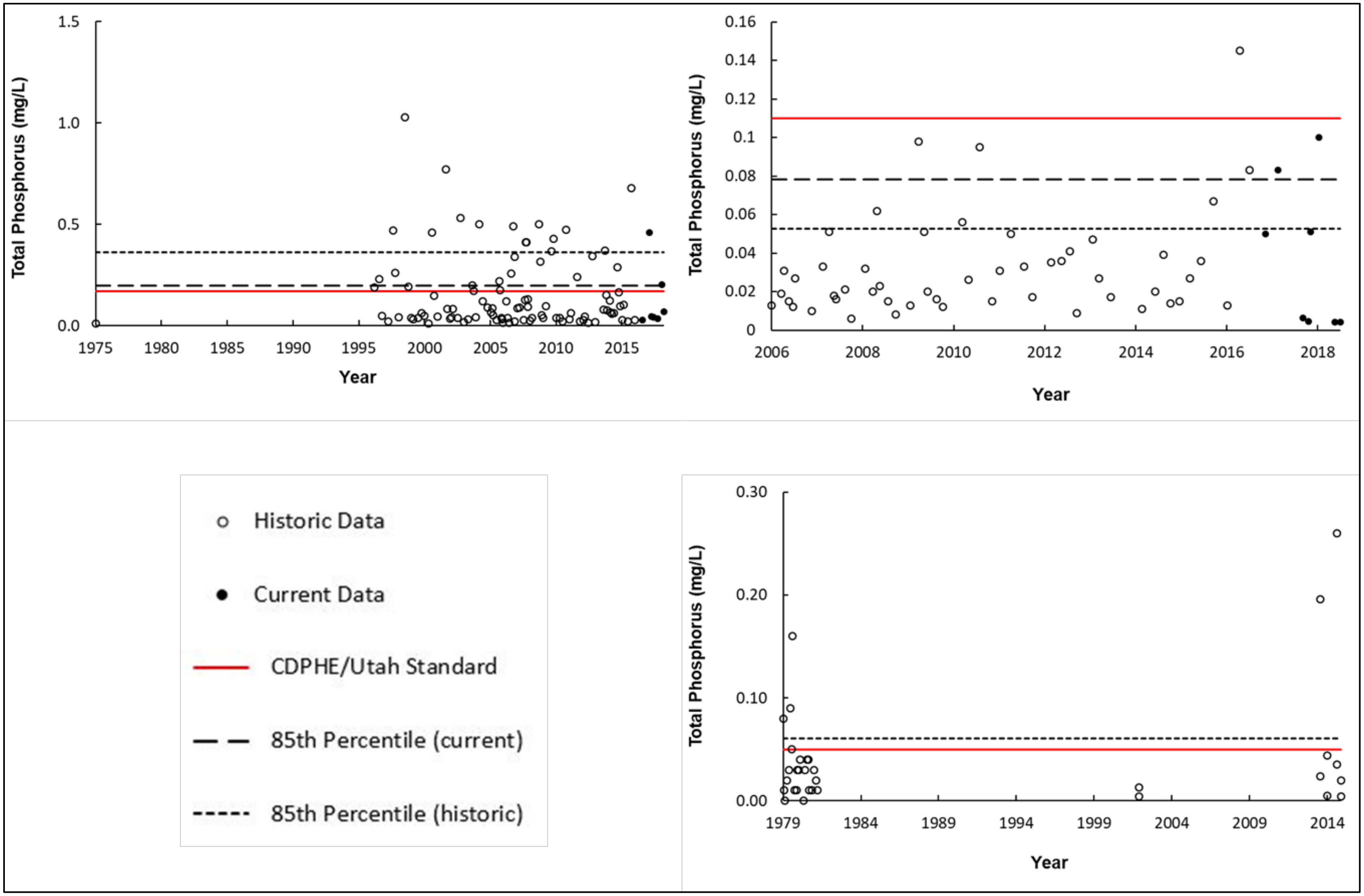


Figure 4.7-21. Phosphorus measurements for the Yampa River at Deerlodge Park, CO (USGS-09260050, top left), the Green River above Gates of Lodore, CO (USGS-404417108524900, top right), and the Green River near Jensen, UT (USGS-09261000, bottom right). Some extreme samples were omitted from Deerlodge and Gates of Lodore to improve the scale of the graph.

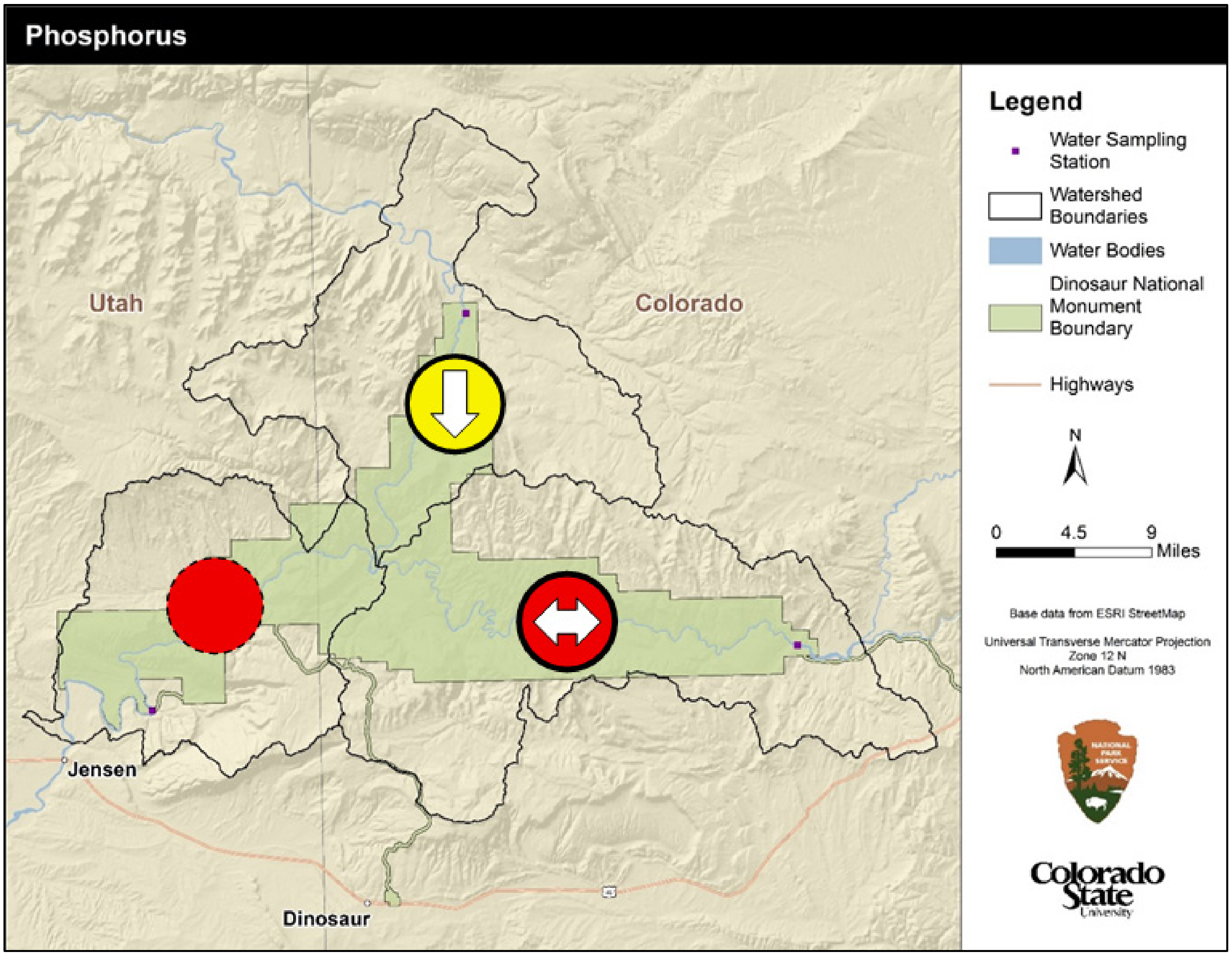


Figure 4.7-22. Phosphorus ratings for each river segment. Raw data are from NWQMC (2018); trends are from the statistical test described in Helsel et al. (2006).

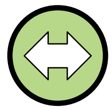
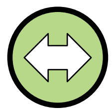
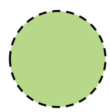
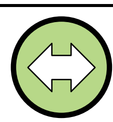
Condition Summary

Cumulative condition and trends for water quality for each of the three river segments as well as overall condition and trend for DINO are shown in Table 4.7-23. All three river segments were in good condition, with YR-D and GR-GoL having an unchanging trend and a high level of confidence in their assessments. GR-J was also found to be in good condition, although with a low level of confidence in the assessment due to a lack of data more recent than 2012.

4.7.5. Uncertainty and Data Gaps

Current water quality data for the Green River near Jensen sampling station would aid in either showing the true condition of this segment, or help solidify the conclusions already drawn in this study for the segment. Aquatic macroinvertebrate data have not been collected in or near the monument since 2011 (Miller et al. 2012). This data gap is noted in the monument's *Foundation Document* (NPS 2015) for the Yampa and Green River System fundamental resource.

Table 4.7-23. Water quality condition and trend summary ratings by station location.

Station Location	Condition Status/Trend	Rationale
Yampa River at Deerlodge Park, CO		Iron and phosphorus warrant significant concern, while sulfate warrants moderate concern. All other indicators and measures for this river segment are in good condition. Confidence in the assessment is high due to the length and age of data sources.
Green River above Gates of Lodore, CO		Sulfate and phosphorus warrant moderate condition, while iron levels warrant significant concern. All other indicators and measures for this river segment were in good condition. This segment had deteriorating trends for iron and phosphorus. However, the overall trend was unchanging. Confidence in the assessment is high due to the length and age of data sources.
Green River near Jensen, UT		Sulfate and phosphorus warrant moderate and significant concern, respectively. The only indicator with a medium or high confidence level (warm season water temperature) had an unchanging trend. Except for warm season water temperature, confidence in indicators and measures was low due to the lack of data records after 2012. Iron and *E. coli* had no records for this segment and did not receive a condition rating. A trend was not given to this segment due to low confidence of the overall assessment.
Water Quality overall		**Overall water quality is in good condition with an unchanging trend and a high level of confidence.**

4.7.6. Sources of Expertise

- Tamara Naumann, Ecologist/Botanist, Dinosaur National Monument.
- Rebecca Weissinger, Ecologist, Northern Colorado Plateau Inventory & Monitoring Network: assistance with framework, data sources and manuscript review.
- Dusty Perkins, Program Manager, Northern Colorado Plateau Inventory & Monitoring Network: manuscript review.

4.7.7. Literature Cited

Battaglin, W.A., and A. Kolok. 2014. Featured collection introduction: Contaminants of emerging concern II. Journal of the American Water Resources Association 50(2):261–265.

Bestgen, K.R. 2018. Evaluate effects of flow spikes to disrupt reproduction of smallmouth bass in the Green River downstream of Flaming Gorge Dam. Final report to the Upper Colorado River Endangered Fish Recovery Program. Denver, Colorado. Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins. Larval Fish Laboratory Contribution 214.

Brown, J.B., and D.P. Thoma. 2012. Assessment of total nitrogen and total phosphorus in selected surface water of the National Park Service Northern Colorado Plateau Network, Colorado, Utah,

and Wyoming, from 1972 through 2007. U.S. Geological Survey Scientific Investigations Report 2012–5043. U.S. Geological Survey, Reston Virginia.

Caissie, D. 2006. The thermal regime of rivers: a review. Freshwater Biology 51(8):1389–1406.

Clarkson, R.W., and M.R. Childs. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia 2000(2):402–412.

Closs, G.P., M. Krkosek, and J.D. Olden. 2015. Conservation of freshwater fishes. Cambridge University Press. Cambridge, UK. ISBN: 9781316467725.

Colorado Department of Public Health and Environment (CDPHE). 2017. Section 303(d) listing methodology 2018 listing cycle. CDPHE Water Quality Control Division. Available at: https://www.colorado.gov/pacific/sites/default/files/303d_LM_2018.pdf (accessed 27 March 2019).

CDPHE. 2018a. Regulation No. 37: classifications and numeric standards for Lower Colorado River Basin, Appendix 37-1: Stream classifications and water quality standards tables. 5 CCR 1002-37. Available at: https://colorado.gov/pacific/sites/default/files/37_2018(06)-Appendix37-1.pdf (accessed 27 March 2019).

CDPHE. 2018b. Regulation No. 31.17: Nutrients. Available at: https://www.colorado.gov/pacific/sites/default/files/WQ_nonpoint_source-Regulation-31-Nutrients-Section-31-17.pdf (accessed 27 March 2019).

CDPHE. 2018c. Regulation No. 37: classifications and numeric standards for Lower Colorado River Basin. 5 CCR 1002-37. Available at: https://www.colorado.gov/pacific/sites/default/files/37_2018(06).pdf (accessed 27 March 2019).

Colorado River District. 2019. Impoundment and Diversion Map for the Yampa and White River Basins. Available at: https://www.coloradoriverdistrict.org/ (accessed 12 March 2019).

Doudoroff, P., and D.L. Shumway. 1970. Dissolved oxygen requirements of freshwater fishes. Food and Agriculture Organization of the United Nations. FAO Fisheries Technical Paper No. 86. Rome.

Environmental Protection Agency (EPA). 1986. Quality Criteria for Water 1986. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/00001MGA.PDF?Dockey=00001MGA.PDF (accessed 02 December 2018).

EPA. 2000. Ambient water quality criteria recommendations: information supporting the development of state and tribal nutrient criteria, rivers and streams in nutrient ecoregion III. EPA 822-B-00-016. Office of Water, Office of Science and Technology Health and Ecological Criteria Division, Washington, D.C. Available at: https://www.epa.gov/sites/production/files/documents/rivers3.pdf (accessed 11 December 2018).

EPA. 2012a. Recreational water quality criteria. Office of Water 820-F-12-058. Available at: https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf (accessed 27 March 2019).

EPA. 2012b. Water: monitoring and assessment, Conductivity. Available at: https://archive.epa.gov/water/archive/web/html/vms59.html (accessed 19 December 2018).

EPA. 2013a. Total solids. Available at: http://water.epa.gov/type/rsl/monitoring/vms58.cfm (accessed 19 November 2013).

EPA. 2013b. Nutrient pollution: the problem. Available at: http://www2.epa.gov/nutrientpollution/problem (accessed 17 December 2013).

EPA. 2013c. Stream flow. Available at: http://water.epa.gov/type/rsl/monitoring/vms51.cfm (accessed 19 November 2013).

EPA. 2013d. Macroinvertebrates and habitat. Available at: http://water.epa.gov/type/rsl/monitoring/vms40.cfm (accessed 19 November 2013).

EPA. 2018a. National recommended water quality criteria. Available at: http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm (accessed 06 December 2018).

EPA. 2018b. STORET Warehouse website. Available at: http://www.epa.gov/storet.

EPA. 2018c. Summary table for the nutrient criteria documents. Available at: http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/2007_09_27_criteria_nutrient_ecoregions_sumtable.pdf (accessed 06 December 2018).

Evans, M., and C. Frick. 2001. The effects of road salts on aquatic ecosystems. NWRI contribution series no. 02:308. National Water Research Institute and University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Foster, M., J.D. Stednick, and W.J. Rice. 2000. Inventory and characterization of upland water resources in Dinosaur National Monument. Watershed Science Program, Colorado State University, Fort Collins, Colorado. Prepared for U.S. National Park Service, Dinosaur National Monument, Colorado and Utah.

Hackbarth, C., and R. Weissinger. 2016. Water quality in the Northern Colorado Plateau Network, water years 2013–2015. Natural Resource Technical Report NPS/NCPN/NRTR— 2016/1332. National Park Service, Fort Collins, Colorado.

Harza, M.H. 2001. Draft Yampa Basin watershed plan, Unpublished Report. Prepared for Colorado Department of Public Health and Environment, Water Quality Control Division and Yampa River Basin Partnership, Steamboat Springs, Colorado.

Harza, M. 2002. Yampa Basin watershed plan, Unpublished Report. Prepared for Colorado Department of Public Health and Environment, Water Quality Control Division and Yampa River Basin Partnership, Steamboat Springs, Colorado.

Helsel, D.R., D.K. Mueller, and J.R. Slack. 2006. Computer program for the Kendall family of trend tests. Scientific Investigations Report 2005–5275. U.S. Geological Survey, Reston, Virginia.

Hinck, J.E., V.S. Blazer, N.D. Denslow, K.R. Echols, T.S. Gross, T.W. May, P J. Anderson, J.J. Coyle, and D.E. Tillitt. 2007. Chemical contaminants, health indicators, and reproductive biomarker responses in fish from the Colorado River and its tributaries. Science of the Total Environment 378(3):376–402.

Iowa Department of Natural Resources (IDNR). 2013. Water quality standards review: chloride, sulfate and total dissolved solids. Available at: https://dnr.mo.gov/env/wpp/index.html (accessed 19 November 2013).

Karp, C.A., and H.M. Tyus. 1990. Humpback chub (*Gila cypha*) in the Yampa and Green Rivers, Dinosaur National Monument, with observations on roundtail chub (*G. robusta*) and other sympatric fishes. The Great Basin Naturalist 50(3):257–264.

McDaniel, L. 2013. Understanding Iowa's Water Quality Standards. Available at: http://www.iowadnr.gov/portals/idnr/uploads/water/standards/ws_fact.pdf (accessed 19 November 2013).

Meals, D.W., J. Spooner, S.A. Dressing, and J.B. Harcum. 2011. Statistical analysis for monotonic trends. Tech Notes 6, November 2011. Developed for U.S. Environmental Protection Agency by Tetra Tech, Inc., Fairfax, Virginia.

Metcalfe, A.N. 2018. Aquatic insect distribution in the Colorado River Basin. Thesis. Northern Arizona University, Flagstaff, Arizona.

Mesner, N., and J. Geiger. 2005. pH factsheet. Utah State University Extension Publication NR/WQ/2005-19. Available at: https://extension.usu.edu/waterquality/files-ou/Publications/pH.pdf (accessed 18 December 2018).

Miller, T. 2002. Dinosaur National Monument Livestock Management Plan DRAFT Environmental Impact Statement.

Miller, S.W., J. Kotynek, and S. Judson. 2012. Draft: contemporary and historic comparisons of aquatic macroinvertebrates in the regulated Green River and unregulated Yampa River within Dinosaur National Monument. BLM/USU National Aquatic Monitoring Center, Department of Watershed Sciences, Utah State University, Logan, Utah.

National Park Service (NPS). 1995. Dinosaur National Monument resource management plan. National Park Service.

NPS. 2003a. Baseline water quality data inventory and analysis: Dinosaur National Monument. Technical Report NPS/NRWRD/NRTR-2003/306. National Park Service, Water Resources Division, Fort Collins, Colorado.

NPS. 2003b. Clean Water Act water quality designated uses and impairments: Dinosaur National Monument. Technical Report NPS/NRWRD/NRTR-2001/282. National Park Service, Water Resources Division, Fort Collins, Colorado.

NPS. 2005. Dinosaur National Monument invasive plant management plan & environmental assessment. National Park Service.

NPS. 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

NPS. 2016. Water quality monitoring in the Northern Colorado Plateau Network. Northern Colorado Plateau Network, Moab, Utah.

National Water Quality Monitoring Council (NWQMC). 2018. Water quality data. Available at: https://www.waterqualitydata.us/portal/ (accessed 03 December 2018).

New Hampshire Department of Environmental Services (NHDES). Undated. Environmental, health and economic impacts of road salt. Available at: http://des.nh.gov/organization/divisions/water/wmb/was/salt-reduction-initiative/impacts.htm# (accessed 19 November 2013).

Roehm, G. 2004. Management plan for endangered fishes in the Yampa River Basin and environmental assessment. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

Safe Drinking Water Foundation (SDWF). 2013. TDS and pH. Available at: http://www.safewater.org/PDFS/resourcesknowthefacts/TDS_AND%20_pH.pdf (accessed 19 November 2013).

Scott, M.L., and J.M. Friedman. 2018. River flow and riparian vegetation dynamics – implications for management of the Yampa River through Dinosaur National Monument. National Park Service. Natural Resource Report NPS/NRSS/WRD/NRR—2018/1619. National Park Service, Fort Collins, Colorado.

Sumsion, C.T. 1976. Water resources of Dinosaur National Monument, Colorado and Utah. U.S. Geological Survey. Prepared for U.S. National Park Service. Salt Lake City, Utah.

Thoma, D., D. Sharrow, K. Wynn, J. Brown, M. Beer, and H. Thomas. 2007. Water quality vital signs monitoring protocol for park units in the Northern Colorado Plateau Network (ver. 1). National Park Service, Moab, Utah.

U.S. Geological Survey (USGS). 2013a. Water properties: dissolved oxygen. Available at: https://www.usgs.gov/special-topic/water-science-school/science/dissolved-oxygen-and-water?qt-science_center_objects=0#qt-science_center_objects (accessed 19 November 2013).

USGS. 2013b. Bacteria in water. Available at: http://water.usgs.gov/edu/bacteria.html (accessed 19 November 2013).

USGS. 2016. Water properties: temperature. Available at: https://water.usgs.gov/edu/temperature.html (accessed 18 December 2018).

USGS. 2018. Comparison of 2016–17 water years and historical water-quality data, Yampa River Basin, Colorado. Available at: https://co.water.usgs.gov/infodata/yampa_summaries/index.html (accessed 01 December 2018).

Utah Office of Administrative Rules (UOAR). 2018. Rule R317-2. Standards of Quality for Waters of the State. Available at: https://rules.utah.gov/publicat/code/r317/r317-002.htm#T16.

Weissinger, R., W. Battaglin, and P. Bradley. 2016. Screening for contaminants of emerging concern in waters of the Northern Colorado Plateau Network: 2015 surface water data. Natural Resource Report NPS/NCPN/NRR—2016/1239. National Park Service, Fort Collins, Colorado.

World Health Organization (WHO). 1996. Guidelines for drinking-water quality: health criteria and other supporting information. World Health Organization, Geneva, Switzerland.

Yard, M.D., L.G. Coggins Jr., C.V. Baxter, G.E. Bennett, and J. Korman. 2011. Trout piscivory in the Colorado River, Grand Canyon: effects of turbidity, temperature, and fish prey availability. Transactions of the American Fisheries Society 140:471–486.

4.8. Yampa and Green River System

4.8.1. Background and Importance

Three unique sections of Big Rivers exist within Dinosaur National Monument (DINO): the relatively wild and unregulated Yampa River, the flow-regulated Green River above the confluence with the Yampa River (hereafter referred to as the upper Green River), and the "partially regulated" Green River below the confluence with the Yampa (hereafter referred to as the lower Green River). The juxtaposition of the highly regulated upper Green River with the largely unregulated Yampa River, as well as the existence of the "partially-regulated" lower Green River just downstream, has the additional benefit of providing a natural laboratory for riverine studies. The existence of these three unique sections of river in close spatial quarters (and all within the monument boundaries) allows for them to be compared and contrasted, and make Dinosaur National Monument a rare and valuable area for paired watershed studies (NPS 2015, Scott and Friedman 2018, Scott et al. 2018).

The Yampa River

The Yampa River Basin is 7,660 mi^2 (19,839 km^2) in area. The portion of the Yampa River within Dinosaur National Monument (Figure 4.8-1) begins in a broad alluvial valley at Deerlodge Park in the monument's southeast corner and quickly enters Yampa Canyon, where it runs west to Echo Park at the confluence with the Green River.

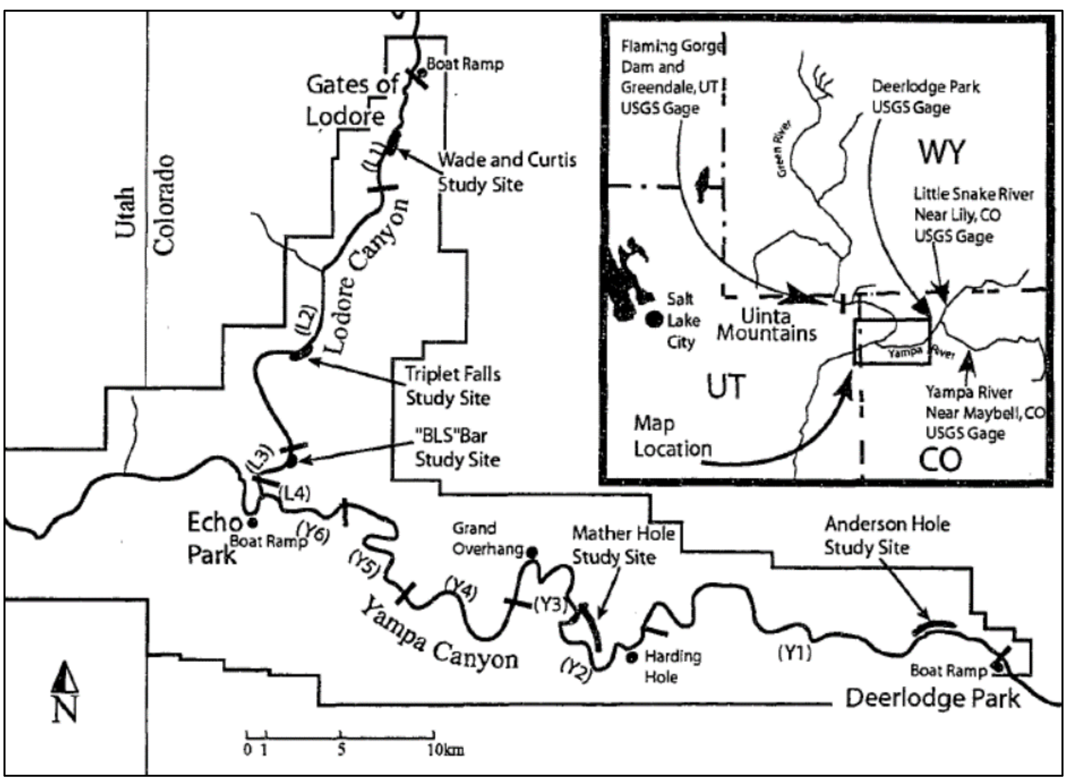


Figure 4.8-1. The upper Green River and Yampa River within Dinosaur National Monument, showing the Y1-Y6 and L1-L4 subdivisions of Larson (2004).

Scott et al. (2018) described three channel types observed on the Yampa, which were based on work done by FLO Engineering (1998), Grams and Schmidt (2002), and Larson (2004). These three channel types are restricted meander, fan-affected, and entrenched meander. The restricted meander channel type is seen in Deerlodge Park, while the latter two were observed within Yampa Canyon.

In Deerlodge Park, the Yampa flows in a low gradient, slightly sinuous unconfined channel through a broad alluvial valley over mostly fine-textured alluvium (Cooper et al. 1999, Elliott and Anders 2005). Vertical channel banks are observed on the outside of meander bends, and depositional point bars are observed on the inside (Merrit and Cooper 2000). The stream bed is comprised of mostly medium- to coarse-grained sand (Elliott et al. 1984).

Downstream of Deerlodge Park, the Yampa enters Yampa Canyon. O'Brien (1984) and Larson (2004) subdivided the Yampa Canyon section of the river into five and six reaches, respectively, based on similar geomorphology. The following paragraphs follow the subdivision convention of Larson (2004) (Figure 4.8-1). The upper 25 miles of the Yampa River in Yampa Canyon (Y1) largely flow through the Morgan Formation, a primarily bedded limestone that dips 7–10 degrees to the southwest (O'Brien 1984). In this upper section of river, the channel is steep and has a boulder and cobble bed. In addition to the Morgan Formation, the river flows through the Red Valley Sandstone, Doughnut Shale, Humbug Formation, and Madison Limestone (Larson 2004). This section of the canyon is generally asymmetrical and very narrow, with steep walls on the south side and gentler, talus-covered slopes on the north, and the channel occupies most of the valley (O'Brien 1984, Larson 2004). Short lengths of this river section are also affected by debris fan deposits that restrict flows; however, these deposits are both topographically lower and spaced farther apart than similar deposits in the Canyon of Lodore, and thus the river does not have the same pool-riffle structure as seen there (Larson 2004). Deposits include point bars and channel margin deposits, as well as some eddy and expansion bars (Scott et al. 2018).

Moving downstream (Y2-Y6), the river begins to flow through the softer Weber Sandstone, beginning just upstream from Harding Hole. Here, the channel slope is substantially lower (0.0012 vs 0.0038) than in the first section of the Canyon, and progressively flattens as the river flows toward Echo Park and its confluence with the Green River (Larson 2004). In place of debris-fans, entrenched meanders are the dominant hydraulic control, and mid-channel gravel bars are found upstream and downstream of these narrow bends. Large alluvial terraces lateral to the channel are also commonly observed (O'Brien 1984, Fischer et al. 1983, FLO 1998, Larson 2004). The canyon in the Weber Sandstone sections is marked by smooth, symmetrical, near or past-vertical walls (O'Brien 1984, Larson 2004).

Both the Y2 and Y3 sections display entrenched meander morphology, but as the river turns northward through the Morgan Formation once again, the Y3 section is markedly more narrow, and has smaller gravel bars and less alluvial sediment (Figure 4.8-1). River section Y4 is broader, flowing through four wide parks with decreased sinuosity; here, floodplain terraces and large islands are common (Larson 2004). The river then reenters a narrower, entrenched meander valley as it flows through the Morgan Formation once more in reach Y5. This section, similar to Y3, is marked by the presence of few alluvial deposits and no gravel bars. Finally, the Yampa River flows into a broad

alluvial valley (Y6) just upstream of the confluence with the Green River, where the channel gradient drops even further and large mid-channel gravel bars are commonly found (O'Brien 1984, FLO 1998, Larson 2004).

The Yampa also displays somewhat unusual sediment dynamics. Comparison of sediment records at gaging stations on the Little Snake River and the Yampa River upstream of the confluence with the Little Snake indicate that the Little Snake Basin is the dominant source of sediment for the Yampa River at Deerlodge Park, supplying nearly 69% of the annual sediment load (and only 27% of the annual runoff) (Andrews 1978).

Additionally, nearly 60% of the sediment load for the entire Yampa Basin as measured at Deerlodge Park is derived from the lower portion of the Little Snake River. Thus, the lower Little Snake is the dominant source of sediment for the Yampa River, notable because it comprises less than 35% of the entire Yampa Basin and contributes merely 3% of the total runoff (Andrews 1978). In direct contrast to this, the eastern side of the Yampa Basin contributes nearly 73% of the annual runoff of the Yampa while contributing only 14% of the annual sediment load (Andrews 1978).

The Upper Green River

Above the confluence with the Yampa River, the upper Green River is a regulated river flowing briefly through the wide, alluvial Browns Park and then largely within the narrow Canyon of Lodore (also called Lodore Canyon). Two channel types occur along this stretch: restricted meanders in Brown's Park and fan-eddy dominated in Lodore Canyon (Grams 1997, Grams and Schmidt 2002).

Larson (2004) subdivided the 30-mile (48 km) long Canyon of Lodore into four sections of similar geomorphology (denoted L1 – L4, Figure 4.8-1), which were also qualitatively described by Grams and Schmidt (2002) (denoted Reach 1, Figure 4.8-2). The canyon trends north-south, and much of it is carved through the Uinta Mountain Group, a primarily quartzitic sandstone that contains occasional siltstone, shale, and conglomerate. Most tributaries within the canyon are aligned with structural features such as faults and joint sets (Grams 1997, Larson 2004).

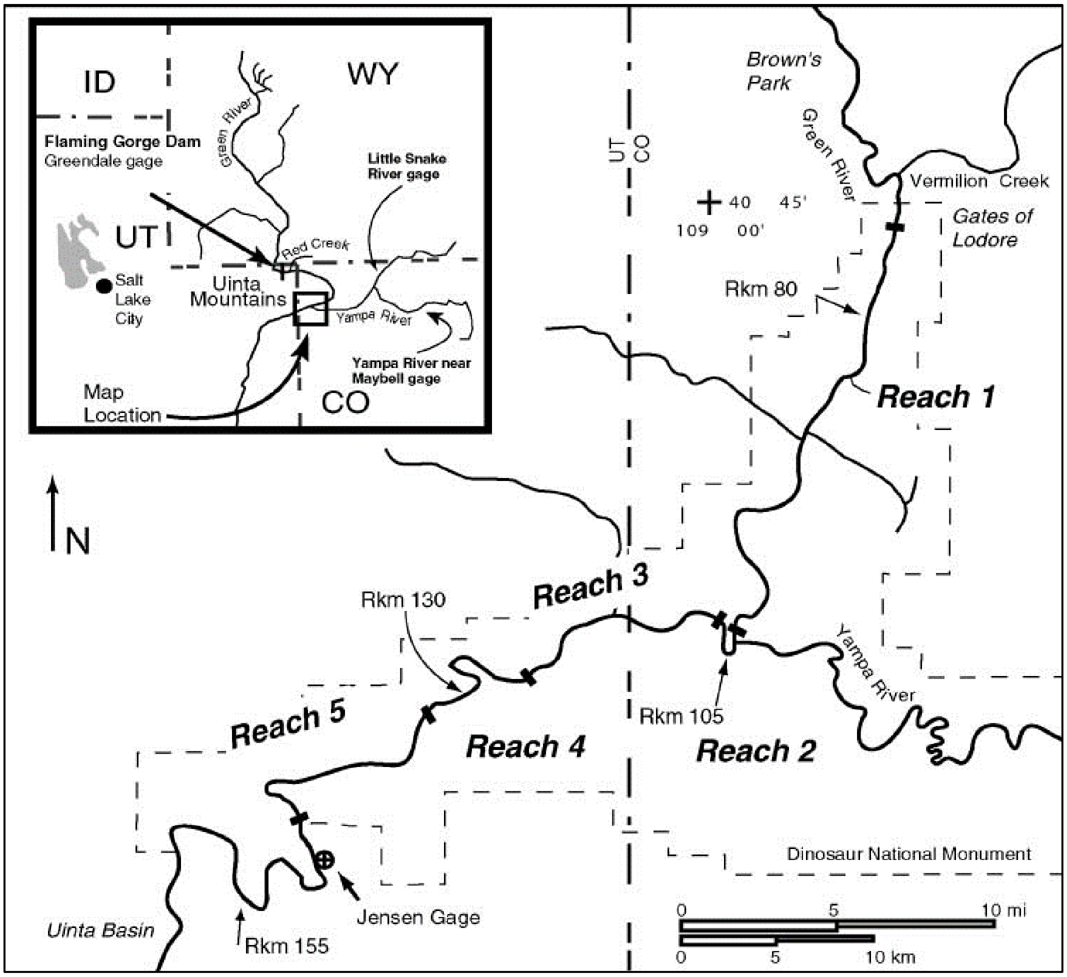


Figure 4.8-2. The upper and lower Green River within Dinosaur National Monument, showing reaches described by O'Brien (1984). From Grams and Schmidt (2002).

The first subsection of the upper Green River (L1) is five times steeper than the second (L2), and the hydraulic and sediment dynamics of each reach are similarly controlled by the tributary-associated debris fans that are present throughout the canyon. These sections are thus referred to as fan-eddy dominated (Grams and Schmidt 2002) and contain the typical sequencing of geomorphic features associated with these complexes. This typical sequencing is: an upstream pool characterized by low hydraulic gradient, a high-gradient, constricted "riffle" section alongside the debris deposit, a recirculation zone characterized by lateral eddies and sand bars, and finally an area of expanding flow often accompanied by a gravel bar composed of reworked sediment from the debris fan (Larson 2004, Grams and Schmidt 2002).

Downstream, the river flows through a mix of geological features for three quarters of the remaining length of the canyon (L3), and the near-vertical canyon walls result in an alluvial valley not much wider than the channel. In this section, most alluvial deposits include substantial mid-channel gravel bars. The final mile of the canyon (L4) widens rapidly as it approaches Echo Park. Here, the Green

River flows largely through the Weber Sandstone once more, which creates backwater effects when the Yampa River is at flood-stage (Larson 2004).

The Lower Green River

The Green River Basin is 48,100 mi^2 (125,000 km^2) in area, and includes the Yampa River Basin. Below the confluence with the Yampa River, the Green River becomes a “partially” regulated river, influenced by both the flows from the regulated upper Green and the unregulated Yampa. Grams and Schmidt (2002) separated this section into four separate reaches (Reaches 2–5, Figure 4.8-2). The confluence with the Yampa occurs at Echo Park, where the river follows a single bend as it flows through the Weber Sandstone (Reach 2). This meander occurs at the same amplitude as the valley, indicative of the incised meander channel type. The river then flows through Whirlpool Canyon and a variety of geologic facies, including the Uinta Mountain Group, Lodore Formation, and Madison Limestone. In this reach, the river does not meander but rather flows through straight sections punctuated by abrupt bends. As in Lodore Canyon upstream of the confluence, this canyon reach is marked by the frequent occurrence of debris fans and is thus a debris-fan dominated reach (Reach 3). Downstream of Whirlpool Canyon the river enters Island Park, another wide alluvial stretch coinciding with soft Tertiary and Mesozoic sediments. Here, the river channel is of the restricted meander type, with lesser meander amplitude than the valley and bedrock contacts on the outside of meander bends (Reach 4). Finally, the river flows through Split Mountain Canyon, another debris-fan dominated canyon, marked again by straight reaches and abrupt bends (Reach 5, Grams 1997).

As in Lodore Canyon, lithology exposed at river level is the primary driver of channel geometry and river gradient along the lower Green River. Additionally, the location and spacing of rapids within debris-fan dominated reaches are driven primarily by the location of debris flows, which in turn are heavily influenced by the geology and hydrology of the tributary basin from which they are derived. Thus, tributary sediment dynamics exert considerable influence on the morphology of the main channel of the Green River in these sections (Grams 1997).

Importance

These river systems are identified by NPS as a fundamental resource that supports both declining and endangered fish and a threatened plant species, contributes greatly to the area’s biodiversity, and offers world class opportunities for rafting and kayaking. They are inextricably linked to the monument’s four magnificent canyons (Scott et al. 2018, NPS 2015).

Along the Yampa River—the last mostly unregulated large river in the Colorado River basin—the natural snowmelt hydrologic regime has been minimally altered by human activities over the last century (Manners et al. 2014, Scott and Friedman 2018). Coupled with a sufficient sediment supply largely derived from the upstream Little Snake River tributary, these naturally-timed flows of adequate volume help to support the wilderness character of Dinosaur National Monument and drive the ecological integrity of the Yampa and lower Green River systems (Manners et al. 2014, NPS 2015). Several studies have chronicled and investigated various aspects of hydrologic and geomorphologic change, and the relationship with the riverine ecosystem, for the section of the Yampa within the monument (O’Brien 1984, Merritt and Cooper 2000, Bestgen 2015, Manners et al. 2014, Schook et al. 2016, Scott and Friedman 2018, Scott et al. 2018).

In contrast, the upper Green River has been significantly impacted by the installation and operation of Flaming Gorge Dam, completed in 1962. A notable body of literature has arisen over the past two decades that has documented, evaluated, and analyzed morphological change and its drivers on the Green River. Additionally, the intertwined dynamics of morphology, riparian vegetation communities, and biodiversity have been investigated along both the upper Green River and the relatively less-regulated lower Green River (Grams 1997, Allred and Schmidt 1999, Grams and Schmidt 1999, Grams and Schmidt 2002, Grams and Schmidt 2005, Merritt and Cooper 2000, Larsen 2004, Alexander 2007, Mueller et al. 2014, Schook et al. 2016, Scott et al. 2018).

Threats and Stressors

The following broad threats and stressors could potentially alter the quantity and timing of streamflows, sediment loads, and overall morphology of the Yampa and Green River systems (NPS 2015):

- Further flow regulation and alteration via in-basin impoundments and transmountain or other diversions.
- Disturbance and sediment resulting from dam decommissioning or dam failure (pers. comm., Salek Shafiqullah, 2019).
- Flow depletion due to human population growth and competing water interests.
- Climate change and associated alteration of snowfall and melt, as well as rainfall distribution and intensity.
- Increasing populations of invasive riparian species and introduction of additional non-native species.
- Expansion of recreational activities along the Yampa River.

Indicators and Measures

Stream Flows

Relatively frequent floods of significant magnitude maintain the wide active channels and checkerboard pattern of bare alluvial surfaces characteristic of natural flowing rivers in this region (Scott and Friedman 2018). Along regulated rivers, which generally have significantly less flow variability than their unregulated counterparts, formerly active surfaces are often transformed into more stable features via vegetation establishment and subsequent narrowing (Scott et al. 2018). These commonly observed differences among rivers with contrasting flow regimes highlight the major influence of streamflow on the geomorphology and sediment dynamics of fluvial systems, which in turn, heavily impact various river-related ecosystems (Wolman and Miller 1960, Grams and Schmidt 2005, Bestgen 2015, Scott and Friedman 2018). Along the largely unregulated Yampa River, potential changes to be expected from streamflow alterations can be gleaned from observations along the Green River, which was once very similar to the Yampa (pre-dam annual flowrate of 55 and 58 m^3/s, respectively) (Cooper et al. 1999).

Essentially, both the magnitude and frequency of peak streamflows (i.e. floods), as well as the magnitude and duration of mean annual flows and baseflows, heavily influence all aspects of the river systems located within DINO. As such, examination of the streamflow regime of each river section is key to the evaluation of the state of the Yampa, upper Green, and lower Green Rivers. The measures used to determine the condition and trend of stream flows for each river segment are *peak flows* and *average flow/baseflow*.

Sediment Loads/Dynamics

The channel of an alluvial river adjusts over time to transport the sediment supplied with the available discharge (Leopold and Wolman 1956, Wolman and Miller 1960, Leopold et al. 1964, Andrews 1986). When the amount of sediment entering a river reach is roughly equivalent to the amount leaving that reach, (i.e. there is no deposition or progressive erosion along the channel or floodplain), a channel is said to be in a state of quasi-equilibrium. Under these conditions, average hydraulic characteristics such as velocity, depth, width, slope, and channel planform are essentially constant. Any change in discharge or sediment supply can result in disequilibrium, and the channel will adjust these variables in such a manner as to re-attain a quasi-equilibrium state (Andrews 1986). In more restricted reaches, such as the canyons that occur on both the Green and Yampa Rivers in the monument, channel adjustment is more readily controlled by the geology of the surrounding canyon. However, changes in sediment supply can still result in changes to local morphology (i.e., bar aggradation resulting from sediment deposition) (Resource Consultants 1991).

Overall, sediment loads are closely tied to the hydrology of the associated river. A change in the stream flow dynamics of a river system can heavily impact the sediment dynamics of that system, which would subsequently result in morphological change. In turn, such morphological adjustments can cause detrimental changes to vital habitats of native fishes and plants. Evaluation of the current state of sediment loads and dynamics compared to those observed under pre-dam conditions is thus an important indicator of the current health of the rivers in DINO, and can be key to predicting how each reach will evolve with respect to any future disturbances (O'Brien 1984, Resource Consultants 1991, Grams and Schmidt 1999, Bestgen 2015). The measures used to determine the condition and trend of sediment loads/dynamics for each river segment are *annual loads and equilibrium condition* and *effective discharge*.

Geomorphology

Geomorphic change is strongly related to discharge and sediment load discussed above, and often results from the alteration of these fundamental processes (Schook et al. 2016). Lightly regulated rivers in the western United States commonly experience rapid channel movement due to significant flow variability, whereas regulated rivers are often marked by a narrow channel bordered by dense vegetation (Scott and Friedman 2018). The identification of a change in river morphology, therefore, is a useful indicator of the impact of alterations to the river's natural regime. Evaluation of morphological change over time (i.e., a history of channel and floodplain evolution) is useful in attempting to predict the impact of future changes.

Furthermore, the physical structure of the stream channel and the associated floodplain are an important driver of biological processes of big river systems. The characteristics of these surfaces are

important aspects of the habitat of both flora and fauna in the river and riparian zone, and often influence ecosystem diversity (Tyus and Karp 1989, Merritt and Cooper 2000, Bestgen 2015). The geomorphology of the Yampa and Green Rivers within DINO is thus an important indicator of the current state of these systems. The measures used to determine the condition and trend of geomorphology for each river segment are *channel width* and *geomorphic features and surfaces*.

4.8.2. Data and Methods

<u>Stream Flows</u>

Streamflow has been monitored at various locations on both the Green and Yampa Rivers since the early 20th century. On the upper Green River, flows at the Green River near Greendale, Utah gage, located 0.37 miles downstream of Flaming Gorge Dam, were recorded starting in 1951, and have been extended continuously back to 1915 using regression techniques and records from gages at Linwood, Utah, and Green River, Wyoming. Records for annual peak streamflow on the upper Green River exist for 1895–1899, 1901–1906, and 1915-present (Grams and Schmidt 2002). For the lower Green River, daily streamflow and peak annual streamflow were recorded beginning in 1947 at Jensen, Utah, downstream of the monument boundary. Finally, streamflow on the Yampa in the monument was monitored by combining flow measurements from the gage on the main stem of the Yampa in Maybell, Colorado, and on the Little Snake at Lily, Colorado. In this manner, streamflow records can be extended back to 1923 (Grams and Schmidt 2002). Additionally, streamflow for Deerlodge Park has been monitored directly since gage installation at Deerlodge Park in 1982 (Elliott and Anders 2005).

Various studies have analyzed streamflow in different capacities on all three river reaches across the better part of three decades. On the Yampa, several investigators have examined the evolution of both total annual discharge and peak annual discharge over time, constructed flow duration curves, and investigated the seasonal distribution of streamflow (Andrews 1978, Andrews 1980, Andrews 1986, O'Brien 1984, Elliott et al. 1984, Grams 1997, Grams and Schmidt 2002, Elliott and Anders 2005, Gray et al. 2011, Manners et al. 2014, Bestgen 2015, Schook et al. 2016, Scott et al. 2018). On the upper Green River, time series of annual peak streamflow and mean and median annual flow have been investigated by various authors in order to evaluate the impact of Flaming Gorge Dam on discharge (Andrews 1986, Grams 1997, Merritt and Cooper 2000, Grams and Schmidt 2002, Alexander 2007, Schook et al. 2016). Similar investigations have been undertaken for streamflow on the lower Green River (Andrews 1986, Grams 1997, Grams and Schmidt 2002, Elliott and Anders 2005, Mueller et al. 2014, Schook et al. 2016, Scott et al. 2018). Data and conclusions from these studies were used in the evaluation of the condition of each river segment within the monument.

<u>Sediment Loads/Dynamics</u>

Studies of the sediment loads and dynamics of all three river reaches began nearly four decades ago and have been updated at irregular intervals in subsequent years. Andrews (1978) evaluated sediment loads of the Yampa River using recorded sediment data at 17 USGS gaging stations in the Yampa River basin. These records were then used to evaluate the contribution of each sub-basin to the overall sediment load of the Yampa River at Deerlodge Park in order to identify source areas. With similar data, Andrews (1980) constructed sediment load-duration and streamflow-duration curves at

15 stations across the Yampa River basin in order to calculate effective discharge (i.e., the discharge that moves the most sediment) for various tributaries of the Yampa River. Additionally, Andrews (1986) used sediment transport and streamflow data at 11 USGS gaging stations to evaluate the impacts of Flaming Gorge Reservoir on the Green River, although only a few of these data and conclusions were relevant to stretches of the Green within DINO boundaries.

In a similar manner, Elliott et al. (1984) examined sediment transport in the lower Yampa River using gaging station and sediment transport records at three stations: Little Snake River near Lily, CO (USGS 09260000), Yampa River near Maybell, CO (USGS 09251000) and Yampa River at Deerlodge Park, CO (USGS 09260050). The first two are upstream of the monument, and the latter represents the sediment load/streamflow that enters the monument via the Yampa River. Sediment transport equations were derived from measured data to relate sediment concentrations to flow, and thus construct a sediment transport history along the lower Yampa River using historical flow records, as well as a sediment budget for this stretch of river.

Elliott and Anders (2005) used an analogous approach to investigate sediment dynamics along the upper Green and lower Green rivers, as well as update previous observations and conclusions on the Yampa River. Streamflow and sediment records were used in conjunction with sediment rating curves to evaluate streamflow and sediment load at five stations, including the upper Green upstream of the monument, the Yampa at Deerlodge Park, and the lower Green River just downstream of the monument at Jensen, Utah.

In a somewhat more limited approach, O'Brien (1984) collected sediment samples at Mathers Hole (just downstream of Yampa Canyon) and used a sediment-transport equation and streamflow measurements to calculate suspended sediment loads for Yampa Canyon. Using similar concentration-discharge relationships derived from field data, mean annual loads were also calculated for Deerlodge Park, as well as the upstream Yampa and Little Snake. Grams and Schmidt (2002) calculated sediment loads on a similar scale, and used sediment concentration measurements in concert with streamflow records to calculate loads at the Jensen, Utah, gage just downstream of DINO for pre-dam (1948–1962) and post-dam (1963–1979) periods.

Finally, Resource Consultants (1991) used the aforementioned existing sources and field measurements to establish and evaluate baseline conditions for the sediment transport dynamics of the Yampa River and Green River systems. Sediment-rating curves were developed and used to calculate annual sediment loads, and the impact of extraneous factors such as climate change on the sediment dynamics of both systems was also investigated.

Overall, the data and conclusions gathered and presented in these studies were used in the evaluation of the trends and conditions of the sediment loads and dynamics of the big rivers found within DINO.

Geomorphology

Significant and extensive studies concerning various aspects of the geomorphology of the Green River have been undertaken by various researchers over the last thirty-plus years. Andrews (1986) measured bankfull width via historical aerial photographs for evidence of channel narrowing along

the Green River. Grams (1997) conducted an extensive study of both the upper and lower Green Rivers through repeated cross sections, analysis of historical photographs, mapping of surficial geology and deposits, and compilation of an inventory of all rapids and riffles. These various techniques were carried out from Browns Park in the northeast corner of the monument to Split Mountain Canyon in the southwest.

Mapping and classification of the geomorphic surfaces and structures found along the Green River was furthered carried out by Grams and Schmidt (2002). They also studied historical photographs for evidence of channel narrowing. Grams and Schmidt (2005) further investigated channel evolution on the Green River using historical photographs and stream gage records. They also constructed a sediment budget for the Green River ranging from Flaming Gorge Dam (outside of DINO) to the confluence with the Yampa at Echo Park (within park boundaries) in order to investigate questions of channel equilibrium.

Alexander (2007) excavated several trenches in the Lodore Canyon and Browns Park region of the Green, and used dendrochronologic analysis, historical photographs, and discharge records to construct a timeline of geomorphic change along the upper Green River. Additionally, 36 cross sections were surveyed and analyzed to further investigate questions concerning channel evolution through the lens of fine sediment storage.

Analysis pertaining to the impact of a more specific event was carried out by Mueller et al. (2014), concerning a controlled release from Flaming Gorge Dam in 2011. Detailed surveys at several locations were used to construct cross sections for comparison with past cross sections, which were used in concert with stratigraphic analysis of nine trenches and documentation of tracer-rock movement to investigate the impact of the 2011 controlled release on the geomorphology of the upper Green River within Lodore Canyon.

In terms of comparative studies, Larson (2004) investigated the distribution of tamarisk along canyon stretches of both the Yampa and upper Green rivers within the monument and how the distribution related to the geomorphology and hydrology of the two reaches. Merritt and Cooper (2000) conducted a similar study using a variety of field sampling techniques and historical photograph analyses to investigate riparian vegetation and channel change. Prior to these, Fischer et al. (1983) mapped and described vegetation and geomorphological features and surfaces, as well as analyzed current and historical photographs along all three river segments in the monument.

The geomorphology of the Yampa River has been similarly investigated and described by a number of studies throughout the past three decades. O'Brien (1984) surveyed 21 cross sections in Yampa Canyon, which were resurveyed by FLO Engineering in 1997 (FLO Engineering 1998). More extensively, Scott et al. (2018) mapped channel types, geomorphic features, geomorphic surfaces, and riparian vegetation from Deerlodge Park to the confluence with the Green River at Echo Park to investigate elements of channel change.

Work comparable to Larson (2004) concerning riparian vegetation and river geomorphology was conducted by Manners et al. (2014). The authors analyzed flow data, excavated several trenches for

stratigraphic and dendrogeomorphic analyses, inspected historical aerial photographs, and mapped riparian vegetation in two reaches of the Yampa River in Yampa Canyon. Scott and Friedman (2018) conducted a similar but more exhaustive survey of riparian vegetation along the Yampa to investigate the relationships between flow, morphology, and vegetative cover and the potential impacts of flow regulation on these dynamics.

The aforementioned studies and the data and conclusions presented therein were all used in the evaluation of the geomorphology of the upper Green River, lower Green River, and Yampa River contained in the subsequent sections.

4.8.3. Reference Conditions/Values

Pre-dam conditions were chosen as a reference to evaluate current trends because they represent a wild, unregulated river. Changes to both the variability and volume of flow for each of the big rivers in DINO directly impact the sediment dynamics and geomorphology of each stretch of river, which in turn affect the vegetation and wildlife found within the riverine ecosystem. As pre-regulation conditions effectively represent an ideal state, a comparison of the current streamflow regime to pre-dam values allows for an accurate assessment of current condition and trends for the big river system within the monument. A reference condition framework for big river segments is shown in Table 4.8-1.

Table 4.8-1. Reference condition framework for Big River indicators and measures. Values are percent of pre-dam conditions for that measure. Sources for reference condition for each indicator are discussed in Section 4.8.3.

Indicator	Measure	Value Relative to Reference Condition		
		Good Condition	Moderate Condition/ Concern	Poor Condition/ Significant Concern
Stream Flows	Peak Flow (m^3/s)	80–100%	50–79%	< 50%
	Average/Minimum Flow (m^3/s)	85–100%	65–84%	< 65%
Sediment Loads/Dynamics	Annual Loads and Equilibrium Condition (tons/yr)	75–100%	40–74%	< 39%
	Effective Discharge (m^3/s)	70–100%	30–69%	< 29%
Geomorphology	Channel Narrowing	–*	–*	–*
	Geomorphic Features and Surfaces	–*	–*	–*

* Narrative ratings for condition are discussed in the *Geomorphology* section.

<u>Stream Flows</u>

Condition ratings for stream flows are based on the percent change in indicators and measures from pre-dam conditions (Table 4.8-1). On the Yampa, the pre-dam two-year flood was about 400 m^3/s. Pre-dam peak annual discharge was generally between 350–425 m^3/s, while mean annual discharge was on the order of 60 m^3/s, and baseflow (minimum mean 7-day flow) was approximately 6 m^3/s. Subject to a snowmelt-dominated hydrologic regime, peak flow on the Yampa generally occurred in late May to early June (Figure 4.8-3) (Grams and Schmidt 2002, Schook et al. 2016).

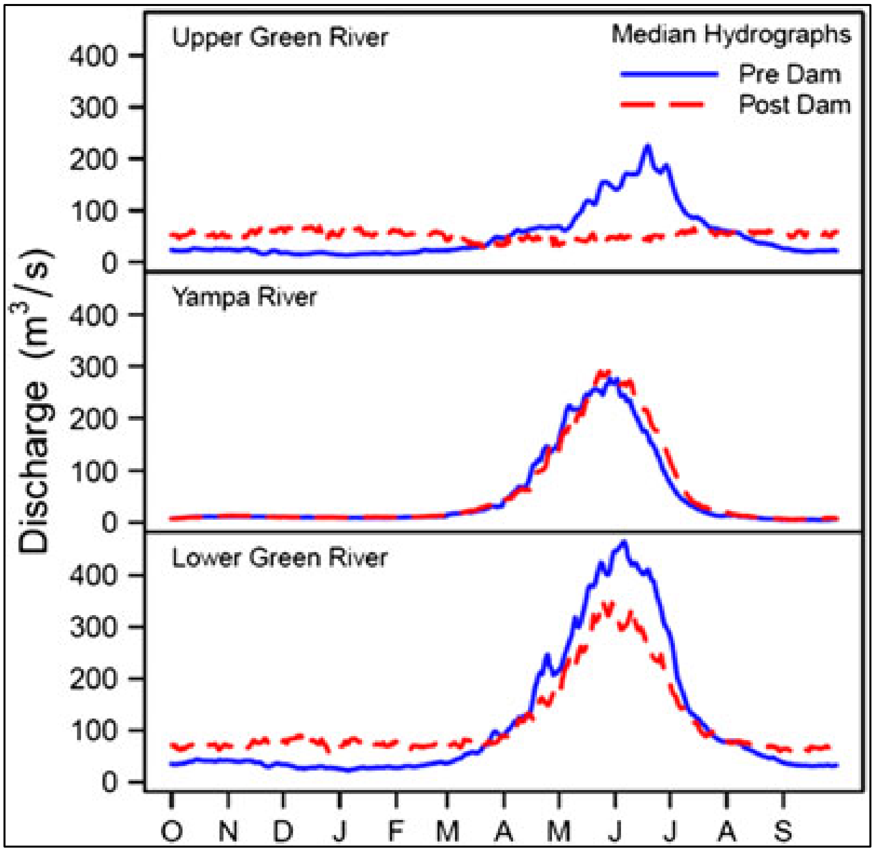


Figure 4.8-3. Pre- and post-Flaming Gorge Dam median annual hydrographs for each river section within the monument. X-axis indicates months from October (O) to September (S). (Schook et al. 2016).

The mean annual peak for the upper Green was around 334 m^3/s pre-Flaming Gorge Dam and the mean annual discharge was 59 m^3/s (Grams 1997, Grams and Schmidt 2002). The pre-dam upper Green also operated under a snowmelt-dominated hydrologic regime, with a mean daily flow peak occurring in late-May to early-June (Figure 4.8-3, Merritt and Cooper 2000, Schook et al. 2016). Pre-dam baseflow was generally between 20–30 m^3/s (Schook et al. 2016). Additionally, flow duration curves show a fairly high degree of variability in daily mean discharge (Alexander 2007).

For the lower Green, the two-year flood for pre-dam years was 626 m^3/s (Grams and Schmidt 2002). Pre-dam median daily peak discharge was on the order of 400 m^3/s and occurred in the late spring/early summer (Figure 4.8-3). Median annual discharge generally peaked between 450–750 m^3/s, and baseflow was ~20 m^3/s (Schook et al. 2016). Flow duration curves indicate a variable, natural flow regime (Andrews 1986).

Sediment Loads/Dynamics

Pre-dam conditions are also an appropriate baseline from which to evaluate the current trend of sediment loads and dynamics on all three stretches of river, as they represent a wild and unregulated state. Significant changes to the quantity and character of transported sediment within the rivers of DINO could have potentially deleterious impacts on channel morphology and the associated habitat of native fishes and vegetation. It is therefore useful to evaluate current sediment loads in light of

pre-dam conditions in order to accurately summarize trends. Additionally, observations of changes from pre- to post-dam time periods on the Green River can be used to evaluate any potential change on the Yampa River caused by future regulation.

On the Yampa River, sediment loads have not changed noticeably from pre-dam to post-dam years (Grams and Schmidt 2002). Various calculations for total sediment load at Deerlodge Park have been tabulated by several authors: 2.0 x 10^6 tons/yr (Andrews 1978, Andrews 1980), 2.04 x 10^6 tons/yr (Elliott et al. 1984), 1.75 x 10^6 tons/yr (O'Brien 1984).

Pre-dam suspended sediment loads for this reach were 1.16 x 10^6 tons/yr (Grams and Schmidt 2005). Loads for the pre-dam upper Green River are represented graphically in Figure 4.8-4. The pre-dam effective discharge curve on the upper Green was fairly flat, which indicated that a range of flows were responsible for significant sediment transport (Grams and Schmidt 2002).

For the lower Green River, the pre-dam (1947–1962) mean annual sediment load was 6.92 x 10^6 tons/yr (Andrews 1986). Grams and Schmidt (2002) calculated a similar pre-dam sediment load at the Jensen gage of 6.50 x 10^6 tons/yr. Grams and Schmidt (2005) calculated a suspended sediment load of 7.16 x 10^6 tons/yr. Additionally, the pre-dam effective discharge for the lower Green was approximately 600 m^3/s (Grams and Schmidt 2002).

Condition ratings for sediment loads/dynamics are based on the percent change in indicators and measures from pre-dam conditions (Table 4.8-1).

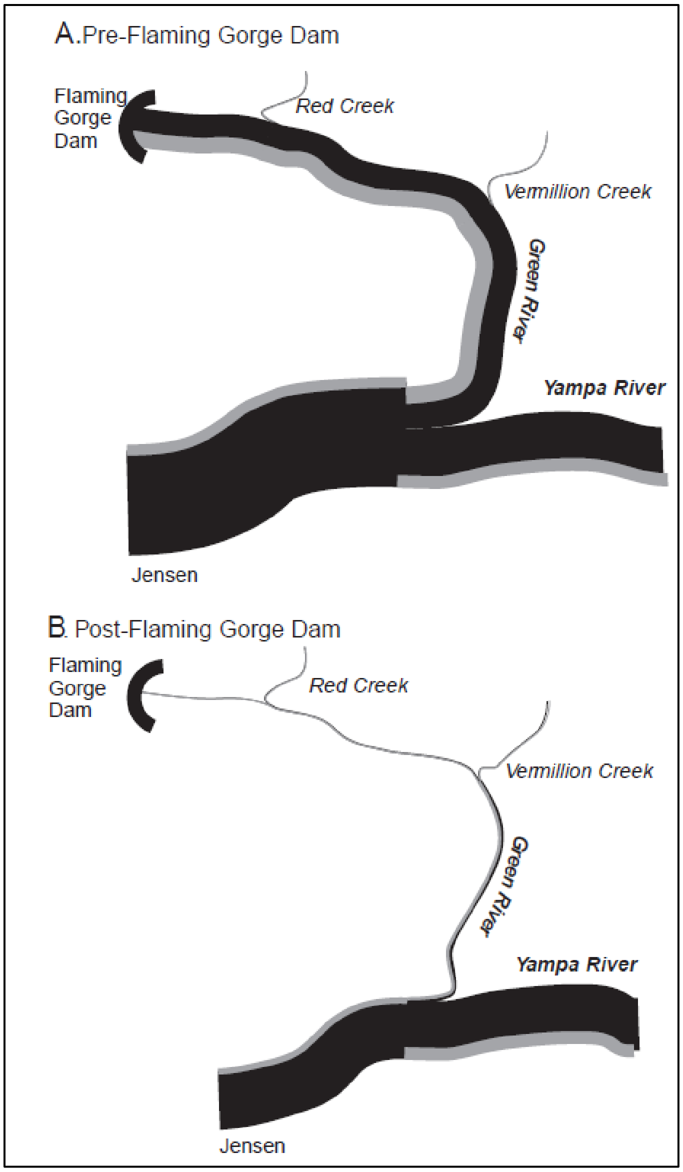


Figure 4.8-4. Pre- and post-dam estimated sediment mass balances for the upper Green, lower Green, and Yampa Rivers. Thickness of lines indicates amount of sediment. The gray portion is the magnitude of uncertainty (i.e., the width of the black line is the minimum estimated load, while the sum of the black and gray line is the maximum estimated load) (Grams and Schmidt 2005).

Geomorphology

For the Yampa River, broad, minimally-vegetated gravel bars in the wide alluvial reaches of Yampa Canyon were identified from pre-1961 photographs (Manners et al. 2014). Additionally, historically active floodplain surfaces were more extensive in the wider reaches of Yampa Canyon and smaller in the narrower stretches (Fischer et al. 1983). The historical Yampa in Deerlodge Park, as it appeared in 1938 aerial photographs, was likely an actively meandering reach, with vertical cutbanks on the outside of meander bends and aggrading point bars on the inside (Merritt and Cooper 2000).

The Green River channel in the Browns Park area was an actively meandering reach in the 30 years before dam closure (1938–1962) and potentially in a state of quasi-equilibrium (Merritt and Cooper 2000). This actively-meandering morphology, which the Yampa at Deerlodge Park still exhibits, is crucial for the success of riparian vegetation, due mainly to the complex interactions of flood frequency, sedimentation dynamics, and water availability associated with it. Dam installation, and the subsequent flow alterations, impact these dynamics, causing the channel to undergo several evolutionary stages: initial narrowing, followed by point bar and bank erosion of the formation of mid-channel bars, then island formation, channel widening, and ultimately the lateral degradation of the channel (Merritt and Cooper 2000).

Additionally, pre-dam historical photographs for both the upper and lower Green River indicate that bare, active channel surfaces were extensive in both canyon-bound and park reaches, such as the eddy bar in Figure 4.8-5 (Grams 1997, Grams and Schmidt 2002). Both gravel and sand deposits were largely devoid of vegetation, suggesting that they were regularly reworked by flood flows, and pre-dam active channel area was fairly large (Grams 1997). Essentially, pre-dam morphology on the upper Green River consisted of an active-channel, a pre-dam floodplain, and an accreting terrace (Alexander 2007).

Figure 4.8-5. Eddy bar in Lodore Canyon, photographed on June 17, 1871 by E.O. Beaman. Bare alluvial surfaces such as this were extensive in pre-dam years, while these bars now tend to be heavily vegetated due to lack of scouring flows (Grams and Schmidt 2002).

The use of pre-dam geomorphological conditions as a reference condition is a practical way to evaluate the current trend of the geomorphology of the Green River. Pre-dam conditions represent a "wild" unregulated channel, and most existing literature separates observations into these two disparate time periods. Current trends on the Yampa River, which retains its "wild" character, can also be used to further contextualize and evaluate trends along the Green River (e.g., to adjust for trends attributable to climate change), but it is more straightforward to compare the post-dam Green River to the pre-dam Green River. For the Yampa River, where flow regulation has been minimal, pre-dam (i.e., pre-1963) conditions were selected as the reference condition for the sake of consistency. Assessment of the condition for geomorphology indicators is largely subjective and based on professional opinion.

4.8.4. Condition and Trend

Yampa River

Stream Flows

Metric 1: Peak flow

Because the Yampa River has remained relatively unregulated, its associated hydrograph has remained relatively consistent over the better part of the last century. Annual mean daily peak flow on the Yampa has changed little over the past 90 years (Figure 4.8-6) (Bestgen 2015). The two-year (i.e., common) flood is on the order of 400 m^3/s for both the pre- and post-dam years (Figure 4.8-7) (Grams and Schmidt 2002). However, the magnitude of larger floods (>5-year recurrence interval) have increased in post-dam years (Manners et al. 2014). Overall, peak mean daily discharge between pre- and post-dam years is effectively unchanged (Figure 4.8-8) (Schook et al. 2016).

In general, flows peak in Deerlodge Park between late-April and mid-June, often with an initial but relatively lower peak sometime in late-April/early-May and subsequent larger peak later in the spring. This behavior is consistent for both pre- and post-dam periods (Schook et al. 2016). The trend of peak flows is mostly unchanged; the consistency with respect to pre-dam values suggests that this indicator is in good condition. Due to the abundance and currentness of data and related analyses, confidence in the assessment is high.

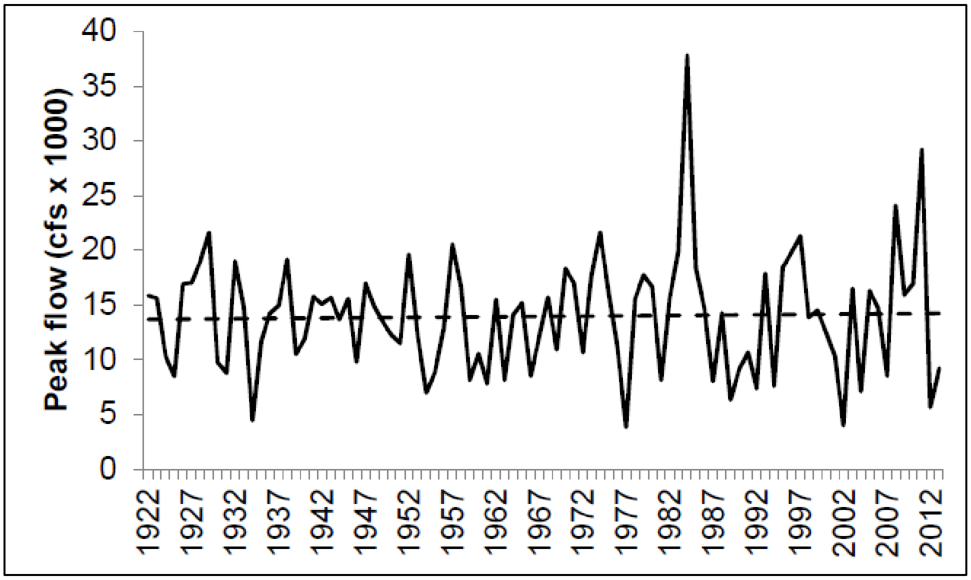


Figure 4.8-6. Annual mean daily peak flow from 1922–2012 for the Yampa River (Bestgen 2015).

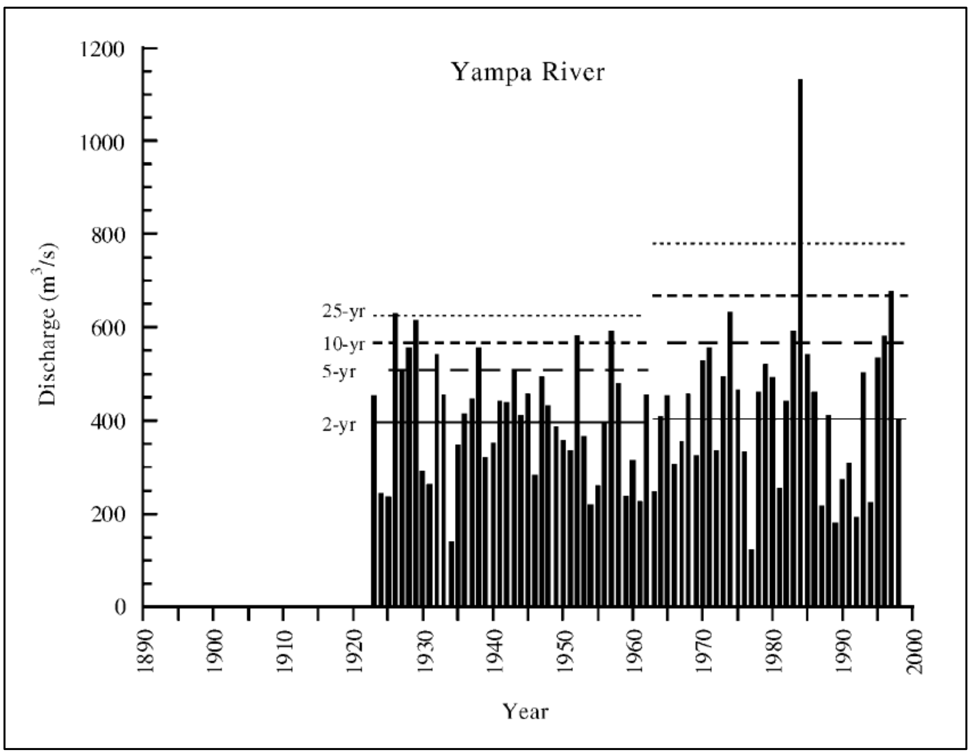


Figure 4.8-7. Annual peak discharge of the Yampa River, showing 2-, 5-, 10-, and 25-year floods for the pre- and post-Flaming Gorge Dam periods (Grams and Schmidt 2002).

