National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Jewel Cave National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/JECA/NRR—2011/477

ON THE COVER
Cave formations in Jewel Cave
Photograph by: GeoSpatial Services 2009

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Acronyms and Abbreviations

AOA - Area of analysis

IPM - Integrated Pest Management

JECA - Jewel Cave National Monument

LCLU - Land cover and land use

LED - Light-emitting diode

MRLC - Multi-Resolution Land Characteristics Consortium

NGP EPMT - Northern Great Plains Exotic Plant Management Team

NGPN - Northern Great Plains Inventory and Monitoring Network

NLCD - National Land Cover Dataset

NPS - National Park Service

NRCA - Natural Resource Condition Assessment

NVCS - National Vegetation Classification System

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

USFS - United State Forest Service

WNS - White-nose syndrome

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Executive Summary

Jewel Cave National Monument (JECA) was established by Theodore Roosevelt in 1908. The 515-ha (1,274-ac) JECA was established to protect the Jewel Cave ecosystem and its unique geologic features for scientific study and public enjoyment. More than 100,000 people visit JECA each year to participate in cave tours and to hike trails in JECA.

As a unit in the National Park System, JECA is responsible for the management and conservation of its natural resources. This mandate is supported by the National Park Service Organic Act of 1916, which directs the Park Service 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."

In 2003, the National Park Service (NPS) Water Resources Division received funding through the Natural Resource Challenge program to systematically assess watershed resource conditions in NPS units, thus establishing the Watershed Condition Assessment Program. This program, now titled the Natural Resource Condition Assessment (NRCA) Program, aims to provide documentation about the current conditions of important park resources through a spatially explicit, multidisciplinary synthesis of existing scientific data and knowledge. Findings from the NRCA, including the report and accompanying map products, will help JECA managers to:

- Develop near-term management priorities
- Engage in watershed or landscape scale partnership and education efforts
- Conduct park planning (e.g., Resource Stewardship Strategy)
- Report program performance (e.g., Department of Interior's Strategic Plan "land health" goals, Government Performance and Results Act)

Specific project expectations and outcomes for the JECA NRCA are listed in Chapter 3.

For the purpose of this NRCA, NPS staff identified key resources referred to as components in the project framework and throughout the assessment. The components selected include natural resources and processes that are currently of the greatest concern to park management at JECA. The final project framework contains nine resource components, along with measures, stressors, and reference conditions for each.

This study involved reviewing existing literature and data for each of the components in the framework, and, where appropriate, analyzing the data to provide summaries or to create new spatial or statistical representations. After gathering data regarding current condition of component measures, those data were compared to reference conditions, when possible, and a qualitative statement of condition was developed. The discussions in Chapter 4 represent a comprehensive summary of available information regarding the current condition of these resources. These discussions represent not only the most current published literature, but also unpublished park information and, most importantly, the perspectives of resource experts (NPS and non-NPS).

The condition of all resources analyzed in this assessment was of low or moderate concern. Multiple data needs remain for every component assessed; however, many are being resolved or will be through NPS inventory and monitoring efforts, such as small mammal or bat inventories. All components have many threats and stressors that could deteriorate the condition of components in the future. Overall, the condition of the assessed resources indicates that the natural resources in JECA are in good condition and stable.

Chapter 1 NRCA Background Information

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

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

- are multi-disciplinary in scope[1]
- employ hierarchical indicator frameworks[2]
- identify or develop logical reference conditions and values to compare against current condition data[3,4]
- emphasize spatial evaluation of conditions and GIS (map) products[5]
- summarize key findings by park areas[6]
- follow national NRCA guidelines and standards for study design and reporting products

> ***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*

Although current condition reporting relative to logical forms of reference conditions and values is the primary objective, NRCAs also report on trends for any study indicators where the

[1] However, the breadth of natural resources and number/type of indicators evaluated will vary by park.
[2] Frameworks help guide a multidisciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition reporting by broader topics and park areas.
[3] NRCAs must consider ecologically based reference conditions as well as 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.
[4] 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-on response (e.g., ecological thresholds or management "triggers").
[5] As possible and appropriate, NRCAs describe condition gradients or differences across the park for important natural resources and study indicators through a set of GIS coverages and map products.
[6] In addition to reporting on indicator-level conditions, investigators are asked to take a 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.

underlying data and methods support it. Resource condition influences are also addressed and can include past activities or conditions that provide a helpful context for understanding current park resource conditions. NRCAs also includes present-day condition influences (threats and stressors) that are best interpreted at park, watershed, or landscape scales, although they do not judge or report on condition status per se for land areas and natural resources beyond the park's boundaries. Intensive cause and effect analyses of threats and stressors or development of detailed treatment options is outside the project scope.

Credibility for study findings derives from data, methods, and reference values used in the project work; are they appropriate for the stated purpose and adequately documented? For each study indicator, where current condition or trend is reported, identifying critical data gaps and describing level of confidence is important, 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 to (1) assist selection of study indicators; (2) recommend study datasets, methods, and reference conditions and values to use; and (3) help provide a multidisciplinary review of draft study findings and products.

NRCAs provide a useful complement to more rigorous NPS science support programs such as the NPS Inventory and Monitoring Program. 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 bring in relevant non-NPS data to help evaluate current conditions for those same Vital Signs. In some cases, NPS inventory datasets are also incorporated into NRCA analyses and reporting products.

Important NRCA Success Factors …

Obtaining valuable input from park and other NPS subjective 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

In-depth analysis of climate change effects on park natural resources is outside the project scope; however, existing condition analyses and datasets developed by an NRCA will be useful for subsequent park-level climate change studies and planning efforts.

NRCAs do not establish management targets for resource indicators. Decisions about management targets must be made through sanctioned park planning and management processes. NRCAs do provide science-based information that will help park managers with an ongoing, longer term effort to describe and quantify their park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[7] and help park management report to government accountability measures.[8]

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Study methods typically involve 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 our present data and knowledge bases across these varied study components.

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 credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Over the next several years, the NPS plans to fund an NRCA project for each of the ~270 parks served by the NPS Inventory and Monitoring Program. Additional NRCA Program information is posted at: http://www.nature.nps.gov/water/NRCondition_Assessment_Program/Index.cfm

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)

[7] NRCAs are an especially useful lead-in to working on a park Resource Stewardship Strategy (RSS), but study scope can be tailored to also work well as a post-RSS project.

[8] 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.

Chapter 2 Introduction and Resource Setting

2.1 Introduction

Enabling Legislation

On 7 February 1908, Theodore Roosevelt signed a proclamation that established JECA:

> Whereas, the natural formation, known as the Jewel Cave, which is situated upon the public land, within the Black Hills National Forest, in the State of South Dakota, is of scientific interest, and it appears that the public interests would be promoted by reserving this formation as a National Monument, with as much land as may be necessary for the proper protection thereof;
>
> Now, therefore, I, THEODORE ROOSEVELT, President of the United States of America, by virtue of the power in me vested by section two of the Act of Congress, approved June eighth, nineteen hundred and six, entitled, "An Act For the Preservation of American Antiquities," do proclaim that there are hereby reserved from settlement, entry, and all forms of appropriation under the public land laws, subject to all prior valid adverse claims, and set apart as a National Monument, all the tracts of land in the State of South Dakota, shown as the Jewel Cave National Monument on the diagram forming a part hereof.
>
> The reservation made by this proclamation is not intended to prevent the use of the lands for purposes consistent with the withdrawal made by this proclamation, or for forest purposes under the proclamation establishing the Black Hills National Forest, but the two reservations shall both be effective on the land withdrawn, but the National Monument herby established shall be the dominant reservation.
>
> Warning is hereby given to all unauthorized persons not to appropriate, injure, or destroy any feature of this National Monument or to locate or settle upon any of the lands reserved by this proclamation (16 USC 431-433 1906).

Geographic Setting

Jewel Cave National Monument (JECA) is a 515-ha (1,274-ac) park in Custer County, located in the southwest corner of South Dakota in the southern Black Hills (NPS 2007). Custer County has a population density of 1.81 individuals/km^2, less than half the average for all of South Dakota (9.9 individuals/km^2) (USCB 2010). The Black Hills, a mountain range in western South Dakota and northeastern Wyoming roughly 200 km long and 100 km wide (Marriott et al. 1999), is named for the dark ponderosa pines (*Pinus ponderosa*) that cover most of the Hills (Marriott et al. 1999). The geology of the area consists of igneous and sedimentary rock, and the soils are loamy (Salas and Pucherelli 1998).

The climate at JECA is semi-arid and frequently windy, with extreme temperature variation between seasons (NPS 2011) (Table 1).

Table 1. Monthly temperature and precipitation normals for Custer Climate Station, 1971–2000, (NOAA 2002).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Temperature (°F)													
Max	35.6	40.1	45.7	53.8	63.4	73.4	80.1	79.5	70.8	58.9	43.9	37.4	56.9
Min	12.4	16.2	20.9	28.0	37.4	46.0	52.1	50.4	41.4	31.3	21.3	14.3	31.0
Average Precipitation (inches)													
Total	0.39	0.63	1.07	2.06	3.31	3.17	3.02	2.38	1.50	1.47	0.67	0.52	20.19

Visitation Statistics

Since 2000, 114,490 people on average have visited JECA per year (NPS 2010a), with the summer months being the busiest. Most JECA visitors come to participate in one of the four cave tours offered; however, some people utilize the 14.9 km of hiking trails at the park to view birds or wildflowers. Park staff also offer interpretive talks and various educational programs.

2.2 Natural Resources

Ecological Units and Watersheds

The Black Hills are part of the U.S. Environmental Protection Agency's (EPA's) Middle Rockies Level III Ecoregion:

> The climate of the Middle Rockies lacks the strong maritime influence of the Northern Rockies. Mountains have Douglas-fir, subalpine fir, and Engelmann spruce forests, as well as some large alpine areas. Pacific tree species are never dominant and forests can have open canopies. Foothills are partly wooded or shrub- and grass-covered. Intermontane valleys are grass- and/or shrub-covered and contain a mosaic of terrestrial and aquatic fauna that is distinct from the nearby mountains. Many mountain-fed, perennial streams occur and differentiate the intermontane valleys from the Northwestern Great Plains. Granitics and associated management problems are less extensive than in the Idaho Batholith. Recreation, logging, mining, and summer livestock grazing are common land uses. (USGS 2010).

The EPA divides Level III ecoregions into smaller Level IV ecoregions. The Black Hills consists of three Level IV ecoregions: the Black Hills Foothills, the Black Hills Plateau, and the Black Hills Core Highlands (Plate 1). JECA is located in the Black Hills Foothills Level IV ecoregion; the U.S. Geological Survey's (USGS's) Northern Prairie Wildlife Research Center offers the following description:

> The Black Hills Plateau ecoregion is a relatively flat, elevated expanse covering the mid-elevation slopes and grasslands of the Black Hills. It includes areas of sharply tilted metamorphic rock and lower elevation granite outcrops. Competing uses, such as logging, farming and ranching, and tourist development, stress this ecosystem. (USGS 2010).

JECA is located within the 4,402-km^2 (1,700 mi^2) Beaver Watershed, most of which is located in neighboring Wyoming (USGS 2011). Surface water resources in the JECA area include several intermittent streams (Hell, Lithograph, Tepee, and others), springs (Chokecherry, Lithograph, Prairie Dog, and others), as well as livestock ponds (NPS 2000b).

Resource Descriptions

Jewel Cave is the major natural resource in JECA. The cave has more than 154 miles of known passageways and is known for a variety of physical features including stalactites, stalagmites, draperies, frostwork, flowstone, boxwork, and hydromagnesite balloons (NPS 2007; NPS 2011). Calcite crystals, which cover a large portion of the cave walls, are the "jewels" of Jewel Cave (NPS 2007) (Photo 1). More than 45% of the known Jewel Cave passages extend beyond JECA boundaries (NPS 2007).

Photo 1. Calcite crystals in Jewel Cave.

Photo 2. Burned ponderosa pine forest, JECA.

The dominant vegetation at JECA is ponderosa pine interspersed with mixed-grass prairie (NPS 2005). Other woody plant species include ash leaf maple (also known as boxelder) (*Acer negundo*), aspen (*Populus* spp.), chokecherry (*Prunus virginiana*), mountain ninebark (*Physocarpus monogynus*), and western snowberry (*Symphoricarpos occidentalis*). Common herbaceous plants include little bluestem (*Schizachyrium scoparium*), side-oats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), and thread-leaf sedge (*Carex filifolia*). The 2000 Jasper Fire significantly altered the vegetation in the park, burning 33,792 ha (83,503 ac) in the Black Hills, including 90% of JECA's land area (NPS 2010b). Photo 2 shows a recently burned ponderosa pine stand.

No federally listed endangered or threatened species are present in JECA; however, JECA is home to nine species of bats, six of which are considered species of concern by the South Dakota Natural Heritage Program: fringed myotis (*Myotis thysanodes*), northern myotis (*Myotis septentrionalis*), western small-footed myotis (*Myotis ciliolabrum*), long-eared myotis (*Myotis evotis*), silver-haired bat (*Lasionycteris noctivagans*), and Townsend's big-eared bat (*Corynorhinus townsendii*) (NPS 2007). JECA contains several rare and sensitive plant species including Hopi tea (*Thelesperma megapotamicum*), Hooker's Townsend-daisy (*Townsendia hookeri*), and smallflower columbine (*Aquilegia brevistyla*) (Marriott and Hartman 1986). The black-backed woodpecker (*Picoides arcticus*) is a species of concern that prefers recently burned conifer forest, habitat that is widespread at JECA following the Jasper Fire. Since the Jasper Fire, the number of woodpeckers in the park has increased in comparison to surrounding National Forest Land, likely due to the absence of commercial salvage logging following the fire, which has removed much of the quality habitat around the park (Panjabi 2005). Marrone (2004) performed a comprehensive inventory of butterflies in JECA and observed 53 species in the park. The tawny crescent butterfly (*Phyciodes batesii*) is another species of concern that occurs in JECA (NPS 2004).

Resource Issues Overview

Exotic species threaten the native plant communities at JECA, and their abundance has increased since the Jasper Fire of 2000 (NPS 2007). Currently, more than 50 exotic plant species exist within JECA (NPS 2005). Canada thistle (*Cirsium arvense*) and leafy spurge (*Euphorbia esula)* are especially prolific at JECA (NPS 2007). JECA employs a crew to control exotic plants each year using mechanical, biological, and chemical treatments. The potential effects that exotic species and the associated treatment methods may have on the cave environment are a concern to park management. Exotic plants consume a large amount of available surface water, potentially altering the natural hydrology above the cave, and pesticide applications can influence groundwater quality, which could affect cave biota (NPS 2005). JECA has established a no-herbicide zone covering 242 ha (600 ac), or about half of JECA, to protect cave resources (NPS 2005).

The Jewel Cave environment is threatened by a variety of potential threats and stressors. The cave's microclimate, determined by parameters that include temperature, relative humidity, and airflow, are altered by changes in visitation and the lighting system used in the cave (NPS 2007). The physical features of Jewel Cave are impacted by visitation, exploration, maintenance, and monitoring activities (NPS 2007). Manganese deposits are present throughout Jewel Cave and are easily transferred to lighter-colored cave features by human footprints and handprints (NPS 2007). Manganese transfer in the cave can cause permanent aesthetic impacts to cave walls and speleothems (cave formations created by the deposition of minerals from water).

Climate change could have dramatic impacts on the ecosystems within JECA (Gitzen et al. 2010). Temperatures in the Northern Great Plains have risen more than 1.1 °C (2 °F) over the past century, and models predict an increase of 2.7–6.7 °C (5–12 °F) during this century (National Assessment Synthesis Team 2000). While precipitation is also expected to increase, evapotranspiration will increase with higher temperatures and longer growing seasons, perhaps resulting in an overall drier climate (National Assessment Synthesis Team 2000).

2.3 Resource Stewardship

Management Directives and Planning Guidance

JECA's strategic plan (NPS 2000a) establishes three broad goal categories for JECA:

- Goal Category I: Preserve Jewel Cave National Monument Resources
  - Ia. Natural and cultural resources and associated values at Jewel Cave National Monument are protected, restored and maintained in good condition and managed within their broader ecosystem and cultural context.
  - Ib. The National Park Service at Jewel Cave National Monument contributes to knowledge about natural and cultural resources and associated values; management decisions about resources and visitors are based on adequate scholarly and scientific information.
- Goal Category II: Provide for the Public Use and Enjoyment and Visitor Experience of Jewel Cave National Monument
  - IIa. Visitors to Jewel Cave National Monument safely enjoy and are satisfied with the availability, accessibility, diversity, and quality of park facilities, services, and appropriate recreational opportunities.
  - IIb. Park visitors and the general public understand and appreciate the preservation of Jewel Cave National Monument and its resources for this and future generations.
- Goal Category III: Ensure Organizational Effectiveness of Jewel Cave National Monument
  - IIIa. The National Park Service at Jewel Cave National Monument uses current management practices, systems, and technologies to accomplish its mission.
  - IIIb. The National Park Service at Jewel Cave National Monument increases its managerial capabilities through initiatives and support from other agencies, organizations, and individuals.

Additionally, NPS Management Policies (NPS 2006) included a statement on cave management:

> The Service will manage caves in accordance with approved cave management plans to perpetuate the natural systems associated with the caves, such as karst and other drainage patterns, air flows, mineral deposition, and plant and animal communities. Wilderness and cultural resources and values will also be protected.

Status of Supporting Science

The Northern Great Plains Inventory and Monitoring Network (NGPN) developed a list of Vital Signs for each park unit based on its key resources (Gitzen et al. 2010), a subset of which were selected for monitoring in JECA (Table 2). Many of the Vital Signs are related to the cave environment and activities that affect that environment.

Table 2. NGPN Vital Signs selected for monitoring in JECA (Gitzen et al. 2010). Those in bold are already monitored by the park or another NPS program while those in italics will likely be monitored in the future, but there are currently no plans to develop a program.

Category	NGPN Vital Signs
Air and Climate	**Weather and climate**
Geology and Soils	Cave meteorology (monitored by JECA and Andreas Pflitsch)
Water	**Groundwater dynamics,** surface water chemistry, cave water chemistry (monitored by JECA), aquatic contaminants, aquatic microorganisms, aquatic macroinvertebrates
Biological Integrity	Exotic plant early detection, **forest insects and diseases,** upland plant communities, land birds
Human use	**Treatments of exotic infestations, visitor use**
Landscapes (ecosystem pattern and process)	**Fire and fuel dynamics,** land cover and use, extreme disturbances, soundscape (aboveground), *viewscape*, *night sky*

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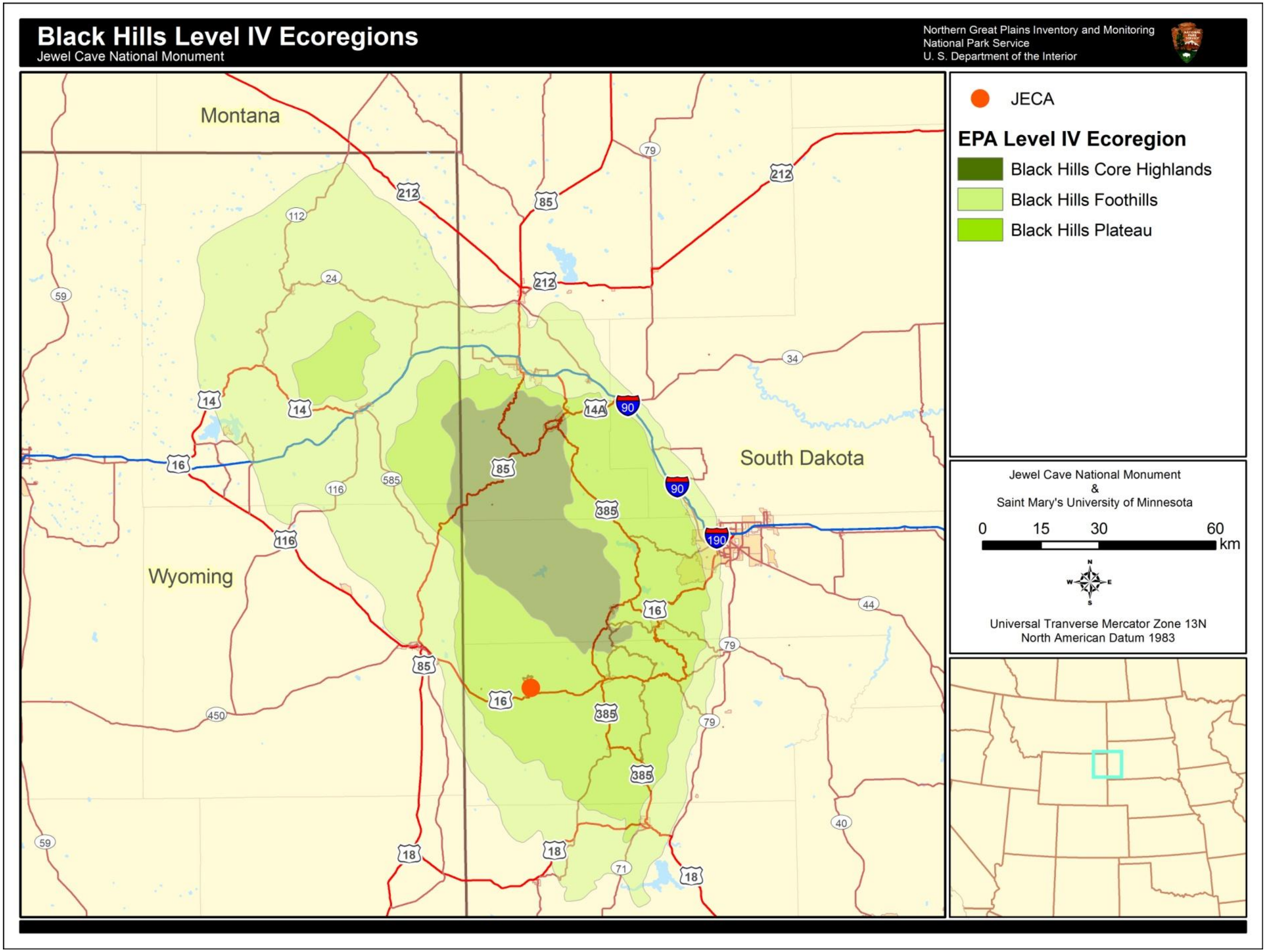

Plate 1. Black Hills Level IV Ecoregions (EPA 2010).

Chapter 3 Study Scoping and Design

This Natural Resource Condition Assessment (NRCA) was a collaborative effort between the National Park Service (NPS) and Saint Mary's University of Minnesota GeoSpatial Services (SMUMN GSS). Stakeholders in this project include Jewel Cave National Monument (JECA) park resource staff and Northern Great Plains Inventory and Monitoring Network (NGPN) staff. Before embarking on the project, specific roles of the NPS and SMUMN GSS were identified. Preliminary scoping meetings were held, and a task agreement and a detailed scope of work document were created in cooperation with the NPS and SMUMN GSS.

3.1 Preliminary Scoping

A preliminary scoping meeting was held 20 October 2009 with SMUMN GSS and NPS staff to determine the purpose of the JECA NRCA, which is to evaluate and report on current conditions of key park resources, evaluate critical data and knowledge gaps, and highlight selected existing and emerging resource condition influences of concern to JECA managers.

NPS provided specific guidance for this NRCA:

- Use of existing data and information to conduct the assessment
- Identification of data needs and gaps driven by the framework categories
- Analysis of natural resource conditions that include a strong geospatial component
- Resource focus and priorities driven primarily by JECA park resource management

This condition assessment provides a "snapshot-in-time" evaluation of resource condition status for a select set of park natural resources, identified and agreed to by the project team. Project findings will aid JECA resource managers in the following objectives:

- Developing near-term management priorities
- Engaging in watershed or landscape scale partnership and education efforts
- Conducting park planning (e.g., General Management Plan, Resource Stewardship Strategy)
- Reporting program performance (e.g., Department of Interior Strategic Plan "land health" goals)

NPS Involvement

Expectations for JECA staff involvement were detailed during project scoping efforts. Park staff participated in project development and planning, reviewed interim and final products, and participated in condition assessment meetings. JECA staff also assisted SMUMN GSS in the identification of information sources, an appropriate resource assessment structure, appropriately scaled resources, threats and stressors, and measures for these resources.

JECA park staff helped to identify other NPS personnel who could provide guidance, technical assistance, and logistical coordination for site visits and discussions with principle investigators and graduate students. Park staff collaborated with the SMUMN GSS Principle Investigator during data mining and status assessment to ensure that the synthesis was consistent with the project goals. Additionally, JECA natural resource staff assisted in developing recommendations for additional analyses to fulfill information needs that would aid in the assessment of park resource conditions. They also reviewed and commented on draft reports and all publishable material submitted from this project in a timely fashion. Involvement of JECA staff in this project ensured that SMUMN GSS efforts met the needs of the park.

The NPS was responsible for informing the SMUMN GSS Principle Investigator of the specific activities required to comply with the "NPS Interim Guidance Document Governing Code of Conduct, Peer Review, and Information Quality Correction for National Park Service Cultural and Natural Resource Disciplines" or any subsequent guidance issued by the NPS Director to replace this interim document.

3.2 Study Design

Component Framework, Focal Study Resources and Components

Selection of Resources and Measures

As defined by SMUMN GSS in the NRCA process, a park "framework" is developed that organizes, in a hierarchical fashion, biogeophysical resource topics considered important in park management efforts. The primary features in the framework are key resource components, measures, stressors, and reference conditions.

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

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

Selection of Reference Conditions

A reference condition is a benchmark for comparison with current values of a given component's measures to determine condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal or objective (e.g., a bison herd no larger than 700 individuals) (adapted from Stoddard et al. 2006).

Reference conditions in this project were identified during the scoping process using input from NPS resource staff. In some cases, reference conditions represent a historical reference in which human activity and disturbance were not major drivers of ecological populations and processes, such as “pre-exotic invasions” or “pre-1908 establishment.” In other cases, peer-reviewed literature and ecological thresholds helped define appropriate reference conditions.

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science’s “State of Our Nation’s Ecosystems 2008” framework (Heinz 2008). Key resources for the park were gleaned from the NGPN Vital Signs Monitoring Plan (Gitzen et al. 2010) and publically available informational materials from JECA. This initial framework was presented to park resource staff to stimulate meaningful dialogue about key resources that should be assessed. Significant collaboration between SMUMN GSS and NPS staff was needed to focus the scope of the NRCA project and finalize the framework of key resource to be assessed.

The NRCA framework was finalized in February 2010 following acceptance from JECA resource staff. It contained nine components (Table 3) and was used to drive the analysis in this NRCA. This framework outlined the resources (components), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each resource for comparison to current conditions.

Table 3. Final JECA Natural Resource Condition Assessment (NRCA) Framework.

Jewel Cave National Monument
Natural Resource Condition Assessment Framework

Components	*Measures*	*Stressors and Emerging Threats*	*Reference Condition*
Extent and Pattern			
Landscape Composition			
Landcover Extent	Landcover change	Climate change, fire management suppression, in-park and outside park development, land use	Pre-1908 landcover (1874 Custer expedition photographs)
	Change in Ponderosa Pine distribution and density	Fire management, pine beetle threat	Pre-1908 establishment (1874 Custer expedition photographs)
Forest Fire	Frequency	Suppression, vegetation, fuel loading, climate change	Natural frequency - historic documentation
	Severity	Suppression, vegetation, fuel loading, climate change	Natural fuel and frequency relationship - historic documentation
	Extent	Suppression, fuel loading, external and internal development and land use	Natural extent - historic documentation
Biological Components			
Ecosystem and Community			
Native Plant Communities	Exotic Plant - Distribution and density	Fire regime, climate changes, moisture patterns, potential atmospheric nitrogen deposition, visitation	Pre-Exotic infestations
Biotic Composition			
Bats	Total number of hibernating bats by genus	General development, human disturbance, climate change	Bat count ranges after 1992 standardized count methodology
Chemical and Physical Characteristics			
Cave Environment			
Microclimate	Temperature (overall heat exchange)	Tour lights, visitation, climate change	Pre 1908 Establishment
	Pressure (air exchange)	Artificial cave entrances, human-caused enlargement of cave passages	Pre 1908 Establishment
	Humidity (overall moisture)	Visitation, climate change	Pre 1908 Establishment
	Wind velocity	Human caused changes in cave passages (sizes, etc)	Pre 1908 Establishment
Water Quality			
Drip Sites	Chloride Concentrations	Possible leak in sewage line, road salt	Un-impacted drip sites
	Nitrate Concentrations	Possible leak in sewage line	Un-impacted drip sites
	Pesticide Concentrations	Exotic plant treatment inside and outside monument boundary	No pesticides
Hydrology			
Changes in infiltration	Permeability	Development, septic systems, Surface Vegetation Changes	Un-impacted drip sites
Goods and Services			
Non-Consumptive			
Soundscape - Cave	Decibel levels	Aluminum walkways, tour group size	"Natural" cave experience
Viewshed - Cave	Natural cave views	Colored lights, breakage of cave features, debris build-up	"Natural" cave experience

Reporting Areas

Reporting zones were not used in this assessment.

