National Park Service
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Natural Resource Stewardship and Science

Badlands National Park

Climate Change Vulnerability Assessment

Natural Resource Report NPS/BADL/NRR—2012/505

ON THE COVER
Overlooking the Badlands Wilderness Area in Badlands National Park
Photograph by: Shannon Amberg, SMUMN GSS.

Badlands National Park

Climate Change Vulnerability Assessment

Natural Resource Report NPS/BADL/NRR—2012/505

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Executive Summary

The impacts of global climate change are a growing concern for natural resource managers worldwide, including those at Badlands National Park (BADL) in South Dakota. By 2100, conditions here are projected to become warmer and drier. The National Park Service (NPS) recognizes the importance of understanding the effects of climate change on park resources across the country and of developing adaptive management strategies to address these effects. Therefore, the NPS Climate Change Response Program initiated a climate change vulnerability assessment (CCVA) for BADL with two priorities in mind: 1) to assess the potential vulnerability to climate change of BADL natural and cultural resources through the development and implementation of a CCVA, and 2) to use the project as a pilot study for developing a methodology for projecting regional climate changes and a process for assessing natural and cultural resource vulnerability to these changes.

A CCVA is an assessment of the likelihood and extent to which projected climatic shifts (including such variables as precipitation and temperature) will have adverse or beneficial influences on a select natural or cultural resource (e.g., species or plant community; sacred sites, archeological artifacts) (IPCC 2007). Objectives for the BADL CCVA include: 1) identify species, plant communities, and other resources likely to be most affected by projected climate shifts and the associated physical and ecological changes, 2) provide an understanding of why these resources are likely to be vulnerable, including the interaction between climate variation and existing stressors to resources, and 3) provide an example for conducting vulnerability assessments that engage natural and cultural resource managers and key stakeholders who have a similar need for vulnerability assessment.

By the end of this century, average annual temperature in the BADL is projected to increase by 3-5° C (approximately 5-9° F) (Figure 1)[1]. While precipitation is likely to increase slightly, conditions will likely become drier due to increased evapotranspiration. Extreme events (e.g., drought, heat waves, thunderstorms) are also likely to become more frequent as well. Climate change projections are discussed in detail in chapter 3.

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

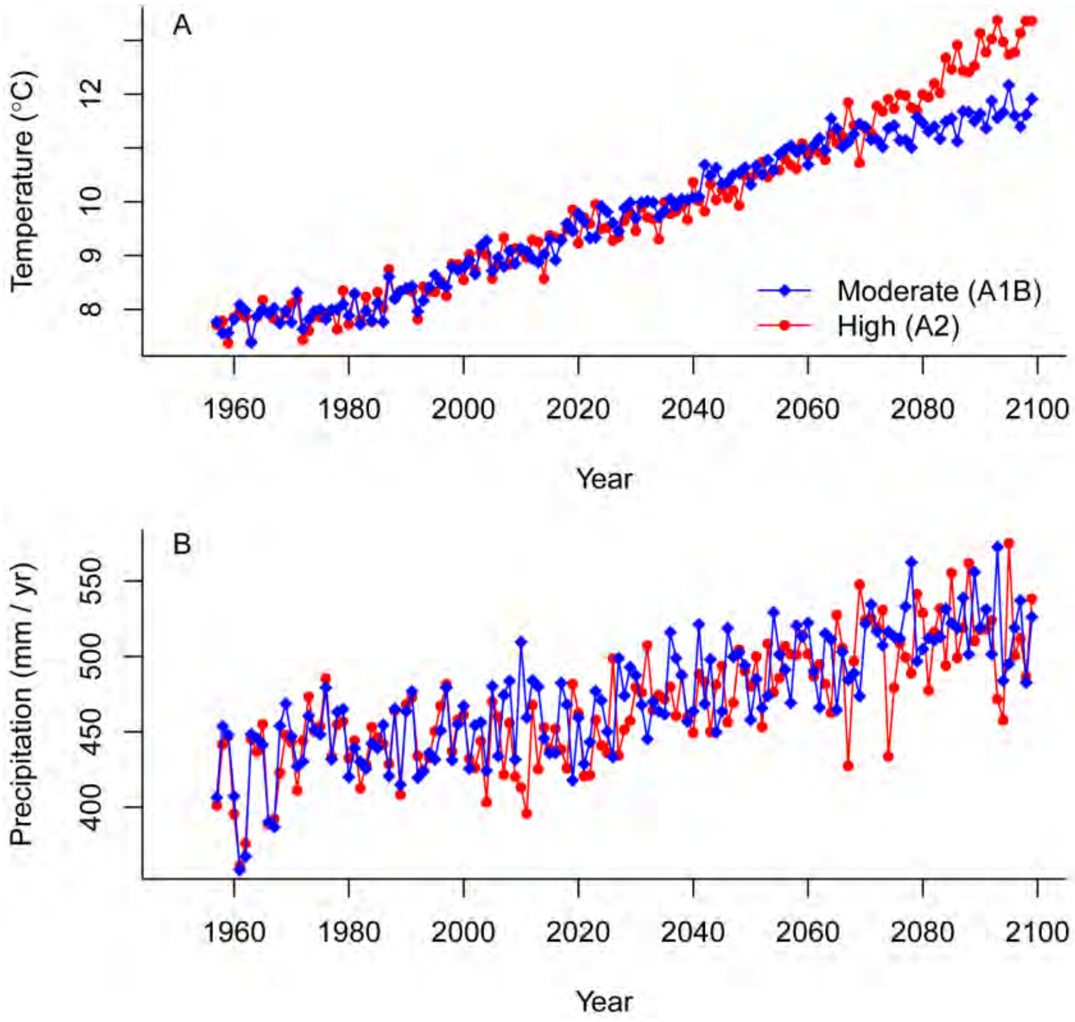

Figure 1. Projected (A) average annual temperature and (B) total annual precipitation changes for the BADL area from a suite of models, driven by a moderate or high CO_2 emissions scenario.

This CCVA assesses the vulnerability of natural resources to climate change at two scales: plant communities and individual wildlife species (or groups of species, such as grasslands birds). Three ecological processes that shaped the BADL landscape (fire, grazing, and erosion) are also addressed, as well as the park's significant paleontological resources. Finally, the potential impacts of climate change on the park's cultural resources (e.g., historic roads, archeological sites, ethnographic resources) are discussed.

BADL is divided into four plant communities based on vegetation classifications. The grassland and sparse badlands plant communities comprise nearly 90% of the park, with the remaining 10% consisting of woodlands and shrublands. Vulnerability to climate change was scored using six variables, as described in chapter 2. The degree of certainty was evaluated for each variable and summed to create an overall confidence for vulnerability. The grassland plant community was categorized as least vulnerable to climate change, as it is not particularly sensitive to extreme climatic events (e.g., droughts, flash floods) and shows a relatively high intrinsic adaptive capacity (Table 1). However, the predicted climate changes may favor short grasses (which typically occur on drier sites in the park) over mid-height grasses, resulting in a change in the structure and composition of the park's grasslands. The shrubland plant community was rated as moderately vulnerable, partially because climate change has the potential to exacerbate non-climate stressors such as invasive plant species. Some shrubland community types, such as sandbar willow shrublands, are likely more vulnerable than others, due to their dependence on specific hydrologic conditions.

Table 1. Summary of ecological community vulnerability to climate change in BADL and confidence in vulnerability ratings.

Plant Community	Climate Change Vulnerability*	Confidence+
Woodlands	High (23)	Moderate (12)
Shrublands	Moderate (18)	Moderate (12)
Sparse Badlands	Moderate (17)	Moderate (13)
Grasslands	Least (13)	High (15)

*6-13= least vulnerable, 14-19 = moderately vulnerable, 20-25 = highly vulnerable, 26-30 = critically vulnerable

+6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence.

The sparse badlands plant community was categorized as moderately vulnerable to climate change, primarily due to its narrow range and the location of BADL towards the southern end of that range. As with shrublands, climate change may also exacerbate current non-climate stressors, particularly invasive species such as sweetclover. The woodland plant community was rated as highly vulnerable to climate change, primarily due to its higher moisture requirements. Many woodland species are sensitive to droughts, which may become more frequent with the predicted climate changes. These changes may also exacerbate non-climate stressors such as pests and diseases.

Overall, the majority of species that make up the plant communities in BADL are not likely to respond rapidly to the climate changes projected for the region, but instead shifts could take decades or longer to occur. It is more likely that managers will see plant communities dissociated and decoupling, depending on plant species sensitivities to climate changes, and reconfiguring into novel combinations. Over the next few decades, it is possible that managers will begin to see the loss of the plant species with the greatest vulnerability (highest sensitivity to climatic changes) in each community, but the plant community as a whole may still retain its overall structure.

Species assessments consist of a narrative discussion based on several factors considered to influence a species' sensitivity to climatic changes (e.g., physiological sensitivity, degree of specialization). The vulnerability of a given species was often correlated with the vulnerability of the plant communities it utilizes. For example, bison and prairie dogs are considered least vulnerable to climate change because their primary habitat, the grassland plant community, is least vulnerable (Table 2).

Table 2. Summary of climate change vulnerability characteristics exhibited by target species or groups of species in BADL.

Species	Physiological Sensitivity	Specialist	Interspecific Interactions	Sensitive Habitat	Non-climate Stressors	Reproductive Potential
Prairie dog		○				○
Black-footed ferret		●	●			○
Swift fox		●	○			
Bighorn sheep	●	○			○	○
Bison		○				○
Mule deer				○	○	○
Bobcat				○	○	
Birds of prey	○	○				○
Grassland birds	○	○			●	
Herpetofauna	○			○	○	○

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic

Some species (and groups of species) were found to be more vulnerable to projected climate changes in the region, while other species were determined to be less vulnerable. Several of the species (or groups of species) targeted for assessment were identified as being more vulnerable to climate change than other native species found in the park. These include black-footed ferrets, bighorn sheep, mule deer, herpetofauna, and grassland bird species. Several characteristics emerged among those species found to be more vulnerable, including having physiological sensitivities to temperature, increased susceptibility to diseases, and reliance on rare, sensitive or highly vulnerable habitat. Conversely, a number of species were found to have low vulnerability to projected climate changes, including bobcat, bison, prairie dogs, swift fox, and birds of prey. These species, to an extent, have physiological or behavioral traits and adaptations that will allow them to better cope with the projected climatic changes in the region, including finding shelter during excessively warm periods, or having more generalized forage or prey item preferences. Although several of these species are specialists or rely on a sensitive habitat, the generalist tendencies they also posses allows for better coping with a change in environmental conditions.

Of the many non-climate stressors identified throughout this assessment for the ecological communities and species, certain stressors repeatedly emerged as likely to have a synergistic reaction with the projected climate changes for the region. These stressors include the encroachment of non-native species into ecological communities and increased susceptibility and prevalence of disease and pests for both ecological communities and individual species.

BADL's paleontological and cultural resources are also addressed in this assessment. Cultural resources are divided into five categories: ethnographic resources (plants and wildlife), archeological resources, museum collections, historic structures, and cultural landscapes. The primary climate-related concern for most of these resources is increased erosion. Climate change is likely to exacerbate this erosion stressor for paleontological and archeological resources, as well as several historic roads.

Overall, this CCVA defines a process for qualitative assessment of natural and cultural resources in BADL; it characterizes the projected regional downscaled climate changes and the best estimates of resource vulnerabilities based on available literature and professional judgment. This assessment shows that the physical, ecological, and cultural resources in BADL exhibit a wide range of climate change vulnerabilities and, consequently, it is likely that managers can expect to see substantial changes in the distribution of many of these resources in the next several decades. This CCVA is a very important first step in understanding how park resources may change with impending climate change. It provides managers a starting point from which to begin identifying the resources that may not cope well with climate changes and those that may be resilient to projected shifts.

Acknowledgments

We acknowledge the efforts of the core project planning group which includes Badlands National Park staff, NPS Climate Change Response Program staff, and Northern Great Plains Inventory and Monitoring Network staff. Special thanks to the BADL natural and cultural resources staff who, throughout the duration of this project, provided technical expertise and intimate knowledge of the resources examined in this report, including Brian Kenner, Eric Brunnemann, Steve Thede, Rachel Benton, Eddie Childers, Milton Haar, Aaron Kaye, Megan Cherry, Ellen Starck, Joshua Delger, and Jeffrey Manning. We greatly appreciate the engagement and involvement of park staff during the tenure of this project. Thank you also to Kara Paintner-Green, Network Coordinator of the Northern Great Plains Inventory and Monitoring Network, who acted as Agreement Technical Representative (ATR) and provided logistical insight on the project. Thanks to John Stamm , USGS Hydrologist, for his assistance with climate data and interpretation. We are especially grateful to Hector Galbraith of the Manomet Center for Conservation Sciences for allowing us to adapt his habitat vulnerability assessment approach and for providing feedback on our assessment methodology. Special thanks are given to Patty Glick of the National Wildlife Federation for her review of our methodology and to Evan Girvetz of The Nature Conservancy for his guidance in interpreting climate data.

In addition to the core project planning group, a number of individuals provided their resource expertise in the form of outside expert reviews of vulnerability assessments. Dan Swanson, NPS Fire Ecologist, provided substantial input to the fire assessment of this document. Amy Symstad (USGS Ecologist) and Beth Burkhart (Botanist, Wind Cave National Park) provided outside expert reviews and insights for the vegetation community assessments. Dr. Larry Stetler, Professor of Geological Engineering at South Dakota School of Mines and Technology, provided expert review of the erosion assessment. Dan Milchunas, Research Scientist at Colorado State University, reviewed the grazing assessment. Randy Griebel (Wildlife Biologist at Buffalo Gap National Grassland) and Greg Schroeder (former Wildlife Biologist at BADL and current Chief of Resources, Wind Cave National Park) provided expert review of the swift fox, prairie dog and black-footed ferret assessments. Susan Skagen, USGS Research Wildlife Biologist, and David Hanni, Science Division Director for Rocky Mountain Bird Observatory, provided expert review of the grassland birds and birds of prey assessments. Rick Wallen, Wildlife Biologist in the Bison Ecology and Management Program in Yellowstone National Park, provided expert review of the bison assessment. Steve Griffin and John Kanta, Wildlife Biologists with the South Dakota Department of Game, Fish and Parks, provided expert review of the mule deer and bighorn sheep assessments, respectively. Caren Goldberg, research scientist and volunteer at BADL, provided review of the herpetofauna assessment. Jill Cowley (NPS Historical Landscape Architect, Intermountain Region), Carrie Mardorf (NPS Cultural Landscape Inventory Coordinator, Intermountain Region), Jay Flaming (NPS Archeologist, Pacific West Region), Teresa Moyer (NPS Archeologist, National Center for Cultural Resources), Pei-Lin Yu (NPS Cultural Resource Specialist, Rocky Mountain CESU), Roberta Young (NPS Landscape Architect, Midwest Region), Michael Evans (NPS Senior Cultural Anthropologist, Midwest Region), Jay Sturdevant (NPS Archeologist, Midwest Region) and Marcy Rockman (NPS Climate Change Adaptation Coordinator for Cultural Resources, National Office) all provided insight and expert review of the cultural resources assessments.

Acronyms and Abbreviations

AET – Actual evapotranspiration

AMO - Atlantic Multidecadal Oscillation

ASMIS - Archeological Sites Management Information System

BADL – Badlands National Park

CCVA – Climate Change Vulnerability Assessment

CCRP - NPS Climate Change Response Program

EPA – Environmental Protection Agency

FMU - Fire Management Units

IPCC – Intergovernmental Panel on Climate Change

MWAC - Midwest Archeological Center

MWRO - Midwest Regional Office

NGPN - Northern Great Plains Inventory and Monitoring Network

NPP – Net Primary Production

NPS - National Park Service

OSPRA - Oglala Sioux Parks and Recreation Authority

PDO - Pacific Decadal Oscillation

PET – Potential evapotranspiration

PRISM - Parameter elevation Regressions on Independent Slopes Model

SDGFP – South Dakota Department of Game, Fish, and Parks

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

SRES – Special Report on Emissions Scenarios

T & E – Threatened and Endangered

USFS - United Stated Forest Service

USGS - United States Geological Survey

WICA - Wind Cave National Park

WCRP - World Climate Research Programme

WICCI - Wisconsin Initiative on Climate Change Impacts

Chapter 1 Introduction

The recent rapid changes in Earth's climate are well documented and include such impacts as significant increases in average temperatures and precipitation in the last 50 years, increased incidence of extreme weather events (e.g., extended drought, heavy rainstorms, and increasingly powerful hurricanes), a rise in sea level, and decline of Arctic sea ice (IPCC 2007). These climatic shifts have already been linked to a number of impacts to natural systems, including such phenological changes as earlier onset of plant greenness, earlier insect emergence and flowering of plants, shifts in the onset of migration and breeding seasons, and changes in geographic ranges (summarized in Stein and Glick 2011). With carbon emissions expected to continue at the current rates, many scientists anticipate even greater influences of climate change to ecosystems and species in the next several decades.

With mounting evidence of the wide-ranging effects of climate change, natural resource managers are increasingly questioning the efficacy of traditional conservation approaches and exploring new, adaptive strategies. Managers must now anticipate an increasingly uncertain future and take into account much longer time frames (e.g., several decades) when developing and adapting conservation goals and strategies. Even further, managers must also consider the synergistic effects of climate and non-climate threats and stressors (such as existing disease, habitat fragmentation, predation, or low genetic diversity) and how these interactions will affect the natural systems and the species they support.