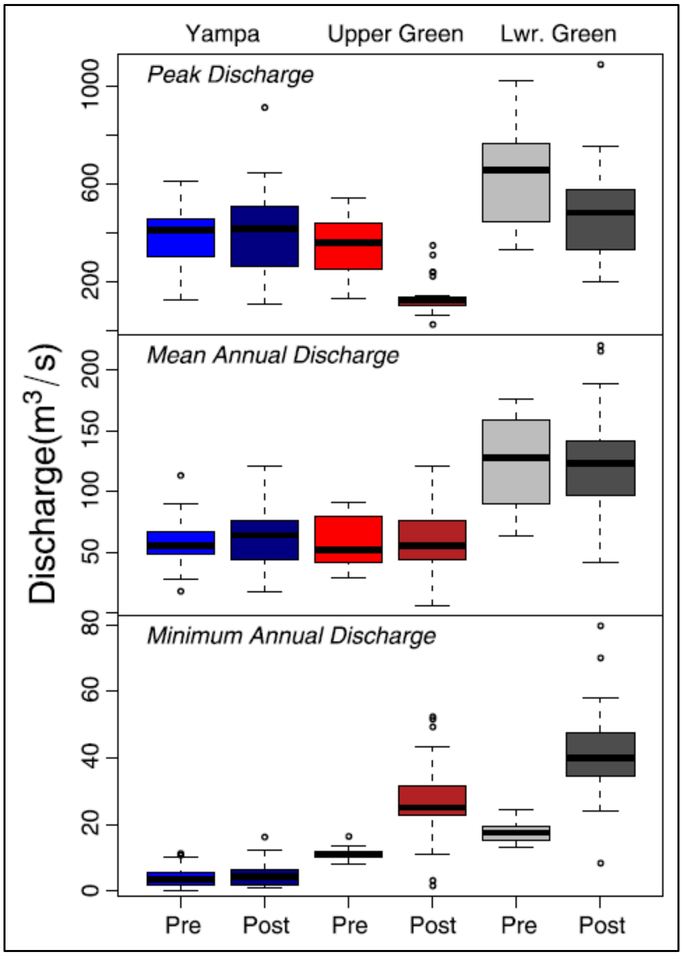


Figure 4.8-8. Pre- and post-dam discharge metrics for three river segments in DINO (Schook et al. 2016).

<u>*Metric 2: Average flow and minimum flow*</u>

Mean daily flow on the Yampa has also remained unchanged from pre- to post-dam years, with a magnitude of roughly 60 m^3/s in both periods (Alexander 1980, Grams and Schmidt 2002, Schook et al. 2016). Similar behavior is observed for baseflow, which was approximately 7 m^3/s for both periods (Schook et al. 2016).

Both average and baseflow appear unchanging. Given that this unchanging trend indicates that natural conditions persist, this indicator is in good condition. Additionally, both the amount and recency of data indicate a high confidence in this assessment.

Sediment Loads/Dynamics

<u>*Metric 1: Annual loads and equilibrium condition*</u>

Manners et al. (2014) estimated the mean annual sediment load at Deerlodge Park to be roughly 1.6 x 10^6 tons/year using the sediment-transport relationship developed by Elliott and Anders (2005) and streamflow records. This is a similar figure to the mean total loads mentioned above of 2.0 x 10^6 tons/yr (Andrews 1978, Andrews 1980), 2.04 x 10^6 tons/yr (Elliott et al. 1984), and 1.75 x 10^6 tons/yr

(O'Brien 1984). Of the total annual sediment load, about 95% is suspended sediment, with bedload making up the remaining 5% (Elliott et al. 1984).

Additionally, available evidence suggests the Yampa River is in a state of equilibrium through Deerlodge Park (Elliott et al. 1984) and in a state of quasi-equilibrium downstream in Yampa Canyon (Resource Consultants 1991). Notably, this calculated equilibrium condition is likely within the margin of error of sediment budget calculations (Grams and Schmidt 2005).

Overall, the mean annual load and equilibrium state of the Yampa River has largely remained unchanged in pre- and post-Flaming Gorge Dam years (Figure 4.8-4, Grams and Schmidt 2005). Therefore, the current trend for annual sediment loads and equilibrium state on the Yampa River seems to be unchanging and this indicator seems to be in good condition. However, confidence in this assessment is low, given the relatively sparse data.

Metric 2: Effective discharge

Effective discharge at the Lily, Colorado, station on the Little Snake and the Maybell, Colorado, station on the Yampa, which together contribute the sediment load to Deerlodge Park, was 127 m^3/s and 258 m^3/s, respectively. These flows were exceeded 1.1% of the time (4 days/yr) and 2.5% (9.1 days/yr), respectively. Clearly, the effective discharge is of relatively frequent occurrence rather than a rare, large magnitude flow, which is consistent with the theory of natural channel adjustment (Wolman and Miller 1960, Andrews 1980). Additionally, bankfull discharge at these locations was measured as 133 m^3/s and 255 m^3/s, respectively, which is also consistent with classical hypotheses of channel evolution (Wolman and Miller 1960, Andrews 1980).

At Deerlodge Park, roughly 25% of the annual sediment load is transported by flows larger than 12,000 ft^3/s, which is exceeded around 2.5% of the time (9.1 days per year). The effective discharge is approximately 11,500 ft^3/s (O'Brien 1984). It is clear that large but common flows play an important role in the sediment dynamics of the Yampa River at Deerlodge Park. This intermittent sediment transport is a significant control on the morphology and associated biological diversity of the river (Elliott et al. 1984). Downstream, in Yampa Canyon, the bankfull discharge, which is commonly accepted to be the effective discharge, is 21,500 ft^3/s, which has a recurrence interval of roughly 20 years. This suggests that large, infrequent floods play a dominant role in the sediment transport within the Yampa Canyon stretch of the river (O'Brien 1984).

Given that the effective discharge for the Yampa River in the monument is consistent with classical theory of channel adjustment (i.e., commonly occurring), and that approximately bankfull discharge transports the largest portion of sediment, this indicator was rated in good condition with an unchanging trend and medium confidence.

Geomorphology

Metric 1: Channel width

The meandering channel planform in Deerlodge Park displayed striking similarity in 1938 and 1994 photographs, suggesting that the channel retained its natural character and was in a state of quasi-equilibrium (Merritt and Cooper 2000). The channel widened between 1938 and 1977 at a rate of 0.5

m/year for a total expansion of 18.6 m, remained largely static between 1977–1984, and then rapidly narrowed by 8% (18 m) from 1984–1994, at a rate of 2.0 m/year. This resulted in a negligible change in width from 1938–1994 (Figure 4.8-9, Merritt and Cooper 2000).

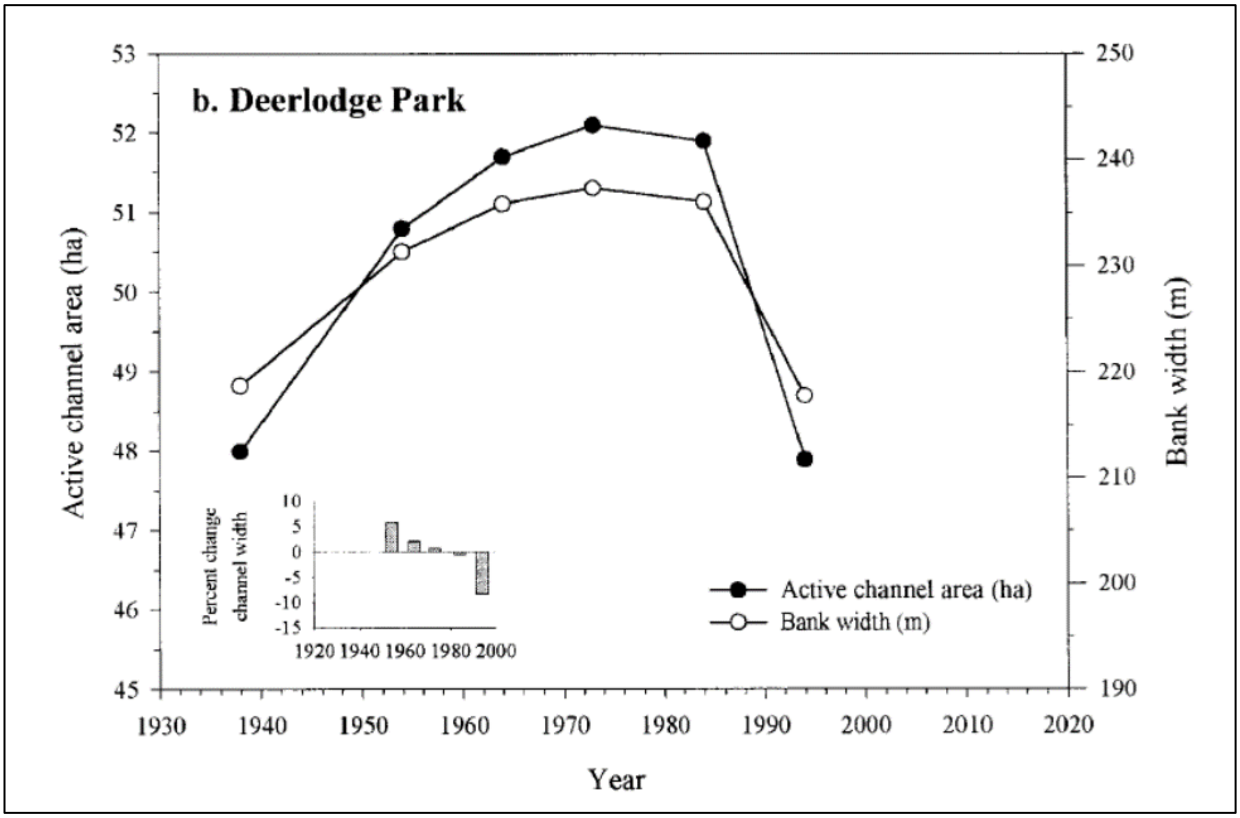


Figure 4.8-9. Active channel area and bank width of the Yampa River in Deerlodge Park from 1938–1994 calculated from historical aerial photography (Merritt and Cooper 2000).

Historical photographs taken between 1961 and 2011 (photographs taken in 1961, 1982, 1983, 1989, 1999, 2005, 2010, 2011) indicated that the active channel of the Yampa River in Yampa Canyon narrowed by 6% over the 50-year time period at Harding Hole and Laddie Park (Manners et al. 2014). These are relatively unconfined stretches, and the widest and most adjustable parts of the canyon (Larson 2004, Manners et al. 2014). From 1961–1982, significant mid-plain floodplain construction took place, but was almost fully offset by floodplain erosion along channel margins, resulting in slight reduction of channel width of 1.2 m (± 0.61; mean difference ± standard deviation) (Figure 4.8-10). From 1982–1989, several large floods slightly widened the channel, by about 1.6 m (± 0.8 m). From 1989–1999 the channel narrowed substantially, initially rather slowly (by 0.7 m ± 0.4 m from 1989–1993) and then rapidly (by 3.5 m ± 0.8 m from 1993–1999). From 1999–2005 the channel continued to narrow by 1.8 m (± 1.0 m), but this was partially offset by channel widening of 0.6 m (± 0.2 m) following large floods in 2008 and 2011 (Figure 4.8-10, Manners et al. 2014).

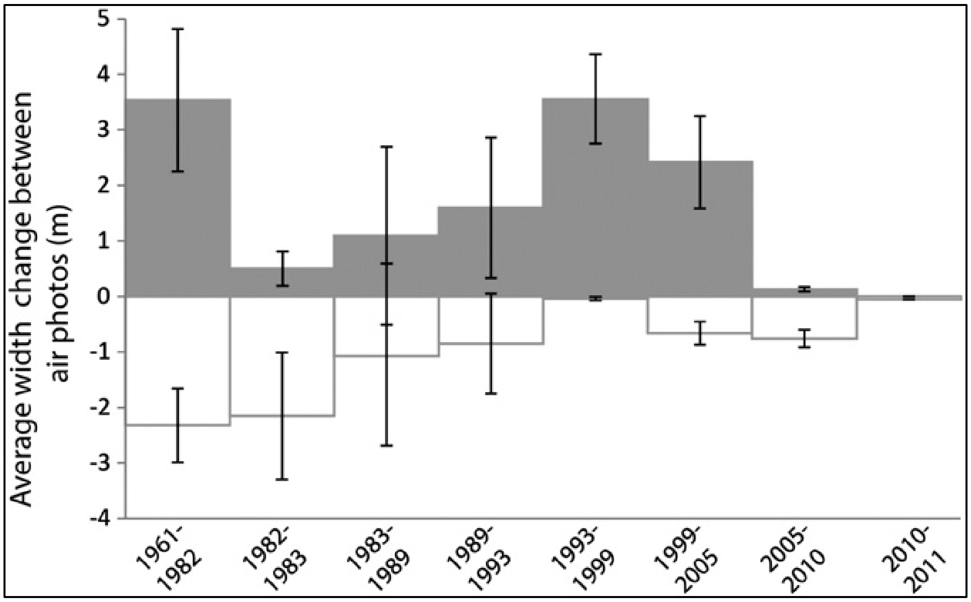


Figure 4.8-10. Rate of channel width change of the Yampa River in Yampa Canyon over time (Manners et al. 2014).

A slight shift in the hydrology of the Yampa River resulted in a significant expansion of tamarisk, which in turn caused channel narrowing of a small but measurable degree. Three percent of channel narrowing on the Yampa occurred along channel margins, 2% due to new floodplain construction on existing, previously active mid-channel bars, and 1% in backwater, eddy-associated areas. Establishment of tamarisk on the channel margins and banks resulted in both enhanced floodplain construction as well decreased floodplain erosion (Manners et al. 2014).

Tamarisk establishment and channel narrowing is a positive feedback loop that enables the rapid channel narrowing observed along the Yampa. However, a dearth of tamarisk cohorts established post-2000, as well as a decreased rate of channel narrowing (Figure 4.8-10), suggest that the Yampa may be approaching a new equilibrium, with balance between sediment supply, flow regime, and the roughness and stability associated with tamarisk. In turn, this suggests that the Yampa is possibly nearing a new, narrower stable state. Future risks to this “new normal” include expansion of the range of the tamarisk beetle, upstream water development in the Yampa Basin, and increased intensity of wet and dry cycles due to climatic drivers. These could push the channel back into a disequilibrium state (Manners et al. 2014).

In summary, the channel in Yampa Canyon appears to have narrowed moderately from the pre-1962 reference state, likely due to a complex interaction between flow sequencing and vegetation establishment (Manners et al. 2014, Scott and Friedman 2018). However, the channel may have stabilized and reached a new quasi-equilibrium condition (Manners et al. 2014), although the possibility remains that a climate change-associated decrease in peak flows could cause additional channel narrowing (Scott and Friedman 2018). Additionally, there is always the risk of future significant flow regulation in the Yampa Basin, which would likely result in further channel narrowing and channel scour associated with extreme events (Manners et al. 2014, Scott and

Friedman 2018). Thus, the trend for channel width has declined slightly since pre-dam years, but this indicator is still in good condition given the relatively minor extent of narrowing. Confidence in this assessment is medium.

Metric 2: Geomorphic features and surfaces

Within the three channel types mentioned previously, there are a variety of geomorphic features, including point bars, mid-channel bars, eddy bars, and various others (Scott et al. 2018). Such features were also extensively discussed in previous work (Larson 2004, Manners 2013, Manners et al. 2014).

Mid-channel gravel bars are reworked to varying extents based heavily on the reach in which they occur. Bars in the steep initial section of Yampa Canyon (Y1, Figure 4.8-1) are largely bare of vegetation, suggesting that they are somewhat regularly inundated. Gravel bars in the lower section appear to accrete on the rising limb of floods and then experience a slight change on the falling limb (Larson 2004). Pre-1961, large bare gravel bars were commonly found in wide reaches of the Yampa River (such as Laddie Park), which suggests that bar reworking and transport of gravel-sized sediment generally occurred annually (Manners et al. 2014). The overwhelming majority of gravel bars in the confined sections of Yampa Canyon appeared to be completely inundated by the two-year flood, thus suggesting that they were frequently reworked (Larson 2004). These mid-channel bars were found to be modified in two different ways over a 50-year period from 1961–2011: 1) lateral growth on the margins of stable bars and 2) deposition on the surface of active-bars, transforming them into stable islands. Overall, these changes account for 32% of the channel narrowing observed along the Yampa (Manners et al. 2014).

Additionally, a heavily monitored gravel bar in Laddie Park was observed to have stabilized over the course of a 50-year period from 1961–2011. This stabilization was indicated by an observable increase in area that experienced no topographic change, from 4,500 m^2 in 1961 to 17,000 m^2 in 2011 (Manners 2013). Observations from two other bars in Yampa Canyon suggest that there is a transition from active mid-channel bars to more stable islands, and that encroachment of tamarisk has altered flow boundary conditions and resulted in the accumulation of fine sediment and conversion of an active bar to a stable island (Manners 2013).

Eddy bars occur in areas of re-circulating flow, are generally composed of fine-grained sand, and often undergo significant alteration due to high flows. Comparison of the distribution of tamarisk seedlings originally mapped in 2002 to post-2003 flood distribution suggested significant reworking of eddy bars along the Yampa (Larson 2004). Approximately 17% of the channel narrowing observed along the Yampa by Manners et al. (2014) occurred in similar areas, which they dubbed flood-stage ponded backwater areas.

Point bars are found on the inside of meander bends and occur most commonly in Yampa Canyon. They are generally composed of gravel overlain with a thin veneer of sand. Some evidence indicated that point bars in Yampa Canyon were reworked in the 2003 flood, which had a peak discharge of 480 m^3/s (Larson 2004). Merritt and Cooper (2000) also identified point bars in Deerlodge Park. Samples from one such bar indicated that it was largely (70%) sand (Merritt and Cooper 2000).

Four distinct types of geomorphic surfaces are found along the Yampa River in DINO: active channel (AC), active floodplain (AF), inactive floodplain (IF), and upland (U) (Scott et al. 2018). The active channel has little evidence of vegetation due to the activity of frequently recurring high flows, while the active floodplain often displays relatively substantial vegetative cover and is generally inundated by the 1.5–2.2-year flood. On the inactive floodplain, large cottonwood and boxelder trees are common in Deerlodge Park and Yampa Canyon, respectively, and it is generally only flooded by flows with a 34-year recurrence interval. Table 4.8-2 summarizes the distribution of these geomorphic surfaces in terms of the percentage of the total Yampa River study area. Active channel and active floodplain surfaces clearly exist to a significant extent along the Yampa River. A large number of these surfaces were also found to have little to no vegetation (Scott et al. 2018). Additionally, in terms of surface evolution, Fischer et al. (1983) found that the active channel and floodplain, which they deemed the floodzone, had not changed significantly over the period of historical photographic record (1945–1982).

Table 4.8-2. The number and area of geomorphic features and surfaces found in the Yampa River study area in DINO, organized by channel type (Scott et al. 2018).

Channel Type	Geomorphic feature	Number	Area (% of study area)			
			Geomorphic feature	Active channel	Active floodplain	Inactive floodplain
Restricted meander	debris fan	0	0	0	0	0
	eddy	0	0	0	0	0
	expansion bar	0	0	0	0	0
	lateral bench	6	28.10	0	3.35	24.75
	lateral bar	2	4.08	4.08	0	0
	mid-channel bar	5	1.96	1.96	0	0
	point bar	4	2.60	2.51	0.09	0
Debris fan-affected	debris fan	109	1.06	0.12	0.05	0
	eddy	75	0.18	0.09	0.07	0.02
	expansion bar	10	0.09	0.08	0.01	0
	lateral bench	111	0.38	0	0.20	0.17
	lateral bar	167	0.41	0.39	0.02	0
	mid-channel bar	7	0.04	0.04	0	0
	point bar	42	0.24	0.18	0.06	0
Entrenched meander	debris fan	14	0.69	0.05	0.03	0.02
	eddy	12	0.07	0.02	0.02	0.03
	expansion bar	3	0.04	0.04	0	0
	lateral bench	88	1.56	0	0.53	1.03
	lateral bar	54	0.45	0.45	0	0
	mid-channel bar	76	1.06	0.65	0.37	0.04
	point bar	45	0.86	0.48	0.22	0.16

All together, these observations are consistent with the characteristic morphology expected of an unregulated river, which supports the idea that the Yampa River is largely a wild riverine system. Evidence suggests that the overall condition is good and the current trend of geomorphic features and surfaces is stable/unchanging. Confidence in the assessment is medium.

Green River Above Confluence

Stream Flows

Metric 1: Peak flow

Closure of Flaming Gorge dam in late 1962 resulted in the reduction of the two-year flood by 57%, from 339 m^3/s to 147 m^3/s. Although the two-year recurrence interval flood had declined by around 12% from the 1895–1930 period to the 1931–1962 period due to climatological change, the overall impact of the flow regulation from the dam is far more substantial (Figure 4.8-11, Grams and Schmidt 2005). In fact, flows in the post-dam period rarely are larger than the power plant capacity of Flaming Gorge Dam of 130 m^3/s, and annual peak flows have only exceeded this value eight times since 1962 (as of 2011, Mueller et al. 2014). Overall, peak flows along the upper Green River decreased significantly in the post-dam period (Figure 4.8-8) (Schook et al. 2016).

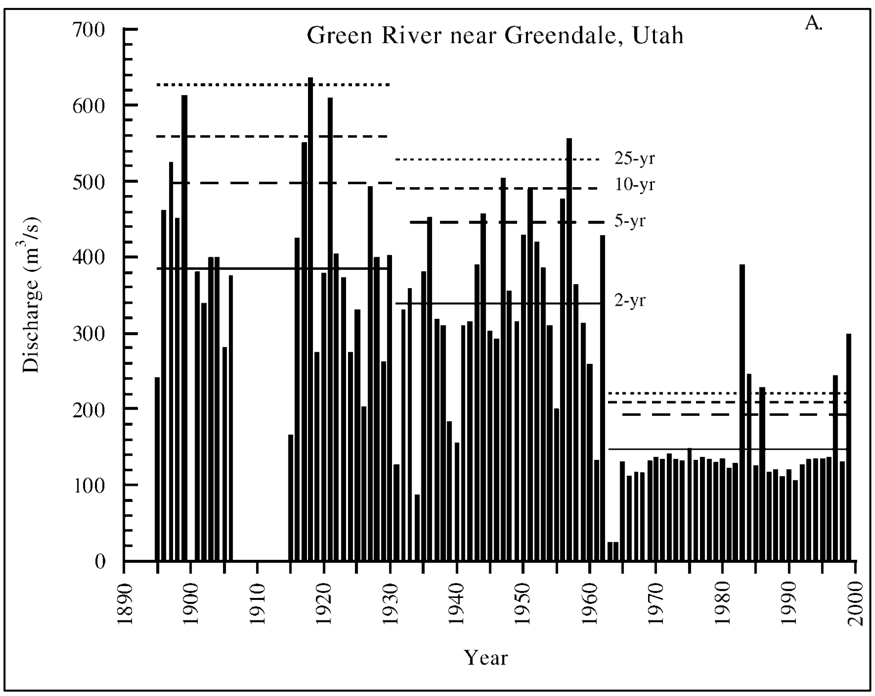


Figure 4.8-11. Annual peak discharge for the upper Green River. Recurrence interval floods are separated into three periods: 1895–1930, pre-dam (1931–1962), post-dam (1962–1999) (Grams and Schmidt 2005).

The pre-dam upper Green behaved similarly to the current Yampa hydrologically, with a snowmelt-driven hydrograph peaking in late-spring/early-summer (Figure 4.8-3). Post-dam, flow is mostly

constant throughout the year, and the peak is roughly the same magnitude nearly every year (Grams 1997, Schook et al. 2016). Thus, peak flows have clearly declined from the pre-dam period, indicating significant concern for this measure. Given the abundance and recency of data, confidence in the assessment is medium.

Metric 2: Average flow and minimum flow

Average flow for the upper Green has remained nearly constant from the pre- to post-dam time period. Post-dam mean annual discharge was 59 m^3/s, compared to 58 m^3/s in pre-dam years (Grams and Schmidt 2002). However, flows of this magnitude occur for a larger duration of the time and, overall, high frequency flows are of a somewhat larger magnitude (Figure 4.8-12, Andrews 1986). Additionally, minimum flows have increased in post-dam years, from 18 m^3/s to 25 m^3/s (Schook et al. 2016, Figure 4.8-8).

Overall, average flow has remained steady but the duration of flows of this magnitude has increased. This does not meet the requirements shown in Table 4.8-1 for a reduction in condition rating. However, as this is not the behavior of a natural river, professional opinion dictates that this metric has declined in post-dam years. This indicator warrants moderate concern with an unchanging trend. Confidence in this assessment is medium given the amount and currency of the data.

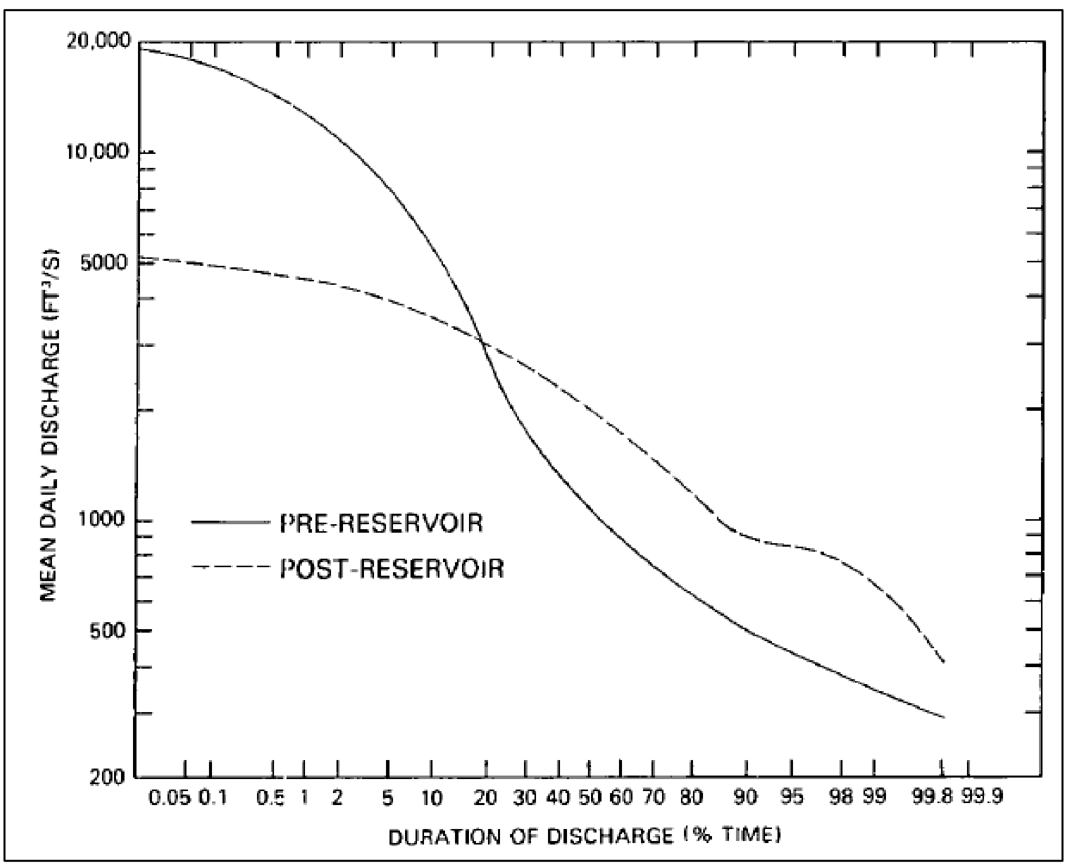


Figure 4.8-12. Duration of mean daily discharge for the upper Green for pre- and post-dam years (Andrews 1986).

Sediment Loads/Dynamics

Metric 1: Annual loads and equilibrium condition

Very few sediment measurements have been taken on the upper Green within the monument boundaries, but a fairly substantial sediment record exists at the Greendale station, located just downstream of the Flaming Gorge Dam and fairly far upstream (roughly 40 miles) of the monument. Suspended sediment load at the Greendale station has declined by about 98% in the post-dam period, from 1.16 x 10^6 tons pre-dam to 0.018 x 10^6 tons post-dam. Post dam, lower discharges transport a much higher proportion of annual sediment load transported (Figure 4.8-13) (Grams and Schmidt 2002).

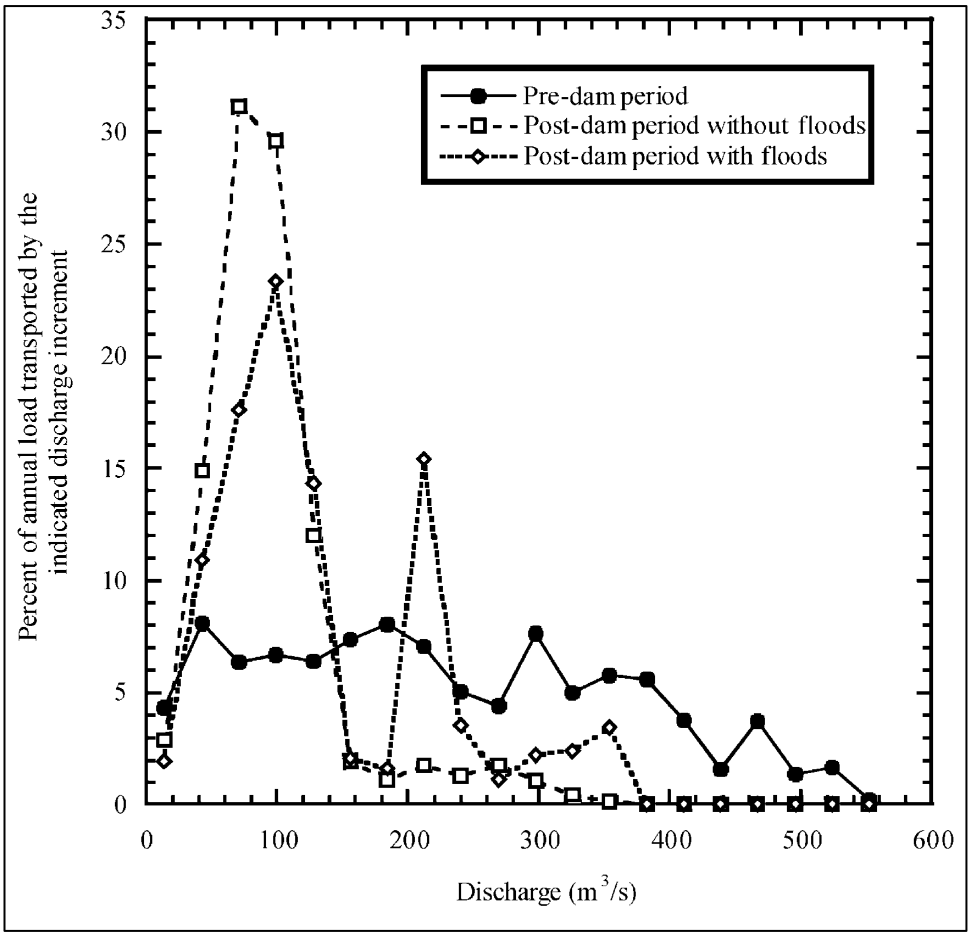


Figure 4.8-13. Effective discharge for the upper Green River, plotted as average sediment load for each discharge increment (Grams and Schmidt 2002).

There is evidence of significant post-dam deposits within all stretches of the upper Green, and constructed sediment budgets indicate the upper Green is accumulating sediment in all reaches, which suggests that it is in a state of disequilibrium (Grams and Schmidt 2002). However, recent evidence suggests that little change in fine-sediment storage has occurred in Lodore Canyon, indicating that it may be approaching an equilibrium condition (Alexander 2007). The available information outlined above suggests that this metric is in poor condition and the trend is

deteriorating. Given the sparse information and disagreement between conclusions, confidence in this assessment is low.

Metric 2: Effective Discharge

Effective discharge in Browns Park just upstream of the monument decreased by 63% in post-dam years, from 7450 ft^3/s to 2750 ft^3/s. The pre-dam effective discharge was exceeded 20 days/year or 5.5% of the time, whereas the post-dam effective discharge was exceeded 99 days/year or 27% of the time (Andrews 1986).

Downstream in Lodore Canyon, post-dam effective discharge has two peaks, one just below the two-year flood/Flaming Gorge power plant capacity discharge of 130 m3/s, and one on the order of the rare post-dam flood (Figure 4.8-13, Grams and Schmidt 2002). This is a marked contrast to the pre-dam effective discharge curve, which was mostly flat, suggesting a wide variety of flows played a significant role in sediment transport dynamics (Grams and Schmidt 2002). It follows from these curves that deposition is thus occurring at lower elevations in the post-dam period, consistent with observations of channel narrowing and floodplain aggradation on the upper Green River (Merritt and Cooper 2000). This accumulation of sediment is detrimental to the habitat of native flora and fauna (Grams and Schmidt 2002, Bestgen 2015).

The effective discharge on the upper Green River has declined from pre-dam conditions and this indicator's condition warrants moderate concern with a deteriorating trend and medium confidence in the assessment.

Geomorphology

Metric 1: Channel narrowing

Post-Flaming Gorge Dam channel narrowing on the Green River at locations downstream of DINO has been well documented (Andrews 1986, Lyons et al. 1992, Allred and Schmidt 1999). Just upstream of the monument boundary, Merritt and Cooper (2000) observed channel narrowing in Browns Park. From 1966–1977, the channel narrowed by roughly 13%, largely due to lateral degradation that resulted from widespread erosion of both banks (Merritt and Cooper 2000). This observed narrowing occurred at a remarkably accelerated rate in post-dam years, increasing to a rate of channel width change of roughly 1%/year from 1966–1977 from 0.5%/year previously. From 1977–1994 the channel then widened by 10% (Figure 4.8-14), illustrating a complex response to the installation of Flaming Gorge Dam (Merritt and Cooper 2000).

Downstream of Browns Park in Lodore Canyon, historical aerial photographs indicate substantial channel narrowing from the pre-dam period (photographs taken between 1871–1922) to the post-dam period (photographs taken between 1995–1997). Overall, there was an average decrease in bankfull channel width in the canyon of 22% from pre-dam to post-dam years (Table 4.8-3, Grams and Schmidt 2002).

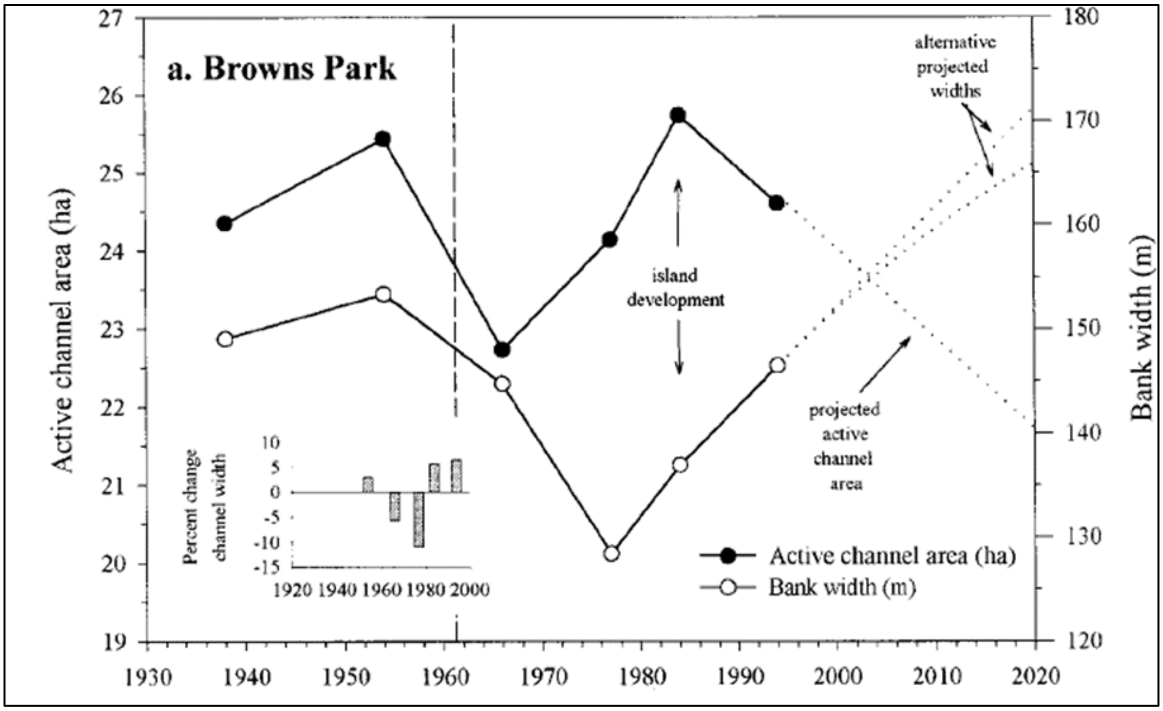


Figure 4.8-14. Channel area and bank width in Browns Park (just upstream of the monument) on the upper Green River (Merritt and Cooper 2000).

Table 4.8-3. Degree of channel narrowing along each stretch of the Green River and the extent to which that narrowing occurs in each geomorphic feature (Grams and Schmidt 2002).

Geomorphic Feature	Characteristic	Canyon of Lodore	Echo Park	Whirlpool Canyon	Island Park	Split Mountain Canyon
Overall	Pre-dam bankful width (m)	72	225	72	218	77
	Post-dam bankful width (m)	56	203	64	163	68
	Percent narrowing	22%	10%	11%	25%	12%
Percent of narrowing in deposit type in fan-eddy complex	Eddy bars	33	5	52	0	11
	Gravel bars	29	0	9	0	79
Percent of narrowing in deposit type not in fan-eddy complex	Channel margin	26	80	15	1	1
	Mid channel	0	0	0	99	0
	Point bars	11	15	24	0	8

From the compiled evidence above, it is clear that channel width has declined with respect to pre-dam conditions on the upper Green River, and to a much greater extent than might be expected simply from climate change (i.e. in comparison to observed narrowing on the Yampa River). This

indicator is in moderate condition with a deteriorating trend. Confidence in this assessment is medium.

Metric 2: Geomorphic features and surfaces

The most extensive geomorphic surface found along all stretches (both canyon and park) of the Green River is the cottonwood-boxelder (c-b) terrace (Figure 4.8-15). This fine-grained deposit occurs, on average, 3.3 m above baseflow water surface upstream of the Yampa confluence. Evidence suggests that the terrace is only inundated by rare floods (Grams 1997). Adjacent to and below the c-b terrace is the intermediate bench, which occurs at an average 1.9 ± 0.7 m above baseflow on the upper Green (Figure 4.8-15). This surface is inundated by events on the order of the 388 m^3/s 1983 flood (Grams 1997). A third surface, designated by Grams (1997) as the post-dam floodplain, is inundated annually in the post-dam flow regime. This surface is found 0.8 (± 0.3 m) above the baseflow water surface on the upper Green River. Lastly, there is the active channel surface, which is generally bare sand, bare gravel, or debris (Grams 1997). For the upper Green River, historical photographs indicate that both the intermediate bench and post-dam floodplain were part of the active channel prior to dam closure (Grams 1997), and are thus post-dam constructed surfaces.

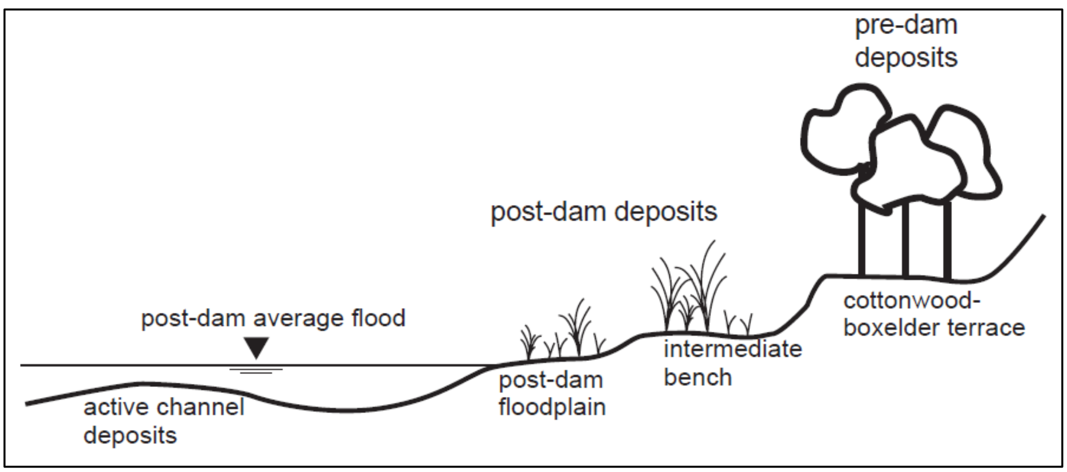


Figure 4.8-15. Geomorphic surfaces found along both the upper and lower Green River and how they relate to the level of the post-dam average flood (~120 m^3/s) (Grams and Schmidt 2005).

In addition to the above-mentioned geomorphic surfaces, identified depositional environments—analogous to geomorphic features—include channel margin bars, point bars, eddy bars, and various others (Table 4.8-4) (Grams 1997). Historically-active mid-channel gravel bars have since been subject to significant deposition of fine-grained sediment and establishment of woody vegetation, thus leading to stabilization (Grams and Schmidt 2002). Overall, deposition on eddy bars in Lodore Canyon accounted for 33% of the observed post-dam channel narrowing, deposition on gravel bars accounted for 29%, and deposition on channel margin and point bars accounted for 26% and 11%, respectively, which have typically been subsequently vegetated. Clearly, deposition is the mechanism most responsible for the growth of these features in Lodore Canyon in the post-dam period (Grams and Schmidt 2002, Alexander 2007).

Table 4.8-4. Area of geomorphic features and surfaces found along the upper and lower Green River within Dinosaur National Monument (Grams 1997).

Geomorphic feature	Geomorphic surface	Area (X 1000 m^2/km)				
		Lodore Canyon	Echo Park	Whirlpool Canyon	Island Park	Split Mountain Canyon
Channel-margin bars	Active	1	51	1	0	0
	Post-dam fp[1]	2	2	1	0	0
	Int. bench[2]	2	15	1	0	0
	Terrace	9	105	3	0	1
Mid-channel bars	Active	0	0	0	20	0
	Post-dam fp	0	0	0	25	0
	Int. bench	0	0	0	40	0
	Terrace	0	0	0	178	0
Point bars	Active	0	55	1	2	2
	Post-dam fp	1	1	1	0	0
	Int. bench	1	2	1	0	1
	Terrace	2	6	0	0	0
Expansion bars	Active	1	0	6	0	4
	Post-dam fp	2	0	1	0	2
	Int. bench	3	0	0	0	5
	Terrace	2	0	0	0	13
Eddy bars	Active	1	2	4	0	2
	Post-dam fp	2	0	1	0	0
	Int. bench	3	1	3	0	1
	Terrace	3	1	3	0	1

[1] Post-dam floodplain

[2] Intermediate bench

This deposition has caused eddy bars to grow via vertical accretion to heights above the level of frequently occurring post-dam floods, resulting in the establishment of vegetation, stabilization, and ultimately the transition from active channel to floodplain surfaces (Alexander 2007). An investigation by Mueller et al. (2014) of the 2011 controlled release flood—the third highest flood peak since the completion and closure of the dam in 1963—suggested that large floods are responsible for aggradation of eddy bars, as well as moderate deposition of fine-grained sediment on the surfaces of gravel bars, but are not able to completely rework the more stable gravel bars themselves or strip them of existing vegetation. This deposition of sand-sized sediment on bars is accompanied by significant scour of bed sediment in the pools of the fan-eddy complex (Mueller et al. 2014).

Overall, geomorphic features and surfaces have been degraded with respect to pre-dam conditions on the upper Green River. Due to substantial channel narrowing, this indicator is in moderate condition

with a deteriorating trend. Additionally, due to the existence of a significant body of work concerning these indicators, the confidence in the assessment is high.

Green River Below Confluence

Stream Flows

Metric 1: Peak flow

Due to the influence of the unregulated Yampa, the Green River downstream of the confluence has been less impacted by the closure of Flaming Gorge Dam than the upper Green. The post-dam two-year flood for the lower Green River is 480 m^3/s, a 23% reduction from the pre-dam 626 m^3/s two-year flood (Figure 4.8-16), and a comparatively small change versus the 57% decrease in the two-year flood magnitude observed on the upper Green River (Grams and Schmidt 2002). Larger floods (e.g. the 10-yr and 25-yr flood) are also reduced in magnitude but, again, not nearly to the degree found upstream from the confluence (Figure 4.8-16) (Grams 1997, Grams and Schmidt 2002).

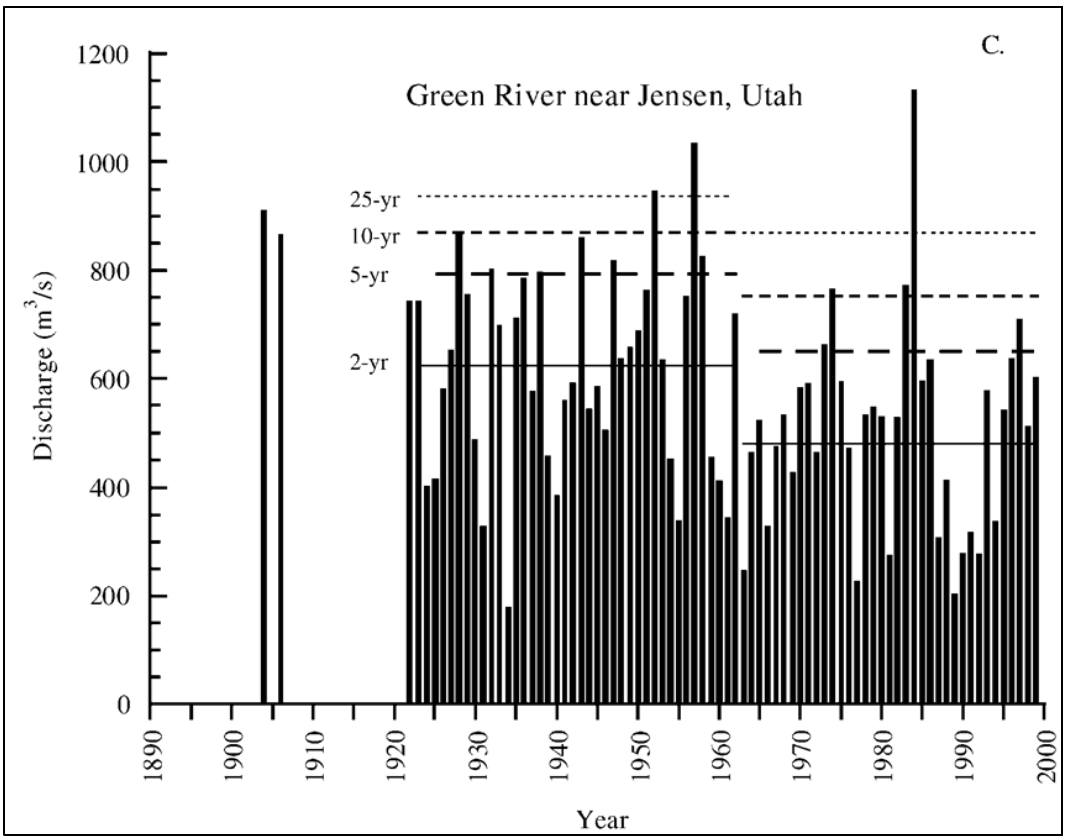


Figure 4.8-16. Annual maximum discharge for the lower Green River, measured at the Jensen, Utah, gage. Magnitudes of the 2, 5, 10, and 25-yr recurrence interval floods for pre- and post-dam years are indicated by horizontal lines (Grams and Schmidt 2002).

In terms of timing, post-dam discharge along the lower Green River behaves similarly to both the Yampa River and the pre-dam Green River, with a snowmelt-driven peak flow occurring in late-

spring/early summer (Figure 4.8-3). The main difference in this peak from pre- to post-dam years, as stated above, is the reduction in magnitude (Schook et al. 2016).

Similar to the upper Green, the available evidence indicates that peak flow has declined in the post-dam years. However, given the relatively lesser decline in peak flow magnitude relative to that occurring in the upper Green, this reduction is a matter of relatively low concern. This indicator is in good condition with a deteriorating trend and medium confidence. Any subsequent regulation of the Yampa poses a threat to this assessment, and would likely result in further reduction of peak flows.

Metric 2: Average flow and minimum flow

Mean annual discharge on the lower Green River has remained essentially the same from pre-dam to post-dam years, and is approximately 130 m^3/s (Figure 4.8-8, Andrews 1986, Schook et al. 2016). On the other hand, baseflow has increased in magnitude, from roughly 20 m^3/s to 40 m^3/s (Figure 4.8-8, Schook et al. 2016). This is also reflected in the difference between flow-duration curves of pre- and post-dam years (Figure 4.8-17). In post-dam years, flows with a duration of 30% and greater are larger in magnitude than in pre-dam years. Thus, although dam installation and flow regulation have not affected the mean annual discharge of the lower Green River, they have had a noticeable impact on higher frequency flows (Andrews 1986). Based on these results, this indicator is in good condition, with an unchanging trend and medium confidence.

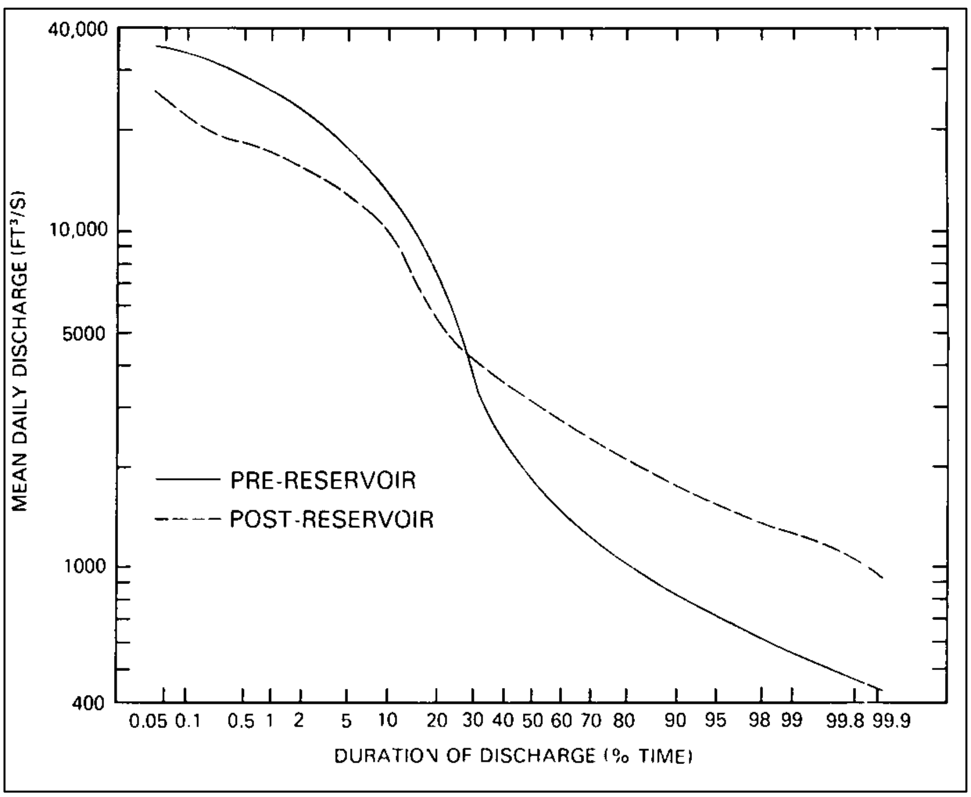


Figure 4.8-17. Duration of mean daily discharge for the lower Green River for pre- and post-dam years (Andrews 1986).

Sediment Loads/Dynamics

Metric 1: Annual load and equilibrium state

The completion of Flaming Gorge Dam in October of 1962 resulted in the reduction of Green River annual sediment loads between 54–57%, from 6.5–6.92 x 10^6 tons/yr to 2.8–3.21 x 10^6 tons/yr, as measured at the Jensen, Utah, gage just downstream of the monument (Andrews 1986, Grams and Schmidt 2002).

Despite the decrease in mean annual sediment load, both the upper and lower Green River in the monument appear roughly in equilibrium post-dam installation, with near agreement in mean annual total of sediment delivered to the river of 3.31 x 10^6 tons/yr and mean annual sediment discharge of 3.21 x 10^6 tons/yr at the Jensen gage just downstream of DINO (Andrews 1986). The lower Green River exhibits similar behavior with an influx of sediment of roughly 0.83 tons/yr and an efflux of about 0.82 tons/year (Table 4.8-5) (Grams and Schmidt 2005). However, measured changes in sand storage on the lower Green are just 1% of the total sand flux through the reach, well within the error of the estimated load, thus making it impossible to firmly state whether erosion or deposition is occurring (Grams and Schmidt 2005).

Table 4.8-5. Sediment budget for all stretches on the upper and lower Green River within Dinosaur National Monument (Grams and Schmidt 2005).

Reach	Length (km)	Erosion/Deposition (10^6 X tons/yr)					
		Post-dam deposits	Terrace erosion	Input to reach	Source of input	Influx	Efflux
Red Canyon[1]	18	1 ± 1	–	8 ± 8	Greendale gage	8 ± 8	7 ± 9
Upper Browns Park[1]	22	7 ± 5	2 ± 1	22 ± 2	Red Creek	29 ± 11	24 ± 17
Swallow Canyon to Gates of Lodore[2]	37	17 ± 12	15 ± 8	22 ± 11	Vermillion Creek	46 ± 28	44 ± 48
Canyon of Lodore	29	4 ± 3	–	–	None measured	44 ± 48	40 ± 51
Echo Park to Jensen Gage	45	10 ± 7	–	786 ± 94	Yampa River	826 ± 145	816 ± 152

[1] outside of DINO boundaries

[2] partially outside of DINO boundaries

Overall, both budgets suggest that the channel may be in equilibrium within the margin of error, although observations of channel narrowing along the lower Green River indicate that some channel adjustment in the post-dam period has taken place (Grams and Schmidt 2005). Given the reduction in sediment load observed for this stretch of the Green River, despite evidence indicating an equilibrium state, annual loads have declined since pre-dam years. However, given evidence of channel narrowing several times previously, this indicator is in moderate condition with a deteriorating trend. Confidence in the assessment is low.

Metric 2: Effective discharge

Just downstream of the monument at the Jensen gage, the effective discharge decreased from 20,500 ft^3/s pre-dam to 11,500 ft^3/s post-dam, for a reduction of 44%. Pre-dam discharge had an exceedance

probability of 3% (equaled or exceeded 11 days/yr) while post-dam had an exceedance probability of 7.5% (27.4 days/yr) (Andrews 1986). The post-dam effective discharge curve is similar in shape to the pre-dam curve, but shifted towards lower discharges (Figure 4.8-18). The post-dam curve has a broad peak that occurs across the 1.5 to 5-year recurrence interval discharges, which results in sediment deposition on the post-dam floodplain and intermediate bench (Grams and Schmidt 2002).

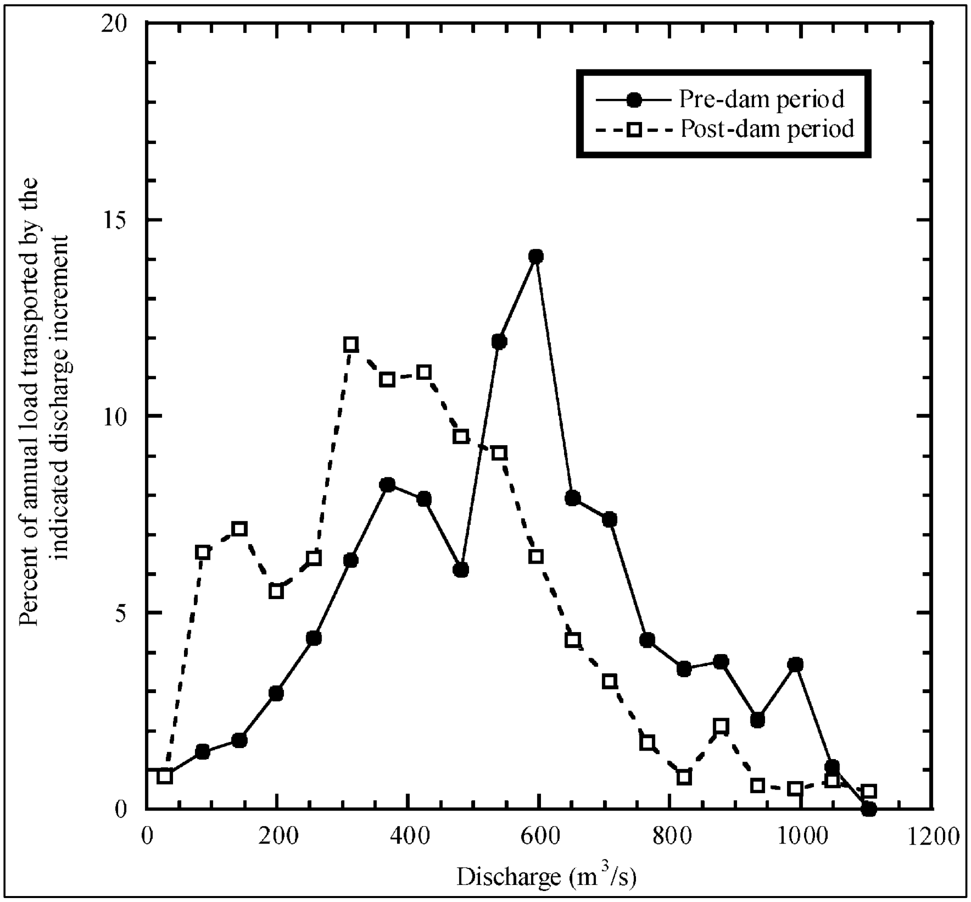


Figure 4.8-18. Effective discharge for the lower Green River, plotted as average sediment load for each discharge increment (Grams and Schmidt 2002).

At the Jensen gage, the discrepancy between pre- and post-dam sediment loads can be explained by the reduction in the magnitude of discharges that are equaled or exceeded <30% of the time. A decrease in the magnitude of flows with a 5% exceedance probability has been offset by an increase in the magnitude of >30% exceedance probability flows, so that mean annual discharge for the Green River has largely remained unchanged from the pre-dam period (Andrews 1986). Therefore, the decrease in sediment transport is the result of a less variable annual hydrograph rather than a decrease in overall mean annual runoff (Andrews 1986).

Overall, effective discharge has declined in the post-dam period. This has resulted in sediment deposition at lower elevations, which is most obviously observed in the fine-grained sand on

previously active gravel bars. Effective discharge for the lower Green River is in moderate condition with a declining trend. Confidence in this assessment was medium.

Geomorphology

Metric 1: Channel narrowing

Historical photographs indicate that the channel narrowed in the period after the closure of Flaming Gorge Dam (Grams 1997). Comparison of photographs taken in Echo Park in 1917 and 1993 show an increase in vegetation consistent with the establishment of a new floodplain. Additionally, the active channel narrowed by ~13% from 1954–1993 (Grams 1997). In Whirlpool Canyon, analysis of historical photographs revealed the presence of deposits similar to those found in areas with confirmed narrowing. Downstream in Island Park, comparison with historical photographs indicates an increase in riparian vegetation, as well as channel narrowing and post-dam floodplain construction. Comparison with 1938 aerial photographs shows that the active channel area decreased by about 25% from 1938–1993 (Grams 1997). Photographic evidence of channel narrowing, in the form of vegetation establishment on once largely bare surfaces, was found in Split Mountain Canyon as well.

Overall, the greatest degree of channel narrowing along both the upper and lower Green River took place in Island Park. Somewhat counterintuitively, observed narrowing in the canyon sections of the lower Green was approximately half of what was observed in Lodore Canyon on the upper Green River (Table 4.8-3). This suggests that the amount of narrowing is in part directly correlated to the amount of flow regulation, as the upper Green River is heavily regulated and the lower Green River only partially (Grams and Schmidt 2002). This indicator is in moderate condition with a deteriorating trend. Confidence in the assessment is medium.

Metric 2: Geomorphic features and surfaces

As for the upper Green River, the most extensive geomorphic feature found along all sections of the lower Green River, save for Whirlpool Canyon, is the cottonwood-boxelder (c-b) terrace (Figure 4.8-15). This fine-grained deposit occurs, on average, 4.2 m above baseflow water surface in this stretch. Evidence suggests that the terrace is only inundated by rare floods, both upstream and downstream of the confluence of the Yampa (Grams 1997). Adjacent to and below the c-b terrace is the intermediate bench, which is 2.4 m (± 0.4m) above baseflow. This surface is likely inundated by events > 600 m^3/s and certainly by events of approximately 1000 m^3/s (Grams 1997). A third surface, designated by Grams (1997) as the post-dam floodplain, is inundated annually in the post-dam flow regime. This surface is found 1.3 m (± 0.4 m) above the baseflow water surface on the lower Green River. The elevation difference between the post-dam floodplain on the upper Green and on the lower Green stems from the differences in post-dam flood regime between the regulated upper Green River and the partially regulated lower Green River. The lower Green River post-dam floodplain is much more of a gradual surface than on the upper Green, and is inundated by the two-year flood (Grams 1997). Historical photographs indicate that both the intermediate bench and post-dam floodplain were part of the active channel prior to dam closure (Grams 1997). Lastly, there is the active channel surface, which is general bare sand, bare gravel, or debris (Grams 1997).

Geomorphic features found along the lower Green River are similar to those found in the previously discussed reaches, and include channel-margin bars, point-bars, eddy bars, mid-channel bars, and expansion bars (Table 4.8-4). In Echo Park, channel-margin bars make up the majority of the geomorphic features, while channel margin bars make up roughly 22% of the area occupied by geomorphic features in Whirlpool Canyon. These deposits are largely insignificant elsewhere along the lower Green. Expansion bars and eddy bars are the dominant features in both canyon sections of the lower Green River, and mid-channel bars are likewise dominant in Island Park (Grams 1997).

As on the upper Green River, a noticeable decrease in the amount of bare, active sand and gravel bars from pre-dam photographs was observed along the lower Green. Essentially, this resulted from the stabilization of these once active deposits by vegetation and the formation of new inset deposits (i.e. the post-dam floodplain and intermediate bench) (Grams and Schmidt 2002). In Split Mountain and Whirlpool Canyon, deposition in the eddy bars and expansion bars of fan-eddy complex accounted for the majority of the observed narrowing (Table 4.8-6) (Grams 1997). These once active deposits were transformed into aggrading floodplain deposits (Grams 1997, Grams and Schmidt 2002). In the wider meandering reaches of Echo Park and Island Park, the overwhelming majority of narrowing occurred in channel margin and mid-channel deposits, respectively. This was largely a result of the deposition of fine-grained sediments on the margins of these previously existing features, and the conversion of once active channel surfaces to post-dam floodplain and intermediate bench surfaces (Grams 1997, Grams and Schmidt 2002).

Table 4.8-6. Percent of narrowing in each reach by geomorphic feature (Grams 1997).

Geomorphic Feature	% of Reach Observed Narrowing					
	Lodore Canyon	Echo Park	Whirlpool Canyon	Island Park	Split Mountain Canyon	Total
Channel margin	26	80	15	1	1	23
Mid-channel	0	0	0	99	0	63
Point bars	11	15	24	0	8	7
Expansion bars	29	0	9	0	79	3
Eddy bars	33	5	52	0	11	3

It is evident that geomorphic surfaces and features are in decline in comparison to the pre-dam, "wild river" conditions. The reduction in the amount of active gravel bars that are frequently reworked is detrimental to endangered native fish that use these environments as spawning habitat, and the accretion of eddy deposits have resulted in the loss of nursery habitat for other native fish (see Section 4.11, *Fish* for discussion of fish habitat). This indicator is in moderate condition with a deteriorating trend. Confidence in the assessment is medium, given the extensive body of work but lack of more recent studies.

Condition Summary

The condition of big rivers relative to physical properties and processes at DINO varies by river segment (Table 4.8-7). An overall rating for the monument is not assigned.

Table 4.8-7. Condition and trend summary for the Yampa River, upper Green River, and lower Green River segments at Dinosaur National Monument.

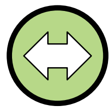
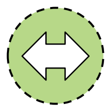
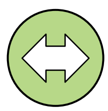
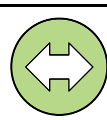
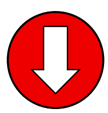
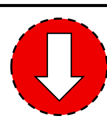
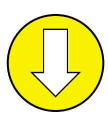
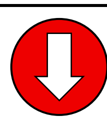
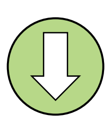
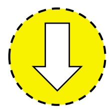
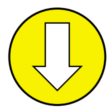
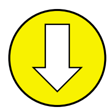
River Segment	Indicator	Condition Status/ Trend	Rationale
Yampa River	Stream Flows		Peak Flows: the 1922–2012 hydrograph and peak flow records show peak flows have remained effectively unchanged from pre- to post-dam years. Average flows and minimum flows: Box plots of mean annual discharge and minimum annual discharge show little to no change from the pre- to post-dam time period.
	Sediment Loads		Annual loads and equilibrium condition: Similarity of the mean annual load calculated from available data for 1978 and then again 2014 (with 36 years of additional data) suggest loads have not substantially changed. Effective discharge: Measured effective discharge is ~bankfull flow.
	Geomorphology		Channel width: Width has decreased slightly (~6%) but stabilized in recent years. Geomorphic features and surfaces: Observed features and surfaces are consistent with the characteristic morphology of an unregulated river.
	Yampa River overall		**The Yampa River system is in good condition with an unchanging trend. Confidence in the assessment is medium.**
Upper Green River	Stream Flows		Peak flows: 2-yr recurrence interval has declined by 57% from pre-dam period. Average flows and minimum flows: Duration of smaller magnitude flows has increased even though average flow is roughly the same.
	Sediment Loads		Annual loads and equilibrium condition: Loads decreased by 98% from pre-dam years at upstream Greendale gage. Effective discharge: Effective discharge decreased by 63%.
	Geomorphology		Channel width: Channel of the Lodore Canyon has narrowed by 22% since dam closure. Geomorphic features and surfaces: Formerly active surfaces have become heavily vegetated and are now infrequently inundated.
	Upper Green River overall		**The upper Green River system warrants significant concern with a deteriorating trend. Confidence in the assessment is medium.**
Lower Green River	Stream Flows		Peak flows: Peak flows have deteriorated from pre-dam years by approximately 23%. Average flows and minimum flows: Average annual flow has remained the same in post-dam years. Baseflow has doubled to 40 m^3/s post-dam.

Table 4.8-7 (continued). Condition and trend summary for the Yampa River, upper Green River, and lower Green River segments at Dinosaur National Monument.

River Segment	Indicator	Condition Status/ Trend	Rationale
Lower Green River (continued)	Sediment Loads		Annual loads and equilibrium condition: Sediment loads have decreased by 54–57% but the channel appears to potentially be in a state of equilibrium. Effective discharge: Effective discharge exceedance probability has increased in post-dam years Effective discharge curve is shifted towards lower magnitude flows.
	Geomorphology		Channel width: The channel has narrowed by 10–25% along the lower Green River). Geomorphic features and surfaces: Active surfaces have decreased in area and formerly active surfaces have become vegetated and more stable.
	Lower Green River overall		**The lower Green River segment warrants moderate concern with a deteriorating trend. Confidence in the assessment is medium.**

4.8.5. Level of Confidence and Data Gaps

Cumulatively, confidence in the assessment is medium due to a mix of extensive datasets for some indicators and measures and datasets considered inadequate due to either lack of continuity or currency. Further implementation of the NCPN Big Rivers Monitoring Protocol (Perkins et al. 2018, NCPN 2018) will help solidify the findings gleaned for this report in the future. This monitoring protocol will also help the monument differentiate impacts to these river systems from climate change versus flow regulation.

4.8.6. Sources of Expertise

- Salek Shafiqullah, RG, PE – Intermountain Regional Hydrologist, National Park Service. Mr. Shafiqullah provided comments on the preliminary draft of this chapter.

- Dusty Perkins, NCPN, provided comments on the draft manuscript.

4.8.7. Literature Cited

Alexander, J.S. 2007. The timing and magnitude of channel adjustments in the upper Green River below Flaming Gorge Dam in Browns Park and Lodore Canyon, Colorado: an analysis of the pre- and post-dam river using high-resolution dendrogeomorphology and repeat topographic survey. Thesis. Utah State University, Logan, Utah.

Allred, T.M., and J.C. Schmidt. 1999. Channel narrowing by vertical accretion along the Green River near Green River, Utah. Geological Society of America Bulletin 111(2):1012–1023.

Andrews, E.D. 1978. Present and potential sediment yields in the Yampa River Basin, Colorado and Wyoming. Water Resources Investigations 78–105. U.S. Geological Survey Water-Resources Division. Lakewood, Colorado.

Andrews, E.D. 1980. Effective and bankfull discharges of streams in the Yampa River basin, Colorado and Wyoming. Journal of Hydrology 46:311–330. Available at: https://doi.org/10.1016/0022-1694(80)90084-0.

Andrews, E.D. 1986. Downstream effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. GSA Bulletin 97(8):1012–1023. Available at: https://doi.org/10.1130/0016-7606(1986)97<1012:DEOFGR>2.0.CO;2.

Bestgen, K.R. 2015. Aspects of the Yampa River flow regime essential for maintenance of native fishes. Final Report submitted to the National Park Service, The Nature Conservancy, and Western Resource Advocates. Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins. Larval Fish Laboratory Contribution 181 NPS/NRSS/WRD/NRR 2015/962, 112.

Cooper D.J, D.M. Merritt, D.C. Andersen, and R.A. Chimner RA. 1999. Factors controlling the establishment of Fremont cottonwood seedlings on the upper Green River, U.S.A. Regulated Rivers: Research and Management 15: 419–440.

Elliott, J.G., and S.P. Anders. 2005. Summary of sediment data from the Yampa River and upper Green River basins, Colorado and Utah, 1993–2002. Scientific Investigations Report 2004-5242. U.S. Geological Survey, Denver, Colorado.

Elliott, J.G., J.E. Kircher, and P. Von Guerard. 1984. Sediment transport in the lower Yampa River, northwestern Colorado. Water Resources Investigations Report 84–4141. U.S. Geological Survey, Lakewood, Colorado.

Fischer, N.T., M.S. Toll, A.C. Cully, and L.D. Potter. 1983. Vegetation along Green and Yampa Rivers and response to fluctuating water levels, Dinosaur National Monument. Unpublished Report. University of New Mexico, Albuquerque, New Mexico.

FLO Engineering. 1998. Green River channel monitoring, field data collection, Yampa and Little Snake Rivers. Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin Project # 72 BC. U.S. Fish and Wildlife Service, Denver, Colorado.

Grams, P.E. 1997. Geomorphology of the Green River in Dinosaur National Monument. Thesis. Utah State University, Logan, Utah.

Grams, P.E., and J.C. Schmidt. 1999. Geomorphology of the Green River in the eastern Uinta Mountains, Dinosaur National Monument, Colorado and Utah. Pages 81–111 *in* A. J. Miller and A. Gupta, editors. Varieties of fluvial form. John Wiley & Sons Limited, Chichester, United Kingdom.