General Approach and Methods

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

<u>Individual Component Assessments</u>

Data Mining

The data mining process (acquiring as much relevant data about key resources as possible) began at the first scoping meeting, where JECA NPS staff provided data and literature in multiple forms, including NPS reports and monitoring plans, reports from various state and federal agencies, published and unpublished research documents, nongovernmental organization reports, databases, tabular data, and charts. Geographic Information Systems (GIS) data were provided by NGPN and by JECA NPS staff. Access was also granted to various NPS online data and literature sources, such as NatureBib and NPSpecies. Additional data and literature were also acquired through online bibliographic literature searches and inquiries on various state and federal government websites.

Data and literature acquired throughout the data mining process were inventoried and analyzed for thoroughness, relevance, and quality in relation to the resource components identified at the scoping meeting.

Data Development and Analysis

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available on the topic and recommendations from JECA staff about analysis. Specific approaches to data development and analysis can be found within the respective component assessment sections located in Chapter 4 of this report.

Preparation and Review of Component Rough Draft Assessments (Phase I Documents)

The process of developing draft documents for each component began with a detailed phone or conference call with resource component experts to verify the most relevant data and literature sources that should be used and to formulate ideas about current condition with respect to the experts' opinions. Information gained in these initial conversations was important for rough draft development, which used data gathered through the data mining process and the insights provided by component experts. Next, the documents were forwarded to the component experts for their initial review and comment.

The preparation of rough draft assessments for each component was a cooperative process involving SMUMN GSS, JECA, and NGPN staff. Although SMUMN GSS analysts relied heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also played a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step was especially important when data or literature about a resource component were limited.

Development and Review of Final Component Assessments (Phase II Documents)
Following review of the component rough drafts (Phase I documents), analysts used the review feedback from resource experts to compile the final component assessments (Phase II documents). Consistent contact with experts was maintained throughout this process to adequately address questions and comments pertaining to rough draft reviews and to ensure accurate representation of JECA and NGPN NPS staff knowledge. Once Phase II documents were completed, they were sent back to expert NPS reviewers for a second, thorough review and to add additional insights. Any comments or feedback received during this second review were incorporated into the assessment document. As a result of this process, and based on the recommendations provided by JECA resource staff and other experts, the final component assessments (Phase II documents) represent the most relevant and current data available and the opinions of park resource staff and resource experts for each component.

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

Format of Component Assessment Documents

Description
The relevance of the resource component to the park and its context within the park setting is described and may represent a unique feature of the park, a key process or resource in park ecology, or a resource of high management priority in the park. Any interrelationships that occur among a given component and other resource components included in the broader assessment are also emphasized.

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

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

Data and Methods
Datasets used to evaluate the component were adjusted or processed as a lead-up to analysis. A discussion of how data were evaluated and analyzed to determine current condition (and trend, when appropriate) is also included.

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

Threats and Stressor Factors
A summary of the threats and stressors that may impact resources and influence the current condition of a resource component are provided. Relevant stressors were described in the scoping process and are outlined in the NRCA framework. However, these are elaborated on to create a summary of threats and stressors based on a combination of available data and literature and discussions with experts and park natural resources staff.

Data Needs and Gaps
Critical data needs or gaps for the resource component are outlined. Specifically, this section discusses how these data needs/gaps, if addressed, would help determine the current condition of a given component in future assessments. In some cases, the data needs/gaps are significant enough to make it inappropriate or impossible to determine condition of the resource component. In these cases, stating the data needs/gaps will help natural resources staff prioritize monitoring or data gathering efforts.

Overall Condition
A qualitative summary statement of the current condition for the resource component is provided, determined after thoughtful review of available literature, data, and any insights from park staff and experts, which are presented in the Current Condition and Trend section. The Overall Condition section summarizes the key findings and highlights the key elements used in determining and justifying the level of concern, if any, that analysts attribute to the condition of the resource component.

Initial designations of current condition for a component (i.e., made by the authors during component rough draft preparation) were subject to review from resource experts during the review process and amended when appropriate to provide a more accurate representation of park staff and experts' interpretation of condition. When applicable, condition designations were made with respect to the defined reference condition; when reference conditions were not available, the opinions of park staff and experts were relied on more heavily to determine condition.

Condition Graphic
A graphical representation of the condition of the component (and trend when appropriate) is provided to give readers a more visual interpretation of the assessed condition. However, these graphics are not intended to replace the written statements of condition, which provide an in-

depth discussion of and justification for the condition attributed by analysts to the resource component.

An example of the condition graphic representing the assessed condition of a component (Figure 1) uses colored circles to indicate a component's condition expressed by level of concern. Red circles signify that a resource is of "significant concern" to park management; yellow circles signify "moderate"; green circles signify "low" concern; and gray circles signify that data are currently insufficient to make a statement about concern or condition of the component.

The arrows nested inside of the circles indicate the trend of the condition of a resource component. Up arrows indicate the condition of the component is improving from reference condition; right arrows indicate a stable condition or trend; down arrows indicate a decline in the condition. These are only used when it is appropriate to comment on the trend of condition of a component. A triple-pointed arrow indicates the trend of the component's condition is currently unknown.

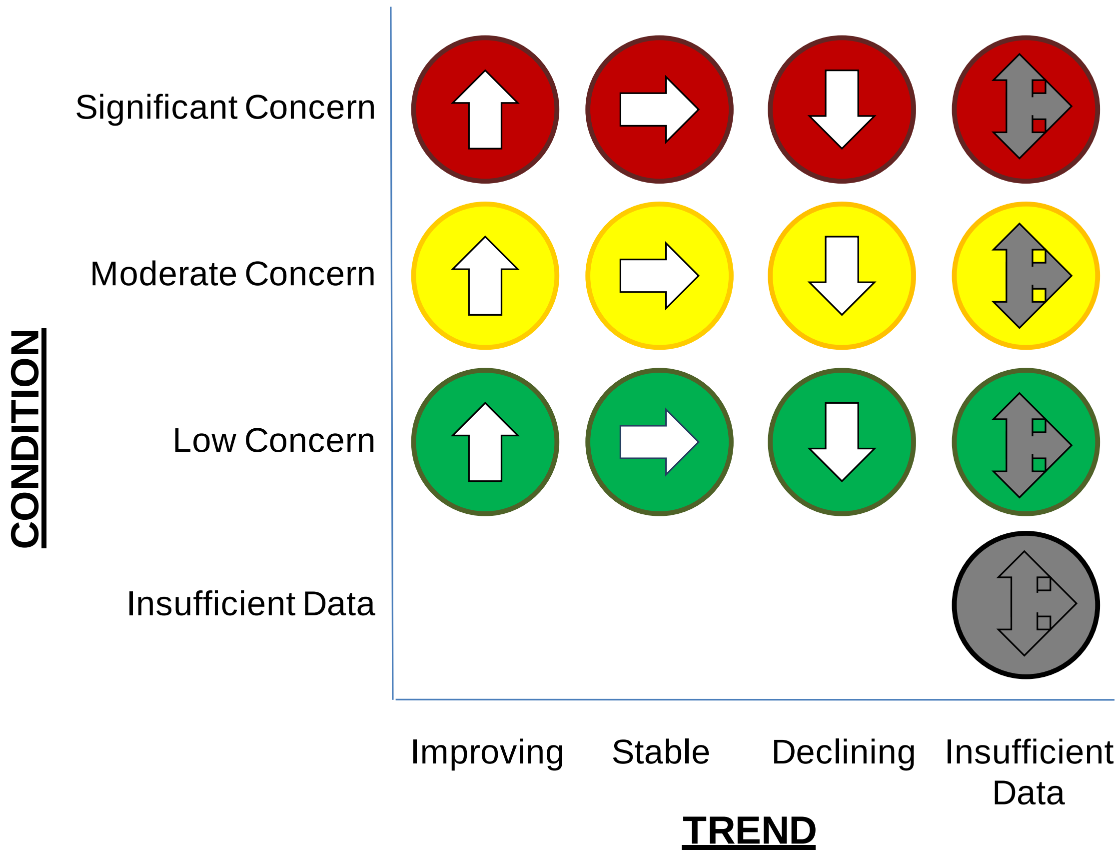

Figure 1. Graphical representation of current conditions and trends of components in JECA.

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

Literature Cited

Formal citations for literature or datasets used in the analysis and assessment of condition for the resource component are provided.

Literature Cited

Gitzen, R. A., M. Wilson, J. Brumm, M. Bynum, J. Wrede, J. Millspaugh, and K. Paintner. 2010. Northern Great Plains Network Vital Signs Monitoring Plan. Natural Resource Report NPS/NGPN/NRR—2010/186. National Park Service, Fort Collins, CO.

Great Lakes Environmental Indicators Project (GLEI). 2010. Glossary, Stressor. Online at: http://glei.nrri.umn.edu/default/glossary.htm. Accessed 9 December 2010.

Stoddard. J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, R. J. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications. 16(4):1267–1276.

Chapter 4 Natural Resource Component Summaries

This chapter presents the background, analysis, and condition summaries for the nine key resource components in the project framework. The following sections discuss the key resources and their measures, stressors, and reference conditions. The order of components follows the project framework (Table 1). The summary for each indicator is arranged around the following sections:

1. Land Cover

2. Fire

3. Native Plant Communities

4. Bats

5. Microclimate

6. Drip Sites

7. Changes in Infiltration

8. Cave Soundscape

9. Cave Viewshed

4.1 Land Cover

Description

Land cover is the physical surface of the earth, including classes of vegetation and classes of land use (e.g., agriculture, residential, transportation) (Comber 2005). Land cover is often portrayed in maps created through field surveys and/or analysis of remotely sensed imagery (Comber 2005). The Northern Great Plains Inventory and Monitoring Network (NGPN) recognizes land cover and land use (LCLU) as a Vital Sign because natural disturbances, stressors, and land management can cause large-scale changes to the general ecosystem composition of NPS units, altering the land cover of a park. In addition, the type, amount, and arrangement of vegetative structural types in park units partially determine the composition and abundance of those units' vertebrate and invertebrate communities (Vinton and Collins 1997).

Ponderosa pine dominates the landscape at Jewel Cave National Monument (JECA). Prior to 2000, the year of the Jasper Fire, land cover in and around JECA was primarily a mix of ponderosa pine woodlands, cropland, grassland, and shrubland (Salas and Pucherelli 1998). Areas in and around JECA also contained ash leaf maple (also known as box elder), quaking aspen (*Populus tremuloides*), and chokecherry forests (Salas and Pucherelli 1998). Most of the disturbed and converted areas were originally natural and were converted to agricultural land. In addition, some relatively small areas classified by the Anderson Level II LCLU (Anderson et al. 1976) as "commercial services" (park roads and infrastructure areas) still exist in the park.

Measures

- Land cover change
- Change in ponderosa pine distribution and density

Reference Condition and Values

The reference condition for this assessment is the land cover pre-1908. Aerial imagery documenting land cover pre-1908 is not available, making a quantitative analysis of land cover change using this reference condition difficult. However, the primary change described in the literature over the last 100 years is the increase in density and expansion of ponderosa pines into the grasslands (Brown and Sieg 1996; Brown and Cook 2006). Historically, frequent fires and open forest stands allowed large, old ponderosa pines to grow (Brown and Cook 2006); however, fire suppression has increased the density of ponderosa pines, leading to smaller trees and a uniform distribution, making the trees more susceptible to severe wildfires and insect infestation (Brown and Cook 2006).

Land cover is naturally a dynamic aspect of ecosystems, driven by natural and human factors. Natural disturbances such as fire, wind-throw, and insect and disease infestations reset vegetation succession. Another natural driver of vegetation and land cover is native ungulate grazing. Native bison (*Bison bison*) were a keystone species of the Great Plains for approximately 10,000 years but were extirpated from the area by the mid-1870s (Brown and Sieg 1996). In addition, ungulates such as elk or deer have the potential to change land cover in the park. The main sources of anthropomorphic land cover change within and surrounding JECA include fire suppression, logging, mining, livestock grazing, and urbanization of the land.

A long history of human settlement in the Black Hills "has resulted in a highly fragmented land ownership pattern, with relatively few lands in public ownership and most of these with well-established multiple use mandates (logging, mining, and livestock grazing). Until recently, few areas have been designated for natural resource protection, and most of these were established for recreation or to preserve unique geological or cultural features rather than native biological diversity" (Fertig and Oblad 2000, p. 13). Fertig and Oblad (2000) also suggest that high road density in the Black Hills prevents many areas from being preserved at a broad landscape level.

Photo 3. Jewel Cave National Monument .

JECA is located in Custer County, South Dakota and, as of 2010, the county had a population density of 13.7 people/km^2 (5.3/mi^2) (U.S. Census Bureau 2010). High human population densities are often associated with significant land cover changes (e.g., conversion from vegetative cover to impervious surfaces). Although the population density in Custer County is low relative to the lower 48 (at 36 people/km^2), land uses such as mining, logging, and livestock grazing (both historic and present) create lasting effects on plant communities and on overall land cover. While logging and surface mining may have more obvious effects on land cover, ecological costs are also often associated with livestock grazing (Fleischner 1994). These ecological costs may not be detectable or measureable by typical land cover and use mapping methods.

Data and Methods

All 32 National Park Service (NPS) Inventory and Monitoring (I&M) Networks collect, manage, analyze, and report long-term data for a select group of physical, chemical, and biological elements and processes in park ecosystems that represent the overall health or condition of a park (NPS 2010a). These elements and processes are called Vital Signs (NPS 2010a). As mentioned in the description of land cover, the NGPN recognizes land cover and land use as a Vital Sign. Although NGPN does not have a protocol for monitoring this Vital Sign, the expected approach includes the acquisition and analysis of fine-scale satellite imagery and measuring land use and coarse vegetation cover within NPS units and within an undetermined buffer of each park. The protocol for this Vital Sign will be developed in the next 1 to 5 years.

Salas and Pucherelli (1998) created the most detailed map to date of land cover (vegetation classes) and land use in JECA using 1993 U.S. Forest Service (USFS) aerial imagery. The map categorizes vegetation associations using the National Vegetation Classification System (NVCS) and Anderson Level II (Anderson et al.1976) LCLU categories using GIS polygons. Refer to Appendix B for a table indicating land cover/land use composition according to Salas and Pucherelli (1998). Data that indicate recent changes at this scale are unavailable; however, the National Land Cover Database (NLCD) 1992-2001 Land Cover Change Retrofit product (Vogelmann et al. 2001) indicates broad land cover class changes that occurred following the Jasper Fire (Fry et al. 2009).

Analyses from the NPScape project provide information regarding land cover and landscape dynamics on a regional scale (i.e., 30 km surrounding JECA; NPS 2011). NPScape is a project created by the NPS Natural Resource Program Center, Inventory and Monitoring Division that monitors landscape dynamics and delivers a suite of landscape-scale datasets, maps, reports, and other products to NPS units. The NPScape project created a conceptual framework that describes three major factors affecting landscape scale dynamics: Natural Systems, Human Drivers, and Conservation Context (Figure 2) (NPS 2010c). Specifically, the project provides land cover data in a 30 m cell size within a 30 km buffer of JECA from the NLCD (Vogelmann et al. 2001; Homer et al. 2004), a coarser resolution and different classification system than the Salas and Pucherelli (1998) vegetation map. The NPScape project also provides several other land cover related datasets, developed using Python® scripts in a GIS (within JECA and an approximately 30 km buffer), including “natural versus converted land cover,” “land cover change,” and “landscape pattern.” These Python® scripts can be used on other datasets (e.g., updated LCLU datasets at finer scales offered by the NLCD) to derive similar GIS products. The project also examines human drivers including population, road density, impervious surfaces, and categorizations of conservation status metrics (NPS 2010b, 2010c).

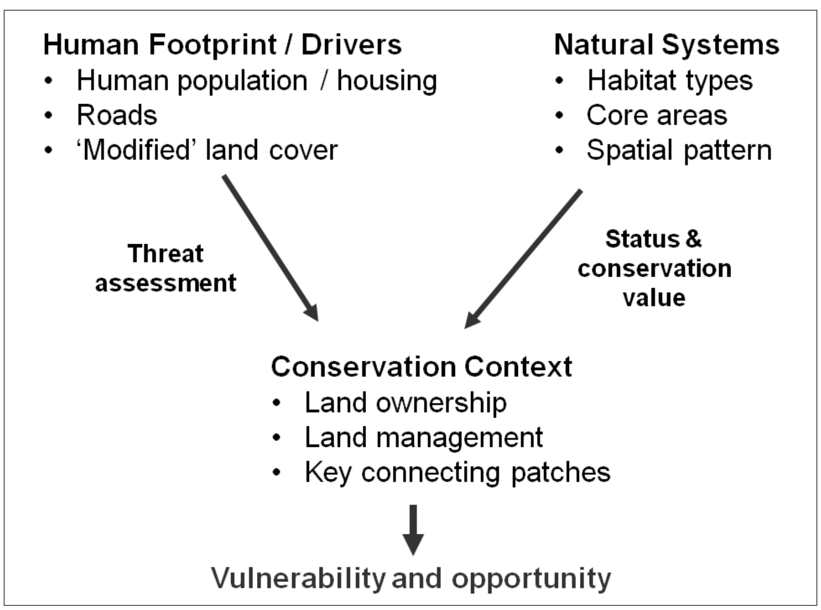

Figure 2. NPScape conceptual framework (NPS 2010c).

The GIS outputs (namely those derived from NLCD) produced by the NPScape project would require significant GIS processing to make any comparisons with the data in Salas and Pucherelli (1998), and meaningful comparisons would be difficult to produce due to different scales and classification methodology used by each dataset (Vogelmann et al. 2001; Homer et al. 2004;

Salas and Pucherelli 1998). However, 1992 to 2001 NLCD change data (Fry et al. 2009) provide insight into general changes in land cover in and surrounding JECA, illustrating regional and JECA-specific land cover changes post Jasper Fire.

Current Condition and Trend

Land Cover Change

Prior to the Jasper Fire in August 2000, the vegetation within JECA consisted of a mosaic of ponderosa pine woodlands, forests, and grass and shrub complex, with the majority of the land cover (97%) being ponderosa pine woodlands and forests (Salas and Pucherelli 1998). Salas and Pucherelli (1998) derived their data from 1993 color infrared aerial photographs and from field sampling at a scale of 1:16,000 (Plate 2). In addition to the land within JECA boundaries, Salas and Pucherelli (1998) mapped an area surrounding the boundaries of JECA. The majority of land cover for the entire study area (including within and outside JECA) consisted of Ponderosa Pine Complex I (59%), Ponderosa Pine Complex II (28%), and Cropland and Pasture (8%) (Table 4). Within the JECA boundaries, primary land cover consisted of Ponderosa Pine Complex I (66%) and Ponderosa Pine Complex II (31%) (

Table **5**). However, current land cover has changed significantly since the Salas and Pucherelli (1998) land cover mapping project. The Jasper Fire destroyed 265 ha (655 ac) of forest (54% of the original forested area), and because of additional loss in the remaining forested area, the total mortality exceeded 60% (M. Wiles, pers. comm., 2011). JECA staff conducted a preliminary examination of 2010 National Agriculture Imagery Program (NAIP) color aerial imagery and estimated that only 44% of land cover within JECA boundaries would still be defined as Ponderosa Pine Complex I or II (R. Ohms, pers. comm., 2011). Percent composition of land use/cover pre-Jasper Fire has been documented (Table 4 and

Table **5**), but the values do not represent the current composition of land use/cover in JECA.

Table 4. Land use/cover in the entire Salas and Pucherelli (1998) study area.

Land use/cover	Area (ha)	Area (ac)	Percent Composition
Residential	0.5	1.2	0.01%
Commercial and Services	1.2	3.0	0.03%
Transportation, Communications, and Utilities	11.6	28.7	0.31%
Cropland and Pasture	321.8	795.2	8.47%
Reservoirs	0.1	0.3	<0.01%
Nonforested Wetland	0.4	1.0	0.01%
Strip Mines, Quarries, and Gravel Pits	1.6	4.0	0.04%
Ash Leaf Maple (Box elder)/Choke Cherry Forest	2.8	6.9	0.07%
Grass / Shrub Complex	75.5	186.6	1.99%
Ponderosa Pine Complex I	2270.5	5610.5	59.73%
Ponderosa Pine Complex II	1099.3	2716.4	28.92%
Quaking Aspen/Choke Cherry Forest	15.9	39.3	0.42%

Table 5. Land use/cover within JECA boundaries (Salas and Pucherelli 1998).

Land use/cover	Area (ha)	Area (ac)	Percent Composition
Ash Leaf Maple (Box elder) / Choke Cherry Forest	2.8	6.9	0.13%
Grass / Shrub Complex	28	69.2	1.31%
Ponderosa Pine Complex I	1,404.8	3,471.3	65.93%
Ponderosa Pine Complex II	670	1,655.6	31.45%
Residential	0.5	1.2	0.02%
Commercial and Services	2.1	5.2	0.10%
Transportation, Communications, and Utilities	9.5	23.5	0.45%
Cropland and Pasture	13	32.1	0.61%

The NPScape project offers a representation of general LCLU and LCLU change in the area within JECA and 30 km surrounding JECA using a reclassification of the 2001 NLCD (Plate 3; Homer et al. 2004). The LCLU categories reclassified for this analysis (Table 6) show that these broad, coarse resolution land cover data indicate recent broad changes in land cover classes in the area. For example, the NPSscape Natural versus Converted land cover data can generalize areas that are more highly influenced by impervious surfaces (such as urban areas and roads) as Converted, and generalize areas that may be nearly completely vegetated as Natural. However, this Natural category does not account for important ecological changes that may have occurred in plant species diversity, plant community composition and structure, and plant species nativity (i.e., native vs. nonnative plant species). Further, the NLCD does not identify livestock grazing as a land use and therefore does not capture it as Converted land, thus missing any associated ecological costs of this land use.

Table 6. 2001 National Land Cover Database (NLCD) reclassification to NPScape land cover "natural vs. converted" (LNC) classes (NPS 2010a).

NLCD Land Cover Class	NPScape Land Cover Class
11 Open Water	2 Natural
12 Perennial Ice/Snow	2 Natural
21 Developed, Open Space	1 Converted
22 Developed, Low Intensity	1 Converted
23 Developed, Medium Intensity	1 Converted
24 Developed, High Intensity	1 Converted
31 Barren Land	2 Natural
32 Unconsolidated Shore	2 Natural
41 Deciduous Forest	2 Natural
42 Evergreen Forest	2 Natural
43 Mixed Forest	2 Natural
51 Dwarf Scrub	2 Natural
52 Scrub/Shrub	2 Natural
71 Grassland/Herbaceous	2 Natural
72 Sedge Herbaceous	2 Natural
73 Lichens	2 Natural
74 Moss	2 Natural
81 Pasture/Hay	1 Converted
82 Cultivated Crops	1 Converted
90 Woody Wetlands	2 Natural
95 Emergent Herbaceous Wetland	2 Natural

The NPScape analysis displays categories of LCLU change from 1992 to 2001 using the NLCD change product (Plate 5) (NPS 2010a). The map reveals some areas changed from Natural to Agriculture (areas in pink on the map) and from Converted to Natural land cover classifications (areas in blue on the map). The composition of this change classification in JECA and 30 km surrounding JECA were documented (Table 7).

Table 7. Land cover change in and around (30 km buffer) JECA, 1992-2001 (NPS 2010a).

Class Name	Total Area ha	ac	Percent Composition
Converted	4,185.94	10,343.7	1.35%
Natural	30,4832.2	753,256.8	98.36%
Natural to Agriculture	676.25	1671.0	0.22%
Natural to Urban	179.7	444.0	0.06%
Converted to Natural	47.7	117.9	0.02%

The original NLCD 1992 to 2001 change data (Fry et al. 2009) indicate a significant area in JECA changed from land cover classes of Forest to Grassland/Shrub, and a small area changed from Forest to Urban (Table 8). These data indicate that according to Anderson Level I land cover classes, more than 13% of JECA's land surface changed from 1992 to 2001. Additionally, large areas immediately adjacent to JECA changed from Forest to Grassland/Shrub (note the areas in pink to the southwest, northeast, and southeast corners of JECA in Plate 6).

Table 8. National Land Cover Database (NLCD) land cover change area and percent composition in JECA, 1992–2001.

Land cover class/change class	Total area (ha)	Total area (ac)	Percent of total area	Percent of change area
Urban	28.7	70.9	5.6	--
Forest	270.2	667.6	52.3	--
Grassland/Shrub	149.8	370.1	29.0	--
Changed: Forest to Urban	0.7	1.8	0.1	1.1
Changed: Forest to Grassland/Shrub	66.9	165.2	13.0	98.9
Totals:	516.2	1,275.7		

Regional land cover change from 1992 to 2001 is depicted by using NPScape's area of analysis (AOA), a 30 km buffer of JECA. The AOA covers a 3,099 km^2 (1,196 mi^2) area. The vast majority of land cover in this area in 2001 was Forest (53%) followed by Grassland/Shrub (44%). The change classification was almost dominated by change from Forest to Grassland/Shrub land cover classes (Table 9).

Table 9. National Land Cover Database (NLCD) land cover area and percent composition in NPScapes AOA (30 km buffer of JECA), 1992–2001.

Land cover class	Total Area (ha)	Total area (ac)	% of total area	% of total change
Open Water	136	336	0.04	NA
Urban	2,859	7,064	0.92	NA
Barren	561	1,386	0.18	NA
Forest	164,660	406,882	53.13	NA
Grassland/Shrub	122,194	301,948	39.43	NA
Agriculture	1,390	3,435	0.45	NA
Wetlands	1,515	3,743	0.49	NA
Land cover class change				
Open Water to Grassland/Shrub	3	7	0.00	0.02
Open Water to Wetlands	1	3	0.00	0.01
Barren to Urban	0	0	0.00	0.00
Barren to Grassland/Shrub	2	4	0.00	0.01
Forest to Open Water	3	6	0.00	0.02
Forest to Urban	159	393	0.05	0.96
Forest to Barren	9	21	0.00	0.05
Forest to Grassland/Shrub	15,002	37,070	4.84	90.32
Forest to Agriculture	517	1,279	0.17	3.12
Forest to Wetlands	211	522	0.07	1.27
Grassland/Shrub to Open Water	5	12	0.00	0.03
Grassland/Shrub to Urban	23	58	0.01	0.14
Grassland/Shrub to Barren	1	3	0.00	0.01
Grassland/Shrub to Forest	360	889	0.12	2.17
Grassland/Shrub to Agriculture	141	348	0.05	0.85
Grassland/Shrub to Wetlands	20	49	0.01	0.12
Agriculture to Grassland/Shrub	49	120	0.02	0.29
Wetlands to Open Water	2	6	0.00	0.01
Wetlands to Urban	2	6	0.00	0.01
Wetlands to Barren	1	1	0.00	0.00
Wetlands to Forest	7	16	0.00	0.04
Wetlands to Grassland/Shrub	51	125	0.02	0.31
Wetlands to Agriculture	41	102	0.01	0.25
Totals:	**309,924**	**765,836**		
Total change area	**16,610**	**41,043**		

Change in Ponderosa Pine Distribution and Density

Brown and Cook (2006) found ponderosa pine distribution and density in the 19th century to be more diverse than it is today. Historically, there were some areas of dense stands of ponderosa pines, as there are currently, but more commonly there were open stands of ponderosa pines that allowed trees to grow large and old (Brown and Cook 2006). Historically, natural disturbances such as fire and mountain pine beetles (*Dendroctonus ponderosae*) naturally thinned stands of small (23 cm diameter or less), densely distributed ponderosa pines, allowing only the healthiest saplings to survive and replace the large and old dying trees (NPS 2010d). In addition, burns would clear ponderosa pine seedlings from prairies, thus limiting encroachment of ponderosa pine forests into prairie areas.