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

A Need for Vulnerability Assessment

Climate change can impair the natural and cultural resources that the National Park Service (NPS) was established to preserve. Jonathon Jarvis, director of the National Park Service has referred to climate change as, "our newest, greatest challenge to maintaining America's natural and cultural heritage unimpaired for future generations" (Jarvis 2009). The NPS recognizes the importance of understanding the impacts and influences of climate change on national park resources and developing adaptive management strategies to best conserve species and ecosystems in light of rapidly shifting climate. A recent initiative in the NPS Climate Change Response Program (CCRP) focuses on building a greater understanding of the effects and influences that projected climate shifts may have on natural and cultural resources across the National Park System. This initiative encourages the use of Climate Change Vulnerability Assessments (CCVAs) as part of a strategy to determine and better understand natural and cultural resource vulnerability to climate change and the synergistic relationships these changes may have with existing threats and stressors to those resources.

With two overarching priorities in mind, the NPS Climate Change Response Program initiated a CCVA for Badlands National Park (BADL). The first project priority was to assess the potential vulnerability to climate change of BADL natural and cultural resources through the development and implementation of a CCVA. Climate change has been a growing concern for BADL managers who wish to have a better understanding of the degree of change projected for the region and the resources that are most vulnerable to the projected changes. A CCVA would estimate the climatic changes and identify those park resources most at-risk and most resilient.

The second priority of the CCVA was to use BADL as a pilot study location for developing a methodology for projecting regional climate changes and a process for assessing natural and cultural resource vulnerability to these changes. It is the intent that the process and methods outlined in this CCVA can serve as a working model for other parks and protected areas that have a similar need for a vulnerability assessment.

The BADL CCVA is a collaborative effort between the National Park Service and Saint Mary's University of Minnesota, GeoSpatial Service (SMUMN GSS). Individuals involved in the development and implementation of this project specifically include BADL park resource staff, Northern Great Plains Inventory and Monitoring Program (NGPN) staff, NPS Climate Change Response Program staff, and SMUMN GSS analysts. The entire collaborative group is hereafter referred to as the "core project planning group."

Objectives for BADL Climate Change Vulnerability Assessment

The potential effects of climate change on park resources has become a growing concern for BADL managers and their partners in recent years and, thus, they have prioritized the identification of those resources most vulnerable to these changes as the first step in an effort to develop appropriate adaptive and mitigative conservation strategies.

The specific objectives outlined for the BADL climate change vulnerability assessment include:

- Identify species, plant communities, and other resources likely to be most affected by projected climate shifts and the associated physical and ecological changes;
- Provide an understanding of why these resources are likely to be vulnerable, including the interaction between climate variation and existing stressors to resources; and
- Develop guidance for conducting vulnerability assessments that engage natural and cultural resource managers and key stakeholders who have a similar need for vulnerability assessment.

To date, a variety of approaches have been used to conduct CCVAs. These range from a fine scale analysis, such as assessing the vulnerability of specific species, to a broader scale that focuses on the vulnerability of entire ecological communities or landscapes. Still other efforts have integrated a multi-scale approach in which both species level and community level vulnerability is considered. This CCVA adopts a multi-scale approach in which the vulnerability of key plant communities within BADL and selected species that rely on these communities for habitat is assessed. The rationale for this approach is discussed in detail in Chapter 2.

What is a climate change vulnerability assessment?

For the purpose of this CCVA, vulnerability is defined as "the extent to which a species, habitat, or ecosystem is susceptible to harm from climate change impacts" (Schneider et al. 2007, as cited by Stein and Glick 2011, pg. 9). Vulnerability consists of three key components: 1) *sensitivity* of a system to climate changes; 2) *exposure* of a system to climate changes; and 3) *capacity* to adapt to those changes (IPCC 2007, as cited by Stein et al. 2011). Sensitivity is a measure of the degree to which a system is affected, either adversely or beneficially, by a given change in climate. Exposure is a measure of the amount of climatic and environmental change that a species or system is likely to experience. Adaptive capacity is the ability of a species or system to accommodate or cope with climatic and environmental change impacts with minimal disruption. Figure 2 illustrates the theoretical relationship among the three components and how they interact to determine overall vulnerability.

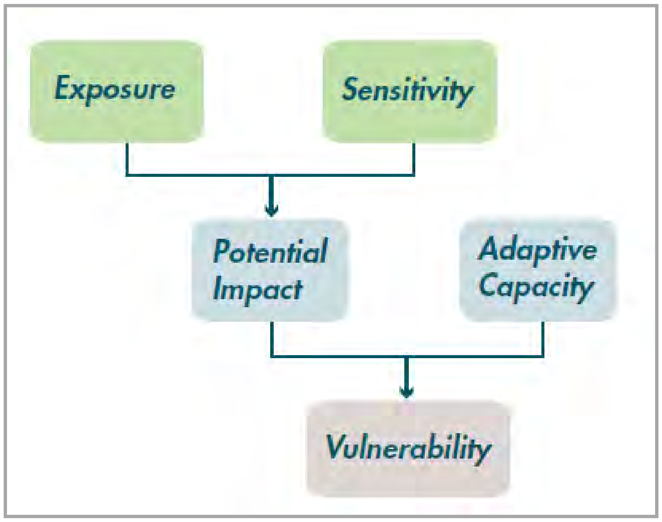

Figure 2. Key components of vulnerability, illustrating the relationship between exposure, sensitivity, and adaptive capacity (Source: Stein et al. 2011).

A CCVA is an assessment of the likelihood and extent to which projected climatic shifts (including such variables as precipitation and temperature) will have adverse or beneficial influences on a given natural or cultural resource (e.g., species, plant community, or ecosystem; sacred sites, archeological artifacts) (IPCC 2007, Stein and Glick 2011). As a result, CCVAs are increasingly viewed as a key tool for providing resource managers with information that can be used to aid adaptation planning efforts for vulnerable natural and cultural resources. Specifically, a CCVA makes three main contributions to resource management. First, a vulnerability assessment helps identify ***which*** resources are most or least vulnerable to estimated climate changes, a determination that better enables managers to prioritize resources for enhanced conservation (Stein and Glick 2011). Second, a CCVA can uncover ***why*** resources are vulnerable or resilient (Stein and Glick 2011). The assessment process helps to determine the characteristics of a resource that make it more vulnerable to or better able to cope with climatic shifts and the associated environmental changes; this information can better equip resource managers with the understanding necessary to develop the most appropriate and practical management responses to climatic shifts in their region. Finally, a CCVA can help elucidate gaps in knowledge that exist for certain cultural and natural resources in general, so that these gaps can be filled and the vulnerability of these resources more accurately assessed.

Background of Badlands National Park

Park History and Purpose

Though several national parks were established in the U.S. as early as 1872, these Federal lands were often managed by various agencies, including the U.S. Forest Service and the U.S. Army. This changed when the National Park Service Organic Act of 1916, signed into law by President

Woodrow Wilson, formally established the National Park Service, an agency of the Department of the Interior with a specific directive to assume responsibility and management of all national parks, monuments, historic places and battlefields (NPS 2008). The directive of the new agency was to:

> promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations. (NPS 2008)

Badlands National Park was first established as a National Monument in 1939 to protect the fossil resources and geologic land forms of the White River Badlands (NPS 2007). Lands on the Pine Ridge Indian Reservation were added in 1968, and the monument was redesignated as a National Park in 1978 (Stevens et al. 2006). Sixty-four thousand acres of the park were legally designated as wilderness in 1976 (NPS 2007). As stated in NPS (2007), the mission of BADL is to:

- Protect the unique landforms and scenery of the White River Badlands for the benefit, education, and inspiration of the public;
- Preserve, interpret, and provide for scientific research of the paleontological and geological resources of the White River Badlands;
- Preserve the flora, fauna, and natural processes of the mixed-grass prairie ecosystem;
- Preserve the Badlands wilderness area and associated wilderness values;
- Interpret the history of the Sioux Nation and Lakota people.

Visitation Statistics

From the 1960s to 2000, BADL received around one million visitors a year (NPS 2010a). Over the past decade, visitation has declined slightly to an average of 900,000 visitors per year, with most visitors coming to the park in the months of July and August (NPS 2010a). Around 35,000 visitors stay in the park's campgrounds each year (NPS 2010a).

Geographic Setting

BADL encompasses 98,240 hectares (242,756 acres) in southwestern South Dakota. The park is divided into two units: the 45,000-hectare (110,000-acre) North Unit, which includes the Sage Creek and Conata Wilderness Areas, and the slightly larger South Unit within the Pine Ridge Indian Reservation (NPS 2007). The South Unit is jointly managed by the NPS and the Oglala Sioux Tribe. The North Unit is almost completely surrounded by Buffalo Gap National Grassland, which is managed by the U.S. Forest Service.

The BADL region has a continental climate characterized by cold winters and hot summers. Extreme temperatures above 38° C (100° F) occur during the summer and temperatures below -18° C (0° F) are not unusual during the winter (NPS 2004). Brief, intense thunderstorms occur frequently during the summer months (NPS 2004). Annual precipitation averages 40.6 cm (16 in.), with 70% falling in May and June. Winter precipitation falls mostly as snow, but gusty winds blow large areas free of snow and sizable drifts may accumulate in road cuts and gullies (NPS 2004). The park's climate is discussed in greater detail in chapter 3 of this report.

BADL lies within the Northwestern Great Plains ecoregion, which encompasses the unglaciated Missouri Plateau (NPS 2004). The ecoregion is a semiarid rolling plain of shale, siltstone, and sandstone punctuated by occasional buttes and badlands (EPA 2010). The park is dominated by mixed-grass prairie and badlands formations with little or no vegetation. Wooded areas are found sporadically along streams and in canyons or "draws" with slightly moister microclimates. More than 400 plant species have been identified within BADL (NPS 2010b).

Common wildlife in BADL include mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), bison (*Bison bison*), black-tailed prairie dog (*Cynomys ludovicianus*), coyote (*Canis latrans*), and numerous small rodents (NPS 2004). More than 200 bird species have been observed (NPS 2004) and at least 11 herpetofaunal and 15 fish species are confirmed in the park. Several threatened, endangered, or candidate wildlife species occur within or near BADL (Table 3). The park has also identified five species of management concern for annual tracking under the Government Performance and Results Act (GPRA): bison, burrowing owl (*Athene cunicularia*), bighorn sheep (*Ovis canadensis*), bald eagle (*Haliaeetus leucocephalus*), and prairie dogs (BADL, Brian Kenner, Chief of Resources, e-mail communication, 12 December 2011). These species were selected either for their ecological importance or their scarcity. The park has recorded nearly 300 archeological sites, curated more than 200,000 archives and artifacts, and manages a variety of historic roads and structures.

Table 3. Threatened, endangered, and candidate species found in or near BADL (NPS 2010c, SDGFP 2010). Additional species identified by the South Dakota Natural Heritage Program or the U.S. Forest Service as rare or sensitive, respectively, are listed in Appendix A.

Common Name	Scientific Name	Abundance	Status
Bald eagle	*Haliaeetus leucocephalus*	Common	State threatened
Peregrine falcon	*Falco peregrinus*	Uncommon	State endangered
Black-footed ferret	*Mustela nigripes*	Uncommon	Federal endangered
Whooping crane	*Grus americana*	Unknown	Federal endangered
Sprague's pipit	*Anthus spragueii*	Uncommon	Federal candidate
Swift fox	*Vulpes velox*	Uncommon	State threatened
Black-tailed prairie dog	*Cynomys ludovicianus*	Common	Federal candidate
Sturgeon chub	*Macrhybopsis gelida*	Unknown	State threatened

Organization of Report

This report is organized into five chapters. The second chapter describes the development of the CCVA project for BADL including an explanation of establishing the project study boundary, the methodologies for assessing vulnerability of the main plant communities, target species, and cultural resources in the park, and the methodology employed in developing the climate change projections for the region. Chapter three presents the projected climate changes for the BADL region and includes a number of tables and graphs that outline and illustrate these shifts. These climatic projections address the exposure element of resource vulnerability. Chapter four addresses the sensitivity and adaptive capacity of park resources to climate changes. This chapter contains the vulnerability assessments for the main plant communities in the park, key faunal species, and cultural resources, as well as an interpretation of how climatic changes will influence the ecological processes of erosion, fire, and grazing. Chapter five highlights a discussion of the findings and presents several major conclusions of the overall assessment.

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Chapter 2 Project Methodology

Project Scoping

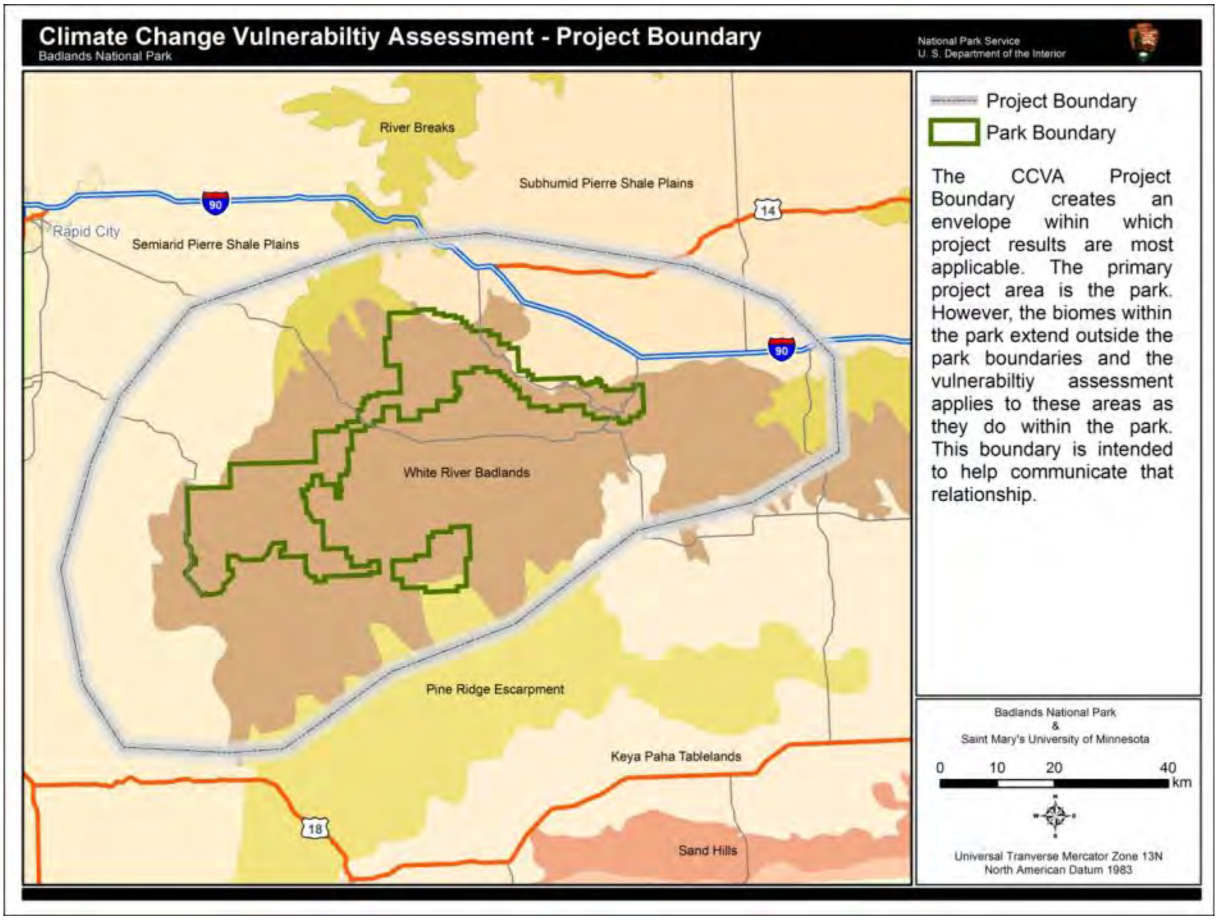
A project scoping meeting was held at BADL from 9-11 November 2010 to discuss goals and objectives, NPS expectations for the project outcome, project design, and the specific NPS and SMUMN GSS project roles. The meeting was two-part in nature. During the first day, BADL resource management staff, SMUMN GSS analysts, NGPN staff, and representatives from the NPS Climate Change Response Program (CCRP) discussed a number of important topics. SMUMN and NPS staff provided an introduction to climate change vulnerability assessments and the different ways they have been carried out to date, as well as the climate projections for the BADL region. The project planning group then outlined an appropriate scope for the BADL vulnerability assessment given project budget and timing and discussed the delineation of the study area boundaries, the park resources that should be targeted, the sources of information to be used for assessment, a peer-review of the assessments to ensure quality, strategies for communication while the project is ongoing, and potential project outputs and products.

Because BADL is located within a patchwork of federal, tribal, and private lands ownership, a cooperative effort among SMUMN, NPS and other key stakeholders was necessary for the overall conceptualization, design, and implementation of the project. Natural and cultural resource experts and managers from the immediate region were invited to attend a half day information and brainstorming session on day two. Additional attendees included representatives from the U.S. Forest Service Buffalo Gap National Grasslands, Oglala Sioux Parks and Recreation Authority (OSPRA), and the U.S. Geological Survey. Attendees were provided a brief introduction to CCVAs and the projected climate changes for the region, followed immediately by a discussion of items to consider in project planning and design. Specifically, the larger group discussed the proposed project boundary, the resources to take into consideration that occur both in BADL and the surrounding area, availability and access to potential sources of data, information, or individual expertise on target resources, and desired level of involvement by various stakeholders as the project progressed. Suggestions from this larger group were recorded and integrated into project planning when appropriate.

A detailed work plan was developed by the project planning group, based on discussions and decisions made at the initial planning meeting. The detailed scope of work highlighted the project objectives, the schedule of work, project tasks assumed by SMUMN GSS, the roles and responsibilities of the project partners (NPS and SMUMN), expectations, and the outputs generated at the conclusion of the project.