Grams, P.E., and J.C. Schmidt. 2002. Streamflow regulation and multi-level flood plain formation: channel narrowing on the aggrading Green River in the eastern Uinta Mountains, Colorado and Utah. Geomorphology 44, 337–360. Available at: https://doi.org/10.1016/S0169-555X(01)00182-9.

Grams, P.E., and J.C. Schmidt. 2005. Equilibrium or indeterminate? Where sediment budgets fail: Sediment mass balance and adjustment of channel form, Green River downstream from Flaming Gorge Dam, Utah and Colorado. Geomorphology 71:156–181. Available at: https://doi.org/10.1016/j.geomorph.2004.10.012.

Gray, S.T., J.J. Lukas, and C.A. Woodhouse. 2011. Millennial-length records of streamflow from three major Upper Colorado River tributaries. Journal of the American Water Resources Association 47(4):702–712. Available at: https://doi.org/10.1111/j.1752-1688.2011.00535.x.

Larson, G.P. 2004. Tamarisk and fluvial geomorphic form in Dinosaur National Monument, Colorado and Utah. Thesis. Utah State University, Logan, Utah.

Leopold, L.B., and M.G. Wolman. 1956. Floods in relation to the river channel. Pages 85–98 *in* Union Geodesy et Geophysics International, Association d'Hydrologie (Symposium in Dijon), Publication no.42.

Leopold, L.B, M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman and Co., San Francisco, California.

Lyons, J.K., M.J. Pucherelli, and R.C. Clark. 1992. Sediment transport and channel characteristics of a sand-bed portion of the Green River below Flaming Gorge Dam, Utah, USA. Regulated Rivers: Research and Management 7: 219–232.

Manners, R.B. 2013. Mechanisms of vegetation-induced channel narrowing on an unregulated canyon-bound river. Dissertation. Utah State University, Logan, Utah.

Manners, R.B., J.C. Schmidt, and M.L. Scott. 2014. Mechanisms of vegetation-induced channel narrowing of an unregulated canyon river: Results from a natural field-scale experiment. Geomorphology 211:100–115. Available at: https://doi.org/10.1016/j.geomorph.2013.12.033.

Merritt, D.M., and D.J. Cooper. 2000. Riparian vegetation and channel change in response to river regulation: a comparative study of regulated and unregulated streams in the Green River Basin, USA. Regulated Rivers: Research & Management 16:543–564. Available at: https://doi.org/10.1002/1099-1646(200011/12)16:6<543::AID-RRR590>3.0.CO;2-N.

Mueller, E.R., P.E. Grams, J.C. Schmidt, J.E. Hazel, Jr., M. Kaplinski, J.A. Alexander, and K. Kohl. 2014. Monitoring and research to describe geomorphic effects of the 2011 controlled flood on the Green River in Canyon of Lodore, Dinosaur National Monument. Scientific Investigations Report 2014-5022. U.S. Geological Survey, Reston, Virginia. Available at: https://doi.org/10.3133/sir20145022.

National Park Service (NPS). 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

Northern Colorado Plateau Network (NCPN). 2018. Northern Colorado Plateau Network big rivers monitoring standard operating procedures: 2018 field season. Unpublished Report.

O'Brien, J.S. 1984. Hydraulic and sediment transport investigation, Yampa River, Dinosaur National Monument, 1983. WRFSL Report No. 83–8. Colorado State University, National Park Service, Water Resources Field Support Laboratory, Fort Collins, Colorado.

Perkins, D.W., M. Scott, G. Auble, M. Wondzell, C. Holmquist-Johnson, E. Wahlig, H. Thomas, and A. Wight. 2018. Big rivers monitoring protocol for park units in the Northern Colorado Plateau Network: Version 1.01. Natural Resource Report NPS/NCPN/NRR— 2018/1707. National Park Service, Fort Collins, Colorado.

Resource Consultants. 1991. Sediment transport studies of the Little Snake, Yampa, and Green River systems. Colorado River Water Conservation District, Glenwood Springs, Colorado and Wyoming Water Development Commission, Cheyenne, Wyoming.

Schook, D.M., E.A. Carlson, J.S. Sholtes, and D.J. Cooper. 2016. Effects of moderate and extreme flow regulation on *Populus* growth along the Green and Yampa Rivers, Colorado and Utah. River Research and Applications 32:1698–1708. Available at: https://doi.org/10.1002/rra.3020.

Scott, M.L., and J.M. Friedman. 2018. River flow and riparian vegetation dynamics – implications for management of the Yampa River through Dinosaur National Monument. Final report submitted to the National Park Service (2018/1619 No. Natural Resource Report NPS/NRSS/WRD/NRR). U.S. Geological Survey, Fort Collins, Colorado.

Scott, M.L., D.W. Perkins, D.M. Merritt, and D.J. Cooper. 2018. Big Rivers Monitoring within Dinosaur National Monument: A summary of monitoring results to detect change in channel condition. Natural Resource Report NPS/NCPN/NRR 2018/1635. National Park Service, Fort Collins, Colorado.

Tyus, C.A., and H.M. Karp. 1989. Humpback chub (*Gila cypha*) in the Yampa and Green rivers, Dinosaur National Monument, with observations on roundtail chub (*G. robusta*) and other sympatric fishes. Great Basin Naturalist 50(3):257–264.

Wolman, G.M., and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology 68(1):54–74.

4.9. Vegetation

4.9.1. Background and Importance

Known for its rich geologic features, Dinosaur National Monument (DINO) also supports a biologically diverse suite of vegetation types. This diversity can be traced to the range of topography and geology present within the monument, which is at the hub of five major biophysical regions (NPS 2015). These regions offer various habitats from river bottoms to montane peaks, riparian corridors and seeps and springs. The lower 46 miles of the Yampa River, the last remaining large, quasi free-flowing river in the Colorado River system, provides important habitat for native and endangered fish and provides a living laboratory to study the riparian system functions and the species that depend on them, such as *Spiranthes diluvialis* (Ute ladies'-tresses, which is listed as threatened). Combinations of topographic features, geologic substrates and other environmental conditions support approximately 30 rare plant taxa within the monument, some of which are endemic to the region. The diversity of habitats and a variety of management regimes impacting the Green and Yampa Rivers provide opportunities for scientific research of riparian systems and the response of biota to different management practices. (NPS 2015). Seeps and springs are numerous within the monument. Their locations are documented but comprehensive surveys of hydrology, site conditions, and floral and faunal characteristics of each feature have not been completed.

Based on discussions with DINO staff during the scoping process, four broad vegetation types are included in this examination: pinyon-juniper woodlands, sagebrush shrublands, native grasslands, and native riparian woody vegetation (Table 4.9-1, Figure 4.9-1). The first three types encompass the majority of the area within the 85,054 ha monument boundary: pinyon-juniper woodlands (49,511 ha or 58%), sagebrush shrublands (11,565 ha or 14%) and native grassland (6,064 ha or 8%). Although native riparian woodlands and shrublands account for only 420 ha (less than 1%) of the monument area, they provide key habitats for numerous plants and animals. Additional riparian habitat dominated by non-native wood communities and herbaceous vegetation communities exist and are mapped, but are not evaluated here.

<u>Threats and Stressors</u>

The diverse ecosystems at DINO are stressed by several human-induced threats as well as ongoing natural processes. Threats to the vegetation communities at DINO include the spread of invasive exotic plant species, excessive disturbance by native and non-native grazers and livestock, altered fire regimes, climate change, and altered hydrology within the riparian zones (NPS 2015). Localized threats to particular locations can include recreational impacts and human land uses such as development and agriculture. Systemic changes attributable to these threats include increasing wildfire frequency and intensity, reductions in snowpack and rainfall (and thus stream/river flows), degradation of air and water quality, spread of invasive non-native plants, incursion of artificial light sources and noise, and alterations in plant and animal communities and populations that are beyond the range of natural variability.

The upland communities at DINO are especially at risk for type conversions and degradation by *Bromus tectorum* (cheatgrass) invasion, which can contribute to altered fire regimes. Modeling by Sherrill and Romme (2012) identified elevation, fire severity, and moisture conditions during the first

year postfire as the most important controls on cheatgrass invasion of burned areas in DINO. Lower fire severity and drier postfire conditions generally were associated with the highest probabilities for cheatgrass cover greater than 10% across the DINO landscape (Sherrill and Romme 2012). Results varied by elevation. Riparian vegetation communities are subject to changes in community composition by invasive exotic plant (IEP) herbaceous species as well as invasive woody plants such as *Tamarix* spp. (tamarisk) and *Elaeagnus angustifolia* (Russian olive). Significant effort was expended to manage these two small trees as well as numerous other invasive plants over the past several decades. Efforts to control tamarisk have been extremely successful in the monument. Starting in the late 1990s, managers began effective control of tamarisk using a combination of physical removal, chemical herbicides and biological control by the tamarisk beetle (*Diorhabda carinulata*). During the summers of 2006 and 2007, a total of 50,000 tamarisk-eating beetles were released at four separate sites in the monument. The beetle has been steadily expanding its range in DINO since the original 2006 releases at Echo Park. At least small numbers can now be found in most tamarisk stands along the Green and Yampa Rivers (NPS 2011).

Table 4.9-1. Extent of ecological systems and their constituent map classes at DINO based on Coles et al. (2008).

Ecological System	Map Unit Name	Area (ha)
Pinyon-Juniper Woodlands	Pinyon-Juniper / Basin Big Sagebrush Woodland	80
	Pinyon-Juniper / Black Sagebrush Woodland	1,021
	Pinyon-Juniper / Herbaceous Woodland	17,910
	Pinyon-Juniper / Littleleaf Mtn Mahogany Shrubland and Woodland	7,028
	Pinyon-Juniper / Mixed Desert Shrub Woodland	2,070
	Pinyon-Juniper / Sagebrush Woodland	6,095
	Pinyon-Juniper / Soil Crust Woodland	3,650
	Pinyon-Juniper / Sparse Understory Woodland	7,115
	Pinyon-Juniper / True Mountain Mahogany Woodland	4,453
	Pinyon-Juniper-Curlleaf Mountain Mahogany Woodland	86
	Rocky Mountain Juniper / Sagebrush Woodland	4
	Total:	**49,511**
Sagebrush Shrublands	Sagebrush/Rabbitbrush Shrubland	10,785
	Sagebrush-Antelope Bitterbrush Shrubland	781
	Total:	**11,565**
Native Grasslands	Native Grasslands	6,640
	Total:	**6,640**
Native Riparian Woody Vegetation	Box Elder / Netleaf Hackberry Woodland	6
	Box Elder Woodland	273
	Broadleaf Cottonwood Woodland	134
	Threeleaf Sumac Riparian Thicket	7
	Total:	**420**

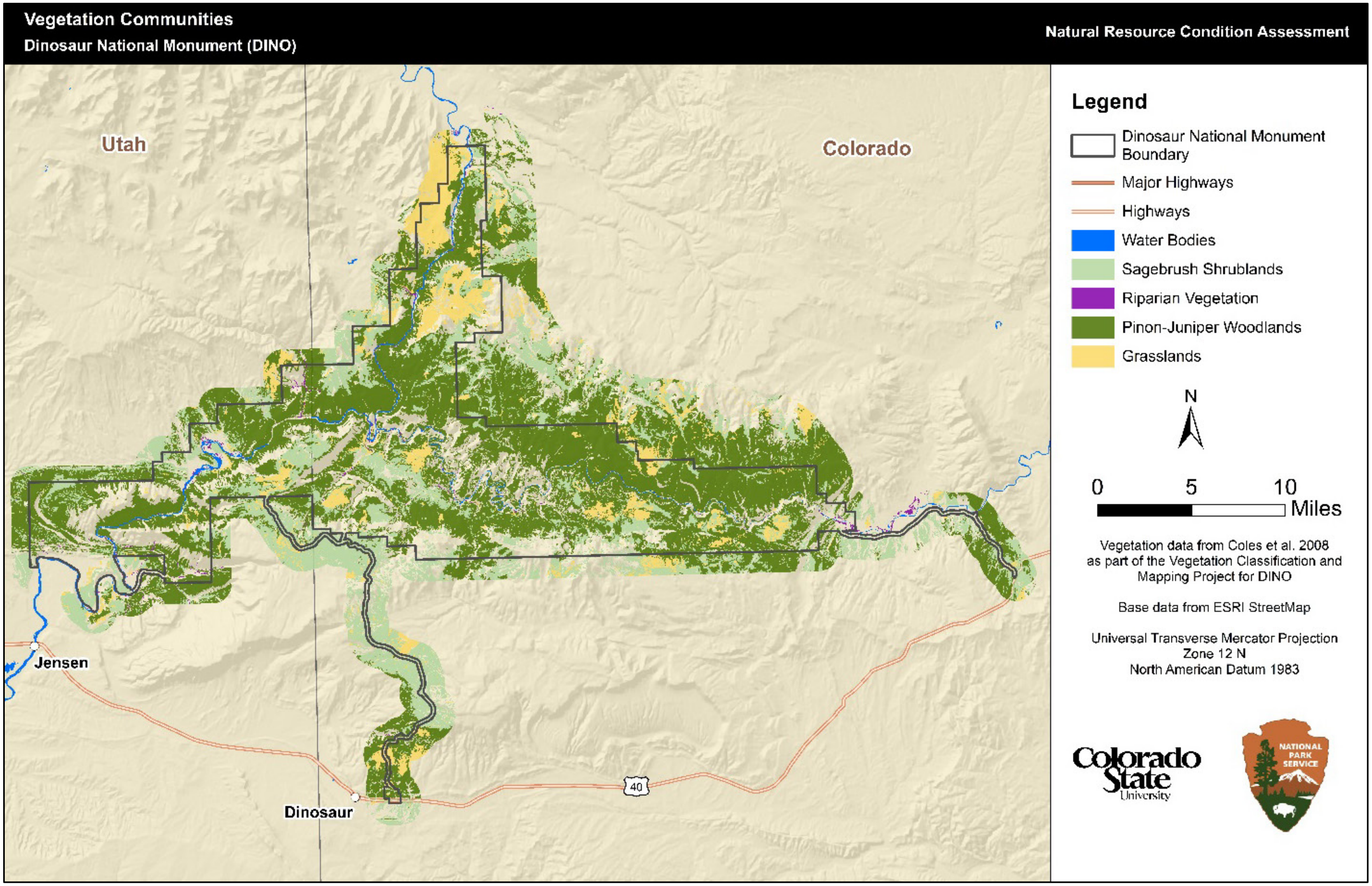


Figure 4.9-1. Map showing pinyon-juniper woodlands, sagebrush/rabbitbrush shrublands, native grassland vegetation, and riparian woodlands and shrubland ecological systems in Dinosaur National Monument, reclassified from Coles et al. (2008) map classes.

A disturbance regime is generally described as a function of type, frequency, predictability, extent, magnitude, relationship to other disturbances, and seasonality (Baker 2009). “Fire regimes” are a convenient way to describe the role and characteristics of fire in a landscape. Fire regimes describe the intermediate drivers between single fire events and long-term climate forcing on ignitions, weather, and fuel (Whitlock et al. 2010). Fire regimes are generally compared to recent historical and pre-historic records, such as those derived from land surveys and fire scars, to determine comparative baselines, although this is not universal and not without criticism (Freeman et al. 2017).

Generally, fire management at NPS units is informed by the historical fire regime concept (Lutes et al. 2006, van Wagtendonk 1991). Here we describe the following key fire regime concepts for each broad vegetative community type: frequency [as measured by the time between fires or fire rotation (in years)], seasonality, extent, and severity (Table 4.9-2). These will be compared to recent historical data, as possible, to determine condition and trend.

Table 4.9-2. Fire regime components (Baker 2009).

Fire Regime Component	Description
Frequency	The amount of time between fires, or, how many fires occur in a given time period. Also sometimes expressed as fire rotation.
Seasonality	The general season during which fires occur
Extent	The size of fires
Severity	The amount of biomass lost as a function of energy released by the fire, or, more generally, the amount of ecosystem change as a result of a fire (Keeley 2009)

Livestock grazing is considered a stressor on numerous park resources and natural processes (NPS 2015). Much of DINO has been grazed for more than a century; ranching began on a large scale in the 1880s and the area was heavily used by both cattle and sheep through the 1920s. The combination of fire suppression and repeated spring and summer grazing pressure has converted much of the sagebrush/perennial grass shrub-steppe to monotypic, decadent Wyoming big sagebrush stands with invasive annual understories (Coles et al. 2008). There are 10 administrative grazing allotments on approximately 32,375 hectares (80,000 acres) with a total maximum grazing preference of about 2,300 animal unit months (AUMs) (Figure 4.9-2). Most livestock grazing is related to inholdings and continues as per the enabling legislation. Grazing pressure varies by allotment. Special regulations for the administration and termination of grazing are found in 36 CFR 7.63, which states that grazing associated with private inholdings shall continue until inholdings are purchased (NPS 2015).

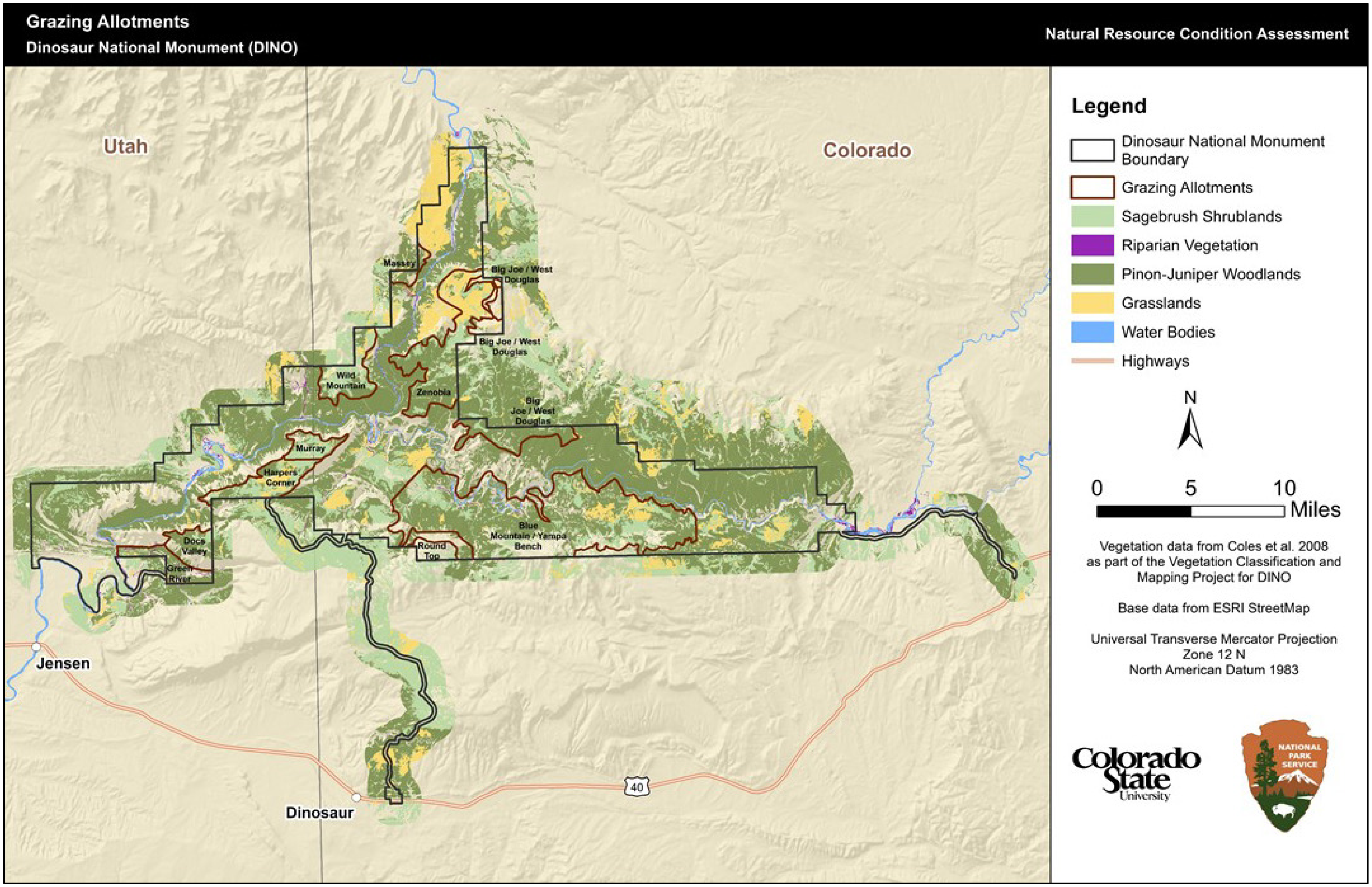


Figure 4.9-2. Current grazing allotments and primary habitat types, Dinosaur National Monument (data source: Dinosaur National Monument).

Little documentation of rangeland condition or stocking levels exists. While there have been several range condition studies performed in certain allotments over the last 40 years, a comprehensive and consistent rangeland health assessment has never been performed across all grazing allotments. Seeps and springs and associated vegetation communities were also heavily impacted by human use and livestock grazing, and likely continue to be degraded by overuse by livestock and native ungulates, although the levels of use and condition of the resources are not documented (pers. comm., Tamara Naumann, 2016). To help promote sustainable use of livestock grazing within the monument while minimizing impacts to other resource values, a comprehensive rangeland health assessment is planned for 2019, the results of which will inform the development of individual allotment management plans within the next 3–7 years. (pers. comm., Emily Spencer, 2019).

<u>Indicators and Measures</u>

- Community composition (% native species)
- Floristic quality: mean Coefficient of Conservatism value (mean C)
- Invasive exotic plant (IEP) species mean relative cover in upland and native vegetation communities (% IEP cover)
- Dominance of cheatgrass in the herbaceous layer
- Priority IEP species cover and patch size severity rank in native riparian vegetation
- Fire regime (frequency, extent, severity)

4.9.2. Data and Methods

The condition of some metrics was assessed using data from the NPS vegetation classification and mapping efforts completed by Coles et al. (2008). The classification, geospatial database, report and other deliverables described and mapped 174 National Vegetation Classification plant associations, alliances, or park special vegetation types within the monument and environs. The associations documented at DINO are represented by 66 map classes (Coles et al. 2008). To facilitate putting the myriad associations into a management and habitat context, the map classes were reorganized into the Ecological Systems framework developed by NatureServe (Comer et al. 2003). Twenty-four ecological systems are known to occur within the DINO vegetation mapping project area. Of these, four were selected to include in this Natural Resource Condition Assessment (Figure 4.9-1): pinyon-juniper woodlands, sagebrush shrublands, native grasslands, and native riparian woody vegetation.

<u>Species Composition and Floristic Quality</u>

Evaluation of these metrics used spatial and tabular data extracted from the DINO PLOTS database (Coles et al. 2008) for vegetation classification plots, observation points, and accuracy assessment (AA) points. A total of 1,659 point locations were available from the vegetation mapping effort (727 vegetation plots, 217 observation points, and 715 accuracy assessment points). Of these, we used 436 vegetation plots in DINO within the four focal vegetation types for floristic quality analysis. A total of 127 observation points and 715 accuracy assessment (AA) plots within the boundary of DINO were used for evaluating cheatgrass presence. Plot locations from the map geodatabase were used to

link final map class assignments to plot data within the PLOTS database for species composition and abundance. Cover class mid-points were used to estimate absolute canopy cover values for each species. Indicators derived from vegetation plot data (% native species, mean C, and % relative IEP cover in upland vegetation communities) are summarized by map unit within larger ecosystem focus types. Each plot or point location is treated as an individual observation; means and confidence intervals summarized by map unit and ecosystem type are presented.

The percent of species in each location that are native was calculated by dividing the number of exotic species present in a plot by the total number of species present in that plot, and subtracting the result from 1.

The basic floristic quality assessment (FQA) index score "mean C" was used to evaluate species composition for each vegetation group. C is the "coefficient of conservatism" (Table 4.9-3), a measure of the degree to which a plant species displays fidelity to a specific habitat or set of environmental conditions (Wilhelm and Ladd 1988). Conservative species are those that have evolved with and are closely adapted to a specific set of biotic and abiotic factors, interactions, and natural disturbances (Wilhelm and Ladd 1988, Wilhelm and Masters 1996). Such species are generally indicative of habitat stability, but can also occur in periodically disturbed habitats. The narrow ecological tolerance of highly conservative species means that they are likely to decline or disappear under conditions that exceed the natural range of variation under which they evolved (Wilhelm and Masters 1996). In contrast, non-conservative or generalist species are those which have a broader ecological niche and don't show fidelity to a specific set of environmental parameters. The mean C score is the average conservatism of all native species documented growing at vegetation plot locations within in the vegetation group.

Table 4.9-3. Summary of coefficients of conservatism (C) used in the FQA for vascular plants. Sources: Andreas et al. 2004, Lemly and Gilligan 2015.

C	Description
0	Wide range of ecological tolerances, non-native opportunistic invaders or native taxa that are often part of ruderal communities.
1–2	Widespread taxa that are not typical of a particular community.
3–5	Intermediate range of ecological tolerances that typify a stable phase of a native community and persist under some disturbance.
6–8	Narrow range of ecological tolerances that typify a stable or near "climax" community. Obligate to more natural areas and can sustain some habitat degradation.
9–10	Obligate to high quality or relatively unaltered natural systems with a narrow range of ecological tolerances that exhibit a high degree of fidelity.

Floristic quality metrics were calculated using the FQA database developed for Colorado by the Colorado Natural Heritage Program. Not all species recorded during DINO vegetation mapping have an assigned C value (e.g., plants only identified to genus, non-vascular plants, or a few instances of

Utah species lacking a Colorado equivalent), but the majority of plant species present were successfully crosswalked to the Colorado list.

Invasive Exotic Plant Cover
Species cover class data for all vegetation plot locations in the three upland vegetation types were extracted from the PLOTS database and converted to cover-class midpoints. The % cover of IEP species was calculated by dividing the total cover of IEP species present in a plot by the total cover of all species present in that plot.

Cheatgrass Dominance
Dominance of cheatgrass in the herbaceous layer was calculated using 127 observation points and 715 Accuracy Assessment points from the vegetation mapping project (Coles et al. 2008). For these locations, field crews recorded the cover class of primary dominant species in each stratum (e.g., the top 3–5 species), but did not make a comprehensive species list. For this analysis, we classified plot values into three categories (Table 4.9-4) based on cheatgrass presence and abundance. The overall value for a vegetation type was determined by the total proportion of locations where cheatgrass was recorded (i.e. with low or high dominance category).

Table 4.9-4. Cheatgrass dominance categories and interpretation used by the authors.

Cheatgrass abundance	Dominance category	Interpretation
Not recorded	Not dominant	May be present, but not a significant component of the understory
Recorded with cover <10%	Low dominance	Present as one of the dominant understory species, may become much more common in the future
Recorded with cover >10%	High dominance	Present as a dominant understory species, most likey to increase in dominance in the future

Priority IEP Species Severity (Native Woody Riparian Areas)
The Northern Colorado Plateau Network (NCPN) parks identified invasive exotic plants (IEPs) as a high-priority vital sign for long-term monitoring (O'Dell et al. 2005). IEPs are a subset of exotic plants "whose introduction does or is likely to cause economic or environmental harm or harm to human health" (Executive Order 13112). IEP lists used for monitoring were developed and periodically updated by reviewing past park literature and state and county weed lists, and consulting with park staff and county weed managers. As an example, the priority IEP list used in 2011 includes existing IEPs and potential IEPs of high management concern (Perkins 2012) (Table 4.9-5).

IEP monitoring data for DINO were available for native woody riparian vegetation from weed mapping and monitoring efforts described in Washuta et al. (2018). Monitoring efforts generally focused on roads, trails, and waterways, which are major vectors for invasive plants, thus capturing the greatest amount of information per unit of time and effort (Perkins 2012). The IEP geodatabase was used to identify survey locations for priority IEP species described in Washuta et al. (2018) that fell within riparian map units assessed in this chapter. The combined occurrence size and cover range schema documented in the 2017 weed mapping geospatial file metadata was crosswalked and applied

to surveyed locations from all available years; size and cover scores were multiplied together, and the resulting severity rank summarized according to the schema from the 2017 mapping (Table 4.9-6). Mean severity ranks were calculated for each species within year, and these values were then averaged over all monitoring years, and for two combined monitoring periods: 2002–2005 (see Dewey et al. 2003, Dewey and Anderson 2005), and 2010–2017, including results from 2010–2011 presented in Perkins (2012). Only species with mapped locations in at least seven of the eight primary monitoring years were included. The overall average severity rank was used as an additonal indicator of community condition, and the change in mean severity rank between the two periods determined trend for this vegetation type.

Table 4.9-5. Priority invasive exotic plant list, DINO, 2010–2011 (Perkins 2012).

Species name (Utah)	Common name	Species name (Colorado)
Aegilops cylindrica	jointed goatgrass	*Aegilops cylindrica*
Arctium minus	burdock	*Arctium minus*
Cardaria chalepensis	orbicular whitetop	*Cardaria chalepensis*
Cardaria draba	hoary cress	*Cardaria draba*
Cardaria pubescens	hairy whitetop	*Cardaria pubescens*
Carduus nutans	musk thistle	*Carduus nutans var. macrolepis*
Centaurea diffusa	diffuse knapweed	*Acosta diffusa*
Centaurea maculosa	spotted knapweed	*Acosta maculosa*
Centaurea repens	Russian knapweed	*Acroptilon repens*
Centaurea solstitialis	yellow starthistle	*Centaurea solstitialis*
Cirsium arvense	Canada thistle	*Breea arvensis*
Cirsium vulgare	bull thistle	*Cirsium vulgare*
Cynoglossum officinale	common hound's-tongue	*Cynoglossum officinale*
Dipsacus sylvestris	teasel	*Dipsacus fullonum*
Elaeagnus angustifolia	Russian olive	*Elaeagnus angustifolia*
Euphorbia esula	leafy spurge	*Tithymalus esula*
Hyoscyamus niger	black henbane	*Hyoscyamus niger*
Lepidium latifolium	broad-leaf pepperwort	*Cardaria latifolia*
Linaria dalmatica	Dalmatian toadflax	*Linaria genistifolia ssp. dalmatica*
Linaria vulgaris	butter-and-eggs	*Linaria vulgaris*
Lythrum salicaria	purple loosestrife	*Lythrum salicaria*
Melilotus officinalis	yellow sweetclover	*Melilotus officinale*
Onopordum acanthium	Scotch thistle	*Onopordum acanthium*
Taeniatherum caput-medusae	Medusahead	*Taeniatherum caput-medusae*
Tamarix chinensis	tamarisk	*Tamarix ramosissima*
Tribulus terrestris	puncturevine	*Tribulus terrestris*

Table 4.9-6a. Priority IEP occurrence severity score derivation – step one.

Action	IEP occurrence size description	Rank	IEP occurrence cover description	Rank
Using size and cover description, determine rank of each	1–3 plants	1	Trace (<1%)	1
	4 plants–40m sq.	2	Low (1–5 %)	2
	40–400m sq.	3	Moderate (6–25 %)	3
	400–1000m sq.	4	High (26–50%)	4
	1000–2000m sq.	5	Majority (51–100%)	5

Table 4.9-6b. Priority IEP occurrence severity score derivation – step two.

Action	Overall severity score (product of two ranks)	Interpretation
Multiply above two ranks together	1 to 5	Very low
	6 to 10	Low
	11 to 15	Moderate
	16 to 20	High
	> 20	Very high

Fire Regime

Fire occurrence data provided by NPS and Sundance Consulting Inc. (2018) were spatially cross-referenced to the mapped vegetation types developed by Coles et al. (2008) and used to calculate fire extents and seasonality for the park and the surrounding area (Figure 4.9-3). Fire frequency data were assessed using tree ring research from DINO (Floyd et al. 2017).

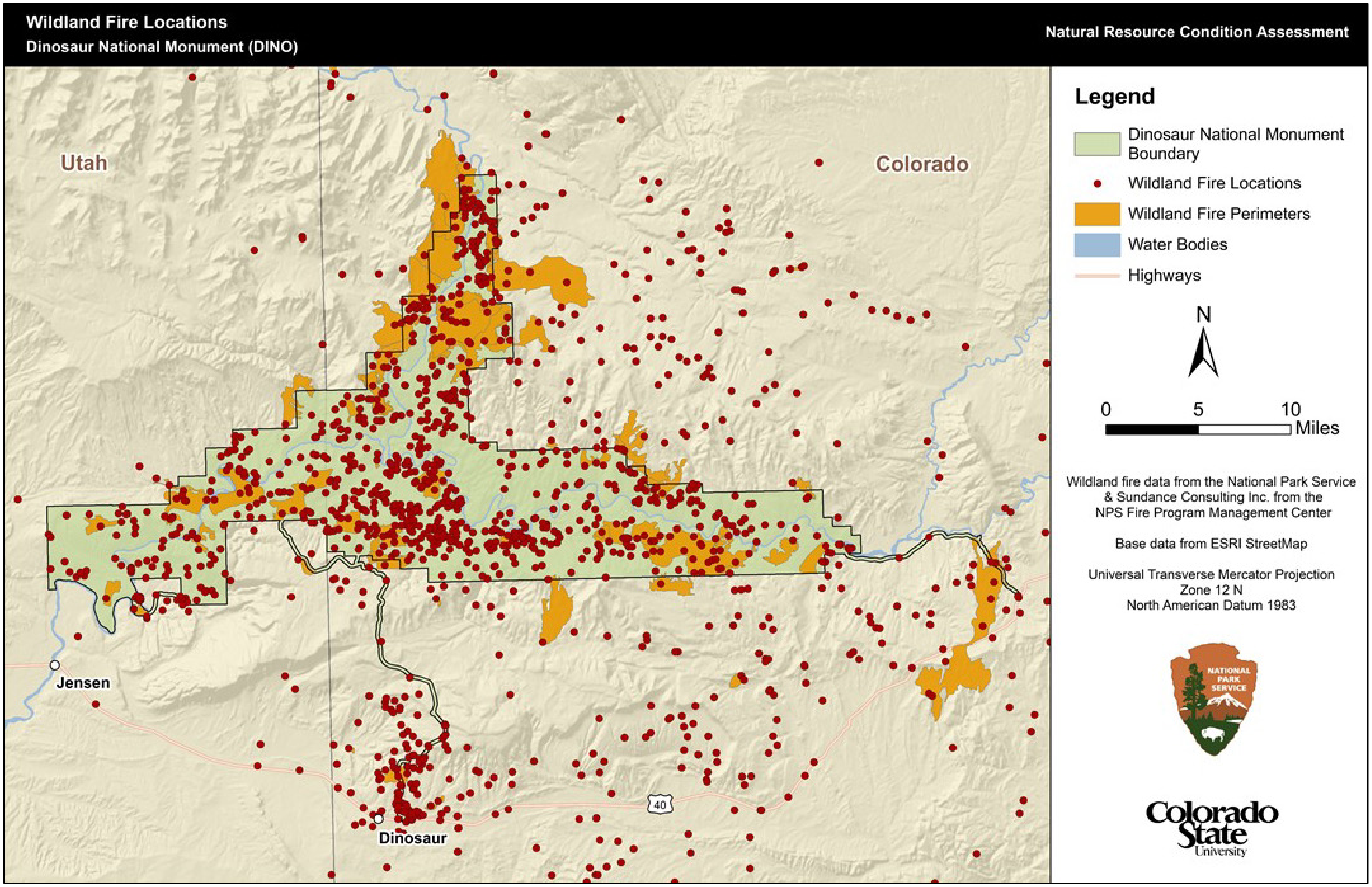


Figure 4.9-3. Locations of documented wildland fires in and around DINO, 1943 to 2017 (data sources noted in map).

4.9.3. Reference Conditions

Vegetation Composition and Diversity Indicators

The ideal situation for DINO vegetation would be an absence of non-native species, reflecting conditions prior to European settlement. Because DINO is relatively undisturbed compared to NPS units in other parts of the country, reference conditions benchmarks are set accordingly (Table 4.9-7).

Table 4.9-7. Reference condition rating framework for vegetation quality indicators for dominant native vegetation types at DINO.

Indicator	Reference or High Quality Condition	Moderate Condition/Warrants Moderate Concern	Warrants Significant Concern
Species composition (% native species)	>=95%	80–95%	<80%
Mean C	>=5.0	4.25–5.0	<4.25
% IEP cover	<5%	5–25%	>25%
% of samples where cheatgrass was recorded as either one of the top 5 dominant herbaceous species or had cover >1%	< 25%	25–50%	>50%
IEP species overall severity rank (riparian only)	1–5	6–15	>15

Information that can be used to determine trends is limited. Pilot sampling to support refinement of methods, sampling designs and sample sizes for sagebrush and pinyon-juniper communities at DINO was undertaken in 2009–2011 (Witwicki 2013). The study plots represented a total of approximately 13,000 acres of low-elevation and high-elevation sagebrush communities within DINO both with and without livestock grazing. The program will be further developed in the coming years to support quantitative assessment of condition and trend in sagebrush and pinyon-juniper communities (pers. comm., D. Witwicki, May 2019). Repeated monitoring for priority IEP species in riparian areas was used to compare two monitoring periods: 2002–2005 and 2010–2017.

Fire Regime Indicators

Fire Frequency:

Pinon-Juniper Woodlands. Fire frequency in pinyon-juniper woodlands varies due to underlying variation in structure and composition (Romme et al. 2009), which makes mean fire intervals difficult to assess. Mean fire intervals are thought to be between 8 and 28 years (Baker and Shinneman 2004). Fire rotation, the time required to burn over an area equal to that of particular landscape once, is estimated at between 400 years and 480 years for the region (Baker and Shinneman 2004) and ca. 550 years for DINO (Floyd et al. 2017). Drivers of variation in frequencies are not clear, but may be linked to soil productivity, rainfall patterns, grass density, and sagebrush presence; the latter two are often affected by grazing history (Romme et al. 2009).

Sagebrush Shrublands. Fire frequency in sagebrush varies by species type. Wyoming (*Artemisia tridentata ssp. wyomingensis*) and basin big sagebrush (*Artemisia tridentata ssp. tridentata*) are

estimated to have fire return intervals of 10–70 years (Innes 2017). By contrast, fire return interval estimates for mountain big sagebrush (*Artemisia tridentata ssp. vaseyana*) range from 10–25 years, to 30–60, to greater than 150 on low productivity sites (Innes 2017). Many fire return interval calculations do not adjust for sampling bias of fire scars. Adjusting for this, Baker (2006) calculated *fire rotations* (the amount of time for a given area to burn entirely) of 325–450 years in basin big sagebrush, 100–240 years in Wyoming big sagebrush, and 70–200 years or more in mountain big sagebrush. Based on studies at DINO, Baker and Arendt (2013) estimated 2,500–5,000 year fire rotations in Wyoming / basin big sagebrush and 458–729 in mountain big sagebrush (Arendt 2014). Overall, fire intervals and fire rotations were long, representing long interval, stand-replacing fire regimes (Baker 2006, Welch and Criddle 2003).

<u>Grasslands</u>. Fire frequency in grasslands is controlled by various interrelated factors, such as site productivity, fuel moistures, and spacing of grass (Brown and Smith 2000). Mountain grasslands have been reported to have fire return intervals between 4 and 20 years (Arno and Gruell 1986), although it is difficult to determine fire histories in pure grasslands where trees cannot record fire scars. Attempts to account for this yield fire *rotations* of 35–100 years (Baker 2006).

<u>Riparian Vegetation</u>. Riparian woodland fire regimes are poorly understood (Bock and Bock 2014). Fire frequency is likely driven by the surrounding vegetation matrix more than the riparian vegetation itself, as many riparian woodland species are not specifically adapted to fire and unlikely to readily carry fire (Taylor 2000, Zouhar 2003, Zouhar 2005).

Seasonality:

<u>Pinyon-Juniper Woodlands</u>. Seasonality of fires in pinon-juniper are driven by summer lightning season, which varies based on local conditions.

<u>Sagebrush Shrublands</u>. Sagebrush historically burned so infrequently that determining seasonality is difficult, but some estimates place it at April–October (Innes 2017).

<u>Grasslands</u>. Fire occurrence in grasslands is tied most directly to fine fuel moisture, which can vary considerably throughout the day as relative humidity changes (Arno and Gruell 1986). These daily changes can vary greatly within seasons, making fires possible during any season. In areas where thatch and other moribund grass is low, green-up will constrain fires.

<u>Riparian Vegetation</u>. Seasonality of riparian woodland fires were historically driven by longer term drought trends (Bock and Bock 2014). Many riparian woodland species have high foliar moisture content and are only available to burn during periods of drought stress. These are most common during the summer. Likewise, fires in riparian woodlands are thought to largely originate in surrounding vegetation matrices, which are themselves driven by summer fuel moisture trends and lightning patterns (Zouhar 2003, Zouhar 2005, Taylor 2000).

Extent:

<u>Pinyon-Juniper Woodlands</u>. Historical fire sizes in pinyon-juniper woodlands were either very small (i.e., single tree or small patch fires) or large (200 – > 3,000 ha) (Table 4.9-8).

Sagebrush Shrublands. Historically, fires in sagebrush shrublands consisted of many small fires and few large fires (Bukowski and Baker 2013). Fires in Wyoming big sagebrush are generally larger than fires in mountain big sagebrush. These variations resulted in a wide variety in fire sizes (Table 4.9-8).

Grasslands. Historical fire sizes in western grasslands are poorly understood and under-researched (Vankat 2013). No conclusive data are available.

Riparian Vegetation. Fire sizes in riparian woodlands are poorly understood and poorly documented (Bock and Bock 2014, Dwire and Kauffman 2003). Due to the generally high moisture content, fires historically were likely very small, with fires during droughts being larger.

Severity:

Pinyon-Juniper Woodlands. Severity of pinyon-juniper fires tends to be bimodal: either very small (single tree) and very low severity, with limited effects on the stand or ecosystem, or larger and stand-replacing (Romme et al. 2009, Baker and Shinneman 2004). These large, high intensity fires are infrequent and high severity, resulting in stand initiation. In pinyon-juniper savannas, surface fires may have occurred historically, but evidence for this is mixed (Baker and Shinneman 2004).

Sagebrush Shrublands. Sagebrush is fire intolerant, and is quickly killed by even low intensity fires (Sapsis and Kauffman 1991, Howard 1999, Innes 2017, Britton and Clark 1985, Baker 2011). All fires in sagebrush are thus by definition "high severity."

Grasslands. Although the applicability of "severity" in grasslands is debated (Stambaugh et al. 2015), mortality from and resilience to wildfires in western grasses varies (Baker 2009). Many species readily recover and flourish post-fire (Brown & Smith 2000). Because of this variation, a low to mixed-severity historical severity class for grassland is likely.

Native Woody Riparian Vegetation. Riparian woody vegetation is generally intolerant of fire (Dwire and Kauffman 2003). Fires that occur result in high vegetation mortality, and are thus high severity.

Fire regime reference conditions for the four habitat types examined are summarized in Table 4.9-8. Conditions falling within these values/ranges would be considered good conditions from an ecological perspective. Assignment of ratings for conditions that appear to fall outside of the reference condition is somewhat subjective.

Table 4.9-8. Reference conditions for fire regime components.

Fire Regime Component	Pinyon-Juniper Woodlands	Sagebrush Shrublands	Grasslands	Riparian Vegetation
Frequency (Mean Fire Rotation)	Regional 400–600 yrs. (Floyd et al. 2004, Shinneman and Baker 2009) and DINO-specific ca. 550 yrs. (Floyd et al. 2017)	20–350 yrs. (Slaton 2016)	5–40 (Arno and Gruell 1986) 35–100 (Baker 2009)	Unknown – likely long
Seasonality	Unknown – likely summer	April–October (Innes 2017)	Variable (Brown and Smith 2000)	Unknown – likely summer
Extent	50 ha (Floyd et al. 2017); 200 – >3000 ha (Miller and Tausch 2001)	20–126,164 ha; geometric mean: 233 ha (Bukowski and Baker 2013)	Unknown (Vankat 2013)	Unknown – likely small.
Severity	High (Baker and Shinneman 2004)	High (Baker 2011)	Low–Moderate (Baker 2009, Brown and Smith 2000)	High (Dwire and Kauffman 2003)

4.9.4. Condition and Trend

<u>Summary Data for Fire Regime</u>

Summaries for fire characteristics for human–caused and natural-caused fires are presented in Table 4.9-9, Figure 4.9-4, and Figure 4.9-5 for the four habitat types examined. These results are incorporated into the condition/trend narratives for each type below.

Table 4.9-9a. Characteristics of fires by ignition type for different vegetation types examined at DINO. Data span 1961–2017 (NPS and Sundance Consulting Inc. 2018).

	Native Grasslands		Pinyon-Juniper Woodlands		Sagebrush Shrublands		Native Riparian Woody Communities	
Variable	**Human-caused**	**Natural**	**Human-caused**	**Natural**	**Human-caused**	**Natural**	**Human-caused**	**Natural**
Number of fires (n)	10	86	25	425	25	100	19	0
Ignitions / Yr	0.18	1.51	0.444	7.46	0.44	1.76	0.33	(none)
Mean Fire Size (ha)	349.41	100.49	22.60	10.48	43.13	13.50	4.45	(none)
Median Fire Size	132.74	0.04	0.04	0.04	6.88	0.04	0.04	(none)
Standard Deviation of Fire Size	636.57	496.30	65.61	62.57	71.87	67.06	18.24	(none)
Maximum Fire Size (ha)	2,082.11	4,461.02	307.56	887.07	323.75	483.20	79.72	(none)
Total Area Burned (ha)	3,494.10	8,642.07	565.06	4,456.40	1,078.29	1,349.91	84.50	(none)

Table 4.9-9b. Fire rotation for different vegetation types examined at DINO. Data span 1961–2017 (NPS and Sundance Consulting Inc. 2018).

Variable	Native Grasslands	Pinyon-Juniper Woodlands	Sagebrush Shrublands	Native Riparian Woody Communities
Fire Rotation	59.01	233 (Floyd et al., 2017)	76 (Baker & Arendt, 2013)	578.67

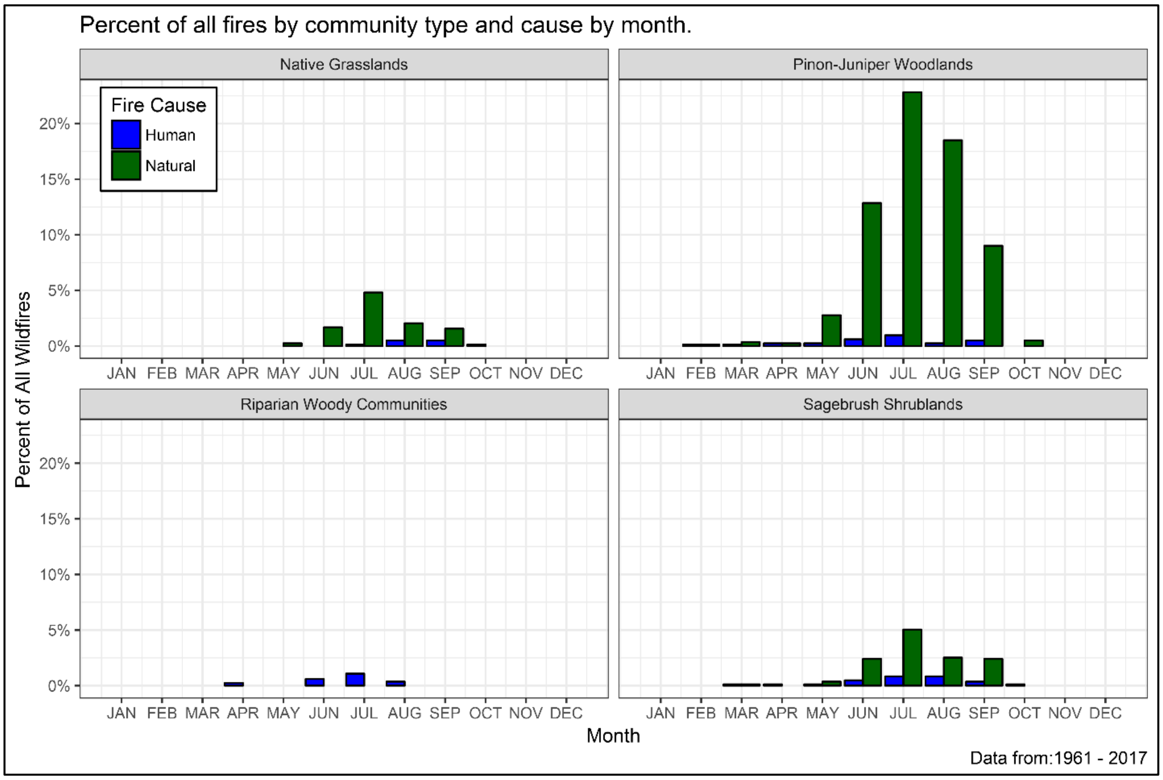


Figure 4.9-4. Seasonality of fires at DINO by cause and vegetation type of origin. Data from 1961 to 2017 (NPS and Sundance Consulting Inc. 2018).

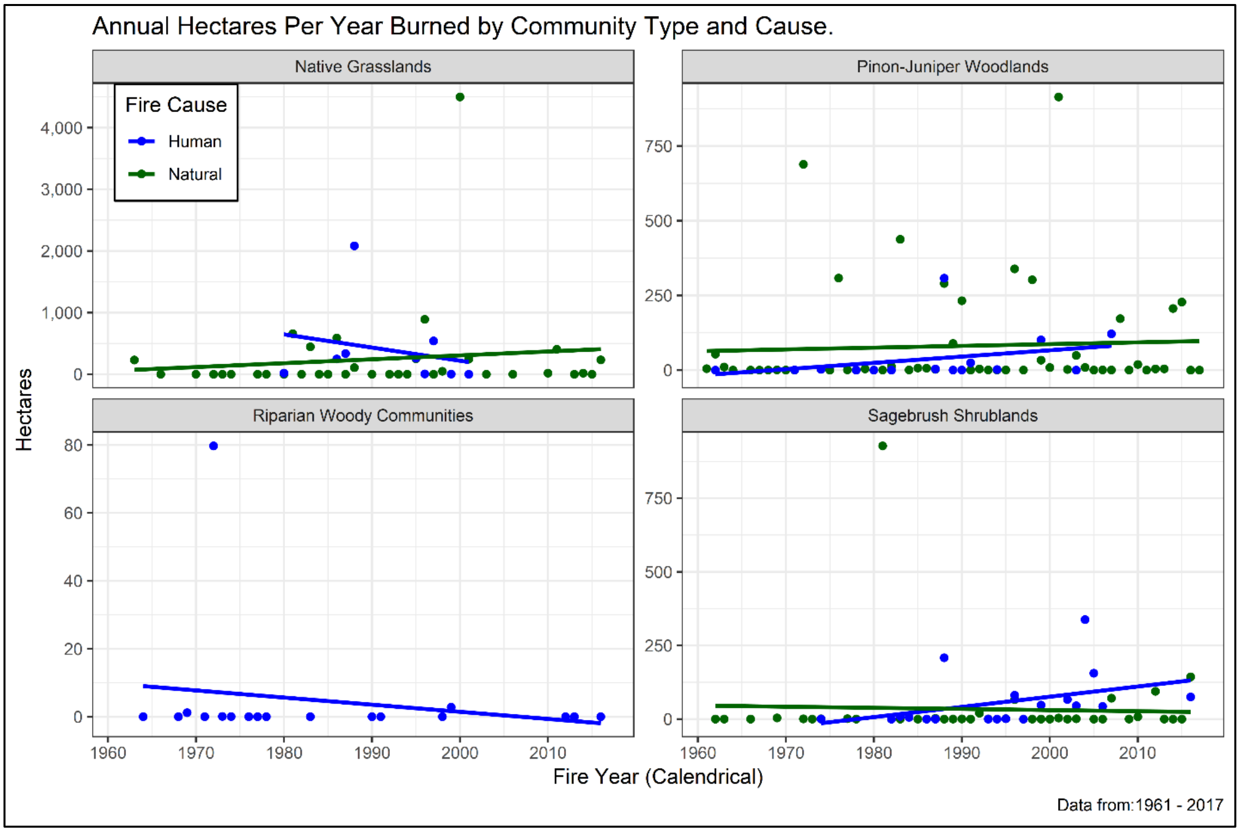


Figure 4.9-5. Hectares burned by year by vegetation type and cause. Linear models were fit to the data (lines shown). Only the relationship with human-ignited sagebrush shrubland hectares was significant (p = 0.08)(NPS and Sundance Consulting Inc. 2018).

Pinyon-Juniper Woodlands Condition

Composition, Quality and IEP Characteristics

The proportion of vegetation plot species that are native is 94.5% over all pinyon-juniper vegetation types at DINO with a 95% confidence interval of +/−0.8%. Individual plot values range from 66.7–100% native, and 41 plots (19%) had only native species present. Although all subtypes have values >89% native species (Table 4.9-10), the overall mean is at the low end of the good condition range.

Table 4.9-10. Vegetation quality metrics for pinyon-juniper woodlands at DINO.

Map unit name	n (vegetation classification plots)	% Native Species	Mean C	% IEP Cover	n (accuracy assessment + observation points)	Cheatgrass Dominance (% of samples)
Pinyon-Juniper / Basin Big Sagebrush Woodland	3	89.1%[2]	4.31[2]	9.5%[2]	17	100%[3]
Pinyon-Juniper / Black Sagebrush Woodland	13	94.8%[1]	5.19[1]	1.1%[1]	41	59%[3]
Pinyon-Juniper / Herbaceous Woodland	62	94.6%[1]	5.04[1]	1.8%[1]	113	27%[2]
Pinyon-Juniper / Mixed Desert Shrub Woodland	2	91.7%[2]	4.82[2]	13.8%[2]	20	30%[2]
Pinyon-Juniper / Sagebrush Woodland	45	93.9%[2]	4.83[2]	2.2%[1]	70	44%[2]
Pinyon-Juniper / Soil Crust Woodland	14	92.1%[2]	4.58[2]	1.2%[1]	45	36%[2]
Pinyon-Juniper / Sparse Understory Woodland	41	94.6%[1]	4.91[2]	2.8%[1]	51	43%[2]
Pinyon-Juniper / True Mountain Mahogany Woodland	25	96.7%[1]	5.17[1]	2.0%[1]	41	34%[2]
Pinyon-Juniper-Curlleaf Mountain Mahogany Woodland	4	95.2%[1]	5.32[1]	1.5%[1]	14	29%[2]
Rocky Mountain Juniper / Sagebrush Woodland	2	95.0%[1]	5.32[1]	0.2%[1]	0	–
Pinyon-juniper Woodlands n and means for all pinyon-juniper subtypes	**211**	**94.5%[1]**	**4.96[1]**	**2.2%[1]**	**412**	**40%[2]**

[1] Green cells – good condition

[2] Yellow cells – moderate concern

[3] Red cells – significant concern

Floristic quality as measured by mean C is generally above 4.5 for pinyon-juniper types (Table 4.9-10), with mean of 4.96 and a 95% confidence interval of 0.8. Individual plot values range from 2.5 to 6.14. IEP relative % cover in pinyon-juniper is generally low with a mean of 2.2% and a 95% confidence interval of 0.6% (Table 4.9-10). With the exception of the Pinyon-Juniper / Basin Big Sagebrush Woodland and Pinyon-Juniper / Mixed Desert Shrub Woodland types, both of which had very low sample sizes, relative % cover of IEP species was less than 3%, indicating that for this metric pinyon-juniper woodlands are in high quality condition. Cheatgrass was recorded as a dominant species in 40% of observation point and AA plot locations. Only 7% of all locations had high (>10%) cheatgrass dominance (primarily those with sagebrush as a primary component), indicating moderate condition for pinyon-juniper woodlands. The trend is unknown.

Fire Regime

Frequency. Fire frequency in the pinyon-juniper woodland of DINO was estimated by Floyd et al. (2017). Based on their analysis, fire frequency has increased at DINO from a historical ca. 550-year stand replacement fire rotation to ca. 360 years. This increase in fire frequency is coincident with declines and consequent conversions of pinyon-juniper to other vegetation types, although these conversions vary based on elevation and other drivers (Arendt and Baker 2013).

Seasonality. Fire occurrence at DINO is strongly seasonal, likely driven by fuel moisture trends and lightning frequency (Figure 4.9-4). Pinyon-juniper fires are most common in July, with a fire season between May and October. Fires have happened, but rarely, in February, March, April, and November.

*Extent***.** The mean fire size in pinyon-juniper woodlands is 22.6 ha for human-caused ignitions and 10.48 for natural ignitions (Table 4.9-9). Median fire size is smaller than the historical averages of 50 ha or up to 200–3,000 ha. Annual area burned is not increasing at a statistically significant rate (Figure 4.9-5).

Severity. Information to evaluate vegetation-specific burn severity was not available.

Based on these results, the fire regime for pinyon-juniper woodlands warrants moderate concern and appears to have a deteriorating trend, likely driven in part by increased fire frequency. Questions about the role of low severity fire remain, but increased high severity fire has led to conversion of pinyon-juniper stands to other vegetation types (notably, sagebrush and grasslands) and has facilitated expansion of exotic annual plant species.

Sagebrush Shrublands Condition

Composition, Quality and IEP Characteristics

The percentage of native species in sagebrush shrubland vegetation plots is 93.6% (+/− 1.2%) over all sagebrush types at DINO (Table 4.9-11). Individual plot values ranged from 71.4–100% native, and 62 plots (43%) had only native species present. The overall mean is slightly below the ideal reference condition of 95%, indicating moderate concern for this metric. Floristic quality as measured by mean C is 4.74 for sagebrush types (Table 4.9-11), with a 95% confidence interval of 0.12. Individual plot values range from 2.0 to 6.17. Percent IEP relative % cover in sagebrush shrublands at DINO is generally less than 5% (Table 4.9-11), with a mean of 4.2% (+/− 1.3%), indicating that for this metric sagebrush shrublands are in good condition. Cheatgrass was recorded as a dominant species in 60% of observation point and AA plot locations. Twenty-five percent of all locations (all were in Sagebrush/Rabbitbrush Shrubland) had high cheatgrass dominance (>10%), indicating poor condition for the sagebrush shrubland understory. The trend is unknown.

Table 4.9-11. Vegetation quality metrics for sagebrush shrublands at DINO.

Map unit name	n (vegetation classification plots)	% Native Species	Mean C	% IEP Cover	n (accuracy assessment + observation points)	Cheatgrass Dominance
Sagebrush/Rabbitbrush Shrubland	126	92.8%[2]	4.64[2]	4.7%[1]	196	62%[3]
Sagebrush/Antelope Bitterbrush Shrubland	163	99.4%[1]	5.50[1]	0.2%[1]	13	31%[2]
Sagebrush Shrublands n and mean for all subtypes	**143**	**93.6%[2]**	**4.74[2]**	**4.2%[1]**	**209**	**60%[3]**

[1] Green cells – good condition

[2] Yellow cells – moderate concern

[3] Red cells – significant concern

Fire Regime

Frequency. Baker and Arendt (2013) calculated a fire rotation of 76 years in sagebrush shrubland at DINO. This is much lower than their calculated historical fire rotations of 2,500–5,000 years and 458–729 years in DINO Wyoming/basin big sagebrush and mountain big sagebrush, respectively.

Seasonality. Sagebrush shrubland fires are most associated with summer months, likely driven by seasonal moisture trends and lightning (Figure 4.9-4). This is consistent with historical trends (Table 4.9-8).

Extent. Modern fire sizes (Figure 4.9-5, Table 4.9-9) are within historical size ranges (Table 4.9-9). Hectares burned by human-ignited fires increased significantly ($p = 0.08$) over the period of record (Figure 4.9-5).

Severity. Although historically fires were likely of high severity (Table 4.9-8), insufficient information exists to assess this by vegetation class.

Based on these results, the fire regime for sagebrush shrublands warrants moderate concern and appears to have a deteriorating trend, mainly due to the positive feedback between increased fire frequency and increased cheatgrass abundance. Sagebrush is adapted to a very infrequent, high severity fire regime. The current fire return interval is more frequent than historical trends and area burned by human ignition has increased significantly during the period of record. Increased fire frequencies will likely contribute to conversions of sagebrush shrublands to grasslands.

Native Grasslands Condition

Composition, Quality and IEP Characteristics

Native grassland vegetation at DINO has somewhat higher levels of non-native species than do the other dominant vegetation types (Table 4.9-12), with the mean percentage of native species equal to 89.7% (+/− 2.9%). A single grassland plot was dominated by non-natives with 60% relative IEP

cover, but other plots ranged from 75–100% native species composition. Twenty plots (33%) had no IEP species present.

Mean C values for native grassland plots had a wider range (1.4 to 6.25) than did pinyon-juniper woodland and sagebrush shrubland plots. The overall average mean C value was 4.42 (+/− 0.25).

Relative percent cover of IEP species in native grasslands was also higher than for the other upland types, with a mean of 5.2% IEP cover (+/− 2.1%). Cheatgrass was recorded as a dominant species in 46% of observation point and AA plots, but only 7% of all locations had high cheatgrass dominance (>10%), indicating moderate condition for the native grassland's understory. All four vegetation composition metrics for native grasslands indicate moderate condition. The trends appear to be unchanging.

Table 4.9-12. Vegetation quality metrics for native grasslands at DINO.

Map Unit Name	n (vegetation classification plots)	% Native Species	Mean C	% IEP Cover	n (accuracy assessment + observation points)	Cheatgrass Dominance (% of samples)
Native Grassland	61	89.7%[2]	4.42[2]	5.2%[2]	95	46%[2]

[1] Green cells – good condition

[2] Yellow cells – moderate concern

[3] Red cells – significant concern

Fire Regime

Frequency. Ninety-six fires occurred during the period of record, resulting in 0.175 human-ignited grassland fires per year and 1.509 natural-ignition grassland fires per year (Table 4.9-9). The mean fire rotation for this period of record is 59.01 years. This is within normal fire rotations (Table 4.9-8).

Seasonality. Grassland fires occur between May and October, with the most natural fires occurring in July (Figure 4.9-4). This is likely consistent with historical trends, as fine fuel-driven grass fires are often driven by fuel moisture levels.

Extent. Mean, median, and maximum grassland fire sizes were the largest compared to the other vegetation types (Table 4.9-9). Changes in area burned per year were not significant (Figure 4.9-5). Because of difficulties in determining fire sizes in grasslands historically, it is unclear how this compares to reference conditions.

Severity. There is insufficient vegetation-specific data to assess fire severity in grasslands, but interpreting severity in the context of grasslands is notably difficult (see discussion above).

Based on these results, the fire regime for grasslands is in good condition. The trend is unknown. Grassland fires are within reference conditions for size and frequency.

Native Riparian Woody Vegetation Condition

Composition, Quality and IEP Characteristics

Sample sizes for native riparian woody vegetation are small. A single plot had no IEP species present; other plots contained 50–92.3% native species. The overall mean for percent native species in this vegetation type was 76.7% (+/− 5.8%), indicating poor condition (Table 4.9-13). Mean C values were also low, averaging 3.68, with a 95% confidence level of 0.6, reflecting an abundance of disturbance-tolerant species and overall poor condition. Relative cover of IEP species was 11.3% (+/− 4.9%) across all units, indicating moderate concern. Cheatgrass was recorded as a dominant species in 75% of observation point and AA plot locations; 48% of all locations had high cheatgrass dominance (>10%), indicating poor condition for the understory of this vegetation type. Three of four metrics indicate poor condition for native riparian woody vegetation.

Table 4.9-13. Vegetation quality metrics for native riparian vegetation at DINO.

Map unit name	n (vegetation classification plots)	% Native Species	Mean C	% IEP Cover	n (accuracy assessment + observation points)	Cheatgrass Dominance (% of samples)
Box Elder / Netleaf Hackberry Woodland	2	82.9%[2]	5.17[1]	29.1%[3]	6	100%[3]
Box Elder Woodland	13	73.8%[3]	3.50[3]	11.3%[2]	75	77%[3]
Broadleaf Cottonwood Woodland	5	78.3%[3]	3.54[3]	5.9%[2]	39	72%[3]
Threeleaf Sumac Riparian Thicket	1	92.3%[2]	4.41[2]	2.2%[1]	6	33%[2]
Riparian Vegetation n and mean for all subtypes	**21**	**76.7%[3]**	**3.68[3]**	**11.3%[2]**	**126**	**75%[3]**

[1] Green cells – good condition

[2] Yellow cells – moderate concern

[3] Red cells – significant concern

Severity ranks (combined size and cover) for frequently mapped IEP species in native riparian woody vegetation were very low to moderate over the mapping period, and some interannual fluctuation can be expected with changing environmental conditions from year to year. In general, these riparian areas have numerous but low-severity IEP occurrences in the range of 5.1 to 8.8 during the most recent monitoring decade (Table 4.9-14), indicating moderate concern. Trends between the two monitoring decades are variable, with an unchanging to improving trend for some IEP species. Comparison of results between the 2002–2005 and 2010–2011 surveys showed that infestations generally increased along the Yampa River, while declining or remaining at similar levels along the upper and lower Green River (Perkins 2012, Perkins et al. 2015). Perkins et al. (2015) found that the upper Green (10.1 patches per ha) had the highest invasive plant patch density followed by the lower Green (4.4 per ha) and the Yampa (3.3 per ha). Invasive species were present in 23%, 19% and 4% of sample quadrats, and an average of 0.28, 0.22 and 0.04 invasive species detected per square meter

was recorded along the upper Green, lower Green and Yampa Rivers, respectively. Most species had significantly ($p \leq 0.02$) higher percent cover on the upper Green than either or both the lower Green and the Yampa River.

Table 4.9-14. Severity rank summary for priority IEP species mapped in riparian woody vegetation types at DINO (summarized from data provided in Washuta et al. 2018).

IEP species	2002–2005 mean (n)	Past severity rating	2010–2017 mean	Current severity rating	Change in severity rank	Trend
Russian knapweed	11.5 (129)	Moderate	8.8 (104)	Low	−3	↑
musk thistle	4.3 (14)	Very low	5.1 (33)	Very low	1	↔
Canada thistle	8.4 (208)	Low	6.7 (149)	Low	−2	↑
bull thistle	4.6 (77)	Very low	5.9 (62)	Low	1	↔
broadleaf pepperwort	10.5 (283)	Moderate	5.7 (190)	Low	−5	↑
yellow sweetclover	6.0 (103)	Low	7.5 (104)	Low	2	↓
tamarisk	9.1 (372)	Low	8.5 (307)	Low	−1	↔

Fire Regime

Frequency. It is difficult to determine historical or natural fire frequency in native riparian woody communities, but it is likely infrequent (Table 4.9-8). Nineteen fires occurred during the period of record (Table 4.9-9). Given that all of these fires were human caused, this likely represents an increase in the number of fires per year relative to historical conditions.

Seasonality. Riparian ignitions are generally in June–August, with one recorded in April (Figure 4.9-4). This is likely driven by fuel moisture, which likely drove historical fire regimes.

Extent. Median and mean fire sizes are small, with the largest fire size only 79 ha (Table 4.9-9). This made up the majority of the total burn area during the period of record. Because ignition frequency is likely increasing due to increased human density, the extent is also increasing relative to historical reference conditions. Area burned by year remains relatively low and did not change significantly within the period of record (Figure 4.9-5).

Severity. Information to evaluate vegetation-specific burn severity was not available.

Based on these results, the fire regime for riparian communities warrants moderate concern with an unknown trend. Wildfire effects on riparian vegetation in the West are poorly understood. The number of anthropogenic ignitions in riparian vegetation is a concern, but this is likely mitigated by small fire size and extent of the area burned over time.

Condition Summary – Vegetation

The condition and trend summary for the primary vegetation types is presented in Table 4.9-15.

Table 4.9-15. Condition and trend summary for selected vegetation types at DINO.

Indicator	Condition Status/Trend	Rationale
Species composition (% native species)		Mean proportion of species that are native was 94.5% +/−0.8%. Trend is unknown.
Mean C		The mean Coefficient of Conservatism value for these woodlands was 4.96 +/−0.8. Trend is unknown.
% IEP cover		Overall mean relative cover of invasive exotic plant species was 2.2%. Trend is unknown.
Cheatgrass dominance		Cheatgrass was recorded as a dominant species in 40% of observation point and AA plot locations. Trend is unknown.
Fire Regime (overall – see condition section for details)		Pinyon-juniper woodlands are declining in DINO, likely driven in part by increased fire frequency. Questions about the role of low severity fire remain, but more frequent and severe fire has led to conversion of pinyon-juniper stands to other vegetation types (notably, sagebrush and grasslands) and has contributed to invasion. The available literature is limited, reducing the confidence in this indicator.
Pinon-Juniper Woodlands overall		–
Species composition (% native species)		Mean proportion of species that are native was 93.6%. Trend is unknown.
Mean C		The mean Coefficient of Conservatism value for these woodlands was 4.74. Trend is unknown.
% IEP cover		Overall mean relative cover of invasive exotic plant species was 4.2%. Trend is unknown.
Cheatgrass dominance		Cheatgrass was recorded as a dominant species in 60% of observation point and AA plot locations. Trend is unknown.
Fire Regime (overall – see condition section for details)		Sagebrush is adapted to a very infrequent, high severity fire regime. The current fire return interval is more frequent than historical trends and area burned by human ignition increased significantly during the period of record. Increased fire frequencies and concurrent increases in cheatgrass abundance will likely contribute to conversions of sagebrush shrublands to grasslands.

Table 4.9-15 (continued). Condition and trend summary for selected vegetation types at DINO.

Indicator	Condition Status/Trend	Rationale
Sagebrush Shrublands overall		–
Species composition (% native species)		Mean proportion of species that are native was 89.7%. Trend is unknown.
Mean C		The mean Coefficient of Conservatism value for these woodlands was 4.42. Trend is unknown.
% IEP cover		Overall mean relative cover of invasive exotic plant species was 5.2%. Trend is unknown.
Cheatgrass dominance		Cheatgrass was recorded as a dominant species in 46% of observation point and AA plot locations. Trend is unknown.
Fire Regime (overall – see condition section for details)		Grassland fire sizes are within reference condition sizes and fire frequency. Trend is unknown.
Native Grasslands overall		–
Species composition (% native species)		Mean proportion of species that are native was 76.7%. Trend is unknown.
Mean C		The mean Coefficient of Conservatism value for these woodlands was 3.68. Trend is unknown.
% IEP cover		Overall mean relative cover of invasive exotic plant species was 11.3%. Trend is unknown.
Cheatgrass dominance		Cheatgrass was recorded as a dominant species in 75% of observation point and AA plot locations. Trend is unknown.
IEP species overall severity rank		Severity ranks for the most commonly mapped IEP species were in the 5–10 range. Trend appears to be unchanging or improving.

Table 4.9-15 (continued). Condition and trend summary for selected vegetation types at DINO.

Indicator	Condition Status/Trend	Rationale
Sagebrush Shrublands overall		–
Fire Regime (overall – see condition section for details)		Wildfire effects on riparian vegetation in the West are poorly understood. The number of anthropogenic ignitions in riparian vegetation is a concern, but this is likely mitigated by the small extent of the area burned. Trend is unknown.
Riparian Woody Vegetation overall		–
Vegetation overall		Condition in the four types examined overall warrants moderate concern. Indicator ratings vary by indicator and vegetation type. Pinyon-Juniper woodlands appear to be in the best condition of the types examined, although altered fire frequency threatens the type. Native riparian woody plant communities were in the poorest condition. Confidence in the assessment is medium.