Fire suppression over the last 100 years significantly altered ponderosa pines forests in the Black Hills, resulting in dense, even-aged stands of ponderosa pines with a uniform distribution across the landscape (NPS 2010d). These characteristics make them susceptible to mass mortalities from severe fires and pests such as mountain pine beetles. Mountain pine beetles are a natural part of the ecosystem that attack small, densely distributed trees, but because of the even-aged stands across the Black Hills, mountain pine beetles pose a significant threat to the ponderosa pine forests as a whole (NPS 2010d). In addition to ponderosa pine stands being more susceptible to mass mortality, the proliferation of dense ponderosa pine stands has led to conversion of much of the grassland areas into ponderosa pine forests (NPS 2010d). The expansion of ponderosa pine forests also extracts much of the nutrients and moisture from the ground, making survival difficult for other vegetation in JECA (NPS 2010d).

Overall, the density of l to 20 cm diameter-class ponderosa pine trees in the Black Hills forests increased approximately 5-fold from 1874 and 1995 (McAdams 1995). In addition, comparisons of more recent photographs to Custer's 1874 expedition photographs show encroachment of ponderosa pines into grasslands and an overall increase in ponderosa pine densities (Progulske 1974). While these qualitative observations have been recorded, more in-depth quantitative analysis of change in ponderosa pine distribution and density in JECA is difficult due to the absence of aerial imagery.

The Jasper Fire of 2000 created significant changes in the canopy of ponderosa pines in JECA and the surrounding area. The 1992 to 2001 NLCD change product data indicate that a significant area of JECA changed from Forest to Grassland/Shrub (Anderson Level I land cover classes) (pink areas, Plate 6). The changed areas appear to coincide with the Jasper Fire high severity areas (Plate 9).

<u>Threats and Stressor Factors</u>

An NPScape examination of all roads within 30 km of JECA using ESRI Streetmap data reveals a dense network of roads (NPS 2010b). A subsequent analysis using this road layer shows patch area between roads (>500 m from the nearest road), illustrating that road density may prevent landscape level land preservation, as Fertig and Oblad (2000) suggest (Plate 7) (NPS 2010b). This analysis treated all roads equally when creating the roadless patch areas, but in reality, roads vary widely in size and use intensity and therefore would likely vary in their effects related to habitat fragmentation. Despite this, roads cause fragmentation of natural landscapes and are viewed here as a stressor to land cover in the area surrounding JECA.

Cattle grazing adjacent to and within JECA are a threat to the land cover because fencing is inadequate (Marriott and Hartman 1986). Cattle damage native plant communities by shifting plant community structure and by removing plant growth. In addition, soil disturbance by cattle creates establishment sites for nonnative and invasive plants. Cattle occasionally migrate into JECA from nearby USFS allotments, and in 1985, a herd of approximately 20 cattle moved into

JECA and stayed for several weeks. This short period was long enough for the herd to graze and trample grassland vegetation to ground level (Marriott and Hartman 1986). Since 1985, other herds of cattle have wandered into JECA for shorter durations, but the extent of the damage has not been recorded and was likely not significant (R. Ohms and M. Wiles, pers. comm., 2011).

Fires are important, naturally occurring events in the Black Hills and Great Plains. A generally accepted ecological concept regarding western North American ponderosa pine forests is that frequent surface fires maintain open forest stands dominated by large, old trees (Brown et al. 2001). The natural fire regime, specifically the fire return interval, has changed since European settlement due to fire suppression, grazing, logging, and fragmentation from human development. In general, fire suppression in the Black Hills most likely led to the dominant coverage (97%) of ponderosa pine communities in JECA prior to the Jasper Fire (Marriott and Hartman 1986). One major reason for the association of ponderosa pine expansion and fire suppression is that periodic burns would normally eradicate pine seedlings from grasslands, but the lack of fire disrupts this natural process (Bock and Bock 1984, Brown and Sieg (1996, 1999) note that the reasons for longer fire intervals after major European settlement include fire suppression policies and reduced fine fuel loads because of livestock grazing, logging, and fragmentation. The reduction in fire frequency (or increases in mean fire return intervals) also causes concern for the occurrence of abnormally severe fires. In the absence of frequent fires, landscapes generally experience increases in fuel accumulation and tree density, leading to intense fires (Strambaugh et al. 2008). As discussed in the native plant communities section of this document (Section 4.3), prescribed fires are set in part to reduce fuel loads, pine density, and the risk of severe wildfires.

Mountain pine beetles are a native species to the Black Hills, and their effects represent a type of natural disturbance to ponderosa pine forests (Burkhart 2011). Just as fire plays an essential role in maintaining healthy forests, mountain pine beetles aid in restricting the expansion of ponderosa pines into native grasslands (Burkhart 2011). However, as the ponderosa pine stands have become denser and more evenly distributed, the uniformly sized trees become more susceptible to epidemic mountain pine beetle outbreaks. The areas at particular risk are patches that have not experienced fire in the last 30 years (Burkhart 2011). Although mountain pine beetles are a natural part of the Black Hills ecosystem, their effects have been exacerbated by fire suppression.

In late 2010, 92 trees scattered across 16.2 ha (40 ac), north of U.S. Highway 16 in JECA were discovered to have infestations of mountain pine beetle. To treat the infested trees, the park had them cut, limbed, and chunked in March 2011. The chunks were rolled over in late May to ensure complete drying of the wood to kill the mountain pine beetle larvae (M. Wiles, pers. comm., 2011). The infestation of 92 trees is likely not a scale sufficient to change land cover type, but a large infestation could cause broad land cover changes over time.

Ponderosa pine forests have the ability to draw extremely large amounts of water from the soil. The proliferation of ponderosa pine forests in JECA since the 1800s has resulted in a significant decrease in soil moisture, lowering the soil-water profile and resulting in a lack of surface water flow. Park staff suspect this may have an impact on infiltration into the cave, thus disrupt the natural hydrologic processes of Jewel Cave. Changes in cave infiltration are discussed in length in Section 4.7 of this document.

Data Needs and Gaps

An updated land cover map comparable to the Salas and Pucherelli (1998) map would provide much higher resolution land cover change information than that currently offered by datasets such as the NLCD. A comparable map would use infrared aerial photography at a 1:16,000 scale and apply the same classification system. In addition, remapping of the area would facilitate a quantitative analysis of the effects of the Jasper Fire (August 2000) on the land use/cover in JECA. To depict important aspects of LCLU dynamics, the standard operating procedures offered in NPS (2010a) can be applied to high resolution vegetation such as the GIS data from Salas and Pucherelli (1998). These map data, however, are likely out of date because of changes that have occurred across JECA, primarily from fire effects (both wildfire and prescribed fire). An update to this map information would provide a more current understanding of these metrics in JECA. JECA is currently working on updating a vegetation map using 2010 NAIP imagery.

NLCD data provide insight to broad land cover composition and land cover change. NLCD 2006 data and 2001 to 2006 NLCD change data have recently become available as provisional data for download via the Multi-Resolution Land Characteristics Consortium website (Fry et al. 2011). These data were not included in this assessment due to the time constraints, but could provide additional and more current understanding of broad land cover changes in and around JECA in the future.

A protocol for reporting and measuring LCLU as a Vital Sign is not yet developed. A fully developed protocol would aid in creating consistency and specificity for this topic for network park units. It could also inform management within JECA and, in some cases, provide information valuable for coordinating conservation efforts with outside groups, especially those managing land surrounding JECA.

Overall Condition

Overall, land cover in JECA is of low to moderate concern. Some evidence suggests that an increase in overall ponderosa pine composition is a natural phenomenon, free of human influence (Marriott and Hartman 1986). However, several years of fire suppression, logging, mining, and livestock grazing have most likely caused changes on the landscape in and around JECA. Fire suppression, logging, and cattle grazing still continue on lands surrounding JECA. Many of the ecological effects of these human influences are not quantifiable using common landscape scale LCLU mapping classification methods, but in general, they have likely led to even-aged stands of ponderosa pines, the spread of invasive plants into native plant communities, and the loss of grassland due to ponderosa pine encroachment.

The Jasper Fire changed the ponderosa pine composition and extent in and around JECA. Prior to the Jasper Fire, ponderosa pines accounted for 97% of land cover within the JECA boundaries (Salas and Pucherelli 1998). NLCD 1992 to 2001 change data (Fry et al. 2009) indicate that 5% of the land area within 30 km of JECA changed from Forest to Grassland/Shrub land cover classes, accounting for 90% of the total change area. Within JECA approximately 13% of the park changed from Forest to Grassland/Shrub land cover classes, accounting for nearly all of the land cover class change. After preliminary examination of aerial photography, park staff determined that the percentage of ponderosa pine land cover in 2010 (post-Jasper Fire) has been reduced to 44% (R. Ohms, pers. comm., 2011).

Sources of Expertise

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Mike Wiles, JECA Chief of Resource Management

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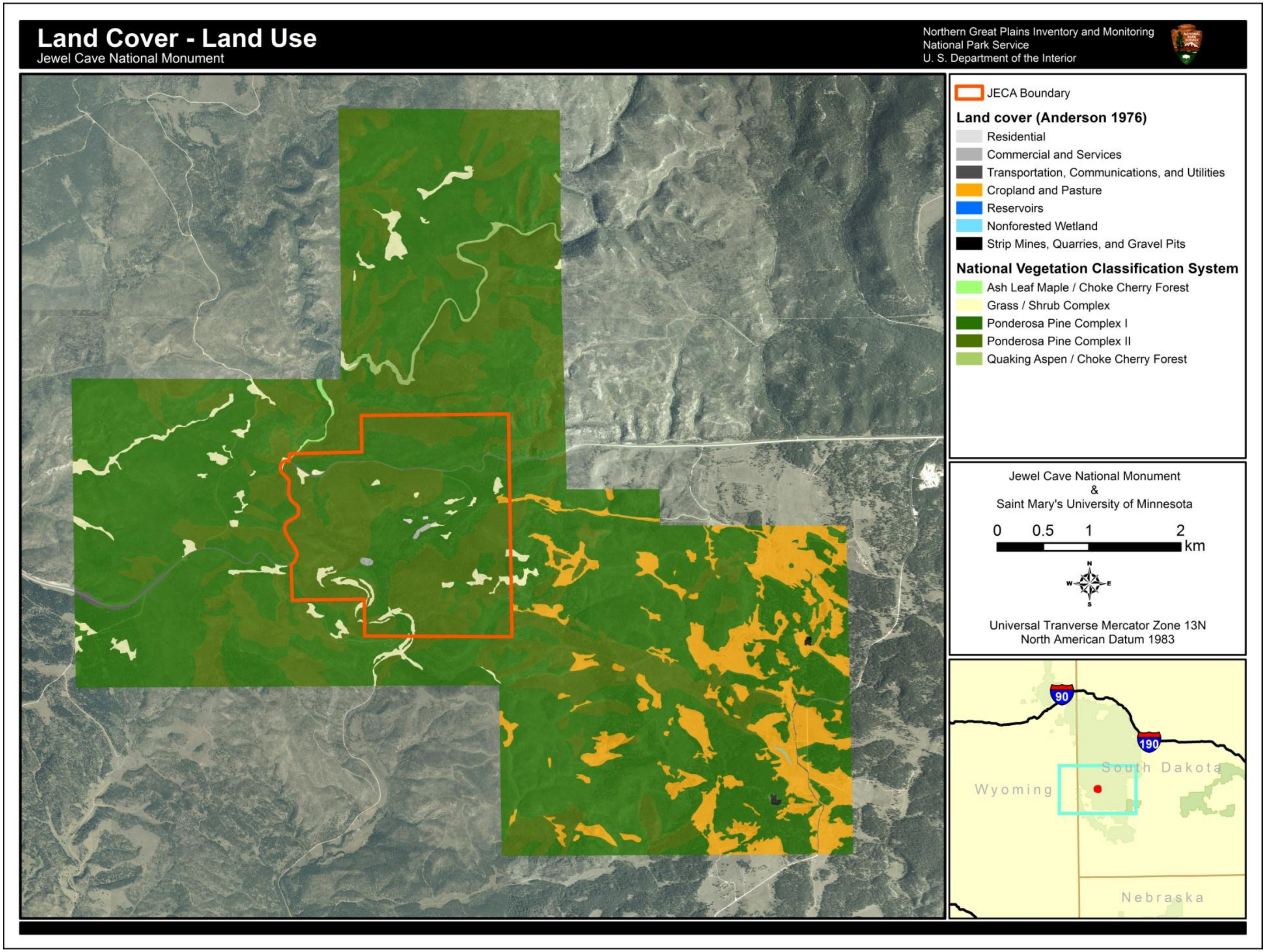

Plate 2. Land cover (vegetation classification) and land use in JECA and immediate surrounding area (Salas and Pucherelli 1998).

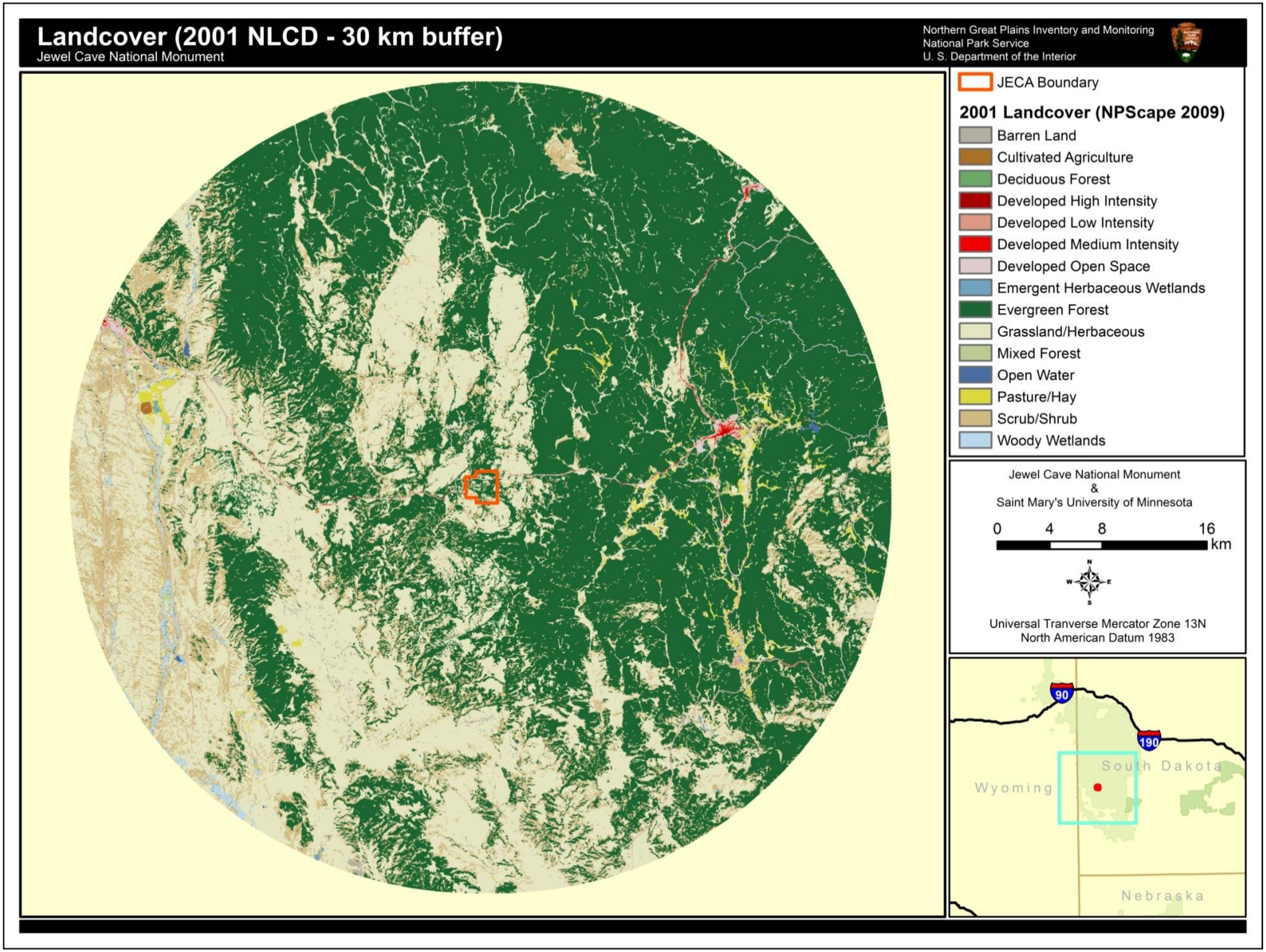

Plate 3. NPScape land cover in JECA and 30 km buffer (Homer et al. 2004; NPS 2010a).

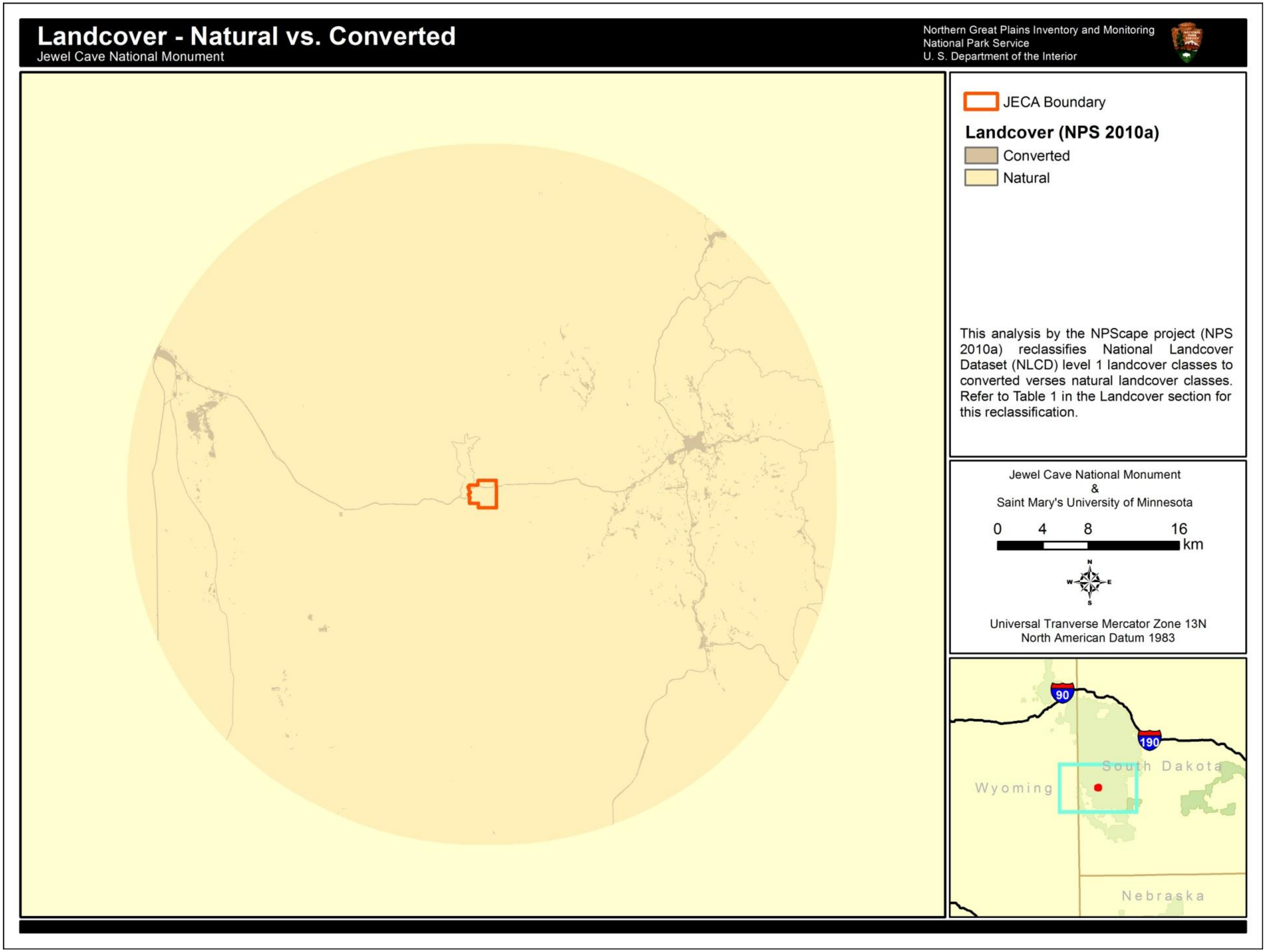

Plate 4. NPScape land cover change (natural vs. converted) in JECA and 30 km buffer (NPS 2010a).

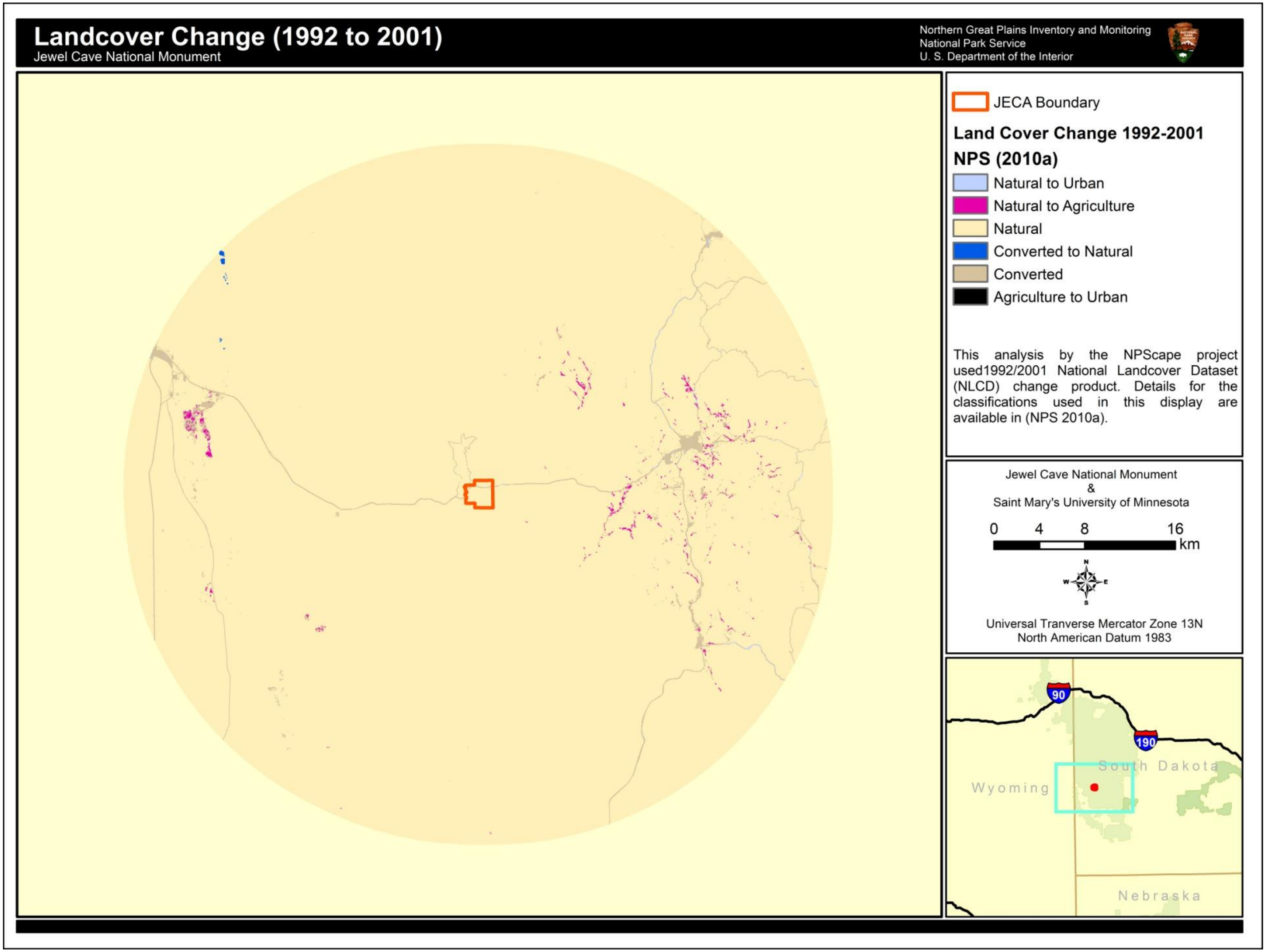

Plate 5. Land cover change within a 30 km buffer of JECA (NPS 2010a).

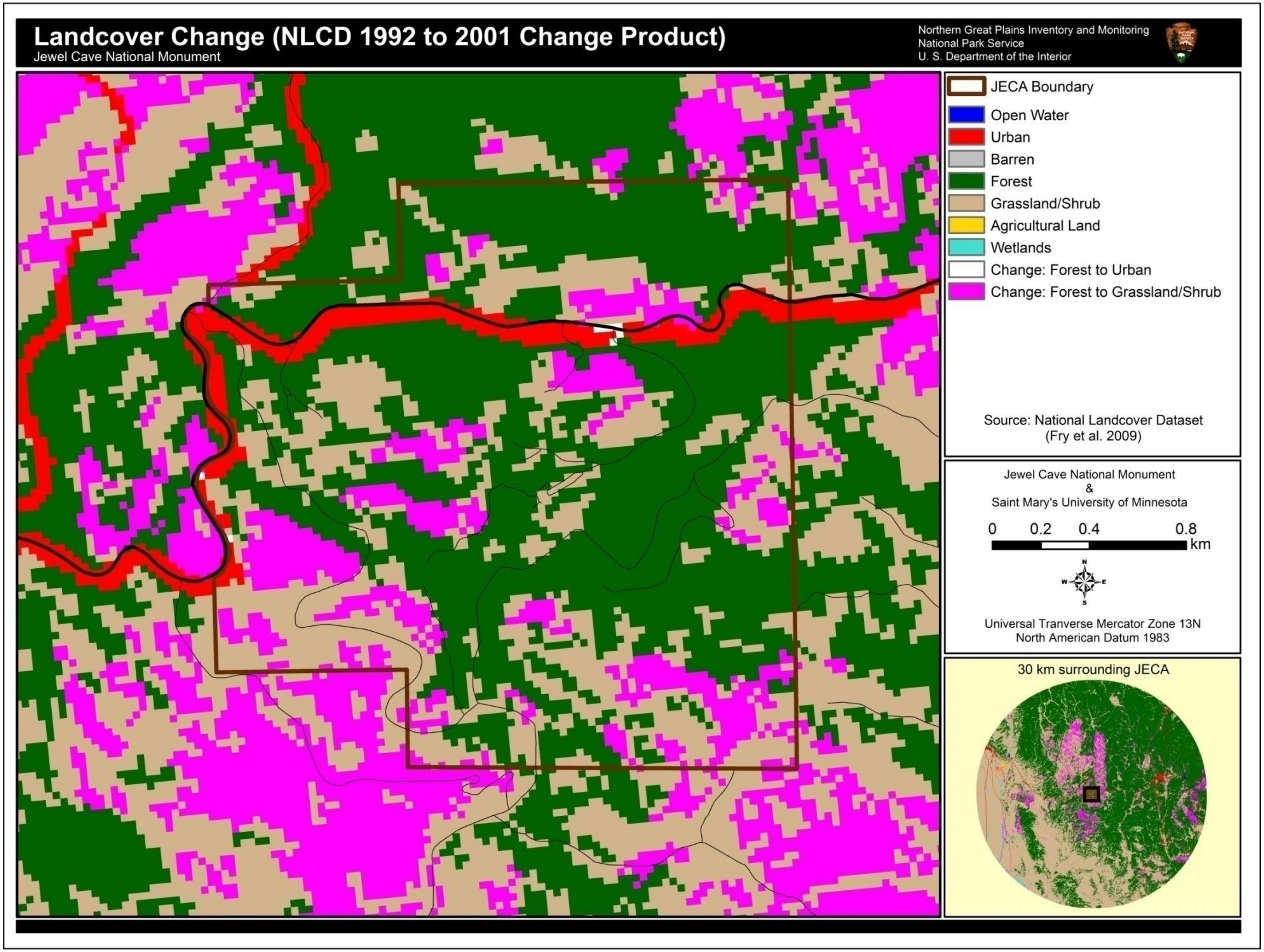

Plate 6. Land cover change in JECA (NLCD 1992 to 2001 Change Product; Fry et al. 2009).