Project Boundary

During project scoping, the project planning group discussed the potential study area bounds and what extent would serve as an appropriate land area for conducting the vulnerability assessment. The project planning group agreed that, although BADL is the primary focus of the vulnerability assessment, many of the park resources (including plant communities, species that use the communities, paleontological and cultural resources) extend outside the park boundary. The project planning group agreed that the study area boundary should communicate that the resources and plant communities characteristic of BADL extend outside of the park boundary; the vulnerability of these resources and ecosystems can be assumed to also extend beyond the park boundary. A key input to decisions on the project boundary was the evaluation of the area needed to sustain biodiversity in the park. The “Protected Area Center Ecosystem” (PACE), as defined by Hansen et al. (2011), was used to define an intitial study area, and this was then modified to accommodate local expertise and cooperative management between NPS and USFS. Figure 3 shows the study area boundary. The boundary line is a wide generalized line and is not intended to imply explicit delineation of included or excluded resources.



The CCVA Project Boundary creates an envelope wihin which project results are most applicable. The primary project area is the park. However, the biomes within the park extend outside the park boundaries and the vulnerabiltiy assessment applies to these areas as they do within the park. This boundary is intended to help communicate that relationship.

Figure 3. BADL Climate Change Vulnerability Assessment study area boundary. The colored polygons show the EPA Level IV Ecoregion Classifications for the area (EPA 2010). These ecoregions helped to delineate the study boundary with regard to the primary biomes that envelope the park and surrounding areas, the White River Badlands.

Historical Climate Patterns and Future Climate Projections

For this assessment, both historical climate patterns and projected climate changes over the next 90 years (out to the year 2100) were examined for the BADL region. Historical climate patterns (mean minimum and maximum temperatures and total precipitation) were analyzed to create a picture of climate in BADL during the past century. This historical view, when compared to climate projections for the next 90 years, helps to illustrate the degree to which climate is anticipated to change in the region during this century.

Evaluating historical climate patterns

The PRISM (Parameter elevation Regressions on Independent Slopes Model) climate group at Oregon State University provides gridded data for various climate parameters with complete coverage for the continental United States from 1895 to the present (Daly et al. 2002; PRISM 2010). Subsets of these data are publicly available for analysis via their web site (http://prism.oregonstate.edu/).

Using PRISM climate data, historical temperature and precipitation patterns for the BADL study area were summarized and evaluated to build a context of historical climate to which future climatic projections may be compared. Specifically, mean monthly minimum and maximum temperature (°C) and total monthly precipitation from 1895 to present were examined. A detailed explanation of the analysis of historical climate patterns in the BADL region is provided in chapter 3.

Creating Climate Change Projections

Climate change has been linked in large part to the release of carbon into the atmosphere and the rate at which emissions occur on a continuous basis. The SRES A1B and A2 family of carbon emissions scenarios are often used to estimate potential future changes in climate; these scenarios are commonly referred to as ‘moderate’ and ‘high’ carbon emissions scenarios (Nakicenovic et al. 2000). Both the A1B and A2 emissions scenarios were used in this assessment to estimate climatic changes in the BADL region through the year 2100.

Estimates of future climate in BADL were created using statistically downscaled model projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset. Results are reported from 14 model-parameter combinations for the moderate (A1B) emissions scenario, and 12 model-parameter combinations for the high (A2) emissions scenario. Appendix B provides a discussion of the climate models and reference periods used for the analysis and justification for their selection, as well as a detailed description of the data sets. A more detailed explanation of how climate change projections were created for the BADL region is provided in chapter 3.

Assessing Vulnerability to Climate Change

Target Resources for Assessment

Assessing vulnerability of natural systems to climate change is a relatively new science and the few examples of CCVAs completed to date exhibit a wide range of approaches to the process, primarily with regard to the scale at which analysis occurs. For instance, some assessments have focused on the vulnerability of certain ecologically influential species in a natural system, particularly those listed as threatened or endangered (Galbraith and Price 2011). Other assessments have focused on the vulnerability of specifically defined ecosystems within a region (e.g., vulnerability of Massachusetts fish and wildlife habitats (Galbraith and O’Leary 2011); species vulnerability assessment for the Middle Rio Grande, New Mexico (Finch et al. 2011)) and, based on the vulnerability of the ecosystem as a whole, make inferences about the subsequent effect on the species that primarily use those ecosystems.

A CCVA that assesses the vulnerability of ecological communities casts a broader net in examining resources, rather than looking at a list of individual species. A focus on the community scale makes it possible to infer that the degree of vulnerability for a community would directly influence the sensitivity and vulnerability of individual species residing in that community. For example, if a community has low vulnerability to climate change and is expected to change very little despite projected climate shifts, it is likely that the diversity of species residing in that community would also not experience much change or stress due to climate change. Likewise, if a community is estimated to be highly vulnerable to climate change and is expected to experience dramatic changes in composition or distribution, it is likely that the species dependent upon that community for habitat would also be affected. Thus, a focus on the vulnerability of ecological communities within a landscape (i.e., the ecosystem or community scale) can provide a larger umbrella under which vulnerability may be examined and inferred for individual species inhabiting those communities.

It is common for natural resource managers in National Parks to focus conservation efforts on a species/population scale, while considering the ecological health and processes at the landscape level. This is the case for resource managers at BADL. Thus, following a series of discussions, the project planning group agreed that a multi-scale vulnerability assessment approach that addresses vulnerability at both the plant community and individual species scales in BADL would be the most appropriate for addressing the information needs of park managers. This multi-scale approach addresses both natural and cultural resources in the park. Specifically, this approach assesses how the likely effects of climate change will affect:

1) the main plant communities that characterize BADL and the surrounding region (defined by vegetation classes in BADL);
2) selected wildlife species (some of which are species of conservation concern – either threatened or endangered) directly through climate shifts or indirectly through effects on the plant communities used as habitat;
3) the main disturbance regimes associated with the BADL landscape (e.g., fire, erosion, and grazing)
4) paleontological resources (e.g., fossils); and
5) cultural resources (e.g. archeological, ethnographic, museum collections, historic structures, and cultural landscapes).

Table 4 lists the wide variety of park resources, both natural and cultural, for which climate change vulnerability is assessed. The main plant communities of the BADL landscape are the primary focus of this vulnerability assessment. One shortcoming of a community-focused assessment is that it may be too broad of an analysis to illuminate the finer details with regard to vulnerability, such as identifying a species that may be critically vulnerable and in need of mitigative management actions. In an effort to avoid this, a number of key wildlife species occurring in the different plant communities, particularly those of significant management concern (such as T & E species) or species viewed as indicators of ecosystem health, as well as several groups of species, were also targeted for assessment. Species vulnerability was assessed largely by their use of plant communities in combination with life history traits.

In addition to being ecologically important, many species occurring in BADL or the surrounding area are culturally significant to the Lakota tribe and other surrounding Native American communities. Thus, additional plant and animal species known to be important to Lakota culture and history, such as the golden eagle or wild turnip, were included in the assessment. The vulnerability of paleontological resources (e.g., fossils) that occur in the rock formations throughout the park were also assessed. The ecological processes of fire, erosion and grazing all play a significant role in BADL and the surrounding landscape and, thus, were examined to better understand how shifting climate may influence current regimes and the plant communities in which they occur.

Table 4. Target plant communities, ecological processes, and natural and cultural resources targeted for vulnerability assessment in BADL. (Bold text indicates a species of conservation concern, either threatened or endangered).

Plant Communities	Ecological Processes	Species	Paleontological Resources	Cultural Resources
Grasslands	Erosion	Bighorn sheep	Fossils	Archeological resources
Shrublands	Fire	Bison		Historic roads/structures
Sparse Badlands	Grazing	**Black-footed ferret**		Museum collections
Woodlands/woody draws		Bobcat		Cultural landscapes
Springs and seeps		Mule deer		Ethnographic resources (i.e., culturally significant plant and animal species)
		Prairie dogs		
		Swift fox		
		Birds of prey (burrowing owl, **bald eagle, peregrine falcon**)		
		Grassland birds (including sharp-tailed grouse and lark bunting)		
		Herpetofauna		

Assessing Natural Resources – Plant Community Level

Variables of Interest

The approach to evaluating the vulnerability of plant communities to climate change in this CCVA is an adaptation of an approach developed by Hector Galbraith (Manomet Center for Conservation Sciences, Manomet, MA) to assess the vulnerability of habitats in 13 northeastern states. Galbraith's approach used 11 variables to assess vulnerability (Galbraith 2011). Each variable is designed to capture to some degree either sensitivity, exposure, or adaptive capacity of a diversity of ecological communities, in an effort to assess their overall vulnerability to climate shifts. Galbraith's approach was adapted by selecting six of the original variables to assess the vulnerability of the woodlands, shrublands, sparse badlands, and grasslands plant communities in the Badlands region. These variables include (descriptions based on Galbraith 2011):

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

2. **Sensitivity to extreme climatic events.** Some plant communities may be more vulnerable than others to extreme climatic events or climate-induced events (drought, floods, ice storms,

windstorms). Such events are projected to become more frequent and/or intense under climate change.

3. **Dependence on specific hydrologic conditions.** Some plant communities are confined to areas with specific and relatively narrow hydrologic conditions. Changes in precipitation amount, type (snow vs. rain), and timing are projected under all climate change models (though the direction and degree of change vary across models), potentially threatening these community types.

4. **Intrinsic adaptive capacity.** While all plant communities are likely to have characteristics that may enable them to withstand the effects of a changing climate, their adaptive capacities (their ability to resist or recover from stress) will vary, depending on their intrinsic and extrinsic characteristics and their condition:

    A. The physical diversity within which a plant community exists may affect its resilience and adaptive capacity: communities with diverse physical and topographical characteristics (variety in aspects, slopes, geologies and soil types, elevations) may be more able to survive climate change than communities that are less varied, since the former, by existing across widely differing conditions, may be at lower risk of being eliminated by any future climatic conditions.

    B. Some plant communities may be intrinsically more resistant to stressors because (for example) they have more rapid regeneration times. Communities in which the recovery period from the impacts of stressors is shorter (<20 years) may have greater intrinsic adaptive capacities than slower developing communities (recovery times of >20 years). For example, woodlands may take a hundred years or more to recover from fire or pest impacts. This may render them intrinsically more vulnerable to the potential intervening effects of climate change than plant communities that have shorter recovery periods (e.g., grasslands or shrub communities).

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

5. **Vulnerability of ecologically influential species to climate change.** Ecologically influential species are those that have substantial influences on community structure. Examples are abundant tree species in a woodland, such as Rocky Mountain juniper in dry coniferous woodlands, or silver sagebrush in mesic shrublands, whose disappearance from the system would significantly alter plant composition and community structure. If there is reason to

believe that ecologically influential species in a plant community are particularly vulnerable to climate change, the whole community may be in jeopardy.

6. **Potential for climate change to exacerbate impacts of non-climate stressors.** For some plant communities, it is likely that significant impacts of climate change will be expressed through their exacerbating or mitigating effects on current or future non-climate stressors. One example is the potential magnifying effects of warming temperatures on cold-limited pest species or invasives (e.g., pine beetle). In this variable it is the intent to capture the potential effects of this interaction between climate change and non-climate change stressors.

General Process:
Each variable was assigned a "best estimate" score from 1 (least vulnerable) to 5 (most vulnerable) on the likely vulnerability of a plant community to future climate change and non-climate stressors (based on the available scientific literature, data, and expert opinion). Scores were summed to produce an overall score of a plant community's vulnerability. The total minimum score was six and the total maximum score is 30. The overall score was then organized into one of four categories: critically vulnerable, highly vulnerable, moderately vulnerable, and less vulnerable. These translate into community response categories ranging from a plant community likely to be eradicated or greatly reduced in extent in the study area to a plant community that may sustain modest reduction or actually increase in extent within the study area. These categories, as used in this assessment, are defined as:

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

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

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

- **6-10 =** Low certainty (approximates <30% certainty) → Low confidence
- **11-14 =** Moderate certainty (approximates 30% to 70% certainty) → Moderate confidence
- **15-18 =** High certainty (approximates >70% certainty) → High confidence

The certainty scores for each variable were then summed up to determine a certainty evaluation for the overall vulnerability score of the plant community. This certainty evaluation becomes a statement of confidence in the overall vulnerability score for the plant community.

When a clear "best estimate" vulnerability score did not stand out, the analyst had the option of assigning an alternative score (a highly possible but less likely outcome than the best estimate) in addition to the best estimate score. The alternative score is the "next best estimate" of vulnerability for a variable, taking into account the uncertainty attached to a variable (i.e., the lack of information or understanding about a plant community or a species). These alternative scores, in conjunction with the best estimate vulnerability score, serve to capture the range of highly likely possibilities that may exist for the vulnerability of a plant community (adapted from Galbraith and Price 2011). When certainty is high, vulnerability will likely be represented by a single value; when certainty is low, vulnerability will be represented by a range of scores. The alternative scores also show the potential direction of the vulnerability, in that an alternative score for a variable may reflect a lesser or greater vulnerability due to uncertainty or data gaps in the literature (see Table 5 below as an example). For instance, the sensitivity of an ecologically influential plant or tree species in a community to extended periods of drought (variable = sensitivity to extreme climatic events) may be debated in the scientific literature in that several sources show a drought tolerance while another source reports an intolerance or sensitivity to drier conditions. In this case, alternative scores could represent lesser or greater vulnerability due to conflicting scientific literature. As another example, a resource may be assigned an alternative score that represents a higher degree of vulnerability due to high uncertainty related to very little or no available scientific data or information.

Table 5. Certainty and alternative vulnerability scores for woodland plant community assessment variables.

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

* For individual variables, 3 = high certainty, 2 = moderate certainty, and 1 = low certainty; total ranges are 6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence.

An Excel worksheet was used to record vulnerability scores assigned to each of the six variables, citations of supporting literature and notes for justification of the assigned values, and assigned alternative and certainty scores.

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

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

Assessing Natural Resources – Species Level

In addition to assessing the vulnerability of the primary plant communities in BADL, park managers requested that a number of key faunal species and groups of species be assessed for vulnerability to climate change. These target species include black-footed ferret, bighorn sheep, bison, bobcat (*Lynx rufus*), mule deer, prairie dog, and swift fox; selected groups of species include birds of prey, grassland birds, and herpetofauna.

The approach to evaluating the vulnerability of target species in BADL to climate change was modeled after the assessment approach used by the Wisconsin Initiative on Climate Change Impacts (WICCI) Wildlife Working Group (2011). Rather than use a system that scores a resource's relative vulnerability based on a set of variables (as is used in the plant community assessments), the species assessments employed a narrative approach wherein detailed narratives about each species were constructed based on a thorough examination of the available scientific literature and data that focus expressly on specific variables or factors considered to influence the species' sensitivity to climatic changes. The resulting narrative is a systematic, but subjective, interpretation of relative vulnerability to climate change based on a set of variables.

Variables of Interest

The variables or factors most important for consideration when assessing species climate change vulnerability are outlined in Chapter 3 of *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment* (Lawler et al. 2011). Many of these variables were also used in the WICCI (2011) wildlife assessment. We adopted six of these variables to aid in our understanding of the potential influences of climate change on selected target species and selected groups of species. The selected variables capture to some degree either sensitivity to climate change or the capacity to adapt to environmental conditions resulting from climate change. These variables include:

1. **Physiological Sensitivity –** Some species may be sensitive to changes in temperature and moisture. Examples of sensitivities to temperature could include maximum/minimum temperature tolerances, species with temperature dependent sex ratios, or plants with frost tolerances or required growing season lengths. Examples of sensitivity to moisture could include germination requirements in plants or moisture requirements for amphibians to survive or breed. Some questions considered for this variable include: will changes in moisture and temperature affect the species in any way? Does the species have specific temperature or moisture thresholds needed to thrive or survive? Does the timing of breeding or migration depend on environmental cues that may be affected by climate shifts?

2. **Dependence on Sensitive Habitats–** Species sensitivities are likely to be strongly linked with the sensitivity to climate change of the plant communities they use as primary habitat. For example, species that rely on intermittent streams for breeding will be affected by climate impacts such as shifts in the timing of seasonal precipitation or extended periods of drought conditions. Some questions considered for this variable include: is the species' primary habitat associated with plant communities that are susceptible to climatic changes? Will the plant communities change substantially in vegetation composition or extent with climate shifts? How will this impact the species using these communities as habitat?

3. **Degree of Specialization (Specialist vs. Generalist) –** Species that utilize multiple plant communities and have multiple food sources/prey items (generalists) will be less susceptible to the impacts of climate change than species that rely on a narrow habitat or a specific food source/prey item (specialists). Some questions considered for this variable include: does the species rely on a particular plant community or a specific food/prey item? Does the species utilize multiple plant communities or food sources?

4. **Interspecific Interactions –** Changes in the abundance or distribution of one species may impact another species. For example, the black-footed ferret depends on prairie dogs as a primary prey item year-round. Warmer temperatures may increase the prevalence of plague among prairie dog colonies, resulting in increased mortality in prairie dogs and a decreased prey base for the black-footed ferret. Some questions considered for this variable include: is

the target species affected by the health or persistence of another species? Is there a necessary or prominent relationship present, such as predator/prey, mutualism, or competition, whose alteration would affect the well-being of the target species?

5. **Reproductive Potential for Adaptation –** This variable characterizes the ability of a species to recover from population declines due to environmental disturbances and to adapt to the new conditions. Longer-lived species that are slow to reach sexual maturity and produce fewer offspring may be at greater risk of extinction from long-term climate changes than those species that are shorter-lived and reproduce rapidly with many offspring. Species with shorter generation times tend to evolve faster than species with longer generation times. Such species may be better able to cope with environmental changes by adapting behaviorally or physiologically as well as recover faster from dramatic disturbance events. Some questions considered for this variable include: How fast can the population grow? How many offspring are produced with each effort? How quickly do adults reach sexual maturity? Categories for assessing reproductive potential of species were adapted from Millsap et al. (1990) and include the age at which females typically first reproduce and the average number of young produced by each female per year. Both traits are indications of a species' ability to rebound after disturbances and recover from resultant population declines. The age that females typically first reproduce is characterized in this assessment as slow (>8 years), moderate (2-8 years), or rapid (<2 years) maturity. The average number of offspring produced by a female each year is characterized as low (0-1 offspring/female/year), moderate (2-6 offspring/female/year), or high (>6 offspring/female/year) fecundity.