4.9.5. Uncertainty and Data Gaps

Field sample data associated with the vegetation mapping inventory and mapping project provide a valuable baseline, but these data were collected between 2002 and 2005, averaging over 15 years old. Approximately 14,000 acres burned between 2005 and 2017, but there is little data to document the impacts and recovery associated with burned areas. While the weed mapping and IEP monitoring are more current, they focused primarily on riparian areas and other higher priority areas such as roadsides and other areas of disturbance and invasion. Empirical fire history data in pinon-juniper woodlands, sagebrush shrublands, and grasslands make comparisons to historical fire regimes difficult (Romme et al. 2009). Fire scars are rare in pinon-juniper woodlands, making estimations of historical fire frequencies difficult. Inferential strategies as used in Floyd et al. (2017) and Arendt and Baker (2013) are useful, but lack of historical spatial fire data makes it difficult to understand the roles of fires in these environments. Notably, low and mixed severity fire may not be captured by fire histories based on stand dynamics or General Land Office (GLO) surveys, and thus may be underestimated in the historical environment. Native riparian woody vegetation fire regimes are under-researched, making it difficult to draw conclusions.

4.9.6. Sources of Expertise

- Dave Hammond, Fire GIS Specialist, Intermountain Region Fire & Aviation Management, National Park Service. Mr. Hammond provided spatial wildland fire occurrence data.
- Dana Witwicki, Northern Colorado Plateau I&M Network, provided helpful reviews.

4.9.7. Literature Cited

Andreas, B.K., J.J. Mack, and J.S. McCormac. 2004. Floristic Quality Assessment Index (FQAI) for vascular plants and mosses for the State of Ohio. Ohio Environmental Protection Agency, Division of Surface Water, Wetland Ecology Group, Columbus, Ohio. Available at: https://www.epa.ohio.gov/portals/35/wetlands/Ohio_FQAI.pdf.

Arendt, P.A. 2014. Historical Fire Rotations in Sagebrush – Grasslands. In Landscape Condition Analysis, Dinosaur National Monument, Final Report (pp. 46–47).

Arendt, P.A., and W.L. Baker. 2013. Northern Colorado Plateau pinon-juniper woodland decline over the past century. Ecosphere 4(8):103.

Arno, S.F., and G.E. Gruell. 1986. Douglas-fir encroachment into mountain grasslands in southwestern Montana. Journal of Range Management 39(3), 272. Available at: https://doi.org/10.2307/3899067.

Baker, W.L. 2006. Fire and restoration of sagebrush ecosystems. Wildlife Society Bulletin 34(1):177–185. Available at: https://doi.org/10.2193/0091-7648(2006)34[177:FAROSE]2.0.CO;2.

Baker, W.L. 2009. Fire in shrublands and grasslands. Page 605 *in* Fire ecology in Rocky Mountain Landscapes, Volume 36. Retrieved from http://books.google.com/books?id=QHISkC37Ot4C&pgis=1

Baker, W.L. 2011. Pre-Euro-American and recent fire in sagebrush ecosystems. Pages 185–202 *in* S. Knick and J. W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitat. University of California Press, Oakland, California.

Baker, W.L., and P.A. Arendt. 2013. Modern fire rotations (1981–2010) in DINO and surrounding areas. In Landscape Condition Analysis, Dinosaur National Monument, Final Report (pp. 48–54).

Baker, W.L., and D.J. Shinneman. 2004. Fire and restoration of pinon-juniper woodlands in the western United States: a review. Forest Ecology and Management 189(1–3):1–21. Available at: https://doi.org/10.1016/j.foreco.2003.09.006.

Bock, C.E., and J.H. Bock. 2014. Effects of wildfire on riparian trees in southeastern Arizona. The Southwestern Naturalist 59(4):568–574. Available at: https://doi.org/10.1894/jem-08.1.

Britton, C.M., and R.G. Clark. 1985. Effects of fire on sagebrush and bittterbrush. Pages 22–26 *in* K. Sanders and J. Durham, editors. Rangeland fire effects: A symposium. Bureau of Land Management, Boise, Idaho.

Brown, J.K., and J.K. Smith. 2000. Wildland fire in ecosystems: effects of fire on flora. General Technical Report RMRS-GTR-42-volume 2. U.S. Forest Service, Ogden, Utah.

Bukowski, B.E., and W.L. Baker. 2013. Historical fire regimes, reconstructed from land-survey data, led to complexity and fluctuation in sagebrush landscapes. Ecological Applications 23(3):546–564. Available at: https://doi.org/10.1890/12-0844.1.

Coles, J.,D. Cogan, D. Salas, A. Wight, G. Wakefield, J. Von Loh, and A. Evenden. 2008. Vegetation classification and mapping project report, Dinosaur National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2008/112. National Park Service, Fort Collins, Colorado.

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow, and J. Teague. 2003. Ecological systems of the United States: A working classification of U.S. terrestrial systems. NatureServe, Arlington, VA. Available at: https://www.natureserve.org/biodiversity-science/publications/ecological-systems-united-states.

Dewey, S., K. Andersen, M. Ballard, E. Lamalfa, M. Pokorny, R. Richards, J. Simonsen, and S. Wood. 2003. An inventory of invasive weeds and rare plants conducted in portions of Dinosaur National Monument (2002–2003) – Final Report. Submitted to Dinosaur National Monument, Dinosaur, Colorado.

Dewey, S.A., and K.A. Andersen. 2005. An inventory of invasive non-native plants in Dinosaur National Monument (2004) – 2005 Addendum Report. Prepared for the National Park Service, Northern Colorado Plateau Network, by Utah State University; Plants, Soils, and Biometeorology Department. Weed Science Research Project Report No. SD0517A.

Dwire, K.A., and J.B. Kauffman. 2003. Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management 178:61–74. Available at: https://doi.org/10.1016/S0378-1127(03)00053-7.

Floyd, M.L., Hanna, D.D., and W.H. Romme. 2004. Historical and recent fire regimes in piñon-juniper woodlands on Mesa Verde, Colorado, USA. Forest Ecology and Management 198, 269–289.

Floyd, M.L., W. Romme, D.P. Hanna, and D.D. Hanna. 2017. Historical and modern fire regimes in piñon-juniper woodlands, Dinosaur National Monument, United States. Rangeland Ecology and Management 70(3):348–355. Available at: https://doi.org/10.1016/j.rama.2016.09.005.

Freeman, J., L. Kobziar, E.W. Rose, and W. Cropper. 2017. A critique of the historical-fire-regime concept in conservation. Conservation Biology 31(5):976–985. Available at: https://doi.org/10.1111/cobi.12942.

Howard, J.L. 1999. *Artemisia tridentata* subsp. *wyomingensis in* Fire Effects Information System website. U.S. Forest Service, Rocky Mountain Research Station. Available at: https://www.fs.fed.us/database/feis/plants/shrub/arttriw/all.html (accessed June 2018).

Innes, R.J. 2017. *Artemisia tridentata* subsp. *vaseyana*, mountain big sagebrush *in* Fire Effects Information System website. U.S. Forest Service, Rocky Mountain Research Station. Available at: https://www.fs.fed.us/database/feis/plants/shrub/arttriv/all.html.

Keeley, J.E. 2009. Fire intensity, fire severity and burn severity: A brief review and suggested usage. International Journal of Wildland Fire 18(1):116–126. Available at: https://doi.org/10.1071/WF07049.

Lemly, J., and L. Gilligan. 2015. Ecological integrity assessment for Colorado wetlands. Field Manual, Version 2.0. Colorado Natural Heritage Program, Fort Collins, Colorado.

Lutes, D.C., R. Keane, J. Caratti, C. Key, N. Benson, S. Sutherland, and L. Gangi. 2006. FIREMON introduction. General Technical Report RMRS-GTR Issue 164 RMRS-GTR, pp. IN-1-IN-9. U.S. Forest Service, Missoula, Montana. – Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-34247402968&partnerID=40&md5=a0d26968e84cd979d6b6e666bba970f5.

Miller, R.F., and R.J. Tausch. 2001. The role of fire in pinyon and juniper woodlands: a descriptive analysis. Proceedings of the invasive species workshop. Tall Timbers Research Station Miscellaneous Publication 11:15–30.

National Park Service (NPS). 2011. Dinosaur National Monument Fact Sheet: Our newest weed warriors. Available at: https://www.nps.gov/dino/learn/management/upload/Weed-Warriors-Brochure-2011.pdf.

NPS. 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

NPS and Sundance Consulting Inc. 2018. Wildland Fire Perimeters. Lakewood, Colorado, USA: NPS Fire Program Management Center. Retrieved from https://mapservices.nps.gov/arcgis/rest/services/WildlandFire/WildlandFire/MapServer.

O'Dell, T., S. Garman, A. Evenden, M. Beer, E. Nance, D. Perry, R. DenBleyker, et al. 2005. Northern Colorado Plateau Inventory and Monitoring Network vital signs monitoring plan. National Park Service, Inventory and Monitoring Network, Moab, Utah.

Perkins, D. 2012. Invasive exotic plant monitoring in Dinosaur National Monument: 2010–2011 field seasons. Natural Resource Technical Report NPS/NCPN/NRTR—2012/569. National Park Service, Fort Collins, Colorado.

Perkins, D., M. Scott, and T. Naumann. 2015. Abundance of invasive, non-native riparian herbs in relation to river regulation. River Research and Applications 32:1279–1288.

Romme, W.H., C. Allen, J. Bailey, W. Baker, B. Bestelmeyer, P. Brown, K. Eisenhart, M. Floyd, D. Huffman, B. Jacobs, R. Miller, E. Muldavin, T. Swetnam, R. Tausch, and P.J. Weisberg. 2009.

Historical and modern disturbance regimes, stand structures, and landscape dynamics in piñon-juniper vegetation of the Western U.S. Rangeland Ecology and Management 62(3):203–222.

Sapsis, D.B., and J.B. Kauffman. 1991. Fuel consumption and fire behavior associated with prescribed fires in sagebrush ecosystems. Northwest Science 65:173–179.

Sherrill, K., and W. Romme. 2012. Spatial variation in postfire cheatgrass: Dinosaur National Monument, USA. Fire Ecology 8(2):38–56.

Shinneman, D.J., and W.L. Baker. 2009. Historical fire and multi-decadal drought as context for piñon-juniper woodland restoration in western Colorado. Ecological Applications 19:1231–1245.

Slaton, M. 2016. Sagebrush natural range of variation. Internal U.S. Forest Service Report. Vallejo, California. Retrieved from https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5434335.pdf.

Stambaugh, M., L.D. Hammer, and R. Godfrey. 2015. Performance of burn-severity metrics and classification in oak woodlands and grasslands. Remote Sensing 7(8):10501–10522.

Taylor, J.L. 2000. *Populus fremontii in* Fire Effects Information System website. U.S. Forest Service, Rocky Mountain Research Station. Available at: https://www.fs.fed.us/database/feis/plants/tree/popfre/all.html (accessed 03 December 2018).

van Wagtendonk, J.W. 1991. The evolution of the National Park Service fire policy. Fire Management Notes 52(4):10–15.

Vankat, J. 2013. Subalpine-montane grassland. Pages 334–370 *in* J. L. Vankat, editor. Vegetation dynamics on the mountains and plateaus of the American Southwest.Springer, Dordrecht, The Netherlands.

Washuta, A,D. Perkins, and L. Gommermann. 2018. Invasive plants on the Yampa River, Echo Park, and Mitten Park in 2017. National Park Service Unpublished Report, Dinosaur, Colorado.

Welch, B.L., and C. Criddle. 2003. Countering misinformation concerning big sagebrush. Research Paper RMRS-RP-40. U.S. Forest Service, Rocky Mountain Research Station, Ogden, Utah.

Whitlock, C., P.E. Higuera, D. McWethy, and C. Briles. 2010. Paleoecological perspectives on fire ecology: Revisiting the fire-regime concept. The Open Ecology Journal 3(2):6–23. Available at: https://doi.org/10.2174/1874213001003020006.

Wilhelm, G., and D. Ladd. 1988. Natural area assessment in the Chicago region. Pages 361–375 *in* R. E. McCabe, editor. Transactions of the 53rd North American Wildlife and Natural Resources Conference. Wildlife Management Institute, Washington, D.C.

Wilhelm, G., and L. Masters. 1996. Floristic Quality Assessment in the Chicago Region. The Morton Arboretum, Lisle, Illinois.

Witwicki, D. 2013. Integrated upland monitoring in Dinosaur National Monument: annual report 2011 (non-sensitive version). Natural Resource Technical Report NPS/NCPN/ NRTR—2013/712.N. National Park Service, Fort Collins, Colorado.

Zouhar, K. 2003. *Tamarix* spp. *in* Fire Effects Information System website. U.S. Forest Service, Rocky Mountain Research Station. Available at: http://www.fs.fed.us/database/feis/ (accessed 03 December 2018).

Zouhar, K. 2005. *Elaeagnus angustifolia in* Fire Effects Information System website. U.S. Forest Service, Rocky Mountain Research Station. Available at: https://www.fs.fed.us/database/feis/plants/tree/elaang/all.html (accessed 03 December 2018).

4.10. Plant Species of Special Concern

4.10.1. Background and Importance

Dinosaur National Monument (DINO) contains one of the largest concentrations of rare plants in the state of Colorado. This 211,000-acre NPS unit sits on the northeastern edge of both the Uinta Basin and (on a larger scale) the Colorado Plateau. The Uinta Basin is renowned for a high number of substrate-specific endemic plant taxa. Thirty-six plant taxa of special concern were known to occur in DINO in the late 1980s (Naumann 1990). Of those, eight are currently ranked G1, G2 or G2/G3, one of which is federally listed – *Spiranthes diluvialis* (NatureServe 2018). NatureServe status ranks are determined for the element's degree of imperilment over its entire range (its Global-rank or G-rank) on a five-point scale (e.g., 1 = extremely rare/imperiled, 5 = abundant/secure). The primary criterion for ranking elements is the number of occurrences. Also of importance are the size of the geographic range, the number of individuals, the trends in both population and distribution, identifiable threats and the number of protected occurrences. We evaluate the condition of these eight rare taxa (Table 4.10-1).

Table 4.10-1. NatureServe Global Conservation Status Ranks for rare plants found at DINO (as of June 2018)(NatureServe 2018).

Latin Name	Common Name	NatureServe Rounded Rank*
Erigeron wilkenii	Wilken's Fleabane	G1
Hymenoxys lapidicola	Rock Hymenoxys	G1
Oenothera acutissima	Narrowleaf Evening-primrose	G2
Oxytropis besseyi var. *obnapiformis*	Bessey's Locoweed	T2
Penstemon scariosus var. *cyanomontanus*	Blue Mountain Beardtongue	T2
Platanthera zothecina	Alcove Bog Orchid	G2
Spiranthes diluvialis	Ute Ladies'-tresses	G2
Zigadenus vaginatus	Sheathed Deathcamas	G2

* G1 – Critically Imperiled—At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors. G2 – Imperiled—At high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors. T2 – Infraspecific Taxon (trinomial)—The status of infraspecific taxa (subspecies or varieties) are indicated by a "T-rank" following the species' global or nation (N) rank, in this case equivalent status to G2 or N2.

The majority of rare plant studies in the monument were completed from 1987 to 1989 (Naumann 1990), and in 2011–2012 by Lyon et al. (2011, 2012) with the Colorado Natural Heritage Program. Surveys for *Spiranthes diluvialis* were conducted by Williams (2010, 2011, 2012, 2015). In general, survey results indicate that while native vegetation and systems are generally intact at DINO, the resources have been impacted by both historic and recent/ongoing factors. Release of water from Flaming Gorge reservoir has modified habitat for *Spiranthes diluvialis* by scouring vegetated soil from the river edges and depositing a thick layer of sand in previously vegetated areas, and inundating orchid habitat for prolonged periods during the growing season. However, regulated base flows on the Green River may help sustain some *Spiranthes* population (pers. comm., Emily Spencer,

February 2019). Habitat for several populations of rare taxa has been altered by past and present livestock-related grazing impacts (Lyon et al. 2012). Impacts include altered plant community composition, increase of exotic species such as cheatgrass (*Bromus tectorum*), soil erosion, and altered hydrology. Current grazing practices in some areas of the monument have also resulted in excessive browsing and trampling of several populations of rare plant taxa as well as upland and riparian plant communities (Lyon et al. 2012).

4.10.2. Data and Methods

Data and reports associated with Naumann (1990) and Lyon et al. (2011, 2012) are the primary data sources represented in the Natural Heritage Database for the taxa of interest. Some additional rare plant mapping was done by Utah State University in the early 2000s, but the monument had no associated details, data or contacts (pers. comm., Emily Spencer, February 2019). Additional data are from Williams' (2011) *Spiranthes diluvialis* surveys and the NatureServe Explorer database. The Coles et al. (2008) vegetation classification and mapping effort did not include observations of the rare plant species.

4.10.3. Reference Conditions

The rare plant taxa currently known from DINO were likely present in suitable habitat, but locally rare even prior to European settlement, primarily due to restricted habitat requirements. For example, *Platanthera zothecina* and *Zigadenus vaginatus* were likely present in specific microclimates favoring them (e.g., hanging gardens and seeps). Others, such as *Erigeron wilkenii* and *Hymenoxys lapidicola,* are local endemics, and would have been rare regionally with a very limited distribution. Current distributions of DINO rare plants are shown in Figure 4.10-1.

Historical inventory and monitoring data provide a baseline for comparison with more recent survey data, where available. For each taxon, condition would be considered good if the abundance/vigor metrics from historical surveys are maintained or increasing, or the condition of known occurrences as evaluated by NatureServe methodology is highly ranked. Table 4.10-2 lists the NatureServe element occurrence ranks and their definitions. For a given taxon, a preponderance of occurrence rankings of A or B would indicate the taxon is in good condition, a preponderance of "C" rankings would indicate the taxon warrants moderate concern, and a preponderance of "D" rankings would indicate the taxon warrants significant concern. The number of occurrences and population size(s) may also influence the condition rating.

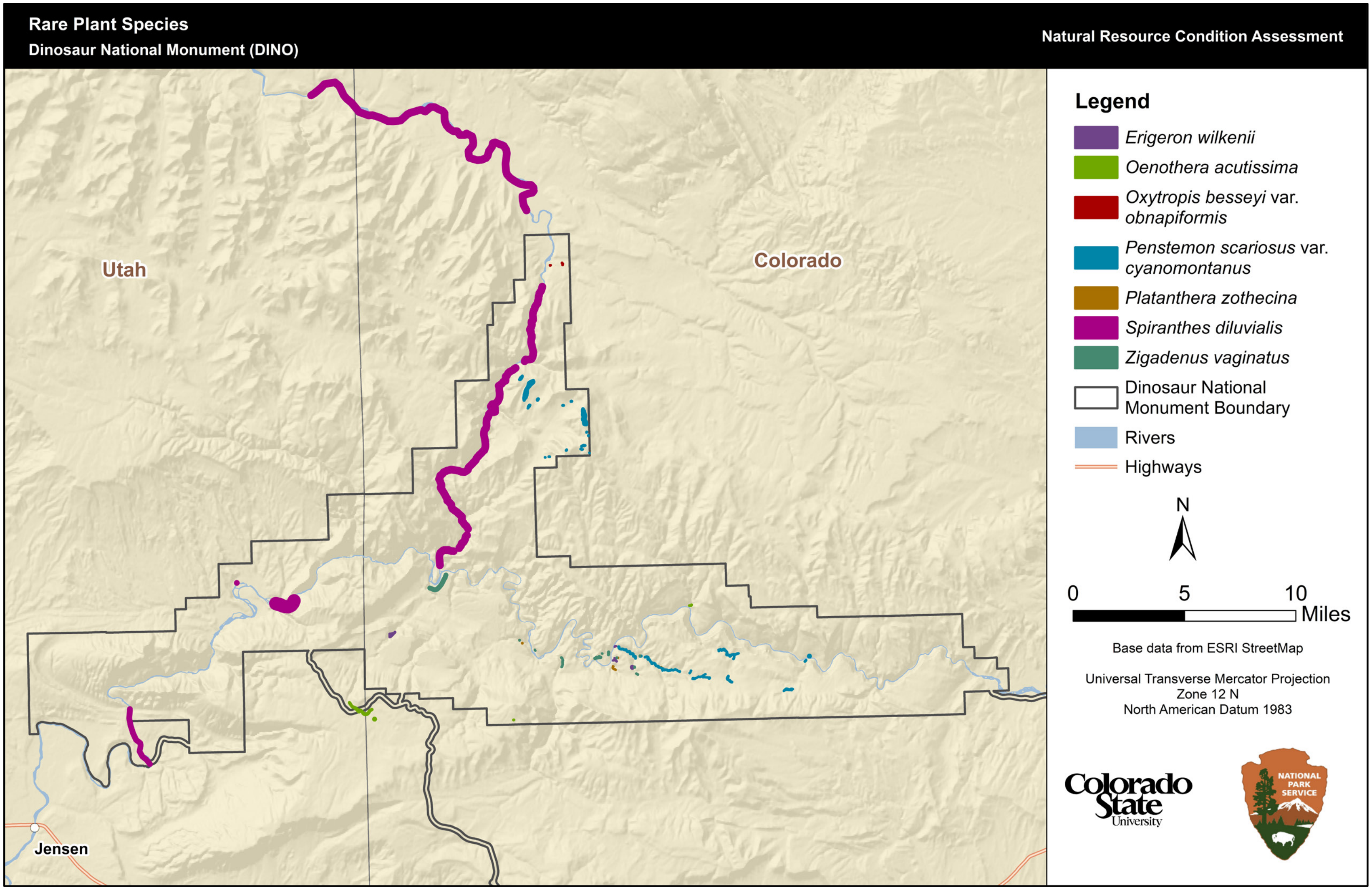


Figure 4.10-1. Rare plant locations in and around Dinosaur National Monument. *Hymenoxis lapidicola* locations are not shown (data provided by Dinosaur National Monument).

Table 4.10-2. NatureServe Element Occurrence Rank (EOR) definitions (NatureServe 2018).

EOR Rank	Definition
A	Excellent viability.
B	Good viability.
C	Fair viability.
D	Poor viability.
H	Historic: known from historical record, but not verified for an extended period of time.
X	Extirpated (extinct within the state).
E	Extant: the occurrence does exist but not enough information is available to rank.
F	Failed to find: the occurrence could not be relocated.

Trends may be evaluated by comparing the number of occurrences from historical inventory data to current values. An increase in the number of occurrences would indicate an improving trend for the taxon. A moderate decline of up to 25% in the number of occurrences of a species would indicate the species is stable to declining. A decrease of more than 25% in the number of occurrences would indicate the species may be in decline.

4.10.4. Condition and Trend

Erigeron wilkenii (Wilken's fleabane)

Description

Erigeron wilkenii is a tap-rooted perennial with slender branches and erect stems reaching 10–20 cm tall. The stems are eglandular and sparsely covered with hairs. The narrow gray-green leaves are mostly basal with entire margins, sparsely eglandular and sparsely covered with hairs. Ray flowers are white-light pink with sparse glandular hairs on the phyllaries. The species is very close to *Erigeron nematophyllus*, but tends to have wider leaves (Spackman et al. 1997).

Erigeron wilkenii (Wilken's fleabane). Photo by Delia Malone, Colorado State University.

Distribution
The species is endemic to DINO and found near Pool and Johnson Canyons (CNHP 2018).

Ecology
Erigeron wilkenii occurs on soils that are derived from sandstone of the Weber Formation and are composed of sandy alluvium deposited by the intermittent Pool Creek and colluvium from cliffs above. Sites are often partially shaded by short statured trees of *Pinus edulis* (pinyon) and *Juniperus osteosperma* (Utah juniper) (O'Kane 1990).

Status
Erigeron wilkenii is classified by NatureServe as globally critically imperiled (G1). There are currently only two verified extant sites in the world: Pool Creek and a site north of Bull Canyon, which are both within DINO. A third site was documented in 1987 in mid Blind Canyon, but has not been relocated in recent surveys (Lyon et al. 2011). Additional specimen collections have been made from other locations both within and outside DINO, however, examinations of these specimens housed at the University of Colorado herbarium were inconclusive, with some apparent confusion between *E. wilkenii* and *E. nematophyllus* (Lyon et al. 2011). Therefore, those specimens are not considered here.

Threats
Lyon et al. (2012) reported abundant cheatgrass (*Bromus tectorum*) downstream of the Pool Creek site in flat areas, but not in the *Erigeron* site at Pool Creek. The predominant land use at both extant sites is recreation.

Condition and Trend
The current condition of this species in DINO is excellent with both occurrences ranked as "A" following NatureServe methodology (CNHP 2018, NatureServe 2018). Trends within the two extant occurrences appear stable based on the number of individuals observed from 1995 to 2012, which remained unchanged. However, overall there is a 33% decline in the number of occurrences from 1987 levels (CNHP 2018), indicating an overall downward trend for this species.

Hymenoxys lapidicola (Stone rubberweed)

Description
Hymenoxys lapidicola is a densely matted cushion plant with small solitary flower heads and basal leaves. The ray and disk flowers are yellow; the leaves are notable with glandular dots on the surface (Utah Native Plant Society 2016).

Hymenoxys lapidicola (Stone rubberweed). Photo with permission from https://nargs.org/photo/hymenoxys-lapidicola.

Distribution

The species is endemic to Uintah County, Utah. It is known from eight locations with a total of approximately 3200 observed plants (NatureServe 2018). In DINO, it is known from a single site at Hog Canyon (Naumann 1990).

Ecology

Hymenoxys lapidicola grows in sandy crevices and pockets of soil associated with Weber Sandstone near Blue and Split Mountains, within pinyon-juniper and ponderosa pine-manzanita communities (NatureServe 2018, Naumann 1990).

Status

Hymenoxys lapidicola is classified by NatureServe as globally critically imperiled (G1). There are eight known occurrences, one of which is found within DINO (NatureServe 2018, Naumann 1990). This taxon was not known from DINO prior to 1989, and there is no additional information on the species in DINO since that time.

Threats

The species is not very vulnerable to human-caused threats because of its relatively inaccessible habitat (NatureServe 2018). Hog Canyon is within a grazing allotment but is largely fenced off from livestock (pers. comm., Emily Spencer, February 2019).

Condition and Trend

The current condition of this species in DINO is unknown.

Oenothera acutissima (Narrowleaf evening-primrose)

Description

Oenothera acutissima is a perennial forb with a basal rosette and a long branching, woody taproot. The linear leaves are bright green to grey-green, moderately thick and stiff, and irregularly dentate.

The petals are reddish-orange before blooming, turning yellow with flowering (Denver Botanic Gardens 2008).

Oenothera acutissima (Narrowleaf evening-primrose). Photo by Delia Malone, Colorado State University.

Distribution

The species is restricted to Moffat County, Colorado, and Daggett, Uintah, and Duchesne counties, Utah. (NatureServe 2018). In DINO, it is currently known from two locations: Round Top Mountain and Stuntz Reservoir. The Stuntz Reservoir occurrence is bisected by a park service road west of the Colorado-Utah border, and a portion of the occurrence is within DINO. A third site, at Five Springs Draw, is now extirpated (pers. comm., Tamara Naumann, 2012).

Ecology

Oenothera acutissima grows along arroyos, in depressions or shallow basins, in meadows or gravelly open areas, and in rock crevices. It is restricted to sandy, gravelly soils, often growing among rocks, and appears to be associated with a red quartzite of the Uinta Mountain Group. Seasonal (spring and early summer) or ephemeral water seems to be an important habitat component. This species tends to occupy locations that receive occasional flushing or spring runoff, such as the shallow channels at the bottom of seasonal or intermittent drainages. In many cases, the shallow drainage channels that support this species are fed by springs. A high percent bare ground and rock may also be important habitat elements. As drainage bottoms become more stable and achieve a higher percent ground cover, this species may be displaced by graminoids. These smaller-scale habitats are found within middle elevation coniferous forests typified by ponderosa and lodgepole pine, rocky mountain juniper-sagebrush communities, and sagebrush scrub (CNHP 2018).

Status

Oenothera acutissima is classified by NatureServe as globally imperiled (G2). There are 27 known occurrences, three of which are found within DINO (NatureServe 2018). This taxon was first documented in DINO in 1987 at two locations—Five Springs Draw and Round Top Mountain. The Five Springs Draw site is now extirpated (pers. comm., Tamara Naumann, 2012). The Round Top site appears unchanging to increasing with 200 individuals observed in 1987 and 285 in 2012. The

third site near Stuntz Reservoir was expanded in 1994 to include a portion of DINO. This site supported 100 individuals in 1994, and the current abundance is unknown.

Threats

Livestock trampling is the most significant threat to this species; most to all DINO sites are affected. Many of the springs that this species inhabits are used to supply water for livestock, exposing plants to trampling. In addition, a few sites are found adjacent to infrastructure such as stock ponds, corrals, and fence lines that concentrate cattle and exacerbate impacts (NatureServe 2018). Within the monument heavy browsing has been observed at the Stuntz Reservoir site, and the Round Top Mountain site is threatened by invasion of exotic species such as *Hordeum brachyantherum* and *Taraxacum officinale* (CNHP 2018).

Condition and Trend

The current condition of this species in DINO is good with both occurrences ranked as "B" following NatureServe methodology (CNHP 2018, NatureServe 2018). Trends appear stable based on the number of individuals observed in 1995 versus 2012, which remained unchanged. However, the number of extant occurrences within DINO has declined from three sites to two sites (33%) during that same period (CNHP 2018), which may indicate a downward trend.

Oxytropis besseyi var. *obnapiformis* (Bessey's locoweed)

Description

Oxytropis besseyi var. *obnapiformis* is a densely hairy perennial forb with a stout taproot and stems up to 20 cm tall. Leaves are all basal, usually equaling or surpassing the flowering stems, and have 9–15 leaflets. Flower stems are 2–19 cm tall, each with 3–20 pink to purple pea flowers. Pods are papery, hairy, and strongly inflated (Barneby 1989).

Oxytropis besseyi var. *obnapiformis* (Bessey's locoweed). Photo by Delia Malone, Colorado State University.

Distribution

Oxytropis besseyi var. *obnapiformis* is a regional endemic of northeastern Utah, southwestern Wyoming, and northwestern Colorado (NatureServe 2018). In DINO, it is currently known from two small sites near Conway Draw and the Lodore Ranger Station (CNHP 2018).

Ecology

Oxytropis besseyi var. *obnapiformis* grows in desert shrublands and pinyon-juniper woodlands often on barrens in either fine-textured or sandy substrates (Welsh et al. 2003).

Status

Oxytropis besseyi var. *obnapiformis* is classified by NatureServe as globally imperiled (T2). There are nearly 30 known occurrences, with 17 in Colorado, and 5 each in Wyoming and Utah. One occurrence comprised of several small sites is found within DINO (CNHP 2018, NatureServe 2018). This taxon was first documented in DINO in 1987 at two small sites near Conway Draw and the Lodore Ranger Station that comprise one element occurrence. The occurrence appears unchanging to improving with 50 individuals observed in 1987 and 200 in 2012.

Threats

In Colorado, occurrences are threatened by oil and gas development, primarily. Other threats include excessive grazing and recreation. The DINO occurrence may be subject to recreation pressure due to its proximity to campgrounds (CNHP 2018). In Wyoming, occurrences may be threatened by road construction due to mineral mining, and recreational off-road vehicles (Fertig 2001). As of 2014, no information was found on threats to this taxon in Utah.

Condition and Trend

The current condition of this species in DINO is good with an occurrence rank of "B" following NatureServe methodology (CNHP 2018, NatureServe 2108). Trends appear stable based on the unchanged number of extant occurrences within DINO, and the number of individuals observed in 1987 versus 2012, which increased slightly (CNHP 2018).

Penstemon scariosus var. *cyanomontanus* (Blue mountain beardtongue)

Description

Penstemon scariosus var. *cyanomontanus* is a perennial forb with several stems decumbent to ascending to 1.5–5 dm tall. Leaves are narrow to spatulate, basal leaves are persistent. Flower stems are 2–19 cm tall, each with 3–20 pink, blue, or purple flowers 24–30 mm long with glandular hairs (Welsh et al. 2003). Glandular hairs on the corolla distinguish the species from its close relatives (Spackman et al. 1997).

Penstemon scariosus var. *cyanomontanus* (Blue mountain beardtongue). Photo by Delia Malone, Colorado State University.

Distribution

Penstemon scariosus var. *cyanomontanus* is a regional endemic of northeastern Utah, and northwestern Colorado (NatureServe 2018). In DINO it is abundant in two major areas of the monument: Johnson Canyon and along the Yampa Bench Road near the head of the Yampa River Canyon; and along Douglas Mountain Boulevard for several miles on BLM land and at the Gates of Lodore monument entrance.

Ecology

Penstemon scariosus var. *cyanomontanus* grows in crevices of sandy soil derived from the Morgan and Weber Sandstone Formations, and on the Uinta Mountain Group Sandstones. It is also found on the Lodore Formation at higher elevations (Naumann 1990). It grows in sagebrush-grassland communities in dry streambeds, on slickrock and crevices of rock outcrops. It is occasionally found in pinyon-juniper woodlands (Naumann 1990, Welsh et al. 2003).

Status

Penstemon scariosus var. *cyanomontanus* is classified by NatureServe as globally imperiled (T2). There are 6 occurrences in Colorado and 5–10 sites in Utah (NatureServe 2018). This taxon was first documented in DINO in 1956 at Doug Chews Cabin. In 1987–1989 an additional 10 sites were found, represented by five CNHP element occurrences: Bear Draw, Douglas Mountain/ Zenobia Peak, Douglas Mountain Boulevard /Chicken Springs, Johnson and Dry Women Canyons, and West Douglas Mountain. In 2011, an additional site was found along the Yampa Bench Road by Lyon et al. (2011). The occurrences at Douglas Mountain/ Zenobia Peak, Douglas Mountain Boulevard /Chicken Springs, and Johnson and Dry Women Canyons appear unchanging to improving based on the number of individuals observed from 1987 to 2011. The current condition of the occurrences at Bear Draw and West Douglas Mountain are unknown, and are now considered historical with last

reported observations from 1987. The newly discovered Yampa Bench Road location was reported to be in good condition in 2011 with 300 individuals observed.

Threats

The primary rangewide threat at this time is considered to be incompatible grazing (Rondeau et al. 2011). In DINO, plants at the roadside near the monument entrance at Zenobia Peak may be threatened by motor vehicles or road maintenance. This road, which provides access to the fire tower on Zenobia Peak, may be closed to the public in the future (Lyon et al. 2011).

Condition and Trend

The current overall condition of this species in DINO is unknown, as over 33% of the locations have no current information available. For the remaining population within DINO the current condition is also unclear as only portions of the sites documented in 1987 were revisited in 2011. The condition of the areas that were revisited was good to excellent (A or B ranked). Based on the number of occurrences, the trend appears to be unchanging to improving overall with an increase of one (17%) in the number of total occurrences. While this may simply reflect the discovery of an additional site and not a true increase in the extent or abundance of the species, it is considered a more robust condition. However, this does not consider the lack of information for two (33%) of the occurrences (CNHP 2018).

Platanthera zothecina (Alcove bog orchid)

Description

Platanthera zothecina is a perennial forb with glabrous oblanceolate to elliptic basal and cauline leaves that clasp the stem. The flowering stalk is erect with a terminal inflorescence of yellowish green to green flowers (Ackerfield 2015). It is distinguished from other species by the spur length, which is 1.5–2 times as long as the lip (Spackman et al. 1997).

Platanthera zothecina (Alcove bog orchid). Photo by Jill Handwerk, Colorado State University.

Distribution

Platanthera zothecina occurs on the Colorado Plateau along the drainages of the Colorado and Green rivers from Dinosaur National Monument to Glen Canyon Natural Resource Area and onto the Navajo Indian Reservation in Colorado, Arizona and Utah (NatureServe 2018).

Ecology

Platanthera zothecina is endemic to seeps, hanging gardens, and moist stream banks in canyons (Naumann 1990, Spackman et al. 1997). In DINO, it is frequently associated with *Epipactis gigantea, Zigadenus vaginatus*, and *Aquilegia micrantha* (Naumann 1990).

Status

Platanthera zothecina is classified by NatureServe as globally imperiled (G2). There are reported to be approximately 60 occurrences rangewide, however, it is unclear if sites in the Navajo Nation are included with counts from Colorado, Arizona and Utah (NatureServe 2018). It is relatively common in hanging gardens throughout the Colorado Plateau (pers. comm., Rebecca Weissinger, Northern Colorado Plateau I&M Network, 2016).

In DINO, it is currently known from five occurrences within the cliffs and seeps above the Yampa River (CNHP 2018, NatureServe 2018). This taxon was first documented in DINO in 1948 at Barn Cave in Red Rock Canyon, and in 1987–88 at Harding Hole and Bull Canyon. The 2011–2012 surveys of Lyon et al. documented two additional occurrences at Johnson Canyon and Laddie Park, with 175 and 11 individuals, respectively. The three previously known sites at Barn Cave, Harding Hole and Bull Canyon were also revisited by Lyon et al. in 2011–2012, and the number of individuals observed were 200+, six (partial survey), and 500, respectively.

Threats

The primary threat at this time is considered hydrologic alteration (Rondeau et al. 2011). The plants occur in hanging garden communities that are dependent on seeps and springs on the cliff faces. Diversion of mesa-top springs and streams for other uses disrupts these ecosystem features (May et al. 1995). Populations in DINO may also be subject to trampling by cattle and competition from non-native species such as cheatgrass (*Bromus tectorum*) and native clematis (*Clematis ligusticifolia*) (CNHP 2018).

Condition and Trend

The current condition of this species in DINO is good based on the ranks of the occurrences (one A, three B, one C) in which 80% are ranked excellent to good. One site is ranked fair due to the low number of individuals. Trends appear unchanging to improving with a 40% increase in the number of known occurrences since 1987–88, and an increase in the number of individuals at two of the three occurrences (CNHP 2018).

Spiranthes diluvialis (Ute ladies'-tresses)

Description

Spiranthes diluvialis is a perennial orchid usually with one stem that is 20–50 cm tall and arising from tuberously thickened roots. Its narrow leaves are 1 cm wide, up to 28 cm long, and persist during flowering. The inflorescence consists of few to many white or ivory flowers clustered in a spike of 3-rank spirals at the top of the stem. The sepals and petals are ascending or perpendicular to the stem. The lateral sepals often spread abruptly from the base of the flower, and sepals are free or only slightly connate at the base. The lip petal is somewhat constricted at the median (NatureServe 2018).

Spiranthes diluvialis (Ute ladies'-tresses). Photo by Bernadette Kuhn, Colorado State University.

Distribution

Spiranthes diluvialis is known from northern and south-central Utah, central to north-central and northwestern Colorado, east-central and southeastern Wyoming, eastern Idaho, southwestern Montana, eastern Nevada, western Nebraska, central to north-central Washington, and British Columbia (pers. comm., Jennifer Penny, 2008; Fertig et al. 2005; NatureServe 2018). In DINO, it is currently known from two occurrences, primarily within the riparian area along the Green River above the confluence with the Yampa River, and also found further downstream as far as Split Mountain Canyon (CNHP 2018, Williams 2011). A small historic population of over 100 plants was found in the Cub Creek/Hog Canyon area in the 1990s. Very few are found today, likely due to livestock disturbance (pers. comm., Emily Spencer, February 2019) or a lack of needed disturbances (pers. comm., Emily Spencer, July 2019).

Ecology

Spiranthes diluvialis is adapted to early to mid-seral, moist to wet conditions, where competition for light, space, water, and other resources is normally limited by periodic or recent disturbance events. Primary occupied habitat types include: (1) alluvial banks, point bars, floodplains, or oxbows associated with perennial streams, with a high water table and short, perennial graminoid- and forb-dominated vegetation maintained by grazing, periodic flooding, or mowing; (2) river floodplain habitats that experience regular spring flooding and/or frequent large scale floods but maintain relatively stable, moist to wet soil in summer, within moist meadow, riparian woodland, or riparian shrubland communities; (3) shores of lakes and reservoirs, in mesic meadow-type vegetation maintained by lake level fluctuations or seasonal flooding of gravel bars; (4) groundwater-fed springs, or sub irrigated meadows where edaphic characteristics (e.g. high water table and calcic

soil), fire, and/or grazing are sufficient to prevent invasion of later seral vegetation; and (5) human-influenced habitats, including perennial stream, river, lakeshore, and spring sites directly associated with human-developed dams, levees, reservoirs, irrigation ditches, reclaimed gravel quarries, roadside barrow pits, and irrigated meadows.

Most documented populations occur in sites in which natural hydrology has been influenced by dams, reservoirs, or supplemental irrigation, and many populations occur within agricultural or urban settings (NatureServe 2018, adapted from Fertig et al. 2005). In DINO, it is typically associated with fluvial geomorphic surfaces along the Green River that have been created or modified by the operation of the Flaming Gorge dam (Williams 2011).

Status

Spiranthes diluvialis is classified by NatureServe as globally imperiled (G2G3). It is reported from approximately 60 sporadic occurrences in lower-elevation wet, herbaceous-dominated habitats in interior western North America. The species was federally-listed as threatened in 1992 when it was only known from Colorado, Utah, and Nevada. It has since also been found in Wyoming, Montana, Nebraska, Idaho, Washington, and British Columbia. Utah and Colorado have the most plants and occurrences. Most occurrences are small; 81% have fewer than 1000 plants and 95% occupy less than 50 acres (NatureServe 2018). At the time of listing, small populations were known to exist along the Green River at Island Park and downstream of Split Mountain Canyon. In 1995, the populations were found in the Canyon of Lodore (Williams 2011). There are currently four occurrences within DINO; one in Colorado (Canyon of Lodore) and the remainder in Utah (Whirlpool Canyon, Island and Rainbow Parks, and below Split Mountain Canyon) (CNHP 2018, Williams 2015). In 2015 surveys, Williams found 4381 individuals in DINO, a substantial increase from the 453 plants found in 2011 and 812 individuals found in 2012, and only moderately lower than the 2010 count of 6253 individuals. The steep decline in 2011 is attributed to the exceptionally long period of high water throughout the spring and early summer of 2011, which delayed the emergence of *Spiranthes* and modified the habitat in significant ways (Williams 2011). River flows in 2012 were similar to 2010, with no prolonged period of high water, but evidence of the 2011 flooding was still visible (both scouring of soils and deposition of sand) during the 2012 surveys and may be contributing to the lower counts observed in 2012 (Williams 2012). Many of these high-water impacts were still evident in 2015, but *Spiranthes* appeared to be recovering, with counts at 70% of 2010 levels (Williams 2015).

Threats

Rangewide threats include: competition from invasive species, vegetation succession, hydrologic alterations, stream/riparian restoration, flooding, road and other construction, recreation-associated impacts, natural herbivory (e.g., by voles), urbanization, loss of pollinators (reduction in the quantity and suitability of available pollinators, particularly certain bees), drought, and improperly timed grazing by livestock or haying/mowing (Fertig et al. 2005). In DINO the primary threats are hydrologic alterations that result in prolonged high-water events on the Green River (Williams 2011). Populations in DINO may also be subject to competition from non-native species such as tamarisk (*Tamarix ramosissima*) (Williams 2011).

Condition and Trend

The current condition of this species in DINO is moderate to good based on the ranks of the occurrences (one A, one B, and two C-D); 50% of the occurrences are in good to excellent condition. Trends appear stable to improving with a 50% increase in the number of known occurrences since 1992 (CNHP 2018). However, Williams (2015) indicates that although a short-term decline occurred in 2011–2012, trends should not be inferred from these data. Counts based only on flowering individuals tend to exhibit large annual fluctuations (Fertig et al. 2005). Without regular monitoring, it is impossible to know how extended periods of inundation resulting from high water flows, such as those in 2011, will affect the long-term viability of the *Spiranthes* population in DINO (Williams 2011). However, based on 2015 inventory results, exceptional high-water events followed by several years of more moderated dam operations may be less damaging than thought in 2011, and in some instances may play a role in habitat maintenance (Williams 2015).

Zigadenus vaginatus (Alcove death camas)

Description

Zigadenus vaginatus is a perennial forb 3–10+ dm tall. Flowers are in panicles or less commonly in racemes. Tepals are 6–7 mm long and white. Leaves are 20–70 cm long and 6–18 mm wide (Spackman et al. 1997).

Zigadenus vaginatus (Alcove death camas). Photo by Jill Handwerk, Colorado State University.

Distribution

Zigadenus vaginatus is a regional endemic known from northeast Arizona (Navajo Nation), eastern Utah and western Colorado (NatureServe 2018). In DINO, it is currently known from eight occurrences, primarily within the cliffs and seeps above the Yampa River. (CNHP 2018).

Ecology

Zigadenus vaginatus is endemic to seeps, hanging gardens, and moist stream banks in canyons (Naumann 1990, Spackman et al. 1997). In DINO, it is either at the base of cliffs or in alcoves in canyons, usually growing with *Aquilegia micrantha,* and is frequently associated with *Platanthera zothecina (*Lyon et al. 2011).

Status

Zigadenus vaginatus is classified by NatureServe as globally imperiled (G2). There are over 30 known occurrences, with at least seven in Colorado, at least six in Arizona and at least 15 in Utah. There are currently eight occurrences within DINO. Of these, one is in Utah and the others are in Colorado (CNHP 2018, NatureServe 2018). The 2011–12 surveys of Lyon et al. increased the number of known locations by four. This taxon was first documented in DINO in 1961 at Echo Park, then in 1987–88 at Harding Hole/Signature Cave, Blind and Johnson Canyons and the Labyrinths. In 2011–2012, Red Rock Canyon, Bull Canyon, Mantle Ranch Road and Laddie Park occurrences were documented. These sites support 60, 150, 30 and 4 individuals, respectively.

Threats

The primary threat at this time is hydrologic alteration (Rondeau et al. 2011). Diversion and use of water from mesa top springs and streams to other uses would disrupt the hydrologic system on which these plants appear to depend. Populations in DINO may also be subject to trampling by cattle and competition from non-native species such as cheatgrass (*Bromus tectorum*) and native clematis (*Clematis ligusticifolia*) (CNHP 2018).

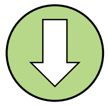
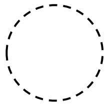
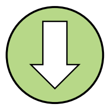
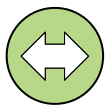
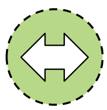
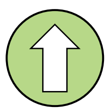
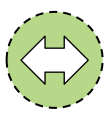
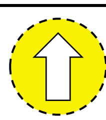
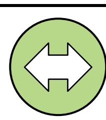
Condition and Trend

The current condition of this species in DINO is fair based on the ranks of the occurrences (1 A, 2 B, 3 C, 1 D, and 1 H). Approximately 63% of the occurrences are in fair to poor condition. Trends appear stable to improving with a 50% increase in the number of known occurrences since 1987–1988 (CNHP 2018).

<u>Condition Summary for DINO Rare Plants</u>

The condition and trend for plants examined is summarized in Table 4.10-3. Overall condition is good, with an unchanging trend and medium confidence.

Table 4.10-3. Condition and trend summary for rare plants at Dinosaur National Monument.

Taxon	Condition Status/Trend	Rationale
Erigeron wilkenii		Two occurrences at DINO are A-ranked and populations appear stable between 1995 and 2012. However, a third site has not been relocated.
Hymenoxys lapidicola		One occurrence at DINO. Current condition and trend unknown.
Oenothera acutissima		Both occurrences at DINO are B-ranked and populations appear stable between 1995 and 2012, but the number of occurrences declined from three to two during that period.
Oxytropis besseyi var. *obnapiformis*		One element occurrence at DINO is B-ranked and populations appear stable between 1987 and 2012.
Penstemon scariosus var. *cyanomontanus*		Six known occurrences on DINO. Sites recently visited show stable populations and were A or B-ranked. Two out of 6 sites have no recent data.
Platanthera zothecina		Four out of five sites ranked B or better. Trends appear to be improving with a 40% increase in the number of known occurrences since 1987–88, and an increase in the number of individuals at two of the three occurrences.
Spiranthes diluvialis		At DINO, two of four sites ranked A (excellent) or B (good). Population totals are highly variable but the trend within the monument appears unchanging although additional sites have been found in recent years.
Zigadenus vaginatus		Five out of eight element occurrences are rated fair (three) or poorer (two). Trends appear unchanging to improving with a 50% increase in the number of known occurrences since 1987–88.
Rare Plants overall		**The resource is in good condition with an unchanging trend. Confidence in the assessment is medium.**

4.10.5. Uncertainty and Data Gaps

Some taxa are very difficult to monitor effectively due to their life-cycle or response to environmental variables. Long-term monitoring is spotty for some species and because the monument is located in both Utah and Colorado, consolidation of occurrence information requires extra effort and/or expense. The monument does not appear to have up-to-date occurrence data or all of the survey reports that have been prepared over the years. Therefore, some occurrence totals may be incomplete, underreported, or inaccurate. The most recent occurrence data for some taxa is not very recent. The impacts of land uses, primarily recreation and livestock grazing, are somewhat understood but are poorly documented and largely anecdotal for the DINO occurrences.

4.10.6. Sources of Expertise

- Walter Fertig, State Botanist – Washington Natural Heritage Program, Department of Natural Resources.
- Tamara Naumann, former DINO Biologist.
- Jennifer Penny, Botanist, British Columbia Conservation Data Centre at Victoria.
- Rebecca Weissinger, Ecologist, Northern Colorado Plateau I&M Network.

4.10.7. Literature Cited

Ackerfield, J. 2015. Flora of Colorado. Botanical Research Institute of Texas, Fort Worth, Texas.

Barneby, R.C. 1989. Fabales. *In* A. Cronquist, A. H. Holmgren, N. H. Holmgren, J. L. Reveal, and P. K. Holmgren, editors. Intermountain flora: Vascular plants of the Intermountain West, U.S.A. Vol. 3, Part B. New York Botanical Garden, Bronx, New York.

Coles, J., D. Cogan, D. Salas, A. Wight, G. Wakefield, J. VonLoh, and A. Evenden. 2008. Vegetation classification and mapping project report, Dinosaur National Monument. Natural Resource Technical Report NPS/NCPN/NRTR-2008/112. National Park Service, Fort Collins, Colorado.

Colorado Natural Heritage Program (CNHP). 2018. Biodiversity Tracking and Conservation System (BIOTICS). Colorado Natural Heritage Program, Colorado State University, Fort Collins.

Denver Botanic Gardens. 2008. Report to the Bureau of Land Management on the survey work conducted for *Oenothera acutissima* W.L. Wagner (Flaming Gorge or narrowleaf evening primrose) by Denver Botanic Gardens in 2008. Unpublished report. Denver, Colorado.

Fertig, W. 2001. State Species Abstract: *Oxytropis besseyi var. obnapiformis*. Wyoming Natural Diversity Database. Available at: http://www.uwyo.edu/wyndd.

Fertig, W., R. Black, and P. Wolken. 2005. Rangewide status review of Ute Ladies'-Tresses (*Spiranthes diluvialis*). Prepared for the U.S. Fish and Wildlife Service and Central Utah Water Conservancy District. 30 September 2005.

Lyon, P., D. Malone, J. Handwerk, and J. Huggins. 2011. Rare plant survey of Dinosaur National Monument, 2011. Prepared for Dinosaur National Monument and the Colorado Natural Areas Program. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

Lyon, P., D. Malone, and J. Handwerk. 2012. Rare plant survey of Dinosaur National Monument, 2012. Prepared for Dinosaur National Monument and the Colorado Natural Areas Program. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

May, C.L., J.F. Fowler, and N.L. Stanton. 1995. Geomorphology of the Hanging Gardens of the Colorado Plateau. Pages 3-24 *in* C. van Riper III, editor. Proceedings of the second biennial

conference on research in Colorado Plateau National Parks. U.S. National Park Service Transactions and Proceedings Series NPS/NRNAU/NRTP-95/11.

NatureServe. 2018. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available at: http://explorer.natureserve.org.

Naumann, T.S. 1990. Inventory of plant species of special concern and the general flora of Dinosaur National Monument 1987–1989. Unpublished Report prepared for the National Park Service, Denver, Colorado.

O'Kane, S.L. 1990. A new species of *Erigeron* (Asteraceae: Astereae) from Colorado. Madroño 37(3):184–189.

Rondeau, R., K. Decker, J. Handwerk, J. Siemers, L. Grunau, and C. Pague. 2011. The state of Colorado's biodiversity 2011. Prepared for The Nature Conservancy. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

Spackman, S., B. Jennings, J. Coles, C. Dawson, M. Minton, A. Kratz, and C. Spurrier. 1997. Colorado rare plant field guide. Prepared for Bureau of Land Management, U.S. Forest Service and U.S. Fish and Wildlife Service by Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

Utah Native Plant Society. 2016. Utah rare plant guide (2003–2016 period). [Internet]. A.J. Frates, editor/coordinator. Utah Native Plant Society, Salt Lake City, Utah. Available at http://www.utahrareplants.org.

Welsh, S.L, N.D. Atwood, S. Goodrich, and L.C. Higgins. 2003. A Utah Flora, third edition, revised. Brigham Young University, Provo, Utah.

Williams, P.A. 2010. Ute Ladies' Tresses Orchid (*Spiranthes diluvialis*) in Dinosaur National Monument: 2010 Green River inventory results. Unpublished Report. Dinosaur National Monument, Dinosaur, Colorado.

Williams, P.A. 2011. Ute Ladies' Tresses Orchid (*Spiranthes diluvialis*) in Dinosaur National Monument: 2011 Green River inventory results. Unpublished Report. Dinosaur National Monument, Dinosaur, Colorado.

Williams, P.A. 2012. Ute Ladies' Tresses Orchid (*Spiranthes diluvialis*) in Dinosaur National Monument: 2012 Green River inventory results. Unpublished Report. Dinosaur National Monument, Dinosaur, Colorado.

Williams, P.A. 2015. Ute Ladies' Tresses Orchid (*Spiranthes diluvialis*) in Dinosaur National Monument: 2015 Green River inventory results. Unpublished Report. Dinosaur National Monument, Dinosaur, Colorado.

4.11. Fish

4.11.1. Background and Importance

The National Park Service protects, preserves, and manages biological resources and related ecosystem processes in the national park system, including aquatic resources. Dinosaur National Monument (DINO) protects 105 miles of the Green and Yampa Rivers of the Upper Colorado River Basin flowing within its boundaries, and over 210,000 acres of associated river canyons and riparian habitat. The Green River is a major tributary of the Colorado River, extending from its headwaters in the Wind River Range in Wyoming and joining the Colorado River at Canyonlands National Park in southern Utah. The Yampa River extends from its headwaters in the Flat Top Mountains of northwestern Colorado and joins the Green River at Echo Park, within DINO. The upper Green River has been highly impacted and altered by Fontenelle Dam and Flaming Gorge Dam, whereas the Yampa is one of the last (mostly) free-flowing major tributaries of the Colorado River (Bestgen 2015). Forty-six miles of the lower Yampa River flow within the boundaries of DINO. Natural flow regime, sediment loads, and temperatures of the Green River have been dramatically altered since 1962, when the Flaming Gorge Dam was constructed. However, because the Yampa River has been minimally altered with only a few small to medium-sized reservoirs near its headwaters, it maintains much of its natural flow patterns and provides critical flows to the Green River below their confluence (Bestgen 2015). The condition of the Green and Yampa Rivers within DINO is examined in detail in Section 4.8.

The Colorado River Basin has among the highest numbers of rare and endangered native fishes of rivers world-wide, and is among the top five basins most impacted by non-native fish in the United States (Stanford and Ward 1986, Carlson and Muth 1989, Fuller et al. 1999, Bestgen 2015). The construction of dams, water diversions, and introductions of non-native fish has caused dramatic population declines of native fish species in the Colorado River Basin (Bestgen et al. 2006, Bestgen 2015). Over 50 species of fish are found in the Yampa and Green Rivers, yet only about one-third are native. Of the fourteen native fish species, four are highly endangered: the razorback sucker (*Xyrauchen texanus*), humpback chub (*Gila cypha*), Colorado pikeminnow (*Ptychocheilus lucius*), and bonytail chub (*Gila elegans*) (Jones and Naumann 2014). Others are in decline, including the roundtail chub (*Gila robusta*), bluehead sucker (*Catostomus discobolus*), and flannelmouth sucker (*Catostomus latipinnis*), which are all considered Species of Concern in Utah and Colorado (Jones and Naumann 2014). As of 2015, populations of most endangered fishes and other native fishes in the Upper Colorado River Basin continue to decline (NPS 2015).

The Upper Colorado River Basin is considered a stronghold for many of the basin's native fishes; populations persist and there is promising potential for recovery (Bestgen et al. 2007, 2008, 2010, Zelasko et al. 2010). The Green and Yampa Rivers within DINO provide crucial habitat for, and help support recovery of, the endangered and declining fish of the Colorado River Basin (Bestgen 2015). The Green River maintains the largest populations of endangered and native fishes of the basin, and because the Yampa River maintains much of its historical flow patterns, temperatures, and sediment loads, it is especially critical for native fish recovery (Bestgen 2015). The protection of the Green and Yampa Rivers within DINO and collaborative efforts among DINO, NPS, other agencies, scientists, conservation organizations, and industry are important for helping to maintain and recover native fish

populations and reduce the impacts of non-native fish (Upper Colorado River Endangered Fish Recovery Program 2017, 2018).

Threats and Stressors

The largest drivers of the decline of native fish populations in the Colorado Basin are dams and introduction of non-native fish (Tyus and Saunders 2000, Bestgen 2015, Upper Colorado River Endangered Fish Recovery Program 2018). The native fish of the Upper Colorado River evolved with and depend on high spring flows fed by snow melt, highly variable temperatures from winter to summer, and heavy sediment loads. The Flaming Gorge Dam, approximately 47 river miles upstream from DINO, regulates the Green River to provide hydroelectric power generation and water for downstream irrigated agriculture. The construction of the Flaming Gorge Dam has reduced peak spring flows by more than 50%, and has impacted water temperatures, turbidity, sediment load, and increased base flows (Bestgen 2015). These conditions are more favorable to many of the non-native fish, which compete with the native species for food and habitat, and prey on native fish (Bestgen 2015). Water development projects continue to be proposed and threaten the populations of native fish (Tyus and Saunders 2000, Bestgen 2015).

Non-native fish found at DINO include smallmouth bass (*Micropterus dolomieu*), burbot (*Lota lota*), common carp (*Cyprinus carpio*), catfish (*Siluriformes* spp.), northern pike (*Esox lucius*), brown trout (*Salmo trutta*), white sucker (*Catostomus commersonii*), and walleye (*Sander vitreus*) (Jones and Naumann 2014). Many occur in high abundance and hybridize with natives. The white sucker, for example, continues to expand its range in the Upper Colorado River Basin and hybridizes with native bluehead and flannelmouth suckers (Bezzerides and Bestgen 2002). Introduction of additional non-native species remains a large threat to native fish of the Colorado River Basin.

Protection of freshwater biodiversity is difficult because it is influenced by the upstream drainage network, the surrounding land, and activity in the riparian zone (Dudgeon et al. 2006). The modifications to the surrounding landscape disrupt ecological functions important to ecosystem integrity and important to maintaining the community and composition of fish species at DINO (Jørgenson and Müller 2000). Consequently, the ecological functioning of DINO depends upon maintaining the natural hydrological systems outside the monument's boundaries.

Indicators and Measures

- Native species richness (S)
- Fish index of biotic integrity (IBI)
- Occurrence and status of fish species of conservation concern

4.11.2. Data and Methods

Understanding the status and trends in fish community composition and abundance, in conjunction with water quality and habitat condition information, improves the understanding of how fish respond to changes in habitat structure and other habitat variables related to land use changes and management activities (Dodd et al. 2008). In 1978–80, 1994–96 and 2002–04, numerous research projects began systematic surveys of fish and their habitat at DINO in the Green River within the

upper and lower Lodore Canyon (Holden and Crist 1981, Bestgen and Crist 2000, and Bestgen et al. 2006). Sample locations in 1978–80 located at the Upper Lodore Canyon reach were stationed at RK (river kilometer) 581, and lower Lodore Canyon reaches were stationed at RK 561 (Holden and Crist 1981) (Fig 4.11-1). Samples collected in 1994–96 and 2002–04 included the original sample points in 1978–80 and additional locations within reaches. Seines and drift nets were used to collect larval form fish, which were then preserved and sent to the Larval Fish Laboratory at Colorado State University for identification. Larval fish collection was conducted during spring, summer, and autumn each sample year. Continuous electrofishing was used to collect information on large-bodied fish along 1.5 to 3 km reaches within the upper and lower Lodore Canyon of the Green River at DINO. All stunned fish were collected and identified to species. Electrofishing collections were conducted twice per year, one in mid to late July and one in mid to late September. It is important to note that data reported here are from the Green River only, not from the (mostly) unregulated Yampa River, and only post-Flaming Gorge Dam construction (1962) data (1978–2006) are included. Fish data for the Yampa River within DINO are available for only specific rare fish species and for removal studies targeting non-native fish. A general study on the fish community, like that conducted on the Green River, is not available for the Yampa (CNHP 2018, Upper Colorado River Endangered Fish Recovery Program 2018). For more detailed methods on the Green River fish monitoring study see Holden and Crist (1981), Bestgen and Crist (2000), and Bestgen et al. (2006).

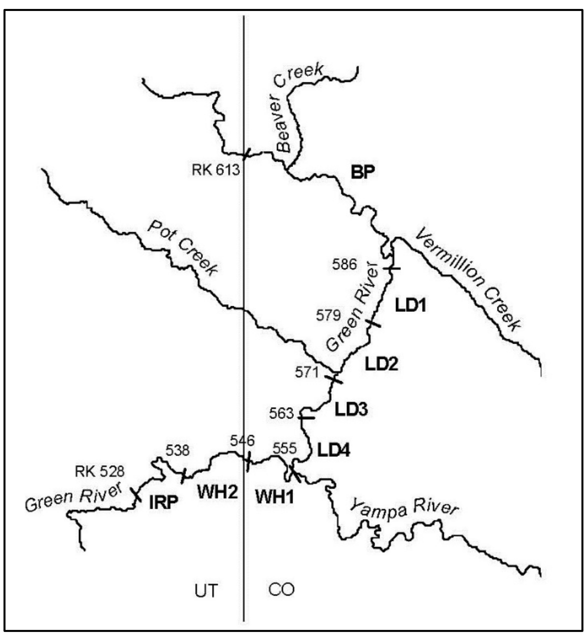


Figure 4.11-1. Reaches sampled as part of the *Lodore-Whirlpool Fish Community Response* study in the area of Dinosaur National Monument. Reaches LD1 to LD4 are in Lodore Canyon. The Lodore Canyon sampling sites used in this assessment were centered on river kilometer 581 in sample reach LD1 and river kilometer 561 in sample reach LD4 (on the map RK = river kilometer) (from Bestgen et al. 2006).

To evaluate trends over time, we compared the occurrence of native species detected during 1978–80 to those detected during the 1994–96 and 2002–04 surveys.

Fish Index of Biotic Integrity (IBI) values were calculated and compared among the following periods: 1978–80, 1994–96, and 2002–04. The fish IBI is based on methodology developed for fish communities of western United States streams and rivers (Whittier et al. 2007a and 2007b). It is important to note that the fish IBI was modified to reflect the fish species and aquatic habitat that are present at DINO. Specialist guilds included in the IBI tend to be associated with more pristine and less degraded freshwater habitats. The biotic or ecological "condition" described by the fish IBI moves along a disturbance gradient from a relatively intact, pristine, high water quality stream with high IBI scores to a more disturbed or degraded landscape with lower water quality and lower IBI scores. For example, sites with higher fish IBI scores consist of a fish community with more lithophilic spawners and native, sensitive lotic species (i.e., specialist guilds), but with fewer omnivores and non-native species (i.e., generalist guilds). A discussion of guild selection and analysis is presented in Whittier et al. (2007b). Classification of fish species observed at DINO into trophic and reproductive behavior guilds followed the classifications as reported in Whittier et al. (2007b). The response guilds incorporated into the fish IBIs are listed in Table 4.11-1.

Table 4.11-1. Fish species guilds used to calculate the IBI score (Whittier et al. 2007a).

Biotic Integrity Element	Guild Category	Response Guild	Number of Species in Guild	Relationship to IBI Score
Functional	Tolerance	Assemblage Tolerance Index (ATI)	N/A*	Positive
	Reproductive	Lithophilic spawners	15	Positive
Compositional	Trophic	Omnivores	14	Negative
	Origin	Non-native species	16	Negative
Structural	Habitat	Native sensitive lotic species	3	Positive

* All fish species across both sites and all years were associated with an ATI score calculated from tolerance values found in Whittier et al. (2007a).

To calculate the IBI score, species are first assigned to guilds based on habitat preference, trophic composition, and reproductive composition (some species may be assigned to more than one guild, depending on their life history traits).

The next step in the fish IBI is to standardize metrics to score from 0 to 10. These scores were calculated using the threshold limits described by Whittier et al. (2007b). Threshold limits were the minimum (5th percentile) and maximum (95th percentile) values as determined at all sites in the xeric ecoregion of the western United States as described in Whittier et al. (2007b). Using these threshold limits, we adjusted each metric to score from 0 (very poor condition) to 10 (good condition) by using the equation:

$$MS = A + (B \times MR)$$

where MS = metric score, MR = raw metric value calculated from the sample reach data, A = the y-intercept in the regression of MS versus MR, and B = the slope in the regression of MS versus MR. Regressions were computed from the points for the upper and lower thresholds, which were assigned

scores of 0 or 10 depending on a metric's relationship with stream site quality. Finally, IBI scores were standardized to score from 0 to 100. The final fish IBI score was calculated as follows:

$$IBI = \frac{(\sum_{i=1}^{N} MS_i) \bullet 10}{N}$$

where IBI = IBI score, MSi = metric score of the i^{th} metric, and N = the number of metrics. A community at the theoretical maximum high IBI score, or highest integrity, consists of a fish community with only specialist guilds and without any generalist guilds.

A broader fish conservation context was evaluated by examining the native fish community to determine which species that occur at DINO are considered species of conservation concern either nationally or within the region of the monument, and to assess the current status (occurrence) of those species at the monument.

To identify fish species that are of conservation concern we used species listed as either endangered or threatened by the U. S. Fish and Wildlife Service (USFWS) under the Endangered Species Act (ESA); U. S. Forest Service (USFS) and Bureau of Land Management (BLM) sensitive species lists; NatureServe G1 to G3 and S1 ranked species; and State lists of endangered, threatened and special concern species.

Most state governments have endangered species statutes or acts, which consider the species' risk of extinction within the state and list at-risk species as either endangered, threatened, or special concern. Listed species are then protected by regulations enforced by state governments preventing activities that negatively impact listed species populations and their critical habitat. Including at-risk fish listed by the states of Colorado and Utah in the condition assessment for DINO recognizes that some species may be declining dramatically at the local scale, even though they are not of high concern nationally.

4.11.3. Reference Conditions

Data assessing overall condition and community structure at DINO in the Green River prior to the installation of the Flaming Gorge Dam are not available. General information about community composition and reproduction is only available for select species between the years 1964 and 1966 (Vanicek and Kramer 1969). For purposes of the condition assessment, fish reference condition for all sampled reaches is based on the 1978–80 sample years (i.e., baseline conditions) (Bestgen et al. 2006). Maintaining or exceeding the level of biodiversity as defined by initial calculation of native species richness (as an index of diversity) and initial list of species of concern (as an index of habitat quality) are considered good condition. The condition of the resource is considered higher if there are more species present and if more species of concern are observed. This implies that the populations of those species are finding suitable habitat that is in good condition and are using the monument more. A rating system for departure from good condition is shown in Table 4.11-2.

Table 4.11-2. Resource condition rating framework for fish at Dinosaur National Monument.

Indicator	Resource is in Good Condition	Condition Warrants Moderate Concern	Condition Warrants Significant Concern
Native Species Richness	>85–100+% of 1978–80 value	70–85% of 1978–80 value	<70% of 1978–80 value
Index of Biological Integrity	53.1–100	35.1–53	0–35
Species of Conservation Concern	>85–100+% of 1978–80 value	70–85% of 1978–80 value	<70% of 1978–80 value

The distribution of IBI scores for xeric western United States streams and rivers for the least disturbed, moderately disturbed, and most disturbed sites was rigorously defined by Whittier et al. (2007b). Threshold levels for IBI scores in this assessment between the least disturbed and moderately disturbed sites were set at the least disturbed sites' first quartile as defined by Whittier et al. (2007b). Similarly, the breakpoint between the moderately disturbed and most disturbed sites was set at the moderately disturbed sites' first quartile. These thresholds create a three-tiered rating system (Table 4.11-2) that includes the following IBI disturbance categories: least disturbed (good integrity) – score of 53.1–100.0; moderately disturbed (moderate integrity) – score of 35.1–53.0; and most disturbed (low-integrity) – score of 0–35.0.

4.11.4. Condition and Trend

<u>Species Richness</u>

The number of native fish species fluctuated between 12 and 15 species from 1978–80 to 2002–04, with richness equaling 15 in 2002–04. This is greater than the management target of 85% of 12 (1978–80), indicating the resource is in good condition (Table 4.11-2). From 1978–80 a total of 25 fish species (native, non-native, and hybrids) were recorded at river sampling stations. The most common species was the non-native red shiner (*Notropis lutrensis*) (Table 4.11-3). The native speckled dace (*Rhinicthys osclus*), flannelmouth sucker (*Catostomus latipinnis*) and bluehead sucker (*Catostomus discobolus*) and the non-native redside shiner (*Richardsonius balteatus*) were also very common. Twelve native fish species and native hybrids contributed to species richness, which is less than 50 percent of the total species richness found at the survey locations in 1978–80 (Table 4.11-3). For the 1994–96 sampling period, there were again 25 species recorded. The most common species observed from 1994–96 was the non-native fathead minnow (*Pimephales promelas*) (Table 4.11-3). Other common species included the flannelmouth sucker, red shiner *(Notropis lutrensis*) and the non-native red shiner and redside shiner. Fourteen native species or native hybrids contributed to the total species richness, which was just over 50 percent of the total number of species recorded. For the 2002–04 sampling period, there were 27 fish species recorded, which was similar the 25 observed in the 1978–80 and 1994–96 sampling periods. The most common species during the 2002–04 period was the red shiner, followed by the fathead minnow, sand shiner (*Notropis stramineus*), and redside shiner, all non-natives suggesting an apparent increase of non-native species (Table 4.11-3). Other common species included the native flannelmouth sucker and white sucker (*Catostomus commersoni*). Fifteen native species and native hybrids were found during this period, which is slightly greater than 50 percent of the total species richness found at the survey locations in 2002–

2004. In 1978–80, there were 25 species recorded (12 of which were either native species or native hybrids), which increased to 27 total species and hybrids recorded (15 of which were either native species or native hybrids) in 2002–04 (Figure 4.11-1 and Table 4.11-3).

Table 4.11-3. Fish species recorded in 1978–80, 1994–96 and 2002–04 in the Green River, Lodore Canyon, Dinosaur National Monument (data from Holden and Crist 1981, Bestgen and Crist 2000, and Bestgen et al. 2006). Federal listed abbreviations: LE = listed endangered, LT = listed threatened, FS = Forest Service sensitive, BLM = Bureau of Land Management sensitive; Nature Serve Global Ranking: G1 = critically imperiled, G2 = imperiled, and G3 = vulnerable; State List Status: SE = state endangered, ST = state threatened, CAS = Utah conservation agreement species, SC = species of concern.