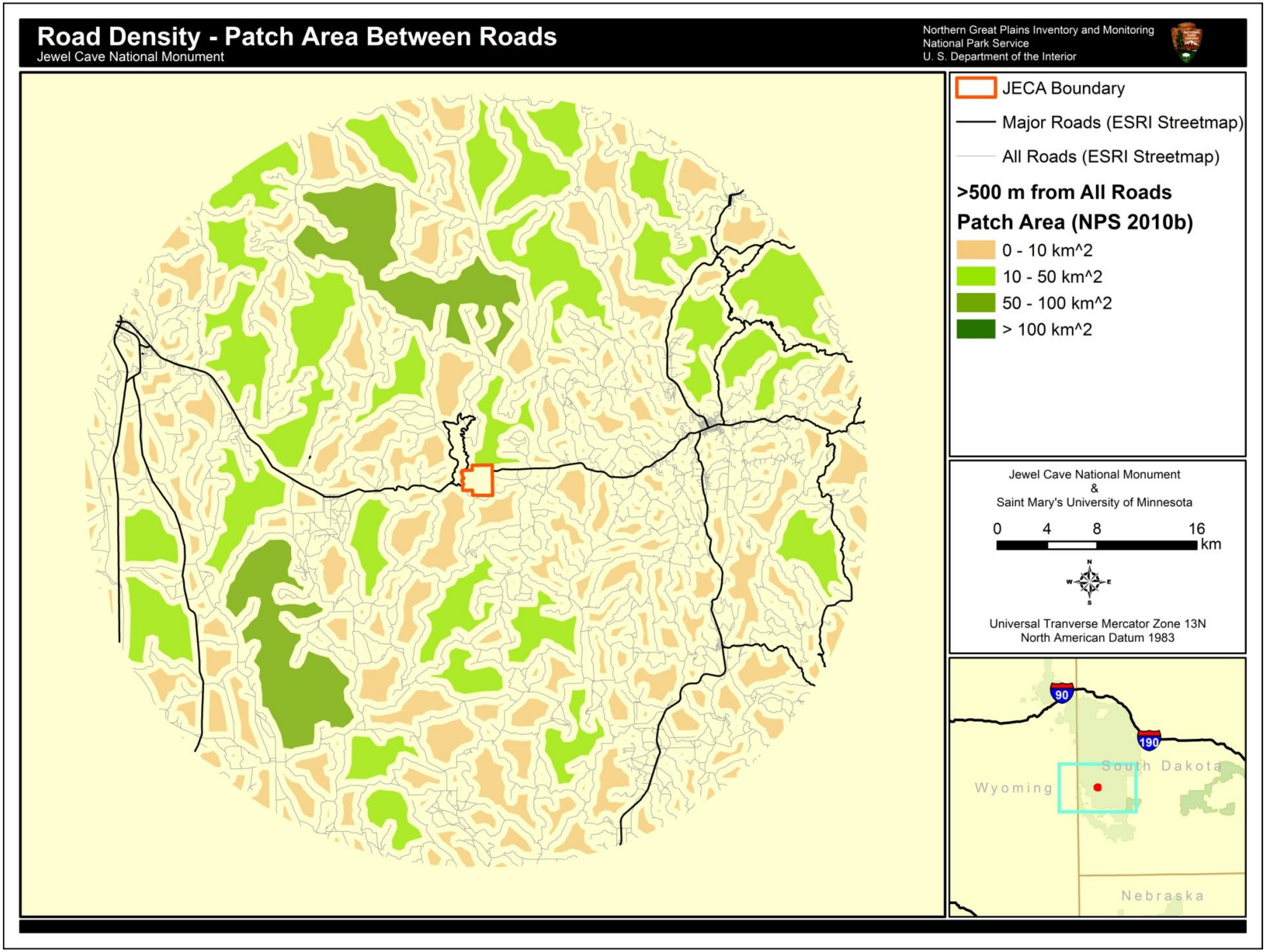

Plate 7. Roadless patch area in JECA, >500 m from nearest road (NPS 2010b).

4.2 Fire

Description

The NPS Fire Management Program defines fire regime as the combination of frequency, predictability, intensity, seasonality, and size characteristics of fire in a particular ecosystem (NPS 2004). Fire was a critical ecological process that influenced both the composition and structure of plant communities in western North America until the widespread settlement by non-Native Americans in the mid- to late 19th century (Brown and Sieg 1996). During presettlement times, fires were generally light (low intensity and severity), frequent (i.e., short fire return interval) surface fires in the Black Hills (NPS 2004). Following European settlement in the late 1800s, landscape scale fires became virtually nonexistent (Brown and Sieg 1996). Fire exclusion caused land cover change; ponderosa pines expanded into the prairie, displacing mixed-grass prairie communities and hardwood trees, and increasing the density of younger, even-aged pine trees in forest stands.

In the Black Hills, years of fire suppression, a long history of intensive timber harvest, and grazing by nonnative herbivores resulted in (1) overstocked patches of saplings and pole-sized trees; (2) reduced tree growth and increased mortality, especially of the older trees in a stand; (3) stagnated nutrient cycling; (4) increased irruptions of insects and diseases; (5) higher fuel loads, including increased vertical fuel continuity ("ladder fuels"); (6) decreased stream flows; and (7) less wildlife habitat for species dependent upon herbaceous vegetation (Brown and Sieg 1996). This, along with favorable conditions for regeneration throughout the 20th century, increased the potential for large-scale fires (Brown and Sieg 1996), such as the Jasper Fire. The Jasper Fire occurred August 2000, starting just west of JECA and burning 33,795 ha (83,508 ac) in the southern Black Hills and approximately 95% of the land area within the JECA boundaries (NPS 2010b). Photo 4, shows a ponderosa pine community along the trail to the Lantern Tour Route, ten years post Jasper fire.

The Jasper Fire altered many ecological processes. The fire destroyed 54% of JECA's total forested area, and mortality exceeded 60% with additional losses (M. Wiles, pers. comm., 2011). It removed canopy vegetation, litter, and duff, and increased the water repellant layer in the soil, leading to increased surface runoff and associated sediment yields (Parenti 2001). The effects of the fires such as the Jasper Fire on hydrologic processes diminish each year for the first 7 years following the fire, but complete watershed recovery can take up to 20 years (Parenti. 2001).

Butler (2007) found the Jasper Fire initially created higher species richness and more broad vegetation community types. However, it also created a landscape that appeared more homogeneous because of increases in plants like Canada thistle and Kentucky bluegrass (*Poa pratensis*); communities began to look more alike, blurring the visible lines between vegetation community types (Butler 2007). The Jasper Fire greatly reduced shrubs, such as ninebark and juniper (*Juniperus communis*) and significantly increased the weedy herbaceous vegetation throughout different vegetation community types. However, the resulting patchwork of burned and unburned ponderosa pine forest in JECA may contain more habitat for a suite of bird species that may have been less common or absent in the park prior to the fire (Panjabi 2002).

Photo 4. Ponderosa pine community burned by the Jasper Fire.

Measures

- Return interval (time between two successive fires within JECA)
- Extent (area of fires over time)
- Severity (the degree of environmental change caused by fire. For example, physical and chemical changes to the soil, conversion of vegetation and fuels to inorganic carbon, and structural or compositional transformations that bring about new microclimates and species assemblages) (Key and Benson 2006)
- Reference Conditions

Fire-return Interval

Brown and Sieg (1996) found high variance in JECA fire intervals, making an average fire interval "difficult to estimate" in JECA (Brown and Sieg 1996 p. 103). They examined 57 trees and 448 fire scars (dated from 1388 to 1900), and the resulting average fire interval was 16 years ± 14 (Table 10). Even with longer presettlement fire intervals, the area's forests are not burning in present day nearly as often as they did in the past, and the data (Table 10) offer both guidelines and justification for an on-going prescribed burn program at JECA (Brown and Sieg 1996).

Table 10. Number of fire intervals, mean fire intervals (MFI±SD), and ranges of fire intervals at four sites and all sites combined in JECA, using all detected fire dates. All sites combined are intervals between fire years recorded at any of the four sites. B. Number of fire intervals (MFI±SD) and ranges of fire intervals at four sites and all sites combined, using fire dates recorded when sample depth ≥2 trees and fire index (or percentage of trees recording a fire in that year) ≥25% (i.e., using dates in middle portions of the range of dates). Reproduced from (Brown and Sieg 1996).

A. Site	**Period**	**No. Fire Intervals**	**MFI (yr)**	**Range (yr)**	**B. Site**	**Period**	**No. Fire Intervals**	**MFI (yr)**	**Range (yr)**
JCS[1]	1597–1900	13	22±23	7–93	JCS	1684–1890	9	23±23	7–79
JCE[2]	1591–1890	13	23±22	1–77	JCE	1668–1890	11	20±15	5–47
JCN[3]	1576–1890	16	20±14	4–45	JCN	1663–1890	11	21±13	6–45
JCC[4]	1388–1890	22	23±18	1–63	JCC	1668–1890	7	32±12	9–47
ALL SITES	1388–1900	34	16±14	1–45	ALL SITES	1576–1890	16	20±14	1–45

[1]Jewel Cave South

[2]Jewel Cave East

[3]Jewel Cave North

[4]Jewel Cave Central

Extent

Synchronous fire scars measured in a fire history study by Brown and Sieg (1996) indicate that fires at JECA were at times extensive enough to burn the entire surface of the present-day JECA. However, some fires scars within a given season may represent different fires, and differences in spatial patterning of fires may have been due to natural fire breaks. Areas such as Hell Canyon north of Hwy 16 and Lithograph Canyon south of JECA headquarters apparently acted as fire breaks during some fire years (Brown and Sieg 1996).

Severity

Brown and Sieg (1996) indicate that prior to land use changes, relatively low-intensity surface fires were frequent and widespread in Black Hills ponderosa pine forests. However, pith dates (year of tree establishment) suggest stand-establishing events occurred in the JECA area in the mid-1500s and again in the early 1600s. These stand-establishing events may have been from high severity, stand-replacing fires.

The timing of fires (seasonality) is another factor that may correlate with fire severity. Brown and Sieg (1996) found that the majority of fire scarring in JECA occurred from July through August, consistent with findings of Higgins (1984); most lightning-ignited fires occurred in July and August in the Northern Great Plains grasslands and pine savannas.

Current Conditions

Fire-return Interval

An unnaturally long fire interval occurred from 1890 to 1994, more than double the longest interval found from 1550 to 1890 (Brown and Sieg 1996). According to NPS fire perimeter data, burned area was minimal in JECA from 1980 to 1999, and only a few prescribed fires have occurred since the 2000 Jasper Fire (Figure 3 andFigure **4**) (NPS 2010a). Following the Jasper Fire, the NGPN fire management program waited eight years before implementing another prescribed fire to allow accumulation of fine fuels, the primary carrier of fire. Although mechanical thinning of ponderosa pines does not provide an equivalent substitute for all fire effects, the JECA fire management plan indicates that fuel reduction occurred in the 1980s and mid-1990s through this method.

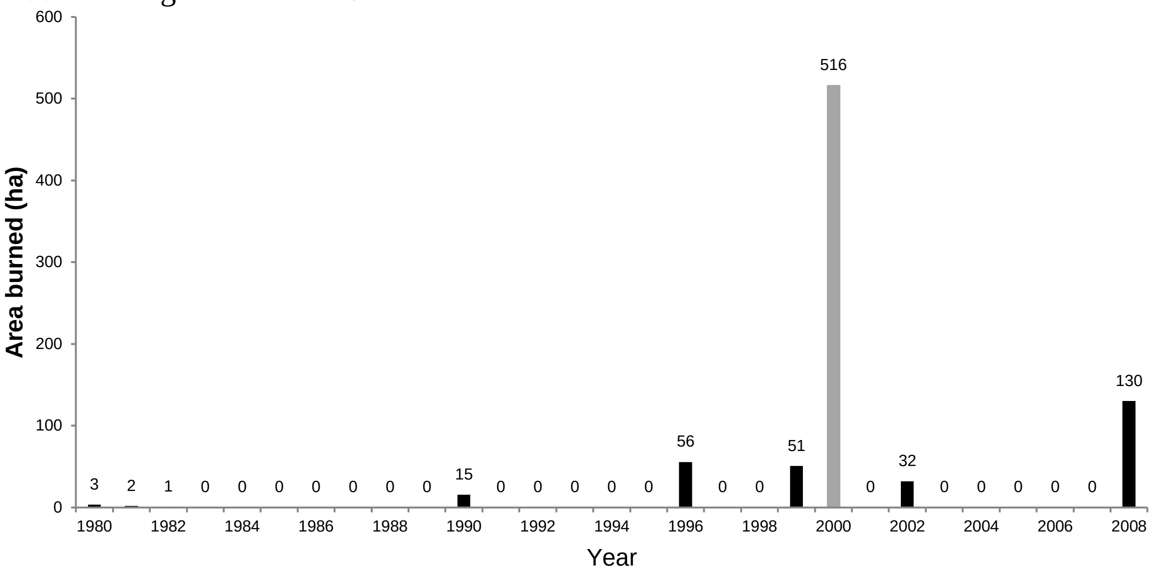

Figure 3. Annual fire area in JECA from 1980–2008 (NPS 2010a). Note: All areas are rounded to the nearest hectare by year. While the spatial data indicate the Jasper Fire burned all of JECA, the 2000 fire season area estimate (in gray) is based on the Jasper Fire burning approximately 95% of JECA land area as indicated in NPS (2004). Fires <0.1 ha occurred in 1987, 1991, and 2006.

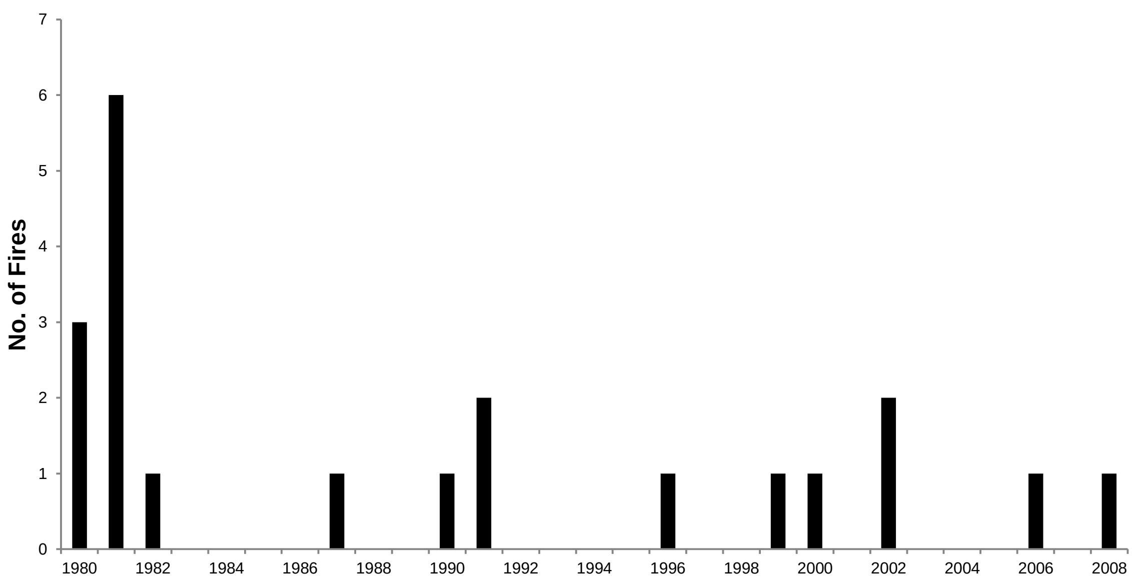

Figure 4. Number of recorded fires by year in JECA from 1980 to 2008 (NPS 2010a).

<u>Extent</u>

Spatial data from 1980 to 1999 indicate that 128 ha (316 ac) of JECA burned before the extensive Jasper Fire of 2000 (NPS 2010a). Since the Jasper Fire, 239 ha (590 ac) or 46% of

JECA has burned under prescription (NPS 2010a). During 2002, in an effort to reduce fuel loads, the NPS used prescribed fires to burn piles of coarse woody debris along U.S. Hwy 16. Then, on 30 October 2008, the NPS conducted a 130 ha (321 ac) prescribed burn, called the Hilltop Fire, in the central portion of the JECA (Plate 8). The Lithograph prescribed fire, 77 ha (190 ac), was conducted last fall (21 September 2010) in the eastern portion of JECA.

Severity

The size, occurrence, and severity of wildfires have increased in dry, low-elevation, ponderosa pine forests in the Black Hills (Lentile et al. 2006). The Jasper Fire in and around JECA offers a recent example of a large fire with a patchy mosaic of burn severity, with 24, 48, and 27% classified as low (surface fire), moderate (mixed surface fire and torching), and high (stand-replacing) severity, respectively (Lentile et al. 2006). The area of the Jasper Fire that burned specifically within JECA is also of mixed severity (Plate 9).

High severity fires threaten native plant communities because they can increase erosion, create seedbeds that encourage invasive plant establishment, and ultimately slow soil and native vegetation recovery. Lentile et al. (2006) recognize that mixed severity fires are complex in their effects across the landscape, and that high stand densities and high canopy bulk density were positively correlated to high burn severity in this fire (Lentile et al. 2006). High severity fires can leave accumulations of large woody fuels and present a risk of fires of increased severity in the future (Lentile et al. 2006). Recent prescribed burns in JECA attempted to reduce fuel loads, thereby lessening the risk of future high severity fires. The 2008 Hilltop Fire achieved a 35% decrease in 1,000-hour fuel loading and a total fuel load reduction of 39% (Figure 5). This was short of the goal to achieve a 70–90% reduction in total fuel loading; however, it was a first step in reducing fuel loads in a relatively large portion of JECA (NPS 2008).

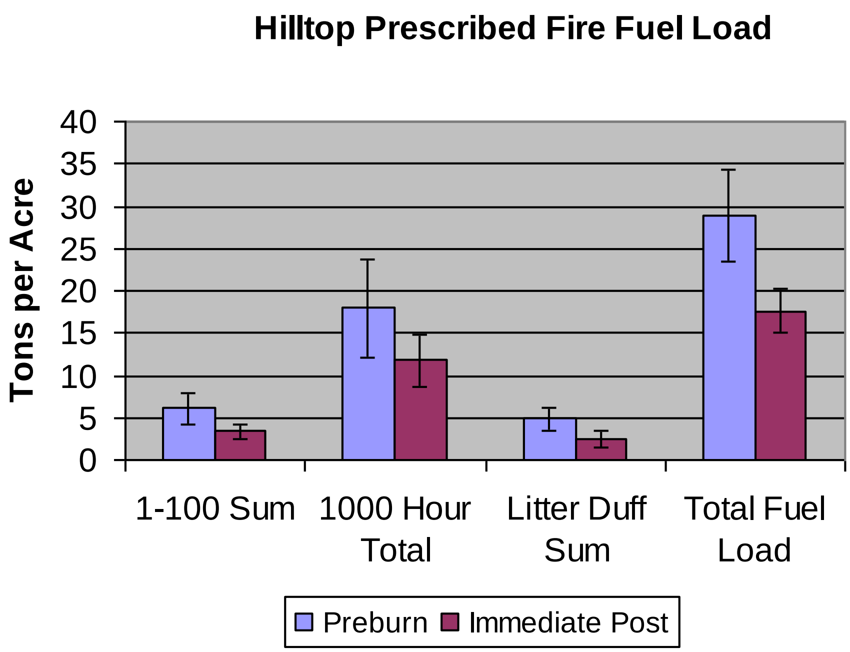

Figure 5. Pre- and post-burn fuel loading by size class for six fuel plots within the Hilltop prescribed burn unit in JECA (NPS 2008).

Threats and Stressor Factors

- Fire suppression can contribute to (1) overstocked patches of saplings and pole-sized trees; (2) reduced tree growth and increased mortality, especially of older trees in a stand; (3) stagnated nutrient cycling; (4) increased irruptions of insects and diseases; (5) higher fuel loads, including increased vertical fuel continuity ("ladder fuels"); (6) decreased stream flows; and (7) less wildlife habitat for species dependent upon herbaceous vegetation fuel loading and changes in forest structure that create ladder fuels(Brown and Sieg 1996). Brown and Sieg (1996) noted that all of these changes were present or may have been present in JECA.

- Exotic plants can out-compete native vegetation, indirectly affecting fire severity, timing, fuel loads, and potentially fire extent and fire return-intervals.

- Internal and external development can create obstacles for prescribed burns.

- Climate change effects could lead to changes in moisture content of fuels, changes in vegetation composition, and changes in the frequency and timing of lightning events.

Data Needs and Gaps

Fire's relationship to cave hydrology is not well understood and represents a potential data need for the park. Ponderosa pines are capable of pulling large amounts of water from the soil, greatly reducing soil moisture and potential water permeation into the cave's drip sites. Understanding how burning Ponderosa pine forests influences soil water extraction is important.

Understanding of fire severity following prescribed burns could lead to potential improvements in prescribed fire management. A 3-year invasive plants research project started in 2010 is ongoing at JECA, Wind Cave National Park (WICA), and Devils Tower National Monument (DETO) to investigate strategies for early detection of target invasive plants following prescribed burns. Measurements of fire severity, fuel loading, and vegetation response on a semipermanent plot basis are part of the ongoing efforts to monitor fire effects in NGPN NPS units. The effects of the Jasper Fire are still evident and being examined by this monitoring. In 1998, three monitoring plots were established and read within the Lithograph burn unit prior to the prescribed burns performed in fall 1998 and 1999. These plots also burned in the Jasper Fire and had their 10-year read in summer 2010. Additional plots were also established within the Hilltop unit (located within the Jasper Fire extent) prior to the prescribed burn in fall 2008; these plots are monitored on an established monitoring schedule.

The use of prescribed burning to control nonnative invasive plants is a developing science and requires more research to determine successful strategies that minimize negative effects on native plant communities.

Climate change may alter vegetation and fire relationships through various mechanisms, including changes in temperature and subsequent plant phenological responses and changes in the timing and amounts of precipitation. Climate change scenario planning may provide insights to fire management.

Overall Condition
The large, mixed severity Jasper Fire burned approximately 34,000 ha (83,980 ac) in the Black Hills and approximately 95% of JECA's surface in August of 2000 (Lentile et al. 2006) resulting in significant increases in ground-level coarse woody debris (mostly classified as 1,000-hr fuels) from fallen fire-killed trees (D. Swanson, pers. comm., 2010). In addition to increasing woody debris, the Jasper Fire caused substantial changes to plant communities, reducing shrubs and increasing exotic herbaceous vegetation, especially Kentucky bluegrass and Canada thistle. However, Butler (2007) expects that shrubs will begin to recover and many of the weedy plants will die off without human intervention.

The ecological process of fire is of moderate concern in JECA. Since the vast majority of the surface of JECA burned in the 2000 Jasper Fire, and the Hilltop and Lithograph prescribed fires burned approximately 46% of the surface in 2008 and 2010, the fire return interval is currently still within its historic average. However, fuel levels, especially down woody fuels, remain relatively high due to the lasting effects of the Jasper Fire. Fuel reduction by prescribed burns remains an ongoing effort in JECA, with the goal to reduce the risk of severe fires in the future.

Sources of Expertise
Mike Wiles, JECA Chief of Resource Management
Dan Swanson, Northern Great Plains Fire Ecologist for the NPS

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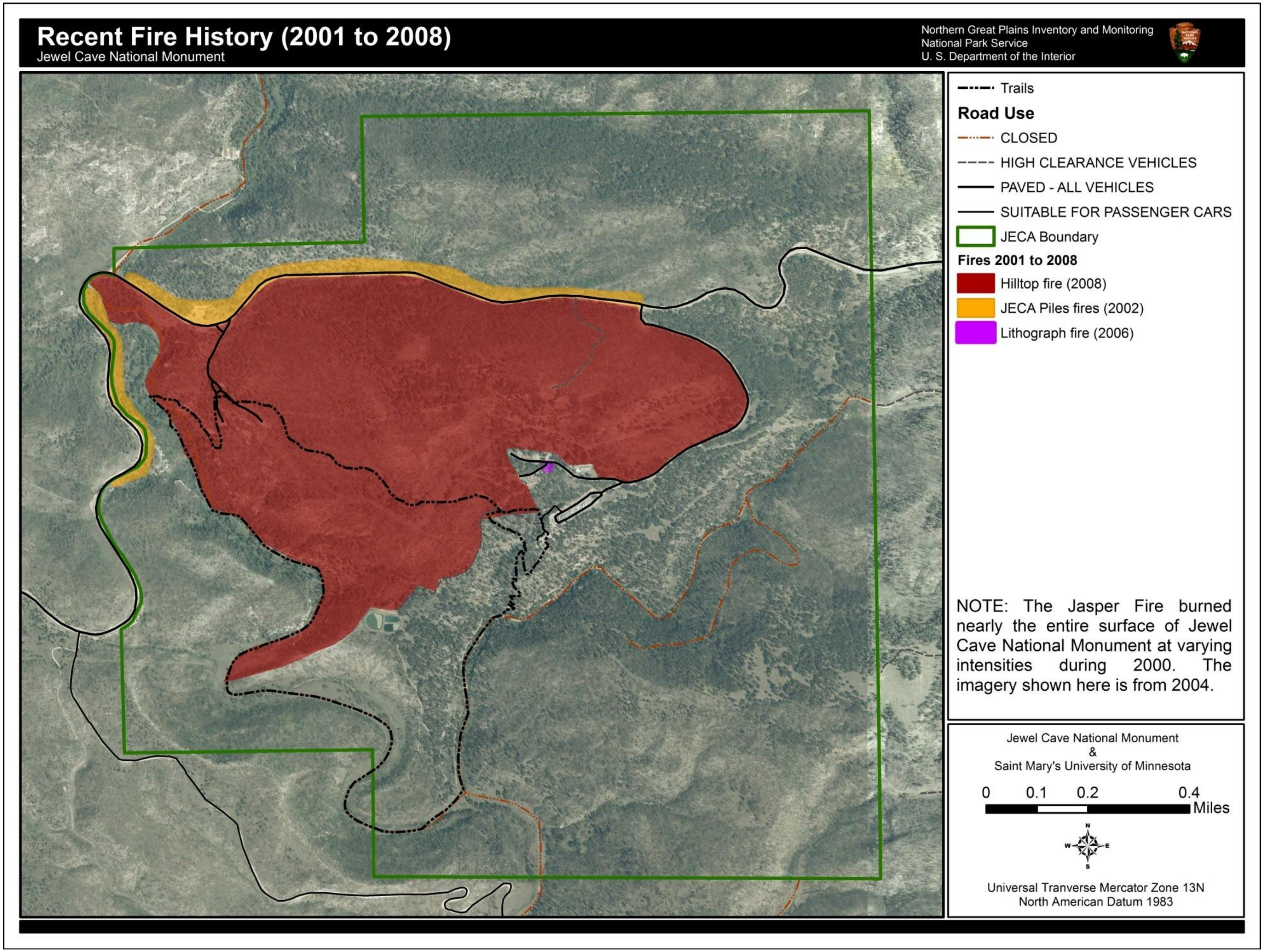

Plate 8. Fire history in JECA from 2001–2008 (NPS 2010a).