6. **Interactions with Non-Climate Stressors –** The effects of existing threats and stressors have the potential to be exacerbated by the influences of climatic changes. For example, susceptibility and rate of exposure of a species to disease or parasites may increase as warming temperatures encourage more rapid transmission of disease.

General Process:

Gathering Literature and Data. For each target species, SMUMN GSS analysts obtained relevant literature and data that were available from the park's libraries and databases. A more global literature search was performed for each species to obtain any additional peer-reviewed or gray literature that BADL managers may not have had. Specific literature search efforts focused on evidence related to the six main variables to be considered for vulnerability to climate change. For instance, searches were conducted for scientific evidence of physiological requirements or sensitivities, interspecific relationships including predator prey or competition, and reproductive strategy (as it relates to ability to reproduce early, often, and have multiple offspring).

SMUMN GSS analysts discussed in depth the literature and data related to each variable and came to an agreement about the most appropriate interpretation of the evidence and what it suggests about relative vulnerability of each species to projected climatic shifts. Specifically, the variables were carefully considered to determine whether the species displays the characteristic or trait fully, partially, or not at all. For each species, these evaluations were summarized in a table that shows whether it displays a characteristic fully (denoted by ●), partially (denoted by ○) or not at all (denoted by --) (see Table 6 below as an example).

Table 6. A summary of the vulnerability characteristics of the swift fox.

Characteristic	Displays Characteristic	Notes
Physiological sensitivity	--	
Specialist	○	Uses grassland plant community almost exclusively
Interspecific interactions	○	Relies on prairie dogs for part of year
Sensitive habitat	--	
Non-climate stressors	--	
Reproductive potential for adaptation	--	

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

Narratives. A narrative was constructed for each species (or group of species) to clearly explain how the scientific evidence related to each. In particular, care was taken to ensure the discussion and explanation provides sufficient detail and transparency to allow a reader to be able to clearly and easily follow the process and logic-steps that lead analysts to conclusions about vulnerability. The purpose of the narratives is to clearly outline the review and evaluation of the scientific literature with regard to each of the variables of interest. When appropriate, GIS products were developed and included in the assessment.

Each species assessment narrative is made up of several sections: 1) the species description; 2) threats and stressors; 3) vulnerability to climate change; and 4) literature cited. The contents of each section are described below.

- Species Description – This section includes a review of the history or background of each species' current and historical range in North America as well as its occurrence in BADL and how this may have changed over time. It also describes the primary habitat and diet or prey item preferences.

- Threats and Stressors – This section provides a review and discussion of the non-climate stressors that are known to impact a species in general, particularly diseases and parasites, predation, habitat fragmentation, disturbances, inter- or intraspecific relationships, low genetic diversity, and anthropogenic pressures (such as development, hunting, or control efforts). The degree of influence these threats and stressors exhibit on each species is also discussed.

- Vulnerability to Climate Change – This section discusses the scientific literature for the six climate sensitivity variables and what the evidence suggests for relative vulnerability in light of the projected climate shifts for BADL and the surrounding region. Also discussed is how natural ecological processes, such as fire or erosion, affect a species and whether an alteration in these processes due to climate change would ultimately make a species more vulnerable to climate change. Finally, a summary table is provided that outlines the relationship of the six variables to each species and whether a species possesses a characteristic or trait fully, partially or not at all. A summary paragraph ties together the information to form a statement of vulnerability to climate change.

- Literature Cited – This section lists all relevant literature that was reviewed and consulted in the assessment.

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

Assessing Culturally Significant Plants and Animals

The climate change vulnerability of selected culturally significant plant and animal species was also examined. Lists of culturally important and significant plant and animal species were requested from and developed in collaboration with cultural resource experts and Oglala Lakota tribal representatives. These lists are not intended to be exhaustive or comprehensive; rather, they are intended to serve as a representation of the diversity of species regarded as significant or important to the regional Native American community.

Once the lists were formulated, the vulnerability to climate change was assessed based on degree of association with BADL plant communities, existing literature, and expert opinion. The vulnerability of culturally significant plants was determined by the vulnerability of the plant community within which they most commonly occur. If a plant species occurs in several plant communities, it was attributed the vulnerability level of the community with the lowest vulnerability. The vulnerability of culturally significant animals was determined by the affinity to certain ecological/plant communities. Animals were attributed the vulnerability designation of the community they most closely depend upon for habitat. For example, if their affinity is quite narrow (e.g., dependent solely on woodlands for habitat), then vulnerability will be the same as that of the community within which they are most closely linked. However, if their affinity is broad, then their vulnerability is considered low due to their ability to utilize a number of different ecological communities to survive.

Assessing Cultural Resources

As developed throughout this report, climate change has the potential to adversely affect all park resources. Techniques for assessing vulnerabilities of cultural resources are not yet as extensively developed as those for natural resources. This assessment applied the framework of sensitivity, exposure, and adaptive capacity as outlined in Stein et al. (2011) to assess cultural resource vulnerability to climate change. This is the first attempt of which the project team is aware that employs this method for cultural resources, and the assessment should be treated as one possible approach for cultural resource vulnerability assessment.

BADL cultural resources fall into five major categories: ethnographic resources, archeological resources, museum collections, historic structures, and cultural landscapes. Ethnographic resources in BADL are most often plants and animals that are culturally significant to the nearby Oglala Lakota community. To address the impact that climate change may have on these ethnographic resources, a list of wildlife and plant species was developed and assessed for vulnerability. The wildlife species list was incorporated into the species level assessment, while the plant species list was incorporated into the plant community level assessments. A discussion of the cultural importance of the resources is detailed in the cultural resource assessment. It is critical to recognize that these lists are not comprehensive; there are many more species in the park that hold cultural value to the Oglala Lakota. Some of the usages described may not be commonly utilized, and different groups may have different uses for different species.

The project team worked with OSPRA, the tribal land management agency on the Pine Ridge Indian Reservation, to produce a list of wildlife species that are important to the Oglala Sioux tribe for traditional use (e.g., medicinal, subsistence, ceremonial) and/or as a land management priority on the Reservation. Sarah Burnette from the USGS Northern Prairie Wildlife Research Center in Jamestown, SD, developed a list of culturally significant plant species. Burnette conducted an ethnobotany study in 2006 in the Lakota Studies Department at Sinte Gleska University in Mission, SD, and developed the list through both structured and informal interviews with Lakota staff in the Department. Both the wildlife and plant lists were reviewed and approved by OSPRA and the Tribal Historic Preservation Officer in Pine Ridge, SD.

The cultural resource assessment is similar to the species assessments in that it employs a narrative approach wherein detailed narratives about each resource (or type of resource) were constructed based on an examination of the available literature and data that focus on cultural resource preservation as it pertains to sensitivity and exposure to climatic changes. The resulting narrative is a systematic, but subjective, interpretation of relative vulnerability to climate change based upon the interaction of threats/stressors with projected climate change.

The variables used by the plant community or species assessments were not appropriate for this assessment. This is because most categories of BADL cultural resources are abiotic, including archeological resources, museum collections, historic structures, and the abiotic components of cultural landscapes. The analyst is not aware of an existing set of variables used to assess the sensitivity and exposure of cultural resources, as is outlined for natural resources in Glick et al. (2011). The cultural resource section, therefore, outlines potential vulnerability through a more qualitative discussion of the interaction of existing threats and stressors to historic preservation with resource sensitivity and exposure to projected climate change.

General Process:

Gathering Literature and Data. For each category of cultural resource, the analyst obtained relevant literature and data that were available from the park, the Archeological Sites Management Information System (ASMIS), the Midwest Archeological Center (MWAC), the Cultural Landscapes Inventory, the South Dakota School of Mines, and the Midwest Regional Office (MWRO). A literature search was conducted for additional information regarding cultural resource management as it pertains to existing threats and stressors and/or the projected impacts of climate change. Discussions regarding the literature and data available were conducted with cultural resource specialists in the park, MWAC, MWRO, and regional and national offices to determine the most appropriate interpretation of the evidence and what it suggests about the relative vulnerability of each resource to projected climatic shifts.

Narratives. A narrative was constructed for each type of cultural resource to describe the literature and data relevant to each. Care was taken to ensure the discussion provided sufficient detail and transparency to allow the reader to be able to clearly follow the process and logic-steps that led the analyst to estimates of vulnerability. Like the species level assessment, each section of the cultural resource assessment narrative is made up of several sections: 1) the description; 2) threats and stressors; and 3) vulnerability to climate change. A section listing all relevant literature is provided at the end of the assessment. The contents of each section are described below.

- Description:
    - Ethnographic Resources: This section describes the concept of ethnographic resources as important to traditionally associated peoples, and briefly outlines the significance of park wildlife and plant species to the Oglala Lakota, including some known traditional uses of the species.
    - Archeological Resources and Museum Collections: There are thousands of archeological resources and museum objects at BADL and each is unique; it is not within the scope of this assessment to analyze each artifact. Instead, these two sections describe these resources more generally, identifying the major resource characteristics and locations (when known).
    - Historic Structures and Cultural Landscapes: These sections include a description of each historic component eligible, or nominated for eligibility, for listing in the National Register. Cultural landscapes and traditional cultural properties are also described in general terms, as it is possible that the park has unevaluated landscapes of historic significance.
- Threats and Stressors – This section provides a review and discussion of the stressors that are known to impact a resource in general, particularly ecological processes such as fire, wind and water erosion, intense precipitation events, and temperature, as well as anthropogenic stressors. A qualitative analysis of the degree of influence these threats and stressors exhibit on each resource is also discussed.
- Vulnerability to Climate Change – This section discusses the relative vulnerability of cultural resources in light of the projected climate shifts in BADL. The discussion centers on how an alteration in current threats and stressors due to climate change affects resource vulnerability, while potentially creating new stressors. A summary paragraph ties together the information to form a statement of vulnerability to climate change.

Assessment Reviews. Once each narrative assessment was completed, it went through an iterative review process among SMUMN GSS analysts for consistency. Assessments were then provided to BADL resource experts and cultural resource specialists in BADL, regional, and national offices for an external review. Documents were examined for accuracy of content and appropriateness of interpretation of available scientific literature; feedback was provided on how to refine the assessment. Following review by experts, the vulnerability assessment was modified to incorporate feedback.

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Chapter 3 Badlands Historic and Projected Climate Summary

This section provides an overview of historical and projected climate patterns. The intent of these analyses is to provide a context developed from historical climate patterns to help readers place or consider the potential effects of future climates. The climate 'experienced' by people living in an area is the integration of the full set of factors – temperature, wind, rainfall, duration of hot or cold spells, cloudiness, etc. A comparison of historical observations to projections can help interpret how changes in temperature and precipitation can affect people and their activities.

Historical Climate Patterns

BADL is located in the semi-arid western Great Plains, where water typically limits plant growth (Running et al. 2004). Because water is such a key driver of natural and production systems, descriptions of climate variability that are associated with drought or aridity are of particular interest. The growth and vigor of vegetation influences physical processes such as erosion as well as the dynamics of native and domestic animals. These are key processes to management, and to the evaluation of climate change vulnerability.

Large areas of the central and western U.S. experienced severe droughts in the 1930s, 1950s, and late 1990s to about 2004 (Woodhouse and Overpeck 1998; Cook et al. 2004). While these recent droughts persisted for multiple years and had profound effects on natural ecosystems and on agricultural production, a longer record reveals sustained droughts that persisted for decades (Woodhouse and Overpeck 1998; Cook et al. 2004). These decades-long droughts affected processes such as broad patterns of fire (Brown et al. 2004), and they emphasize the vulnerability of the region to precipitation deficits. Projections of future climates that include temperatures that increase evaporation, or changes in precipitation that change soil water availability, are likely to be particularly important and these are emphasized in our analyses.

The climate at any location is largely determined by factors that operate primarily at global to regional scales. At a global scale, the Earth has experienced a generally warming trend over the past century, closely correlated with increases in the greenhouse gas CO_2 (Figure 4; Karl et al. 2009). Global patterns of warming are modified by very broad-scale teleconnections, regional and local conditions, and the degree of warming or cooling varies geographically. Mote and Redmond (2012) provide a clear and comprehensive review and evaluation of climate drivers at local to global scales with a focus on the western United States.Recent historical climate patterns for the BADL ecological study area were evaluated using PRISM gridded climate data. These data are produced by the

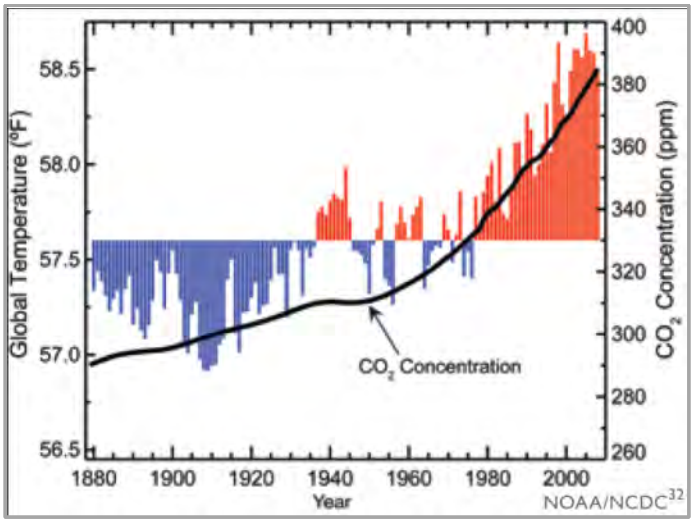

Figure 4. Annual average temperature measured over the all the Earth's land and oceans surfaces. Red and blue bars indicate years with temperatures above and below the 1901-2000 average, and the black line is the trend in atmospheric CO_2 concentration. Figure from Karl et al. (2009).

PRISM climate group at Oregon State University (Daly et al. 2002; PRISM 2010), and subsets of data are freely available via their web site (http://www.prism.oregonstate.edu/). PRISM is gridded data at 4 km resolution with complete coverage for the continental United States from 1895 to the present.

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

While PRISM data are both spatially and temporally complete, older data are estimated from fewer on-the-ground observations and these data are thus generally less reliable than more modern observations. PRISM data for the BADL area are likely highly reliable for analyses at the spatial and temporal scale of this analyses. Davey et al. (2007) inventoried climate observation stations relevant to monitoring parks in the NGPN, and their report included 40 records of stations relevant to evaluating BADL. Eight of these 40 stations included climate observations from earlier than 1910. PRISM uses correlations between stations for infilling missing data, and the more than 100 years of observations provides a very rich data set to develop and evaluate these relationships. PRISM data are well-suited for evaluating regional-scale and longer-term climate patterns and dynamics, but they cannot capture weather dynamics at the scale of local convection storms that occur between observation stations, for example.

PRISM data used for historical analyses are at a monthly time step, and the variables are:

- mean monthly minimum temperature (°C)
- mean monthly maximum temperature (°C)
- total monthly precipitation (mm/month)

To examine seasonal and long-term variation, these climate variables were averaged by season, year, and for 10-year periods. Periods of analysis are:

Winter = December, January, and February
Spring = March, April, and May
Summer = June, July, and August
Fall = September, October, and November
For averaging, decadal periods are 1900-1909, 1910-1919, … 2000-2009.

For 10-year rolling means, the 10-year mean is plotted as a point at the final year of the period (e.g., the mean of 1895-1904 is plotted as the point for 1904). The R statistical language versions 2.13.2 and 2.14.0 (R Development Core Team 2011) were used for analyses. Unless otherwise noted, all analyses were based on the spatial area defined as the BADL CCVA ‘ecological region’.

Reference Period

In this report, the 10-year period from January 1957 to December 1966 is used as a reference (or ‘normal’) period for comparing climate variation over time. This period was used so our results would be consistent with ongoing climate and hydrological studies being conducted by the USGS South Dakota Water Science Center. Stamm et al. (unpublished manuscript) noted that this is a good period for comparing climate and streamflow data to other periods, based on climate observations and the availability of records from streamflow gaging stations. The number of stream gaging stations rapidly declines prior to 1957 (reviewed by Stamm et al., unpublished manuscript).

Climate Trends

Over the entire period of 1895-2010 the PRISM data exhibited a trend towards warming for both maximum (Tmax) and minimum (Tmin) average annual temperature (Figure 5). The linear warming trends are 0.7^{o} C per century for Tmax, and 1.2^{o} C per century for Tmin. There is no apparent trend in precipitation over this period (Figure 5)[2].

Departures from the overall mean (Figure 6) more clearly illustrate climatic periods. In Figure 6, note the ‘dust-bowl’ period in the 1930s compared to the recent drought in the late 1990s-2000s. During the dust bowl, sustained high temperatures were accompanied by precipitation levels that were well below average. In contrast, the most recent drought had precipitation that was below normal, but not exceptionally so. However, temperatures in the late 1990s and the following decade were consistently very high, especially minimum temperatures. These patterns are clearly illustrated by the 10-year rolling average (Figure 7), which ‘washes out’ much of the year-to-year variation and emphasizes broader patterns. Figure 7 clearly shows the very different patterns of precipitation in the dust bowl era versus the recent drought. In Figure 5 and Figure 6, note that ‘very high’ temperatures are less than 1.5^{o} C above average. Climate projections include temperature increases over the next 40 years that will exceed 1.5^{o} C.

There were no obvious sustained seasonal differences in trends in Tmax, Tmin, and precipitation over the period of record (Figure 8). In the historical record, temperatures in all seasons exhibited a slight warming trend, the sum of which accounted for the overall annual increase. In the past decade or two, temperatures in winter have increased more than in other seasons, but it’s not yet clear whether this is a long-term pattern or shorter-term variation. Precipitation is highly variable between seasons and years, and there were no consistent historical trends for any season (Figure 8).