Common Name	Species Name	Non-native	1978–80	1994–96	2002–04	Federal Status	Nature Serve Global Ranking	State List Status
Black bullhead	*Ameiurus melas*	X	4	0	12	–	–	–
Bluehead X White hybrid	–	–	0	28	19	–	–	–
Bluehead sucker[1]	***Catostomus discobolus***	**–**	**610**	**659**	**342**	**FS, BLM**	**–**	**UT:CAS**
Brown trout	*Salmo trutta*	X	33	123	270	–	–	–
Channel catfish	*Ictalurus punctatus*	X	15	42	145	–	–	–
Colorado pikeminnow[1]	***Ptychocheilus lucius***	**–**	**4**	**9**	**19**	**LE**	**G1**	**CO:ST, UT:SE**
Common carp	*Cyprinus carpio*	X	166	161	371	–	–	–
Creek chub	*Semotilius atromaculatus*	–	4	0	12	–	–	–
Cutthroat trout[1]	***Oncorhynchus clarkii***	**–**	**20**	**9**	**7**	**LT**	**–**	**CO:ST, UT:CAS**
Fathead minnow	*Pimephales promelas*	X	202	2069	2975	–	–	–
Flannelmouth x Blueheaded	–	–	0	32	26	–	–	–
Flannelmouth sucker[1]	***Catostomus latipinnis***	**–**	**1284**	**1808**	**1245**	**FS, BLM**	**G3**	**UT:CAS**
Flannelmouth x Blueheaded x White hybrid	–	–	0	7	19	–	–	–
Flannelmouth x White hybrid	–	–	2	20	94	–	–	–
Green sunfish	*Lepomis cyanellus*	X	0	9	276	–	–	–
Green sunfish X Bluegill hybrid	–	X	0	0	12	–	–	–
Mottled sculpin	*Cottus bairdi*	–	47	28	38	–	–	–

[1] Federally listed species (also in bold)

Table 4.11-3 (continued). Fish species recorded in 1978–80, 1994–96 and 2002–04 in the Green River, Lodore Canyon, Dinosaur National Monument (data from Holden and Crist 1981, Bestgen and Crist 2000, and Bestgen et al. 2006). Federal listed abbreviations: LE = listed endangered, LT = listed threatened, FS = Forest Service sensitive, BLM = Bureau of Land Management sensitive; Nature Serve Global Ranking: G1 = critically imperiled, G2 = imperiled, and G3 = vulnerable; State List Status: SE = state endangered, ST = state threatened, CAS = Utah conservation agreement species, SC = species of concern.

Common Name	Species Name	Non-native	1978–80	1994–96	2002–04	Federal Status	Nature Serve Global Ranking	State List Status
Mountain sucker[1]	***Catostomus platyrhynchus***	**–**	**27**	**0**	**0**	**FS, BLM**	**–**	**CO:SC**
Mountain whitefish	*Prosopium williamsoni*	–	2	80	173	–	–	–
Northern pike	*Esox lucius*	X	0	7	12	–	–	–
Rainbow trout	*Oncorhynchus mykiss*	X	93	19	33	–	–	–
Razorback sucker[1]	***Xyrauchen texanus***	**–**	**4**	**0**	**0**	**LE**	**G1**	**CO:SE, UT:SE**
Red shiner	*Notropis lutrensis*	–	1625	1806	7871	–	–	–
Redside shiner	*Richardsonius balteatus*	X	895	1227	1906	–	–	–
Roundtail chub[1]	***Gila robusta***	**–**	**152**	**7**	**19**	**FS, BLM**	**G3**	**CO:SC, UT:SC**
Razorback Flannelmouth hybrid	–	–	4	7	0	–	–	–
Sand shiner	*Notropis stramineus*	X	9	59	2140	–	–	–
Smallmouth bass	*Micropterus dolomieu*	X	0	7	80	–	–	–
Speckled dace	*Rhinicthys osclus*	–	1365	509	230	–	–	–
Utah chub	*Gila atraria*	–	5	0	0	–	–	–
White sucker	*Catostomus commersoni*	–	15	586	920	–	–	–

[1] Federally listed species (also in bold)

The slope of the linear regression line for mean native fish and native hybrid species richness per sample station was positive, but not statistically significant ($r^2 = 0.92$, $p = 0.18$), suggesting an unchanging trend in the richness of the fish community over time. The 90 percent confidence intervals for native species richness for 1994–1996 are relatively broad, indicating high variability among samples and/or small sample sizes (Figure 4.11-2). The mean native fish species and native hybrids per sample station recorded at DINO in 2002–04 was 15 species, greater than the 1978–80 value and greater than the management target of 85% of the 1978–80 benchmark of 12 species. Results indicate the resource is in good condition (Table 4.11-2).

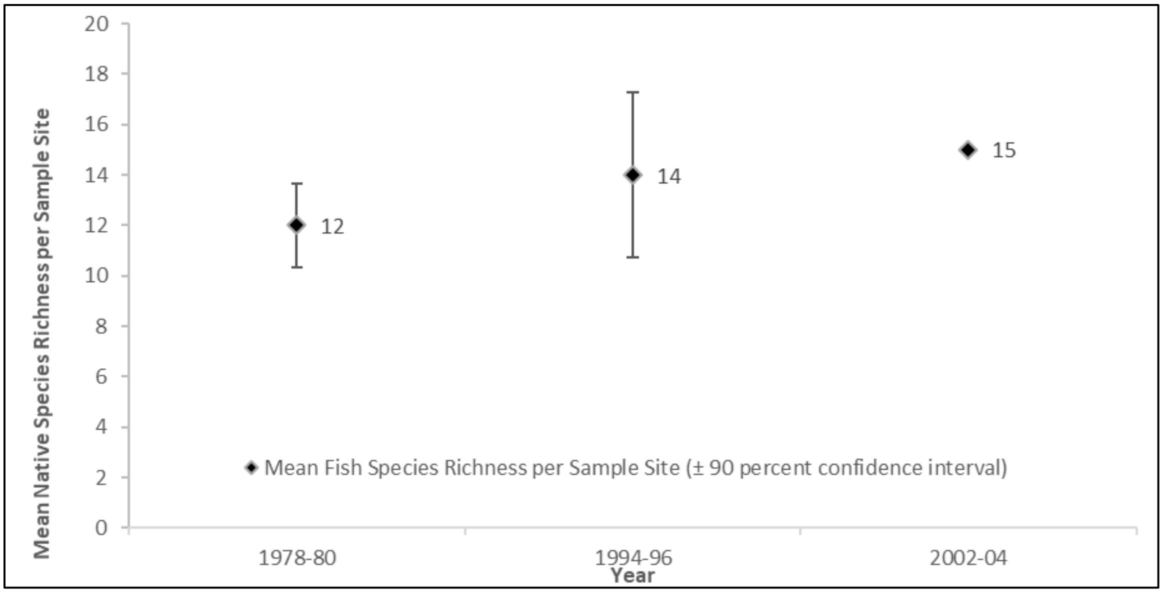


Figure 4.11-2. Trends in mean native fish species richness per sample site at Dinosaur National Monument, Jensen, Utah, from 1978–80, 1994–96, and 2002–04 with 90 percent confidence intervals (data from Holden and Crist 1981, Bestgen and Crist 2000, and Bestgen et al. 2006).

Index of Biotic Integrity

The mean fish IBI score per sample station in 2002–04 was 43 compared to the 1978–80 score of 38. These IBI scores indicate that composition of the fish community at DINO during that period warrants moderate concern (Table 4.11-2). The slope of the linear regression line for the fish IBI score was positive, but not statistically significant ($r^2 = 0.56$, $p = 0.38$), indicating the biotic integrity of the fish community was relatively unchanged between 1978 and 2004. The 90 percent confidence intervals for the IBI scores overlap, also suggesting lack of changes in the IBI since monitoring began in the 1970s at DINO (Figure 4.11-3).

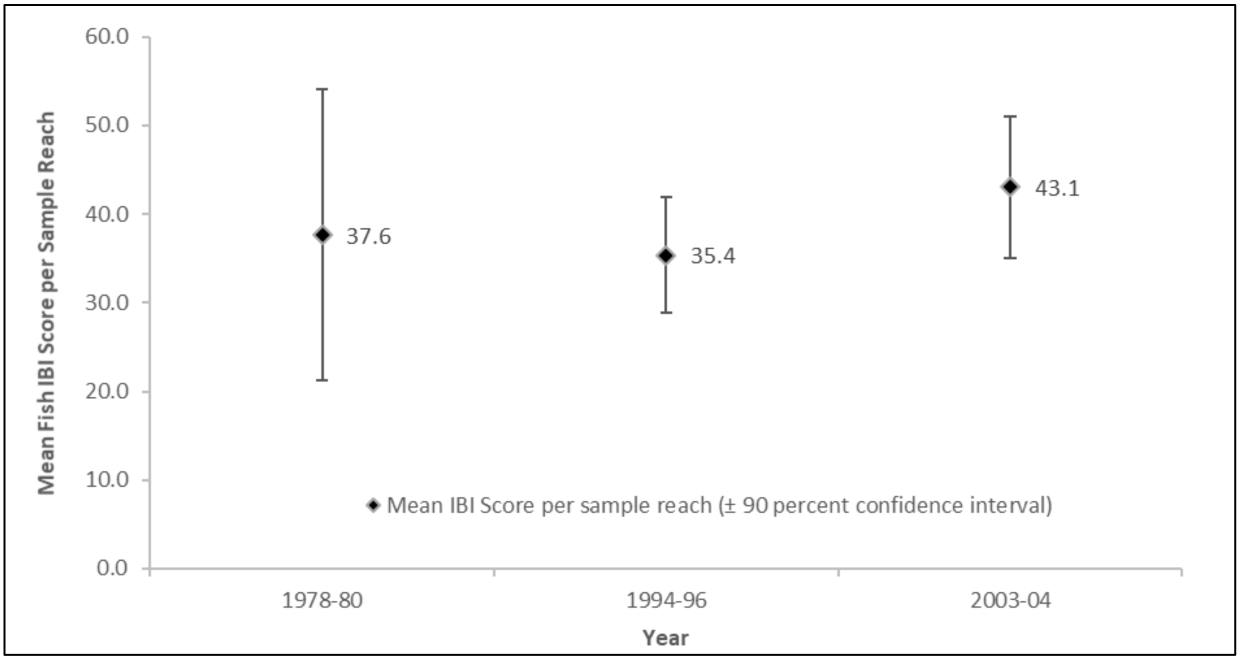


Figure 4.11-3. Fish species IBI scores per sample site at Dinosaur National Monument for 1978–80, 1994–96, and 2002–04 sample periods (data summarized from Holden and Crist 1981, Bestgen and Crist 2000, and Bestgen et al. 2006).

<u>Species of Concern</u>

Numerous species of concern were observed over the course of sampling at DINO (Table 4.11-3). The Colorado pikeminnow and razorback sucker are both federally endangered and the cutthroat trout (*Oncorhynchus clarkii*) is federally threatened under the ESA. The Colorado pikeminnow increased in numbers during the study period while the other two species declined or in the case of the razorback sucker was completely absent in the 1995–96 and 2002–04 sampling periods (Table 4.11-3). Colorado pikeminnow abundance increased by only 15 individuals, but this represented an increase in the population of nearly 400 percent at DINO.

The mean number of fish species of concern per sample site fluctuated between 6 and 4.5 species from 1978–80 to 2002–04 with 4.5 species present in 2002–04. This is 75% of the management target of 85% of 6 (1978–80), indicating the resource warrants moderate concern (Table 4.11-3, Figure 4.11-4). From 1978–80, species of concern present in the Lodore Canyon reach of the Green River include the bluehead sucker, Colorado pikeminnow, cutthroat trout, flannelmouth sucker, mountain sucker (*Catostomus platyrhynchus*) and the roundtail chub (Table 4.11-3). From 1994–96, species of concern present included the bluehead sucker, Colorado pikeminnow, cutthroat trout, flannelmouth sucker, and the roundtail chub (Table 4.11-3). In 2002–04, species of concern present included the bluehead sucker, Colorado pikeminnow, cutthroat trout, flannelmouth sucker, and the roundtail chub. Of these seven species, the only one that showed a consistent increase from the 1978–80 sampling period through the 2002–2004 period was the Colorado pikeminnow and the only species showing a decline was the cutthroat trout (Table 4.11-3). Assessing trend for the mountain sucker is problematic because the species was present only during the 1994–96 sampling period.

The most common species of concern across all survey years was the flannelmouth sucker followed by the bluehead sucker and roundtail chub (Table 4.11-3).

The slope of the linear regression for the mean number of fish species of concern per sample site was negative, but not statistically significant ($r^2 = 0.52$, $p = 0.49$), suggesting an unchanging trend in the population of DINO fish species of concern.

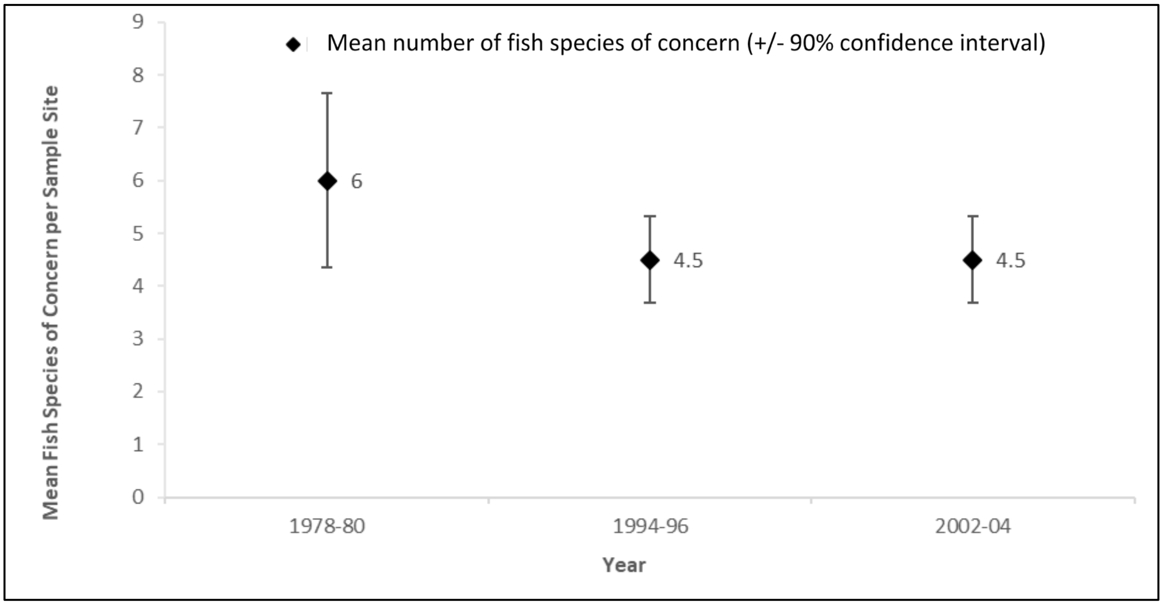
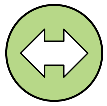
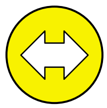
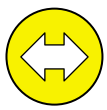
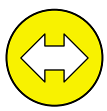


Figure 4.11-4. Number of fish species of concern per sample site at Dinosaur National Monument, Jensen, Utah, from 1978–80, 1994–96, and 2002–04 (data summarized from Holden and Crist 1981, Bestgen and Crist 2000, and Bestgen et al. 2006).

Overall Condition and Trend

The values for the metrics of total species richness, fish IBI, and number of species of concern present across study years suggest that the fish resource at DINO warrants moderate concern. The federally-listed endangered Colorado pikeminnow and razorback sucker and the federally-listed threatened Colorado cutthroat trout were present. The structure of the fish community at DINO is representative of a moderately disturbed habitat (Table 4.11-4). The values for these metrics over time suggest an unchanging trend in fish community diversity and structure at DINO.

Table 4.11-4. Condition and trend summary for fish at Dinosaur National Monument between 1978 and 2004.

Indicator	Condition Status/Trend	Rationale
Native Species Richness (S)		Mean native Green River fish species richness per sample site in Lodore Canyon fluctuated between 12 and 15 species from 1978–80 to 2002–04 with mean richness equaling 15 in 2002–04 (resource is in good condition). Quantitative assessment of native fish monitoring data indicates a slight, statistically insignificant, increasing trend in native species richness from 1978–80 to 2002–04. Native species accounted for only about 50% of total species richness.
Fish Index of Biotic Integrity		In 2002–04, the Green River mean fish IBI score in Lodore Canyon was 43.1 (condition warrants moderate concern). Quantitative assessment of the fish mean IBI scores indicates a stable trend in the biotic integrity of the fish community from 1978–80 to 2002–04.
Species of Conservation Concern		The number of Green River fish species of concern in Lodore Canyon fluctuated between 6 and 4.5 species from 1978–80 to 2002–04 with 4.5 species present in 2002–04 (resource warrants moderate concern). Quantitative assessment of the monitoring data indicates a slight, statistically insignificant, decline in the number of fish species present from 1978–80 to 2002–04.
Fish overall		**Condition warrants moderate concern with an unchanging trend. Confidence in the assessment is medium.**

4.11.5. Data Gaps and Uncertainty

Confidence in this assessment was medium. Assessments of ecological change should preferably use long-term data spanning decades (Holmes 2010, Magurran et al. 2010). Comprehensive data collected over an extended time period is needed to assess the natural temporal fluctuation of the condition indicators used in an assessment and to assure the accuracy of the assessment (Dornelas et al. 2012). The nine years of monitoring data available for this assessment collected over a 26-year period offer a sound foundation upon which to base the assessment and continued monitoring will enable the assessment of variability over time and space and assure the accuracy of the assessment (Dornelas et al. 2012). However, data gaps in this assessment are significant. Data reported here are only from the Green River above the confluence with the Yampa River, and are only based on post-dam construction from 1978–2004. Data are lacking from the (mostly) unregulated Yampa River from the same time period or more recently. Bestgen and others have continued to collect data on fishes in the Green River within DINO since 2006 (Bestgen et al. 2018), but these data as they correspond to the collection sites in Lodore Canyon used in this assessment were not available for this report. This report was written in 2019, so the data evaluated here are 15 years old. Additional monitoring over time of fishes within DINO, not only in the Green River but also in the Yampa River, would provide more powerful comparisons of fish population health and recovery across DINO's rivers and reaches.

Other factors that make the available data used for this assessment particularly robust is the fact that both seining and electrofishing were used to capture all size classes of fish present and the same stream reaches and the same number of reaches were sampled in every year of monitoring. Both of these factors control for potential bias in the fish data by improving the probability of detecting a fish that is actually present and by controlling for any differences in sampling effort. This can be a problem when assessing native species richness and the number of species of conservation concern, and when calculating the index of biotic integrity, all of which are influenced by the number of species and individuals encountered.

Another important potential source of bias occurs when monitoring data collected over multiple years are collected by multiple observers with varying skills in surveying fish populations. This variation could introduce measurement error into the data, leading to bias in the number of fish detected by different observers. This bias can reduce the ability to identify trends in the indicators (Dornelas et al 2012). This bias can be controlled by using standardized sampling protocols and subjecting observers to rigorous training prior to engaging in field sampling of the fish community as has been done by the Lodore-Whirlpool Fish Community Response monitoring study (Bestgen et al. 2018, Bestgen et al. 2006).

4.11.6. Sources of Expertise

- Kevin Bestgen, Senior Research Scientist and Director of the Larval Fish Laboratory, Department of Fish, Wildlife, and Conservation Biology, Colorado State University Fort Collins, Colorado, is responsible for conducting the Lodore-Whirlpool Fish Community Response monitoring study at DINO. Authors discussed with Kevin his research and sources of available data.

4.11.7. Literature Cited

Bestgen, K. 2015. Aspects of the Yampa River Flow Regime Essential for Maintenance of Native Fishes. Final Report submitted to the National Park Service, The Nature Conservancy, and Western Resource Advocates. Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins. Larval Fish Laboratory Contribution 181 NPS/NRSS/WRD/NRR 2015/962, 112.

Bestgen, K.R., and L. Crist. 2000. Response of the Green River fish community and habitat to construction and re-regulation of Flaming Gorge Dam, 1962–1996. Final report to the Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin. Larval Fish Laboratory Contribution 109. DOI: 10.13140/RG.2.2.14443.95529

Bestgen, K., K. Zelasko, R.I. Compton, and T. Chart. 2006. Response of the Green River fish community to changes in flow and temperature regimes from Flaming Gorge Dam since 1996 based on sampling conducted from 2002 to 2004. Final report submitted to the Biology Committee, Upper Colorado Endangered Fish Recovery Program. Larval Fish Laboratory Contribution 144. DOI: 10.13140/RG.2.2.34629.04323.

Bestgen, K.R., J.A. Hawkins, G.C. White, K.D. Christopherson, J.M. Hudson, M.H. Fuller, D.C. Kitcheyan, R. Brunson, P. Badame, G.B. Haines, J. Jackson, C.D. Walford, and T.A. Sorensen. 2007. Population status of Colorado pikeminnow in the Green River Basin, Utah and Colorado. Transactions of the American Fisheries Society 136:1356–1380.

Bestgen, K.R., K.A. Zelasko, R.I. Compton, and T.E. Chart. 2008. Survival, condition, habitat use, and predation on stocked bonytails (*Gila elegans*) in the Green River, Colorado and Utah. The Southwestern Naturalist 53:488–494.

Bestgen, K.R., J.A. Hawkins, G.C. White, C.D. Walford, P. Badame, and L. Monroe. 2010. Population status of Colorado pikeminnow in the Green River basin, Utah and Colorado, 2006–2008. Final report to the Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin. U. S. Fish and Wildlife Service, Denver, Colorado. Larval Fish Laboratory Contribution 161. DOI: 10.13140/RG.2.2.30801.74085

Bestgen, K.R., E. Kluender, K.A. Zelasko, and T. Jones. 2018. Monitoring effects of Flaming Gorge Dam releases on the Lodore and Whirlpool Canyon fish communities. Upper Colorado River Endangered Fish Recovery Program: Project Annual Report. Available at: http://www.coloradoriverrecovery.org/documents-publications/work-plan-documents/arpts/2018/nna/FR-115-FY2018AR-Final.pdf (accessed December 2018).

Bezzerides, N., and K. Bestgen. 2002. Status of roundtail chub (*Gila robusta*), flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*) in the Colorado River Basin. Final report to the U. S. Bureau of Reclamation, Salt Lake City, Utah. Larval Fish Laboratory Contribution 118. DOI: 10.13140/RG.2.2.30723.09769

Carlson, C.A., and R.T. Muth. 1989. The Colorado River: Lifeline of the American Southwest. Canadian Special Publication of Fisheries and Aquatic Sciences 106:220–239.

Colorado Natural Heritage Program (CNHP). 2018. STReaMS – The Species Tagging, Research and Monitoring System website. Available at: https://streamsystem.org/ (accessed November 2018).

Dodd, H.R., D.G. Peitz, G.A. Rowell, D.E. Bowles, and L.W. Morrison. 2008. Protocol for monitoring fish communities in small streams in the Heartland Inventory and Monitoring Network. NPS/HTLN/NRR–2008/052. National Park Service, Fort Collins, Colorado.

Dornelas, M., A.E. Magurran, S.T. Buckland, A. Chao, R.L. Chazdon, R.K. Colwell, T. Curtis, K.J. Gaston, N.J. Gotelli, M.A. Kosnik, B. McGill, J.L. McCune, H. Morlon, P.J. Mumby, L. Ovreas, A. Studeny, and M. Vellend. 2012. Quantifying temporal change in biodiversity: challenges and opportunities. Proceedings of the Royal Society B 280:1–10.

Dudgeon, D., A.H. Arthington, M.O. Gessner, Z.I. Kawabata, D.J. Knowler, C. Lévêque, R.J. Naiman, A.H. Prieur-Richard, D. Soto, M.L.J. Stiassny, and C.A. Sullivan. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews of the Cambridge Philosophical Society 81:163–182.

Fuller, P.L., L.G. Nico, and J.D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society Special Publication 27. American Fisheries Society, Bethesda, Maryland.

Holden, P.B., and L.W. Crist. 1981. Documentation of changes in the macroinvertebrate and fish populations in the Green River due to inlet modification of the Flaming Gorge Dam. Contract No. 0-07-40-S1357 for Water and Power Resources Service. Bio/West, Inc., Logan, Utah.

Holmes, R.T. 2010. Avian population and community processes in forest ecosystems: Long-term research in the Hubbard Brook Experimental Forest. Forest Ecology and Management 262:20–32.

Jones, T., and T. Naumann. 2014. Guide to important fish species in Dinosaur National Monument. US Fish and Wildlife Service and NPS, Vernal, Utah.

Jørgenson, S.E., and F. Müller. 2000. Handbook of ecosystem theories and management. CRC Press, Boca Raton, Florida.

Magurran, A.E., S.R. Baillie, S.T. Buckland, J. McP. Dick, D.A. Elston, E.M. Scott, R.I. Smith, P.J. Somerfield, and A.D. Watt. 2010. Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. Trends in Ecology and Evolution 25:574–582.

National Park Service. 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

Stanford, J.A., and J.V. Ward. 1986. Fish of the Colorado system. Pages 385–402 *in* B. R. Davies and K. F. Walker, editors. The ecology of river systems. Springer Science+ Business Media, Dordrecht, Netherlands.

Tyus, H.M., and J.F. Saunders. 2000. Nonnative fish control and endangered fish recovery: Lessons from the Colorado River. Fisheries 25:17–24.

Upper Colorado River Endangered Fish Recovery Program. 2017. The path to fish recovery in the Upper Colorado River Basin.

Upper Colorado River Endangered Fish Recovery Program. 2018. Upper Colorado River Endangered Fish Recovery Program website. Available at: http://www.coloradoriverrecovery.org/index.html (accessed 1 May 2018).

Vanicek, D.C., and R.H. Kramer. 1969. Life history of the Colorado squawfish, *Ptuchocheilus licius*, and the Colorado chub, *Gila robusta*, in the Green River in Dinosaur National Monument, 1964–1966. Transactions of the American Fisheries Society 98:581–596.

Whittier, T.R., R.M. Hughes, G.A. Lomnicky, and D.V. Peck. 2007a. Fish and amphibian tolerance values and an assemblage tolerance index for streams and rivers in the western USA. Transactions of the American Fisheries Society 136:254–271.

Whittier, T.R., R.M. Hughes, J.L. Stoddard, G.A. Lomnicky, D.V. Peck, and A.T. Herlihy. 2007b. A structured approach for developing indices of biotic integrity: Three examples from streams and rivers in the western USA. Transactions of the American Fisheries Society 136:718–735.

Zelasko, K.A., K.R. Bestgen, and G.C. White. 2010. Survival rates and movement of hatchery-reared razorback suckers in the Upper Colorado River Basin, Utah and Colorado. Transactions of the American Fisheries Society 139:1478–1499.

4.12. Greater Sage-Grouse

4.12.1. Background and Importance

The greater sage-grouse (*Centrocercus urophasianus*), a member of Family Phasianidae (grouse and turkeys), was historically found throughout the sagebrush ecosystems of western North America (Schroeder et al. 1999). A status review under the Endangered Species Act conducted by the U.S. Fish and Wildlife Service (the Service) found that the greater sage-grouse remains relatively abundant and well-distributed across the species' 173-million acre range and does not face the risk of extinction now or in the foreseeable future. The Service's decision follows an unprecedented conservation partnership across the western United States that has significantly reduced threats to the bird across 90 percent of the species' breeding habitat. The Service has determined that protection for the greater sage-grouse under the Endangered Species Act is no longer warranted and is withdrawing the species from the candidate species list (USFWS 2019).

Adult male greater sage-grouse, courtship display, Mono County, California. Photo by Marc Dantzher.

The bird is considered a Tier I species of greatest conservation need by the State of Colorado (CPW 2015) and a species of greatest conservation need by the State of Utah (Utah Wildlife Action Plan Joint Team 2015). Northwestern Colorado is located on the southern edge of greater sage-grouse range, but a high percentage of sage-grouse habitat in the state is considered a priority for conservation. The North Park and northwestern Colorado populations hold significant sage-grouse numbers and research on genetics and movement (Fedy et al. 2012, Thompson 2012) suggests they are critical in linking Utah and Wyoming populations. Sage-grouse habitat is about evenly split between federal and private ownership (USFWS 2019).

Although the greater sage-grouse occurs within Dinosaur National Monument (DINO), no active lek sites are documented within the monument. The species is iconic within sagebrush ecosystems including areas surrounding DINO, and is popular with birders who revel at watching and photographing males displaying at lek sites. Greater sage-grouse distribution and populations have been greatly reduced since the 1920s because of habitat alteration and degradation, including the adverse effects of cultivation, fragmentation, reduction of sagebrush and native herbaceous cover, development, introduction and expansion of invasive plant species, encroachment by trees, and issues related to livestock grazing (Schroeder et al. 2004). Though the species once occupied a vast range

across western North America, from extreme southern Canada through New Mexico, the greater sage-grouse now exists in restricted areas across a fragmented landscape. The population surrounding DINO persists within the pre-European settlement geographic range of the species (Figure 4.12-1). Populations have been extirpated in five states and one Canadian province, all at the periphery of the original distribution (Schroeder et al. 1999, Braun 1998). A 30 percent decline in population since 1985 is estimated for Colorado (Braun 1998). General habitat descriptions note that greater sage-grouse are adapted to a mosaic of sagebrush habitats throughout their range. Winter range is dominated by various taxa of *Artemisia* (sagebrush) (Schroeder et al. 1999).

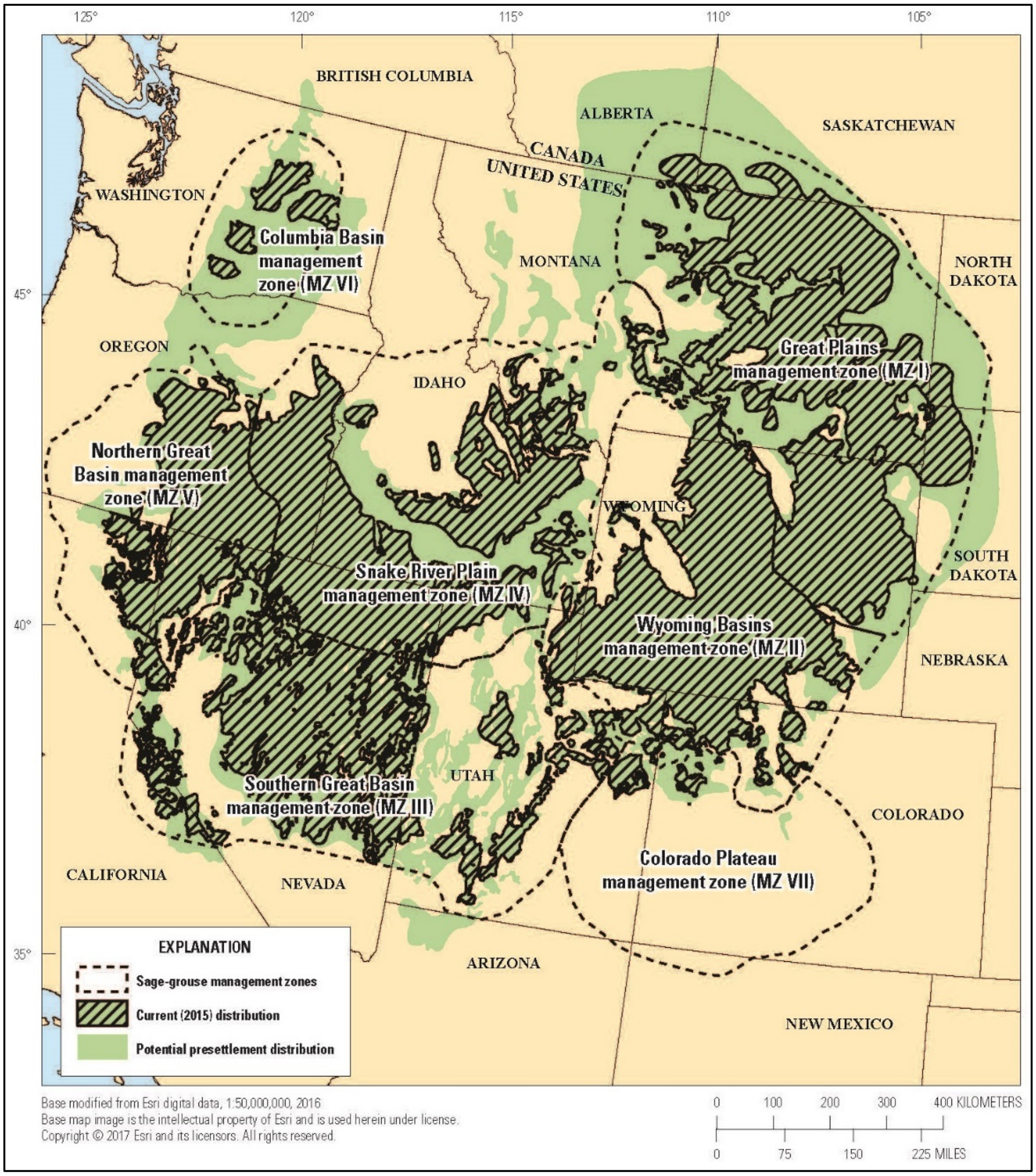


Figure 4.12-1. The current breeding distribution of greater sage-grouse in the United States and southern Canada and past distribution in North America (adapted from Hanser et al. 2018).

The greater sage-grouse is a very large grouse (2.2–6.3 lbs. and 18–30 inches long). It is a ground-dwelling bird with a heavily-marked plumage of gray and white giving it a speckled appearance. Its long tail is pointed and also speckled and can be pitched vertically and fanned when the adult male bird is displaying. When males are displaying on leks, the feathers on either side of their neck are erect, yellow combs above the eyes are displayed and unfeathered yellow/orange sacs along the lateral sides of the neck are inflated.

Greater sage-grouse are most easily observed during breeding season when males are actively attracting and competing for mates at leks. Lek sites are situated on broad ridgetops, grassy swales, dry playas and disturbed sites (such as burns, cultivated fields, airstrips, gravel pits, and roads) that are all characterized by having less herbaceous and shrub cover than surrounding habitats (Shroeder et al. 1999). The absence of tall shrubs, trees, or other obstructions appears to be critical for continued use of lek sites, which typically are close to suitable nesting habitat that consists of sagebrush greater than 6 inches tall with a canopy cover above 20 percent (CDW 2008, Wakkinen et al. 1992, Wallestad and Schladweiler 1974). In contrast, wintering habitat in Colorado is characterized by sagebrush that is 12–16 inches tall with a canopy cover of more than 25 percent (Schoenberg 1982). Nests are bowls of grass, forbs, and feathers placed under tall sagebrush ranging from 11–31 inches in height (Connelly et al. 2000, Schroeder et al. 1999).

After eggs hatch, the hen and chicks remain in areas of sagebrush similar to their nesting habitat, but hens and their broods may move to riparian wet meadows, hay meadows or alfalfa fields if rainfall is low and vegetation in sagebrush habitat dries out (Connelly et al. 2000, Fischer et al. 1996).

As with many wildlife species, the diet of greater sage-grouse is dependent on season, age, sex, and availability. Common food items include sagebrush, forbs and insects, with sagebrush being dominant for adults and insects for juveniles (Schroeder et al. 1999). Primary predators for adult and juvenile greater sage-grouse are avian raptors, common raven, coyotes, fox and bobcats while nest predators are more diverse, including American crows, badgers, weasels and ground squirrels (Schroeder et al. 1999).

At DINO, the success of the greater sage-grouse is dependent upon the continuity of quality habitat for lekking, roosting, nesting, and fledging found mainly outside of the monument. Low recruitment, as indicated by nest and chick survival, is a limiting factor in sage-grouse population growth. The leading cause of sage-grouse nest failure is nest loss to predators (Moynahan et al. 2007, Coates and Delehanty 2010, Webb et al. 2012). Insect populations, which are vital for juvenile survival, are sensitive to periodic drought and can limit population growth of grouse and their relatives (Flanders-Wanner et al. 2004).

Threats and Stressors

The predominant threats in Colorado are habitat fragmentation and loss of sagebrush from activities such as energy development, associated infrastructure, agricultural conversion, invasive grasses and fire, with ex-urban development as a localized stressor (USFWS 2019).

A significant threat to greater sage-grouse at DINO and throughout much of the species' range is regional-scale, climate-driven mortality of sagebrush that has contributed to declines in sagebrush-dependent bird species (Miller et al. 2017, Palmquist et al. 2016, Schrag et al. 2010). Given current climate projections, modeling indicates that the loss of sagebrush attributable to a changing climate could potentially cause a 71 percent loss of greater sage-grouse breeding range and a loss of 92 percent of their winter range by 2080 (Homer et al. 2015, NAS 2013). Habitat losses are likely to be significant due to drought and die-off of sagebrush, and increases in fire frequency, attributable to both rising temperatures and expansion of exotic annual *Bromus* grasses ultimately causing conversion of sagebrush systems to grassland (Shi et al. 2018, Bradley at al. 2016, Coates et al. 2016).

Greater sage-grouse are also threatened at DINO by expanding oil and gas production within the landscape surrounding the monument. Modeling of anthropogenic disturbance including oil and gas disturbance suggests that greater sage-grouse lekking populations are negatively impacted by human activities (Decker at al. 2017, Edmunds et al. 2017, Green et al. 2017). Research suggests that a maximum development density of one well pad within 2 kilometers of leks is required to avoid measurable effects within one year. Less than six well pads in total within 10 km of leks is the maximum density to avoid potential long-term declines in lek counts (Hanser et al. 2018, Gregory and Beck 2014).

Greater sage-grouse are also susceptible to West Nile virus (WNv), which is known to cause a high rate of mortality in the species (Walker et al. 2007). Modeling of WNv indicates that increases in temperature in western North America attributable to climate change will result in the spread of WNv into the core areas of sagebrush habitat causing both increased occurrence of WNv in greater sage-grouse and increased mortality (Schrag et al. 2010).

Indicators and Measures

- Percent of sagebrush habitat modeled as suitable within the monument
- Disturbance index associated with modeled suitable habitat
- Regional vulnerability of greater sage-grouse to climate change
- Regional male lek attendance

4.12.2. Data and Methods

A MaxEnt model developed for greater sage-grouse in northwestern Colorado was used to identify suitable habitat for the grouse within DINO (pers. comm., Brian Holmes, 2018). MaxEnt is a program for modelling species distributions from presence-only species records (Elith et al. 2011). The software is based on the maximum-entropy approach for modeling species niches and distributions. From a set of environmental factors that are relevant to habitat suitability and georeferenced occurrence localities, the model expresses a probability distribution where each grid cell has a predicted suitability of conditions for the species. Under particular assumptions about the input data and biological sampling efforts that led to occurrence records, the output can be interpreted as predicted probability of presence, or as predicted local abundance (Phillips et al. 2019).

The model was extrapolated from habitat and occurrences in Utah to identify suitable habitat for greater sage-grouse on the Utah portion of the monument. The variables modeled included elevation, slope, topographic relief, distance to juniper habitat, distance to riparian habitat, solar radiation, landscape disturbance, and sagebrush cover. These variables were chosen a priori and no other variables were analyzed for potential inclusion into the model. The generated model's area under the curve (AUC) for training data was 0.819 with a random prediction AUC of 0.5. Results from the two studies enable an evaluation of the extent and quality of greater sage-grouse habitat within the monument and the surrounding area.

Research suggests that anthropogenic disturbances have negative effects on habitat quality for plant and animal species (Decker et al. 2017, Haddad et al. 2015, McKelvey 2015). Geospatial models of anthropogenic disturbance on the landscape are useful in a variety of conservation activities, including condition assessments (Decker et al. 2017, Haines et al. 2013). Decker et al. (2017) developed a spatial disturbance index for greater sage-grouse habitat across the species' range in Colorado using data collected in 2017. This distance-based disturbance model is a composite index of the distance effects of mappable infrastructure on greater sage-grouse habitat across the landscape. Literature associated with studies of radio-equipped greater sage-grouse was used to establish distance effects for transmission lines, highways, unpaved roads, and producing natural gas/oil wells. For other anthropogenic features, Decker et al. (2017) applied literature-derived distances established for what they considered the most similar feature type. This spatial disturbance index focuses on depicting the degradation of otherwise suitable greater sage-grouse habitat due to anthropogenic disturbance. The spatial disturbance index was used to assess the condition of suitable greater sage-grouse habitat within DINO.

The vulnerability of the greater sage-grouse to climate change effects was evaluated using the Climate Change Vulnerability Index (CCVI) (Young et al. 2016). The CCVI is a Microsoft Excel-based spreadsheet tool developed by NatureServe. It is designed as a rapid-assessment tool designed to assess the vulnerability of a plant, animal, or lichen to climate change in a defined geographic area and it is intended to be used primarily for practical planning purposes by natural resource managers. The intended application scale of the tool is up to the state or province level. The primary purpose of the CCVI is to produce a relative ranking or priority list for species of concern with respect to climate change vulnerability. The CCVI uses a scoring system that integrates a species' predicted exposure to climate change within an assessment area and three sets of factors associated with climate change sensitivity, each supported by published studies: 1) indirect exposure to climate change, 2) species-specific sensitivity and adaptive capacity factors (including dispersal ability, temperature and precipitation sensitivity, physical habitat specificity, interspecific interactions, and genetic factors), and 3) documented response to climate change.

Colorado State University worked with DINO staff to gather existing lek survey data and search the published literature for relevant greater sage-grouse population data. Unpublished long-term lek data were available for the entire region surrounding DINO (CPW 2019, Utah Division of Wildlife Resources 2019).

4.12.3. Reference Conditions

Understanding the extent and quality of greater sage-grouse habitat within DINO is complicated by historical land uses. The nearly 30,000 acres of sagebrush habitat at DINO was grazed by domestic livestock to varying degrees over time and much of the monument is stilled grazed today including areas on the monument that are currently used by greater sage-grouse (NPS 2015).

Suitable greater sage-grouse habitat encompasses large contiguous areas of native vegetation with a minimum area of approximately 6 to 62 square miles to provide for multiple aspects of species life requirements (USFS 2015). Within these landscapes, a variety of sagebrush community compositions exist without invasive species, which have variations in subspecies composition, co-dominant vegetation, shrub cover, herbaceous cover, and stand structure to meet seasonal requirements for food, cover, and nesting for the greater sage-grouse (USFS 2015).

In areas of greater sage-grouse suitable habitat, 70% or more of the lands capable of producing sagebrush should have from 10 to 30% sagebrush canopy cover and less than 10% conifer canopy cover (USFS 2015). In addition, breeding and nesting habitat should provide an herbaceous vegetation layer at least 6 inches tall to allow for overhead and lateral concealment of nesting and early brood-rearing life stages (see Table 4.12-1) (Pyke et al. 2015). Brood-rearing habitat located in wet meadows and riparian areas should contain a rich diversity of perennial grasses and forbs relative to site potential. Forb cover may be limited by site resources (for example, precipitation and soil depth); therefore, forb composition should be managed to maximize the site's potential within brood-rearing habitat, focusing especially on forbs that flower and fruit during the early brood-rearing period (Pyke et al. 2015). Moist environments should be maintained to provide prominent forb habitat (Pyke et al. 2015). Winter habitat should consist of sagebrush at a height and density necessary for providing food and cover during the winter period (Table 4.12-1) (USFS 2015). Winter habitats must provide sagebrush tall enough to stay above the snow so birds can forage. Exposed ridges often provide habitat because winds tend to blow snow from the ridges into drainages. Care should be taken to conserve all areas of sagebrush in greater sage-grouse winter range because suitable sagebrush stands are often very limited in severe winters (Pyke et al. 2015).

Table 4.12-1. Seasonal habitat desired conditions for the greater sage-grouse at the landscape scale (USFS 2015).

Seasonal Use	Attribute	Indicators	Desired Condition	Reference
BREEDING AND NESTING (March 1-June 15) Apply 4 miles from active leks.	Lek security	Proximity of trees	Trees or other tall structures are none to uncommon within 1.86 miles of leks.	Baruch-Mordo et al. 2013 Connelly et al. 2000 Doherty 2008 Holloran and Anderson 2005 Stiver et al. 2015
	Lek security	Proximity of sagebrush to leks	Adjacent protective sagebrush cover within 328 feet of lek	Stiver et al. 2015
	Cover	Seasonal habitat extent (Percent of seasonal habitat meeting desired conditions)	>80% of the breeding and nesting habitat	Connelly et al. 2000
	Cover	Sagebrush canopy cover	15 to 25%	Connelly et al. 2000 Connelly et al. 2003 Stiver et al. 2015
	Cover	Sagebrush height – Arid sites[1]	12 to 32 inches	Connelly et al. 2000 Stiver et al. 2015
	Cover	Sagebrush height – Mesic sites[2]	16 to 32 inches	Connelly et al. 2000 Stiver et al. 2015
	Cover	Predominant sagebrush shape	>50% in spreading [3]	Stiver et al. 2015
	Cover	Perennial grass canopy cover – Arid sites[1]	>10%	Connelly et al. 2000 Stiver et al. 2015
	Cover	Perennial grass canopy cover – Mesic sites[2]	>15%	Connelly et al. 2000 Stiver et al. 2015
	Cover	Perennial grass height	≥6 inches to provide overhead and lateral concealment from predators.	Connelly et al. 2000 Connelly et al. 2003 Stiver et al. 2015
	Cover	Perennial forb canopy cover – Arid sites[1]	>5%	Connelly et al. 2000 Stiver et al. 2015
	Cover	Perennial forb canopy cover – Mesic sites[2]	>10%	Connelly et al. 2000 Stiver et al. 2015

[1] 10–12 inch precipitation zone; *Artemisia tridentata wyomingensis* is a common big sagebrush sub-species for this type site (Stiver et al. 2015).

[2] >12 inch precipitation zone; *Artemisia tridentata vaseyana* is a common big sagebrush sub-species for this type site (Stiver et al. 2015).

[3] Sagebrush plants with a spreading shape provide more protective cover than sagebrush plants that are more tree or columnar shaped (Stiver et al. 2015).

Table 4.12-1 (continued). Seasonal habitat desired conditions for the greater sage-grouse at the landscape scale (USFS 2015).

Seasonal Use	Attribute	Indicators	Desired Condition	Reference
BROOD-REARING/ SUMMER[4] (June 16-October 31)	Cover	Seasonal habitat extent (Percent of seasonal habitat meeting desired conditions)	>40% of the brood-rearing/summer habitat	Connelly et al. 2000
	Cover	Sagebrush canopy cover	10 to 25%	Connelly et al. 2000 Connelly et al. 2003 Stiver et al. 2015
	Cover	Sagebrush height	16 to 32 inches	Connelly et al. 2000 Connelly et al. 2003
	Cover	Perennial grass and forb canopy cover	>15%	Connelly et al. 2000 Connelly et al. 2003
	Cover	Riparian areas/mesic meadows	Proper Functioning Condition [5]	–
	Cover	Upland and riparian perennial forb availability	Preferred forbs are common with several preferred species present [6]	Connelly et al. 2000 Stiver et al. 2015
	Cover	Sagebrush cover adjacent to riparian areas/mesic meadows	Within 328 feet.	Stiver et al. 2015
WINTER[4] (November 1-February 28)	Cover and Food	Seasonal habitat extent (Percent of seasonal habitat meeting desired conditions)	>80% of the winter habitat	Connelly et al. 2000 Connelly et al. 2003 Stiver et al. 2015
	Cover and Food	Sagebrush canopy cover above snow	>10%	Connelly et al. 2000 Connelly et al. 2003 Stiver et al. 2015
	Cover and Food	Sagebrush height above snow	>10 inches [7]	Connelly et al. 2000 Connelly et al. 2003 Stiver et al. 2015

[4] Seasonal dates can be adjusted; start and end dates may be shifted either earlier or later, but the number of days cannot be shortened or lengthened.

[5] Existing land management plans for desired conditions for riparian areas/wet meadows (including spring seeps) may be used in place of properly functioning conditions, if appropriate for meeting greater sage-grouse habitat requirements.

[6] Preferred forbs are listed in Table III-2 of Stiver et al. (2015). Overall total forb cover may be greater than that of preferred forb cover since not all forb species are listed as preferred in Table III-2.

[7] The height of sagebrush remaining above the snow depends upon snow depth in a particular year. Intent is to manage for tall, healthy sagebrush stands.

Because accurate records of greater sage-grouse presettlement abundance at DINO do not exist, it is difficult to establish a reference condition that adequately portrays pre-European settlement population sizes. Recent long-term lek count data suggest that densities reached some of their highest levels in the early-2000s, when mean male greater sage-grouse lek counts were approximately 750

males per lek for multiple years (Clifton 2003). However, land management practices of that era and those still prevalent today can be detrimental to greater sage-grouse production (Hanser et al. 2018, Rice et al. 2016, Blomberg et al. 2012). Reference conditions for breeding success are poorly defined for the area. Likely, the best metrics for assessing condition of the greater sage-grouse at DINO are the percent of sagebrush habitat on DINO modeled by the MaxEnt procedure as suitable for greater sage-grouse breeding, and the condition of that habitat as defined by the spatial disturbance index developed for greater sage-grouse habitat within the region of northwestern Colorado by Decker et al. (2017). The results for climate change vulnerability are not incorporated in the condition rating, but did weigh in for the trend rating. A rating system for departure from good condition for greater sage-grouse at DINO is shown in Table 4.12-2.

Table 4.12-2. Resource condition rating framework for greater sage-grouse at Dinosaur National Monument.

	Condition Status		
Indicator	**Resource is in Good Condition**	**Condition Warrants Moderate Concern**	**Condition Warrants Significant Concern**
Percent of DINO Sagebrush Habitat Modeled as Suitable	>85% suitable	70–85% suitable	<70% suitable
Condition of Modeled Suitable Habitat	>75% none – low disturbance	50–75% none – low disturbance	<50% none – low disturbance
Regional Male Lek Attendance	>85–100+% of 2005 value	70–85% of 2005 value	<70% of 2005 value
Regional Vulnerability to Climate Change	na (trend only)	na (trend only)	na (trend only)

4.12.4. Condition and Trend

<u>Percent of DINO Sagebrush Habitat Modeled as Suitable</u>

The MaxEnt model estimated approximately 17,000 acres of suitable greater sage-grouse habitat within DINO compared to approximately 30,000 acres of total sagebrush habitat available in the monument (Coles et al. 2008) (Figure 4.12-2). Approximately 59 percent of sagebrush habitat was classified as suitable, indicating the condition of the resource warrants moderate concern (Table 4.12-2). The severe topographic relief associated with the river canyons present at DINO are unsuitable for the greater sage-grouse, which prefer more gentle terrain (Walker et al. 2016, Severson et al. 2017). Consequently, much of the sagebrush habitat at DINO is not suitable for greater sage-grouse (pers. comm., Brian Holmes, 2019). Analysis of Northern Colorado Plateau Network (NCPN) vegetation data indicates sagebrush habitat at DINO is in moderate condition with cheatgrass common and reported as a dominant species in 60 percent the monitored locations. It is suspected that increased fire frequencies and concurrent increases in cheatgrass abundance will likely contribute to conversions of sagebrush shrublands to grasslands at DINO (see Section 4.9, *Vegetation* above). Projected changes in climate are expected to cause climate-driven mortality of sagebrush

(Homer et al. 2015, NAS 2013), but there is no evidence that decline has begun at DINO or in the surrounding region.

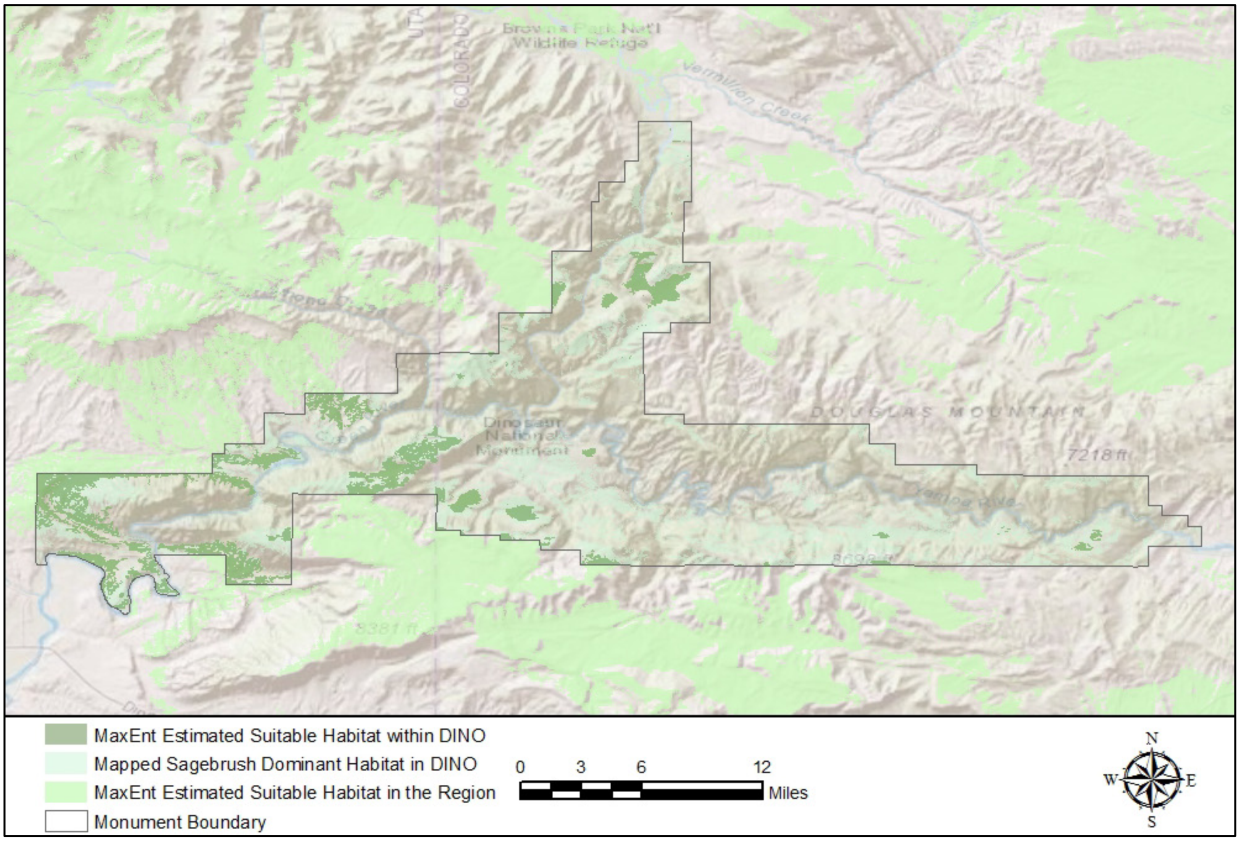


Figure 4.12-2. Modeled suitable greater sage-grouse and sagebrush-dominated habitat within Dinosaur National Monument and surrounding area (data source: Brian Holmes, Colorado Parks and Wildlife).

Telemetry data from radio-equipped greater sage-grouse in the area of DINO indicate that grouse are actively using suitable sagebrush habitat on the monument (pers. comm., Brian Holmes, 2018) (Figure 4.12-3). Although there are 44 active lek sites within 10 miles of the monument, largely concentrated along the south and the northwest boundaries, no leks are documented in the monument. Seven lek sites are all within 2 miles of the monument boundary. Greater sage-grouse activity within DINO is concentrated in areas northeast of Tanks Peak in the Blue Mountain area, the Round Top Mountain – Roundtop Lookout area, Canyon Overlook north of Harlan Cabin, Ruple Point and north of the Island Park Road near McKee Spring. Radio-telemetry monitoring results indicate that these areas support both nesting and winter populations of greater sage-grouse but that habitat suitable for brooding females does not occur on the monument (pers. comm., Brian Holmes, 2019).

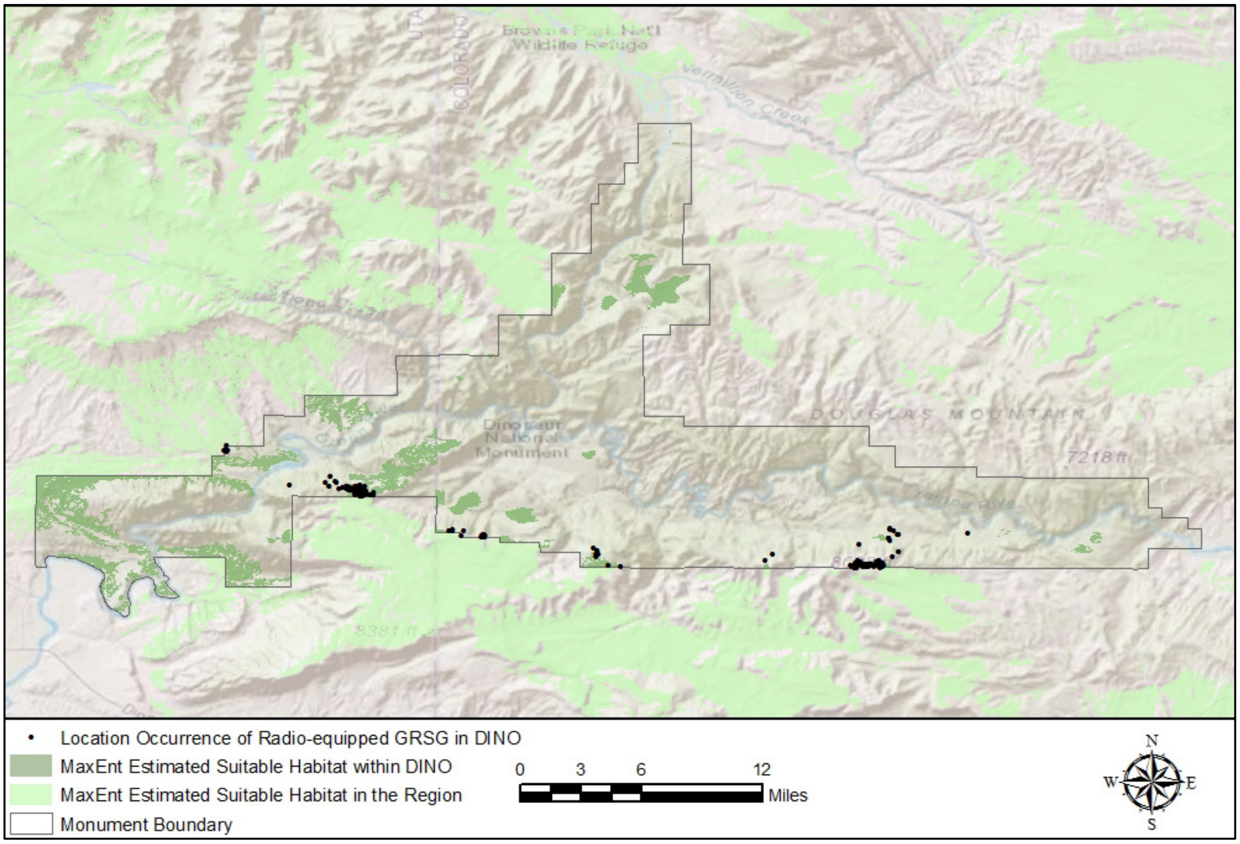


Figure 4.12-3. Telemetry locations of radio-equipped greater sage-grouse (GRSG) and modeled suitable habitat at Dinosaur National Monument (data source: Brian Holmes, Colorado Parks and Wildlife).

<u>Condition of Modeled Suitable Habitat</u>

Suitable sagebrush habitat modeled using MaxEnt at DINO is approximately 30,000 acres. Of this total, 59 percent of the habitat falls within the no disturbance and low disturbance categories, suggesting that condition of the greater sage-grouse-suitable habitat at DINO warrants moderate concern (Table 4.12-2 and Figure 4.12-4). Trends in condition of suitable sagebrush habitat at DINO is unknown as the greater sage-grouse spatial disturbance index exists only for the year 2017.

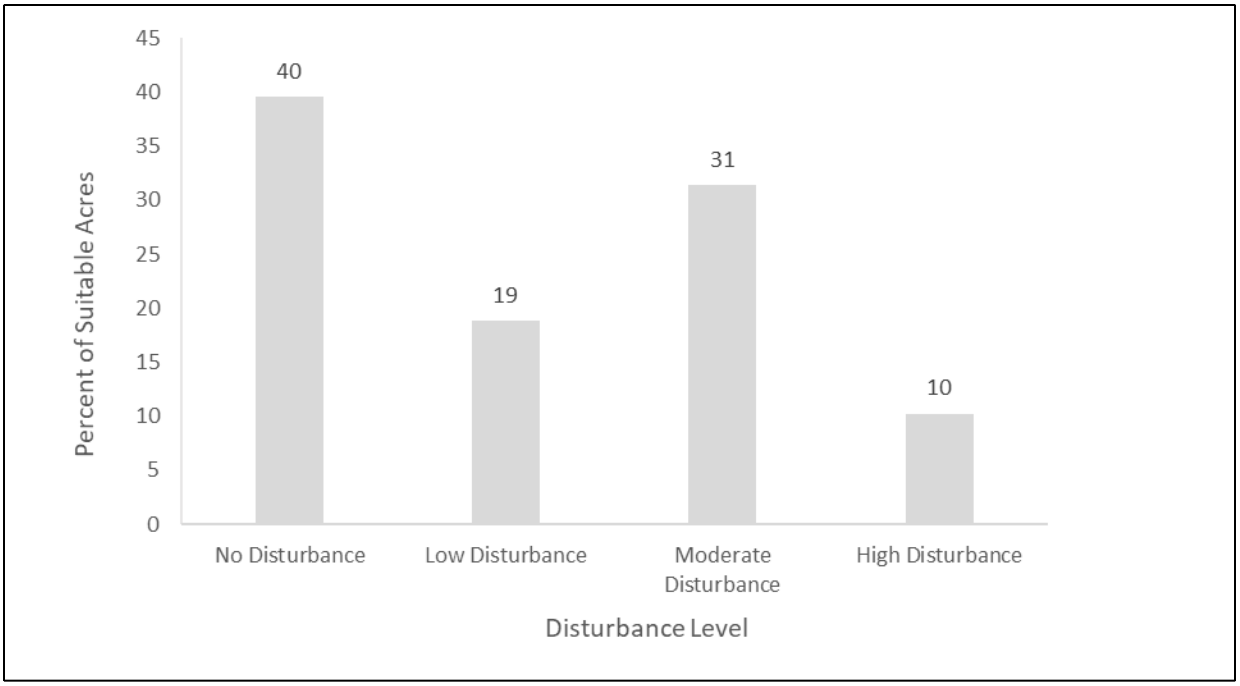


Figure 4.12-4. Assessment of condition of the suitable greater sage-grouse habitat for the year 2017 at Dinosaur National Monument (data source: Brian Holmes, Colorado Parks and Wildlife).

<u>Regional Male Lek Attendance</u>
The most-consistent data on greater sage-grouse abundance from the region surrounding DINO comes from traditional lek surveys. The technique is popular because it is easy to implement, is relatively inexpensive, and data analysis and interpretation are straightforward (Clifton and Krementz 2006).

The abundance of greater sage-grouse within DINO is poorly understood because there are no leks currently on DINO and there has never been a lek recorded within the monument. Efforts to locate sites suitable for lekking have not been undertaken and the MaxEnt modeling effort did not attempt to identify suitable lek sites within the monument. Location data for greater sage-grouse at DINO is limited to recently-conducted telemetry tracking of grouse by Colorado Parks and Wildlife (pers. comm., Brian Holmes, 2019). The mean number of males observed per lek during lek counts within the vicinity of Dinosaur National Monument declined by more than 50 percent between 2006 and 2010, and then more than doubled from 2010 to 2017 (Fig 4.12-5).

The mean number of male greater sage-grouse per lek site fluctuated between 375 and 1,327 individuals from 2005 to 2017 with 921 males present per lek in 2017. The 2017 value is greater than the 711 mean males per lek observed in 2005 indicating the resource is in good condition (Table 4.12-2, Figure 4.12-5).

The slope of the linear regression line for the mean number of male greater sage-grouse per lek was positive, but insignificant ($r^2 = 0.22$, $p = 0.1$). The 90 percent confidence intervals for the mean

number of male greater sage-grouse per lek suggest high variability in the number of males per lek (Figure 4.12-5).

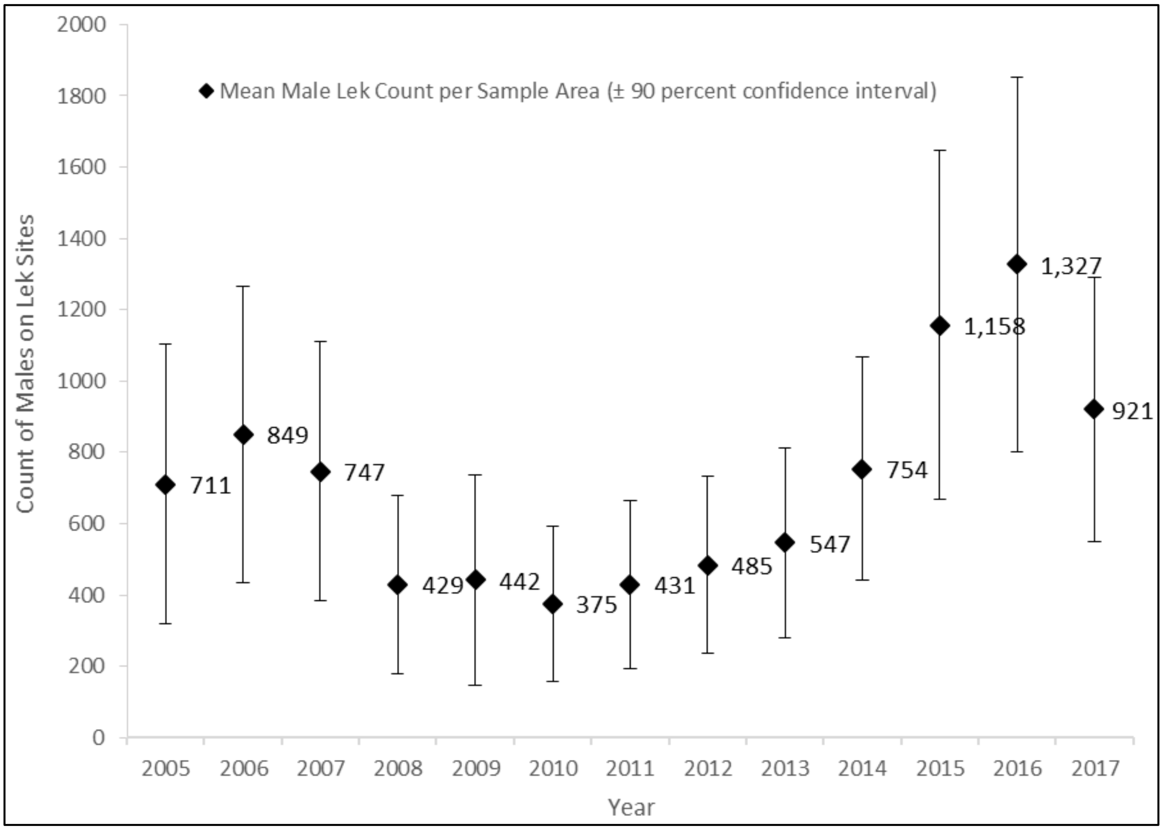


Figure 4.12-5. Means and 90 percent confidence intervals for the number of male greater sage-grouse observed per occupied lek within the vicinity of Dinosaur National Monument, 2005–2017 period (data source: Brian Holmes, Colorado Parks and Wildlife).

Regional Vulnerability to Climate Change

Each vulnerability factor was scored and results were compiled into an overall CCVI rating for the species (Table 4.12-3). By 2050, within its current range in northwestern Colorado and northeastern Utah, the species was considered extremely vulnerable. Confidence in the species information used in the assessment was very high. This result is similar to that published by CNHP (2015), whose CCVI assessment for the greater sage-grouse in Colorado determined that the species would be highly vulnerable under current predictive models of climate change.

The main factors of greater sage-grouse biology that make the species susceptible to alterations in climate include its significant reliance on sagebrush for nesting habitat, overwintering habitat and food, while sagebrush communities are expected to decline under current projections of climate change. Greater sage-grouse sensitivity to West Nile virus, which is expected to spread into the core areas of sagebrush habitat over time, is anticipated to cause increased occurrence of WNv in greater sage-grouse and increased mortality (Schrag et al. 2010). The impacts of increasing spread of *Bromus* grasses may cause conversion of sagebrush systems to grasslands and concurrent increases in

fire frequency, intensifying the loss of sagebrush habitat (Shi et al. 2018, Bradley at al. 2016, Coates et al. 2016). The climate change indicator was assigned a medium degree of confidence because of a *sufficient data* status and moderate level of CCVI confidence. The estimated vulnerability of greater sage-grouse to climate change was used as a trend indicator while other metrics were used to assess condition of the species at DINO.

Table 4.12-3. Summary of CCVI factor ratings for the greater sage-grouse at Dinosaur National Monument.

CCVI Category	CCVI Factor Influencing Vulnerability	Degree to Which Factor Influences Vulnerability
INDIRECT EXPOSURE TO CLIMATE CHANGE	1) Exposure to sea level rise	Neutral
	2a) Distribution relative to natural barriers	Neutral
	2b) Distribution relative to anthropogenic barriers	Neutral
	3) Predicted impact of land use changes resulting from human responses to climate change	Neutral
SENSITIVITY AND ADAPTIVE CAPACITY	1) Dispersal and movements	Neutral
	2ai) Predicted sensitivity to changes in temperature: historical thermal niche	Neutral
	2aii) Predicted sensitivity to changes in temperature: physiological thermal niche	Neutral
	2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche	Neutral
	2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche	Somewhat Increase
	2c) Dependence on a specific disturbance regime likely to be impacted by climate change	Somewhat Increase
	2d) Dependence on ice, ice-edge, or snow-cover habitats	Neutral
	3) Restriction to uncommon geological features or derivatives	Neutral
	4a) Dependence on other species to generate habitat	Increase
	4b) Dietary versatility (animals only)	Somewhat Increase
	4c) Pollinator versatility (plants only)	Not applicable
	4d) Dependence on other species for propagule dispersal	Neutral
	4e) Sensitivity to pathogens or natural enemies	Somewhat Increase
	4f) Sensitivity to competition from native or non-native species	Somewhat Increase
	4g) Forms part of an interspecific interaction not covered by 4a-d	Neutral
	5a) Measured genetic variation	Neutral
	5b) Occurrence of bottlenecks in recent evolutionary history	Neutral

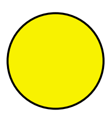
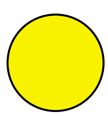
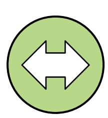
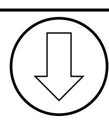
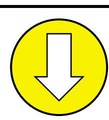
Table 4.12-3 (continued). Summary of CCVI factor ratings for the greater sage-grouse at Dinosaur National Monument.