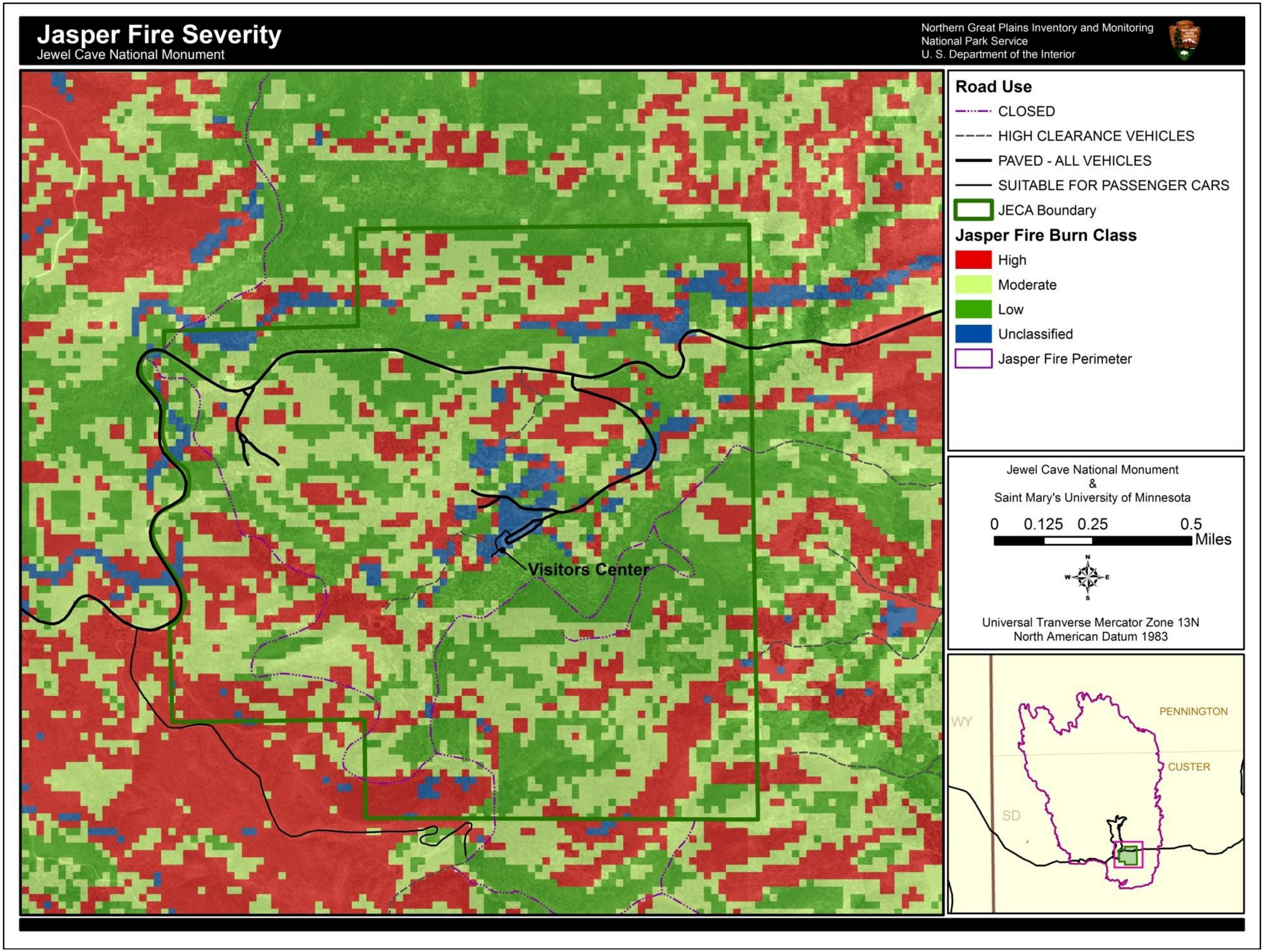

Plate 9. Jasper Fire severity and regional extent.

4.3 Native Plant Communities

Description

Most of JECA's 516 ha (1,274 ac) landscape is dominated by ponderosa pine forest communities (Marriott and Hartman 1986). Building on vegetation inventory work by previous NPS staff (Jim Shives, Penny Knuckles, and John Roth), Marriott and Hartman's (1986) vegetation survey found flora consisting of 393 taxa in 65 families. The authors note that this flora was "surprisingly diverse" considering most of JECA was forested (p. 3). Seven taxa were listed as rare in South Dakota by the South Dakota Natural Heritage Program, but their status has changed since the 1986 publication. Most are no longer considered species of concern in the state of South Dakota; however, the current status of these taxa in terms of presence and abundance, specifically in JECA, is unavailable. Refer to Appendix C for a list of these species and their state and global rankings.

Salas and Pucherelli (1998) created the vegetation map of JECA in the mid-1990s. Approximately 42 and 53% of JECA was categorized as Ponderosa Pine Complex I and II vegetation, respectively. These complexes include multiple vegetation associations (Table 11). Despite domination of ponderosa pine associations and complexes, small areas of other plant associations contribute greatly to JECA's overall plant diversity. Salas and Pucherelli (1998) defined 13 specific vegetation associations in JECA, including four forest associations, three woodland associations, three herbaceous associations, one shrubland association, one wetland community, and one disturbed community (Table 11) (Salas and Pucherelli 1998). Refer to Plate 2 for a representation of area of each vegetation association plus disturbed land cover classes mapped according to Anderson Level II land cover classes (e.g., residential, commercial) and other nonvegetated classes (e.g., bare rock).

Table 11. Vegetation associations within JECA (Salas and Pucherelli 1998).

Vegetation Associations
Ponderosa Pine / Mountain Ninebark Forest
Ponderosa Pine / Common Snowberry Forest
Ponderosa Pine / Bearberry Woodland
Ponderosa Pine / Sun Sedge Woodland
Ponderosa Pine / Common Juniper Woodland
Ponderosa Pine / Little Bluestem Wooded Herbaceous Vegetation
Quaking Aspen / Choke Cherry Forest
Ash Leaf Maple (Box Elder)/ Choke Cherry Forest
Western Snowberry Shrubland
Little Bluestem – Grama (Side-Oats, Blue) – Threadleaf Sedge Herbaceous Vegetation
Western-Wheat Grass – Blue Grama – Threadleaf Sedge Herbaceous Vegetation
Kentucky Bluegrass Disturbed Community
Sedge Dominated Wetland Community (undefined alliance)

Since mapping efforts in the late 1990s, the 2000 Jasper Fire and some prescribed fires have changed the vegetation composition in JECA. The Jasper Fire burned nearly all of JECA (over 90%) in August 2000 (NPS 2010). Quantifiable comparisons between pre- and post-fire (2002, 2003, 2004) vegetation are offered by Butler and Wacker (2007). This study specifically focused on the impacts of the fire on introduced plant species. According to a preliminary examination of 2010 NAIP aerial imagery, approximately 44% of JECA's land surface is Ponderosa Pine Complex I (P1) or II (P2) vegetation types. The 1998 Salas and Pucherelli map contained approximately 95% P1 and P2 ponderosa pine vegetation types, representing a significant reduction in ponderosa pine cover.

Butler and Wacker (2007) noted some changes in 1996 plot-level vegetation data (collected as a part of the Salas and Pucherelli 1998 mapping effort) compared with data collected in 2002, 2003, and 2004. General changes observed in the sample vegetation plots were that the actual number of broad plant community types (e.g., Ponderosa Pine/Shrub Woodland) increased from five identified by Salas and Pucherelli (1998) to seven identified in Butler and Wacker (2007). Despite the increase in the number of community types, the authors note that the Jasper Fire homogenized the appearance of the landscape by creating a lack of spatial variation, therefore blurring the lines between plant community types. The warm season grasses such as little bluestem were significantly reduced because the Jasper Fire occurred in August, whereas Kentucky bluegrass (a cool season grass) became dominant in many of the study plots.

NGPN identifies native plant communities as a high priority resource and a Vital Sign. Native plant communities act as an indicator of broad ecological change because plant community composition is affected by many of the same stressors acting on terrestrial and riparian ecosystems (Symstad 2004). The protocol for monitoring plant community composition is complete. Parameters that will be monitored beginning in 2011 include frequency and percent cover of all species and select functional groups, species richness and diversity, forest structure, and herbaceous layer vegetation height (Symstad et al. 2011). Ongoing research through the NGPN Fire Effects program and an invasive early detection research study are examining the effects of fire on invasive nonnative plant species in JECA.

In addition to a diversity of native plants, JECA also contains many nonnative plant species. In 1986, Marriott and Hartman documented forty-eight nonnative plant species, specifically noting invasive species including leafy spurge, Canada thistle, and field bindweed (*Convolvulus arvensis*). According to Marriott and Hartman (1986), these species were considered noxious weeds in Custer County. Today, South Dakota provides a state list of noxious weeds, defining them as plants that are sufficiently detrimental to the state to warrant enforcement and control measures. Noxious weeds are also listed at the local or county level; JECA refers to the Custer County list. Since 1986, the list of nonnative plant species documented in JECA has grown to 64 species (Appendix A; NPS 2007a). JECA currently has three species on the state of South Dakota noxious weeds list: Canada thistle, Russian knapweed (*Centaurea repens*), and leafy spurge; and five species in JECA are Custer County noxious weeds: houndstongue (*Cynoglossum officinale*), spotted knapweed (*Centaurea maculosa*), field bindweed, and bull thistle (*Cirsium vulgare*).

For this assessment, nonnative plant diversity, abundance, density, and distribution are examined as a way to assess the overall condition of native plant communities in JECA. NPS defines native species as those that “have occurred or now occur as a result of natural processes on lands designated as units of the national park system” (NPS 2001) defines native plants as:

> Those species that occupy or could occupy park lands directly or indirectly as the result of deliberate or accidental human activities. Exotic species are also commonly referred to as nonnative, alien, or invasive species. Since an exotic species did not evolve in concert with the species native to the place, the exotic species is not a natural component of the natural ecosystem at that place.

Measures

- Diversity (absolute and relative diversity of nonnative plant species to native plant species)
- Abundance (absolute and relative abundance of nonnative plant species to native plant species)
- Density (% cover)
- Distribution (occurrence of nonnative plants across JECA’s landscape)

Reference Conditions and Values

The reference condition for this assessment is a historic reference to a landscape prior to the introduction of nonnative species. Many nonnative plant species were introduced intentionally for food production and aesthetic purposes since settlement of the area. Other plant species have been unintentionally introduced. A landscape without any nonnative plants is not a realistic expectation for management; however, zero nonnative plants acts as a baseline for comparison of current conditions and will serve as a comparison for future conditions.

Data and Methods

The primary data sources for reporting on the status of nonnative plants in JECA include a master plant list (NPS 2007a), GIS data including nonnative plant locations (points and polygons), JECA annual exotic plant control work-plans and treatment summaries, and Northern Great Plains Exotic Plant Management Team (NGP EPMT) annual reports. These data were not manipulated beyond creating tabular and graphical summaries.

Additional plot level data were collected by fire effects monitoring over the last few years. These data were not examined for this analysis because the sample sizes were relatively small or were not necessarily representative of JECA as a whole because they were collected within a specific burn unit.

Data and conclusions from an ongoing study (data collection to end in 2012) designed to determine strategies for efficient early detection of invasive plants after prescribed fire will provide further information for the measures of nonnative plants identified in this assessment, but only for a small portion (15%) of JECA. Amy Symstad, Dan Swanson, and Wes Newton, the principal investigators for this project, are examining 20 target invasive species in the Lithograph burn unit of JECA along with a few other burn units in WICA and DETO. Along with several environmental factors (e.g., slope aspect, slope grade, position on slope, forest structure, tree canopy cover, fire behavior), they will record frequency and cover of the target invasive plant species in each sample plot.

Monitoring and Treatment Efforts

Monitoring and control of nonnative plant species are important because invasive species threaten the structural and functional integrity of natural communities (Walker and Smith 1997; Masters and Sheley 2001, as cited in Butler 2007). Likewise, nonnative plants are often viewed as stressors to native plant communities because they threaten plant species composition and community structure by direct displacement and by competing for available water and nutrients. Symstad (2004) states the abundance and diversity of nonnative plants, both absolute and relative to native species, is one of the greatest management concerns in nearly all NGPN parks. Nonnative plant species can become invasive and replace native plants, often negatively altering wildlife habitat, reducing biological diversity, and altering natural processes such as fire regimes, nutrient cycling, hydrology, and successional patterns (NPS 2005).

The NGP EPMT and JECA staff uses an integrated pest management (IPM) approach to control several species of noxious, nonnative plants in the park (NPS 2008). A variety of treatment methods are applied, including cultural, manual, mechanical, chemical, and biological control, depending on parameters such as season, plant species targeted, and other considerations, including proximity to sensitive areas such as those potentially hydrologically connected to Jewel Cave. JECA has delineated a “no-herbicide treatment zone” covering nearly half of JECA’s total acreage, where pesticide treatments of nonnative plants are not allowed (NPS 2007b). This zone may be revised based upon new geological information (NPS 2007b). Treatments can also include the use of prescribed fire, but because fire effects on many nonnative plants are unknown in this system, it is only used for a few species (e.g., Kentucky bluegrass). Cultural treatments include methods such as seeding native plants and irrigation immediately following seeding. These methods help the growth of desirable native plants while decreasing the opportunities for nonnative plant growth. Mechanical treatments used to date in JECA include cutting or pulling plants and bagging seed heads. Chemical treatments involve spraying herbicides using backpack sprayers. Biological control treatments include the release of insects that feed on specific invasive plant species. For example, flea beetles that feed on leafy spurge plants have been used since 1998, and gall flies and stem-mining weevils have been used as methods to control Canada thistle.

Nonnative plant management is focused on priority species including Canada thistle and leafy spurge (NPS 2005). Field bindweed was recently removed from the state list noxious weed list and is now limited to lawn areas of JECA (R. Ohms, pers. comm., 2011). Refer to Appendix D for a list of state and local noxious weeds. JECA staff manually control nonnative species, document treated areas, and map new infestations. The NGP EPMT comes to JECA to treat nonnative plants each year, sometimes in both the spring and the fall, with the exception of 2006 to 2008, when the NGP EPMT did not visit JECA. From 2002 through 2009, either JECA staff and/or the NGP EPMT treated a variable number of acres for nonnative plants (Table 12) (NPS 2009). In 2009, the NGP EPMT and JECA staff treated over 10.5 ha (26 ac) of Canada thistle in the area of the Hilltop prescribed fire using a new herbicide called aminopyralid (NPS 2009). As of 2011, no aminopyralid has been detected in the cave, but water quality monitoring will be ongoing (NPS 2009).

Table 12. Area of nonnative plants treated and inventoried by the Northern Great Plains Exotic Plant Management Team (NGP EPMT) (NPS 2009).

	2002	2003	2004	2005	2006	2007	2008	2009	Total
Treated Areas									
hectares	0.33	32.36	32.93	0.36	---	---	---	10.59	76.57
acres	0.82	79.97	81.36	0.89	---	---	---	26.17	189.21
Inventoried Areas									
hectares	43.30	91.01	100.82	5.60	---	---	---	27.51	268.24
acres	107.00	225.03	249.13	13.83	---	---	---	67.99	662.98

JECA staff conducts the primary invasive plant control across JECA. Each summer, a seasonal crew cuts and pulls plants, bags seed heads, sprays invasive plants, and releases biocontrol insects. JECA staff maintains treatment records in both spreadsheet and GIS form. The GIS data, allow staff to revisit sites to conduct follow-up treatments and to track the treatments conducted at each specific site. Polygons are used to represent infestations >10 feet in diameter, whereas points are used to represent sites <10 feet in diameter.

Current Condition and Trend

Nonnative Plant Diversity

According to a master plant species list, approximately 16% of the total species identified in JECA are nonnative (NPS 2007a). JECA contains 323 native plant species, 64 nonnative species, and 4 species with undetermined nativity considered to be "present in the park" (NPS 2007a) (see Appendix A for a list of nonnative plant species). In addition, 16 native species and 3 nonnative species are considered "probably present." The master list also includes 70 unconfirmed natives, 2 unconfirmed nonnatives, and 36 false reports. Plant families representing the majority of the nonnative plant species considered present in the park by the master plant species list include Poaceae (16 species), Asteraceae (10 species), Brassicaceae (9 species), and Fabaceae (8 species).

Nonnative Plant Abundance

The abundance column of the JECA master plant list states "unknown" for the vast majority of nonnative plant species identified. The only "common" species as indicated by the list were Kentucky bluegrass, yellow sweet clover (*Melilotus officinalis*), and cheat grass (*Bromus tectorum*). Butler and Wacker (2007) noted particular species increased significantly in abundance following the Jasper Fire, including the nonnative Canada thistle and natives horseweed (*Conysa canadensis*), *Elymus* spp., needle-and-thread (*Hesperostipa comata*), side oats grama, snowberry, northern bedstraw (*Galium boreale*), yarrow (*Achilliea millefolium*), and cudweed sagewort (*Artemisia ludoviciana*). Butler and Wacker (2007) state that, while decreases occurred in shrubs such as mountain ninebark and common juniper following the Jasper Fire, these shrubs should begin to recover as many of the early seral weedy plants die off on their own. A new effort to update the 1999 vegetation map and some data from NGPN efforts will provide a better future understanding of the changes that have occurred since the Jasper Fire.

Other indications of nonnative plant abundance come from GIS data developed by JECA. Through 2009, 8 species have been mapped in GIS (inventoried using GPS units). According to these data, Canada thistle covers the largest area of any mapped plant species for the period of record and represents the vast majority of individual records (88%) in the GIS polygon data, followed by leafy spurge at 10% of the individual records. Therefore, further discussion of nonnative plant species density and distribution are focused on Canada thistle and leafy spurge. Other species inventoried with consistency using polygons include field bindweed, musk thistle, spotted knapweed, and Russian knapweed. Common tansy (*Tanacetum vulfare*) was noted in the GIS point data in 2008 in two locations. As of 2010, data for other species such as houndstongue, bull thistle, and common mullein (*Verbascum thapsus*) are sparse and incomplete.

Additional species that were mapped from 2001–2010 and represented as GIS points include common tansy, houndstongue, musk thistle, and spotted knapweed. The point data also indicate Canada thistle as covering the most area, followed by leafy spurge. Another species occupying a significant portion of the total mapped area was musk thistle. Although either unmapped or inconsistently collected in the GIS data, other nonnative plants of concern include common mullein and black henbane (*Hyoscyamus niger*) (NPS 2005).

Large increases in Canada thistle following the Jasper Fire in 2000 were observed in JECA. Since then (2001 to 2010), Canada thistle has continued to be prevalent in JECA. Biological and mechanical control efforts began in 1996, and a varying combination of monitoring and biological, mechanical, and some chemical control treatments have occurred each year through 2010. GPS mapping of Canada thistle began in 2001. GPS sites of infestations have been revisited since 2003, and new site locations were added and some deleted each year. GIS polygons were created for infestations larger than a 3.04 × 3.04 m (10 × 10 ft) area. According to the GIS polygons, the number of unique sites of Canada thistle has been variable, as has total area, with a maximum of 36.7 ha (90.6 ac) in 2010 (Table 13).

Leafy spurge was treated using biological controls prior to 1998. Monitoring, biological, and mechanical controls were conducted from 1998 through 2000. In 2001, chemical control efforts were added. Since then a varying mix of integrated pest management efforts were implemented in JECA (Table 14). Site numbers were first established in the 1990s, along with documentation of treatments and reporting of sites and acreage to the JECA superintendent. GPS mapping of leafy spurge began in 2001. According to annual inventory and treatment summaries, leafy spurge has been held to less than 4 acres across the park, but the number of sites has steadily increased (Table 13).

Table 13. Canada thistle and leafy spurge sites and total areas present in JECA by year, 2001–2010.

	Canada thistle			Leafy spurge		
Year	# of sites	ha	ac	# of sites	ha	ac
2001	212	17.7	43.8	26	0.5	1.2
2002	243	18.7	46.1	34	1.1	2.9
2003	234	17.9	44.2	31	1.3	3.3
2004	247	17.9	44.3	37	1.1	2.7
2005	264	20.4	50.5	37	1.1	2.8
2006	295	21.1	52.2	37	1.1	2.8
2007	327	28.5	70.3	39	1.4	3.5
2008	323	31.2	77.1	38	1.1	2.8
2009	325	34.0	84.0	41	1.2	2.9
2010	344	36.7	90.6	42	1.3	3.3

Table 14. Monitoring and control activities of Canada thistle and leafy spurge in JECA,1996–2010.

Activity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Canada thistle															
Monitoring			x	x	x	x	x	x	x	x	x	x	x	x	x
Biological Control	x	x	x	x											
Mechanical Control	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Chemical Control						x		x	x					x	x
Leafy spurge															
Monitoring				x	x	x	x	x	x	x	x	x	x	x	x
Biological Control			x	x	x	x	x						x	x	x
Mechanical Control					x	x	x	x	x	x	x	x	x	x	x
Chemical Control						x	x	x	x	x					

Nonnative Plant Density

JECA staff estimates the density of select nonnative species in JECA during field work and records the estimates in GIS polygon data. For most polygons each year, from 2002 through 2009, densities were estimated through on-the-ground observation by using four descriptive density categories (using the NGP EPMT data dictionary): trace (0–25%), light (20–50% cover), moderate (50–75% cover), and heavy (75–100% cover). Some of the older records are not categorized in the GIS data (polygons); overall, however, most of the total area infested with Canada thistle in JECA during 2010 was categorized light density, and a relatively even proportion of areas were either not categorized or categorized as heavy, moderate, or trace densities (Figure 6). Leafy spurge areas (polygons) were categorized primarily as light or trace density, with the remaining proportion of total area relatively even (noncategorized, heavy, and moderate densities) (Figure 7).

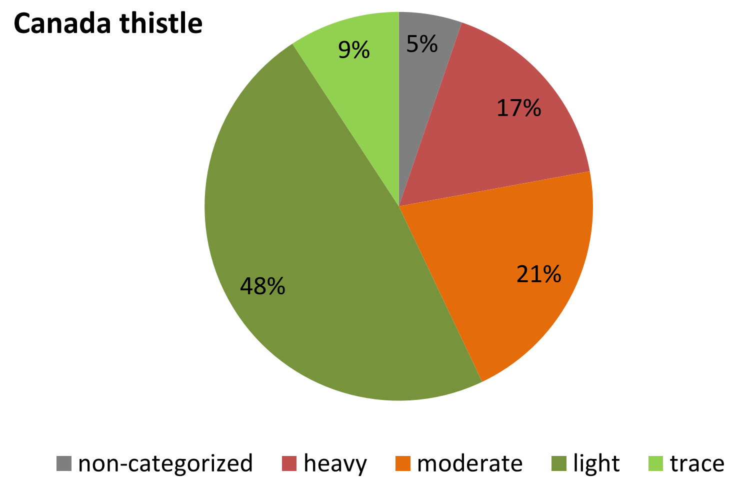

Figure 6. Percentage by area of Canada thistle densities in JECA (2010). Densities were estimated by field observation. All individual GIS records (polygons) were used for this summary.

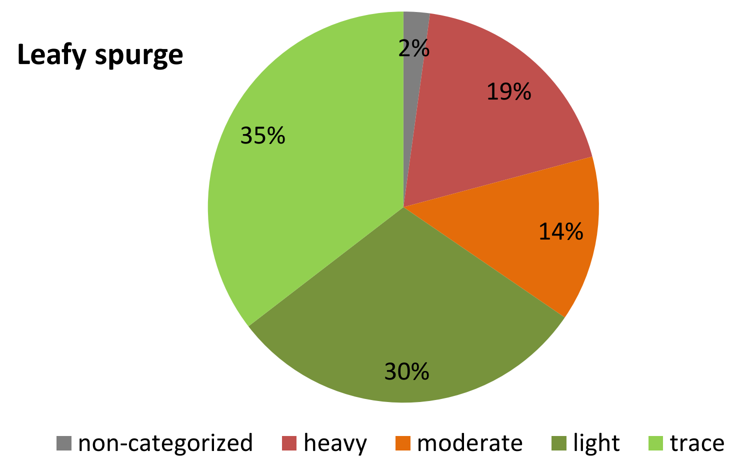

Figure 7. Percentage by area of leafy spurge densities in JECA (2010). Densities were estimated by field observation. All individual GIS records were used for this summary

Nonnative Plant Distribution

Examination of GIS data developed for the most recent year (2010), both points and polygons, indicated that Canada thistle is prevalent throughout JECA (Plate 10). Leafy spurge seems, to be more common along some of the park roads with some larger infestations in the southeast portion of JECA (Plate 10). Other invasive plants such as Russian knapweed, spotted knapweed, and musk thistle contain very few records, but the data are complete and indicate these species are not prevalent in JECA. Both spotted knapweed and Russian knapweed are relatively new invaders, first discovered along U.S. Highway 16 in 2007 and 2010, respectively. Musk thistle was first documented in 2003.

Complete park-wide inventories are not conducted every year; therefore, distribution is not necessarily representative of the actual distribution of a given species across JECA in a given year. However, Rene Ohms (pers. comm., 2011) suggests that, for the primary targeted species (i.e., Canada thistle and leafy spurge), the GIS data are largely representative of on-the-ground conditions in a given year. She also suggests that a difficulty lies in balancing limited time and monies on inventory, control, and measuring control effectiveness. The last park-wide search and inventory for invasive plants in JECA occurred during 2001 and 2002.

Threats and Stressor Factors

This section is a standard element in this document, designed to present important stressors and threats to a given valued resource. In this case, nonnative and invasive species are themselves stressors to the valued resource of native plant communities. During scoping of this project, JECA staff developed the following list of important factors that can affect the diversity, abundance, distribution, and density of nonnative plants: fire regime, climate changes, moisture patterns, potential atmospheric nitrogen deposition, and visitation.

- Fire regime (e.g., fire return interval, fire severity) may affect nonnative plant establishment. For example, an extremely severe fire resulting from large fuel accumulations could create enough disturbance to establish sites for early seral nonnative plant species. Butler and Wacker (2007) found increases in some early seral plant species such as Canada thistle after the Jasper Fire in 2000. Conversely, nonnative plants could affect fire behavior by altering fuel dynamics. For example, if the relative abundance of nonnative forbs were to prevent native grasses from becoming established, the type and amount of fuel available for fires could be altered.

- Future climate changes may alter invasive plant species mechanisms of transport and introduction, climatic constraints on invasive species, distribution of existing invasive species, the impact of existing invasive species, and the effectiveness of management strategies (Hellman et al. 2008). Temperatures in the Northern Great Plains have risen more than 1.1 °C (2 °F) in the last century (National Assessment Synthesis Team 2000), and climate models predict a temperature rise of 2.75 to 5.5 °C (5 to 10 °F), with possibly slightly more precipitation during this century (Gitzen et al. 2010).

- Atmospheric nitrogen deposition from various air pollution sources is a concern in the Black Hills. This deposition acts as a fertilizer for plants and may affect productivity of plant species differentially and, therefore, alter plant community composition (Allen et al. 2009).

- Visitation creates opportunities for nonnative plants to be spread by seeds and propagules hitch-hiking on visitors' clothing and vehicles. Visitation can also result in localized disturbances such as soil scuffing and movement along walking trails, which could establish sites for some nonnative and invasive plant species.

Data Needs and Gaps

The development of a GIS-based protocol for examining the extent, distribution, and density of nonnative plant species or infestations would allow year-to-year data comparisons. Most important, a protocol designed to monitor treatment effectiveness would aid nonnative plant management. JECA staff recognizes the time-consuming nature of a comprehensive park-wide inventory of nonnative plants to make data more comparable year to year; however, a protocol with a better planned repeat interval would inform management on the status of nonnative and invasive plant species, and thereby provide indications for the overall condition of native plant communities in JECA.

Categorizing the invasiveness of individual nonnative plant species could help JECA management focus their control efforts on plant species that may pose risks in terms of ecological harm. One example of an invasive categorization, offered for a different state and ecological context, is the plant invasiveness ranking for Alaska, developed by the USFS (Carlson et al. 2008). Another example, relevant to the Northern Great Plains, is the Alien Plant Ranking System (USGS 2011), a cooperative effort between the NPS, USGS, Ripon College, and University of Minnesota, designed to help land managers make decisions regarding invasive nonnative plants (USGS 2011). NPS (2001, as cited in NPS 2005) states that a nonnative plant must meet several criteria to be managed (control up to and including eradication):

- Interferes with natural processes and the perpetuation of natural features, native species or natural habitats; or
- Disrupts the genetic integrity of native species; or
- Disrupts the accurate presentation of a cultural landscape; or
- Damages cultural resources; or
- Significantly hampers the management of a park or adjacent lands; or
- Poses a public health threat as advised by the U.S. Public Health Service (which includes the Centers for Disease Control and the NPS Public Health Program); or
- Creates a hazard to public safety.

Information regarding the abundance, distribution, and density of nonnative plants not considered noxious weeds by the State of South Dakota (or at the county level) or known to meet the above criteria is extremely limited in JECA.

<u>Overall Condition</u>

While a return to a landscape completely free of nonnative plant species in JECA is an unrealistic expectation, the Northern Great Plains Exotic Plant Management Plan provides a guide for park managers to “reduce the impacts of (or threats from) exotic plants to native plant communities and other natural and cultural resources” (NPS 2005, p. 1–4). The continued goal is to reduce negative effects of nonnative plant species across JECA by control through integrated pest management.