The dependence of local climate on broader patterns is emphasized by comparing BADL historical climates to global trends (Figure 4 and Figure 6). Even at a global scale, the high temperatures during the dust bowl and the past several decades are apparent. Weather and long-term climates for BADL will be determined largely by regional to global-scale drivers.

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

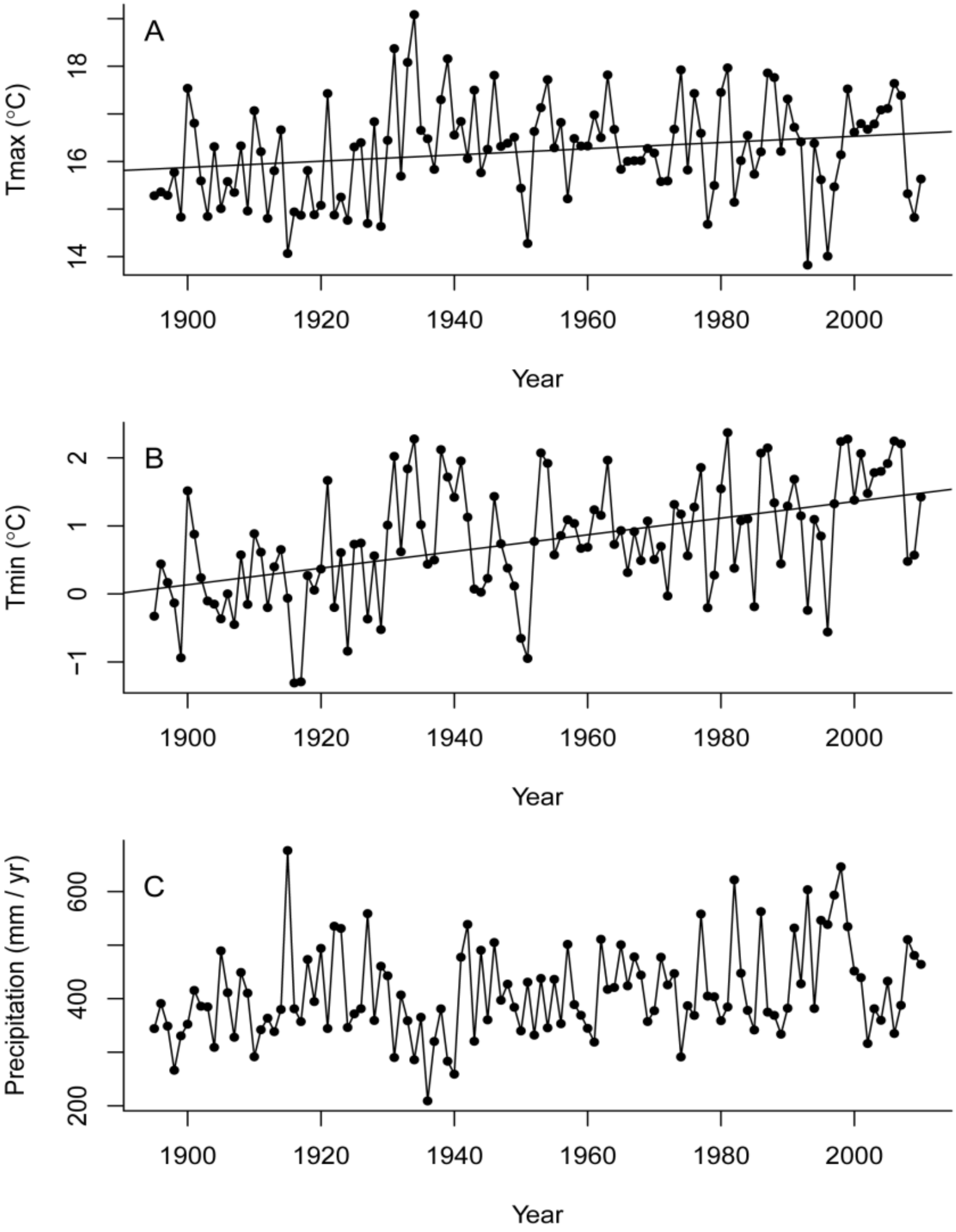

Figure 5. Trends in (A) maximum monthly temperature, (B) minimum monthly temperature, and (C) annual precipitation for the Badlands ecological CCVA region. The linear regressions for Tmax and Tmin were significant ($P < 0.001$).

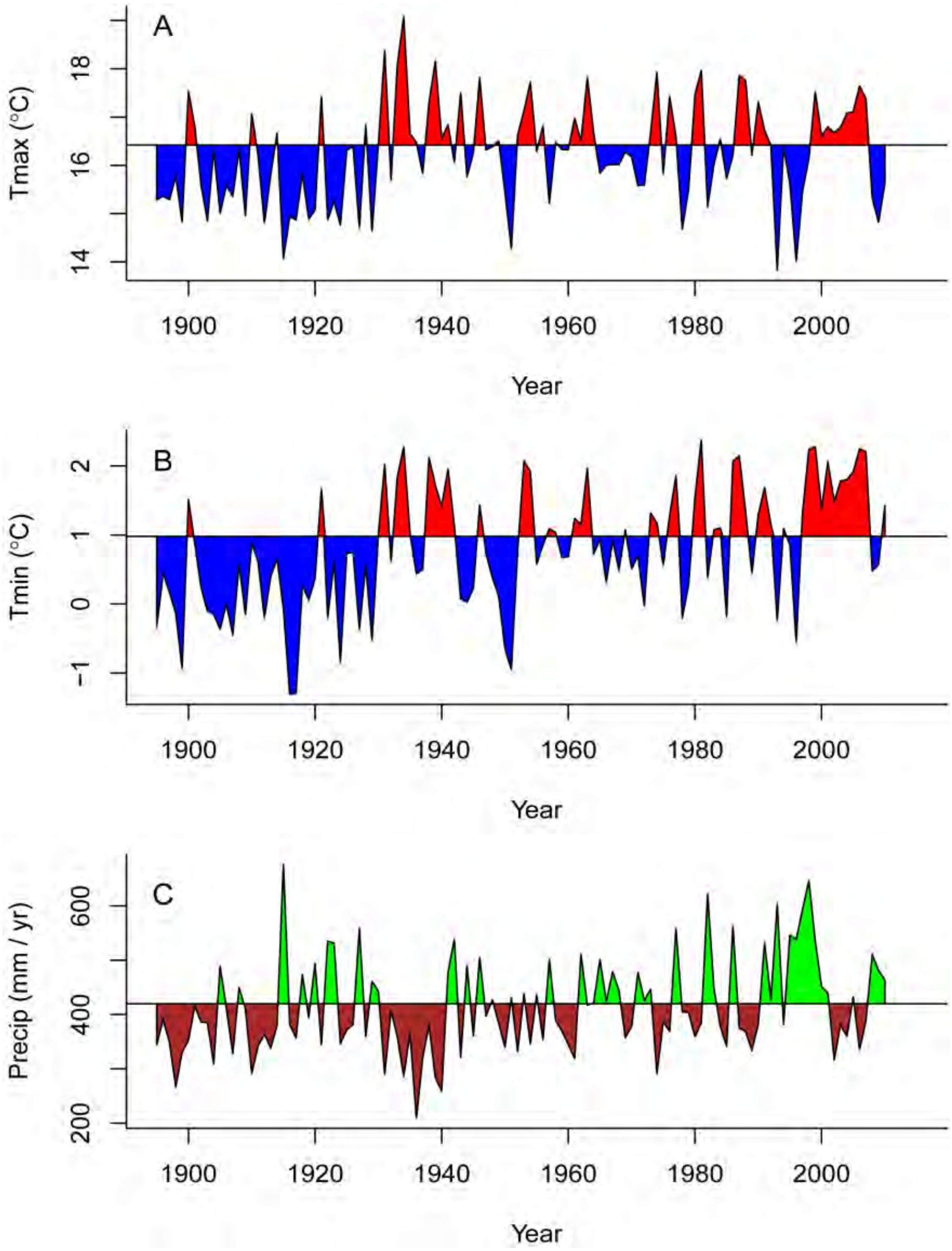

Figure 6. Trends in annual average (A) maximum temperature (Tmax), (B) minimum temperature (Tmin), and (C) total annual precipitation, emphasizing departures from the 1957-1966 reference period (horizontal line).

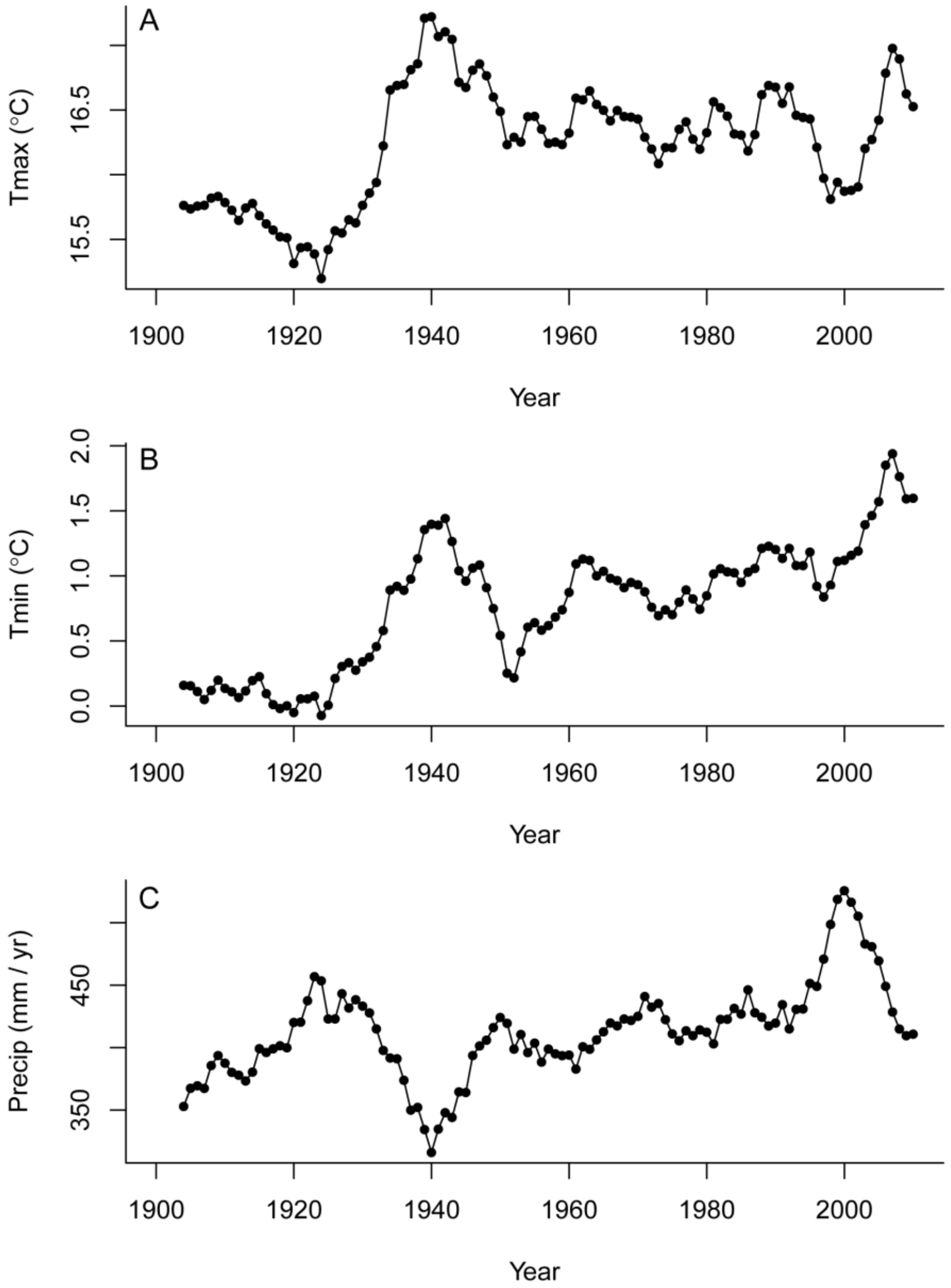

Figure 7. Ten-year rolling mean annual (A) maximum temperature (B) minimum temperature, and (C) precipitation.

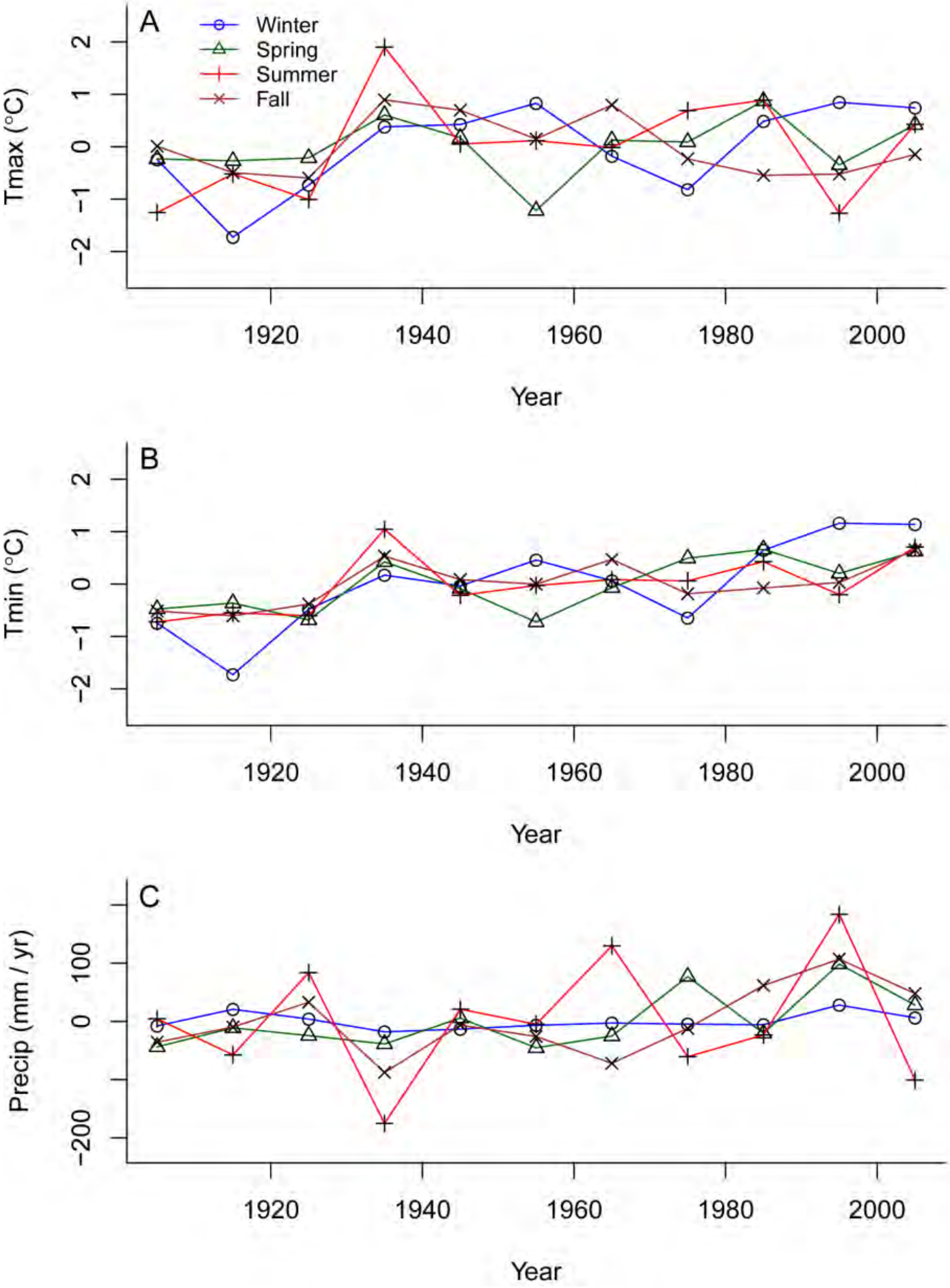

Figure 8. Departures in decadal averages from the long-term average mean (A) maximum and (B) minimum temperatures, and (C) precipitation by season for the Badlands CCVA ecological region. Each point is the average for the preceeding 10 years.

Projected Climate Trends

To evaluate how climate might change in the future, the Intergovernmental Panel on Climate Change (IPCC) developed a set of scenarios that represent different futures determined in complex ways by demographic development, socio-economic development, and technological change (Nakicenovic et al. 2000). For the purposes of this report, the main differences in the scenarios can be summarized by differences in projected emissions of CO_2, the atmospheric component that is primarily responsible for global warming (IPCC 2007). Analyses in this report use the A1B and A2 family of scenarios, which are referred to in this report as 'moderate' and 'high' emissions scenarios (Figure 9; Nakicenovic et al. 2000). These emission scenarios have very similar rates of atmospheric CO_2 increases until about 2050, when the A2 (high) scenario diverges with greater projected emissions of greenhouse gases than the A1B (moderate) family of scenarios. Since these emissions scenarios were published (Nakicenovic et al. 2000), the rate of increase in atmospheric CO_2 has equaled or exceeded the highest projected emissions scenarios examined by the IPCC (Rahmstorf et al. 2007).