CCVI Category	CCVI Factor Influencing Vulnerability	Degree to Which Factor Influences Vulnerability
SENSITIVITY AND ADAPTIVE CAPACITY (continued)	6) Phenological response to changing seasonal temperature and precipitation dynamics	Somewhat Increase

<u>Overall Condition and Trend</u>

The four condition metrics indicate the condition of the greater sage-grouse warrants moderate concern at DINO, with a declining trend and medium confidence in the assessment (Table 4.12-4). Vulnerability of the species to climate change appears high. Continued and enhanced frequency of fire, the spread of *Bromus* grasses, climate-driven mortality of sagebrush and climate-induced spread of West Nile virus in greater sage-grouse core areas could act in tandem to potentially reduce future populations of greater sage-grouse at the monument.

Table 4.12-4. Condition and trend summary for greater sage-grouse at Dinosaur National Monument.

Indicator	Condition Status/Trend	Rationale
Percent of DINO Sagebrush Habitat Modeled as Suitable		The MaxEnt model of suitable greater sage-grouse habitat within DINO, which is the only reliable source for this indicator, found 58.5% of sagebrush habitat in DINO is suitable for greater sage-grouse, which indicates that the resource warrants moderate concern. There is no trend information for this metric.
Condition of Modeled Suitable Habitat		The greater sage-grouse spatial disturbance index created in 2017, which is the only reliable source for this indicator, found that 59% of the habitat modeled by MaxEnt as suitable for greater sage-grouse within DINO has not been impacted by disturbance or has experienced low impacts due to disturbance, which indicates that condition of suitable grouse habitat at DINO warrants moderate concern. There is no trend information for this metric.
Regional Male Lek Attendance		Mean male lek counts fluctuated between a mean of 375 to 1,327 individuals per lek from 2005 to 2017 with male lek counts averaging 921 in 2017, greater than the management target of 85% of 711, the mean recorded per lek in 2005. Analysis of greater sage-grouse monitoring data indicated a stable trend in male greater sage-grouse counts between 2005 and 2017.
Climate change vulnerability		The climate change vulnerability analysis estimated that the species is extremely vulnerable with regard to climate change through 2050. Only the trend in this indicator is applied to the overall rating of this resource.
Greater sage-grouse overall		**Condition warrants moderate concern with a deteriorating trend. Confidence in the assessment is medium.**

4.12.5. Uncertainty and Data Gaps

The biggest data gap is lack of information on the condition and trend of the sagebrush community at DINO. The vegetation classification and map produced by Coles et al. (2008) was begun in 2002. NCPN has since collected other upland vegetation data in sagebrush habitats (Witwiki 2013). However, the NCPN data is not robust enough to enable habitat quality condition and trend for park-wide sagebrush habitats. Monitoring data identifying trends in the cover of sagebrush communities and their condition relative to disturbance within DINO would improve understanding of the monument's role in the regional conservation of greater sage-grouse. Research documenting vegetation composition and height, understory cover, herbaceous characteristics, live and residual vegetation and the potential loss of sagebrush habitat as regional climate continues to change would be very helpful in understanding the habitat for this at-risk species. Monitoring efforts to assess both the spread of *Bromus* grasses and changes in fire frequency within DINO sagebrush communities would also help understand how the ecology and persistence of the sagebrush system is changing at DINO. Other specific data gaps related to sage-grouse life-stages include vegetation heights and structure, horizontal/understory cover, abundance and quality of grasses and forbs, and up-to-date plant community maps and data. These latter data elements can indicate the extent and quality of nesting cover, brood-rearing cover, foraging habitat, etc. Monitoring trends in the incidence and spread of West Nile virus in greater sage-grouse populations of the area will assist in understanding the threat that WNv presents to the grouse population.

Consistent and unbiased population monitoring data are necessary to understand trends in the greater sage-grouse population. Although traditional lek counts are the easiest method of getting annual data on male density, they tend to underestimate population size (Clifton and Krementz 2006). Nonetheless they are sensitive to changes in populations over time. Mark-resight methodology can estimate populations more accurately but are more expensive. Assessments of breeding success are valuable to understand how recruitment bolsters population stability, but, as with mark-resight sampling, requires greater investment of time and money (McNew 2010).

4.12.6. Sources of Expertise

- Brian Holmes, Colorado Parks and Wildlife conservation biologist for northwest Colorado stationed in Meeker, Colorado, is the point of contact for greater sage-grouse on the Colorado portion of the monument. Mr. Holmes supplied much of the data used in this assessment. Brian Maxfield, a sensitive species biologist with the Utah Division of Wildlife, is the expert on greater sage-grouse for northeastern Utah.

4.12.7. Literature Cited

Baruch-Mordo, S., J.S. Evans, J.P. Severson, D.E. Naugle, J.D. Maestas, J.M. Kiesecker, M.J. Falkowski, C.A. Hagen, and K.P. Reese. 2013. Saving sage-grouse from trees: a proactive solution to reducing a key threat to a candidate species. Biological Conservation 167: 233–241.

Blomberg, E.J., J.S. Sedinger, M.T. Atamian, and D.V. Nonne. 2012. Characteristics of climate and landscape disturbance influence the dynamics of greater sage-grouse populations. Ecosphere 3(6):55. Available at: http://dx.doi.org/10.1890/ES11-00304.1.

Bradley, B.A, C.A. Curtis, and J.C. Chambers. 2016. *Bromus* response to climate and projected changes with climate change. Pages 257–274 *in* M. J. Germino, J. C. Chambers, and C. S. Brown, editors. Exotic brome-grasses in arid and semiarid ecosystems of the western US. Springer International Publishing, Switzerland.

Braun, C.E. 1998. Sage grouse declines in western North America: What are the problems? Proceedings of the Western Association of Fish and Wildlife Agencies 78:139–156.

Clifton, A.M. 2003. Using mark-resight techniques to estimate numbers of greater prairie-chickens in tallgrass prairie, Flint Hills, Kansas. Thesis. University of Arkansas, Fayetteville, Arkansas.

Clifton, A.M., and D.G. Krementz. 2006. Estimating numbers of greater prairie-chickens using mark-resight techniques. Journal of Wildlife Management 70:479–484.

Coates, P.S., and D.J. Delehanty. 2010. Nest predation of greater sage-grouse in relation to microhabitat factors and predators. Journal of Wildlife Management 74:240–248.

Coates, P.S., M.A. Ricca, B.G. Prochazka, M.L. Brooks, K.E. Doherty, T. Kroger, E.J. Blomberg, C.A. Hagen, and M.L. Casazza. 2016. Wildfire, climate, and invasive grass interactions negatively impact an indicator species by reshaping sagebrush ecosystems. Proceedings of the National Academy of Sciences 113:12745–12750. Available at: https://doi.org/10.1073/pnas.1606898113.

Coles, J., D. Cogan, D. Salas, A. Wight, G. Wakefield, J. Von Loh, and A. Evenden. 2008. Vegetation classification and mapping project report, Dinosaur National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2008/112. National Park Service, Fort Collins, Colorado.

Colorado Division of Wildlife (CDW). 2008. Colorado greater sage-grouse conservation plan. Available at: https://sagemap.wr.usgs.gov/docs/rs/2008%20Colorado%20Plan.pdf (accessed 6 February 2019).

Colorado Natural Heritage Program (CNHP). 2015. Climate Change Vulnerability Assessment for Colorado Bureau of Land Management. K. Decker, L. Grunau, J. Handwerk, and J. Siemers, editors. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

Colorado Parks and Wildlife (CPW). 2015. Colorado's 2015 state wildlife action plan. Available at: http://cpw.state.co.us/aboutus/Pages/StateWildlifeActionPlan.aspx.

CPW. 2019. Unpublished data on greater sage grouse male lek counts for the northwest region, Meeker, Colorado.

Connelly, J.W., M.A. Schroeder, A.R. Sands, and C.E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28:967–985.

Connelly, J., K. Reese, and M. Schroder. 2003. Monitoring of greater sage-grouse habitats and populations. Station Bulletin 80, Contribution 979. University of Idaho, College of Natural Resources Experiment Station. Moscow, Idaho.

Decker, K.L., A. Pocewicz, S. Harju, M. Holloran, M N. Fink, T.P. Toombs, and D.B. Johnston. 2017. Landscape disturbance models consistently explain variation in ecological integrity across large landscapes. Ecosphere 8(4):e01775. Available at: https://doi.org/10.1002/ecs2.1775.

Doherty, K. 2008. Sage-grouse and Energy Development: Integrating Science with Conservation Planning to Reduce Impacts. University of Montana. Missoula, Montana.

Edmunds, D.R., C.L. Aldridge, M.S. O'Donnell, and A.P. Monroe. 2017. Greater sage-grouse population trends across Wyoming. Journal of Wildlife Management 82:397–412.

Elith, J., S.J. Phillips, T. Hastie, M. Dudik, Y.E. Chee, and C.J. Yates. 2011. A statistical explanation of MaxEnt for ecologists. Density and Diversity 17:43–47.

Fedy, B.C., C.L. Aldridge, K.E. Doherty, M. O'Donnell, J.L. Beck, B. Bedrosian, M.J. Holloran, G.D. Johnson, N.W. Kaczor, C.P. Kirol, C.A. Mandich, D. Marshall, G. McKee, C. Olson, C.C. Swanson, and B.L. Walker. 2012. Interseasonal movements of greater sage-grouse, migratory behavior, and an assessment of the core regions concept in Wyoming. The Journal of Wildlife Management 76:1062–1071.

Fischer, R.A., K.P. Reese, and J.W. Connelly. 1996. Influence of vegetal moisture content and nest fate on timing of female sage grouse migration. The Condor 98:868–872.

Flanders-Wanner, B.L., G.C. White, and L.L. McDaniel. 2004. Weather and prairie grouse: dealing with effects beyond our control. Wildlife Society Bulletin 32:22–34.

Green, A.W., C.L. Aldridge, and M.S. O'Donnell. 2017. Investigating impacts of oil and gas development on greater sage-grouse. Journal of Wildlife Management 81:46–57.

Gregory, A.J., and J.L. Beck. 2014. Spatial heterogeneity in response of male greater sage-grouse lek attendance to energy development. PloS ONE 9(6):e97132. Available at: https://doi.org/10.1371/journal.pone.0097132.

Haddad, N.M, L.A. Brudvig, J. Clobert, K.F. Davies, A. Gonzalez, R. . Holt, T.E. Lovejoy, J.O. Sexton, M.P. Austin, C.D. Collins, W.M. Cook, E.I. Damschen, R.M. Ewers, B.L. Foster, C.N. Jenkins, A J. King, W.F. Laurance, D.J. Levey, C.R. Margules, B.A. Melbourne, A.O. Nicholls, J.L. Orrock, D.-Xia Song, and J.R. Townshend. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances 1(2):e1500052. Available at: http://advances.sciencemag.org/content/1/2/e1500052.abstract.

Haines, S.S., J.E. Diffendorfer, L. Balistrieri, B. Berger, T. Cook, D. DeAngelis, H. Doremus, D.L. Gautier, T. Gallegos, M. Gerritsen, E. Graffy, S. Hawkins, K.M. Johnson, J. Macknick, P. McMahon, T. Modde, B. Pierce, J.H. Schuenemeyer, D. Semmens, B. Simon, J. Taylor, and K. Walton-Day. 2013. A framework for quantitative assessment of impacts related to energy and mineral resource development. Natural Resources Research 23:3–17.

Hanser, S.E., P.A. Deibert, J.C. Tull, N.B. Carr, C.L. Aldridge, T.C. Bargsten, T.J. Christiansen, P.S. Coates, M.R. Crist, K.E. Doherty, E.A. Ellsworth, L.J. Foster, V.A. Herren, K.H. Miller, A. Moser, R.M. Naeve, K.L. Prentice, T.E. Remington, M.A. Ricca, D.J. Shinneman, R.L. Truex, L.A. Wiechman, D.C. Wilson, and Z.H. Bowen. 2018. Greater sage-grouse science (2015–17)—Synthesis and potential management implications. U.S. Geological Survey Open-File Report 2018–1017. U.S. Geological Survey, Reston, Virginia. Available at: https://doi.org/10.3133/ofr20181017.

Holloran, M.J., and S.H. Anderson. 2005. Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. Condor 107:742–752.

Homer, C.G., G. Xian, C.L. Aldridge, D.K. Meyer, T.R. Loveland, and M.S. O'Donnell. 2015. Forecasting sagebrush ecosystem components and greater sage-grouse habitat for 2050: Learning from past climate patterns and Landsat imagery to predict the future. Ecological Indicators 55:131–145.

McKelvey, K.S. 2015. The effects of disturbance and succession on wildlife habitat and animal communities. Pages 143–156 *in* M. L. Morrison and H. A. Mathewson, editors. Wildlife habitat conservation: concepts, challenges and solutions. Johns Hopkins University Press, Baltimore, Maryland.

McNew, L.B., Jr. 2010. An analysis of greater prairie-chicken demography in Kansas: the effects of human land use on the population ecology of an obligate grassland bird. Dissertation. Kansas State University, Manhattan, Kansas.

Miller R.F., D.E. Naugle, J.D. Maestas, C.A. Hagen, and G. Hall. 2017. Special Issue: Targeted woodland removal to recover at-risk grouse and their sagebrush-steppe and prairie ecosystems. Rangeland Ecology and Management 70(1):1–8.

Moynahan, B.J., M.S. Lindberg, J.J. Rotella, and J.W. Thomas. 2007. Factors affecting nest survival of greater sage-grouse in northcentral Montana. Journal of Wildlife Management 71:1773–1783.

National Audubon Society (NAS). 2013. Developing a management model of the effects of future climate change on species: a tool for the landscape conservation cooperatives. Unpublished Report prepared for the U.S. Fish and Wildlife Service.

National Park Service (NPS). 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

Palmquist, K.A., D.R. Schlaepfer, J.B. Bradford, and W.K. Lauenroth. 2016. Mid-latitude shrub steppe plant communities: climate change consequences for soil water resources. Ecology 97:2342–2354. Available at: https://doi.org/10.1002/ecy.1457.

Phillips, S.J., M. Dudík, and R. Schapire. 2019. MaxEnt software for modeling species niches and distributions (Version 3.4.1). Available at: https://biodiversityinformatics.amnh.org/open_source/maxent/ (accessed 13 January 2019)

Pyke, D.A., J.C. Chambers, M. Pellant, S.T. Knick, R.F. Miller, J.L. Beck, P.S. Doescher, E.W. Schupp, B.A. Roundy, M. Brunson, and J.D. McIver. 2015. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 1. Concepts for understanding and applying restoration: U.S. Geological Survey Circular 1416.Available at: http://dx.doi.org/10.3133/cir1416.

Rice, M.B., L.G. Rossi, and A.D. Apa. 2016. Seasonal habitat use by greater sage-grouse (*Centrocercus urophasianus*) on a landscape with low density oil and gas development. PLoS ONE 11(10):e0165399.doi:10.1371/journal.pone.0165399.

Schoenberg, T.J. 1982. Sage grouse movements and habitat selection in North Park, Colorado. Thesis. Colorado State University, Fort Collins, Colorado.

Schrag, A., S. Konrad, S. Miller, B. Walker, and S. Forrest. 2010. Climate-change impacts on sagebrush habitat and West Nile virus transmission risk and conservation implications for greater sage-grouse. GeoJournal 76:561–575.

Schroeder, M.A., J.R. Young, and C.E. Braun. 1999. Greater sage-grouse (*Centrocercus urophasianus*), version 2.0. *In* A. F. Poole and F. B. Gill, editors. Birds of North America. Cornell Lab of Ornithology, Ithaca, New York. Available at: https://doi.org/10.2173/bna.425.

Schroeder, M.A., C.L. Aldridge, A.D. Apa, J.R. Bohne, C.E. Braun, S.D. Bunnell, J.W. Connelly, P.A. Deibert, S.C. Gardner, M.A. Hilliard, G.D. Kobriger, S.M. McAdam, C.W. McCarthy, J.J. McCarthy, D.L. Mitchell, E.V. Rickerson, and S.J. Stiver. 2004. Distribution of sage-grouse in North America. The Condor 106:363–377.

Severson, J.P., C.A. Hagen, J.E. Maestas, D.E. Naugle, J.D. Forbes, and K.E. Reese. 2017. Effects of conifer expansion on greater sage-grouse nesting habitat selection. The Journal of Wildlife Management 81:86–95.

Shi, H., M. Rigge, C.G. Homer, G. Xian, D.K. Meyer, and B. Bunde. 2018. Historical cover trends in a sagebrush steppe ecosystem from 1985 to 2013: Links with climate, disturbance, and management. Ecosystems 21:9123–929. Available at: https://doi.org/10.1007/s10021-017-0191-3.

Stiver, S.J., E.T. Rinkes, D.E. Naugle, P.D. Makela, D.A. Nance, and J.W. Karl, editors. 2015. Sage-Grouse Habitat Assessment Framework: A Multiscale Assessment Tool. Technical Reference 6710-1. BLM and Western Association of Fish and Wildlife Agencies, Denver, Colorado.

Thompson, T.R. 2012. Disperal ecology of greater sage-grouse in northwestern Colorado: evidence from demographic and genetic methods. Dissertation. University of Idaho, Moscow, Idaho.

U.S. Fish and Wildlife Service (USFWS). 2019. Greater Sage-grouse web site. Available at: https://www.fws.gov/greatersagegrouse/index.php (accessed 2 February 2019).

U.S. Forest Service (USFS). 2015. Greater sage-grouse record of decision for northwest Colorado and Wyoming. U.S. Forest Service dated September 2015. U.S. Forest Service, Lakewood, Colorado.

Utah Division of Wildlife Resources. 2019. Unpublished data on male lek counts of greater sage grouse for the northern region, South Ogden, Utah.

Utah Wildlife Action Plan Joint Team. 2015. Utah Wildlife Action Plan: a plan for managing native wildlife species and their habitats to help prevent listing under the Endangered Species Act. Publication number 15-14. Utah Division of Wildlife Resources, Salt Lake City, Utah.

Wakkinen, W.L., K.P. Reese, and J.W. Connelly. 1992. Sage grouse nest locations in relation to leks. Journal of Wildlife Management 56:381–383.

Walker B.L., D.E. Naugle, K.E. Doherty, and T.E. Cornish. 2007. West Nile virus and greater sage-grouse: estimating infection rate in a wild bird population. Avian Diseases Digest 2:14.

Walker, B.L., A.D. Apa, and K. Eichhoff. 2016. Mapping and prioritizing seasonal habitats for greater sage-grouse in northwestern Colorado. The Journal of Wildlife Management 80:63–77.

Wallestad, R.O., and P. Schladweiler. 1974. Breeding season movements and habitat selection of male sage grouse. Journal of Wildlife Management 38:634–637.

Webb, S.L., C.V. Olsen, M.R. Dzialak, S.M. Harju, J.B. Winstead, and D. Lockman. 2012. Landscape features and weather influence nest survival of a ground-nesting bird of conservation concern, the greater sage-grouse, in human-altered environments. Ecological Processes 1:4.

Witwicki, D. 2013. Integrated upland monitoring in Dinosaur National Monument: annual report 2011 (non-sensitive version). Natural Resource Technical Report NPS/NCPN/ NRTR—2013/712.N. National Park Service, Fort Collins, Colorado.

Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.01. NatureServe, Arlington, Virginia.

4.13. Bats

4.13.1. Background and Importance

Bats are inconspicuous components of parks in the Colorado Plateau ecoregion and are an important natural resource in riparian and upland landscapes in parks of the NPS Northern Colorado Plateau Inventory and Monitoring (I&M) Network (NCPN) (Miller et al. 2003). The NCPN facilitates inventories of resources and other vital signs within sixteen parks in four western states, including Dinosaur National Monument (DINO). Prioritization of inventory needs for DINO in 2000 determined that bats are important fauna with nearly the entire Colorado bat fauna represented at DINO (approximately 15 species) (NPS 2000).

Bats are a management concern due to rarity, sensitivity and/or potential management problems. The spotted bat (*Euderma maculatum*) had been proposed for protection under the Endangered Species Act (ESA), but was removed from the candidate list in 1996 and currently has no status under the ESA. Regional, range-wide and statewide trend data are not available for the spotted bat, so population status and trend cannot be assessed (Luce and Keinath 2007). The spotted bat is considered to have a low degree of threat, and populations are likely relatively stable or slowly declining; the bat is not known to be affected by white-nose syndrome (NatureServe 2018).

With its canyons, big rivers, and riparian, forest and shrubland ecosystems (Coles et al. 2008), DINO contains habitat for nearly all the bat species known to inhabit Colorado, including the following species of concern: Brazilian free-tailed bat (*Tadarida brasiliensis*), fringed myotis (*Myotis thysanodes*), hoary bat (*Lasiurus cinereus*), spotted bat (*Euderma maculatum*) and Townsend's big-eared bat (*Corynorhinus townsendii pallescens*). The ponderosa pine and pinyon-juniper woodlands in DINO provide important bat habitat (Armstrong et al. 2011). Regional-scale, climate-driven mortality of pinyon pines has caused widespread declines in both pinyon woodland habitat and pinyon cone production, resulting in reductions in at-risk pinyon-juniper woodland specialists, including most of the above-mentioned bat species of concern. The Brazilian free-tailed bat, spotted bat and Townsend's big-eared bat all forage in pinyon-juniper woodland (Armstrong et al. 2011). DINO also provides extensive semi-desert shrubland habitat for the Brazilian free-tailed bat, fringed myotis and Townsend's big-eared bat, which forage in sagebrush systems and are in decline across the American West (Miller et al. 2017). Widespread losses in sagebrush habitat have led to declines in sagebrush-dependent animals (Gilbert and Chalfoun 2011, Rosenberg et al. 2016).

The monument also protects 105 miles of the Green and Yampa Rivers and over 210,000 acres of associated river canyons, rock cliffs, crevices, caves and riparian habitat. The river canyons contain healthy bat roosting habitat; the riparian forests supply foraging habitat for Townsend's big-eared bat and foraging and roosting habitat for the hoary bat; the canyons, cliffs, crevices and caves also offer roosting habitat for the Brazilian free-tailed bat, fringed myotis, spotted bat and Townsend's big-eared bat.

In North America, bats are threatened by white-nose syndrome (WNS), a disease caused by the fungus *Pseudogymnoascus destructans* that can result in the loss of entire bat colonies. To date, WNS, has been reported in 33 states and seven Canadian provinces. White-nose syndrome has not

been reported in Colorado or Utah (White-Nose Syndrome Response Team 2019), but it may be only a matter of time before the fungus finds its way to DINO. Two bat species of concern found in DINO, the Brazilian free-tailed bat and Townsend's big-eared bat, have tested positive for *P. destructans*, but diagnostic signs of white-nose syndrome have not been documented in these two species. Research into methods to control human access to bat hibernacula and to prevent the spread of disease by limiting human activity and decontaminating gear used in hibernacula will be important for bat conservation in North America and at DINO (Alves et al. 2014, Frick et al. 2016).

Threats

The threats to bats at DINO include the human-caused or natural spread of WNS; disturbance of cave, crevice and mine habitat used for both winter hibernacula and summer roosting; and the continuing loss of mature forest habitat required for both foraging and maternity roosting. Climate change, hydrologic alteration and livestock grazing contribute to large-scale conversion of mesic riparian habitats to increasingly xeric communities throughout the West (Alves et al. 2014, Luce and Keinath 2007). These threats and their impacts can be both local and regional in scale, and can ultimately impact migratory patterns and ranges of the bats that inhabit DINO. Chronic and widespread habitat modifications disrupt ecological functions important to ecosystem integrity and to maintaining the bat community at DINO (Jørgensen and Müller 2000). Consequently, the ecological functioning of DINO depends upon maintaining the natural systems within and outside park boundaries.

Indicators and Measures

- Total bat abundance – all species
- Native bat species richness
- Occurrence and status of bat species of conservation concern

4.13.2. Data and Methods

Bat mist-net surveys were initiated at seven sites in DINO in 1982 (Bogan and Mollhagan 2010). These surveys ultimately included 42 different sites surveyed intermittently in and around DINO through 2010 (Table 4.13-1, Figure 4.13-1). Acoustic bat surveys using bat detectors to record bat calls for later analysis were conducted at 21 sites at DINO in 2009, 2010 and 2011 (Neubaum and Navo 2011) (Figure 4.13-1).

The sites, number of sites surveyed and the type of survey conducted varied by year (Table 4.13-1). A total of 50 different sites were surveyed in the 10 years that sampling occurred; a majority of sites were only surveyed in one year (28). The number of sites sampled per year ranged from three to 21. The number of years sampled per site ranged from one to six and averaged 1.82 (Table 4.13-1).

The mist-net protocol followed scientifically accepted methods for such surveys (e.g., Kunz and Kurta 1988, Kunz et al. 2009) and the nets were deployed across and around bodies of water (e.g., Haystack Rock Reservoir) and in perceived flyways (e.g., Hog Canyon, Split Mountain) (Bogan and Mollhagan 2010). The lengths of nets ranged from 3–20 meters and numbers of nets deployed on any single evening varied from one to five, depending on the area and shape of the body of water. Mist

nets were set up shortly before sunset and tended for several hours until bat activity declined. For acoustic surveys, bat echolocation calls were digitally recorded over an entire night on high capacity memory cards and transferred to laptop computers (Hayes 2000). SonoBat 3 software was used to analyze call data by species based on quantitative parameters from western call libraries included with the software (Neubaum and Navo 2011). Mean values of the indicators per sample site and unit of effort were used to assess condition and trend by comparing mist-net abundance data for native species between 1982 and 2010.

Table 4.13-1. Type of bat sampling by site and year at Dinosaur National Monument (sampling data from Bogan and Mollhagan (2010) and Neubaum and Navo (2011)). Survey type: Mist-netting = Mn, Acoustic = A.

Sample Site	1982	1985	1987	1988	1989	1990	2008	2009	2010	2011	No. Years Sampled
Alcove Brook	–	Mn	–	–	–	–	–	–	–	–	1
Bear Draw	–	–	Mn	–	–	–	–	–	–	–	1
Bear Draw Reservoir	–	–	–	–	–	–	Mn	Mn	–	–	2
Big Joe Campground	Mn	–	–	–	–	–	–	Mn	Mn, A	–	3
Buffham Place	–	–	–	Mn	–	–	–	–	–	–	1
Buffham Reservoir	–	–	–	Mn	–	–	Mn	–	–	–	2
Bull Canyon Pool	–	–	–	–	–	–	–	–	Mn	–	1
Canyon Overlook	–	–	–	–	–	Mn	–	–	–	–	1
Chew Reservoir	–	–	–	–	–	Mn	Mn	–	–	–	2
Cottonwood Creek Pond	–	–	–	–	–	–	–	–	Mn, A	–	1
Cottonwood Creek	–	–	–	–	–	Mn	–	–	–	–	1
Cub Creek	–	–	–	–	Mn	Mn	Mn	Mn	–	–	4
Deerlodge Park	–	–	–	–	–	–	–	–	A	–	1
Dry Woman Reservoir	–	–	Mn	–	–	–	Mn	Mn	Mn, A	–	4
Echo Park	–	–	–	–	–	–	–	–	A	–	1
Ely Creek	Mn	–	–	–	–	–	–	Mn	–	–	2
Five Springs	–	–	–	Mn	–	–	–	–	–	–	1
Gates Of Lodore	–	–	–	–	–	–	–	A	A	–	2
Harding Hole	Mn	–	–	–	–	–	–	Mn	Mn, A	A	4
Haystack Rock Reservoir	–	Mn	Mn	–	Mn	–	Mn	Mn	Mn, A	–	6
Haystack Rock	Mn	–	–	–	–	–	–	A	–	–	2
Hog Canyon	–	–	–	–	–	–	Mn	–	–	–	1
Jct Bull/Serviceberry	–	–	–	–	–	–	–	–	A	–	1
Jones Hole Campground	–	–	–	–	–	–	–	Mn, A	–	–	1

Table 4.13-1 (continued). Type of bat sampling by site and year at Dinosaur National Monument (sampling data from Bogan and Mollhagan (2010) and Neubaum and Navo (2011)). Survey type: Mist-netting = Mn, Acoustic = A.

Sample Site	1982	1985	1987	1988	1989	1990	2008	2009	2010	2011	No. Years Sampled
Laddie Park	–	–	–	–	–	–	–	Mn	A	A	3
Limestone Camp	–	–	–	–	–	–	–	A	A	–	2
Massey Camp	–	–	–	–	–	Mn	–	–	–	–	1
Massey Pond	–	–	–	–	–	–	Mn	–	–	–	1
Massey Reservoir	–	–	–	–	–	Mn	Mn	Mn	–	–	3
Massey Troughs	–	–	–	–	–	Mn	–	–	–	–	1
Morris Ranch	–	–	–	–	Mn	Mn	Mn	Mn	–	–	4
Old Bassett Cabin	–	–	–	Mn	–	–	–	–	–	–	1
Pool Creek	–	–	–	–	–	–	–	–	Mn, A	–	1
Pool Creek at Echo Park	Mn	–	–	–	–	–	Mn	Mn	–	–	3
Pool Creek Petroglyphs	–	–	–	Mn	Mn	–	Mn	Mn	–	–	4
Pool Creek Ranch	–	–	–	Mn	Mn	–	Mn	–	–	–	3
Pot Creek	Mn	–	–	–	–	–	–	Mn	–	–	2
Red Rock Slough	–	–	–	–	–	–	–	–	Mn, A	–	1
Rippling Brook	Mn	–	–	–	–	–	–	Mn	–	–	2
Snow Reservoir	–	–	–	–	–	–	–	Mn	–	–	1
Split Mountain	–	–	–	–	–	–	Mn	Mn	–	–	2
Starvation Valley Pool	–	–	–	–	–	–	–	–	Mn, A	–	1
Starvation Valley Pour-Off	–	–	–	–	–	–	–	–	Mn, A	–	1
State Line Camp	–	–	–	–	–	–	–	–	A	–	1
Tepee Hole	–	–	–	–	–	–	–	–	–	A	1
The Steps	–	–	–	–	–	–	–	–	Mn	–	1
Vermillion Creek	–	Mn	–	–	–	–	Mn	–	–	–	2
Volleyball Beach	–	–	–	–	–	–	–	–	A	–	1
Whispering Cave	–	–	–	–	–	–	–	–	Mn	–	1
Winnies Grotto	–	–	–	–	–	–	–	A	–	–	1
Total Sites per Year	7	3	3	6	5	8	15	21	20	3	Mean = 1.8 surveys/site

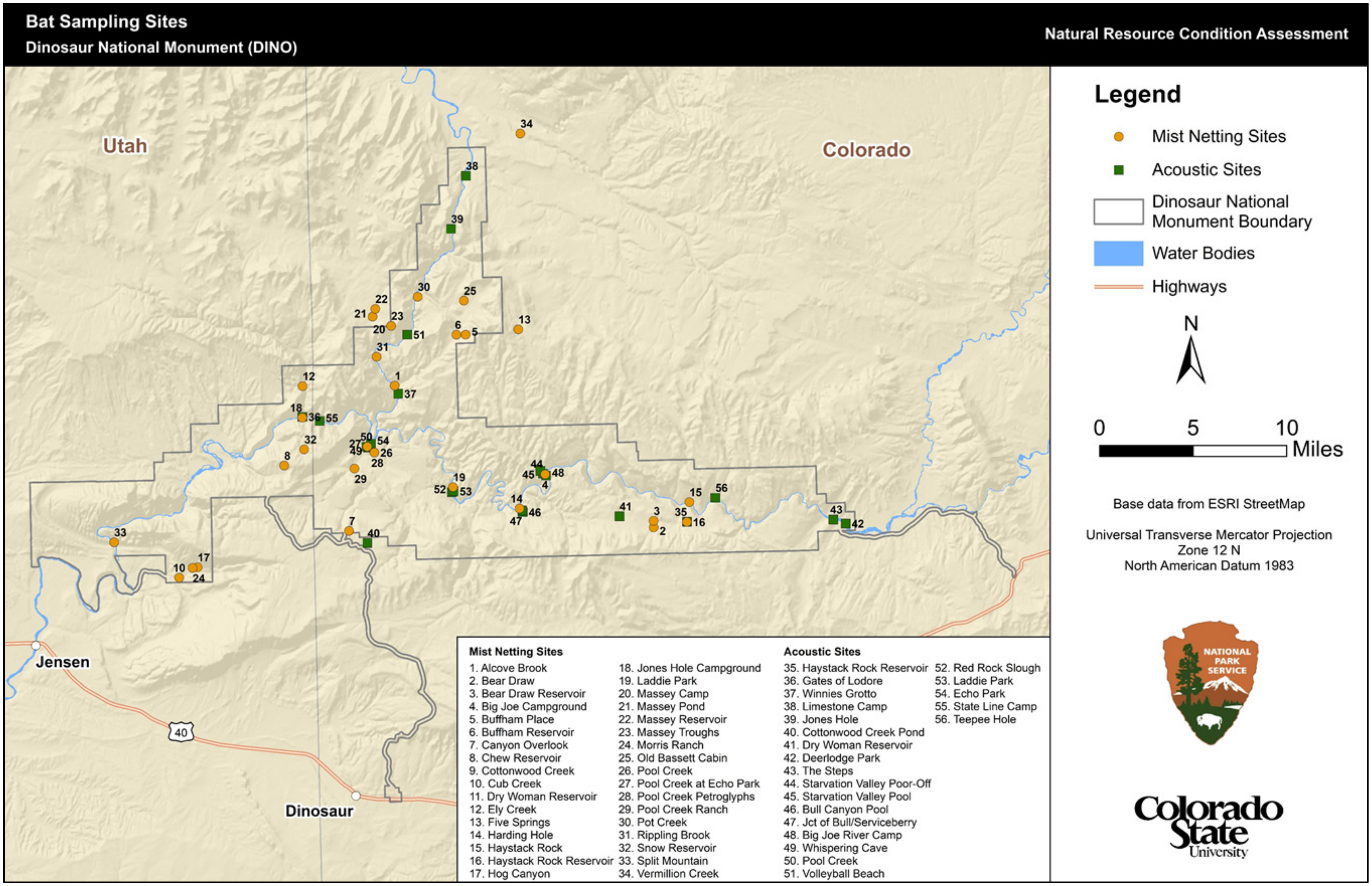


Figure 4.13-1. Bat sample sites on Dinosaur National Monument, 1982–2011. Bat sampling location data provided by NPS.

The acoustic surveys from 2009 through 2011 were not used in the analysis of abundance. The calculation of mean abundance per site and sampling effort in those years was not possible because acoustic recording only allows for quantification of the number of calls recorded by species, not the number of distinct individuals present.

To evaluate the occurrence and status of species of conservation concern within the monument, we used the occurrence of species listed as either endangered or threatened by the U. S. Fish and Wildlife Service (USFWS); U. S. Forest Service (USFS) and Bureau of Land Management (BLM) sensitive species lists; NatureServe G1 to G3 and S1 ranked species; and state lists of endangered, threatened and special concern species. Our intent was to determine which species that occur in DINO are considered species of conservation concern at either a national or local scale, to assess the current status (occurrence) of those species in the monument, and to evaluate the potential for the monument to play a role in conserving those species. This analysis was restricted to those species that were either breeding in the monument or that were residents. Those species occurring during migration only and incidental occurrences of species outside of their normal range were excluded.

4.13.3. Reference Conditions

Little historical survey data exist for DINO (see Section 4.13.2). Bat surveys using mist netting and acoustic sampling were conducted in DINO from 1982 through 2011 (Bogan and Mollhagan 2010, Neubaum and Navo 2011). The initial year of bat surveying (1982) is used as the reference condition. Maintaining or exceeding the level of biodiversity as measured by the 1982 estimates of total abundance for all species (as an index of population size), native bat species richness (as an index of diversity) and the number of species of conservation concern recorded in 1982 are considered good condition. The condition of the resource is considered higher if more species of concern are observed, because this implies that the populations of those species are increasing and/or they are using the monument more. A condition rating framework for bats is shown in Table 4.13-2.

Table 4.13-2. Resource condition rating framework for bats in Dinosaur National Monument.

	Condition Status		
Indicator	**Resource is in Good Condition**	**Condition Warrants Moderate Concern**	**Condition Warrants Significant Concern**
Total Bat Abundance – All Species	>85–100+% of 1982 value	70–85% of 1982 value	<70% of 1982 value
Native Species Richness	>85–100+% of 1982 value	70–85% of 1982 value	<70% of 1982 value
Bat Species of Conservation Concern	>85–100+% of 1982 value	70–85% of 1982 value	<70% of 1982 value

4.13.4. Condition and Trend

<u>Total Abundance – All Species Combined</u>

The mean bat species abundance per sample site and sampling effort recorded in the years sampled between 1982 and 2010 was variable, ranging from a low of 4.6 recorded in 1982, to a high of 17.2

in 2009 (Figure 4.13-2). In 2010, mean abundance was 11.1, greater than the mean abundance per sample site of 4.6 recorded in 1982, indicating the resource was in good condition in 2010 (Table 4.13-2). The slope of the linear regression line for bat mean abundance per sample site and sampling effort was positive and significant ($r^2 = 0.47$, $p = 0.04$), suggesting an increasing trend in the abundance of the bat population at DINO over time. The 90 percent confidence intervals for mean bat abundance for the years sampled between 1982 and 2010 have a high degree of overlap, suggesting few differences in the values and relatively high intra-year variability, especially in 1985 and 2008 through 2010.

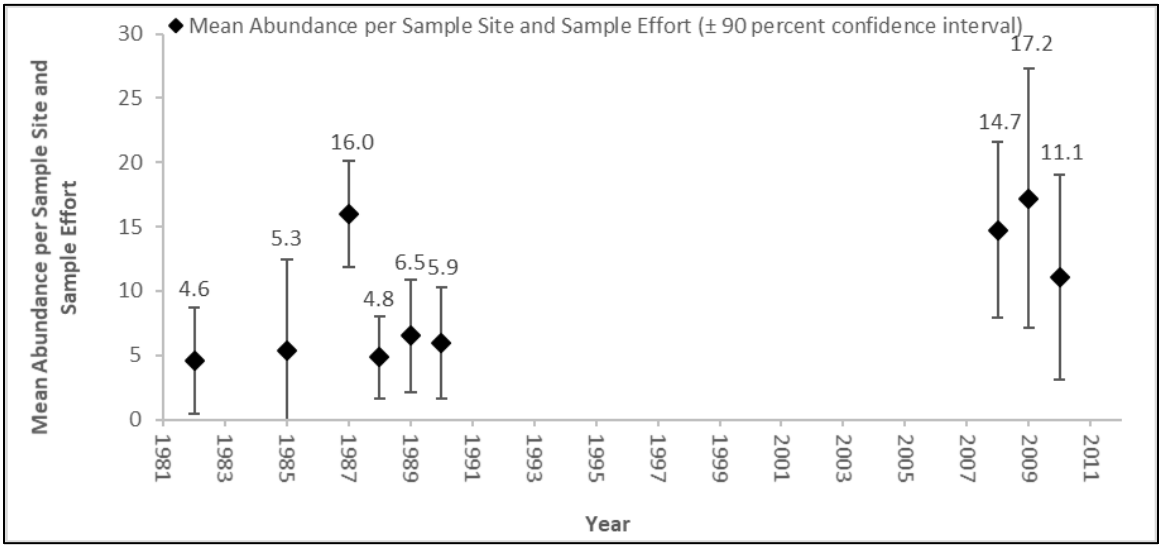


Figure 4.13-2. Means and 90 percent confidence intervals by site for total bat abundance (all species, standardized for sampling effort) at Dinosaur National Monument from 1982 to 2010 using mist-net data only (summary of data from Bogan and Mollhagan (2010) and Neubaum and Navo (2011)).

Species Richness

For mist net data, the mean number of native bat species sampled per site was 5.8 in 2010 (n=12) and 1.9 in 1982 (n=7), an increase of 3.9 species or 305 percent. This indicates that the resource is in good condition (Table 4.13-2 and Figure 4.13-3). Species recorded are listed in Table 4.13-3. The number of native bat species across all sample sites (mist netting and acoustic monitoring data) totaled 15 in 2011; the most common species by the number of calls recorded was the silver-haired bat (*Lasionycteris noctivagans*) (Table 4.13-3). The hoary bat (*Lasiurus cinereus*), canyon bat (*Parastrellus hesperus*), western small-footed myotis (*Myotis ciliolabrum*) and Yuma myotis (*Myotis yumanensis*) were the next most common.

Table 4.13-3. Bat species documented by mist-net surveys in 1982 and/or 2010 at Dinosaur National Monument (summary of data from Bogan and Mollhagan (2010) and Neubaum and Navo (2011)). Federal status abbreviations: BLM = Bureau of Land Management sensitive, FS = Forest Service sensitive, T = U.S. Fish and Wildlife Service listed as threatened; NatureServe Status S1 = state extremely rare; State List Status SC = state species of concern in Utah, Colorado, or both.

Common name	Species	Federal Status	NatureServe Status	State List Status
Big brown bat	*Eptesicus fuscus*	–	–	–
Brazilian free-tailed bat[1]	***Tadarida brasiliensis***	**–**	**S1**	**–**
California myotis	*Myotis californicus*	–	–	–
Fringed myotis[1]	***Myotis thysanodes***	**BLM, FS**	**–**	**SC**
Hoary bat[1]	***Lasiurus cinereus***	**FS**	**–**	**–**
Little brown myotis	*Myotis lucifugus*	T	–	–
Long-eared myotis	*Myotis evotis*	–	–	–
Long-legged myotis	*Myotis volans*	–	–	–
Pallid bat	*Antrozous pallidus*	–	–	–
Silver-haired bat	*Lasionycteris noctivagans*	–	–	–
Spotted bat[1]	***Euderma maculatum***	**BLM, FS**	**–**	**SC**
Townsend's big-eared bat[1]	***Corynorhinus townsendii***	**BLM, FS**	**–**	**SC**
Canyon bat	*Parastrellus hesperus*	–	–	–
Western small-footed myotis	*Myotis ciliolabrum*	–	–	–
Yuma myotis	*Myotis yumanensis*	–	–	–

[1] Species of concern (also in bold)

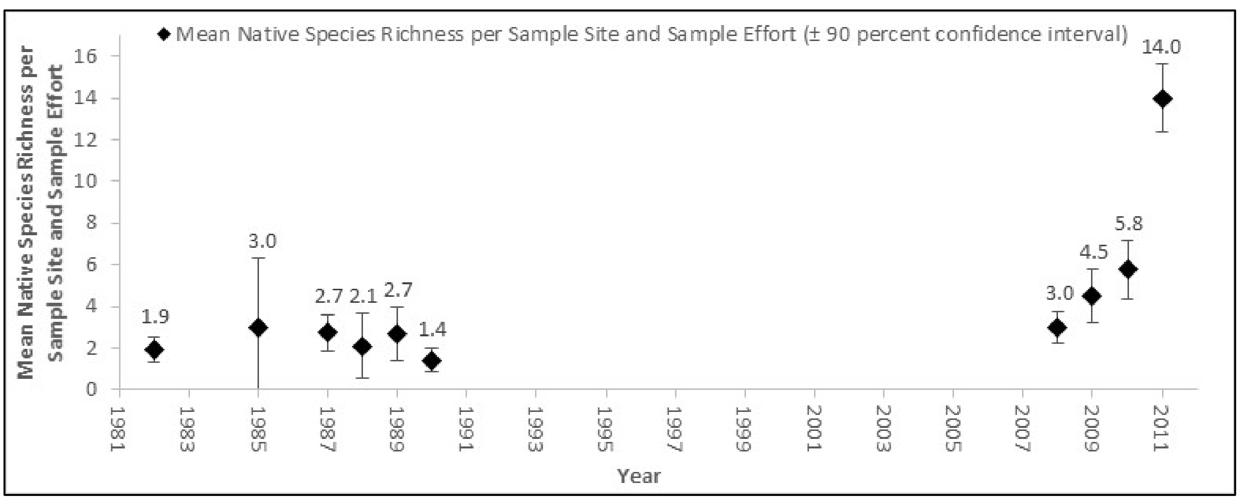


Figure 4.13-3. Means and 90 percent confidence intervals by site for native bat species richness at Dinosaur National Monument from 1982 to 2011 using both mist-net and acoustic monitoring data (summary of data from Bogan and Mollhagan (2010) and Neubaum and Navo (2011)).

Excluding the high richness values detected by acoustic monitoring in 2011, the slope of the linear regression for mean native bat species richness per sample site and sampling effort was not statistically significant ($p > 0.1$), suggesting unchanging richness of the bat community at DINO over time. None of the 90 percent confidence intervals for any year surveyed between 1982 and 2010 overlap with the 90 percent confidence interval for 2011. Within-year variability was especially high in 1985. Native bat species richness per sample site and sampling effort was highest in 2011 relative to all other years sampled (Figure 4.13-3). Given that there were only three sites surveyed in 2011, high native species richness in that year is likely due to differences in sampling methodology, i.e., use of acoustic detectors, compared to previous years (Table 4.13-1).

Species of Concern

There were five species of concern observed over the course of sampling at DINO (Table 4.13-3). The fringed myotis, hoary bat, spotted bat and Townsend's big-eared bat are listed by either the Bureau of Land Management, the U. S. Forest Service, or both as sensitive species; of these species all but the hoary bat are listed as species of special concern by either Colorado, Utah or both states (Table 4.13-3). The Brazilian free-tailed bat is listed as extremely rare in Colorado by NatureServe (Table 4.13-3).

An average of 4.0 species of conservation concern per sample site was recorded in 2011 surveys, which was greater than a mean of 0.2 species of conservation concern reported in 1982, indicating the resource was in good condition (Figure 4.13-4). A total of five bat species of conservation concern were recorded at DINO in 2011 (Table 4.13-3). This was greater than the three bat species of conservation concern recorded in 1982 (Table 4.13-3). The most common bat species of conservation concern recorded at DINO in 2011 was the hoary bat, followed by the Brazilian free-tailed bat, spotted bat, fringed myotis and the Townsend's big-eared bat (Table 4.13-3). All of the species of conservation concern increased in number between the 1982 survey and the 2011 survey (Table 4.13-3). The Brazilian free-tailed bat and spotted bat were not recorded at DINO in the initial 1982 survey. The spotted bat was not recorded at DINO until 2008, while the Brazilian free-tailed bat was first recorded at DINO in 1987.

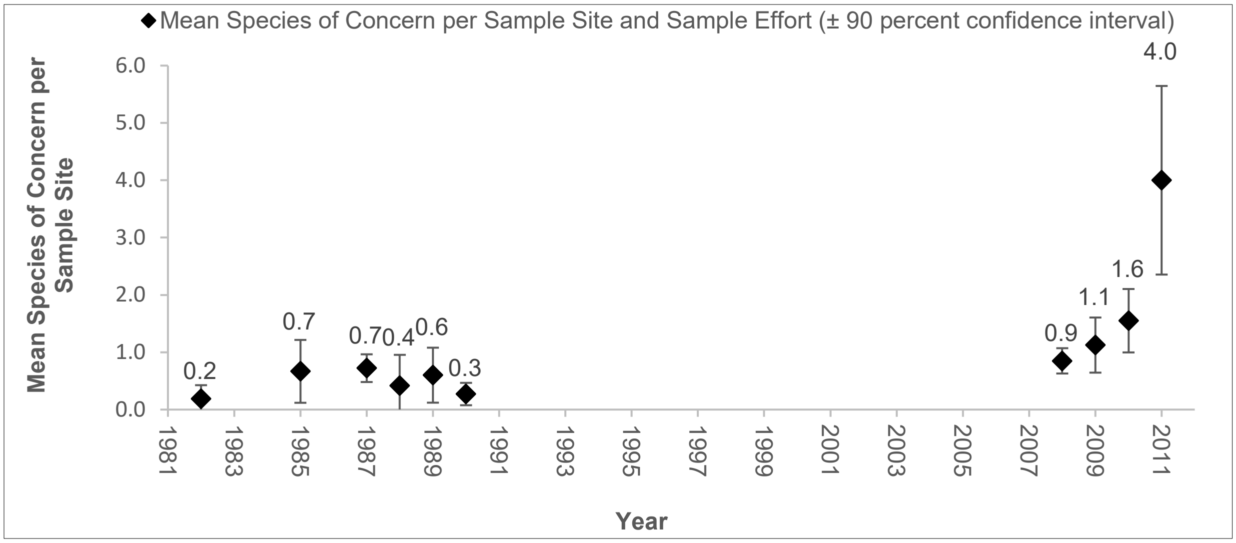


Figure 4.13-4. Means and 90 percent confidence intervals by site for bat species of conservation concern at Dinosaur National Monument from 1982 to 2011 using both mist-net and acoustic monitoring data (summary of data from Bogan and Mollhagan (2010) and Neubaum and Navo (2011)).

The slope of the linear regression for mean bat species of conservation concern per sample site, adjusted for sampling effort, was positive and statistically significant ($r^2 = 0.46$, $p = 0.03$), suggesting an increase in the number of bat species of conservation concern at DINO over the survey period. None of the 90 percent confidence intervals for any year surveyed between 1982 and 2010 overlap with the 90 percent confidence interval for the last year surveyed (2011). The confidence interval was extremely large for the 2011 mean. Native bat species richness per sample site and sampling effort was higher in 2011 relative to all other years sampled (Figure 4.13-4). However, it is possible the 2011 increase in native species richness is an artifact of the differences in sampling methodology. In 2011, there were only three sites surveyed and one of those sites was surveyed for the first time (Table 4.13-1). In addition, from 1982 through 2009 bats were surveyed using mist nets; in 2010 both mist-netting and acoustic sampling was performed; and in 2011only acoustic sampling was conducted.

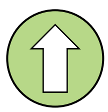
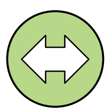
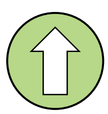
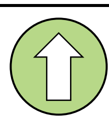
<u>Overall Condition and Trend</u>
The metrics examined indicate that the bat community at DINO is in good condition, with statistically significant increases in total abundance across the survey period and number of species of conservation concern in 2010–2011 compared to earlier surveys (Table 4.13-4 and Figures 4.13-2, 4.13-3 and 4.13-4). Confidence in the assessment is medium.

4.13.5. Uncertainty and Data Gaps
The 10 years of monitoring data collected over a 29-year period is a sound foundation for continued monitoring spanning multiple decades (Holmes 2010, Magurran et al. 2010). Continued monitoring will enable the assessment of status and variability over time and space (Dornelas et al. 2012). Confidence in this assessment was medium as is the confidence in the trend analyses. There are several elements in the survey methods used at DINO that create this uncertainty. The first is that two different methods of surveying were used. From 1982 through 2010 Bogan and Mollhagen (2010)

mist-netted for bats at multiple sites within DINO. From 2009 through 2011 Neubaum and Navo (2011) acoustically sampled for bats at multiple sites within DINO. The two methods have the potential to vary in their ability to detect the bats that are actually present. This would bias any comparisons of the condition indicators among years when differing bat sampling protocols were used.

Secondly, monitoring the same sites consistently over time would provide much stronger trend data. A total of 50 different sites were surveyed in the 10 years that sampling occurred and a majority of those sites (28) were only surveyed in one year. Consequently, consistent and comprehensive monitoring could produce results different from those presented here.

Table 4.13-4. Condition and trend summary for bats at Dinosaur National Monument.

Indicator	Condition Status/Trend	Rationale
Total Bat Abundance – All Species		Mean bat species abundance per sample site adjusted for sampling effort fluctuated between 4.6 and 17.2 individuals from 1982 to 2010 with mean abundance equaling 11.1 in 2010 (good condition), more than the management target of 85 percent of 4.6, the value recorded in 1982. Analysis of the bat sampling data indicates an improving trend in mean bat species abundance from 1982 to 2010.
Native Species Richness		Mean native bat species richness per sample site ranged from 1.4 to 5.75 species between 1982 and 2010. Values for 2010 and 2011 were markedly higher due to better species detectability using acoustic monitoring methods.
Species of Conservation Concern		The mean number of bat species of conservation concern per sample site ranged from 0.2 to 4.0 species from 1982 to 2011. Species of conservation concern averaged 4.0 in 2011, which exceeded the management target of 85 percent of 0.2, the value recorded in 1982. The number of bat species of conservation concern was highest in 2011 compared to other years.
Bats overall		**Condition is good with an improving trend. Confidence in the assessment is medium.**

Lastly, this assessment is based upon monitoring data collected by two different research teams over multiple years. Variation among collectors/observers could introduce non-sampling error, which could reduce the ability to identify statistically significant trends in the resource (Dornelas et al. 2012). The bias associated with data collection is reduced by having researchers adhere to standardized data collection methods, but that does not reduce the potential bias (or variability) resulting from the turnover in collectors over time.

4.13.6. Sources of Expertise

- Dr. Michael Bogan is a retired biologist formerly at the U.S. Geological Survey, Fort Collins Science Center, and a retired Associate Professor, Department of Biology, University of New Mexico, Albuquerque, New Mexico. Dr. Bogan conducted the mist-netting surveys at DINO from 1982 through 2010 with Tony Mollhagen.

- Dr. Mollhagen is owner of Natural History Associated, Lubbock, Texas. As an Associate Professor he taught courses in Water Chemistry, Process Chemistry, Water and Wastewater Analysis, Environmental Measurement, Environmental Risk Assessment and Limnology at Texas Tech University, Lubbock, Texas prior to his retirement in Summer 2003.

- Daniel Neubaum is a conservation biologist at Colorado Parks and Wildlife, Terrestrial Section, Grand Junction, Colorado, and he conducted the acoustic bat sampling at DINO from 2009 through 2011 with Kirk Navo.

- Kirk Navo is a retired conservation biologist at Colorado Parks and Wildlife and currently is the owner of Head First Biological, LLC, working on bat conservation and the use of acoustics in wildlife management.

4.13.7. Literature Cited

Alves, D.M.C.C., L.C. Terribile, and D. Brito. 2014. The potential impact of white-nose syndrome on the conservation status of North American bats. PLoS ONE 9:1–7.

Armstrong, D.M, J.P. Fitzgerald, and C.A. Meaney. 2011. Mammals of Colorado, second edition. University of Colorado Press, Boulder, Colorado.

Bogan, M.A., and T.R. Mollhagen. 2010. Resurvey for bats (Chiroptera) at Dinosaur National Monument, Colorado/Utah, 2008–2009. National Park Service, Dinosaur National Monument, Dinosaur, Colorado.

Coles, J., D. Cogan, D. Salas, A. Wight, G. Wakefield, J. Von Loh, and A. Evenden. 2008. Vegetation classification and mapping project report, Dinosaur National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2008/112. National Park Service, Fort Collins, Colorado.

Dornelas, M., A.E. Magurran, S.T. Buckland, A. Chao, R.L. Chazdon, R.K. Colwell, T. Curtis, K.J. Gaston, N.J. Gotelli, M.A. Kosnik, B. McGill, J.L. McCune, H. Morlon, P.J. Mumby, L. Ovreas, A. Studeny, and M. Vellend. 2012. Quantifying temporal change in biodiversity: challenges and opportunities. Proceedings of the Royal Society B 280:1–10.

Frick, W.F., S.J. Puechmaille, and C.K.R. Willis. 2016. White-nose syndrome in bats. Pages 245–262 *in* C. C. Voigt and T. Kingston, editors. Bats in the Anthropocene: conservation of bats in a changing world. Springer International, New York, New York.

Gilbert, M.M., and A.D. Chalfoun. 2011. Energy development affects populations of sagebrush songbirds in Wyoming. Journal of Wildlife Management 75:816–824.

Hayes, J.P. 2000. Assumptions and practical considerations in the design and interpretation of echolocation-monitoring studies. Acta Chiropterologica 2:225–236.

Holmes, R.T. 2010. Avian population and community processes in forest ecosystems: long-term research in the Hubbard Brook Experimental Forest. Forest Ecology and Management 262:20–32.

Jørgensen, S.E., and F. Müller, editors. 2000. Handbook of ecosystem theories. CRC Publishers, New York, New York.

Kunz, T.H., and A. Kurta. 1988. Capture methods and holding devices. Pages 1–29 *in* T.H. Kunz, editor. Ecological and behavioral methods for the study of bats. Smithsonian Institution Press, Washington, D.C.

Kunz, T.H., R. Hodgkison, and C.D. Weise. 2009. Methods of capturing and handling bats. Pages 3–35 *in* T. H. Kunz and S. Parsons, editors. Ecological and behavioral methods for the study of bats, second edition. Johns Hopkins University Press, Baltimore, Maryland.

Luce, R.J., and D. Keinath. 2007. Spotted bat (*Euderma maculatum*): a technical conservation assessment. [Online]. U.S. Forest Service, Rocky Mountain Region. Available at: http://www.fs.fed.us/r2/projects/scp/assessments/spottedbat.pdf (accessed 06 January 2019).

Magurran, A.E., S.R. Baillie, S.T. Buckland, J.M. Dick, D.A. Elston, E.M. Scott, R.I. Smith, P.J. Somerfield, and A.D. Watt. 2010. Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. Trends in Ecology and Evolution 25:574–582.

Miller R.F., D.E. Naugle, J.D. Maestas, C.A. Hagen, and G. Hall. 2017. Special Issue: Targeted woodland removal to recover at-risk grouse and their sagebrush-steppe and prairie ecosystems. Rangeland Ecology and Management 70(1):1–8.

Miller, M.E., D. Sharrow, and L. Cudlip. 2003. Northern Colorado Plateau vital signs network and prototype cluster plan for natural resources monitoring – phase II report. NPS Northern Colorado Plateau Network.

National Park Service (NPS). 2000. Inventory study plan for vascular plants and vertebrates. Northern Colorado Plateau Network Inventory and Monitoring Program. Moab, UT

NatureServe. 2018. NatureServe Explorer: An online encyclopedia of life website, version 7.1. NatureServe, Arlington, Virginia. Available at: http://explorer.natureserve.org (accessed 24 January 2019).

Neubaum, D.J., and K.W. Navo. 2011. Acoustic sampling of bat species in Dinosaur National Monument: 2011 progress report. National Park Service, Dinosaur National Monument, Dinosaur, Colorado.

Rosenberg, K.V., J.A. Kennedy, R. Dettmers, R.P. Ford, D. Reynolds, J.D. Alexander, C.J. Beardmore, P.J. Blancher, R.E. Bogart, G.S. Butcher, A.F. Camfield, A. Couturier, D.W. Demarest, W.E. Easton, J.J. Giocomo, R.H. Keller, A.E. Mini, A.O. Panjabi, D.N. Pashley, T.D.

Rich, J.M. Ruth, H. Stabins, J. Stanton, and T. Will. 2016. Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee. Available at: https://www.partnersinflight.org/resources/the-plan/

White-Nose Syndrome Response Team. 2019. White nose syndrome occurrence map. Available at: https://www.whitenosesyndrome.org/where-is-wns (accessed May 15, 2019).

4.14. Birds

4.14.1. Background and Importance

Dinosaur National Monument (DINO) is located on a high plateau in a cold desert region intersected by the Green and Yampa rivers of the Upper Colorado River Basin, and provides a diversity of important habitat for migratory, breeding, and resident bird communities of the Intermountain West. It harbors 174 different vegetation types with the most dominant broad types including pinyon-juniper woodland, sagebrush shrubland, and grassland habitat (Coles et al. 2008). The most extensive broad habitat is pinyon-juniper woodland comprising almost 50 percent of the cover within the monument, followed by sagebrush shrubland (Coles et al. 2008). The other habitat type examined in the context of bird communities is Rocky Mountain Lower Montane-Foothill Riparian Woodland (referred to here as lowland riparian habitat), an important habitat for birds that occupies less than 1% of the monument along the Green and Yampa rivers and major tributaries (Coles et al. 2008).

With its varied habitats and topography, DINO supports over 200 year-round or part-time resident bird species. Common species include juniper titmice (*Baeolophus ridgwayi*) and pinyon jays (*Gymnorhinus cyanocephalus*) associated with the pinyon-juniper woodlands; sagebrush sparrows (*Artemisiospiza nevadensis*), sage thrashers (*Oreoscoptes montanus*), and greater sage-grouse (*Centrocercus urophasianus*) associated with the sagebrush habitat; bald eagles (*Haliaeetus leucocephalus*), Canada geese (*Branta canadensis*), and great blue herons (*Ardea herodias*) associated with the riparian habitats along the Green and Yampa rivers; and swifts, turkey vultures (*Cathartes aura*), peregrine falcons (*Falco peregrinus*), and other raptors associated with its canyon walls.

The monument provides important pinyon-juniper habitat for DINO bird communities. Some regional, climate-driven mortality of pinyon pines has caused widespread declines in this woodland habitat and pinyon cone production, and resulted in reductions in at-risk pinyon-juniper woodland specialists such as juniper titmice and pinyon jays (Redmond et al. 2012, Rosenberg et al. 2016). Pinyon jays have undergone an 85% long-term decline across their range (Redmond et al. 2012, Rosenberg et al. 2016). DINO also provides extensive habitat for sagebrush-dependent birds. Sagebrush shrublands are also in decline across the American West (Miller et al. 2017). Declines in sagebrush-dependent bird species have followed widespread losses in sagebrush habitat (Gilbert and Chalfoun 2011, Rosenberg et al. 2016). For example, the sagebrush sparrow has lost approximately 50% of its historical habitat and declined across much of its geographic range (about a 1% population decline per year) since 2005 (Sauer et al. 2017).

DINO also protects 105 miles of the Green and Yampa rivers and associated riparian habitat. Although the upper Green River, above the confluence with the Yampa River, has been impacted by impoundments/regulation, the Yampa is one of the last (mostly) free-flowing tributaries of the Colorado River and one of the few in the American West (Bestgen 2015). The relatively unaltered flow regime of the Yampa helps maintain healthy riparian habitat for birds at DINO.

Threats and Stressors

Dinosaur National Monument lies within a remote region, with relatively low human impact. However, threats within the monument to DINO bird communities include overgrazing and trampling by livestock, especially of sagebrush and riparian habitat, and invasion of sagebrush habitat by non-native cheatgrass (*Bromus tectorum*) (Witwicki 2013). Additionally, recreational use, oil and gas development, and climate change are increasing local threats. Many threats to the DINO bird community exist beyond monument boundaries, including climate change, livestock grazing, residential and commercial development, and damming of the upper Green River. These stressors can impact bird populations locally, regionally, and throughout their migratory range (Hansen and Gryskiewicz 2003). Impacts include habitat loss and fragmentation, water pollution, and the disruption of hydrologic flow regimes. These modifications disrupt ecological functions important to ecosystem integrity relative to high quality habitats within the region (Jørgenson and Müller 2000).

Climate change is causing dramatic declines in snow pack and reduced runoff across the West, with consequent impacts on riparian habitat on which many bird species in the arid West depend (Mote et al. 2018). Climate change also is predicted to shift the distribution of pinyon-juniper habitat across the American West and cause regional-scale mortality of pinyon and juniper, concurrent with expected losses in populations of bird species that depend on this habitat (McDowell et al. 2016, Johnson et al. 2017). Climate change also is a growing threat to the sagebrush ecosystem, with predicted declines in habitat for sagebrush obligate species (Bradley 2010, Schlaepfer et al. 2012, Homer et al. 2015). Further, the spatial extent of the sagebrush ecosystem has declined by about 50% due to livestock overgrazing, exotic species invasion (especially cheatgrass) that increases fire frequency, conversion to agriculture, urban expansion, energy and other development, with several sagebrush-dependent bird species now at risk (Schroeder et al. 2004, Anderson and Inouye 2001). Additionally, water development projects continue to be proposed across the Upper Colorado River Basin and threaten the Green and Yampa rivers and associated riparian habitat (Tyus and Saunders 2000, Bestgen 2015). Consequently, the ecological functioning of DINO depends upon maintaining the natural systems within and outside the monument's boundaries. Changes in land use can disrupt ecological function by reducing the functional size of a reserve, disrupting ecological processes and flows across the landscape, damaging or eliminating unique or rare habitats, creating excessive edges, and increasing human populations and associated disturbance (Hansen and Gryskiewicz 2003).

Indicators and Measures

- Native species richness (S)
- Bird index of biotic integrity (IBI)
- Occurrence and status of bird species of conservation concern

4.14.2. Data and Methods

The Northern Colorado Plateau Network (NCPN) has implemented long-term monitoring of birds at network parks including DINO (McLaren and White 2016). The effort aims to track changes in bird community composition and abundance, and to monitor bird response to changes in habitat structure

and other habitat variables related to management activities (McLaren and White 2016). NCPN began systematic surveys of breeding birds and their habitat at DINO in 2005 in three key habitats: pinyon-juniper (PJ), sagebrush shrubland (SA), and lowland riparian (LR) (McLaren and White 2016). These habitats support relatively distinct bird communities. The pinyon-juniper woodland is dominated by pinyon pine (*Pinus edulis*) and juniper species (*Juniperus* spp.), and occurs along ridges and mesas at elevations just above 1,500 meters (McLaren and White 2016). The sagebrush shrubland is dominated by big sagebrush (*Artemisia tridentata*) and mountain sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana*). The lowland riparian habitat is mostly comprised of Fremont cottonwood (*Populus fremontii*) and boxelder (*Acer negundo*) along perennial streams, often within deep canyons. The non-native tamarisk (*Tamarix ramosissima*) is also present.

Here, we report on data collected by Bird Conservancy of the Rockies (BCR) staff from 2005–2017 (Roberts et al. 2018, McLaren and White 2016). BCR staff sampled birds along a series of transects established across each habitat type (SA, PJ, LR), with four transects per habitat (Figure 4.14-1). Fifteen, 5-minute point-counts were established at 250 m intervals along each transect, during which all bird species detections were recorded. From 2005 through 2013, BCR staff surveyed each transect twice during the peak breeding season, but in 2014, 2015 and 2017 each site was surveyed only once. Data were not available for 2016. Detailed methods and survey protocols are described in Daw et al. (2017) and Rocky Mountain Bird Observatory (2018).

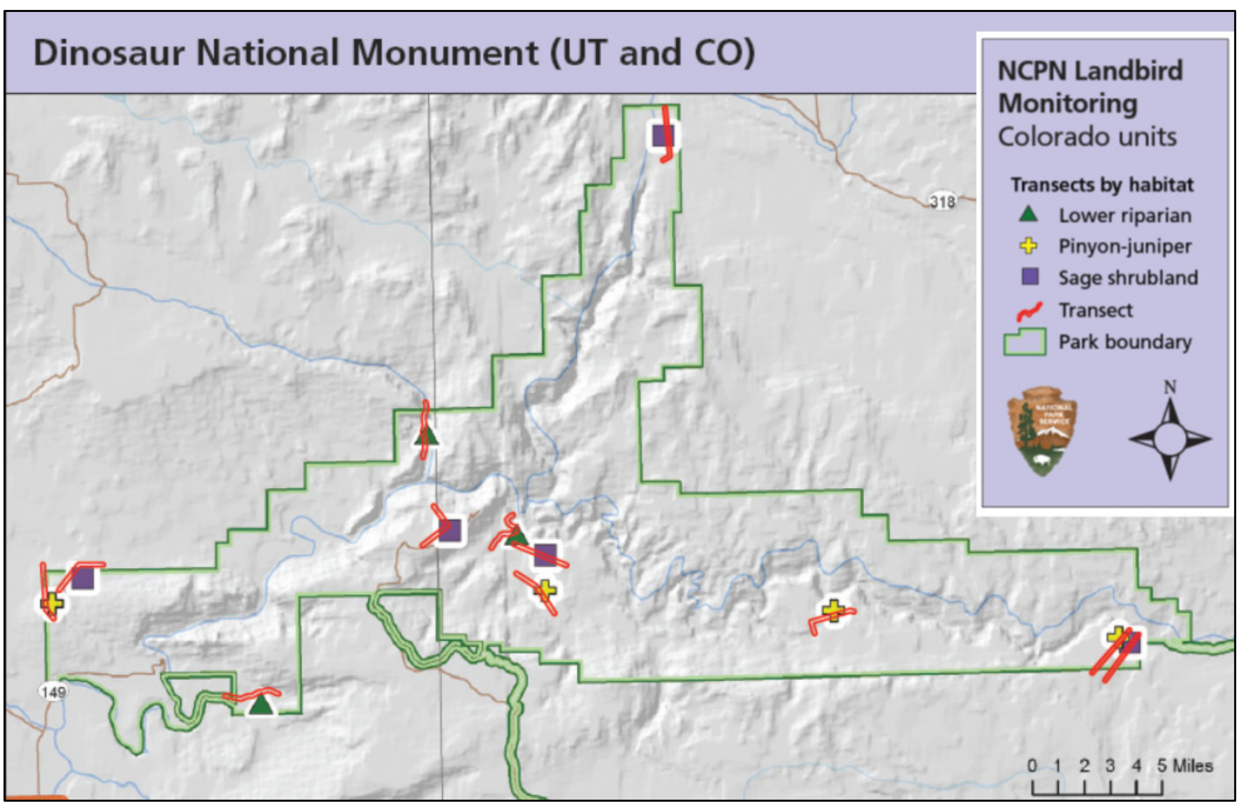


Figure 4.14-1. Bird transect locations by habitat type at Dinosaur National Monument (Daw et al. 2017).

To evaluate trends over time, we compared the occurrence of species detected during the initial survey conducted at DINO in 2005 to species detected during the 2017 survey. We compared species richness at the start of the study period (2005) to the end of the study period (2017) separately for each of the three habitat types. Only native species were included in calculations of species richness.

We also calculated bird Index of Biotic Integrity (IBI) values for each of the three habitat types, and compared this index between the years 2005 and 2017. The bird IBI follows methodology developed for bird communities of the mid-Atlantic Highlands (O'Connell et al. 1998a). It is important to note that the bird IBI was modified from O'Connell et al. (1998a) to reflect the land-use and land-cover types of the NCPN (e.g., PJ, SA, and LR). The bird IBI is based on 17 response guilds defined by a life history or "guild" category. Each guild is broadly classified as "specialist" or "generalist" based on the guild's relationship to specific elements of biotic integrity that are associated with avian ecology. Response guilds negatively associated with biotic integrity elements (e.g., omnivore, exotic, resident, temperate migrant, nest predator/brood parasite, shrub nester, and forest generalist) are considered "generalist" guilds and sites with proportionally fewer of these species receive higher ranks than sites with greater numbers of these species (Table 4.14-1).

Each response guild is assigned to either all of the habitat types being analyzed or only to the specific habitat type(s) that the guild applies to. For example, the guild "bark prober" was only applied to birds recorded in the two woodland habitats, pinyon-juniper and low-elevation riparian (Table 4.14-1).

Table 4.14-1. Bird species guilds used to calculate the IBI score at Dinosaur National Monument (guilds modified from O'Connell et al. (1998a)). Abbreviations for habitat types: PJ – pinyon-juniper, LR – low-elevation riparian, SA – sagebrush shrubland, and ALL – guild associates with all three habitats.

Biotic Integrity Element	Guild Category	Response Guild	Habitat	Number of Species in Guild	Guild Classification
Functional	Trophic	Omnivore	ALL	42	Generalist
	Insectivore Foraging Behavior	Bark prober	PJ, LR	3	Specialist
	Insectivore Foraging Behavior	Lower canopy forager	PJ, LR	25	Specialist
	Insectivore Foraging Behavior	Ground gleaner	ALL	11	Specialist
Compositional	Origin	Exotic	ALL	3	Generalist
	Migration Status	Resident	ALL	40	Generalist
	Migration Status	Temperate	ALL	12	Generalist
	Number of Broods	Single brooder	ALL	61	Specialist
	Population Limiting	Nest predator/Brood parasite	ALL	7	Generalist

Table 4.14-1 (continued). Bird species guilds used to calculate the IBI score at Dinosaur National Monument (guilds modified from O'Connell et al. (1998a)). Abbreviations for habitat types: PJ – pinyon-juniper, LR – low-elevation riparian, SA – sagebrush shrubland, and ALL – guild associates with all three habitats.