Using only the measures of nonnative plant density, diversity, extent, and distribution, the condition of native plant communities is a moderate concern in JECA. In JECA, 64 nonnative plant species are known to occur, comprising approximately 16% of the total plant documented species (including native plant species). Canada thistle has emerged as the invasive species with the largest area and greatest investment in control efforts, followed by leafy spurge. Increases in the area and number of individual infestations of thistle over the last several years are noted, whereas the overall area and number of individual infestations of leafy spurge is generally stable over the last several years. Despite the observational categorization of individual invasive, nonnative plant infestations (primarily Canada thistle and leafy spurge), the overall density of nonnative plants is a data gap for this assessment.

Nonnative and invasive plants are just one aspect of understanding the status of native plant communities. Additional measures of native plant communities would help create a more holistic understanding of their overall conditions.

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Rene Ohms, JECA Physical Science Technician
Amy Symstad, Ph.D., USGS Research Ecologist

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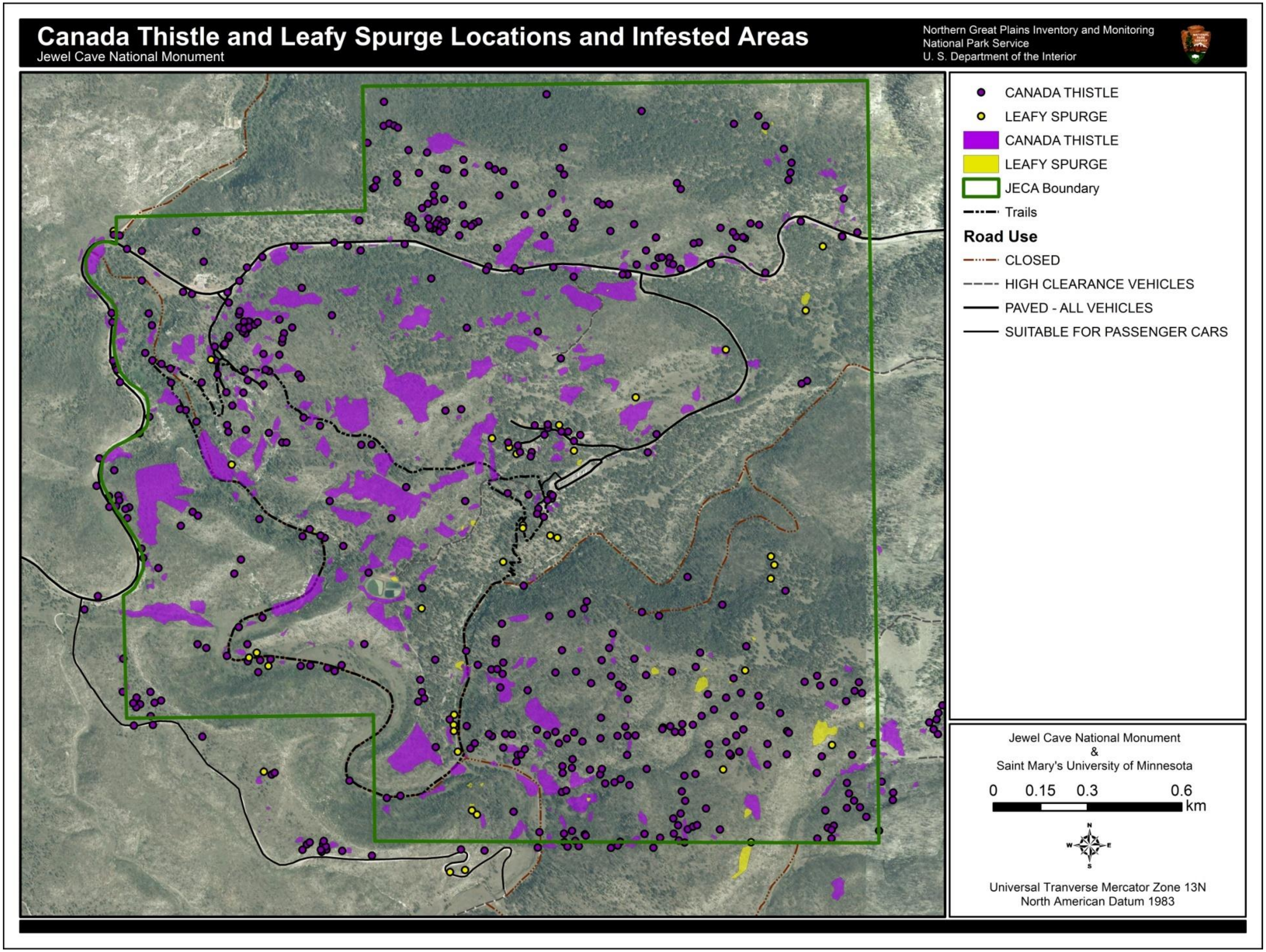

Plate 10. Canada thistle and leafy spurge locations in JECA, 2010.

4.4 Bats

Description

Today, JECA supports nine species of bats: western small-footed myotis, little brown myotis (*Myotis lucifugus*), long-legged myotis (*Myotis volans*), fringed myotis, northern myotis, big brown bat (*Eptesicus fuscus*), Townsend's big-eared bat, hoary bat (*Lasiurus cinereus*), and silver-haired bat (Anderson 1989; Choate and Anderson 1997). These bat species forage near various water sources in the park, including springs, settling ponds, and stock tanks (NPS 2011a). Cryan (1997) found that most (91%) bats that utilized the cave during the summer are male. Cryan (1997) suggests that females seasonally disperse away from the cave during the summer.

Bats are relatively new to Jewel Cave. The original cave entrance was small, and the strong airflow likely would have deterred bats from flying into or out of the cave (based on observations at Jasper Cave; M. Wiles, pers. comm., 2011). When the cave entrance was enlarged to permit human entry in the early 1900s, a building at the entrance blocked bats from entering. Around 1935, following removal of entrance obstructions, bats began to utilize Jewel Cave primarily as a hibernaculum (hibernation location) (M. Wiles, pers. comm., 2011).

Jewel Cave is a prime hibernaculum for bats in the Black Hills because of its size and multitude of different passages (J. Tigner, pers. comm., 2011). The hibernating colony of Townsend's big-eared bats at JECA is the largest known in the western U.S. (Worthington and Bogan 1993). Joel Tigner (pers. comm., 2011) noted that Townsend's big-eared bats hibernate at several locations in the Black Hills, and that the same individuals do not necessarily use Jewel Cave each year due to temperature variation and other unexplored factors. Most bats that hibernate in Jewel Cave roost at alternative locations during the summer (Mattson 1994).

Measures

- Total number of hibernating bats by genus

Reference Conditions and Values

The JECA bat count ranges following the 1992 standardized count methodology serve as the reference condition. The management goal for bats in Jewel Cave is to maintain the status quo since count standardization (M. Wiles, pers. comm., 2011).

Data and Methods

JECA staff provided hibernaculum bat count data for 1992 through 2010 in Excel spreadsheet format (NPS 2009b). JECA staff provided annual bat count reports of hibernating bat numbers by genus for each of the survey routes. These data were extracted to an Excel spreadsheet, which was used to define the measure for this component. Graphs and summary statistics from the bat counts were used to describe and qualitatively assess the condition. Mike Wiles, JECA Chief of Resources, also provided expert knowledge and interpretation of the data.

Current Condition and Trend

Hibernating Bats by Genus

A letter written by J. Wesley Warner dated 2 December 1959 provides the earliest Jewel Cave bat count information. This letter, which refers to counts prior to 1959, states that 3,500 to 4,500 bats hibernated in Jewel Cave (Anderson 1989). Additional survey data are available from 1959 through 1990. In 1992 the current count methodology was introduced. During mid-January to early February, JECA staff groups of two to three people perform bat surveys along two routes, the Dungeon and Milk rivers, by counting each individual bat along both routes; however, surveyors estimate numbers when roosting bats are in large clusters (NPS 2009a, 2011b). JECA staff did not survey bats in 2010 due to poor weather conditions the previous fall (2009), which made the hibernating bats more vulnerable to disturbance.

Since 1992, yearly total counts of wintering bats at JECA (Townsend's big-eared bats and *Myotis* spp.) ranged between 1,072 and 1,604 with a mean of 1,291 (NPS 2009b, 2001b). The number of *Myotis* spp. has remained stable compared to Townsend's big-eared bat numbers. *Myotis* spp. counts ranged from 181 to 595 with a mean of 432. Townsend's big-eared bat counts ranged from 593 to 1,187 with a mean of 862 and no clear trend (Figure 8). The total bat count from 1992 to 2011 indicates total hibernating bats increased over this time (Figure 9).

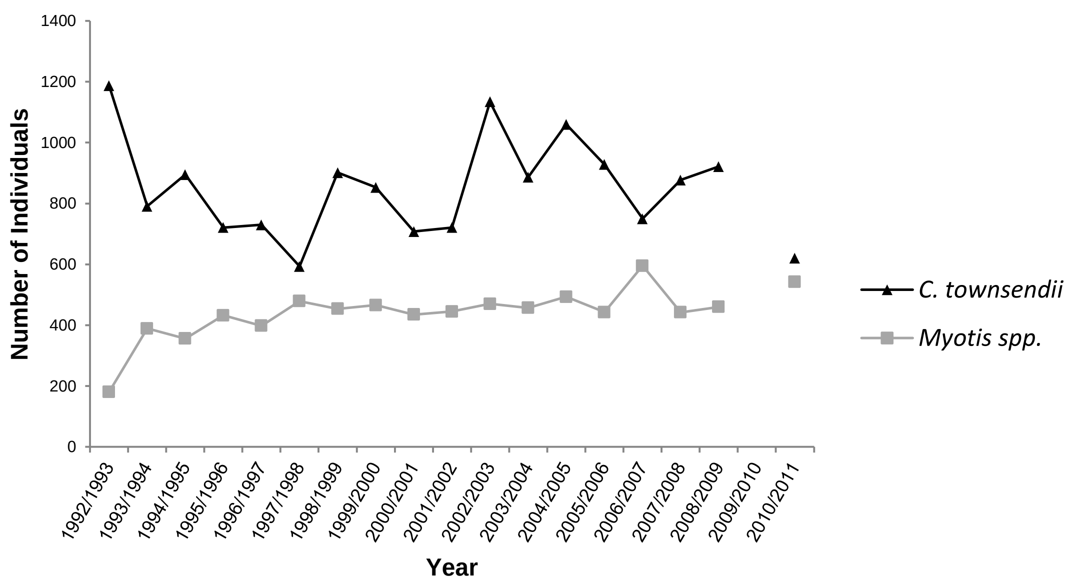

Figure 8. JECA bat counts, *C. townsendii* and *Myotis* spp., 1992–2011. No survey data for 2009/2010 (NPS 2009b, 2011b).

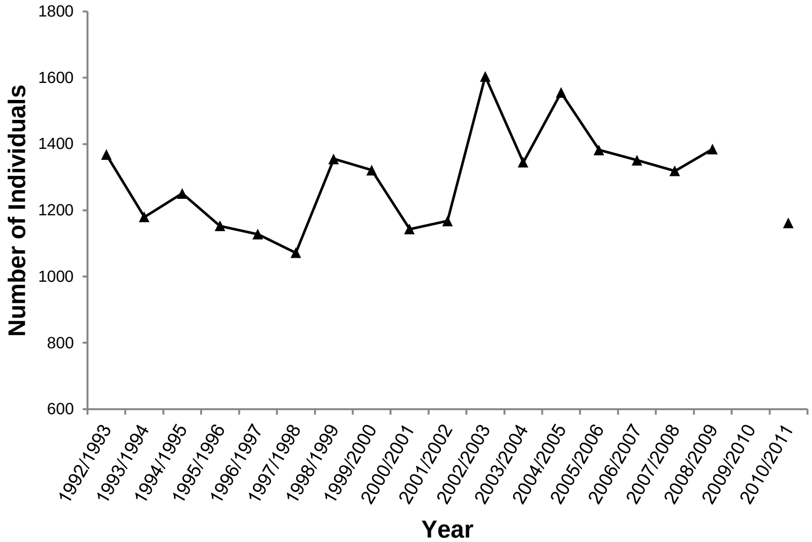

Figure 9. JECA bat counts, total, 1992–2007. No survey data for 2009/2010 (NPS 2009b, 2011b).

Surveyors observed more hibernating bats along the Dungeon Route than the Milk River Route every year from 1997 to present (Figure 10). Most years, the number of bats hibernating in each route fluctuated (Figure 10). Following the 2004/2005 and 2008/2009 years of parity, the number of bats located in the different routes diverge sharply (Figure 10). The distribution pattern of the bats is likely an artifact of the microclimate in the cave. While bats usually prefer the Dungeon Route, mild winters might encourage a more even dispersal of bats, but this hypothesis is unexplored (M. Wiles, pers. comm., 2011). Alternatively, during mild winters bats might utilize hibernacula other than Jewel Cave that offer similar or better conditions (J. Tigner, pers. comm., 2011).

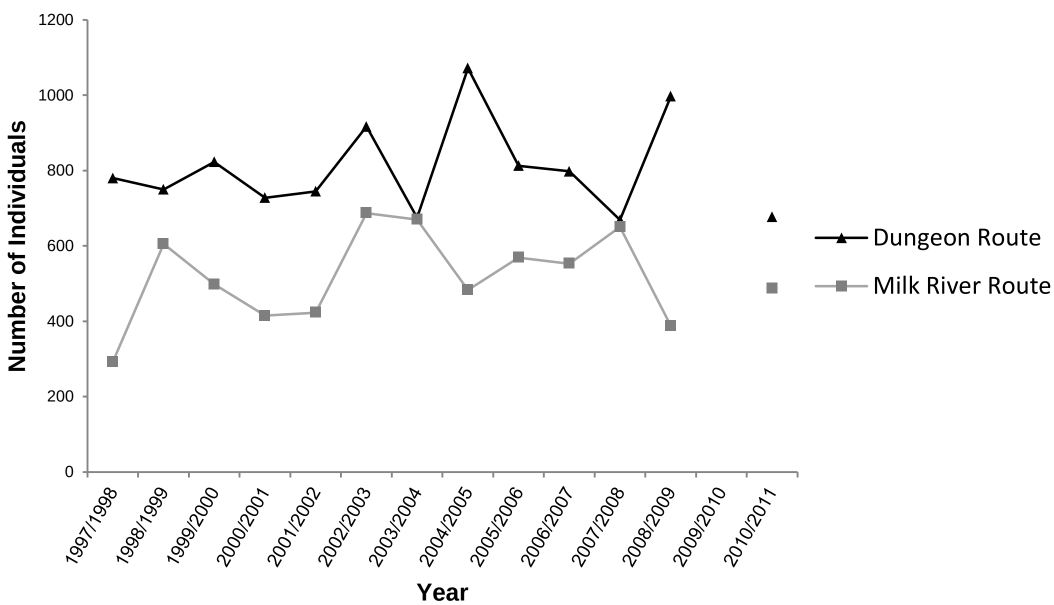

Figure 10. JECA bat counts, by route, 1997–2009. No survey data for 2009/2010 (NPS 2009b, 2011b).

Threats and Stressor Factors

Joel Tigner (pers. comm., 2011) noted that one of the greatest threats to bats in the Black Hills is disturbance during hibernation. Hibernating bats will often avoid disturbances by locating areas within a cave that are void of humans or other threats that cause arousal. These locations, aside from being free from disturbances, have a specific range of temperatures and humidity that allow the bats to enter hibernation safely and successfully. If humans happen upon hibernating bats and create a disturbance, an energetically expensive arousal results; bats can burn fat equivalent to 67 days of torpor during such events (Thomas et al. 1990), and frequent disturbances at a roost colony often result in the bats relocating. While relocation reduces the threat of disturbance, the bats typically hibernate at an alternate location with a less than optimal temperature range, and hence a higher risk of not surviving the winter (Tuttle 2003).

Natural predators of bats often include skunks, raccoons, snakes, feral cats and dogs, and some raptor species (particularly owls). Most predators feed opportunistically on bats rather than specialize on bats as a primary prey species. When present in an area, feral cats present a great risk to hibernating bat populations. In fall 1997, one feral cat killed approximately 250 bats at the Jewel Cave entrance over several weeks before it was captured and dispatched (M. Wiles, pers. comm., 2011).

White-nose syndrome (WNS; Photo 5), the most significant threat to bat populations in the United States, was first discovered in four caves in Albany, New York in winter 2006–2007. Colonies of bats in these caves were well studied before the WNS outbreak. After the outbreak, colonies of hibernating bats in these caves lost 81–97% of their populations (USGS 2010). Bats are adapted to high rates of survival and produce few offspring, so it is unlikely that the affected bat species will quickly recover (USGS 2009).

Photo 5. Little brown bat affected by White-nose syndrome hanging at Greeley Mine in Stockbridge, Vermont. (Courtesy of Katherine Whittemore, USFWS).

Initially, scientists could not determine what was affecting bats in these cave colonies. In summer 2009, however, scientists identified a previously unknown species of cold-thriving fungus (*Geomyces destructans*). This fungus thrives in low temperatures (5–14 °C) and high levels of humidity (>90%), conditions that are characteristic of the bodies of hibernating bats and the caves in which they hibernate. Although WNS was named for the obvious symptom of white noses on infected bats, the most vulnerable parts of the bats that are often infected are the wings (USGS 2010), which make up about 85% of a bat's total body surface area. Healthy wing membranes are vital to bats; they help to regulate body temperature, water balance, and flight (USGS 2010).

Bats infected with WNS experience a disturbance in their hibernation arousal patterns. Typically, bats will store large amounts of fat prior to hibernation, and most of that energy is used up during natural arousals during the winter. During these natural arousals, bats will consume up to 90% of their stored fat to warm up their body, urinate, drink, mate, restimulate their immune system, and relocate their roost within the colony (USGS 2010). When WNS irritates bats enough to bring them out of torpor, bats can run out of stored body fat and starve.

WNS is not currently present in South Dakota; however, as of May 2011, WNS occurred in 16 states (Connecticut, Indiana, Kentucky, Maine, Maryland, Massachussets, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Vermont, Virginia, and West Virginia) and in four Canadian provinces (New Brunswick, Nova Scotia, Ontario, and Quebec) (USFWS 2011). In addition, the fungus associated with WNS exists in three other states (Delaware, Missouri, and Oklahoma) (USFWS 2011). Among the species hardest hit by WNS are little brown bats (*Myotis lucifugus*), which are present in JECA. The sudden and widespread mortality associated with WNS is unprecedented for hibernating bats; widespread disease outbreaks have not been previously documented (USGS 2009).

Fire also poses a threat to the bat population at JECA. Fire was a natural process in the Northern Great Plains, but “changes in vegetation brought about by fire suppression and altered land uses over the past century may impact fire dynamics and, therefore, species responses” (Schmidt et al. 2004). Because species responses are unknown, Schmidt et al. (2004) suggest that burns should be small and applied on a rotational basis. In addition, pre- and post-burn surveys for small mammals and bats should be employed to better understand how species are reacting to fire. They also suggest that surveys take place during periods other than lactation and maternity, preferably in late fall.

Data Needs and Gaps

No active bat management currently occurs at JECA because bat counts have been relatively stable since 1992. Data needs for this component are tied to future stressor mitigation. Joel Tigner (pers. comm., 2011) noted that the most important determinates of cave use by bats during a given year are microclimate and absence of disturbance. Current microclimate monitoring at the cave entrance is inefficient because of an unreliable power supply (300-foot extension cord with no backup) (M. Wiles, pers. comm., 2010). Installing reliable power and data transfer lines to service the Jewel Cave entrance would make real-time data capture possible and enhance cave microclimate monitoring capabilities.

A power source would also strengthen cave entrance security because remote surveillance would always be possible. Break-ins are not an overwhelming problem in Jewel Cave, but the sensitivity of hibernating bats to human presence is a reason for concern (M. Wiles, pers. comm., 2011).

Power would also enable infrared monitoring of hibernating bats. Jewel Cave bats move during hibernation, but intensive monitoring of these movements is not possible without disturbing the bats. Infrared monitoring would give JECA staff the ability to document normal hibernation behavior and the capability to detect abnormal behavior early, which could prevent problems related to disturbance, climate change, or other stressors prior to significant harm.

Real-time microclimate data would expand the knowledge of bat behavior and the cave's susceptibility to climate change (M. Wiles, pers. comm.). Bat hibernation patterns likely correlate to temperature, pressure, humidity, and airflow (, Moore et al. 1996; Cryan 1997; M. Wiles, pers. comm.; J. Tigner, pers. comm.; 2011). Accurate readings of these parameters could help explain yearly changes in bat counts. These data could also determine net heat and water mass exchange at different time intervals, providing a better understanding of climate change and the bats' response to its effects.

Currently, no current research is examining the summer usage of JECA for breeding and roosting. Cryan (1997) examined this, but an update of this study could benefit management.

<u>Overall Condition</u>

The bats of Jewel Cave are in good condition. Since the standardization of survey methodology in 1992, bat populations have not fluctuated in an unusual manner. However, because of the potential of continued westward spread of WNS, the JECA staff should continue monitoring the bat colony. In addition, continued consideration of hibernating bats' sensitivity to disturbance is a priority for ensuring population health for the Black Hills.

Sources of Expertise

Joel Tigner, Bat Biologist, Batworks, LLC
Mike Wiles, Chief of Resource Management, JECA

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4.5 Cave Microclimate

Description
As part of the NPS management program to achieve desired future conditions, NPS monitors cave microclimate and determines its relationship to natural conditions (NPS 2007). In a general sense, microclimate is a local atmospheric zone where the climate differs from the surrounding area, which can be within a few square feet to as large as many square miles. Four variables describe the microclimate in a cave environment: temperature, pressure, humidity, and wind velocity. With respect to Jewel Cave, the microclimate can change in the walk-in entrances and near tour routes as indicated by various studies completed in Jewel Cave.

Measures

- Temperature
- Barometric pressure
- Humidity
- Wind velocity

Reference Conditions and Values
No information is available regarding pre-1908 cave microclimate conditions.

Data and Methods
Studies explaining Jewel Cave's microclimate were used for this assessment. No data were compiled or manipulated for analysis.

Current Condition and Trend

<u>Temperature (overall heat exchange)</u>
Moore et al. (1996) determined Jewel Cave's ambient air temperature to be 9.4 ^{o}C (49 °F). A 2004 study conducted by Marc Ohms, NPS Physical Science Technician, at Wind Cave National Park, concluded that temperature fluctuation from artificial lighting raises the temperature immediately around the fixtures but does not affect a larger area (NPS 2007). However, cave tours increase the localized cave temperature by as much as 2 °F for up to 2 hours following a tour (NPS 2007). Wiles (1998) documented similar effects at Jewel Cave, and Dr. Andreas Pflitsch, Professor, Geography Department at Ruhr University, Germany, determined that long-term impacts do not extend beyond about 500 feet of the tour routes.

Overall heat exchange is a function of the specific heat contained within the air mass (composed of a dry air component and an absolute humidity component) and the net movement of the air mass over time. The exchange of heat occurs throughout the year. During the winter months, the cave's temperature is greater than the average outside temperature; as a result, warmer air exits and cooler air flows into the cave. In the summer the exchange of heat reverses (Conn 1966). An NPS study on overall heat and moisture exchange in Jewel Cave is underway and results are pending (M. Wiles, pers. comm., 2011).

Pressure (air exchange)
Another factor that affects cave environment is the change in barometric pressure. Conn (1966) determined that entrance winds at Jewel Cave originate from barometric pressure changes. When barometric pressure rises, air flows into the cave to equalize the pressure, and when pressure drops, air flows out for the same reason. During the study, airflow reversal occurred 4 times a day in Wind Cave and 1 to 1.5 times per day in Jewel Cave. Jewel Cave requires about 24 hours to equalize one-half the air. As an example in Jewel Cave, from a no-flow state, if the mercury rises 0.25 inch and then steadies, air will continue to blow for more than 3 days before the wind drops to 1 mi/hr (Conn 1996).

Humidity (overall moisture)
Between 1984 and 1985, a temperature and humidity impact study at Wind Cave examined natural entrance tour routes and walk-in entrances (NPS 2007). This study showed that unnatural airflow through open walk-in entrances caused temperature fluctuations approximately 600 feet into the cave and in one year removed more than 100,000 gallons of water from the cave air, "significantly affecting natural humidity levels" (NPS 2007). Subsequent installation of airlock doors has eliminated all detectable impact (M. Wiles, pers. comm., 2011). Wiles (2008) reports similar observations at Jewel Cave in 1985–1986, but noted very little change in relative humidity along the scenic tour route, and no water loss from evaporation pans left in the cave for 1 year.

Overall moisture exchange is a function of the absolute humidity contained within the air volume and the net movement of the air volume over time. The exchange of moisture occurs throughout the year, with air always leaving the cave at nearly 100% relative humidity and entering the cave at less than 100% relative humidity (M. Wiles, pers. comm., 2011). The NPS study examining overall heat and moisture exchange in Jewel Cave will provide more information on cave humidity in the future.

Wind Velocity
Within Jewel Cave, wind velocity has been measured at more than 35 mph (M. Wiles, pers. comm., 2011). Since 2001, the low-velocity component has been measured at the historic cave entrance (Pflitsch et al. 2010) in the range of −40 to 40 dm/s (−0.45 to 0.45 mph). Air-flow events measured at the historic cave entrance exhibit strong variations in speed; up to 1 m/s (2.2 mph) every minute. The authors note little variation between winter and summer velocities and that the velocities are shaped by arometric processes. Temperature is also important in determining specific airflow patterns and the volume of air exchanged in and out of the cave. Cave winds can continue in one direction for three straight days or more and then reverse direction (Conn 1966). Andreas Pflitsch observed continuous flow in one direction for more than seven days (M. Ohms, pers. comm., 2011).

From measurements taken at Jewel Cave, Pflitsch et al. (2010) conclude that the Jewel Cave System has a volumetric size of 400 million m^3 (14.1 billion ft^3).

Some data gaps occur due to issues with the instrumentation's power supply. An uninterrupted record of wind velocity is required to establish an airflow mass balance and calculate the net exchange of energy and water (M. Wiles, pers. comm., 2011). The park is pursuing a project to establish a reliable power supply to meet this need.

Threats and Stressor Factors

Studies confirm that added lighting and visitation increase temperature and biota growth along tour routes (NPS 2007). Electrical systems and other stressors impact a cave's ecosystem by adding heat to the cave, which advances algal growth (NPS 2007). Jewel Cave accommodates more than 80,000 visitors each year. Wiles (1998) reports calculations by Dr. Neville Michie, Director of the Michie Cave Research Laboratory, that human body heat contributed more than 40% of the total heat input at Jewel Cave during the summer tourist season; the remaining 60% is introduced by the electrical lighting system (M. Wiles, pers. comm., 2011).

A 1996 cave biota and trophic interaction study conducted along Jewel Cave's tour routes showed that human activity increased carbon and nitrogen levels (Moore et al. 1996). As visitors pass through the cave, they shed skin and lint fibers from clothing. Condensation that forms on these fibers can dissolve cave surfaces and minerals that increase carbon and nitrogen in the cave ecosystem. Humans also contribute to unnaturally high cave biota populations by bringing in nonnative species, increasing levels of bacteria, fungi, protozoa, nematodes, and microarthropods along tour routes (Moore et al. 1996).

No data are available regarding climate change in JECA.

No data are available regarding anthropomorphic changes of cave passages in Jewel Cave. However, a study conducted by Andreas Pflitsch is pending.

Data Needs and Gaps

- A continuous record of wind velocity with no data gaps

- Overall heat and moisture exchange is in progress (M. Wiles, pers. comm., 2011)

- Andreas Pflitsch is completing a summary of his research to date that includes observations on the human impact on caves (M. Wiles, pers. comm., 2011).

- A potential need may include a spatial 3-D map (ArcScene) illustrating locations and extent of impact to cave biota and mineralogy from wind, cave lighting, and tour locations

- Andreas Pflitsch has collected 7 years of microclimate data for Jewel Cave that should be used in future assessments. He is currently completing a final report of his findings.

Overall Condition

Studies from the 1990s through 2006 in Jewel Cave and at nearby Wind Cave indicate that localized impacts to caves can significantly alter cave ecosystems but are limited to entrances, tour routes, and the their immediate vicinity (Moore et al. 1996; Wiles 1998, 2008). Temperature fluctuations caused by cave tours, lighting, and electrical systems alter cave biota and mineral resources (Wiles 1998); artificial cave entrances create wind velocity linked to temperature and pressure changes that impact localized cave humidity levels (Wiles 2008); and human lint fibers increase biologic impact (Moore et al. 1996). Although studies indicate localized microclimate changes occur naturally, the trend of visitation and its effects on biota, temperature, and humidity may create the potential for a worsening trend in the condition of the cave's microclimate. There are no known microclimate impacts in the other 99% of the known cave (M. Wiles, pers. comm., 2011). Broad-scale impacts, such as those that could be caused by climate change, are as yet unknown.