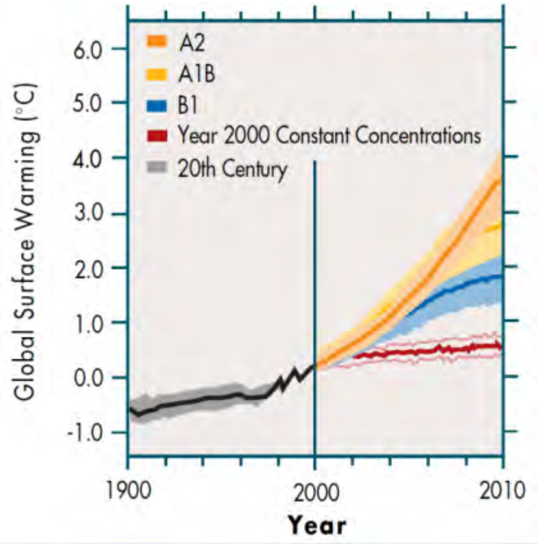

Figure 9. Emissions scenarios from the IPCC report (figure from Nakicenovic et al. 2000).

Statistically downscaled model projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset were used in these analyses. The archive used to acquire data provides bias-corrected and spatially downscaled climate projections derived from CMIP3 data (Maurer et al. 2007) and the data are served from: http://gdo-dcp.ucllnl.org/downscaled _cmip3_projections/. These data are typically referred to as 'Bias Correction followed by Spatial Disaggregation (BCSD)', and they are corrected for model-observation biases in mean monthly temperature and then processed at various spatial scales (i.e., 'disaggregated') to accommodate mis-matches between the global model outputs and local topographical and other effects (see Wood et al. 2004 for details). Data in these analyses were downscaled to 1/8 degree (about 12 km). Results from 14 model-parameter combinations for the moderate (A1B) scenario, and 12 model-parameter combinations for the high (A2) emissions scenario are reported here. A full list of the climate models used and the analysis procedures is provided by Gross (2012 – Appendix B).

Increases in average annual temperature directly reflect projected changes in greenhouse gases, and projections from the moderate and high emissions scenarios are indistinguishable until after about 2050 (Figure 10A). The rate of average annual temperature increase for the period of projections is 3.2^{o} C per century for the moderate scenario, and 3.9^{o} C per century for the high emissions scenario. For context, the dust bowl and 2000s drought had temperatures about 1.5^{o} C above average. Precipitation is generally projected to increase (Figure 10B) but there is considerable variation in projections, and confidence in precipitation projections is much lower than for temperature projections. While confidence in projections of seasonal or total precipitaiton are low, the models consistently project increased variation in both seasonal and annual precipitation. Increased variation will generally lead to an increased frequency of multi-year droughts.

Overall, the climate is likely to be much hotter and plant-available moisture will likely decline due to changes in evapotranspiration. Evapotranspiration (ET) is the amount of moisture returned to the atmosphere through the combination of evaporation and plant transpiration. Climate scientists are concerned with two aspects of ET: actual evapotranspiration (AET) and potential evapotranpiration (PET). As its name suggests, AET is the amount of evapotranspiration that is actually occurring. PET is "a measure of the ability of the atmosphere to remove water from the surface" (Pidwirny 2006) and can be thought of as "moisture demand" (Girvetz, in review). Higher temperatures will drive greater rates of evapotranspiration, thus even with an increase in precipitation, soil water levels are projected to decrease (Cowell and Urban 2010). By the end of the 21st century, Cowell and Urban (2010) projected an increase in PET of 221 mm for the Great Plains region. The projected increase in PET for the Great Plains region is about 10 times the projected increase in precipitation, resulting in a huge increase (161 mm) in soil water defecit. If these projections are realized, the average soil water levels (and deficit) will equal those experienced during the dust bowl.

The ratio of AET to PET is used as an 'aridity index' that indicates the amount of moisture available to plants (TNC, Evan Girvetz, Senior Scientist, e-mail communication, 7 June 2011). For example, a 0.15 decrease in this ratio can be interpreted as a 15% increase in aridity, or 15% less moisture available for plants (E. Girvetz, e-mail communication, 8 June 2011). While AET is not expected to change much during the winter and spring, projections for the BADL region overall indicate a 2-10% increase in aridity (from a 1960-1990 reference period) during the summer and fall by 2050 (ClimateWizard 2011, Plate 4 and Plate 5). By 2100, aridity is projected to increase by approximately 12-13% in the summer and fall (A2 scenario, Plate 4 and Plate 5) (ClimateWizard 2011). During the drought of 2004, as a comparison, the AET/PET ratio was 5-10% lower than the reference period. Projected annual and seasonal changes in aridity index are displayed in Plate 1-Plate 5.

Temperatures are projected to increase an average of 2-3^{o} C from the 1960 (i.e., 1957-1966) reference period by 2050 (Table 7 and Table 8). Most projections include greater temperature increases in summer and fall than in winter and spring. Projected temperatures by the end of the century are dramatically hotter – on the order of 4-6^{o} C hotter than the 1960 reference period (again, recall the 1.5^{o} C anomaly in the dust bowl and recent drought). Projected precipitation changes reflect the general tendency for warmer climates to generate convection storms, and the projections overall suggest that the warmer seasons – spring and summer – are likely to experience an average increase in precipitation. The climate data used in these analyses provided no information on patterns of precipitation (e.g., drizzles vs. thunderstorms), but general predictions are for more temperature extremes and associated weather (Diffenbaugh and Ashfaq 2010; IPCC 2011).

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

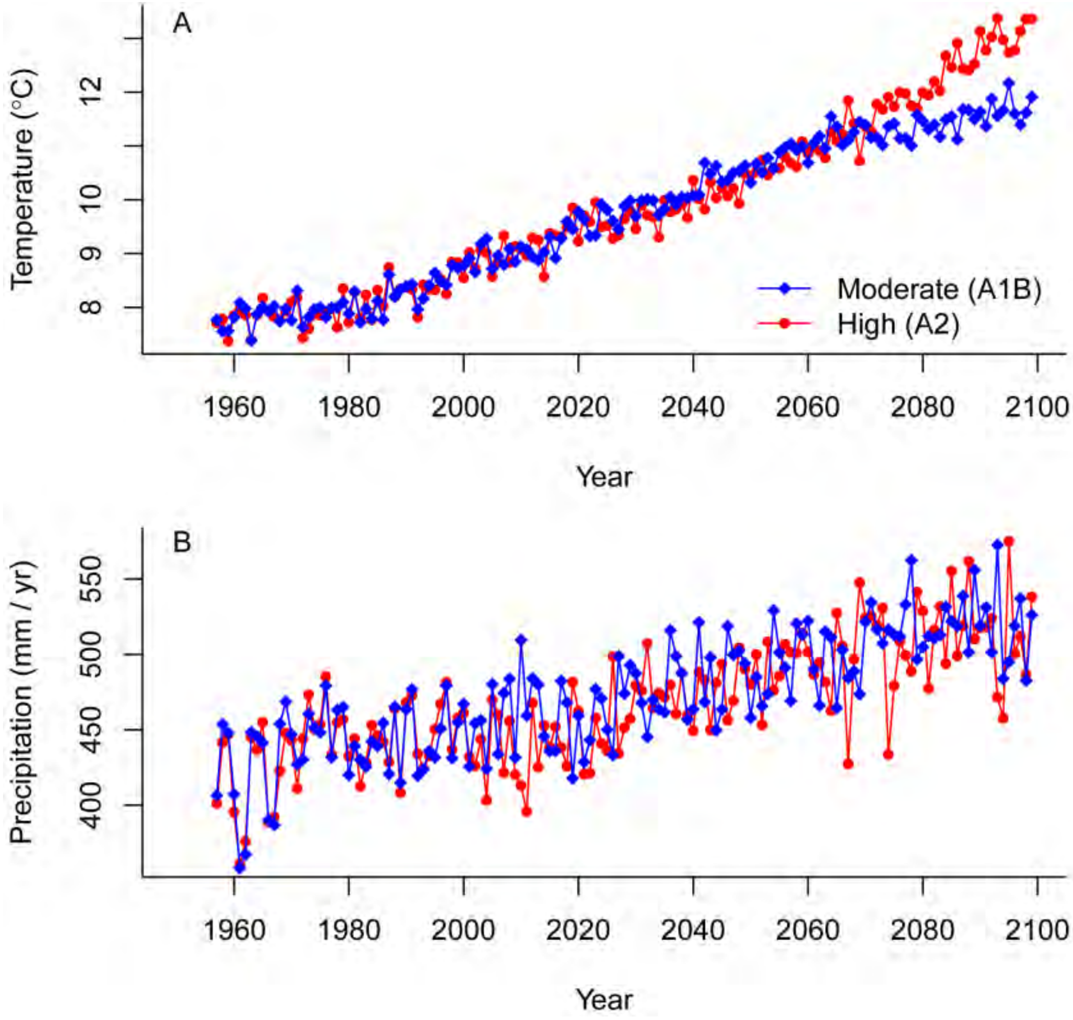

Figure 10. Projected (A) average annual temperature and (B) total annual precipitation changes from a suite of models, driven by a moderate or high CO_2 emissions scenario. Points and lines are averages across a suite of model-parameter combinations.

Table 7. Projected average annual temperature and total precipitation from a suite of climate models. Data are means for a moderate (A1B) and high (A2) emissions scenario, averaged across all model-parameter combinations and 10-year periods.

	Projected values from GCMs					**Difference from 1960 Reference**			
	Winter	Spring	Summer	Fall		Winter	Spring	Summer	Fall
A1B Temperature (° C)					A1B Temperature (°C)				
1960	-4.4	7.7	21.6	8.9	1960	0.0	0.0	0.0	0.0
2005	-3.2	8.8	22.8	10.1	2005	1.2	1.0	1.2	1.2
2050	-1.7	10.0	24.8	11.9	2050	2.7	2.3	3.2	2.9
2100	-0.5	10.7	26.2	13.0	2100	3.9	3.0	4.5	4.1
A2 Temperature (°C)					A2 Temperature (° C)				
1960	-4.4	7.7	21.6	8.9	1960	0.0	0.0	0.0	0.0
2005	-3.1	8.5	22.9	10.2	2005	1.3	0.8	1.3	1.3
2050	-2.0	9.7	24.7	11.9	2050	2.4	2.0	3.0	2.9
2100	0.4	12.1	27.9	14.4	2100	4.8	4.4	6.3	5.5
A1B Precipitation (mm/season)					A1B Precipitation (mm/season)				
1960	28	137	173	72	1960	0	0	0	0
2005	31	148	192	81	2005	3	11	18	9
2050	36	168	206	77	2050	7	30	33	5
2100	36	185	211	80	2100	8	48	38	8
A2 Precipitation (mm/season)					A2 Precipitation (mm/season)				
1960	28	137	171	73	1960	0	0	0	0
2005	32	142	183	72	2005	3	6	13	-1
2050	36	170	196	75	2050	8	33	25	1
2100	42	172	213	80	2100	13	35	42	6

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

Table 8. Climate Change Variables for Badlands National Park: Climate scenarios used for the Badlands vulnerability assessment are the IPCC A1B and A2 family of scenarios for emissions, commonly referred to as medium and high emissions scenarios for greenhouse gases (Nakicenovic et al. 2000; IPCC 2007). These scenarios are similar until approximately 2050, when the A2 scenario diverges with increasingly greater projected emission of GHGs than A1B.

Climate Variable	Projected Trend	Observed 2001-2010[1]	Observed Trend 1895-2010[1]	Range of Expected Change[3]		Confidence and Other Sources[2]
				Moderate emissions (A1B)	High emissions (A2)	
Temperature - Annual	↑		Tmin[4] + 1.2 °C / century Tmax + 0.7 °C / century	2050: + 1.5-2.5 °C 2100: + 2.5-4.5 °C	2050: + 1.5-2.5 °C 2100: + 3.5-6 °C	Very High confidence
Temperature - Winter	↑	Tmin: -10.1 °C Tmax: 3.3 °C	Tmin + 1.8 °C / century *** Tmax + 1.3 °C / century *	2050: + 1.5-4 °C 2100: + 2.5-5 °C	2050: + 1.5-3.5 °C 2100: + 4-6.5°C	High confidence
Temperature - Summer	↑	Tmin: 13.2 °C Tmax: 29.4 °C	Tmin + 1.0 °C / century ** Tmax + 0.6 °C / century	2050: + 2-4.5 °C 2100: + 3-6°C	2050: + 2-4.5 °C 2100: + 5-8 °C	High confidence
Precipitation – Annual average	↑	417 mm	+ 6 mm / mo *	2050: + 5-25% 2100: + 5-30%	2050: + 5-30% 2100: + 5-30%	Medium confidence
Precipitation – Winter	↔	27 mm	No change	2050: + 5-15% 2100: + 5-30%	2050: + 5-15% 2100: + 10-30%	Low to Medium confidence
Precipitation – Summer	↔	163 mm	No change	2050: + 5-30% 2100: + 5-30%	2050: + 5-30% 2100: + 10-30%	Low to Medium confidence
Soil moisture for plant growth	↓		.	2050: - 5% 2100: - 7-8%	2050: - 2-3% 2100: - 12-13%	Medium confidence; Climate Wizard; Cowell and Urban 2010
Drought	↑		No long-term trends in N. America	Based on current definitions, more frequent droughts are very likely due to increasing temperatures, stable or slightly increasing average precipitation, and a projected increase in weather variation.		Very High confidence; Easterling et al. 2000; Cook et al. 2004; IPCC 2011
Extreme temperatures and precipitation	↑		(Historical data not evaluated)	Temperature: By 2080-2100, temperatures now considered extreme likely to occur every 2-4 years. Precipitation: Uncertain, but general expectation is that extreme precipitation events will be more frequent, even if overall precipitation is unchanged.		Very High confidence; Min et al. 2011; Easterling et al. 2000; Karl et al. 2009; IPCC 2011

[1] Unless noted otherwise, current condition and 20th century change were calculated from PRISM data (http://www.prism.oregonstate.edu/),

[2] Confidence notation follows IPCC (IPCC 2007)

[3] Unless noted otherwise, evaluations of analyses described in this chapter and Appendix A.

[4] Tmin = monthly average minimum temperature; Tmax = monthly average maximum temperature

*, **, *** Significance from linear regression. * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$

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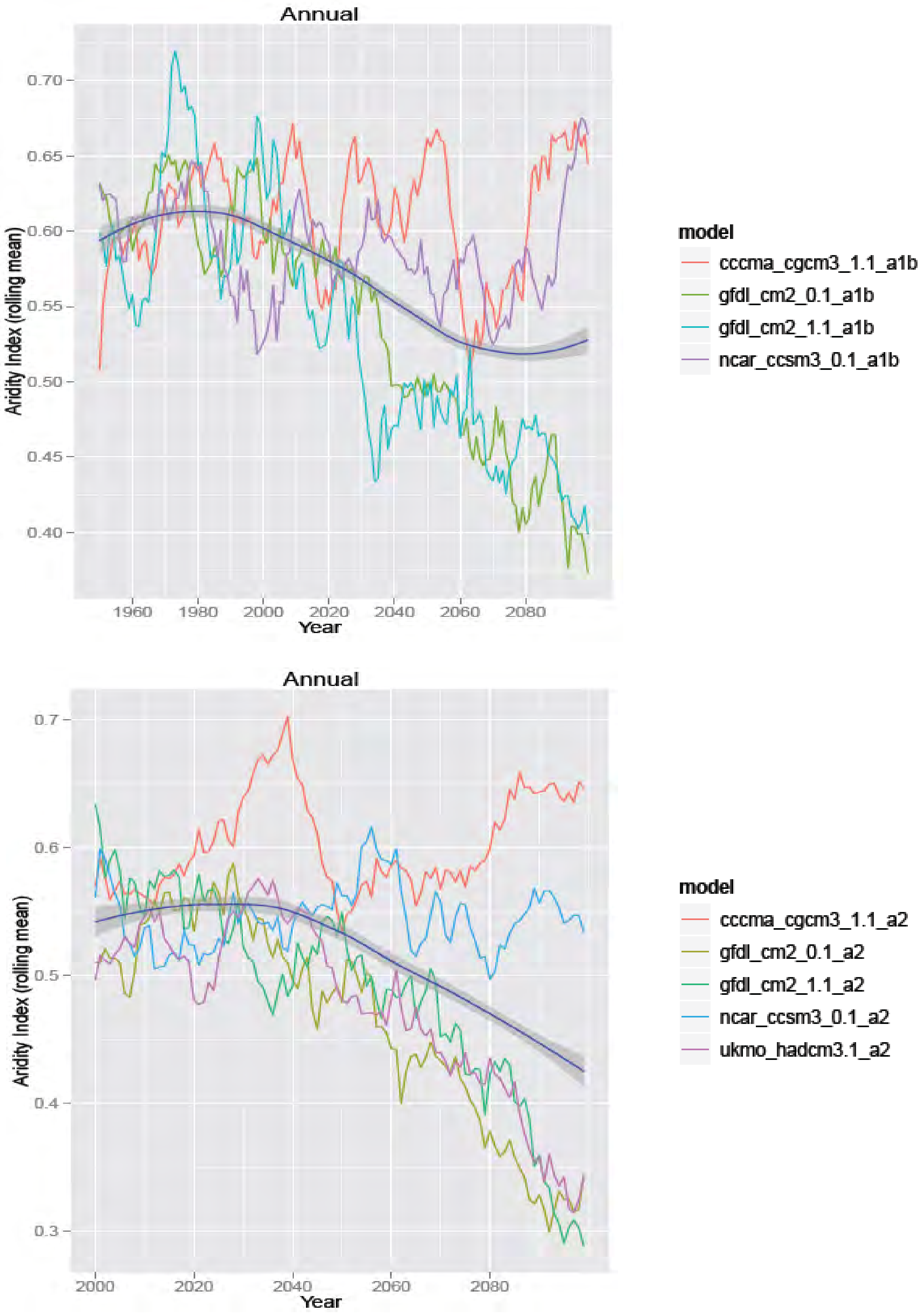


Plate 1. Change in annual aridity index under the A1B (top) and A2 (bottom) scenarios through 2100 (Note that A1B plots begin at 1950 while A2 plots start with 2000).