Biotic Integrity Element	Guild Category	Response Guild	Habitat	Number of Species in Guild	Guild Classification
Structural	Nest Placement	Cliff nester	LR	7	Specialist
	Nest Placement	Ground nester	ALL	27	Specialist
	Nest Placement	Canopy nester	PJ, LR	28	Specialist
	Nest Placement	Shrub nester	SA, LR	21	Generalist
	Primary Habitat	Riparian obligate	LR	16	Specialist
	Primary Habitat	Shrubland obligate	SA	7	Specialist
	Primary Habitat	Forest generalist	ALL	38	Generalist
	Primary Habitat	Forest obligate	PJ, LR	12	Specialist

Specialist guilds included in the IBI tend to be associated with either extensive pinyon-juniper woodland, sagebrush, or riparian vegetation cover. Therefore, higher IBI scores reflect bird communities associated with aspects of mature pinyon-juniper woodland structure, function, and composition for the pinyon-juniper woodland IBI, mature sagebrush habitat structure, function, and composition for the sagebrush IBI, and mature riparian habitat structure, function, and composition for the lowland riparian IBI. For example, sites with higher pinyon-juniper woodland IBI scores consist of a bird community with more pinyon-juniper woodland-dependent species, bark probers, canopy nesters, forest obligates (i.e., specialists). The high IBI-score sites would tend to have fewer omnivores, exotic/non-natives, nest predators/brood parasites, residents, and generalists. Guild selection considerations are discussed in Crewe and Timmermans (2005) and O'Connell et al. (1998a).

To calculate the IBI score, species are first assigned to guilds (some species may be assigned to more than one guild, depending on their life history traits) (Table 4.14-1). The proportional species richness of each guild at each sample site is then calculated by dividing the number of species detected within a specific guild by the total number of species detected. The next step in the bird IBI is to rank each category of proportional species richness for each guild on a scale of 5 (high integrity) to 0 (low integrity) (Marshall et al. 2016, O'Connell et al. 2000, O'Connell et al. 1998b). For specialist guilds, the highest-occurrence category is ranked a "5," the next highest a "4," etc. For generalist guilds, the ranking is reversed; a "5" is assigned to the lowest-occurrence category. Therefore, a site can receive a rank of "5" for a guild if the site supports the highest category of proportional species richness for a specialist guild or the lowest category of proportional species richness for a generalist guild. The final bird IBI score is then calculated by summing the ranks for each guild's proportional species richness, across all guilds and all sample sites.

A community at the theoretical maximum high IBI score, or highest integrity, consists of a bird community with only specialist guilds and without any generalist guilds. A bird community with a high IBI score will then contain more specialist guild members and fewer generalist guild members. The DINO bird IBI ranks bird communities according to the proportional representation of 17 behavioral and physiological response guilds (Table 4.14-1). The integrity represented by a particular IBI score is based upon a theoretical maximum community integrity and how IBI scores for reference sites ranging from pristine condition to more degraded condition relate to that theoretical maximum score. The biotic or ecological "condition" described by the bird IBI then moves along a disturbance gradient from relatively intact, extensive, mature pinyon-juniper woodland, sagebrush shrubland, or lowland riparian habitat with high IBI scores to more disturbed, degraded pinyon-juniper woodland, sagebrush shrubland, or lowland riparian habitat with low IBI scores. A gradient of disturbance for western bird community IBI scores has not been determined with which to evaluate the bird community here. Consequently, this report only assesses the relative change in score over time (not the actual score) to evaluate the status of biological integrity of the bird communities over time at DINO.

Conservation Context – The Occurrence and Status of Species of Conservation Concern
Our intent for this section was to determine which species that occur at DINO are considered species of concern at either a national or local scale, and to assess the current status (occurrence) of those species at DINO. This analysis was restricted to those species that were either breeding at the monument or that were residents.

To identify priority conservation species we used federal and state threatened and endangered species lists and lists developed by Partners in Flight (PIF), a cooperative effort among federal, state and local government agencies that identifies and assesses species of conservation concern based on biological criteria including population size, breeding distribution, non-breeding distribution, threats to breeding, threats to non-breeding, and population trend (Panjabi et al. 2012). Partners in Flight assessments are conducted at both the national and regional scale. At the national scale, the PIF North American Landbird Conservation Plan identifies what are considered "Red Watch List Species" and "Yellow Watch List Species" (Rosenberg et al. 2016). Red Watch List Species are considered by PIF as those with the greatest need for conservation due to a combination of small and declining populations, limited distributions, and high threats throughout their ranges (Rosenberg et al. 2016). Yellow Watch List Species are defined as those species that are not declining but that are vulnerable due to small ranges and populations with moderate threats or species with population declines and moderate to high threats (Rosenberg et al. 2016).

Partners in Flight has also adopted Bird Conservation Regions (BCRs), after the North American Bird Conservation Initiative. BCRs are ecologically distinct regions in North America with similar bird communities, habitats and resource management issues. Regional bird conservation plans are developed by PIF using the BCRs as the unit of planning and the same principles of concern (Red Watch List and Yellow Watch List species) are applied at the scale of the BCR. This approach recognizes that some species may be declining dramatically at the local scale even though they are not of high concern nationally. Dinosaur National Monument is within Physiographic Area 87:

Colorado Plateau; the conservation plan for this area was also reviewed to identify those bird species that are of conservation priority within the local area (Colorado Partners in Flight 2000).

4.14.3. Reference Conditions

Comprehensive bird surveys using a statistically rigorous sample design were implemented in 2005 (Roberts et al. 2018). Few data exist for bird status prior to that effort. Bird reference condition for mature pinyon-juniper woodland, sagebrush shrubland, and lowland riparian habitat sample sites is based on the initial NCPN 2005 bird survey results. Actions causing changes to habitat like livestock grazing may have affected bird community composition and bird species abundances at DINO prior to 2005. The authors acknowledge that the 2005 bird community at DINO may be altered compared to the historical bird community. However, given the time frame over which data for the DINO bird community is available, the 2005 data was selected as the reference condition standard. Maintaining or exceeding the level of biodiversity as defined by initial calculation of native species richness (as an index of diversity) and the initial quality of bird community composition as defined by the initial IBI score are considered good condition. We also used the number of species of concern recorded in the initial survey year of 2005 as the reference condition for comparison with year 2017. The condition of the resource is considered higher if more species of concern are observed. This implies that the populations of those species are increasing and/or they are using the monument more. A condition rating framework for birds is shown in Table 4.14-2.

Table 4.14-2. Resource condition rating framework for birds at Dinosaur National Monument.

	Condition Status		
Indicator	**Resource is in Good Condition**	**Condition Warrants Moderate Concern**	**Condition Warrants Significant Concern**
Native Species Richness	>85–100+% of 2005 value	70–85% of 2005 value	<70% of 2005 value
Index of Biological Integrity	>85–100+% of 2005 value	70–85% of 2005 value	<70% of 2005 value
Bird Species of Conservation Concern	>85–100+% of 2005 value	70–85% of 2005 value	<70% of 2005 value

4.14.4. Condition and Trend

Pinyon-Juniper Birds

Native Species Richness

A mean of 19.3 native species was recorded per transect and 30 species total were recorded at pinyon-juniper sampling sites in 2017. The most common species were the black-throated gray warbler (*Setophaga nigrescens*) and gray flycatcher (*Empidonax wrightii*) followed by the blue-gray gnatcatcher (*Polioptila caerulea*), mourning dove (*Zenaida macroura*), and violet-green swallow (*Tachycineta thalassina*) (Table 4.14-3). The 2017 value for native species richness was only 60% of the 32 native species recorded during the initial 2005 bird survey at DINO (Figure 4.14-2). Therefore, pinyon-juniper bird species richness at DINO in 2017 warrants significant concern.

The slope of the general linear regression for mean native pinyon-juniper bird species richness per sample site was negative and statistically significant ($r^2 = 0.72$, $p = 0.0004$), suggesting a deteriorating trend in richness of the pinyon-juniper bird community at DINO. The 90% confidence intervals for mean native bird species richness per sample site for the years 2005 to 2017 indicate variability within the sample periods (Figure 4.14-2).

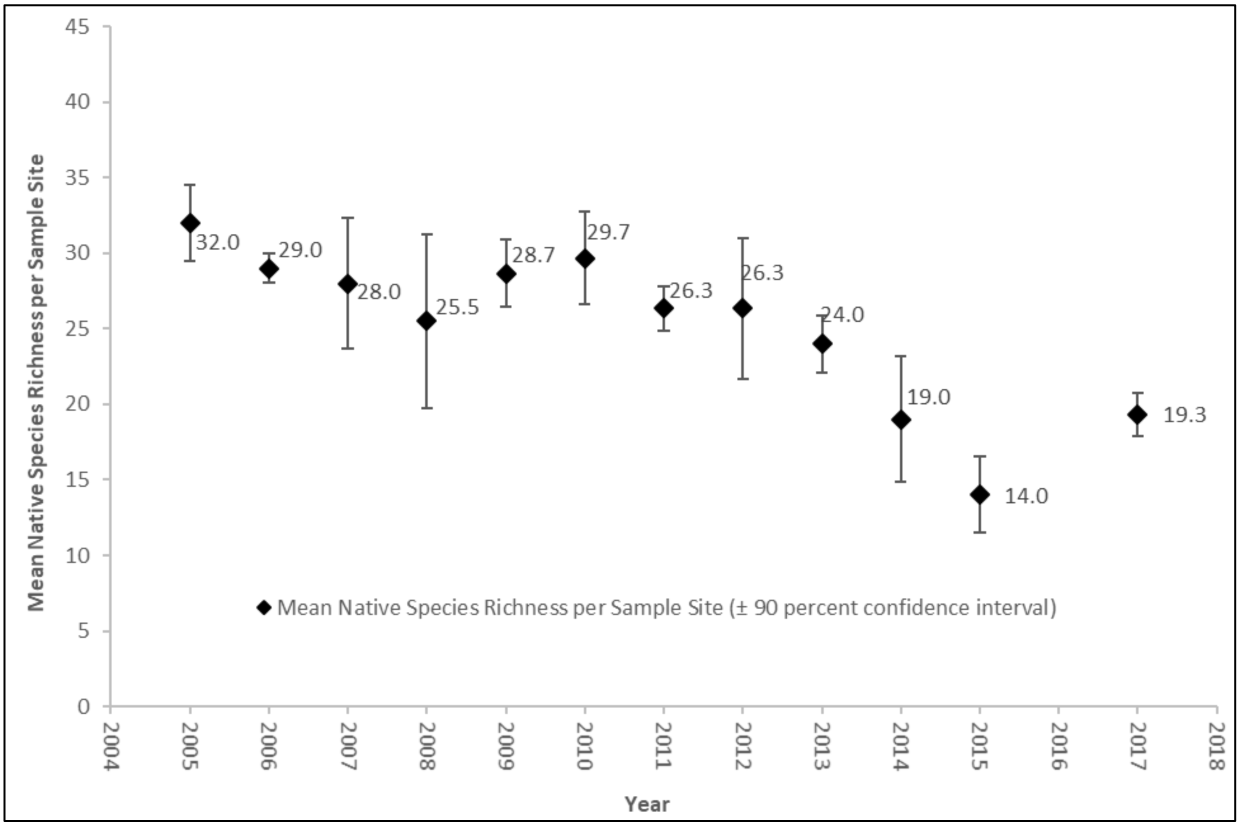


Figure 4.14-2. Means and 90 percent confidence intervals by year for native bird species richness per sample site for pinyon-juniper habitat at Dinosaur National Monument from 2005–2017 (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network).

Table 4.14-3. Bird species recorded in 2005 and 2017 at pinyon-juniper survey stations in Dinosaur National Monument (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network). No federally threatened or endangered (T/E) species or State listed species of concern were detected.

Common Name	Species Name	Detected 2005	Detected 2017
American Robin	*Turdus migratorius*	8	0
American Kestrel	*Falco sparverius*	0	1
Ash-throated Flycatcher	*Myiarchus cinerascens*	24	16
Barn Swallow	*Hirundo rustica*	0	1
Bewick's Wren	*Thryomanes bewickii*	24	8
Black-billed Magpie	*Pica hudsonia*	1	0
Black-chinned Hummingbird[1]	*Archilochus alexandri*	2	3
Black-throated Gray Warbler[1]	*Setophaga nigrescens*	101	63
Black-throated Sparrow	*Amphispiza bilineata*	4	0
Blue-gray Gnatcatcher	*Polioptila caerulea*	27	25
Brewer's Sparrow[1]	*Spizella breweri*	6	0
Broad-tailed Hummingbird	*Selasphorus platycercus*	4	1
Brown-headed Cowbird	*Molothrus ater*	6	3
Bushtit	*Psaltriparus minimus*	2	0
Canyon Wren	*Catherpes mexicanus*	1	0
Cassin's Finch	*Haemorhous cassinii*	0	2
Chipping Sparrow	*Spizella passerina*	42	7
Clark's Nutcracker	*Nucifraga columbiana*	1	4
Cliff Swallow	*Petrochelidon pyrrhonota*	1	0
Common Nighthawk[2]	***Chordeiles minor***	**0**	**1**
Common Poorwill[1]	*Phalaenoptilus nuttallii*	1	1
Common Raven	*Corvus corax*	27	7
Cooper's Hawk	*Accipiter cooperii*	2	0
European Starling	*Sturnus vulgaris*	4	0
Gray Flycatcher[1]	*Empidonax wrightii*	44	28
Gray Vireo[1,2]	***Vireo vicinior***	**14**	**10**
Green-tailed Towhee	*Pipilo chlorurus*	1	0
Hairy Woodpecker	*Picoides villosus*	3	0
House Finch	*Carpodacus mexicanus*	15	4
Juniper Titmouse[1]	*Baeolophus ridgwayi*	9	13
Lark Sparrow	*Chondestes grammacus*	21	0
Lesser Goldfinch	*Spinus psaltria*	0	2
Mountain Bluebird	*Sialia currucoides*	56	1

[1] Partners in Flight Priority Species for Physiographic Area 87: Colorado Plateau (also highlighted).

[2] Partners in Flight species considered of continental importance (also in bold).

Table 4.14-3 (continued). Bird species recorded in 2005 and 2017 at pinyon-juniper survey stations in Dinosaur National Monument (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network). No federally threatened or endangered (T/E) species or State listed species of concern were detected.

Common Name	Species Name	Detected 2005	Detected 2017
Mountain Chickadee	*Poecile gambeli*	5	0
Mourning Dove	*Zenaida macroura*	60	27
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	1	0
Osprey	*Pandion haliaetus*	1	0
Pinyon Jay[1,2]	***Gymnorhinus cyanocephalus***	**47**	**14**
Plumbeous Vireo	*Vireo plumbeus*	16	0
Red-tailed Hawk	*Buteo jamaicensis*	2	0
Rock Pigeon	*Columba livia*	1	0
Rock Wren	*Salpinctes obsoletus*	48	15
Say's Phoebe	*Sayornis saya*	9	0
Spotted Towhee	*Pipilo maculatus*	24	30
Vesper Sparrow	*Pooecetes gramineus*	9	0
Violet-green Swallow	*Tachycineta thalassina*	5	23
Virginia's Warbler[1,2]	***Oreothlypis virginiae***	**7**	**0**
Western Meadowlark	*Sturnella neglecta*	38	3
Western Scrub Jay	*Aphelocoma californica*	17	10
White-breasted Nuthatch	*Sitta carolinensis*	3	1
White-throated Swift[1]	*Aeronautes saxatalis*	6	5

[1] Partners in Flight Priority Species for Physiographic Area 87: Colorado Plateau (also highlighted).

[2] Partners in Flight species considered of continental importance (also in bold).

Bird Index of Biotic Integrity

Pinyon-juniper bird IBI score averaged 42.8 per sample site in 2017. This was greater than 85 percent of the 2005 IBI score of 38.2, indicating that composition of the pinyon-juniper bird community in DINO is in good condition (Figure 4.14-3 and Table 4.14-2). The slope of the general linear regression for the pinyon-juniper bird IBI scores was not statistically significant, indicating relative stability in the biotic integrity of the bird community at DINO over time ($p > 0.05$). Relatively wide confidence intervals for the scores reduces the confidence in this assessment. (Figure 4.14-3).

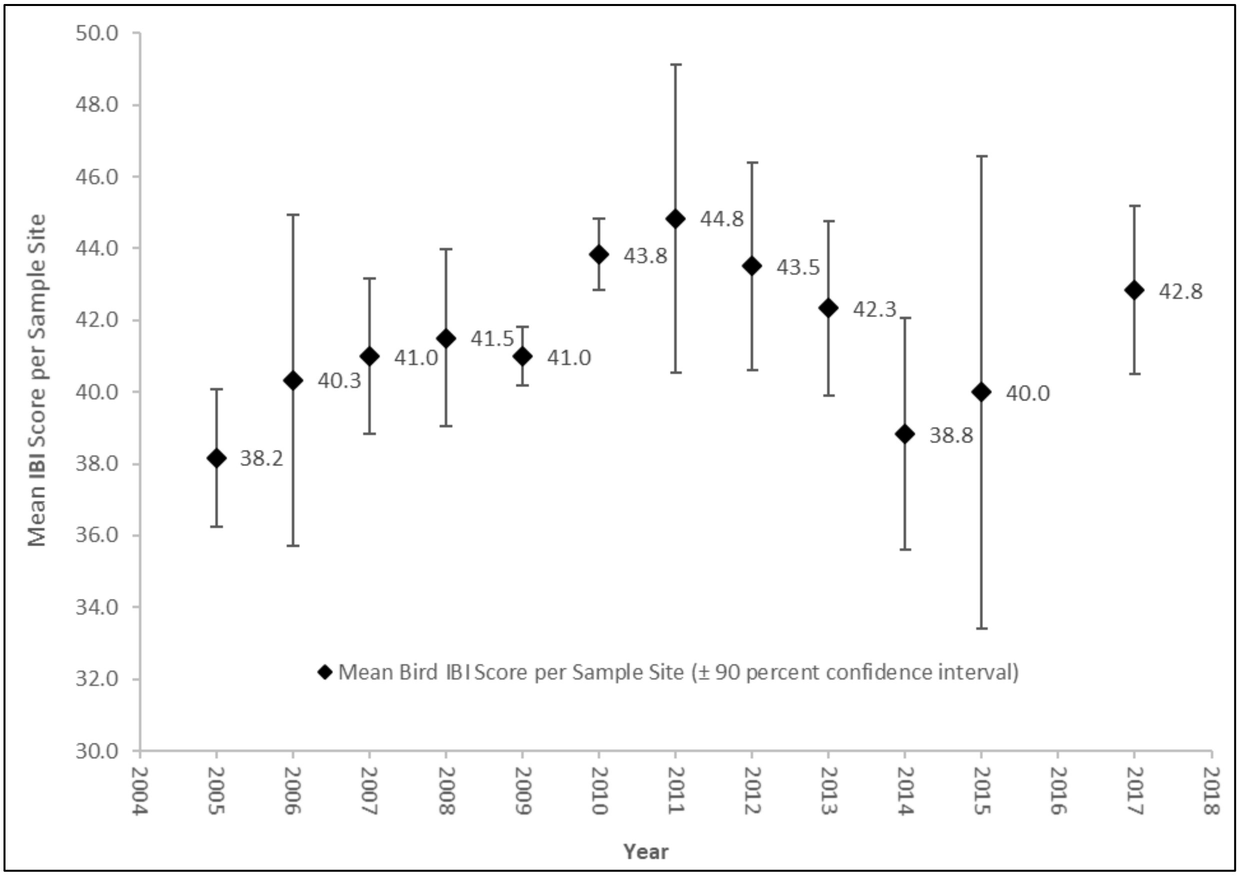


Figure 4.14-3. Means and 90 percent confidence intervals for native bird IBI scores for pinyon-juniper sites at Dinosaur National Monument from 2005–2017 (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network).

Species of Conservation Concern

In 2017, there were 5.7 pinyon-juniper bird species of concern recorded per sample site at DINO. This is 74% of 7.7 (the number recorded in 2005), indicating that the resource warrants moderate concern in 2017 (Table 4.14-2). Nine species found at DINO during the 2017 pinyon-juniper bird survey are listed as Partners in Flight birds of concern (Rosenberg et al. 2016) (Table 4.14-3). The counts for one of these species of concern, the pinyon jay, were noticeably less in 2017 compared to 2005 (Table 4.14-3). Species of concern detected during the 2005 survey but not detected in 2017 include the Brewer's sparrow (*Spizella breweri*) and Virginia's warbler *(Oreothlypis virginiae)* (Table 4.14-3).

The slope of the general linear regression for pinyon-juniper bird species of concern was negative and statistically significant ($r^2 = 0.38$, $p = 0.03$), suggesting a declining trend in the number of pinyon-juniper bird species of concern (Figure 4.14-4). There is a consistent decline in the mean number of bird species of concern between 2013 and 2015, followed by an increase in 2017 (Figure 4.14-4).

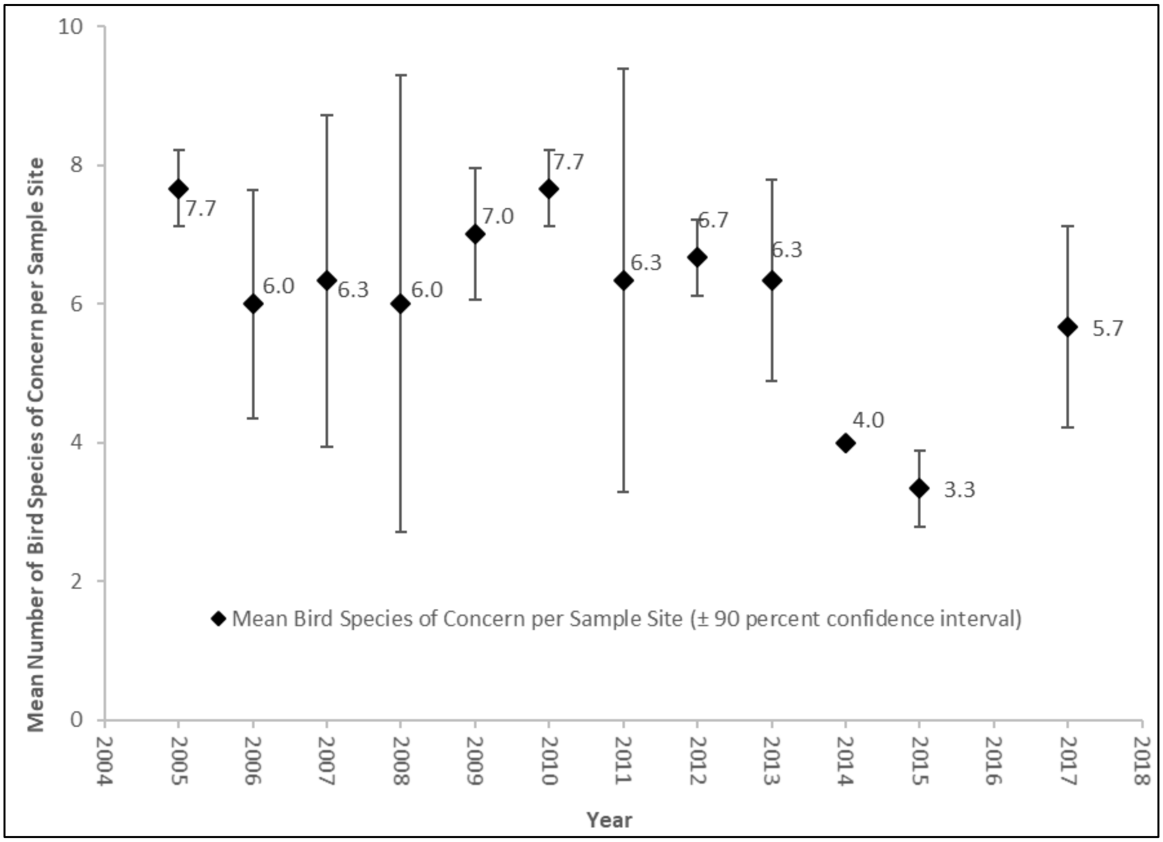


Figure 4.14-4. Means and 90 percent confidence intervals for bird species of conservation concern in pinyon-juniper sample sites at Dinosaur National Monument from 2005–2017 (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network).

<u>Sagebrush Shrubland Birds</u>

Native Species Richness

Native species richness per site averaged 19.3 and a total of 51 native species were recorded at sagebrush shrubland sampling sites in 2017. The 19.3 native species per sample site recorded in 2017 was greater than the target of 85% of the 20.7 species per sample site recorded in 2005. The most common species were the Brewer's sparrow, lark sparrow (*Chondestes grammacus),* and western meadowlark (*Sturnella neglecta*). The blue-gray gnatcatcher, green-tailed towhee (*Pipilo chlorurus*), pinyon jay, spotted towhee *(Pipilo maculatus)* and vesper sparrow (*Pooecetes gramineus*) were all moderately common (Table 4.14-4). Comparing mean sagebrush bird native species richness between 2005 and 2017 indicates that the sagebrush shrubland bird community was in good condition in 2017 (Figure 4.14-5).

The slope of the general linear regression for mean bird species richness per sample site showed an insignificant, unchanging trend in the richness of native sagebrush shrubland bird species at DINO. Overlapping 90 percent confidence intervals for nearly all years suggests high variability in the data (Figure 4.14-5).

Table 4.14-4. Bird species recorded in 2017 and 2005 along sagebrush shrubland survey transects in Dinosaur National Monument (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network). No federally threatened or endangered (T/E) species were detected. The State listed species of special concern that were detected are indicated by the designation SC.

Common Name	Species Name	T/E	Detected 2005	Detected 2017
American Goldfinch	*Carduelis tristis*	–	1	0
American Kestrel	*Falco sparverius*	–	1	1
American Robin	*Turdus migratorius*	–	20	0
Ash-throated Flycatcher	*Myiarchus cinerascens*	–	16	6
Barn Swallow	*Hirundo rustica*	–	0	1
Bewick's Wren	*Thryomanes bewickii*	–	10	8
Black-billed Magpie	*Pica hudsonia*	–	15	14
Black-headed Grosbeak	*Pheucticus melanocephalus*	–	1	1
Black-throated Gray Warbler[1]	*Dendroica nigrescens*	–	31	8
Black-throated Sparrow	*Amphispiza bilineata*	–	5	4
Blue-gray Gnatcatcher	*Polioptila caerulea*	–	29	36
Brewer's Blackbird[1]	*Euphagus cyanocephalus*	–	1	0
Brewer's Sparrow[1]	*Spizella breweri*	–	150	61
Broad-tailed Hummingbird	*Selasphorus platycercus*	–	2	1
Brown-headed Cowbird	*Molothrus ater*	–	5	1
Bullock's Oriole	*Icterus bullockii*	–	1	1
Bushtit	*Psaltriparus minimus*	–	21	0
Canada Goose	*Branta canadensis*	–	28	0
Canyon Wren	*Catherpes mexicanus*	–	2	0
Chipping Sparrow	*Spizella passerina*	–	26	9
Clark's Nutcracker	*Nucifraga columbiana*	–	2	0
Common Nighthawk[2]	***Chordeiles minor***	**–**	**0**	**2**
Common Raven	*Corvus corax*	–	24	17
Common Yellowthroat	*Geothlypis trichas*	–	1	5
Cooper's Hawk	*Accipiter cooperii*	–	1	0
Dusky Flycatcher	*Empidonax oberholseri*	–	1	0
Dusky Grouse	*Dendragapus obscurus*	–	1	0
Eurasian Collared Dove	*Streptopelia decaocto*	–	0	1
European Starling	*Sturnus vulgaris*	–	9	4
Gray Flycatcher[1]	*Empidonax wrightii*	–	11	11
Gray Vireo[1,2]	***Vireo vicinior***	**–**	**5**	**6**
Greater Sage Grouse[1,2]	***Centrocercus urophasianus***	**SC**	**1**	**0**
Green-tailed Towhee	*Pipilo chlorurus*	–	53	29

[1] Partners in Flight Priority Species for Physiographic Area 87: Colorado Plateau (also highlighted).

[2] Partners in Flight species considered of continental importance (also in bold).

Table 4.14-4 (continued). Bird species recorded in 2017 and 2005 along sagebrush shrubland survey transects in Dinosaur National Monument (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network). No federally threatened or endangered (T/E) species were detected. The State listed species of special concern that were detected are indicated by the designation SC.

Common Name	Species Name	T/E	Detected 2005	Detected 2017
Hairy Woodpecker	*Leuconotopicus villosus*	–	0	1
Horned Lark[1]	*Eremophila alpestris*	–	2	0
House Finch	*Carpodacus mexicanus*	–	5	4
House Wren	*Troglodytes aedon*	–	0	2
Juniper Titmouse[1]	*Baeolophus ridgwayi*	–	5	9
Lark Sparrow	*Chondestes grammacus*	–	105	71
Lazuli Bunting	*Passerina amoena*	–	10	9
Mountain Bluebird	*Sialia currucoides*	–	18	5
Mountain Chickadee	*Poecile gambeli*	–	1	0
Mourning Dove	*Zenaida macroura*	–	72	30
Northern Flicker	*Colaptes auratus*	–	1	1
Northern Flicker Red-shafted	*Colaptes auratus*	–	3	2
Northern Mockingbird	*Mimus polyglottos*	–	0	1
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	–	0	2
Peregrine Falcon[1]	*Falco peregrinus*	–	0	2
Pinyon Jay[1,2]	***Gymnorhinus cyanocephalus***	**–**	**11**	**22**
Plumbeous Vireo	*Vireo plumbeus*	–	3	3
Red-breasted Nuthatch	*Sitta canadensis*	–	1	0
Red-tailed Hawk	*Buteo jamaicensis*	–	3	2
Red-winged Blackbird	*Agelaius phoeniceus*	–	0	1
Rock Wren	*Salpinctes obsoletus*	–	48	12
Sage Thrasher	*Oreoscoptes montanus*	–	3	3
Sagebrush Sparrow[1]	*Artemisiospiza nevadensis*	–	42	12
Say's Phoebe	*Sayornis saya*	–	16	4
Song Sparrow	*Melospiza melodia*	–	8	0
Spotted Towhee	*Pipilo maculatus*	–	44	36
Turkey Vulture	*Cathartes aura*	–	1	0
Vesper Sparrow	*Pooecetes gramineus*	–	94	27
Violet-green Swallow	*Tachycineta thalassina*	–	6	4
Virginia's Warbler[1,2]	***Vermivora virginiae***	**–**	**3**	**0**
Warbling Vireo	*Vireo gilvus*	–	1	0
Western Bluebird[1]	*Sialia mexicana*	–	0	4

[1] Partners in Flight Priority Species for Physiographic Area 87: Colorado Plateau (also highlighted).

[2] Partners in Flight species considered of continental importance (also in bold).

Table 4.14-4 (continued). Bird species recorded in 2017 and 2005 along sagebrush shrubland survey transects in Dinosaur National Monument (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network). No federally threatened or endangered (T/E) species were detected. The State listed species of special concern that were detected are indicated by the designation SC.

Common Name	Species Name	T/E	Detected 2005	Detected 2017
Western Kingbird[1]	*Tyrannus verticalis*	–	0	1
Western Meadowlark	*Sturnella neglecta*	–	63	51
Western Scrub Jay	*Aphelocoma californica*	–	6	5
Western Tanager	*Piranga ludoviciana*	–	2	0
Western Wood Pewee	*Contopus sordidulus*	–	0	1
White-throated Swift[1]	*Aeronautes saxatalis*	–	7	1
Yellow-breasted Chat	*Icteria virens*	–	6	7
Yellow-rumped Warbler	*Setophaga coronata*	–	1	0
Yellow Warbler	*Dendroica petechia*	–	2	0

[1] Partners in Flight Priority Species for Physiographic Area 87: Colorado Plateau (also highlighted).

[2] Partners in Flight species considered of continental importance (also in bold).

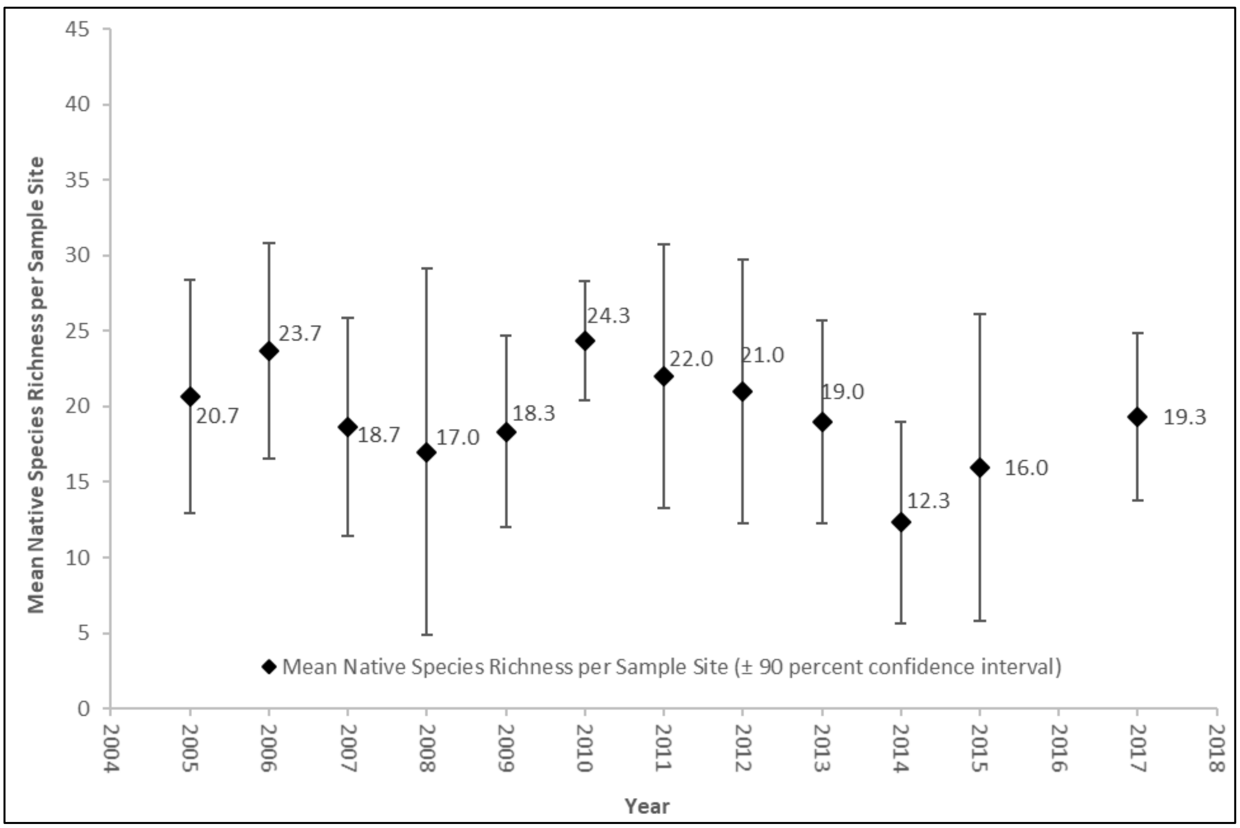


Figure 4.14-5. Means and 90% confidence intervals by year for native bird species richness per sample site for sagebrush shrubland habitat at Dinosaur National Monument from 2005–2017 (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network).

Bird Index of Biotic Integrity

The mean sagebrush shrubland bird IBI score per sample site of 38.7 in 2017 was greater than 85 percent of the 2005 IBI score of 38.2, indicating that composition of the sagebrush shrubland bird community in DINO was in good condition in 2017 (Figure 4.14-6 and Table 4.14-2). The slope of the general linear regression for the sagebrush shrubland bird IBI scores was not statistically significant ($p > 0.05$). Confidence intervals for the IBI scores suggest relatively low within-year variability for this habitat type (Figure 4.14-6).

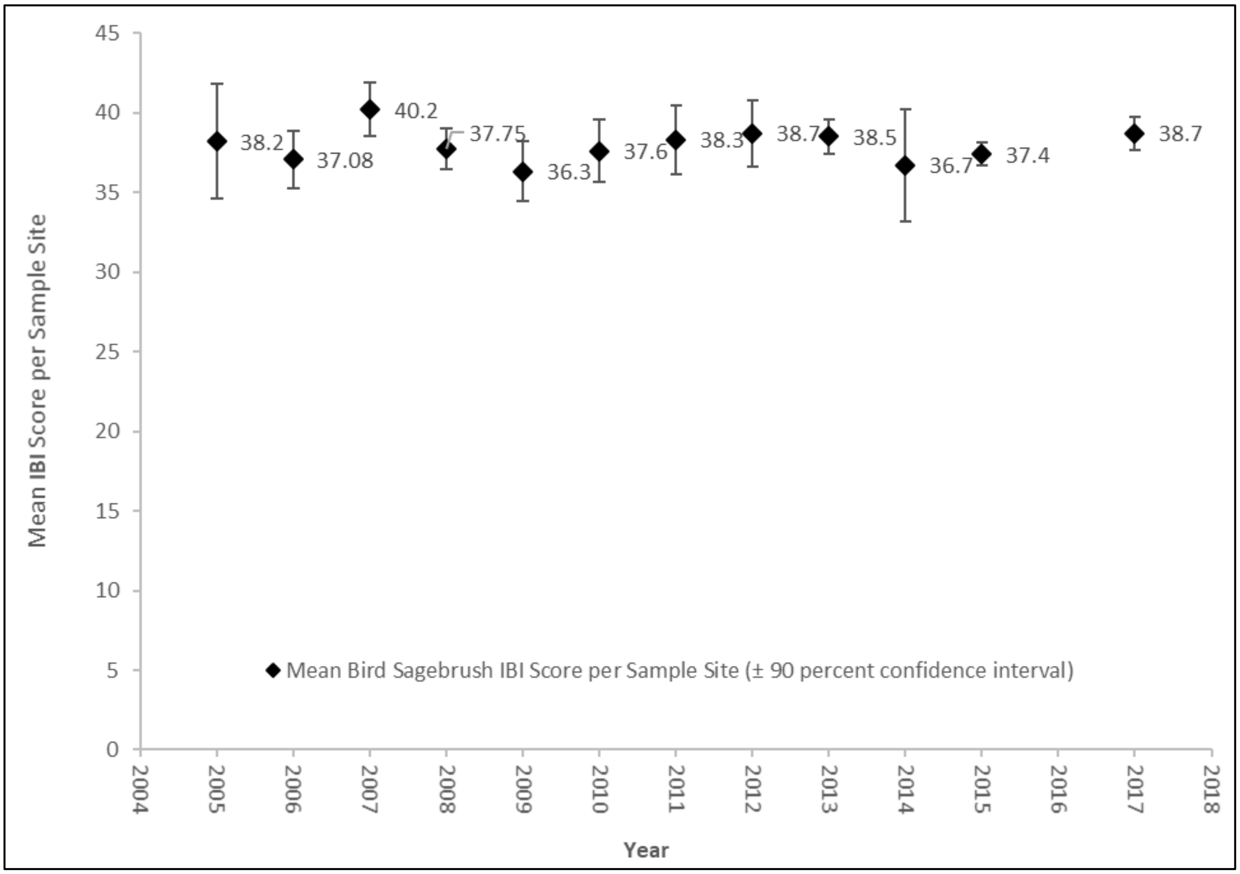


Figure 4.14-6. Means and 90% confidence intervals for native bird IBI scores for sagebrush shrubland sites at Dinosaur National Monument from 2005–2017 (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network).

Species of Conservation Concern

In 2017, there were 4.3 sagebrush shrubland bird species of concern recorded per sample site at DINO. This is 81% of 5.3 (the number recorded in 2005), indicating the condition warrants moderate concern (Table 4.14-2). Twelve species found in DINO during the 2017 sagebrush shrubland bird survey are listed as Partners in Flight birds of concern (Rosenberg et al. 2016) (Table 4.14-4). In 2005 there were also 12 bird species detected that are listed as Partners in Flight birds of concern, although some of these species differed from those detected in 2017 (Table 4.14-4). Species of concern detected in the 2005 survey that were absent in the 2017 survey include the Brewer's blackbird (*Euphagus cyanocephalus*), greater sage-grouse, horned lark (*Eremophila alpestris*), and

Virginia's warbler (Table 4.14-4). Species of concern detected in the 2017 survey that were absent in 2005 include the common nighthawk (*Chordeiles minor*), peregrine falcon (*Falco peregrinus*), western bluebird (*Sialia mexicana*), and western kingbird (*Tyrannus verticalis*) (Table 4.14-4). Black-throated gray warblers and sagebrush sparrows are species of concern that were more common in 2005, and still present in 2017 but in much lower numbers (Table 4.14-4). Pinyon jays were the only species of concern that were found in much higher numbers in 2017 than in 2005 (Table 4.14-4). The sagebrush sparrow is a sagebrush obligate and was the only species of conservation concern to show a significant decline within the sagebrush habitat between 2005 and 2017 ($r^2 = 0.32$, $p = 0.039$). Sagebrush sparrows have been shown to decline significantly with oil and gas development (Gilbert and Chalfoun 2011). Their apparent decline over the monitoring period at DINO could be related to regional declines in sagebrush habitat, which includes impacts of increased oil and gas development throughout the region.

The slope of the general linear regression for sagebrush shrubland bird species of concern was not significant, suggesting an unchanging trend. There also was considerable overlap in the 90 percent confidence intervals among the years 2005 to 2017 and high intra-period variability (Figure 4.14-7).

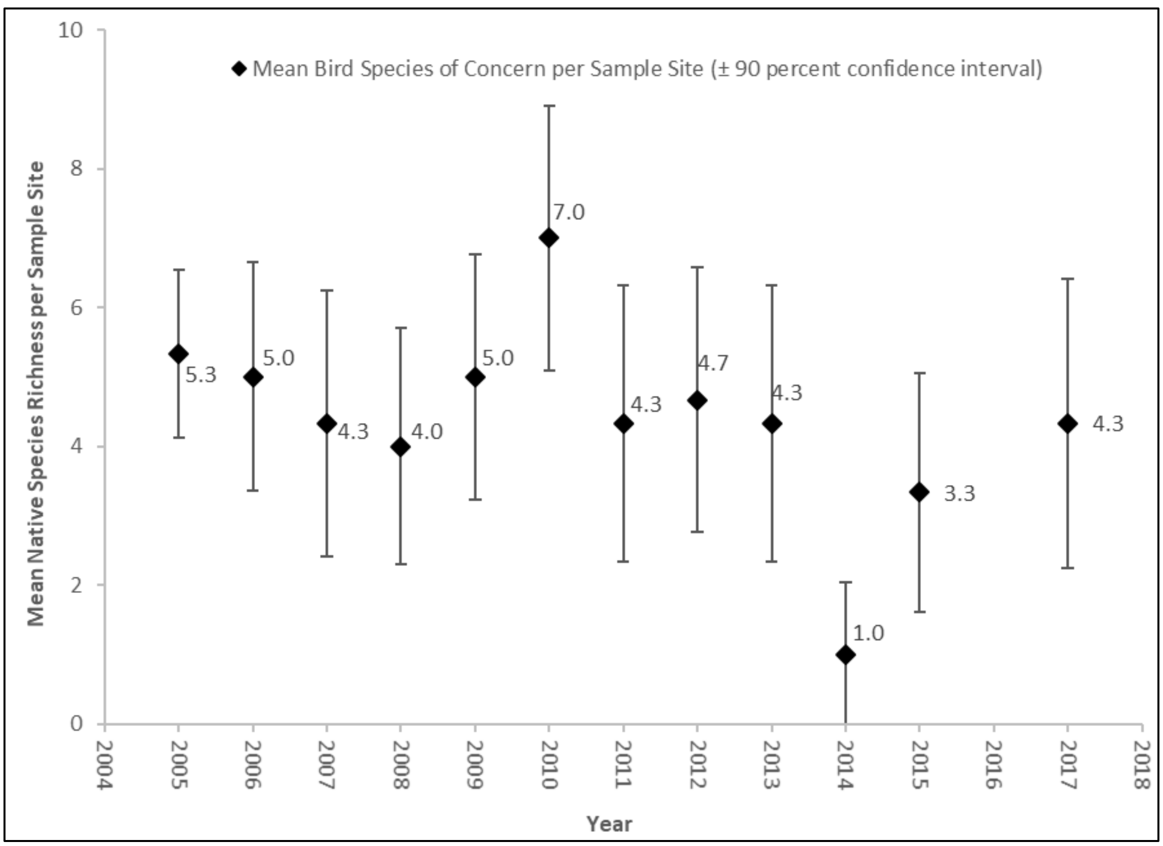


Figure 4.14-7. Means and 90% confidence intervals per site for native sagebrush shrubland bird species of concern at Dinosaur National Monument (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network).

Lowland Riparian Birds

Native Species Richness

There was a mean of 22.7 native species and 39 species in total recorded along lowland riparian sampling transects in 2017. The most common species was the yellow warbler (*Dendroica petechial*), followed by the spotted towhee, lazuli bunting (*Passerina amoena*), and yellow-breasted chat (*Icteria virens*) (Table 4.14-5). The 22.7 native species per sample site recorded in 2017 was 71.6% of the 31.7 species per sample site recorded in 2005 (Figure 4.14-8), indicating that the lowland riparian bird community at DINO warrants moderate concern in 2017 (Table 4.14-2). The slope of the general linear regression for bird species richness per sample site was negative and statistically significant ($r^2 = 0.55$, $p = 0.006$), suggesting a decline in richness of the lowland riparian native bird community at DINO over the sampling period.

Table 4.14-5. Bird species recorded in 2017 and 2005 at lowland riparian survey transects in Dinosaur National Monument (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network). No federally threatened or endangered (T/E) species or State listed species of concern were detected.

Common Name	Species Name	Detected 2005	Detected 2017
American Dipper	*Cinclus mexicanus*	0	2
American Goldfinch	*Carduelis tristis*	4	5
American Kestrel	*Falco sparverius*	0	1
American Robin	*Turdus migratorius*	8	19
Ash-throated Flycatcher	*Myiarchus cinerascens*	4	5
Bewick’s Wren	*Thryomanes bewickii*	2	0
Black-billed Magpie	*Pica hudsonia*	2	0
Black-chinned Hummingbird[1]	*Archilochus alexandri*	3	0
Black-headed Grosbeak	*Pheucticus melanocephalus*	3	0
Black-throated Gray Warbler[1]	*Dendroica nigrescens*	22	6
Blue-gray Gnatcatcher	*Polioptila caerulea*	9	17
Brewer’s Blackbird[1]	*Euphagus cyanocephalus*	2	0
Brewer’s Sparrow[1]	*Spizella breweri*	1	0
Broad-tailed Hummingbird	*Selasphorus platycercus*	3	1
Brown-headed Cowbird	*Molothrus ater*	5	–
Bullock’s Oriole	*Icterus bullockii*	1	0
Bushtit	*Psaltriparus minimus*	0	1
Canyon Wren	*Catherpes mexicanus*	3	3
Chipping Sparrow	*Spizella passerina*	4	7
Cliff Swallow	*Petrochelidon pyrrhonota*	8	0
Common Raven	*Corvus corax*	10	9

[1] Partners in Flight Priority Species for Physiographic Area 87: Colorado Plateau (also highlighted).

[2] Partners in Flight species considered of continental importance (also in bold).

Table 4.14-5 (continued). Bird species recorded in 2017 and 2005 at lowland riparian survey transects in Dinosaur National Monument (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network). No federally threatened or endangered (T/E) species or State listed species of concern were detected.

Common Name	Species Name	Detected 2005	Detected 2017
Common Yellowthroat	Geothlypis trichas	3	2
Cooper's Hawk	Accipiter cooperii	1	1
Cordilleran Flycatcher	Empidonax occidentalis	1	0
Dusky Flycatcher	Empidonax oberholseri	1	0
Gray Flycatcher1	Empidonax wrightii	1	0
Gray Vireo[1,2]	**Vireo vicinior**	**1**	**0**
Great Blue Heron	Ardea herodias	1	0
Green-tailed Towhee	Pipilo chlorurus	6	0
House Finch	*Carpodacus mexicanus*	4	3
House Wren	*Troglodytes aedon*	14	16
Indigo Bunting	*Passerina cyanea*	0	1
Lark Sparrow	*Chondestes grammacus*	4	6
Lazuli Bunting	*Passerina amoena*	115	54
Lesser Goldfinch	*Carduelis psaltria*	1	11
Lincoln's Sparrow	*Melospiza lincolnii*	1	0
Mountain Bluebird	*Sialia currucoides*	0	5
Mourning Dove	*Zenaida macroura*	3	4
Northern Flicker	*Colaptes auratus*	1	2
Northern Harrier[1]	*Circus cyaneus*	1	1
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	0	2
Osprey	*Pandion haliaetus*	0	2
Plumbeous Vireo	*Vireo plumbeus*	11	6
Rock Wren	*Salpinctes obsoletus*	6	8
Sagebrush Sparrow[1]	*Artemisiospiza nevadensis*	1	0
Say's Phoebe	*Sayornis saya*	5	2
Song Sparrow	*Melospiza melodia*	33	21
Spotted Towhee	*Pipilo maculatus*	48	65
Turkey Vulture	*Cathartes aura*	1	1
Violet-green Swallow	*Tachycineta thalassina*	6	22
Warbling Vireo	*Vireo gilvus*	13	10
Western Kingbird[1]	*Tyrannus verticalis*	1	0
Western Meadowlark	*Sturnella neglecta*	3	0
Western Tanager	*Piranga ludoviciana*	2	1

[1] Partners in Flight Priority Species for Physiographic Area 87: Colorado Plateau (also highlighted).

[2] Partners in Flight species considered of continental importance (also in bold).

Table 4.14-5 (continued). Bird species recorded in 2017 and 2005 at lowland riparian survey transects in Dinosaur National Monument (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network). No federally threatened or endangered (T/E) species or State listed species of concern were detected.

Common Name	Species Name	Detected 2005	Detected 2017
White-throated Swift[1]	*Aeronautes saxatalis*	12	7
Wild Turkey	*Meleagris gallopavo*	1	1
Yellow-breasted Chat	*Icteria virens*	38	24
Yellow rumped Warbler	*Setophaga coronata*	1	0
Yellow Warbler	*Dendroica petechia*	122	69

[1] Partners in Flight Priority Species for Physiographic Area 87: Colorado Plateau (also highlighted).

[2] Partners in Flight species considered of continental importance (also in bold).

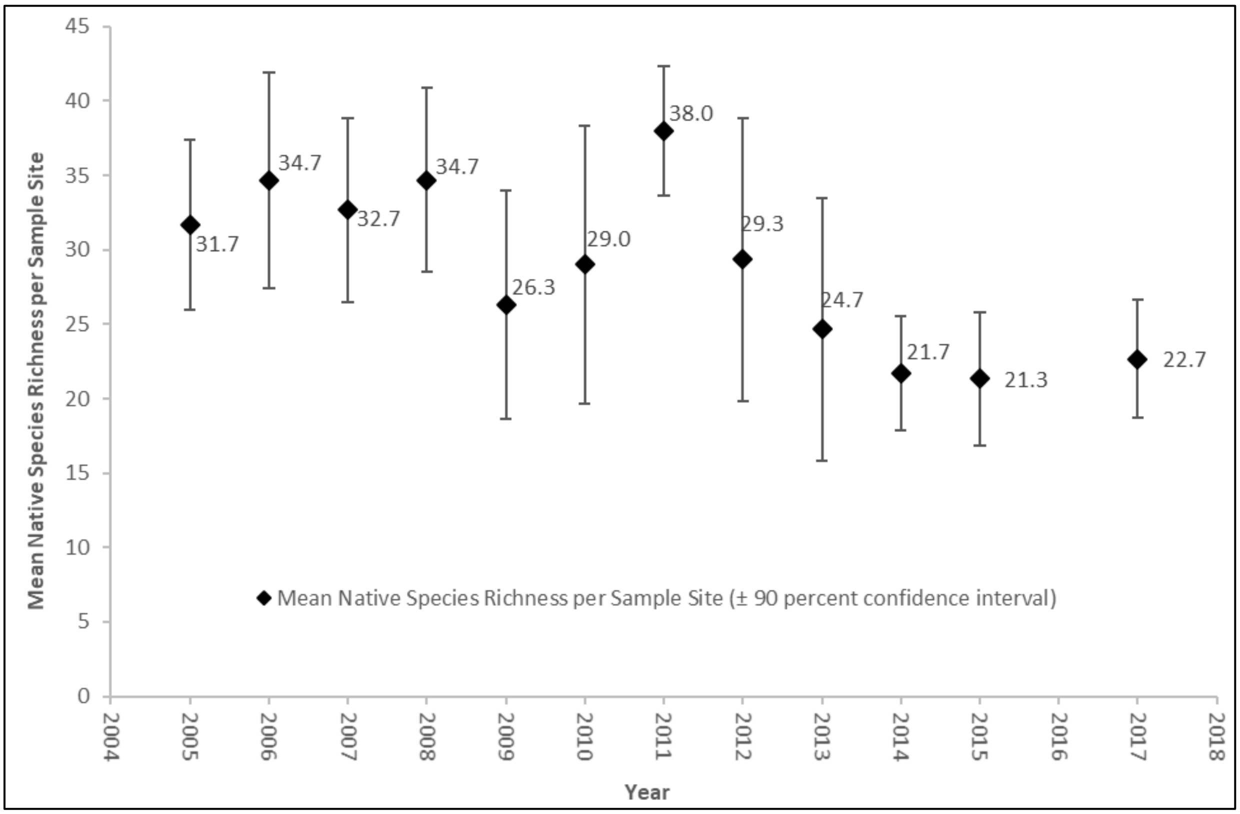


Figure 4.14-8. Means and 90% confidence intervals by year for native bird species richness per sample site in lowland riparian habitat at Dinosaur National Monument from 2005 to 2017 (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network).

Bird Index of Biotic Integrity

The mean lowland riparian bird IBI score per sample site of 53.2 in 2017 was greater than 85 percent of the 2005 IBI score of 51.3, indicating that composition of the lowland riparian bird community in DINO is in good condition (Figure 4.14-9 and Table 4.14-2). The slope of the general linear regression for the lowland riparian bird IBI scores indicates an insignificant, unchanging trend over

time ($p > 0.05$). Additionally, the 90% confidence intervals for the IBI scores are relatively narrow, suggesting low variability across sites (Figure 4.14-9).

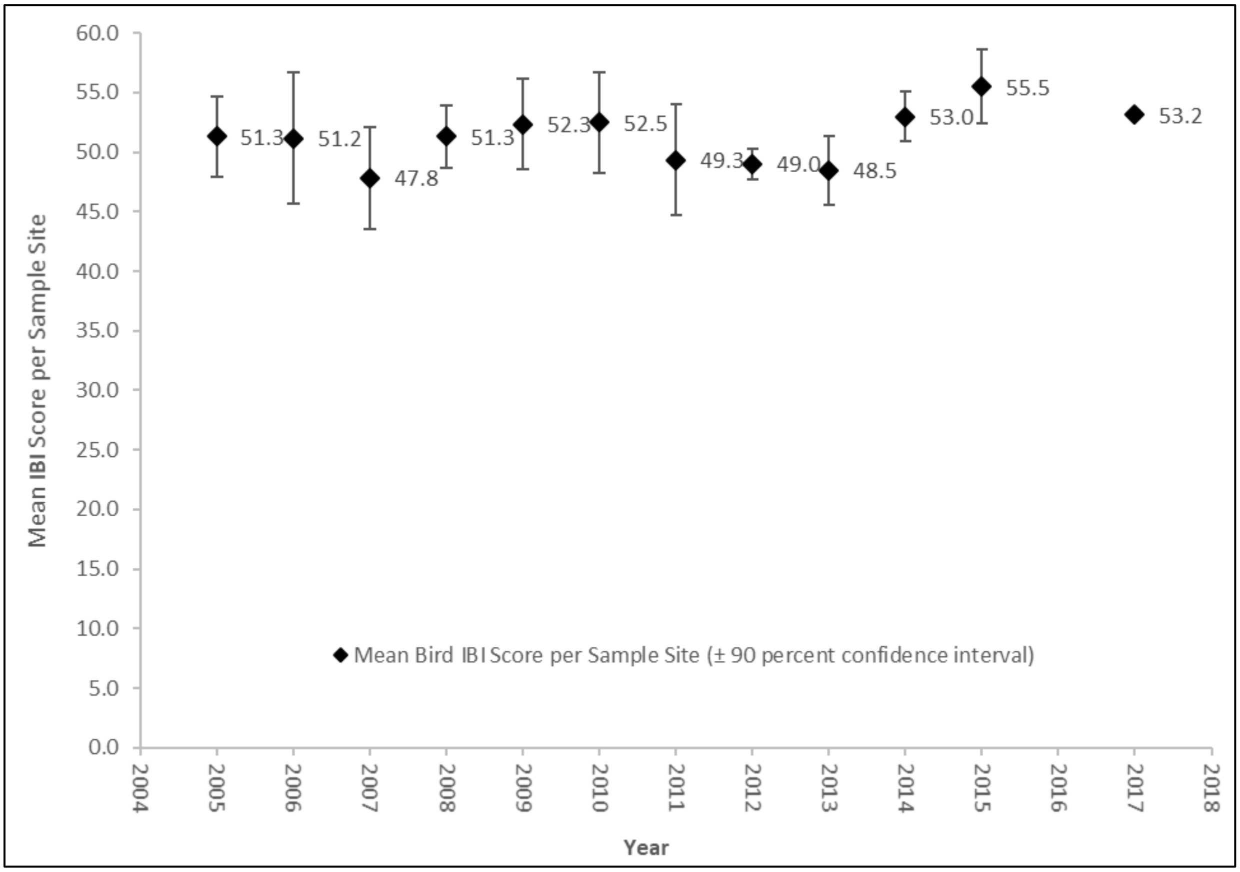


Figure 4.14-9. Means and 90% confidence intervals for native bird IBI scores per sample site for lowland riparian sites at Dinosaur National Monument from 2005–2017 (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network).

Species of Conservation Concern

In 2017, a mean of two species of concern was recorded per sample site from the lowland riparian bird community at DINO. This was 38% of 5.3 (the number recorded in 2005), indicating the resource warrants significant concern (Figure 4.14-10 and Table 4.14-2). Three species found at DINO during the 2017 lowland riparian bird survey are listed as Partners in Flight birds of concern while 10 of the species detected in 2005 were listed as Partners in Flight birds of concern (Rosenberg et al. 2016) (Table 4.14-5). Species of concern detected in the 2005 survey that went undetected in the 2017 survey include the black-chinned hummingbird (*Archilochus alexandri*), Brewer's blackbird, Brewer's sparrow, gray flycatcher, gray vireo (*Vireo vicinior*), sagebrush sparrow, and the western kingbird (Table 4.14-5). Species of concern that were present in both years, but fewer in number in 2017 compared to 2005, were the black-throated gray warbler and the white-throated swift (Table 4.14-5). Despite some differences between 2005 and 2017, there was no statistically significant trend for any of the species of conservation concern across the study period.

The slope of the general linear regression for lowland riparian bird species of concern was negative and statistically significant ($r^2 = 0.38$, $p = 0.03$), suggesting a decrease in the number of lowland riparian bird species of concern over time. The 90% confidence intervals for mean number of bird species of concern are very wide for some years (Figure 4.14-10), indicating high variability in the data.

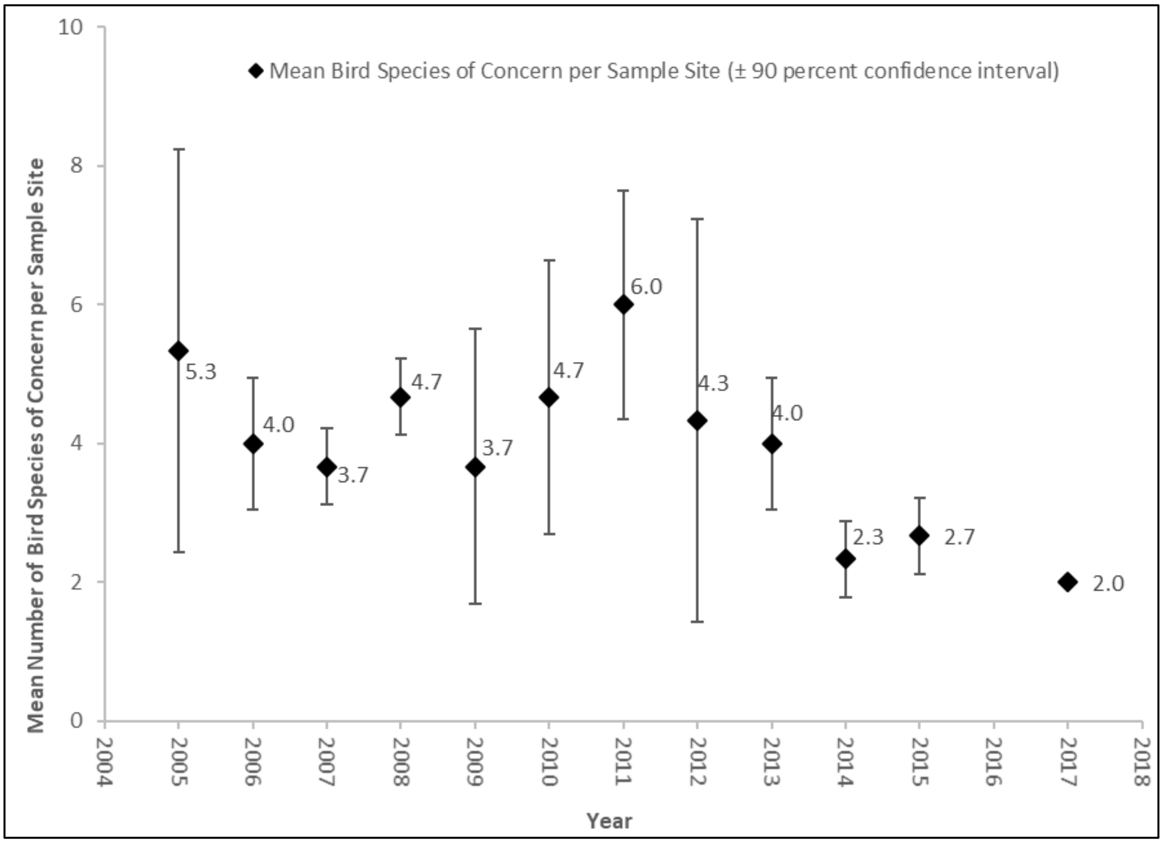


Figure 4.14-10. Means and 90 percent confidence intervals for bird species of concern in lowland riparian sample sites at Dinosaur National Monument from 2005–2017 (data for summary provided by the Northern Colorado Plateau Inventory and Monitoring Network).

<u>Overall Condition and Trend by Habitat Type</u>

Results for native species richness, bird IBI, and the number of species of concern present in 2017 indicate that the DINO pinyon-juniper, sagebrush shrubland, and lowland riparian bird communities are in moderate condition. The community structure and the number of obligate pinyon-juniper, sagebrush shrubland, and lowland riparian birds are representative of a moderately disturbed landscape (Table 4.14-6). The bird community condition of the pinyon-juniper and lowland riparian bird communities warrant moderate concern and show deteriorating trends, while the sagebrush shrubland habitat was in good condition and exhibited an unchanging trend. Results for the 2005 to 2017 period suggest an overall deteriorating trend in the bird community composition at DINO.

Table 4.14-6. Condition and trend summary for birds at Dinosaur National Monument.

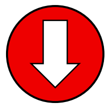
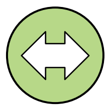
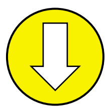
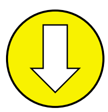
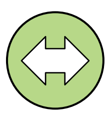
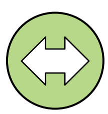
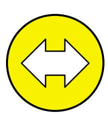
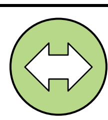
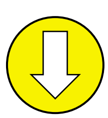
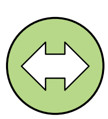
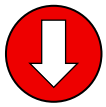
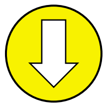
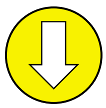
Indicator	Condition Status/Trend	Rationale
Native Species Richness (S)		Native pinyon-juniper woodland bird species richness fluctuated between a mean of 14 and 32 species per site from 2005 to 2017, with mean richness of 19.3 native bird species per site in 2017, less than the management target of 85 percent of 32, warranting significant concern. Analysis of the pinyon-juniper woodland monitoring data indicates a decline in native species richness between 2005 and 2017.
Bird Index of Biotic Integrity		In 2017, the pinyon-juniper woodland mean bird IBI score of 42.8 per site was greater than 85% of 38.2, the mean score in 2005. The mean score per site fluctuated from 38.2 to 44.8 between 2005 and 2017. IBI scores indicate an unchanging trend in the biotic integrity of the bird community.
Species of Conservation Concern		The number of bird species of concern fluctuated between a mean of 1.0 and 7.7 species per site between 2005 and 2017 with a mean of 5.7 species per site present in 2017. This was 74% of 7.7, the mean score in 2005. Results indicate a decline in the number of bird species of concern present between 2005 and 2017.
Pinyon-Juniper Woodland overall		–
Native Species Richness (S)		Mean native bird species richness in sagebrush shrubland ranged between 12.3 and 24.3 species per site from 2005 to 2017 with mean richness of 19.3 native bird species per site in 2017, greater than the management target of 85 percent of a mean of 20.7 per site recorded in 2005. The trend was unchanging.
Bird Index of Biotic Integrity		In 2017, the sagebrush mean bird IBI score of 38.7 per site was greater than 85% of 38.2, the mean score in 2005. The mean score per site fluctuated from 36.3 to 40.2 between 2005 and 2017. Analysis of sagebrush IBI scores indicates an unchanging trend in the biotic integrity of the bird community between 2005 and 2017.
Species of Conservation Concern		The number of bird species of concern fluctuated between a mean of 1 and 7 species per site between 2005 and 2017 with a mean of 4.3 species per site present in 2017, which is 81% of 5.3, the mean in 2005. The trend was unchanging between 2005 and 2017.
Sagebrush Shrublands overall		–
Native Species Richness (S)		Native lowland riparian bird species richness fluctuated between a mean of 21.3 and 38 per site from 2005 to 2017 with mean richness of 22.7 per site in 2017, which is 72% of 31.7, the mean in 2005. The data indicate a decline in native species richness between 2005 and 2017.
Bird Index of Biotic Integrity		In 2017, the lowland riparian mean bird IBI score of 53.2 per site was greater than 85% of 51.3, the score in 2005. The mean score per site fluctuated from 48.7 to 55.5 between 2005 and 2017. The trend was stable between 2005 and 2017.

Table 4.14-6 (continued). Condition and trend summary for birds at Dinosaur National Monument.

Indicator	Condition Status/Trend	Rationale
Species of Conservation Concern		The number of bird species of concern fluctuated between 6 and 15 species between 2005 and 2017, with 5 species present in 2017, which is 56% of 9, the number detected in 2005. The data indicate a decline in the number of bird species of conservation concern between 2005 and 2017.
Lowland Riparian overall		–
Birds overall		**Overall bird community condition warrants moderate concern with a deteriorating trend. Confidence in the assessment is medium. Bird IBI scores were consistently good. The condition of other indicators varied by habitat type.**

4.14.5. Uncertainty and Data Gaps

Surveys over the study period provide a considerable amount of data upon which to assess condition and recent trends. The key uncertainty related to the assessment of the bird community at DINO is in the limited years of data upon which the assessment is based. Assessments of ecological change should use long-term data spanning decades rather than the 12 years of monitoring used for this assessment (Holmes 2010, Magurran et al. 2010). Continued monitoring could either support or refute the outcome of the current assessment. Comprehensive data collected over an extended time period is needed to assess the natural temporal fluctuation of the condition indicators used in this assessment and to assure the accuracy of the assessment (Dornelas et al. 2012). This assessment is based upon monitoring data collected over multiple years by multiple trained volunteer observers with varying skills in conducting point counts. Non-sampling errors associated with the use of multiple volunteers over long time periods could introduce error, including bias associated with varying detection capabilities of the observers, which can reduce the ability to identify statistically significant trends in the data (Dornelas et al. 2012).

Another factor potentially affecting the quality of the data is the probability that a bird that is present during the time the point count is occurring is detected. The protocols used for monitoring birds in the NCPN rely on a 5-minute count interval. Extending the interval to 10 minutes would improve the probability of detecting a species. In addition, because points are surveyed only once per year after 2011, there is always the chance that rare or less vocal species will go undetected. This can be a problem when calculating the index of biotic integrity, which is calculated based on the number of species within different guilds.

The trends reported here are limited to breeding birds detected at three of the major habitats within DINO in 11 years over a 12-year period. These data provide a good indicator of trends in populations of bird species during this period, but because the monument is so diverse in habitat and topography, the monitoring efforts are likely missing bird species that associate with other habitats at DINO that are not being monitored. Expanding monitoring at DINO into additional habitat types would provide

a more complete picture of bird population trends across the monument. Additionally, data on the abundance of migratory and wintering birds at DINO are lacking and investigation of bird populations during these periods is an important need. With the climate rapidly changing throughout the region, in addition to other local, regional and global threats, continued long-term monitoring of the bird communities at DINO is important.

4.14.6. Sources of Expertise

- Matthew McLaren is the Integrated Monitoring in Bird Conservation Regions Coordinator for the Bird Conservancy of the Rockies. Matthew was involved in the bird surveys conducted for the National Park Service, Northern Colorado Plateau Network and authored many of the bird reports culminating from that survey work.

- Greg Shriver is a Professor of Wildlife Ecology in the Department of Entomology and Wildlife Ecology, College of Agriculture and Natural Resources, University of Delaware. He is responsible for continuation of the bird monitoring within the Northern Colorado Plateau Network and is one of the authors of the 2018 bird monitoring report completed for the National Park Service.

- Helen Thomas is the Data Manager for the Northern Colorado Plateau Inventory and Monitoring Network. Helen is the point of contact for data inquiries for the Network.

4.14.7. Literature Cited

Anderson, R.S., and J.E. Inouye. 2001. Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. Ecological Monographs 71:531–556.

Bestgen, K. 2015. Aspects of the Yampa River flow regime essential for maintenance of native fishes. Final Report submitted to the National Park Service, The Nature Conservancy, and Western Resource Advocates. Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins. Larval Fish Laboratory Contribution 181 NPS/NRSS/WRD/NRR 2015/962, 112.

Bradley, B.A. 2010. Assessing ecosystem threats from global and regional change: Hierarchical modeling of risk to sagebrush ecosystems from climate change, land use and invasive species in Nevada, USA. Ecography 33:198–208.

Coles, J., D. Cogan, D. Salas, A. Wight, G. Wakefield, V. Loh, J., and A. Evenden. 2008. Vegetation classification and mapping project report, Dinosaur National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2008/112. National Park Service, Fort Collins, Colorado.

Colorado Partners in Flight. 2000. Physiographic Region 87: Colorado Plateau. Colorado Land Bird Conservation Plan. Available at: https://partnersinflight.org/ (accessed 27 Apr 2018).