Sources of Expertise

Mike Wiles, JECA Chief of Resource Management. Marc Ohms, NPS Physical Science Technician, at Wind Cave National Park and Dr. Andreas Pflitsch, Professor, Geography Department at Ruhr University, Germany also provided information.

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4.6 Drip Sites

Description

Water is deposited in Jewel Cave at a number of drip sites after infiltrating through the soil and bedrock layers above. Water is rare within the cave; <0.25% of known cave passages contain water resources (NPS 2007; M. Wiles, pers. comm., 2011). Drip sites are susceptible to water quality degradation from contaminants, including chloride, nitrate, and pesticides. A variety of sources contribute to degradation, including storm water runoff from impermeable surfaces, pesticide treatment of exotic plants, and potential sewage line leaks. Although potential impacts are not well understood, JECA considers water quality and quantity to be critical factors in the cave environment (NPS 2007). Cave and karst systems are strongly related to local and regional hydrology, so any threat to water quality, quantity, or natural hydrologic patterns could impact cave biota, mineral deposits, and speleothems (NPS 2004a). Four drip sites within Jewel Cave are used for drinking water for cavers; therefore nutrient and chemical concentrations must be within drinking water standards.

Measures

- Chloride concentrations
- Nitrate concentrations
- Pesticide concentrations

Reference Conditions and Values

Drip sites that are unimpacted by chloride or nitrate and contain no pesticides serve as the reference condition for this component. Normal background chloride concentrations are <5.0 mg/L in areas not influenced by surface development, and the highest background nitrate concentration is 2.0 mg/L; therefore, sites with concentrations exceeding these values would be considered impacted (M. Wiles, pers. comm., 2011).

Data and Methods

Approximately 75 discrete drip sites occur in Jewel Cave (M. Wiles, pers. comm., 2011). Results from water quality studies conducted at JECA, including those at cave drip sites, are located in the U.S. Environmental Protection Agency's STORET database. Chloride and nitrate data have been collected in Jewel Cave since 1985 in multiple studies, as well as long-term monitoring conducted by JECA. Three cave drip sites are monitored by JECA long-term: the Dungeon Room, New Wet Room East (NWE), and a site referred to as the "JCA" site, adjacent to the Wild Caving Tour route in the cave. The monitored sites were selected based on their accessibility and historic contamination (M. Wiles, pers. comm., 2011).

Alexander et al. (1989) published the first water quality measurements for cave drip sites at JECA from 1985 to 1988. NPS (2000) analyzed existing water quality data for JECA through 1998, including data from the three long-term monitoring sites. Williamson (2008) analyzed this dataset in more detail and calculated average concentrations for different chemical constituents across all cave drip sites.

Pesticide data have been collected occasionally at certain Jewel Cave drip sites to test for any infiltration of chemicals used in JECA or on adjacent land. Unpublished results of recent herbicide testing (NPS 2003, 2004b, 2009b) were provided by JECA.

Data collected after 1998 have not been entered into the STORET database and have not been analyzed in any publication. GeoSpatial Services used data provided by JECA from 1991 to 2010 to calculate mean concentrations of chloride and nitrate over this time period at the three monitored drip sites. Photo 6 shows a technician collecting a water quality sample at a drip site in Jewel Cave.

Current Condition and Trend

<u>Chloride Concentrations</u>

Alexander et al. (1989) found wide variability in chloride concentrations at Jewel Cave drip sites during their 1985 to 1988 study. Drip sites isolated from surface development had very low chloride concentrations, <10 mg/L. The NWE and Dungeon Room sites had the highest chloride concentrations, 50 to 65 mg/L and 111 mg/L, respectively. Sites associated with the sewage lagoon had concentrations between 30 and 40 mg/L (Alexander et al. 1989).

Photo 6. Collecting a water quality sample at a Jewel Cave drip site (NPS).

Nepstad and Wiles (1993) conducted water quality sampling in Jewel Cave between 1991 and 1993 and found elevated chloride levels in areas below surface development in JECA. Chloride concentrations ranged between 0 and 200+ mg/L in the Dungeon Room, which may be hydrologically linked to a surface spring adjacent to U.S. Highway 16. Concentrations reached 20+ mg/L at sites near the visitor center, with chloride levels decreasing away from the center (Nepstad and Wiles 1993).

NPS (2000) summarized chloride data for the Dungeon Room and JCA site between 1991 and 1998, and NWE between 1991 and 1994. The Dungeon Room had the highest mean chloride concentration at 174 mg/L; NWE had an average concentration of 48 mg/L; and the JCA site had a mean concentration of 4.86 mg/L (NPS 2000). Chloride levels in the Dungeon Room and NWE were significantly higher than the natural background level of <5.0 mg/L, likely because of hydrologic connections to surface development where salt runoff can infiltrate. The Dungeon Room is suspected to be impacted by salt in highway runoff, and NWE is suspected to be impacted by a sewer line leak or as a residual impact from a previous leak (M. Wiles, pers. comm., 2011).

Williamson (2008) analyzed existing STORET data through 1998 and noted high chloride concentrations at three sites: Dungeon Room, Mezzanine, and Near Bacon Drapery (NBD). These sites also showed high variability between samples and are suspected to be impacted by a leaking sewer line or as a residual impact from a previous leak (M. Wiles, pers. comm., 2011). Williamson (2008) found a total chloride average of 31.6 mg/L for all drip site samples through 1998. This mean value is higher than expected background levels due to sites such as the Dungeon Room that exhibited significantly higher chloride concentrations. Impacted sites are also sampled much more frequently, biasing the mean value toward sites with high concentrations.

Between 1991 and 2010, mean chloride concentrations were 164 mg/L for the Dungeon Room, 48.6 mg/L for NWE, and 6.63 mg/L for JCA (NPS 2011, unpublished data). These concentrations are basically unchanged from the earlier dataset analyzed by NPS (2000).

Nitrate Concentrations

Alexander et al. (1989) found that Jewel Cave drip sites generally contained low nitrate concentrations. The highest concentrations, 3.6 to 6.2 mg/L, were measured in 1985 under the sewage lagoon prior to the lining of the lagoon in summer 1985. The High Water site, which lies below the lagoon, was resampled in 1988, yielding a concentration of 3.54 mg/L, down from 5.82 mg/L in 1985, but still high compared to the average for Jewel Cave (Alexander et al. 1989). Water in the sewage lagoon was known to leak into the bedrock prior to its reconstruction in 1985 and may have contributed to the elevated nitrate concentrations (Alexander et al. 1989, M. Wiles, pers. comm., 2011).

Nepstad and Wiles (1993) found that nitrate levels rarely exceeded 2 to 3 mg/L on average in Jewel Cave. Concentrations were notably higher at sites located close to surface development but were within the normal background range at undisturbed drip sites (Nepstad and Wiles 1993).

NPS (2000) analyzed nitrate data from various cave sites, including the Dungeon Room, NWE, and the JCA site. Between 1991 and 1998, the Dungeon Room had an average total nitrate concentration of 0.637 mg/l; between 1991 and 1994, NWE averaged 1.166 mg/L; and between 1993 and 1998, the JCA site averaged 0.843 mg/L (NPS 2000). Williamson (2008) analyzed the same dataset and found an average total nitrate concentration for all measured cave drips sites of 0.7 mg/L.

Between 1991 and 2010, the mean nitrate concentration was 0.71 mg/L for the Dungeon Room drip site; 1.38 mg/L for the NEW drip site; 0.64 mg/L for the JCA drip site (NPS 2011, unpublished data). Nitrate concentrations at these sites have remained fairly stable on average since the previous analysis conducted by NPS (2000).

Pesticide Concentrations

The primary pesticides of concern in JECA are herbicides used above the cave to control exotic and invasive plants. The most problematic herbicides are those that are mobile in the environment and have “low adsorption coefficients, and are highly persistent, highly soluble, or both” (NPS 2007). JECA has records detailing herbicide applications in 2003, 2004, and 2009/2010 in and around JECA, and subsequent water quality testing results for compounds at cave drip sites (Table 15, Table **16**, and Table **17**). Herbicides used within JECA boundaries include aminopyralid, clopyralid, glyphosate, and imazapic (NPS 2003, 2004b, 2009b). Picloram and 2,4 D have been applied in the vicinity of the cave by USFS and Custer County (NPS 2003, 2004b, 2009b). Dicamba was found in trace amounts in one water sample from 2004, although there were no known applications by JECA or local agencies (NPS 2004b; R. Ohms, pers. comm., 2011). Picloram is an example of a highly mobile herbicide that has been used in the vicinity of JECA.

Table 15. JECA hydrologic herbicide testing in 2003.

Site ID	Site Description	Date	Clopyralid (ppb)	Imazapic (ppb)	2,4 D (ppb)	Picloram (ppb)
LMC	Lots More Cave	5/29/2003	None Detected	None Detected		
NWE	New Wet Room East	6/2/2003	None Detected	None Detected		
LMC	Lots More Cave	6/19/2003	None Detected	None Detected		
NWE	New Wet Room East	6/23/2003	None Detected	None Detected		
HW	High Water	7/2/2003	None Detected			
LMC	Lots More Cave	7/3/2003	None Detected		0.261	
STT	Side Track Tap	8/20/2003	None Detected	None Detected	None Detected	None Detected
LMC	Lots More Cave	8/22/2003	None Detected		None Detected	None Detected
HW	High Water	8/22/2003	None Detected		None Detected	None Detected

Table 16. JECA hydrologic herbicide testing in 2004.

Site ID	Site Description	Date	Clopyralid (ppb)	2,4 D (ppb)	Picloram (ppb)	Glyphosate (ppb)	Dicamba (ppb)
LMC	Lots More Cave	5/25/2004	None Detected	None Detected	None Detected	None Detected	
LMC	Lots More Cave	7/1/2004	None Detected	<0.020	None Detected	None Detected	<0.020
LMC	Lots More Cave	7/27/2004	None Detected	<0.020	None Detected	None Detected	
LMC	Lots More Cave	8/31/2004	None Detected	None Detected	None Detected	None Detected	

Table 17. JECA hydrologic herbicide testing in 2009–2010.

Site	Date	Aminopyralid (ppb)
High Water	8/19/2009	None Detected
New Wet Room East	8/19/2009	None Detected
High Water	9/14/2009	None Detected
New Wet Room East	9/14/2009	None Detected
High Water	10/15/2009	None Detected
New Wet Room East	10/15/2009	None Detected
High Water	11/3/2009	None Detected
New Wet Room East	11/3/2009	None Detected
High Water	1/25/2010	None Detected
New Wet Room East	1/25/2010	None Detected

Threats and Stressor Factors

The sewage lagoon in JECA lies above cave passages and has leached contaminants into groundwater in the past. The lagoon was unlined prior to 1985, allowing water to seep into underlying limestone for 10 to 15 years (M. Wiles, pers. comm., 2011). It is believed that raw sewage water from the lagoon did not enter the cave passages, although Alexander et al. (1989) detected elevated nitrate and chloride levels inside the cave beneath the lagoon (M. Wiles, pers. comm., 2011). The sewage lagoon is no longer thought to be a threat to water quality; however, the lining beneath the lagoon is an impermeable surface over the cave, potentially restricting natural infiltration that may have occurred prior to the construction of the sewer lagoon (M. Wiles, pers. comm., 2011).

Road salt is a likely source of chloride contamination to cave drip sites from nearby impermeable surfaces. U.S. Highway 16 passes through JECA over known cave passages and outside JECA boundaries over additional passages. Cars that pick up salt from the highway drip water onto the parking lot, which can then runoff and infiltrate the cave. Salt runoff likely contributes to elevated chloride levels that have been detected at a number of cave drip sites (NPS 2007).

The presence of exotic plant species in JECA could degrade water quality inside the cave due to herbicide applications. JECA uses an integrated pest management approach for noxious plant control, which includes utilizing mechanical removal and biocontrol methods; herbicides are only used in JECA if these options are not feasible. In addition, JECA has a “no-pesticide treatment zone” covering about one-half the total area of JECA to protect the most sensitive areas; this zone may be redefined in the future based on new geological information (NPS 2007; M. Wiles, pers. comm., 2011). The main plant species treated with herbicide are Canada thistle and leafy spurge. The most recent herbicide application in JECA was aminopyralid used on Canada thistle; none was detected in cave sampling (NPS 2009a, 2009b). Herbicide applied on land adjacent to JECA has infiltrated into the cave in the past, proving that land use activities outside of JECA boundaries can impact the cave (NPS 2003).

Data Needs and Gaps

Data collected since 1998 have not been entered into the STORET database, and there are no published analyses of this information. A comparison of all existing drip site water data would be useful to construct long-term trends and potentially correlate data with land use activities and changes.

<u>Overall Condition</u>
Chloride concentrations have shown the widest variability of the measures for this component. Most cave drip sites are not associated with surface development and have low chloride concentrations; however, a few sites have shown much higher relative concentrations. These sites are considered impacted, but the effects of high chloride levels on cave resources are unknown. Chloride concentrations are of moderate concern.

Nitrate concentrations at drip sites in Jewel Cave tend to be low, with the highest recorded levels occurring in the 1980s beneath the unlined sewage lagoon. Currently, nitrates remain low, indicating that sewage leaching is no longer an issue at JECA. Nitrate concentrations are of low concern.

Pesticide concentrations are generally undetectable at drip sites within the cave. The herbicide 2-4 D, which has been used on surrounding USFS land and by Custer County, was detected in low concentrations in a few samples taken in 2003 at the Lots More Cave site. Dicamba was detected in one sample in 2004 at the Lots More Cave site. These findings represent a minor short-term impact from pesticides on cave drip sites. Aminopyralid was not detected in sampling conducted in 2009 and early 2010. Pesticide concentrations are of low concern.

Sources of Expertise
Mike Wiles, JECA Chief of Resource Management
Rene Ohms, JECA Physical Science Technician

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4.7 Changes in Infiltration

Description

Infiltration is a complex hydrologic process at JECA that affects water quantity and quality within the cave. Infiltration changes due to development and surface vegetation changes can influence speleothem development and cave biota (NPS 2007). Vegetation cover greatly affects the amount of evapotranspiration that occurs on the landscape and therefore the amount of water available for infiltration into the cave at drip sites. The Jasper Fire of 2000 dramatically altered the landscape at JECA, causing greater than 60% mortality of the ponderosa pine forest at JECA, and altering soil infiltration characteristics.

Measures

- Permeability

Reference Conditions and Values

The reference condition for this component is defined as unimpacted drip sites within Jewel Cave. There are currently about 75 known cave drip sites, four of which are monitored by JECA (NPS 2007; M. Wiles, pers. comm., 2011). The volume of water deposited at drip sites could be altered if infiltration processes change.

Data and Methods

Primary sources of information for this component were the Wiles (1992) study of infiltration at JECA and Wind Cave, the JECA Cave and Karst Management Plan (NPS 2007), and personal communication with Mike Wiles.

Current Condition and Trend

<u>Permeability</u>

Permeability measures the degree of connectivity between pores in the soil and underlying bedrock, and in the case of JECA, cave passages as well (M. Wiles, pers. comm., 2011). Adequate permeability must exist for water to infiltrate through the soil and bedrock to reach the cave at localized drip sites. The soils at JECA are classified as well-drained, and therefore they are not easily saturated and rarely produce surface runoff. The five different soil units in JECA are described as having "moderate" to "moderately rapid" permeability, ranging from 0.6 to 6.0 inches/hr (NPS 2007).

Infiltration into Jewel Cave is distributed unevenly beneath three distinct zones of the landscape. These are defined as the zone of restricted infiltration, the zone of continuous infiltration, and the zone of sporadic infiltration, which have widely varying rates of infiltration (Figure 11; Wiles 1992). Mike Wiles (pers. observ. 2010) observed that the Minnelusa formation (which overlies the Madison Aquifer and the majority of Jewel Cave) contains an impermeable layer, about 100 feet above the top of the Madison Aquifer, which prevents water from infiltrating into most of the cave. He hypothesizes that the water moves laterally over the impermeable layer until it finds a fracture or erosional breach that allows access to the basal Minnelusa and the Madison Aquifer. In areas where there is no surface disturbance, more than 97% of meteoric water evapotranspirates before it can move beyond the soil. Most of the water that infiltrates into the cave enters through outcrops of the Limestone and Chert subunit (subunit II) and the Lower Sandstone subunit (subunit I) within the zone of continuous infiltration (Wiles 1992).

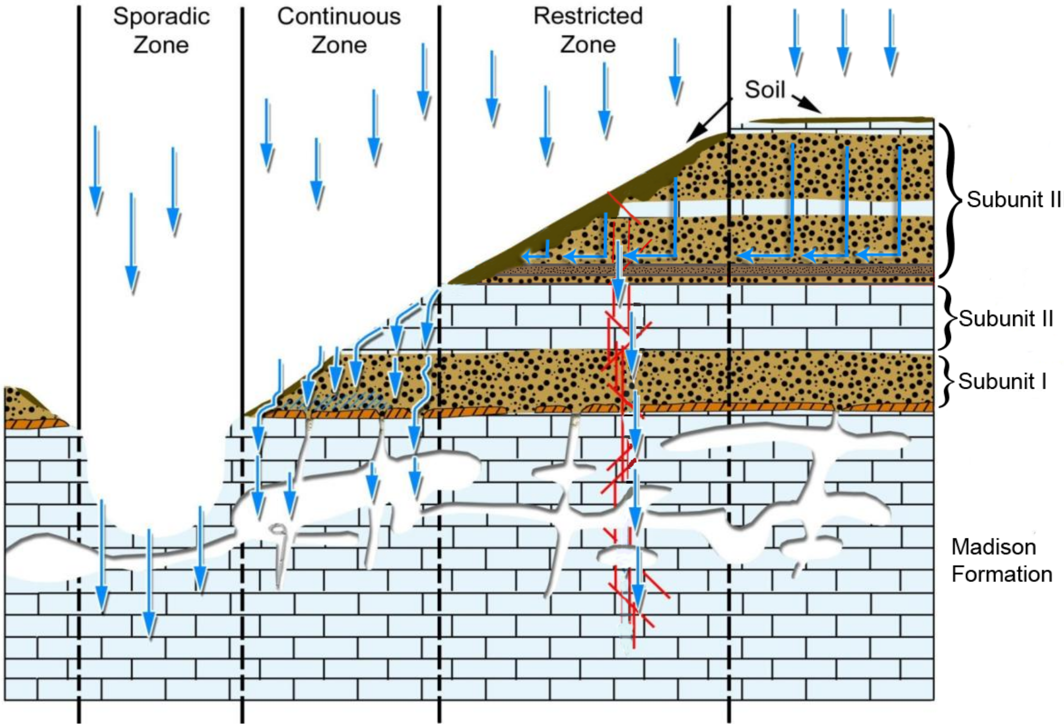

Figure 11. Infiltration model for Jewel Cave. Subunit I = Lower Sandstone and paleosol; Subunit II = Limestone and Chert; Subunit III = Sandstone with Limestone Cap. Other subunits not present in the immediate area, although some of these subunits are present within JECA. This figure does not display evapotranspiration, which is 97% in all zones except the continuous and sporadic zones. Strata tilt slightly to the left, which is indicated by the left-facing arrows representing flow in the figure (modified from Wiles 1992).

Minnelusa Formation (subunits 1-3 represented in Figure 11)

subunit VI **brecciated sandstone, limestone, and anhydrite** (top of unit not found in map area)
tan, buff, yellow to red, brecciated sandstone; thin beds of unbrecciated limestone and sandstone; limestone contains fossilized brachiopods

subunit V **varicolored sandstones, ~ 120 feet thick**
bright red, yellow, and light tan, fine to coarse grained sandstones; light blue-gray chert balls near bottom; limestone near base weathers like upper dolomite of subunit IV

subunit IV **interbedded dolomite and sandstone, ~ 120 feet thick**
basal calcareous medium to coarse grained sandstone; basal sandstone is 1-5 feet thick; other sandstones may be bright red and yellow in places; top of unit is white slabby dolomite commonly with manganese dendrites; unit weathers into colluvial slopes

subunit III **sandstone with limestone cap, ~ 120 feet thick**

- **IIIm** limestone cap, ~ 30 feet thick
  sometimes very sandy; silicified fossils of *Chaetetes milliporaceous* form distinctive marker on upper bedding surface; subtle outcrops; on steep slopes, often covered by float of subunit IV

- **IIIs** varicolored sandstone, ~ 90 feet thick
  poorly exposed; weathers into colluvial slopes
  where exposed often quartzitic, with well-cemented gravel quartzite near bottom

subunit II **thinly bedded cherty limestone, ~ 50 feet thick**
limestone beds up to 2 feet thick form subtle outcrops; interbedded sandstones and shales up to 6 inches thick

subunit I **crossbedded sandstone, ~ 40 feet thick**
varicolored medium to coarse-grained crossbedded basal sandstone is thickness compensatory with upper red siltstone; poorly exposed; weathers into colluvial slopes

Wiles (1992) estimated the drip rates in Jewel Cave in 1989 and 1990 (Figure 12) by monitoring six drips sites within the zone of continuous infiltration. The majority of cave drip sites are located close to surface valleys and draws in areas where impermeable layers in the bedrock have eroded. Drip rates spike in the spring months following snow melt (Figure 12).Other drip sites are attributed to the concentration of runoff from impermeable surface development such as buildings and pavement, and the breaching of impermeable strata by the elevator shaft entering the cave (NPS 2007).

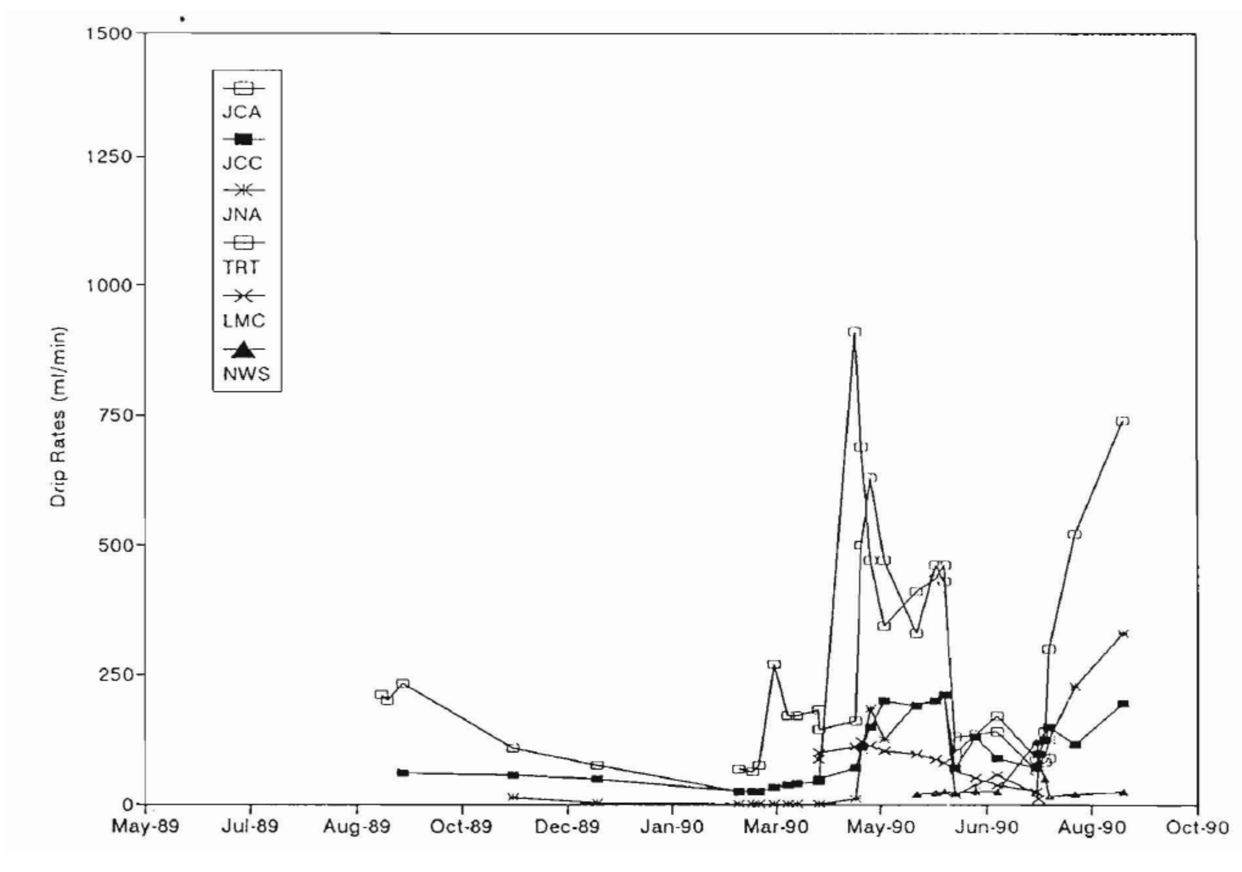

Figure 12. Drip rates at Jewel Cave, 1989–1990 (Wiles 1992).

During the summer months, evapotranspiration demand (especially by ponderosa pines) exceeds water availability, and surface vegetation depletes the remaining water in storage (Wiles 1992). Evapotranspiration has been estimated at 95% by Orr and Vanderheid (1973) and 97% or higher by Wiles (1992), leaving only a fraction of total precipitation available for infiltration. Spring snow melt and rainfall provide the majority of the yearly groundwater recharge available for infiltration (M. Wiles, pers. comm., 2011).

The Jasper Fire altered the hydrology of JECA by removing canopy vegetation, litter and duff cover, and by increasing the water-repellant layer in the soil (M. Parenti 2001). Canopy interception and evaporation is greatly reduced because of the fire, and transpiration by ponderosa pine and other plants is also substantially decreased; thus, water contact with the soil is thus increased. The water repellant properties of the soil were also increased as a result of the fire, however, decreasing soil permeability in the upper layers and lowering infiltration potential. The result of these changes in JECA was an increase in surface runoff following the wildfire, which led to higher peak flows in JECA's watershed following storm events (M. Parenti 2001). The effects of the fire diminish each year, but full recovery of the watershed could take up to 20 years (M. Parenti 2001).

The substantial reduction in ponderosa pine cover above the cave passages is expected to increase infiltration. However, a drought in the region began in 2000 coinciding with the Jasper Fire, lasting until 2008, and no change in infiltration at cave drip sites has been documented to date (NPS 2007). The bedrock has a certain storage capacity that must be reached before water enters the cave at drip sites, and infiltration is still likely recharging this storage volume (M. Wiles, pers. comm., 2011).

Surface development in JECA has disturbed natural rock layers near the surface, increasing permeability. Buildings and the parking lot have created impermeable surfaces over the cave, decreasing permeability in these areas. JECA plans to build a new parking lot in 2014, and while a permeable pavement was considered, the idea was rejected because it would increase permeability above natural levels on the site. Even an increase in clean water infiltration has the potential to damage sensitive cave features (e.g., the hydromagnesite balloons). Urbanization on the surrounding landscape has decreased permeability, causing flow to occur in tributaries of Hell Canyon and Lithograph Canyon on occasion; these tributaries are almost always dry (M. Wiles, pers. comm., 2011). The potential implications for cave infiltration are unknown.

<u>Threats and Stressor Factors</u>
Construction of impermeable surfaces has altered the natural hydrology of JECA. Some of the cave drip sites seem to be linked to development of buildings and pavement on the surface. Dye trace analyses have shown a direct hydrologic link between parking lot runoff and certain passages of Jewel Cave (NPS 2007). Drip site locations in the cave may have been altered due to human development on the landscape. Based on studies of similar circumstances at Wind Cave, other contaminants such as hydrocarbons and metals are likely infiltrating into the cave from the parking lot, but this relationship is not well understood at JECA (NPS 2007).

The sewage lagoon in JECA lies above the cave and has leached effluent in the past, although it is believed that that effluent did not enter the cave directly (M. Wiles, pers. comm., 2011). Prior to 1985, the sewage lagoon was inadequately lined and was not functioning properly. Alexander et al. (1989) found mildly elevated levels of nitrate and chloride in pools and drip sites underneath the lagoon during a dye tracing study that began in 1985. The sewage lagoon has since been reconstructed and relined to prevent contamination of the cave. The lagoon is no longer considered a threat in regard to effluent leaching, but the plastic lining acts as an impermeable surface above the cave that potentially precludes natural infiltration of water, which may have occurred prior to the construction of the sewage lagoon (M. Wiles, pers. comm., 2011).