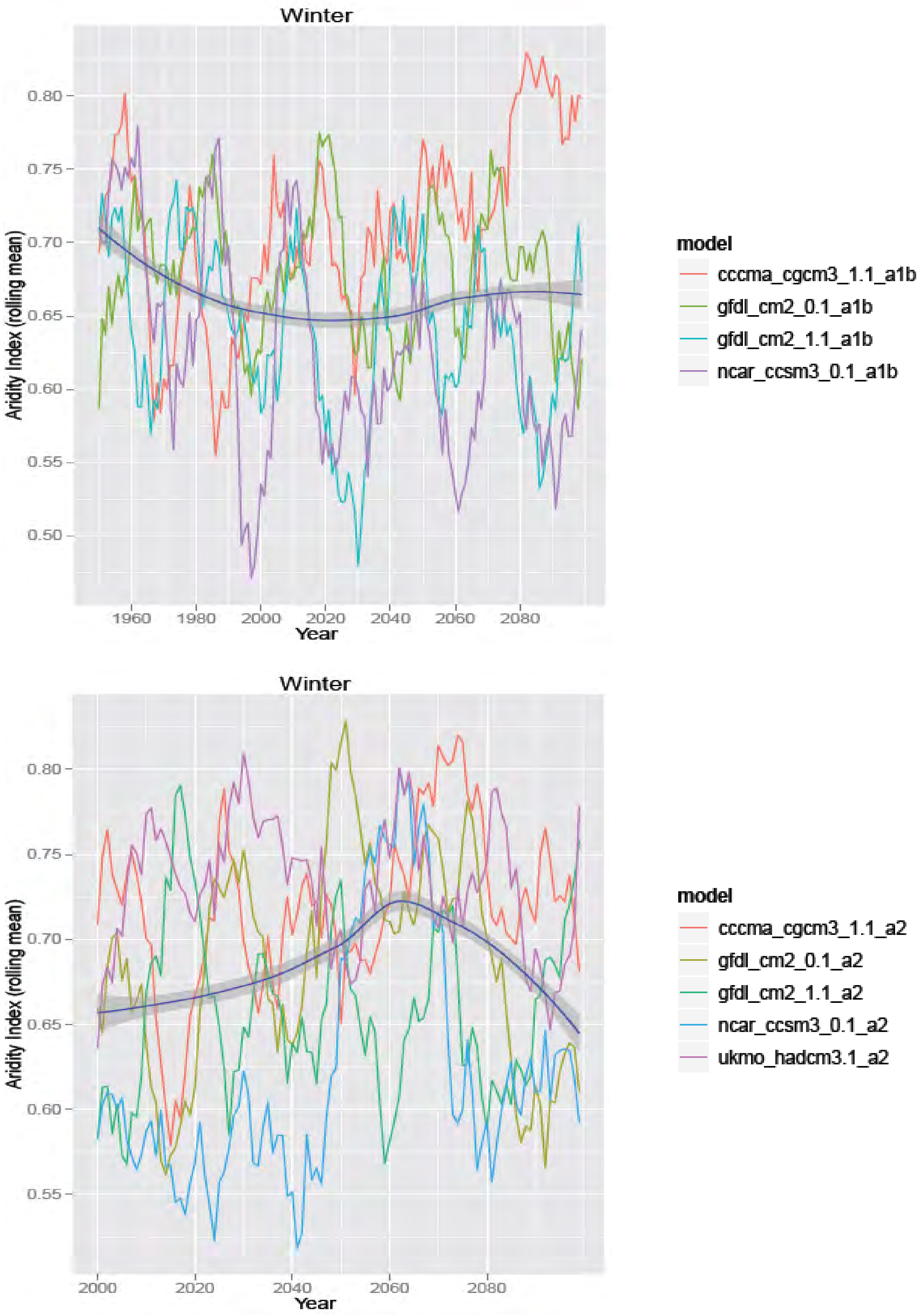


Plate 2. Change in winter aridity index under the A1B (top) and A2 (bottom) scenarios through 2100 (Note that A1B plots begin at 1950 while A2 plots start with 2000).

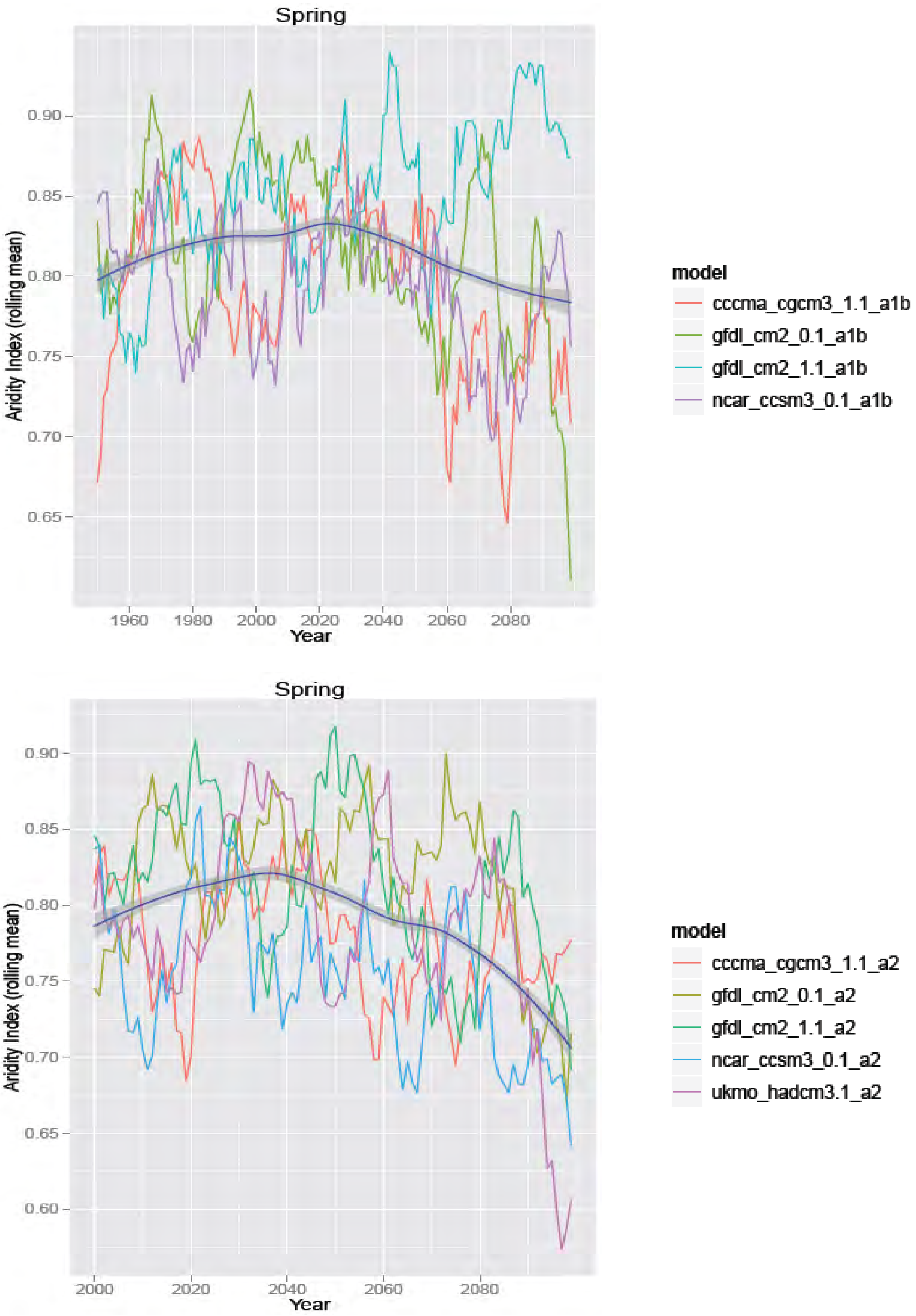


Plate 3. Change in spring aridity index under the A1B (top) and A2 (bottom) scenarios through 2100 (Note that A1B plots begin at 1950 while A2 plots start with 2000).

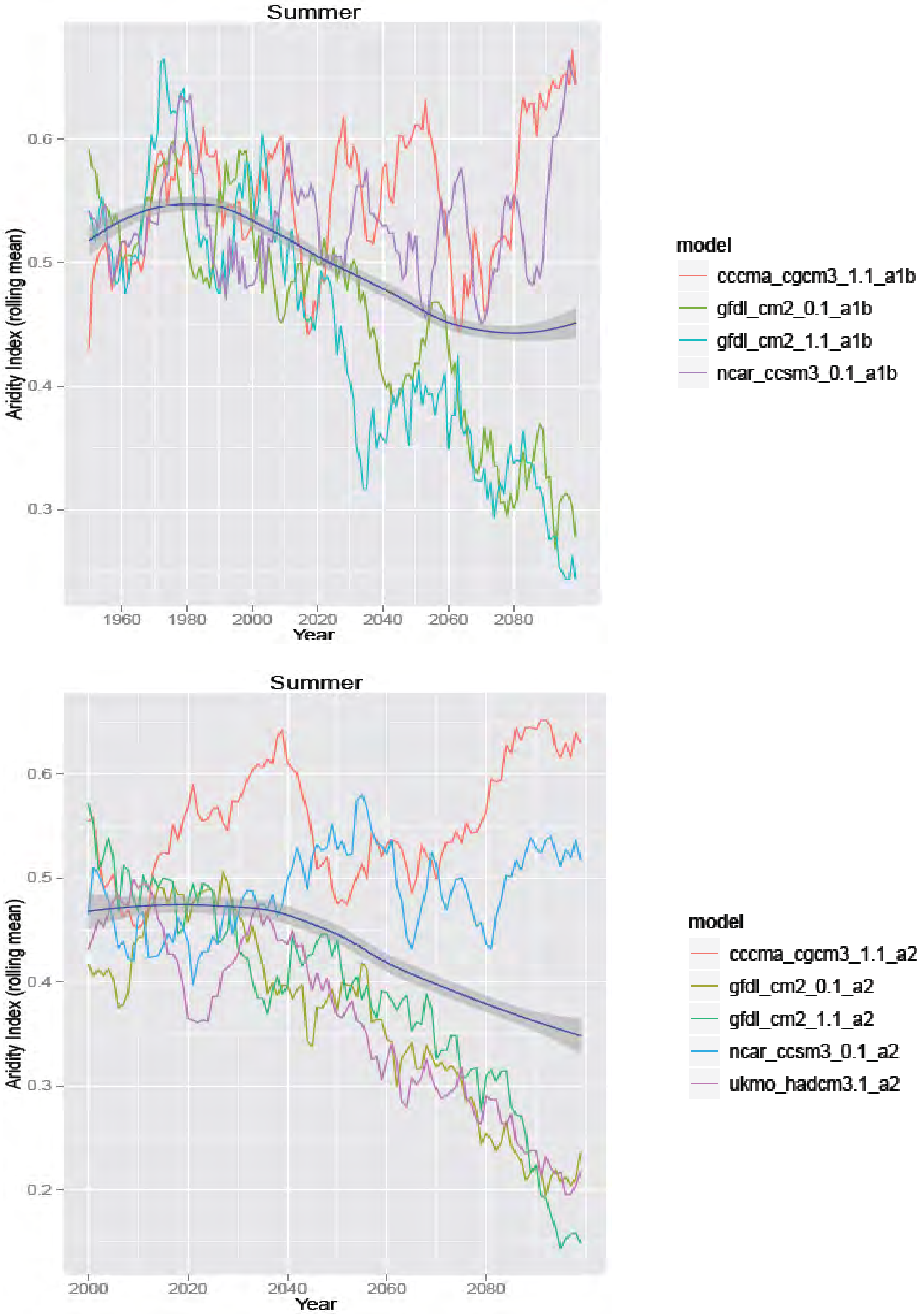


Plate 4. Change in summer aridity index under the A1B (top) and A2 (bottom) scenarios through 2100 (Note that A1B plots begin at 1950 while A2 plots start with 2000).

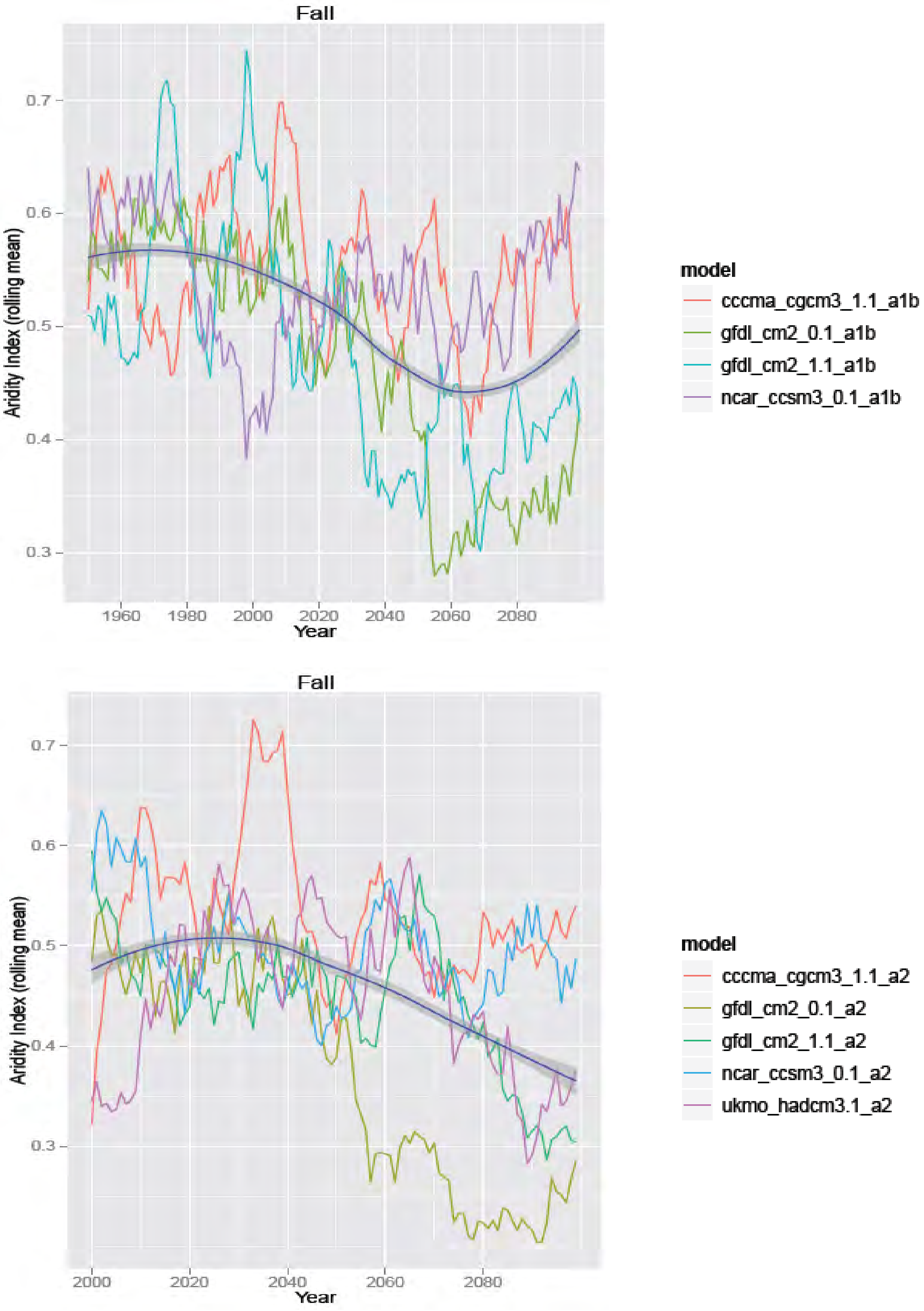
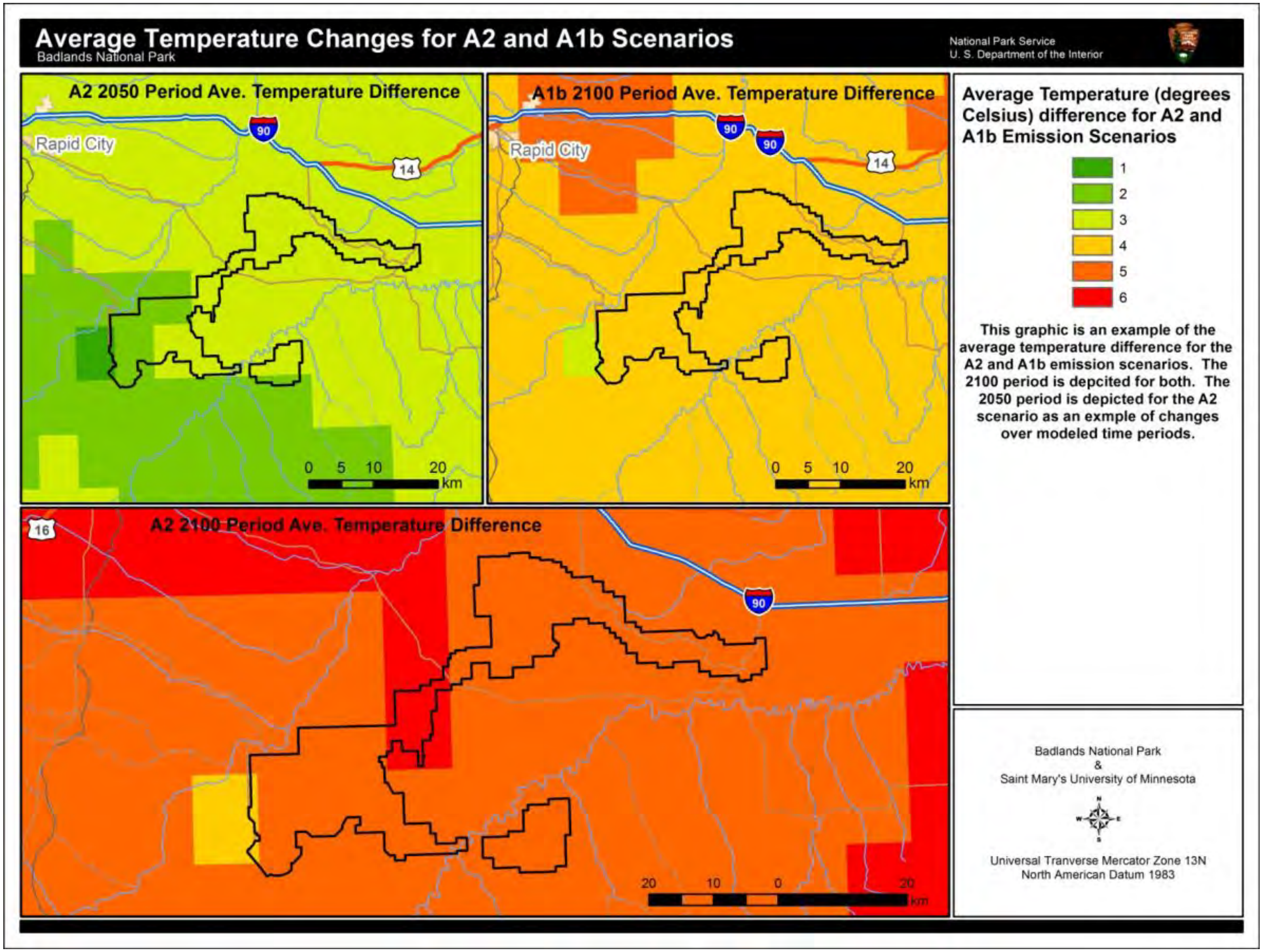


Plate 5. Change in fall aridity index under the A1B (top) and A2 (bottom) scenarios through 2100 (Note that A1B plots begin at 1950 while A2 plots start with 2000).