Crewe, T.L., and S.T.A. Timmermans. 2005. Assessing biological integrity of Great Lakes coastal wetlands using marsh bird and amphibian species. Wetland3-EPA-01 Technical Report. Marsh Monitoring Program, Bird Studies Canada.

Daw, S., M. Beer, and S.L. Garman. 2017. Landbird monitoring protocol narrative for park units in the Northern Colorado Plateau Network: version 1.03. Natural Resource Report. NPS/NCPN/NRR—2017/1428. National Park Service. Fort Collins, Colorado.

Dornelas, M., A. E. Magurran, S.T. Buckland, A. Chao, R.L. Chazdon, R.K. Colwell, T. Curtis, K.J. Gaston, N.J. Gotelli, M.A. Kosnik, B. McGill, J.L. McCune, H. Morlon, P.J. Mumby, L. Ovreas, A. Studeny, and M. Vellend. 2012. Quantifying temporal change in biodiversity: challenges and opportunities. Proceedings of the Royal Society B 280:1–10.

Gilbert, M.M., and A.D. Chalfoun. 2011. Energy development affects populations of sagebrush songbirds in Wyoming. Journal of Wildlife Management 75:816–824.

Hansen, A., and D. Gryskiewicz. 2003. Interactions between Heartland National Parks and surrounding land use change: development of conceptual models and indicators for monitoring. Prepared for the National Park Service Heartland Network by Montana State University.

Holmes, R.T. 2010. Avian population and community processes in forest ecosystems: Long-term research in the Hubbard Brook Experimental Forest. Forest Ecology and Management 262:20–32.

Homer, C.G., G. Xian, C.L. Aldridge, D.K. Meyer, T.R. Loveland, and M.S. O'Donnell. 2015. Forecasting sagebrush ecosystem components and greater sage-grouse habitat for 2050: Learning from past climate patterns and Landsat imagery to predict the future. Ecological Indicators 55:131–145.

Johnson, K., G. Sadoti, and J. Smith. 2017. Weather-induced declines in piñon tree condition and response of a declining bird species. Journal of Arid Environments 146:1–9.

Jørgenson, S.E., and F. Müller. 2000. Handbook of ecosystem theories and management. CRC Press, Boca Raton, Florida.

Magurran, A.E., S.R. Baillie, S.T. Buckland, J. McP. Dick, D.A. Elston, E.M. Scott, R.I. Smith, P.J. Somerfield, and A.D. Watt. 2010. Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. Trends in Ecology and Evolution 25:574–582.

Marshall, M., C. Tzilkowski, and K. Callahan. 2016. Streamside bird monitoring protocol for the Eastern Rivers and Mountains Network: Protocol narrative version 3.0. Natural Resource Report NPS/ERMN/NRR—2016/1224. National Park Service, Fort Collins, Colorado. Available at: https://www.nps.gov/im/ermn/streamside-birds.htm (accessed February 2018).

McDowell, N.G., A.P. Williams, C. Xu, W.T. Pockman, L.T. Dickman, S. Sevanto, R. Pangle, J. Limousin, J. Plaut, D.S. Mackay, J. Ogee, J.C. Domec, C.D. Allen, R.A. Fisher, X. Jiang, J.D. Muss, D.D. Breshears, S.A. Rauscher, and C. Koven. 2016. Multi-scale predictions of massive conifer mortality due to chronic temperature rise. Nature Climate Change 6:295–300.

McLaren, M., and C. White. 2016. Landbird monitoring in the Northern Colorado Plateau Network: 2015 field season. Natural Resource Report. NPS/NCPN/NRR—2016/1316. National Park Service, Fort Collins, Colorado.

Miller R.F., D.E. Naugle, J.D. Maestas, C.A. Hagen, and G. Hall. 2017. Special Issue: Targeted woodland removal to recover at-risk grouse and their sagebrush-steppe and prairie ecosystems. Rangeland Ecology & Management 70:1–8.

Mote, P.W., S. Li, D.P. Lettenmaier, M. Xiao, and R. Engel. 2018. Dramatic declines in snowpack in the western US. npj Climate and Atmospheric Science 1:2.

O'Connell, T.J., L.E. Jackson, and R.P. Brooks. 1998a. A bird community index of biotic integrity for the mid-Atlantic Highland. Environmental Monitoring and Assessment 51:145–156.

O'Connell, T.J., L.E. Jackson, and R.P. Brooks. 1998b. The bird community index: a tool for assessing biotic integrity for the mid-Atlantic Highlands, final report. Penn State Cooperative Wetlands Center, Report No. 98-4. Forest Resources Laboratory, Pennsylvania State University, University Park, Pennsylvania.

O'Connell, T.J., L.E. Jackson, and R.P. Brooks. 2000. Bird guilds as indicators of ecological condition in the central Appalachians. Ecological Applications 10:1706–1721.

Panjabi, A.O., P.J. Blancher, R. Dettmers, and K.V. Rosenberg. 2012. The Partners in Flight Handbook on Species Assessment, version 2012. Partners in Flight Technical Series No. 3.

Redmond, M.D., F. Forcella, and N.N. Barger. 2012. Declines in pinyon pine cone production associated with regional warming. Ecosphere 3(12):1–14.

Roberts, S.G., E.L. Tymkiw, Z.S. Ladin, and W.G. Shriver. 2018. Landbird monitoring in the Northern Colorado Plateau Network: 2017 field season. Natural Resource Report NPS/NCPN/NRR—2018/1605. National Park Service, Fort Collins, Colorado.

Rocky Mountain Bird Observatory. 2018. Rocky Mountain Avian Data Center: Data Collection website. Available at: http://rmbo.org/v3/avian/DataCollection.aspx (accessed 15 May 2019).

Rosenberg, K.V., J.A. Kennedy, R. Dettmers, R.P. Ford, and D. Reynolds. 2016. Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee.

Sauer, J.R., D.K. Niven, J.E. Hines, D.J. Ziolkowski, Jr, K.L. Pardieck, J.E. Fallon, and W.A. Link. 2017. The North American Breeding Bird Survey, Results and Analysis 1966–2015. Version 2.07.2017 USGS Patuxent Wildlife Research Center, Laurel, Maryland.

Schlaepfer, D.R., W.K. Lauenroth, and J.B. Bradford. 2012. Effects of ecohydrological variables on current and future ranges, local suitability patterns, and model accuracy in big sagebrush. Ecography 35:374–384.

Schroeder, M.A., C.L. Aldridge, A.D. Apa, J.R. Bohne, C.E. Braun, S.D. Bunnell, J.W. Connelly, P.A. Deibert, S.C. Gardner, M.A. Hilliard, G.D. Kobriger, S.M. McAdam, C.W. McCarthy, J.J. McCarthy, D.L. Mitchell, E.V. Rickerson, and S.J. Stiver. 2004. Distribution of Sage-Grouse in North America. The Condor 106:363–376.

Tyus, H.M., and J.F. Saunders. 2000. Nonnative fish control and endangered fish recovery: Lessons from the Colorado River. Fisheries 25:17–24.

Witwicki, D. 2013. Integrated upland monitoring in Dinosaur National Monument: annual report 2011 (non-sensitive version). Natural Resource Technical Report. NPS/NCPN/NRTR—2013/712.N. National Park Service. Fort Collins, Colorado.

4.15. Bighorn Sheep

4.15.1. Background and Importance

Bighorn sheep (*Ovis canadensis*) are iconic of the western United States; sheep perched on sheer cliff faces are a favorite image for monument visitors to photograph. Bighorn sheep are habitat specialists requiring steep, rocky terrain with open visibility and shallow snow cover in winter. They avoid forested areas because of restricted visibility (Singer and Gudorf 1999) of predators. Habitat suitable for bighorn sheep is relatively limited and patchily distributed on the landscape.

Bighorn sheep are native to western North America, but they have been extirpated from large portions of their historical range and currently exhibit a patchy distribution over what was once a mostly continuous area (Figure 4.15-1). Prior to European settlement of the western United States, bighorn sheep were widespread in nearly all steep habitats in the mountains, foothills, river breaks, and prairie badlands. Bighorn sheep suffered catastrophic declines in the late 1800s and 1900s and have existed since then as small, isolated groups in a highly fragmented distribution (Singer and Gudorf 1999). There are several subspecies of bighorn sheep. The Rocky Mountain bighorn sheep (*Ovis c. canadensis*), hereafter "bighorn sheep," is currently found from the mountains of southern British Columbia and Alberta into Washington, Montana, Oregon and Idaho, with disjunct populations in the Rocky Mountains of Wyoming and Colorado, including at DINO.

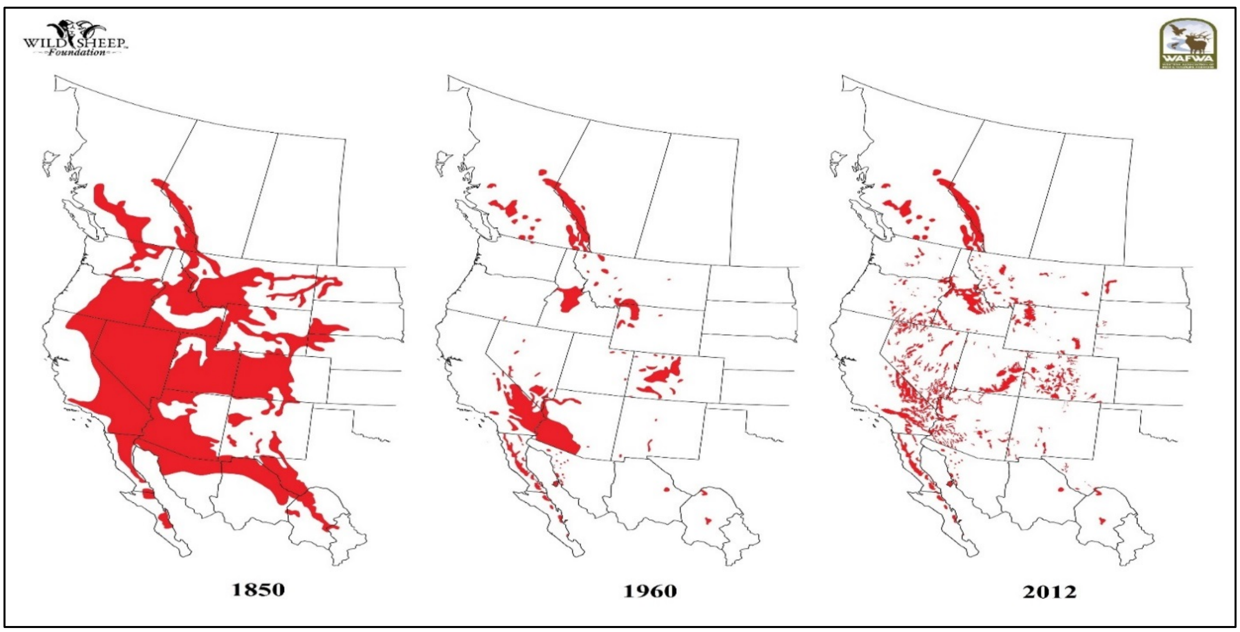


Figure 4.15-1. Distribution (probable 1850) of bighorn sheep in North America 1850–2012 (after Buechner 1960, Western Association of Fish and Wildlife Agencies 2018 and the Wild Sheep Foundation 2018).

At DINO, an estimated 1,000 bighorn sheep occupied the monument and Green River corridor in pre-settlement times, but historic hunting and negative impacts on the ecosystem from extensive grazing, coupled with a series of disease epidemics led to their extirpation in northwestern Colorado by the 1940s (Singer and Gudorf 1999). The NPS reintroduced a total of 99 bighorn sheep to DINO

beginning in 1952 (32 sheep introduced), with introductions continuing in 1984 (19 sheep added), 1997 (21 sheep added) and 2000 (27 sheep added). The reintroduction was considered a moderate success, attaining population levels that were only a fraction of their historic numbers (George et al. 2009, Singer and Gudorf 1999). In 1997 a second reintroduction effort was implemented to restore bighorn sheep to the historic habitat of the entire Green River corridor, extending outside of the monument. At the time of the 1997 regional effort, the bighorn sheep population in the Green River corridor was estimated to number around 400 individuals with 300 of those in DINO (Singer and Gudorf 1999).

Bighorn sheep at Dinosaur National Monument. Photo courtesy of NPS.

At the time of this assessment, there were an estimated 7,000 bighorn sheep in Colorado with approximately 168 individuals residing within DINO distributed across three herds. Dinosaur National Monument includes key habitat defined by Colorado Parks and Wildlife as important bighorn sheep production, summer concentration and winter concentration areas, and habitat in Utah defined as crucial habitat by the Utah Division of Wildlife Resources (Figure 4.15-2).

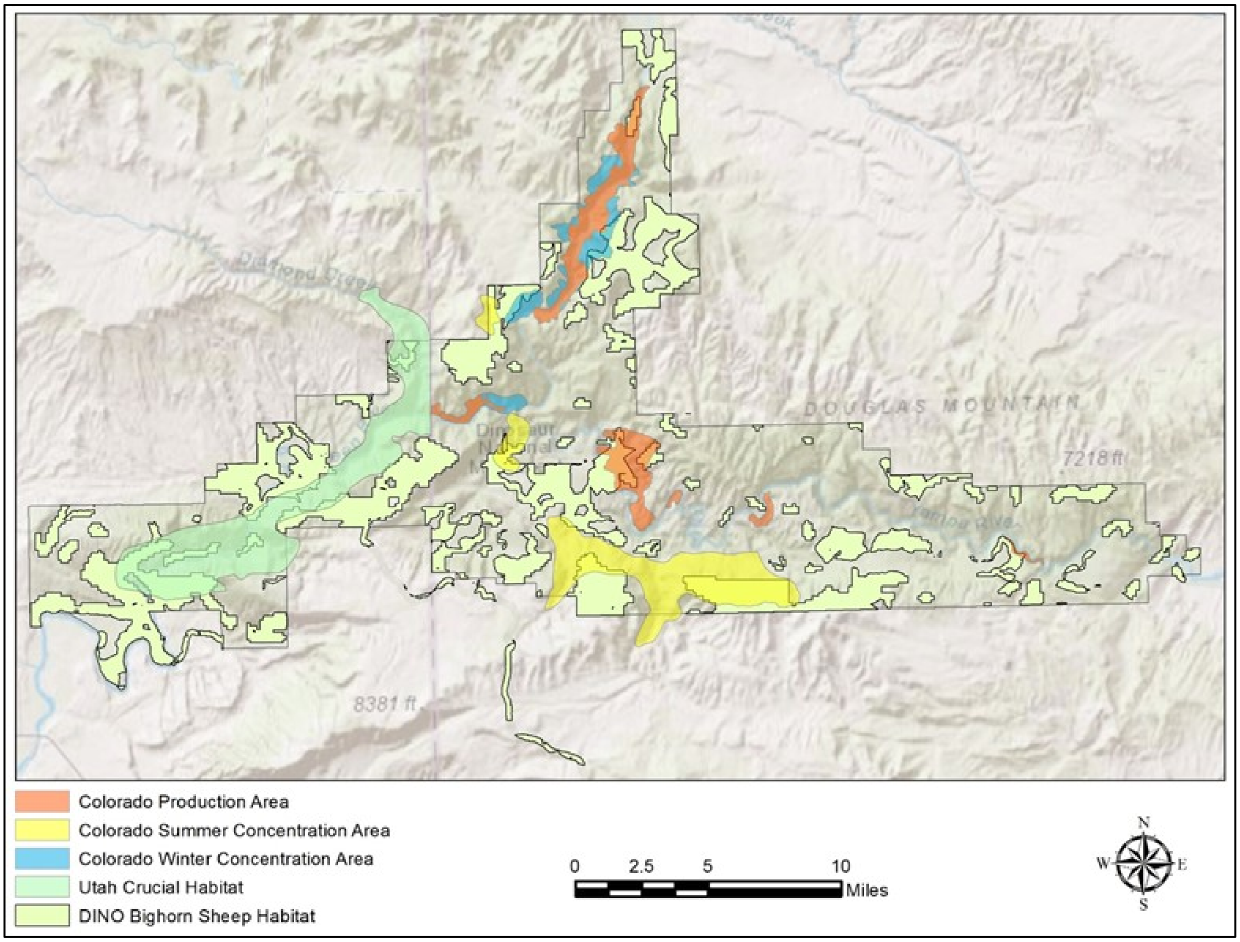


Figure 4.15-2. Key habitat in Utah and Colorado for bighorn sheep at Dinosaur National Monument (data sources: Colorado Parks and Wildlife 2011, Utah Department of Natural Resources 2006, Sweanor et al. 1994).

Production areas are those areas used by pregnant female bighorn sheep from May through June. Summer concentration areas are favored by bighorn sheep from mid-June through mid-August and are characterized by high quality forage, security, and lack of disturbance. Winter concentration areas are focal areas within the bighorn sheep winter range where densities are at least 200% greater than within the surrounding winter range. Crucial habitat is defined as habitat essential to life history requirements of bighorn sheep. The degradation and loss of crucial habitat will lead to significant declines in carrying capacity and/or numbers of bighorn sheep.

Threats

Bighorn sheep are hypersensitive to exotic diseases transmitted by domestic sheep, particularly pneumonia caused by *Pasteurella corynebacterium*, *Mycoplasma ovipneumoniae* and other agents (Buechner 1960, Beecham et al. 2007). This sensitivity to pneumonia coupled with a narrow habitat niche makes the persistence of bighorn sheep populations tenuous (Singer et al. 2001). Within a herd exposed to certain diseases, die-offs often involve loss of 50 percent of the herd over a few months, and appear related to stress, which interacts with endemic lungworm infestations and lowers the

animals’ resistance to organisms such as *Pasteurella* bacteria. The animals subsequently die from acute bronchopneumonia (Cassaigne et al. 2010, Gross et al. 2000).

Fourteen blood serum samples collected in 2006 as part of a monument-wide bighorn sheep movement and genetics study were submitted for *Mycoplasma ovipneumoniae* testing in December 2017. Antibodies were detected in 13 of 14 individual samples tested at levels consistent with previous exposure or current infection (as of time of sampling) with *Mycoplasma ovipneumoniae*. Over 30% of the tested animals had high levels of antibodies, which is consistent with populations that have been exposed to *Mycoplasma ovipneumoniae*. In other words, animals very likely had *Mycoplasma ovipneumoniae* prior to the initiation of or concurrently with the 2006 study. This result is not surprising considering the likely overlap/nearness of domestic sheep within and surrounding the monument and indicates the entire bighorn sheep population has likely been exposed to the disease over a long period of time. Bighorn sheep have been translocated to DINO several times from multiple locations over decades. Disease history of the source herds used for translocation individuals to DINO is unknown, but could also have been a source of the disease into the DINO sheep population (pers. comm., Emily Spencer, July 2019).

Disease is such an important factor contributing to population transience in bighorn sheep that limiting grazing by domestic sheep in the vicinity of bighorn sheep herds is one of the primary management tools to prevent disease outbreaks and conserve the species (Gross et al. 2000).

Bighorn sheep require open landscapes with uninterrupted views in order to detect and avoid predators (Singer and Gudorf 1999). Fire suppression and resulting encroachment of tall dense shrubland and forest is another threat as it impedes sightlines and has been a major cause of habitat loss in Colorado including at DINO (Wakelyn 1987).

A strict dominance hierarchy in rams’ limits breeding and causes naturally-occurring, small genetically effective population sizes in bighorn sheep herds (Singer and Gudorf 1999). The lack of connectivity and/or loss of genetic variability due to habitat fragmentation, habitat loss, increased human disturbance, competition with domestic livestock, and predation on small, isolated herds exacerbates this genetic isolation and is a serious threat for bighorn sheep within the DINO region (Beechham et al. 2007, Epps et al. 2005, Hogg et al. 2006). This lack of genetic diversity can be accentuated within small populations of reintroduced bighorn sheep due to inbreeding depression (Olson et al. 2013, Olson et al. 2012, Singer et al. 2000a, Fitzsimmons et al. 1997).

Bighorn sheep are also sensitive to impacts expected due to climate change (Epps et al. 2004). As climate warms, vegetation communities shift in composition or distribution. Species with small population sizes, fragmented distributions, low dispersal capability and a metapopulation structure, such as bighorn sheep, may be particularly vulnerable because dispersal to new sites may be limited (Walther et al. 2002, Singer and Gudorf 1999). Drought due to climate change has the potential to decrease habitat quality or area, and can cause declines in the number of available habitat patches. This in turn can bring about extirpation of a metapopulation before all habitat becomes unsuitable (Hanski 1999).

These threats and associated impacts act locally, regionally and within the extent of migratory patterns of the bighorn sheep that inhabit DINO. The aforementioned activities result in bighorn sheep die-offs and the loss of habitat and genetic viability in the monument's bighorn sheep population. In turn, these modifications disrupt ecological functions important to ecosystem integrity and potentially important to maintaining the bighorn sheep population at DINO (Jørgensen and Müller 2000). Consequently, the ecological functioning of DINO, upon which the bighorn sheep depend, is itself dependent upon maintaining the natural systems within and outside the monument's boundaries. Changes in land use are linked to ecological function by five mechanisms: land use activities reduce the functional size of a reserve; land use activities including grazing by domestic sheep alter the flow of energy, materials or pathogens across the landscape irrespective of administrative boundaries, and disrupt the ecological processes dependent upon those flows both outside and inside the monument; habitat conversion outside the monument may eliminate unique habitats, such as seasonal habitats and migration corridors; the negative influences of land use activities may extend into the monument and create edge effects; and increased human population density may directly impact the monument through increased recreation and human disturbance (Hansen and Gryskiewicz 2003).

Indicators and Measures

- Population Size and Viability
- Proximity of Suitable Habitat to Domestic Grazing Allotments
- Landscape Condition
- Regional Vulnerability to Climate Change

4.15.2. Data and Methods

Data sources include post-hunt population estimates of the DINO herd from Colorado Parks and Wildlife (CPW) that were based on general agency observation by biologists from the NPS, CPW, USFS, BLM and USGS conducted from 2002 through 2018 and aerial surveys conducted in 2006 by CPW (CPW unpublished data). A compendium report on the bighorn sheep at DINO is currently in preparation by the U.S. Geological Survey Northern Rocky Mountain Science Center but data and draft findings were not available to support the NRCA. DINO conducted river-based bighorn sheep population and recruitment monitoring trips in 2018 and 2019, timed to capture lamb production and mid to late season survivorship. Data collected include group composition (group size, sex, age class), location, fecal pellet samples, as well as any evidence of disease (pers. comm., Emily Spencer, July 2019). The 2018–2019 results were not incorporated into this assessment.

Additional spatial data were used to assess conditions affecting bighorn sheep populations within and surrounding DINO. Lands in and around Dinosaur National Monument in Colorado and Utah were evaluated by the NPS, Colorado Parks and Wildlife and Utah Department of Natural Resources to identify habitat suitable to support populations of bighorn sheep (Sweanor et al. 1994, Colorado Parks and Wildlife 2011, Utah Department of Natural Resources 2006). Current active allotments designated for sheep grazing on adjacent Bureau of Land Management property were used to

document the proximity of domestic sheep grazing to bighorn populations within DINO (BLM 2018). While the disease risk related to domestic sheep includes all potential sources of risk, including domestic sheep and goats anywhere on the landscape, and not just BLM grazing allotments, no information regarding livestock grazing outside of BLM lands was available. Relative landscape condition, as modeled for Colorado (Decker et al. 2017), was used to gauge the disturbance of the habitat mapped as suitable for bighorn sheep within the Colorado portion of DINO. An analogous map of landscape condition was not available for that portion of the DINO bighorn sheep habitat located within Utah.

What constitutes a minimum viable population in bighorn sheep is controversial (Berger 1999, Wehausen 1999, Smith et al. 1991, Berger 1990), but populations are considered secure for standard population viability (PVA) goals of greater than 200 years at sizes of 300–500 individuals (Singer et al. 2000b). Populations of 100–299 individuals are considered secure for shorter time periods; populations of 75–99 individuals are considered moderately secure (Singer at al. 2000b, Singer and Gudorf 1999). Protocols in Smith et al. (1991) and population size and population trend of bighorn sheep as estimated by CPW biologists were used to assess the viability of bighorn sheep at DINO against these standard values for PVA.

The vulnerability of bighorn sheep to the effects of climate change was evaluated using the Climate Change Vulnerability Index (CCVI) (Young et al. 2016). The CCVI is a Microsoft Excel-based spreadsheet tool developed by NatureServe. It is designed as a rapid-assessment tool to assess the vulnerability of a plant, animal, or lichen to climate change in a defined geographic area. The CCVI is intended to be used primarily for practical planning purposes by natural resources managers. The intended application scale of the tool is up to the state or province level. The primary purpose of the CCVI is to produce a relative ranking or priority list for species of concern with respect to climate change vulnerability. The CCVI uses a scoring system that integrates a species' predicted exposure to climate change within an assessment area and three sets of factors associated with climate change sensitivity, each supported by published studies: 1) indirect exposure to climate change, 2) species-specific sensitivity and adaptive capacity factors (including dispersal ability, temperature and precipitation sensitivity, physical habitat specificity, interspecific interactions, and genetic factors), and 3) documented response to climate change.

4.15.3. Reference Conditions

Few historical bighorn sheep survey data exist for DINO. Bighorn sheep surveys relying on observations by government biologists at DINO are available for the period from 2002 to 2018. Population estimates for this period are used to assess population viability. There are no historical data on the extent of suitable bighorn sheep habitat at DINO nor is there historical information on landscape condition for DINO, but the percent of habitat within DINO modeled by Sweanor et al (1994) as suitable and the condition of that habitat as defined by the spatial disturbance index developed for the region of northwestern Colorado by Decker et al. (2017) are also used as metrics for assessing the condition of bighorn sheep at DINO. The results for the climate change vulnerability evaluation were not used in the condition rating, but did influence the trend rating. A condition rating framework for bighorn sheep is shown in Table 4.15-1.

Table 4.15-1. Resource condition rating framework for bighorn sheep at Dinosaur National Monument.

Indicator	Condition Status: Resource is in Good Condition	Condition Status: Condition Warrants Moderate Concern	Condition Status: Condition Warrants Significant Concern
Viable Population Size for all herds combined	≥300 individuals in DINO population	100–299 individuals in DINO population	<100 individuals in DINO population
Proximity of Domestic Sheep Grazing Allotments	>10 miles from habitat	7–9.9 miles from habitat	<7 miles from habitat
Disturbance within Suitable Habitat	>75% none-low disturbance	50–75% none-low disturbance	<50% none-low disturbance
Regional Vulnerability to Climate Change	n/a (trend only)	n/a (trend only)	n/a (trend only)

4.15.4. Condition and Trend

Viable Population Size

The most consistent data on bighorn sheep abundance from DINO comes from CPW post-hunt population estimates based on observations by biologists from the NPS, CPW, USFS, BLM and USGS. Estimates of the total population of bighorn sheep from three sites/herds within DINO remained steady at 168 individuals from 2002 through 2018. Estimates of herd numbers have not changed over the 17-year period, which suggests that the estimates are based on limited information. The Green River-Ladore Canyon herd is estimated at 90 individuals, the Harper's Corner-Jones' Hole herd is estimated at 40 individuals, and the Yampa River herd is estimated at 38 individuals. Using protocols from multiple researchers (Singer et al. 2000b, Berger 1999, Singer and Gudorf 1999, Wehausen 1999, Smith et al. 1991, Berger 1990), habitat suitability parameters and an estimated herd size of 168 individuals suggests that there is sufficient suitable habitat to support a viable population of over 100 individuals with a 95 percent probability of persistence for 100 years. This value of population size and PVA indicates that the population size of bighorn sheep at DINO warrants moderate concern (Table 4.15-1). Based on available estimates, the trend appears unchanging.

Proximity of Domestic Grazing Allotments

There are 17 active domestic sheep grazing allotments on BLM property within 10 miles of modeled suitable bighorn sheep habitat in DINO (BLM 2018, Sweanor et al. 1994) (Figure 4.15-3). There is one domestic sheep grazing allotment within the monument. Spatially, there is greatest proximity between suitable bighorn sheep habitat in DINO and the Daniels Canyon and Split Mountain allotment on the southwestern boundary of DINO in Utah, and the Sawmill Canyon and Disappointment allotments on the eastern boundary of DINO in Colorado. All four of these allotments abut mapped suitable bighorn sheep habitat within DINO. The two Colorado allotments abutting DINO were last grazed by domestic sheep in 2005 while the two Utah allotments were grazed in 2011. The BLM Rangeland Administration System identified two active permits that have been recently grazed by domestic sheep: the Upper Coal Creek allotment in Colorado, which was grazed in 2019 and is within nine miles of suitable bighorn sheep habitat in DINO, and the Davis

Draw allotment in Utah, which was grazed in 2014 and is within seven miles of mapped suitable bighorn sheep habitat within the monument. The number of allotments that have recently been grazed by domestic sheep and their distance from mapped suitable bighorn sheep habitat within DINO indicate that this metric for bighorn sheep at DINO warrants moderate concern (Table 4.15-1). No trend data are available for this metric.

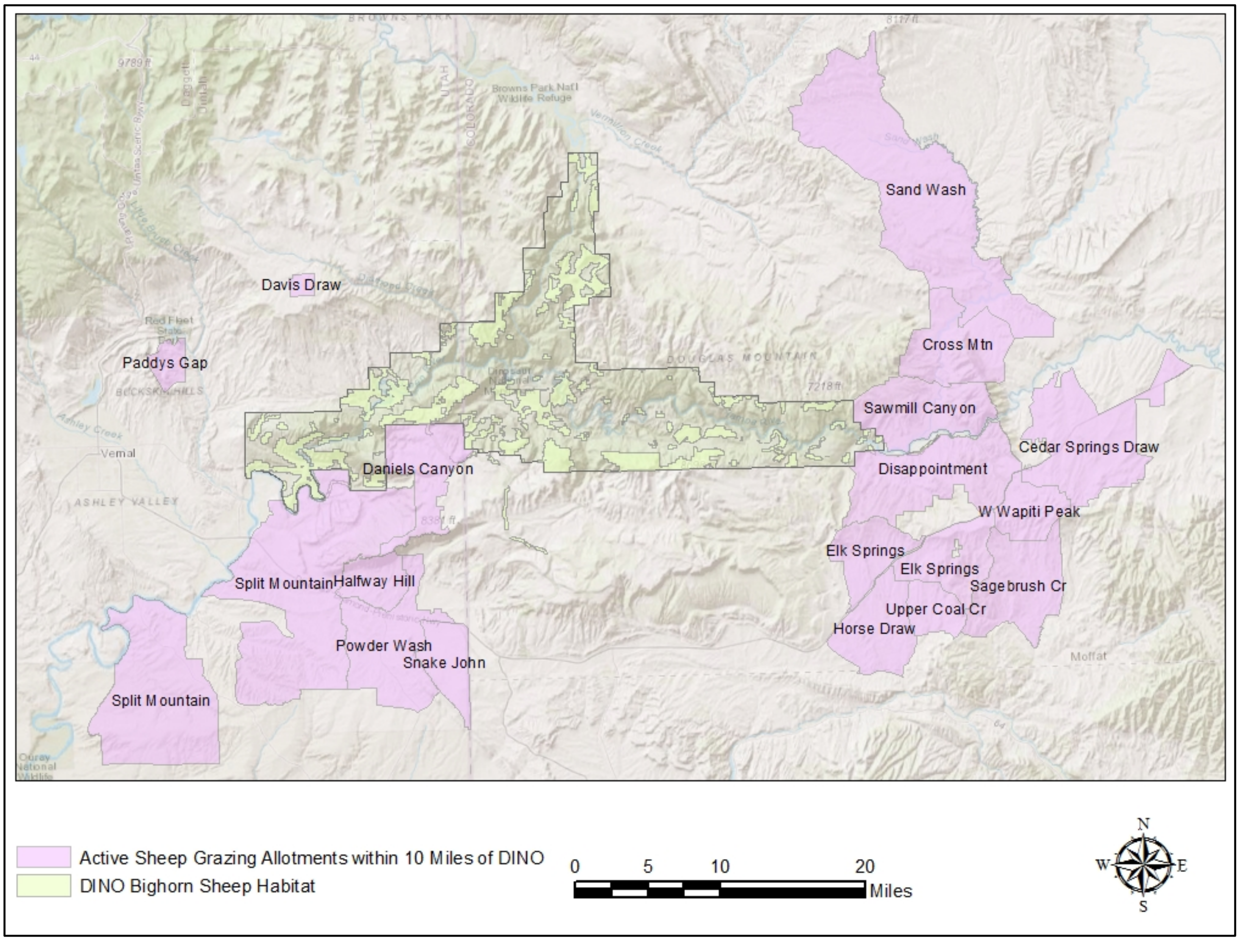


Figure 4.15-3. Domestic sheep grazing allotments in proximity to modeled suitable bighorn sheep habitat in Dinosaur National Monument (BLM 2018, Sweanor et al. 1994).

<u>Disturbance within Suitable Habitat</u>

Sweanor et al. (1994) estimated that approximately 37,000 acres of suitable bighorn sheep habitat exist within DINO (Figure 4.15-3). Of this total, 96 percent of the habitat falls within the no disturbance to low disturbance categories from 2007 CPW disturbance data, suggesting that suitable bighorn sheep habitat at DINO is in good condition (Table 4.15-1, Figure 4.15-4). The trend in the condition of suitable bighorn sheep habitat at DINO is unknown.

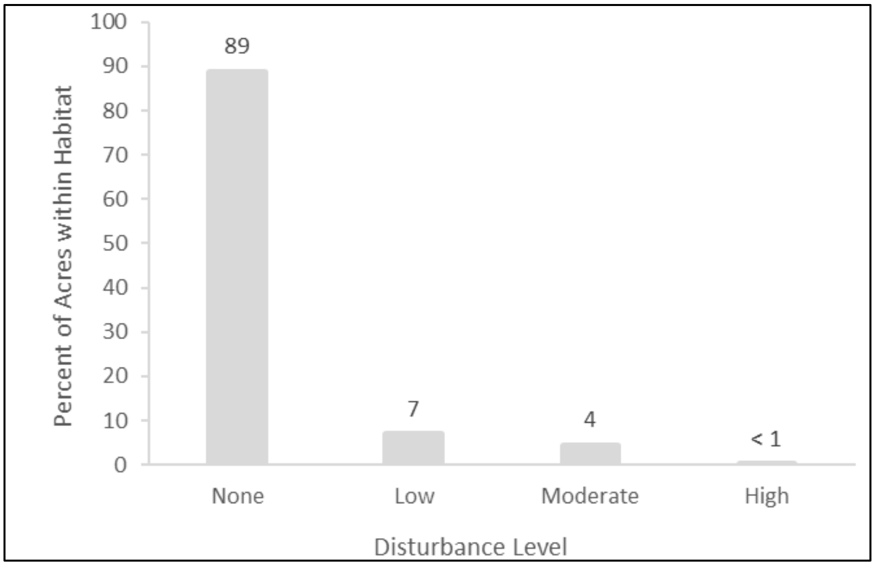


Figure 4.15-4. Percent of the suitable bighorn sheep habitat by disturbance level (2007 CPW data) at Dinosaur National Monument.

Regional Vulnerability to Climate Change

Each vulnerability factor was scored and results were compiled into an overall CCVI rating for the species (Table 4.15-2). By 2050, within its current range in northwestern Colorado and northeastern Utah the species was considered Moderately Vulnerable. Confidence in the CCVI species information used in the assessment was very high. This result is similar to that published by Colorado Natural Heritage Program (2015), whose CCVI assessment for desert bighorn sheep (*Ovis canadensis nelson*) in Colorado determined that the species is Presumed Stable under current predictive models of climate change.

The main factors of bighorn sheep biology that increase the species susceptibility to alterations in climate include their sensitivity to pneumonia, resistance to which is expected to decline as increased drought in the region due to climate change reduces bighorn sheep health and immune response (Epps et al. 2004). Secondly, genetic diversity of bighorn sheep populations is relatively low, particularly in reintroduced populations (Olsen et al. 2013, Olsen et al. 2012, Beecham et al. 2007, Epps et al. 2005, Hogg et al. 2006). With less genetic variability, bighorn sheep may have less adaptability to the expected rate of climate change, making the species more vulnerable to its impacts. Lastly, there is evidence that bighorn sheep are vulnerable to impacts expected under current climate change scenarios (Hauptfeld and Kershner 2014, Mawdsley and Lamb 2013, Epps et al. 2004). The climate change indicator was assigned a high degree of reliability because of the availability of sufficient data and consequently, a high level of confidence. The estimated vulnerability of bighorn sheep to climate change was used only as a trend indicator while other metrics were used to assess condition of the species at DINO. Confidence in the vulnerability assessment as it affects the resource is medium.

Table 4.15-2. Summary of Climate Change Vulnerability Index (CCVI) factor ratings for bighorn sheep at Dinosaur National Monument.

CCVI Category	Factor Influencing Vulnerability	Degree to Which Factor Influences Vulnerability
INDIRECT EXPOSURE TO CLIMATE CHANGE	1) Exposure to sea level rise	Neutral
	2a) Distribution relative to natural barriers	Neutral
	2b) Distribution relative to anthropogenic barriers	Neutral
	3) Predicted impact of land use changes resulting from human responses to climate change	Somewhat Increase
SENSITIVITY AND ADAPTIVE CAPACITY	1) Dispersal and movements	Neutral
	2ai) Predicted sensitivity to changes in temperature: historical thermal niche	Neutral
	2aii) Predicted sensitivity to changes in temperature: physiological thermal niche	Neutral
	2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche	Neutral
	2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche	Neutral
	2c) Dependence on a specific disturbance regime likely to be impacted by climate change	Somewhat Increase-Neutral
	2d) Dependence on ice, ice-edge, or snow-cover habitats	Neutral
	3) Restriction to uncommon geological features or derivatives	Somewhat Increase
	4a) Dependence on other species to generate habitat	Neutral
	4b) Dietary versatility (animals only)	Neutral
	4c) Pollinator versatility (plants only)	Not applicable
	4d) Dependence on other species for propagule dispersal	Neutral
	4e) Sensitivity to pathogens or natural enemies	Somewhat Increase
	4f) Sensitivity to competition from native or non-native species	Neutral
	4g) Forms part of an interspecific interaction not covered by 4a-d	Neutral
	5a) Measured genetic variation	Somewhat Increase
	5b) Occurrence of bottlenecks in recent evolutionary history	Neutral

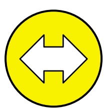
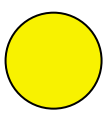
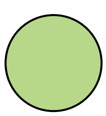
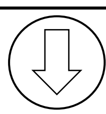
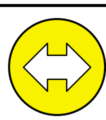
Table 4.15-2 (continued). Summary of Climate Change Vulnerability Index (CCVI) factor ratings for bighorn sheep at Dinosaur National Monument.

CCVI Category	Factor Influencing Vulnerability	Degree to Which Factor Influences Vulnerability
SENSITIVITY AND ADAPTIVE CAPACITY (continued)	6) Phenological response to changing seasonal temperature and precipitation dynamics	Neutral

<u>Overall Condition and Trend</u>

The four measures of condition indicate that bighorn sheep warrant moderate concern at DINO, with an unchanging trend and medium confidence level (Table 4.15-3). Vulnerability of the species to climate change appears moderate. Climate-induced increases in susceptibility to infection, relatively low genetic diversity, proximity to domestic sheep grazing, and other negative impacts of climate change on bighorn sheep could act in tandem to reduce the population of bighorn sheep at the monument in the future.

Table 4.15-3. Condition and trend summary for bighorn sheep at Dinosaur National Monument.

Indicator	Condition Status/Trend	Rationale
Population Viability		Habitat suitability parameters and an estimated monument-wide herd size of 168 individuals suggest that there should be sufficient suitable habitat to support a viable population of over 100 individuals with population viability persistence for roughly 100 years. Population estimates suggest that the herd and total population sizes have been stable over the past several decades.
Proximity of Domestic Grazing Allotments		The number of total active allotments within ten miles of the monument boundary (17), the number of abutting allotments that have recently been grazed by domestic sheep (2) and the proximity of allotments to mapped suitable bighorn sheep habitat on DINO (9 and 7 miles) warrant moderate concern for the DINO population. No trend information is available for this indicator.
Disturbance within Suitable Habitat		The landscape disturbance index created in 2017 is the only reliable source of information for this indicator. Ninety-six percent of the habitat modeled by Sweanor et al. (1994) as suitable for bighorn sheep within DINO has not been impacted by disturbance or has experienced low impacts due to disturbance. The measured value of habitat disturbance indicates that this indicator is in good condition. No trend information is available for this indicator.
Climate change vulnerability		The climate change vulnerability analysis estimated that the species is moderately vulnerable with regard to climate change through 2050. This implies an anticipated deteriorating trend in the resource.
Bighorn sheep overall		**Condition warrants moderate concern. Confidence in the assessment is medium. Current trend appears unchanging, but moderate climate change impacts are anticipated.**

4.15.5. Uncertainty and Data Gaps

There is a lack of information on the threat of infection with *Pasteurella* bacteria or other pneumonia agents. Monitoring trends in the incidence and spread of such agents in DINO bighorn sheep populations would help managers understand the threat of *Pasteurella* bacteria and other agents to the DINO bighorn sheep population. Consistent and unbiased population monitoring data via aerial surveys or other means is needed to understand trends in the bighorn sheep population at DINO. Although general observations of bighorn sheep by agency biologists are the easiest method of getting annual data on abundance, their accuracy is unknown. It's possible that changes in bighorn sheep abundance are occurring and are not being captured by the current approach.

4.15.6. Sources of Expertise

- Darby Finley, Colorado Parks and Wildlife conservation biologist for the Northwest Colorado Region, Meeker, Colorado, is the point of contact for bighorn sheep on the Colorado portion of the monument.

4.15.7. Literature Cited

Beecham, J.J., Jr., C.P. Collins, and T.D. Reynolds. 2007. Rocky Mountain Bighorn Sheep (*Ovis canadensis*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. Available at: http://www.fs.fed.us/r2/projects/scp/assessments/rockymountainbighornsheep.pdf (accessed 01 February 2019).

Berger, J. 1990. Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. Conservation Biology 4:91–98.

Berger, J. 1999. Intervention and persistence in small populations of bighorn sheep. Conservation Biology 13:432–435.

Buechner, H.K. 1960. The bighorn sheep in the United States: its past, present, and future. Wildlife Monographs, No. 4. Wildlife Society.

Bureau of Land Management (BLM). 2018. Rangeland administrative system reports, permits schedule report. U.S. Bureau of Land Management, Washington, D.C. Available at: https://reports.blm.gov/reports/RAS/.

Cassaigne, I.G., R.A. Medellín, and J.A. Guasco O. 2010. Mortality during epizootics in bighorn sheep: effects of initial population size and cause. Journal of Wildlife Diseases 46:763–771.

Colorado Natural Heritage Program. 2015. Climate change vulnerability assessment for Colorado Bureau of Land Management. K. Decker, L. Grunau, J. Handwerk, and J. Siemers, editors. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

Colorado Parks and Wildlife (CPW). 2011. CPW all species activity mapping data. Available at: https://www.arcgis.com/home/item.html?id=190573c5aba643a0bc058e6f7f0510b7.

Decker, K.L., A. Pocewicz, S. Harju, M. Holloran, M.N. Fink, T.P. Toombs, and D.B. Johnston. 2017. Landscape disturbance models consistently explain variation in ecological integrity across large landscapes. Ecosphere 8(4):e01775. Available at: https://doi.org/10.1002/ecs2.1775.

Epps, C.W., D.R. McCullough, J.D. Wehausen, V.C. Bleich, and J.L. Rechel. 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology 18:102–113. Available at: https://doi.org/10.1111/j.1523-1739.2004.00023.x.

Epps C.W., P.J. Palsbøll, J.D. Wehausen, G.K. Roderick, R.R. Ramey II, and D.R. McCullough. 2005. Ecological Letters 8:1029–1038. Available at: https://doi.org/10.1111/j.1461-0248.2005.00804.x.

Fitzsimmons, N.N., S.W. Buskirk, and M.H. Smith. 1997. Genetic changes in reintroduced Rocky Mountain bighorn sheep populations. The Journal of Wildlife Management 61(3):863–872. Available at: https://www.jstor.org/stable/pdf/3802195.pdf?refreqid=excelsior%3A11ac17e3e408676aa7c5756d0013bbca.

George, J.L., R. Kahn, M.W. Miller, and B. Watkins. 2009. Colorado Bighorn sheep management plan 2009–2019. Special report number 81. Colorado Division of Wildlife, Denver, Colorado.

Gross, J.E., F.J. Singer, and M.E. Moses. 2000. Effects of disease, dispersal, and area on bighorn sheep restoration. Restoration Ecology 8:25–37.

Hansen, A., and D. Gryskiewicz. 2003. Interactions between Heartland National Parks and surrounding land use change: development of conceptual models and indicators for monitoring. Prepared for the National Park Service Heartland Network by Montana State University.

Hanski, I. 1999. Metapopulation ecology. Oxford University Press, New York.

Hauptfeld, R.S., and J.M. Kershner. 2014. Sierra Nevada Individual Species Vulnerability Assessment Briefing: Bighorn Sheep. Version 1.0. EcoAdapt, Bainbridge Island, WA.

Hogg, J.T., S.H. Forbes, B.M. Steele, and G. Luikart. 2006. Genetic rescue of an insular population of large mammals. Proceedings of the Royal Society B 273:1491–1499. Available at: https://doi.org/10.1098/rspb.2006.3477.

Jørgensen, S.E., and F. Müller. 2000. Handbook of Ecosystem Theories and Management. CRC Press, Boca Raton, Florida.

Mawdsley, J., and R. Lamb. 2013. Climate-change vulnerability assessment for priority species. The H. John Heinz III Center for Science, Economics and the Environment, Washington D.C.

Olson, Z.H., D.G. Whittaker, and O.E. Rhodes Jr. 2012. Evaluation of experimental genetic management in reintroduced bighorn sheep. Ecology and Evolution 2:429–441. Available at: https://onlinelibrary.wiley.com/doi/epdf/10.1002/ece3.97.

Olson, Z.H., D.G. Whittaker, and O.E. Rhodes Jr. 2013. Translocation history and genetic diversity in reintroduced bighorn sheep. The Journal of Wildlife Management 77:1553–1563. Available at: https://wildlife.onlinelibrary.wiley.com/doi/10.1002/jwmg.624.

Singer, F.J., and M.A. Gudorf. 1999. Restoration of bighorn sheep metapopulations in and near 15 national parks: Conservation of a severely fragmented species. U.S. Geological Survey Open File Report 99-102, Midcontinent Ecological Science Center, Fort Collins, Colorado.

Singer, F.J., C.M. Papouchis, and K.K. Symonds. 2000a. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8:6–13. Available at: https://onlinelibrary.wiley.com/doi/pdf/10.1046/j.1526-100x.2000.80061.x.

Singer, F.J., V.C. Bleich, and M.A. Gudorf. 2000b. Restoration of bighorn sheep metapopulations in and near 15 national parks. Restoration Ecology 8:14–24.

Singer, F.J., L.C. Zeigenfuss, and L. Spicer. 2001. Role of patch size, disease, and movement in rapid extinction of bighorn Sheep. Conservation Biology 15:1347–1354.

Smith, T.S., J.R. Flinders, and D.S. Winn. 1991. Habitat evaluation procedure for Rocky Mountain bighorn sheep in the Intermountain West. Great Basin Naturalist 51:205–225. Available at: https://scholarsarchive.byu.edu/gbn/vol51/iss3/3.

Sweanor, P.Y., M.A. Gudorf, S. Chambers, F.J. Singer, J.A. Bissonette, J. Ellenberger, T.L. Johnson, S. Petersburg, R. Schiller, and K. Symonds. 1994. Bighorn sheep habitat assessment of the greater Dinosaur National Monument area, Colorado and Utah. Filename dino_suitable_bighorn_habitat_1.e00. First analysis. National Park Service, Denver, Colorado.

Utah Department of Natural Resources. 2006. Bighorn sheep (*Ovis canadensis*) habitat maps. Available at: https://dwrcdc.nr.utah.gov/ucdc/downloadgis/disclaim.htm.

Wakelyn, L.A. 1987. Changing habitat conditions on bighorn sheep ranges in Colorado. The Journal of Wildlife Management 51:904–912.

Walther, G.-R., E. Post, P. Convey, A. Mensel, C. Parmesan, T.J.C. Beebee, J.-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416:389–395.

Wehausen, J.D. 1999. Rapid extinction of mountain sheep populations revisited. Conservation Biology 13:378–384.

Western Association of Fish and Wildlife Agencies. 2018. Boise, Idaho. Available at: https://www.wafwa.org/committees___groups/wild_sheep_working_group/maps/.

Wild Sheep Foundation. 2018. Bozeman, Montana. Available at: http://www.wildsheepfoundation.org/.

Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.01. NatureServe, Arlington, Virginia.

Chapter 5. Summary and Conclusions

This section summarizes condition and trend results for focal resources. It examines and highlights management implications and interrelationships among resources, reinforces relationships between resource condition and landscape context elements, and consolidates data gaps.

5.1. Condition Summary and Management Implications

A total of 15 focal resources were examined: five addressing landscape context – system and human dimensions, three addressing chemical and physical attributes, and seven addressing biological attributes. Status and trend assigned to each focal resource and a synopsis of supporting rationale are presented in Table 5.5-1.

5.1.1. Landscape Context –System and Human Dimensions

Landscape context – system and human dimensions included land cover and land use, night skies, natural sounds, climate change, and visual resources (Table 5.1-1). Climate change and land cover/land use were not assigned a condition or trend—they provide important context to the monument and natural resources, and can act as stressors. Some of the land cover and land use-related stressors at DINO and in the larger region are related to historical land uses, grazing and the expansion of gas and oil exploration and production in the region. Nationwide modeling of anthropogenic sound level impacts indicates that modern noise intrusions are moderately increasing the existing ambient sound level above the natural ambient sound level near DINO. Dark night skies are high quality. Indications are that the climate in this region is already becoming hotter, possibly wetter, and is potentially more prone to more frequent and extreme weather events. Trends in the indicators are projected to continue or accelerate by the end of the century. Climate change is happening and is affecting resources, but is not considered *good* or *bad* per se. The information synthesized in that section is useful in examining potential trends in the vulnerability of several sensitive biological resources below.

There are opportunities to mitigate the effects of local landscape context stressors through planning, management and mitigation. Stressors driven by more distant factors such as haze from population centers hundreds of miles away, or the effects of Flaming Gorge Reservoir on water quality and river function are more difficult to mitigate. Collectively, this synthesis supports resource planning and management within the monument, and provides a foundation for collaborative conservation with other landowners and agencies in the surrounding area.

5.1.2. Chemical and Physical Environment

The supporting chemical and physical attributes at the monument include its air quality, water quality and river processes (Table 5.1-1). The condition of these resources can affect human dimensions of the monument such as visibility and scenery as well as biological components such as vegetation health and stream biota. Air quality warranted moderate concern, while water quality was in good, although declining, condition.

Table 5.1-1. Summary of focal resource condition and trend for Dinosaur National Monument.

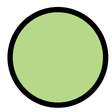
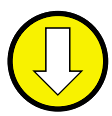
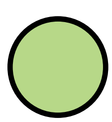
Ecosystem Attribute	Resource	Condition and Trend	Rationale for Overall Condition/Trend Rating
Landscape Context – System and Human Dimensions	Land Cover and Land Use	For context only – condition and trend are not assigned	Overall, the area surrounding the monument is mostly natural with some agricultural and rural land use. Population densities in the area are low and there has been a gradual increase in exurban vs. rural settlement, although the percent change is very small. Most of the stressors to the landscape surrounding DINO are related to historical land uses, grazing and the expansion of gas and oil exploration and production. Although these changes may appear minimal at site scales, collectively, these elements may compound the effects of other resource stressors.
	Night Skies		Night skies are in good condition with an unknown trend. All-sky Light Pollution Ratio (ALR) for DINO varied from 0.17 to 0.32 across the 4 sites analyzed, which is considered good condition. Three out of four sites had a Bortle Class of 3 for a rating of good condition. The fourth site, Green River Campground, had a Bortle Class of 4, which warrants moderate concern. The rural and undeveloped nature of the surrounding area and the lack of large population centers protects the resource. Confidence in the assessment is high.
	Natural Sounds		The condition of the soundscape at DINO warrants moderate concern with a deteriorating trend. State transportation projections indicate that traffic volumes on CO-64 near the monument will increase by 2020. Noise from aircraft was also audible from 8% to 28% of the time during the listening sessions. Nationwide modeling of anthropogenic sound level impacts indicates that modern noise intrusions are moderately increasing the existing ambient sound level above the natural ambient sound level of the park. The confidence associated with these ratings is high due to the wide range of measures available including quantitative metrics.
	Climate Change	For context only – condition and trend are not assigned	Changing climate is anticipated to impact the Colorado Plateau in a number of ways, and is likely to compound the effects of existing stressors and increase the vulnerability of forests and shrublands to pests, invasive species, altered fire regimes, and loss of native species. Species ranges and ecological dynamics are already responding to recent climate shifts, and current natural areas including NPS units will likely be unable to support all species, communities and ecosystems currently present, some of which form the core of the NPS mission.
	Visual Resources		Visual resources at DINO are in good condition. This assessment is a baseline inventory for DINO, therefore there is no trend. The level of confidence for the scenic inventory value is high because nearly all of the views identified as important by the park were inventoried, the views inventoried represent most of the monument, and view assessments were done in the field.

Table 5.1-1 (continued). Summary of focal resource condition and trend for Dinosaur National Monument.

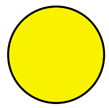
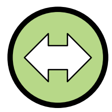
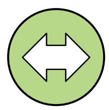
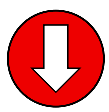
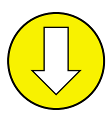
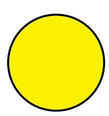
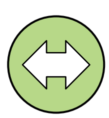
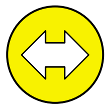
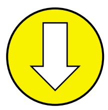
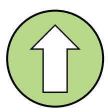
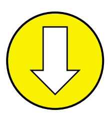
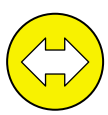
Ecosystem Attribute	Resource	Condition and Trend	Rationale for Overall Condition/Trend Rating
Chemical and Physical Environment	Air Quality		Based on the evaluation of air quality indicators, air quality condition warrants moderate concern, with no discernable trend. Confidence in the assessment is medium. Ozone-related impacts to human health and wet deposition of nitrogen were rated in the poor condition category. Impacts to air quality appear to be largely from distant sources that are affecting regional air quality.
	Water Quality		Overall water quality is in good condition with an unchanging trend and a high level of confidence. Phosphorus (all segments), sulfates (for the Upper and Lower Green River segments) and iron (for the Yampa River) were found to be in moderate to poor condition.
	Yampa and Green River System	  	The condition of the resource varies among river segments. The physical condition of the Yampa River is mostly natural, with few impoundments. In the upper Green River, stream flows, sediment loads and geomorphology have been substantially altered due to the influence of Flaming Gorge Reservoir upstream of the monument. The lower Green River segment below the confluence with the Yampa River has been somewhat degraded due to the altered flows, sediment loads and geomorphology. The effects of the Flaming Gorge Reservoir on the Lower Green River are more muted than on the Upper Green due to the influence of the mostly natural Yampa River.
Biological – Plants	Vegetation		The overall condition of vegetation at DINO warrants moderate concern. Indicator ratings vary by indicator and vegetation type. Pinyon-Juniper woodlands appear to be in the best condition of the types examined, although altered fire frequency is a threat. Native riparian woody plant communities were in the poorest condition. Sagebrush shrublands and grasslands were both in moderate condition. Confidence in the assessment is medium.
	Plant Species of Special Concern		Overall condition is good for this resource, with an unchanging trend and medium confidence. The current condition of *Hymenoxys lapidicola* (stone rubberweed) is unknown, while *Zigadenus vaginatus* (alcove death camas) was rated in moderate condition. All other species analyzed were rated in good condition.

Table 5.1-1 (continued). Summary of focal resource condition and trend for Dinosaur National Monument.

Ecosystem Attribute	Resource	Condition and Trend	Rationale for Overall Condition/Trend Rating
Biological – Animals	Fish		Total species richness, fish Index of Biological Integrity, and number of species of concern present across study years suggest that the fish resource at DINO warrants moderate concern. The federally-endangered Colorado pikeminnow and razorback sucker and the federally-threatened Colorado cutthroat trout are present. The structure of the fish community at DINO is representative of a moderately disturbed landscape. The values for these metrics calculated across study years suggest an unchanging trend in fish community diversity and structure at DINO.
	Greater Sage-grouse		The condition of the greater sage-grouse warrants moderate concern at DINO, with a deteriorating trend and medium confidence in the assessment. Vulnerability of the species to climate change appears high. Continued and enhanced frequency of fire, the spread of *Bromus* grasses, climate-driven mortality of sagebrush, habitat fragmentation from multiple sources and climate-induced spread of West Nile virus in greater sage-grouse core areas could act in tandem to potentially reduce future populations of greater sage-grouse at the monument.
	Bats		The metrics examined indicate that the bat community at DINO is in good condition, with statistically significant increases in total abundance across the survey period and unchanging to increasing native species richness over time. Confidence in the assessment is medium. The potential for future declines in bat populations is substantial due to white-nose syndrome and continued loss of mature forest habitat due to climate change and other stressors.
	Birds		Condition of birds at DINO warrants moderate concern with a deteriorating trend. Confidence in the assessment is medium. Pinon-juniper woodland and lowland riparian communities warranted moderate concern and sagebrush shrublands were in good condition.
	Bighorn sheep		The condition of bighorn sheep warrants moderate concern at DINO, with an unchanging trend and medium confidence level. Vulnerability of the species to climate change appears moderate. Climate-induced increases in susceptibility to infection, relatively low genetic diversity, proximity to domestic sheep grazing and other negative effects of climate change on bighorn sheep could reduce populations of bighorn sheep at the monument in the future.

Air quality in the region is in decline due to increased oil and gas production in the Uintah Basin of northeastern Utah (UDEQ 2016, Sullivan 2016). Oil and gas operations increase deposition through increased regional nitrogen emissions, decrease visibility due to the release of haze-causing agents such as NOx and fugitive dust, and increase ozone levels due to the release of precursor gases that lead to the formation of ozone (Sullivan 2016, UDEQ 2016). Other regional and local pollution sources that cause haze and contribute to visibility impairment throughout the region include

automobiles, coal- and oil-fired power plants, smelters, wildfires, and urban emissions (Peterson et al. 1998). Power generation plants in Hayden and Craig, Colorado, are occasional sources of pollution affecting the monument (pers. comm., Tamara Naumann, April 2016).

The largest single stressor to water quality at DINO is the effect of Flaming Gorge Reservoir on the Upper (and to a lesser extent the Lower) Green River. In addition, human population growth, transmountain diversions, in-basin depletions and impoundments, increasing nonpoint pollution sources, and competing water interests threaten both the Yampa and Green rivers. Increase in mean annual temperature and drought, dust on snow, and other climate change effects can and have altered timing, magnitude, and duration of snowmelt, with significant implications for river ecosystem health and function (NPS 2015). Agricultural land uses (which are primarily rangeland and hay production, as shown in section 4.1) in the Yampa and Green River basins are a likely contributor to at least a portion of the nutrient issues within the large river systems of DINO.

Physical structure and processes for three different segments of the Yampa and Green River system were examined. The primary driver of change in the large river systems at DINO is the creation and ongoing operations of the Flaming Gorge Reservoir and Dam on the Green River upstream of the monument in southwestern Wyoming. The effects of the reservoir on the Green River provide an interesting case study for the effects of upstream impoundments on rivers when compared to the relatively free-flowing Yampa River. As expected, our analysis of these river segments showed the Yampa River to be in good condition, the Upper Green River segment to be in poor condition, while the Lower Green River was in moderate condition as this segment represents the combined state of the Upper Green and its confluence with the Yampa. Going into the future, these two river systems will also allow researchers to study the effects of climate change on these systems, and how they compare and contrast in their response to its present and future effects.

5.1.3. Biological Component – Plants

The floral biological components examined included vegetation and plant species of special concern (Table 5.1-1). Threats to vegetation communities at DINO include the spread of invasive exotic plant species, excessive disturbance by native and nonnative grazers and livestock, altered fire regimes, climate change, and altered hydrology within river riparian zones (NPS 2015). Localized threats to particular locations can include recreational impacts and human land uses such as development and agriculture. Livestock grazing is also considered a stressor on numerous park resources and natural processes (NPS 2015; pers. comm., Tamara Naumann, 2016).

The Uintah Basin is renowned for a high number of substrate-specific endemic plant taxa, with several dozen plant taxa of special concern known to occur in DINO. Impacts to rare plants at DINO include altered plant community composition, increase of exotic species such as cheatgrass (*Bromus tectorum*), soil erosion, and altered hydrology. Current grazing practices in some areas of the monument have also resulted in excessive browsing and trampling of several populations of rare plant taxa as well as upland and riparian plant communities (Lyon et al. 2012). However, the condition of these rare plant species at the monument was found to be good overall, with only *Zigadenus vaginatus* (alcove death camas) receiving less than the highest rating. *Hymenoxys lapidicola* (stone rubberweed) was not given a rating due to lack of data.

5.1.4. Biological Component – Animals

The faunal biological components examined included fish, greater sage-grouse, bats, birds and bighorn sheep (Table 5.1-1). All but bats were found to be in moderate condition, with bats earning a good condition rating. Fish and birds have been impacted primarily by flow modification and landscape development. Impacts to greater sage-grouse and bighorn sheep populations have been linked to effects of climate change. Climate change effects on sage-grouse that could occur or are already taking place in the region include: increased susceptibility and exposure to infectious agents, increased fire frequency, and spread of invasive plants that effect habitat and food sources. Greater sage-grouse declines have also come from landscape fragmentation and development. Stressors affecting habitat quality and continuity, as well as climate change, are a common thread for the animal species examined.

5.2. Data Gaps and Uncertainties

The identification of data gaps during the course of the assessment is an important outcome of the NRCA (Table 5.2-1). In some cases, significant data gaps contributed to low confidence in the condition or trend assigned to a resource. Primary data gaps and uncertainties encountered were lack of recent survey data; availability of consistent, long-term data; and incomplete understanding of the ecology of rare resources. Notably missing are current and inclusive population and supporting habitat surveys for reptiles and amphibians. Great Basin Spadefoot toad (*Spea intermontana*), Tiger Salamander (*Ambystoma tigrinum*) and Northern Leopard frog (*Rana pipiens*) all occur within the monument. Water availability, land use, climate change and disease issues adversely effect these species. Impacts cannot be adequately addressed without inclusive surveys for these and other herptile species (pers. comm., Morgan Wehtje, December 2020). Additional data gaps realized during the scoping phase eliminated some resources of concern from our analysis. These included surveys of abiotic and biotic characteristics of seeps and springs, inventory and characterization of hanging garden plant communities, vegetation/rangeland condition and livestock stocking data related to grazing management, and the condition of vegetation and soil resources impacted by native ungulates, primarily elk and deer.

Table 5.2-1. Data gaps identified for focal resources examined at Dinosaur National Monument.

Ecosystem Attribute	Resource	Data Gaps
Landscape Context – System and Human Dimensions	Land Cover and Land Use	The primary source of uncertainty is associated with assumptions regarding the relationships between land ownership and conservation status. Although information about ownership and protection status can be useful, the degree to which biodiversity is represented within the existing network of protected areas is largely unknown. Protection status and extent must be combined with assessments of conservation effectiveness (e.g., location, design, and progress toward conservation objectives) to achieve more meaningful results. Disturbances associated with oil and gas activities surrounding the park and their effects on natural resources are poorly documented, both individually and collectively. Much of the disturbance and habitat fragmentation from oil and gas activities is not adequately captured by the NLCD data.
	Night Skies	No trend was discernible due to a lack of data over time.
	Natural Sounds	No evaluative research to determine the social impacts of existing soundscape conditions on visitor experiences has been collected on-site in DINO.
	Climate Change	Climate change projections are complex with inherently high uncertainty. More specific guidance for monument adaptation is needed.
	Visual Resources	For the view importance assessment, the assessment team lacked information or local expertise to complete some of the fields for viewpoint and viewed landscape importance. Input from park staff regarding cultural, historical, or regulatory importance of the area associated with each viewpoint and viewed landscape was not available but could easily be added to the assessment to improve accuracy and completeness.
Chemical and Physical Environment	Air Quality	Local air monitoring stations vs. interpolated regional data would improve accuracy.
	Water Quality	Current data for the Green River near Jensen sampling station would aid in either showing the true condition of this segment, or help solidify the conclusions already drawn in this study for the segment.
	Yampa and Green River System	Further implementation of the NCPN Big Rivers Monitoring Protocol will help solidify the findings gleaned for this report in the future. This monitoring protocol will also help the monument differentiate impacts to these river systems from climate change versus flow regulation.
Biological – Plants	Vegetation	Field sample data associated with the vegetation mapping inventory and mapping project provides a valuable baseline, but averages over 15 years old. Weed mapping is focused primarily on riparian areas and other higher priority areas such as roadsides. There are no other robust landscape-scale sources of vegetation community data for the monument.
	Plant Species of Special Concern	Long-term monitoring is spotty for some species. The most recent occurrence data for some taxa is several years old.
Biological – Animals	Fish	Additional monitoring over time of fishes within DINO, not only in the Green River but also in the Yampa River, would provide more powerful comparisons of fish population health and recovery across DINO's rivers and reaches.
	Greater sage-grouse	The biggest data gap is lack of information on the condition and trend of the sagebrush community at DINO. Traditional lek counts (such as those used here) often underestimate population size.

Table 5.2-1 (continued). Data gaps identified for focal resources examined at Dinosaur National Monument.

Ecosystem Attribute	Resource	Data Gaps
Biological – Animals (continued)	Bats	Consistency in monitoring designs would increase the confidence of the assessment.
	Birds	Uncertainty in the analysis stems from limited years of data collected by multiple observers with varying identification expertise.
	Bighorn sheep	There appears to be a lack of information on the threat of infection with *Pasteurella* bacteria or other pneumonia agents. Monitoring trends in the incidence and spread of such agents in DINO bighorn sheep populations would help managers understand the threat of *Pasteurella* bacteria and other agents to the DINO bighorn sheep population. Consistent and unbiased population monitoring data via aerial surveys or other means is needed to understand trends in the bighorn sheep population at DINO. The accuracy of agency population estimates is unknown. It is possible that changes in bighorn sheep abundance are occurring and are not being captured by the current approach.
	Amphibians	Missing are current and inclusive population and supporting habitat surveys for reptiles and amphibians.

5.3. Conclusions

The results for the landscape context and focal resources examined consolidate existing information relative to benchmarks of condition. Dinosaur National Monument is still a place where visitors can experience solitude, high-quality and expansive scenery, dark night skies and wild rivers. While the majority of the monument's lands are remote and untouched by modern visitors, historical and continuing land uses within the monument such as livestock grazing, coupled with dynamic stressors related to biotic (e.g., invasive exotic plants) and abiotic (e.g., air quality, visibility, and changing climate) conditions degrade numerous focal resources and most importantly stress numerous species, communities and ecosystems within the monument. The links between increasing cheatgrass, altered fire regimes, changing climate and habitat degradation for species within the monument appears clear, as these drylands are especially susceptible to current and future effects of co-occurring climate change and land uses (Copeland et al. 2017). Moreover, the broader regional picture is remarkable, with extensive areas surrounding the park impacted by oil and gas activities, other land use degradation and regional air quality problems.

Sub-regional and monument-specific mitigation and adaptation strategies are needed to maintain or improve the condition of some resources over time. Climate change may dictate that land managers consider novel approaches to management, broadening their adaptive management approaches to consider a range of options that reconcile targets of "naturalness" as well as climate-driven alternatives (Hobbs et al. 2014, Hansen et al. 2014). This has been described as a shift from "restoration" to "renovation", although the empirical results for the effectiveness of the intervention strategies are not well documented (Prober et al. 2019). At the same time, it is unclear how climate change science and adaptation actions are being considered in project management and planning by land managers (Kemp et al. 2015). Success will require acknowledging a "dynamic change context"

that manages widespread and volatile problems while confronting uncertainties, managing natural and cultural resources simultaneously and interdependently, developing broad disciplinary and interdisciplinary knowledge, and establishing connectivity across broad landscapes beyond park borders (National Park Service Advisory Board Science Committee 2012).

5.4. Literature Cited

Copeland, S.M., J.B. Bradford, M.C. Duniway, and R.M. Schuster. 2017. Potential impacts of overlapping land-use and climate in a sensitive dryland: a case study of the Colorado Plateau, USA. Ecosphere 8(5):e01823.10.1002/ecs2.1823.

Hansen, A.J., N. Piekielek, C. Davis, J. Hass, D. Theobald, J. Gross, W. Monahan, T. Olliff, and S. Running. 2014. Exposure of U.S. National parks to land use and climate change. Ecological Applications 24(3):484–502.

Hobbs, R.J., D. Cole, L. Yung, E. Zavaleta, G. Aplet, F.S. Chapin III, P. Landres, D.J. Parsons, N. Stephenson, P. White, D. Graber, E. Higgs, C. Millar, J.M. Randall, K.A. Tonnessen, and S. Woodley. 2014. Guiding concepts for park and wilderness stewardship in an era of global environmental change. Frontiers in Ecology and the Environment 8(9):483–490.

Kemp, K.B., J. Blades, P. Klos, T. Hull, J. Force, P. Morgan, and W. Tinkham. 2015. Managing for climate change on federal lands of the western United States: perceived usefulness of climate science, effectiveness of adaptation strategies, and barriers to implementation. Ecology and Society 20(2):17.

Lyon, P., D. Malone, and J. Handwerk. 2012. Rare plant survey of Dinosaur National Monument, 2012. Prepared for Dinosaur National Monument and the Colorado Natural Areas Program. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

National Park System Advisory Board Science Committee. 2012. Revisiting Leopold: resource stewardship in the National Parks. National Park Service, Washington, D.C.

National Park Service (NPS). 2015. Foundation Document, Dinosaur National Monument. National Park Service, Dinosaur, Colorado.

Peterson, D.L., T.J. Sullivan, J.M. Eilers, S. Brace, D. Horner, K. Savig, and D. Morse. 1998. Assessment of air quality and air pollutant impacts in national parks of the Rocky Mountains and Northern Great Plains. Regional Air Quality Reviews. Technical Report NPS D-657. National Park Service – Air Resources Division, Denver, Colorado.

Prober, S., V. Doerr, L. Broadhurst, K. Williams, and F. Dickson. 2019. Shifting the conservation paradigm: a synthesis of options for renovating nature under climate change. Ecological Monographs 89(1):e01333.

Sullivan, T.J. 2016. Air quality related values (AQRVs) for Northern Colorado Plateau Network (NCPN) parks: Effects from ozone; visibility reducing particles; and atmospheric deposition of

acids, nutrients and toxics. Natural Resource Report NPS/NCPN/NRR—2016/1169. National Park Service, Fort Collins, Colorado.

Utah Department of Environmental Quality (UDEQ). 2016. 2016 annual report. Utah Division of Air Quality, Salt Lake City, Utah.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 122/175193, April 2021

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525