Surface vegetation plays an important role in the level of infiltration reaching Jewel Cave. An increase in tree stand density contributes to higher evapotranspiration and a decrease in soil moisture. This in turn lowers the soil–water profile, resulting in a lack of surface water flow.

The Jasper Fire burned almost all the land above Jewel Cave in 2000, removing 54% of all forested area and causing >60% mortality of the pine trees present (M. Wiles, pers. comm., 2011). This decreased the evapotranspiration potential for the area and increased the amount of water available for groundwater recharge. These factors greatly increase the infiltration potential into the cave, although JECA staff has not noticed many changes to the cave, likely because of the drought between 2000 and 2008 (NPS 2007).

Noxious weeds have prospered in JECA following the Jasper Fire, potentially altering the surface hydrology at JECA (NPS 2007). Vegetation management, particularly invasive species control, can affect hydrologic patterns and water volume entering the cave. The ongoing removal of these plants may impact the level of evapotranspiration and surface permeability.

Data Needs and Gaps

Although JECA has not observed any noticeable changes in drip site infiltration, quantitative data should be collected to measure potential future changes.

Overall Condition

Based on the reference condition of unimpacted drip sites, infiltration is in good condition, although it is has been altered from a predevelopment state. Surface vegetation changes following the Jasper Fire have not yet caused any noticeable changes to infiltration at cave drip sites. The condition of infiltration is of low concern.

Sources of Expertise

Mike Wiles, JECA Chief of Resource Management

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Wiles, M. E. 1992. Infiltration at Wind and Jewel Caves, Black Hills, South Dakota. M.S.Thesis. South Dakota School of Mines and Technology, Rapid City, SD.

4.8 Underground (Cave) Soundscape

Description

The definition of soundscape in a National Park is the total ambient sound level of the park, composed of both natural ambient sound and anthropomorphic sounds (NPS 2000). This component deals specifically with the soundscape inside Jewel Cave. The "key natural sound conditions" in Jewel Cave include quietness, water dripping, wind blowing, and occasional bat vocalization (M. Wiles, pers. comm., 2011). Jewel Cave's soundscape is threatened primarily by human-introduced noises into the environment.

Measures

- Ambient sound level: ambient sounds measured in A-weighted decibels (dBA). As described in BridgeNet (2005), different frequencies (A-weighted, B-weighted, and C-weighted) are used to compute loudness levels. The most common measurement used is the A-weighted decibel scale (dBA), which approximates the sensitivity to the human ear. In an A-weighted decibel scale, everyday sounds range from 30 dBA (very quiet) to 90 dBA (very loud).
- Distribution of nonnatural sounds: any sound that is not part of the natural soundscape (e.g., vehicles, airplanes and helicopters, and other human activities).

Reference Conditions and Values

The reference condition for soundscape in Jewel Cave is a "natural" experience, or a soundscape not influenced by nonnatural sounds. Although there are no studies regarding soundscape conditions inside Jewel Cave, baseline measurements could be taken after cave tours end and artificial light fixtures are turned off (M. Wiles, pers. comm., 2011).

Data and Methods

No data have been collected by the NPS inside Jewel Cave related to the soundscape. There is currently no NPS protocol for collecting data in underground soundscapes.

Current Condition and Trend

<u>Ambient Sound Level</u>
No ambient sound level data have been collected in Jewel Cave to date.

<u>Distribution of Nonnatural Sounds</u>
No distribution data of nonnatural sound have been collected to date.

<u>Threats and Stressor Factors</u>
JECA staff reports that aluminum walkways, tour groups, and electric lights contribute to soundscape stress in Jewel Cave. Aluminum walkways create a "rattle-like" sound as tour groups travel through the cave. JECA staff investigated the cost of replacing the aluminum walkway with a new, stainless steel walkway that would reduce the sound created as tour groups walk through Jewel Cave (M. Wiles, pers. comm., 2011). Reducing tour group size from the current limit of 30 people to 15 to 20 people would reduce nonnatural sound levels within the cave (M. Wiles, pers. comm., 2011).

The electric lighting system includes a few mercury vapor lights, and their electrical ballasts create an unnatural humming sound that often elicits some of the first comments made by people in tour groups when entering the lit cave rooms (M. Wiles, pers. comm., 2011). Future plans are to replace the current lighting system with quieter light-emitting diode (LED) lighting.

<u>Data Needs and Gaps</u>
No baseline soundscape data are available for JECA, although it would be complete silence for more than 99% of the cave. The establishment of a long-term monitoring effort would ensure that soundscape condition is quantitatively measured and assessed in the future.

<u>Overall Condition</u>
Condition of soundscape inside the cave is of moderate concern because of loud walkways and lighting, but plans are underway to address this by replacing aluminum walkways with steel walkways and replacing mercury vapor lighting fixtures with quieter LED lighting. In Jewel Cave, the majority of nonnatural sounds occur as a result of people walking on aluminum tour structures and from the current lighting system (M. Wiles, pers. comm., 2011).

Sources of Expertise
Mike Wiles, JECA Chief of Resource Management

Literature Cited

BridgeNet International. 2005. Pre and Post Hulett Airport Noise Measurement Survey Devils Tower National Monument. Final Report. Summer 2003/2004.

National Park Service (NPS). 2000. Directors Order #47: Soundscape Preservation and Noise Management (http://www.nps.gov/policy/DOrders/DOrder47.html). Accessed 15 September 2010.

4.9 Cave Viewshed

Description

A viewshed is the area that can be visually observed from a particular location. The NPS is charged with protecting viewsheds within its jurisdiction under the Organic Act (16 U.S.C. l). In JECA, the cave is the major natural feature in the park, so preserving its viewshed is particularly important. JECA was established to preserve the abundant calcite crystal formations in Jewel Cave (Santucci et al. 2001). The visitor experience of these unique features is diminished by any alteration of natural views.

Measures

- Natural cave views

Reference Conditions and Values

The reference condition for the cave viewshed in JECA is defined as a "natural cave experience."

Data and Methods

Quantitative data concerning the cave viewshed at JECA are currently unavailable. Personal communication with Mike Wiles, JECA Chief of Resource Management, and the JECA Cave and Karst Management Plan (NPS 2007) provided the majority of information regarding the viewshed of Jewel Cave.

A photo-monitoring program was recently established inside Jewel Cave to capture changes to important cave features and representative areas over time. Cameras are positioned to take precise duplicates of previous photographs, and a digital comparison technique is being developed to compare the difference in pixels between photographs to determine change over time (M. Wiles, pers. comm., 2011).

Photo-monitoring can be co-located with Petri dishes to quantify the level of dust disturbance or deposit on cave features. JECA has established a policy that reflectivity of cave features should not be changed by more than 10%; photo-monitoring will establish a baseline from which to measure future changes (M. Wiles, pers. comm., 2011). These monitoring stations are established adjacent to travel routes within the cave where the vast majority of disturbance occurs (Photo 7) (NPS 2007).

Photo 7. Image taken at a photo-monitoring site showing a light band on the rock where the white flagging tape had previously been. Darker areas on either side of the band are dust accumulation on the limestone (Mike Wiles, JECA).

Current Condition and Trend

Natural Cave Views

Photo 8. Cave speleothems, dripstones/flowstones left, nailhead spar calcite crystals right.

JECA was established to protect Jewel Cave, currently the second longest known cave system in the world. The cave has a wide variety of unique speleothems (Photo 8), including common calcite formations such as stalactites, stalagmites, flowstone, and frostwork. Dry portions of the cave contain gypsum formations such as needles, beards, flowers, and spiders, and manganese mineral deposits are common throughout the cave. Jewel Cave also includes very rare formations called a "hydromagnesite balloons," small, pearly white bubbles of hydromagnesite (NPS 2007) (Photo 9).

Photo 9. Example of a hydromagnesite balloon (NPS Photo).

The manganese precipitate (often referred to simply as manganese) in Jewel Cave is brown to black in color and is easily smeared onto lighter colored limestone formations or found as handprints on cave walls (NPS 2007) and visitor footprints along the Wild Caving Tour route and the Scenic Tour path (M. Wiles, pers. comm., 2011). Cave features can occasionally be cleaned to remove manganese discoloration, but in some cases the damage is permanent (NPS 2007).

The historical entrance to Jewel Cave was enlarged by blasting circa 1900 to allow human access. This action altered the natural condition of the cave by letting additional light and debris into the cave (Santucci et al. 2001), and subsequent cave tours have led to a variety of changes. Moore et al. (1996) conducted a biota survey of JECA, part of which involved sampling fiber inputs from cave tourists, including clothing, skin, and hair fibers and determined that the debris was heavily concentrated around the established tour routes inside the cave.

The photo-monitoring program at JECA will help management mitigate future impacts to the natural views in the cave. For example, if photographic comparisons show that a cave feature's reflectivity has been impacted by 5%, JECA could prorate the number of people per tour to reduce the level of disturbance, require a certain shoe type, or clean the feature if possible.

Several proactive policies are in place regarding visitors in the cave. Off-trail cavers travel in single file lines to minimize the affected area; cave camping, a high impact activity, is restricted to one site that is covered in tarps; and rest stops for eating and drinking are restricted to established locations in larger rooms to isolate potential impact (M. Wiles, pers. comm., 2011).

Threats and Stressor Factors

While the natural condition within the cave is darkness, lighting must be used along the scenic cave tour route (NPS 2007). Two types of artificial lighting are currently used in the cave: incandescent, which emits a yellowish light, and mercury vapor, which emits a bluish light. JECA is investigating replacing the current lighting with sunlight-spectrum LED lighting, which would better represent a natural condition (M. Wiles, pers. comm., 2011).

Breakage of cave features by visitors is occasionally an issue when people accidentally make contact with a sensitive feature (M. Wiles, pers. comm., 2011). Many cave features are quite delicate, and regardless of cause, the damage represents a threat to the natural views of the cave.

Debris accumulation and disturbance of cave sediments by visitors constitute a major threat to the natural cave views and experience of Jewel Cave. Moore et al. (1996) documented that people touring the cave disturb introduced debris as well as natural cave sediments, spreading dust from the established tour route onto surrounding cave features such as limestone walls, which can be discolored (M. Wiles, pers. comm., 2011). Similarly, the discoloration of cave walls and features by transfer of manganese threatens the natural condition and appearance of the cave.

Data Needs and Gaps

The results of the newly implemented photo-monitoring program inside Jewel Cave will be a valuable source of information regarding visual changes to the cave. Photographic information can be used to quantify changes over time to certain areas of the cave.

Overall Condition

Several forms of visual degradation to cave resources have been qualitatively documented in Jewel Cave; however, the majority of these impacts are focused in a relatively small area adjacent to major tour trails. NPS (2007) describes the cave system as “nearly pristine,” and the new photo-monitoring program will help to identify threats before they irreversibly alter the natural appearance of the cave. The condition of cave viewshed at JECA is of low concern.

Sources of Expertise

Mike Wiles, JECA Chief of Resource Management.

Literature Cited

Moore, J. C., J. A. Clarke, M.E. Heimbrook, S. P. Mackessy, and P. Jablonski. 1996. Survey of the Biota and Trophic Interactions within Wind Cave and Jewel Cave. Colorado State University, Fort Collins, CO. Final Report.

National Park Service (NPS). 2007. Cave and Karst Management Plan: Environmental Assessment. U.S. Department of Interior. Jewel Cave National Monument, Custer County, SD .

Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An Inventory of Paleontological Resources Associated with National Park Service Caves. Technical Report NPS/NRGRD/GRDTR-01/02. National Park Service, Lakewood, CO.

Chapter 5 Discussion

5.1 Component Data Gaps

The identification of key data and information gaps is an important objective of Natural Resources Condition Assessments (NRCAs). Data gaps or needs are pieces of information that are currently unavailable but would help categorize the status and overall condition of a key resource component. Data gaps and needs exist for all key resource components assessed in this NRCA (Table 18).

Table 18. Data gaps for JECA Natural Resource Condition Assessment (NRCA) components.

Component	Data Gaps
Land Cover Extent	-updated finer-scale land cover/vegetation map data; however 2006 NLCD data have recently become available and provide indications of recent broad land cover change.
Fire	-fire’s relationship to cave hydrology -measurements of fire severity, fuel loading, and vegetation response to fire (in progress, NGPN Fire Ecology) -prescribed fire effects for controlling nonnative invasive plants -potential effects of climate changes on fire and vegetation relationships
Native Plant Communities	-protocol for monitoring native plants (in progress, NGPN Inventory and Monitoring) -a categorization of invasiveness for nonnative plants -information regarding abundance, distribution, and density of nonnative plants not considered noxious by the state of South Dakota -methods for measuring nonnative plant treatment effectiveness
Bats	-future stressor mitigation -real-time microclimate data
Cave Microclimate	-summary of Pflitsch’s research (in progress) - overall heat and moisture exchange data -a continuous record of wind velocity
Cave drip Sites	-correlation of land use activities to changes in drip site water quality -analysis of recent drip site data
Changes in Cave Infiltration	-quantitative data on drip site infiltration
Cave Soundscape	-baseline soundscape data
Cave Viewshed	-results from the new photo-monitoring program in the cave

5.2 Component Condition Designations

Chapter 5 combines and discusses the common threads in findings regarding the components featured and provides a review of the conditions assigned to each natural resource component in JECA (Table 19). The graphics represented are symbols for the overall condition and trend assigned to each of the measures, but are not intended to substitute for in-depth accounts and explanations of the assigned conditions for each component, which are based on multiple factors.

Table 19. Component condition designations in JECA.

	Components	Measures	Reference Condition	Condition
Geographic Extent and Pattern				
Landscape Composition				
	Land cover extent	Landcover change	Pre-1908 land cover	
		Change in ponderosa pine distribution and density	Pre-1908 establishment	
	Fire	Frequency	Pre-1908 land cover	
		Severity	Pre-1908 establishment	
		Extent	Pre-1908 establishment	
Biological Components				
Ecosystem and Community				
	Native plant communities	Exotic plant distribution and density	Pre-exotic infestation	
Biotic Composition				
	Bats	Total number of hibernating bats by genus	Bat count ranges after 1992 standardized count methodology	
Chemical and Physical Characteristics				
Cave Environment				
	Microclimate	Temperature (overall heat exchange)	Pre-1908 establishment	
		Pressure (air exchange)	Pre-1908 establishment	
		Humidity (overall moisture)	Pre-1908 establishment	
		Wind velocity	Pre-1908 establishment	
Water Quality				
	Drip Sites	Chloride concentrations	Un-impacted drip sites	
		Nitrate concentrations	Un-impacted drip sites	
		Pesticide concentrations	No pesticides	
Hydrology				
	Changes in infiltration	Permeability	Un-impacted drip sites	
Goods and Services				
Non-Consumptive				
	Soundscape - Cave	Decibel levels	"Natural" cave experience	
	Viewshed - Cave	Natural cave views	"Natural" cave experience	

All component conditions at JECA are of low or moderate concern (Table 19). The condition of components related directly to Jewel Cave are generally of low concern with stable conditions, except for cave soundscape and chloride concentrations at certain drip sites, which are of moderate concern. Overall, the condition of Jewel Cave resources is of low concern.

Most measures of noncave resources (i.e., land cover, native plant communities, fire, and bats) indicate conditions of moderate concern. The condition of native plant communities in JECA is of moderate concern with a declining condition due to a steady influx of nonnative plants. The measures for land cover and fire indicate a condition somewhere between low and moderate concern. The condition of bats at JECA is of low concern. Overall, the condition of terrestrial resources identified in this assessment is of moderate concern, but stable.

5.3 Park-wide Condition Observations

Jewel Cave is the major natural resource in JECA, containing stalactites, stalagmites, draperies, frostwork, flowstone, boxwork, and hydromagnesite balloons (NPS 2007, 2011). Multiple threats exist to the condition of these unique physical features in the cave, including contaminated water, changes in infiltration, dust and debris accumulation, smearing of manganese onto other cave features, and changes to the cave's microclimate. Cave features are sensitive to the quality and quantity of water entering the cave at drip sites, both of which have been altered by above-ground human activities. Cave tours are the primary visitor activity in JECA. Visitors introduce debris and stir up dust along tour routes, which can impact cave features and biota, and they transfer dark colored manganese to the surface of lighter colored features. Jewel Cave's microclimate is altered near the artificial cave entrances and in the immediate vicinity of tour routes, but otherwise remains constant. Impacts to cave resources by these various threats have been minor and localized to the cave tour routes, and the NPS (2007) describes the cave as in nearly pristine condition. The natural soundscape of Jewel Cave is impacted by nonnatural sounds from people walking on the aluminum walkways, sounds from large tour groups, and from humming emitted by the electrical lighting system. There are plans to replace the walkway and lighting system to reduce the level of nonnatural sounds in the cave.

In conclusion, the aboveground resources in the park play are an important aspect of the condition of Jewel Cave. The native plant communities, fire, and land cover components are intrinsically linked, and changes in these dynamic components can influence cave components, such as infiltration or drip sites; consequently, stressors to these above-ground resources are a concern for all resources within JECA. To further complicate management, much of Jewel Cave is located outside of the park boundary, making management of fire and plants on non-NPS lands an important aspect of Cave resource components. Even with this complicated scenario, the conditions of most resources examined in this assessment are of low concern.

Literature Cited

National Park Services (NPS). 2007. Cave and Karst Management Plan - Environmental Assesment. U.S. Department of the Interior. Jewel Cave National Monument. Custer, SD.

National Park Service (NPS). 2011. Discover Buried Treasure. Online (http://www.nps.gov/jeca/index.htm). Accessed 14 February 2011.

Appendices

Appendix A. Nonnative plant species indicated as "present in park" and their status as either a state (South Dakota) or county noxious weed in JECA (NPS 2007[1]).

Scientific Name	Common Name	Noxious
Agropyron cristatum	crested wheatgrass	
Agrostis stolonifera var. stolonifera	creeping bentgrass	
Alyssum desertorum	desert madwort	
Amaranthus retroflexus	redroot amaranth	
Arctium minus	lesser burrdock	
Artemisia biennis	biennial wormwood	
Bromus commutatus	bald brome	
Bromus inermis var. inermis	smooth brome	
Bromus inermis var. pumpellianus	Pumpelly's brome	
Bromus japonicus	Japanese brome	
Bromus tectorum	cheatgrass	
Camelina microcarpa	littlepod false flax	
Capsella bursa-pastoris	shepherd's purse	
Carduus nutans	nodding plumeless thistle	
*Centaurea stoebe**	spotted knapweed*	
Chenopodium album	lambsquarters	
Cirsium arvense	Canada thistle	x
Cirsium vulgare	bull thistle	x
Conringia orientalis	hare's ear mustard	
Convolvulus arvensis	field bindweed	
Coronilla varia	purple crownvetch	
Cynoglossum officinale	gypsyflower	
Daucus carota	Queen Anne's lace	
Descurainia pinnata ssp. filipes	western tansymustard	
Descurainia sophia	herb sophia	
Elaeagnus angustifolia	Russian olive	
Elymus repens	quackgrass	
Eragrostis cilianensis	stinkgrass	
Erysimum cheiranthoides	wormseed wallflower	
Euphorbia esula	leafy spurge	x
Hyoscyamus niger	black henbane	
Kochia scoparia	Mexican-fireweed	
Lactuca serriola	prickly lettuce	
Lappula squarrosa	European stickseed	
Leonurus cardiaca	common motherwort	
Marrubium vulgare	horehound	
Matricaria discoidea	disc mayweed	
Medicago lupulina	black medick	
Medicago sativa	alfalfa	
Melilotus alba	white sweetclover	
Melilotus officinalis	yellow sweetclover	

Note: spotted knapweed was discovered in JECA in 2007. Russian knapweed was discovered in 2010.

Date were queried from:

[1] National Park Service (NPS). 2007a. JECA certified plant species list. Retrieved from the Inventory and Monitoring Program, Northern Great Plains Network website, Last updated 21 August 2007. Online at: http://science.nature.nps.gov/im/units/ngpn/inventory/parkspslists.cfm Accessed 12 January 2010.

Appendix A. Nonnative plant species indicates as "present in park" and their status as either a state (South Dakota) or county noxious weed in JECA (NPS 2007[1]). (continued)

Scientific Name	Common Name	Noxious
Nepeta cataria	catnip	
Phleum pratense	timothy	
Plantago major	common plantain	
Poa compressa	Canada bluegrass	
Poa palustris	fowl bluegrass	
Poa pratensis	Kentucky bluegrass	
Poa trivialis	rough bluegrass	
Polygonum achoreum	leathery knotweed	
Portulaca oleracea	little hogweed	
Potentilla norvegica ssp. monspeliensis	Norwegian cinquefoil	
Rumex crispus	curly dock	
Rhaponticum repens (Centaurea repens)	Russian knapweed	x
Salsola tragus	prickly Russian thistle	
Setaria viridis	green bristlegrass	
Silene latifolia ssp. alba	bladder campion	
Sisymbrium altissimum	tall tumble mustard	
Sisyrinchium montanum	strict blue-eyed grass	
Solanum rostratum	buffalobur nightshade	
Sonchus asper	spiny sowthistle	
Taraxacum laevigatum	rock dandelion	
Taraxacum officinale	common dandelion	
Thinopyrum ponticum	tall wheatgrass	
Thlaspi arvense	field pennycress	
Tragopogon dubius	yellow salsify	
Trifolium hybridum	alsike clover	
Trifolium pratense	red clover	
Trifolium repens	white clover	
Verbascum thapsus	common mullein	

Note: spotted knapweed was discovered in JECA in 2007. Russian knapweed was discovered in 2010.

Date were queried from:

[1] National Park Service (NPS). 2007a. JECA certified plant species list. Retrieved from the Inventory and Monitoring Program, Northern Great Plains Network website. Last updated 12 August 2011. Online at: http://science.nature.nps.gov/im/units/ngpn/inventory/parkspslists.cfm Accessed 12 January 2010.

Appendix B. Area of mapping units within the entire project area and within JECA (Salas and Pucherelli 1998[1]).

				Hectares (acres)		% Composition	
Map Unit	**Description**	**Anderson Level II Code**	**Description**	**Within mapping area**	**Within park boundary**	**Mapping area**	**Park boundary**
-	-	11	Residential	0.5 (1.2)	0.5 (1.2)	<0.1	<0.1
-	-	12	Commercial and Services	2.1 (5.2)	2.1 (5.2)	<0.1	0.4
-	-	14	Transportation, Communications and Utilities	11.6 (28.7)	2.0 (4.9)	<0.1	0.4
-	-	21	Cropland and Pasture	321.8 (795.2)	1.0 (2.5)	8.5	0.2
-	-	53	Reservoirs	0.10 (0.2)	0.0 (0.0)	<0.1	<0.1
-	-	62	Nonforested Wetland	0.4 (1.0)	0.0 (0.0)	<0.1	<0.1
-	-	75	Strip Mines, Quarries, and Gravel Pits	1.6 (4.0)	0.0 (0.0)	<0.1	<0.1
BW	Ash Leaf Maple (Box elder) / Choke Cherry Forest	-	-	2.8 (6.9)	0.0 (0.0)	<0.1	<0.1
GS	Grass / Shrub Complex	-	-	75.5 (186.6)	21.6 (53.4)	2.0	4.0
P1	Ponderosa Pine Complex I	-	-	2,270.5 (5,610.5)	227.6 (562.4)	59.7	42.0
P2	Ponderosa Pine Complex II	-	-	1,099.3 (2,716.4)	287.4 (710.2)	28.9	53.0
PT	Quaking Aspen / Choke Cherry Forest	-	-	15.9 (39.3)	0.0 (0.0)	0.4	<0.1
			Totals:	3,801.7 (9,394.2)	542.0 (1,339.3)		

[1] Salas, D. E., M. J. Pucherelli. 1998. USGS-NPS Vegetation mapping Jewel Cave National Monument, South Dakota.

Appendix C. Rare plants of South Dakota occurring at JECA (Hautcooper et al. 1985[1]). Reproduced from Marriott and Hartman (1986[2]).

Taxon	1986 SDNHP Status*	State Rank (2011) SD NHP*	Global Rank (2010) (NatureServe™)*	Comments	Status at JECA
Richardson's Sedge (*Carex richardsonii*)	U	Delisted	G5	occurs in forests of Black Hills; rare or extirpated in ND, WY	two collections from pine forest on ridges south of Lithograph Canyon and in old area southeast of residence
Ross Sedge (Carex rossii)	C (p)	Delisted	G5	several occurrences in pine forests of Black Hills and northwest SD	occasional in open pine forests
Idaho Fescue (*Festuca idahoensis*)	U	S4	G5	reported for w SD but no sites have been verified	one collection from drew south of VC parking lot; first known SD collection
(*Stipa robusta* or *Achnatherum robustum*)	U	S3	G5	few occurrences in pine savannahs of Black Hills	one collection from JECA cited by Thomasson (1981)
Beautiful Fleabane (*Erigeron formosissimus*)	U	S4	G5	occurs in meadows of Black Hills; often confused with *E. glabellus*	occasional in forest openings and on disturbed sites
Nippleseed, Thelesperma (*Thelesperma megapotamicum*)	U	S3S4	G5	occurs in dry soil of southwest SD; a primarily southern Great Plains species	several individuals near steps from Visitor Center to parking low (probably planted)
Hookers' Townsendia (*Townsendia hookeri*)	U	S3	G5	few reports for exposed sites of southwwest SD	many individuals on road-cuts of U.S. Hwy 16 east of Hell Canyon

*Current (2011) South Dakota Natural Heritage Program Rank and Global Rank (NatureServe™) columns were added to the original table from the South Dakota Game, Fish and Parks website and the NatureServe website, 2010).

Status Codes and definitions

C - uncommon; apparently secure in state but warrants monitoring; may be localized or declining. (1986)
U - status undetermined; possible rare, declining or extirpated in state; more information needed. (1986)
(p) - peripheral: a species whose occurrence in SD represents the edge of its natural range. (1986)
S3 - vulnerable - Vulnerable in the nation or state due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation.
S4 – Apparently secure (2011)
SNR – not ranked by state (2011)
G5 - Demonstrably secure, though it may be quite rare in parts of its range, especially at the periphery.

[1] Hautcooper, W. C., D. J. Ode, J. A. Person, and G. M. Vandel III. 1985. Rare animals and plants of South Dakota. Prairie Naturalist 17:143–165

[2] Marriott, H., and R. L. Hartman. 1986. A survey of the vegetation of Jewel Cave National Monument. Completion Report, University of Wyoming, NPS Research Center Project.

Appendix D. State and local noxious weeds (not all in JECA) (Custer County, South Dakota).

State Noxious Weed List (South Dakota Department of Agriculture)

- leafy spurge (*Euphorbia esula*)
- Canada thistle (*Cirsium arvense*)
- perennial sow thistle (*Sonchus arvensis*)
- hoary cress (*Cardaria draba*)
- Russian knapweed (*Rhaponticum repens*)
- purple loosestrife (*Lythrum salicaria*)
- saltcedar (*Tamarix aphylla*)

Local (Custer County) Noxious Weeds List

- absinth wormwood (*Artemisia absinthium*)
- black henbane (*Hyoscyamus niger*)
- bull thistle (*Cirsium vulgare*)
- chicory (*Cichorium intybus*)
- common Burdock (*Arctium minus*)
- common mullein (*Verbascum thapsus*)
- common tansy (*Tanacetum vulgare*)
- dalmatian toadflax (*Linaria dalmatica*)
- diffuse knapweed (*Centaurea diffusa*)
- field bindweed (*Convolvulus arvensis*)
- giant knotweed (*Polygonum sachalinense*)
- houndstongue (*Cynoglossum officinale*)
- musk thistle (*Carduus nutans*)
- phragmites (*Phragmites australis*)
- plumeless thistle (*Carduus acanthoides*)
- poison hemlock (*Conium maculatum*)
- puncturevine (*Tribulus terrestris*)
- Scotch thistle (*Onopordum acanthium*)
- spotted knapweed (*Centaurea maculosa*)
- sulfur cinquifoil (*Potentilla*)
- St. Johnswort (*Hypericum perforatum*)
- yellow toadflax (*Linaria vulgaris*)

The Department of the Interior protects and manages the nation’s natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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