This graphic is an example of the average temperature difference for the A2 and A1b emission scenarios. The 2100 period is depcited for both. The 2050 period is depicted for the A2 scenario as an exmple of changes over modeled time periods.

Plate 6. Projected changes in temperature for the BADL region by 2050 for the A2 scenario (upper left) and by 2100 for the A1B and A2 scenarios.

Chapter 4 Vulnerability Assessments

This chapter presents a brief description and vulnerability assessments or discussions for the following natural and cultural resources of BADL:

4.1 Plant Communities

4.2 Ecological Processes

4.3 Species

4.5 Cultural Resources

4.5.1 Ethnographic Resources
4.5.2 Archeological Resources
4.5.3 Museum Collections
4.5.4 Historic Roads and Structures
4.5.5 Cultural Landscapes

4.1.1 Woodlands

Summary:

Wooded areas cover only a small portion of BADL but provide vital resources for park wildlife. There are four main woodland types in BADL: ponderosa pine/Rocky Mountain juniper and Rocky Mountain juniper/little-seed ricegrass on drier uplands, and green ash - (American elm)/ chokecherry and eastern cottonwood - (peachleaf willow)/ sandbar willow in more mesic areas. Woodlands were scored as "highly vulnerable" to climate change, but with uncertainty in some areas due to a lack of information about the plant community's response to environmental variables. Climate change will likely exacerbate existing threats such as invasive species, pests and pathogens, and drought.

Description

Wooded areas are a relatively minor component of the vegetation in BADL, covering just less than 2% of the land area (Plate 7; Von Loh et al. 1999). Their distribution is primarily limited by available soil moisture (Girard et al. 1989, as cited by Gitzen et al. 2010; Guevara 1997). Although not common, woodlands are very important within the park, providing food and shelter for wildlife in the adjacent grasslands (Sieg 1988, 1991; Lesica 2003, as cited by Gitzen et al. 2010). The upland wooded areas of BADL primarily consist of two plant community types: ponderosa pine/Rocky Mountain juniper woodland and Rocky Mountain juniper/little-seed ricegrass woodland. Rocky Mountain juniper woodland, the most common type in the park, occurs in draws, on side-slope slumps, and on the edges of buttes and tables where soils are shallow and loamy (Von Loh et al. 1999). Canopy cover is generally dense but rarely exceeds six meters in height (as reviewed by NatureServe 2011).

Photo 1. A woodland in Badlands National Park (photo by Shannon Amberg, SMUMN GSS, 2010).

Ponderosa pine/Rocky Mountain juniper woodlands are found in well-drained loamy soils on moderate slopes, and occur on the rims of tables and buttes in BADL (Von Loh et al. 1999, NatureServe 2011). They are most common at higher elevations in the southern unit of the park (Von Loh et al. 1999). Ponderosa pine (*Pinus ponderosa*) is the dominant species in this woodland plant community type, forming a moderately open canopy 10-20 m tall, with a subcanopy of Rocky Mountain juniper (*Juniperus scopulorum*) 2-4 m tall (as reviewed by NatureServe 2011). Shrub and herbaceous cover is generally sparse and consists of species typical of dry prairie, such as little bluestem (*Schizachyrium scoparium*) and sideoats grama (*Bouteloua curtipendula*) (Von Loh et al. 1999).

At lower elevations, Rocky Mountain juniper/little-seed ricegrass woodlands often intermix with deciduous woodlands. The two dominant deciduous woodland types in BADL, found primarily in riparian areas, are green ash – (American elm)/ chokecherry woodland and eastern cottonwood – (peachleaf willow)/ sandbar willow woodland (Von Loh et al. 1999). Green ash (*Fraxinus pennsylvanica*) and American elm (*Ulmus americana*) are the most common hardwoods in the park, found on mesic sites such as the bottoms of draws, river floodplains, and toeslopes of sand hills. Soils in these locations are generally loamy and moderately well-drained with a sparse herbaceous layer (as reviewed by NatureServe 2011). Cottonwood-willow woodlands occur primarily as small clumps along minor streams and around seeps, springs, and ponds (Von Loh et al. 1999). The soils are alluvial deposits of sand, silt, and clay, and are therefore generally poorly developed. This riparian woodland community type is particularly prone to invasion by exotic plant species (as reviewed by NatureServe 2011). More detailed descriptions of the park's woodland plant community types are available in Von Loh et al. (1999).

Woody draws, mostly located on northerly slopes, are ephemeral channels that contain deciduous trees such as green ash, chokecherry (*Prunus virginiana*), and American elm. Guevara (1997) studied these areas and the hydrological factors that control their distribution within BADL. He found differences in both soil moisture and soil texture between woody draws and similar draws supporting grasslands within the park. Spring recharge and dry season water loss were significantly higher in the woody draws, implying that they receive and/or store more moisture than grassy draws (Guevara 1997). Woody draws also were associated with soils low in clay content, suggesting that high clay contents may exacerbate moisture stress for woody vegetation "due to the low unsaturated hydraulic conductivity and infiltration, and strong moisture retention resulting in less available moisture" (Guevara 1997, p. 59). The fine texture of clay soils could also inhibit tree root growth (Guevara 1997).

Photo 2. Bison grazing near a green ash woody draw (photo by Shannon Amberg, SMUMN GSS, 2011).

Culturally Significant Plant Species

The BADL woodland plant community supports 11 species explicitly identified as culturally important to the Oglala Lakota (Table 9).

Table 9. Culturally significant plant and fungus species found in the woodlands plant community (Burnette 2006; M. Haar, written communication, 1 June 2011) and examples of their uses (White 2002). This is a selection of species considered to be culturally important and is not intended to be a comprehensive list.

Scientific name	Common name	Uses
Fraxinus pennsylvanica	green ash	arrows/pipes
Juniperus virginiana	eastern red cedar	medicinal/ritual
Lycoperdon gemmatum	puff ball (mushroom)	food/medicinal/ritual
Mentha arvensis	wild mint	food/tea
Prunus americana	wild plum	food
Populus deltoides	cottonwood	firewood/horse fodder
Prunus pumila var. *besseyi*	sand cherry	food
Prunus virginiana	chokecherry	food
Rhus aromatica/trilobata	fragrant sumac	smoked w/ tobacco
Rosa woodsii	woods rose	food
Shepherdia argentea	buffalo berry	food/ritual

Ecological Processes

The relationship between fire and woodlands in BADL is complicated. Fires occur naturally in western pine-juniper forests, often stimulating stand regeneration, and regular low-intensity fires are important in maintaining ponderosa pine stand health and stability (NPS 2004). Prescribed fire has been used in nearby Wind Cave National Park to maintain healthy ponderosa pine woodlands, increasing their resilience to insect outbreaks (WICA, Beth Burkhart, Botanist, written communication, 5 October 2011). However, only large mature ponderosa pines generally survive more intense fires (Brown 2006), while large diameter Rocky Mountain junipers can survive only light surface fires (Scher 2002, as cited by Gitzen et al. 2010). Smaller trees are killed by most fires and do not resprout. Repeated fires could kill the juniper seed source within a stand, reducing regeneration and eventually leading to a conversion to shrubland or grassland, perhaps dominated by exotic species (as reviewed by Gitzen et al. 2010). In healthy green ash woodlands, fire is likely to have a regenerating effect. However, in degraded sites with few mature trees, "fire may do more harm than good," aiding the establishment of exotic grasses and pushing the woodland towards a transition to shrubland or grassland (Gitzen et al. 2010, p. 59, citing Lesica 2003).

Ungulate grazing and browsing is generally light in the park's woodlands, but can occasionally cause problems. Heavy use by bison and other ungulates can increase erosion, particularly in Rocky Mountain juniper woodlands on shallow soils, leading to slumps that would remove the junipers (Sieg 1991, as cited by Gitzen et al. 2010). These open areas could be colonized by shrubs or exotic plants. Bison use of green ash woodlands is considered moderate "and does not hinder woody regeneration", but an increase in the abundance of white-tailed deer (*Odocoileus virginianus*) could impact the plant community (Gitzen et al. 2010, p. 58, citing Hansen et al. 1984 and Irby et al. 2000). Ungulate use in wooded riparian/stream areas also has the potential to cause soil compaction and trampling of streambank vegetation (B. Burkhart, written communication, 5 October 2011). In Rocky Mountain National Park, elk (*Cervus elaphus*) browsing has greatly reduced the establishment and recruitment of woody plants such as cottonwood in riparian areas (Gage and Cooper 2005). Similar impacts could be seen within BADL if ungulate use of riparian areas increased, potentially impacting the structure of these woodlands.

Existing Threats and Stressors

Little research has been done into the threats facing plant communities as a whole. However, stressors upon several of the dominant tree species within BADL woodlands are well documented. Ponderosa pine woodlands are threatened by the mountain pine beetle (*Dendroctonus ponderosae*), an aggressive species of bark beetle native to the pine forests of western North America (Logan and MacFarlane 2010). Bark beetles are among the largest source of natural disturbance in pine forests throughout the continent (Ayers and Lombardero 2000). In recent decades, billions of coniferous trees across millions of hectares have been killed by native bark beetles in North American forests, and several of the current outbreaks are among the largest and most severe in recorded history (Bentz et al. 2010). Beetle infestations and the associated damage often increase the probability of fire in woodlands, while fire in turn can increase a woodland's vulnerability to insects and disease (Ayers and Lombardero 2000). While no mountain pine beetle infestations have been reported in BADL, severe outbreaks are occurring in the Black Hills National Forest just 100 miles west of the park (USFS 2010).

It is currently unknown if mountain pine beetle is a serious threat to BADL ponderosa pine woodlands, given their relatively small size and isolated nature. The density and structure of pine stands also influence their susceptibility to pine beetle attack (Negron et al. 2008). Researchers in the Black Hills have found that higher density stands with a high portion of large trees are more likely to be attacked by pine beetles (Negron et al. 2008). Therefore, the maintenance of diverse, multi-aged or open (low density) ponderosa pine stands may be the key to minimizing pine beetle damage (Shepperd and Battaglia 2002).

Green ash trees face a variety of biological threats in the northern Great Plains. A native heart-rot fungus (*Perenniporia fraxinophila*) may be slowing tree growth and weakening trunks and limbs (Lesica et al. 2003). Although it does not appear to directly cause canopy dieback, it "may contribute to the decline of ash woodlands, especially where drought stress is common" (Lesica et al. 2003, p. 153). Lesica et al. (2003) found that the incidence of *P. fraxinophila* in eastern Montana was associated with a decline in mean annual precipitation in the region. Ash yellows, a disease caused by phytoplasma, also reduces tree growth rates and eventually kills some trees (Sinclair and Griffiths 1994, Gleason et al. 1997, as cited by Walla et al. 2000). While common in the Great Plains, it is unknown if this disease is a serious threat in BADL. One non-native species that has not yet been found in the park but may pose a serious threat is the emerald ash borer beetle (*Agrilus planipennis*). The emerald ash borer has not been reported in the state of South Dakota to date, but has the potential to completely devastate any ash woodland it invades (NE Forest Service 2011).

The degree to which invasive plant species threaten woodlands in the park has not yet been determined. Yellow sweetclover (*Melilotus officianalis*) comprised 9% of the herbaceous layer in some Rocky Mountain juniper stands studied by Sieg (1991), but the impact of this species on the plant community as a whole has not been studied (Gitzen et al. 2010). Kentucky bluegrass (*Poa pratensis*) is found in mesic woodlands, but both the status and impacts of invasives in these woodlands is uncertain (Von Loh et al. 1999, Gitzen et al. 2010). Russian olive (*Elaeagnus angustifolia*), a non-native tree species that thrives on all soil types, has been documented in the park and is becoming established along rivers and perennial streams across the Great Plains (Von Loh et al. 1999). Saltcedar (*Tamarix ramosissima*) has also been observed in the park and other species of tamarisk are likely present or encroaching (NGPN 2011). According to Stromberg et al. (2007, p. 382; citing Sher et al. 2000, Glenn and Nagler 2005), saltcedar's "deep roots, drought and salt tolerance, prolonged period of seed dispersal and unpalatability to livestock" allow it to compete with and potentially replace cottonwood and willow species in riparian areas.

Climate Change Vulnerability

Analysis of the woodland plant community within BADL showed that it is highly vulnerable to climate change with an overall score of 22 (Table 10).

Table 10. The vulnerability assessment results for the woodland plant community of BADL.

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

* 6-13= least vulnerable, 14-19 = moderately vulnerable, 20-25 = highly vulnerable, 26-30 = critically vulnerable

The woodland community types of BADL are generally in the central part of their latitudinal ranges (Plate 8) and are therefore unlikely to be significantly vulnerable to an increase in temperature alone. However, since woodlands require mesic soil conditions, changes in precipitation and evapotranspiration will likely have a substantial influence on this plant community. Climate models project a 4-8° C (7-14° F) increase in summer temperatures by 2100 and greater evapotranspiration rates which, despite a predicted increase in annual precipitation, would lead to overall drier conditions (up to a 15% increase in aridity) (Climate Wizard 2011a). If conditions become drier with more frequent and severe droughts, the riparian woodlands and some upland species such as ponderosa pine are likely to be negatively affected. In a study of the ecotone between ponderosa pine and juniper woodlands in New Mexico during the 1950s, researchers found that the ecotone "shifted extensively and rapidly" in favor of the juniper woodland due to extensive pine mortality during a severe drought (Allen and Breshears 1998, p. 14839). Drought stress was also found to be a common cause of green ash canopy dieback in the northern Great Plains (Lesica et al. 2003), with prolonged drought and lower water tables leading to high mortality of mature ash trees (Albertson and Weaver 1945, as cited by Gitzen et al. 2010). Since the mid-1970s, Forest Service researchers have suggested that woody draws "are in danger of extinction, as many woody stands have been replaced by grasses and forbs" (Guevara 1997, p. 1; citing Boldt et al. 1978). Riparian species such as cottonwood and willows are generally drought-intolerant, with seedlings showing the highest vulnerability to extended dry conditions (Stella and Battles 2010). If prolonged dry periods greatly reduce or eliminate seedling recruitment, cottonwood-willow woodlands could become increasingly rare on the BADL landscape.

Climate change, for example greater temporal variation in precipitation, may also lead to seasonal changes in hydrology that could affect riparian woodlands. While these changes have not been investigated in BADL or the northern Great Plains, an analysis of historic hydrologic data for Rocky Mountain streams illustrates the potential impacts of climate change. Researchers found four changes in streamflow seasonality over the past century: 1) a slight increase in winter flows, 2) an increase in early spring flows producing a more gradual rise to spring peak levels, 3) an earlier spring peak, and 4) a decline in summer flows, especially in the late summer (Rood et al. 2008). Rood et al. (2008) predicted that changes in winter and early spring flow would have minimal influence on riparian woodland species, since they are dormant at these times, but the decline in late summer flows could have a significant influence on riparian woodlands (Table 11). This decline "would impose chronic drought stress along river reaches in arid and semi-arid ecoregions", especially for cottonwoods and willows, where water from streams regularly infiltrates into the riparian groundwater table during the hot and dry summer months (Rood et al. 2008). Reduced summer flows would particularly affect mature trees further from the streams, young saplings, and seedlings (Rood et al. 2008).

Table 11. A summary of the probable impacts on riparian woodlands due to changes in the seasonality of streamflows in the central Rocky Mountains (from Rood et al. 2008).

	Impact on floodplain (riparian) forests
Increased winter flows	Slight influence. Cottonwoods, willows and other deciduous riparian plants are leafless and physiologically relatively inactive and insensitive in winter. Changing winter flow regime will impact ice formation and break-up that provides a fluvial geomorphic force that produces colonization sites for seedlings and scarifies cottonwoods and willows, promoting clonal suckering.
Earlier spring run-off and peak flows	Slight to considerable stress. Plant phenology (life cycle timing) is coordinated with patterns of the natural flow regime, including floodplain inundation, bank scour and deposition, and water stage patterns that influence surface moisture and groundwater. The partial uncoupling of the phenology of cottonwoods and willows with the river flow regime would reduce seedling recruitment and may limit colonization to lower bank elevations, resulting in narrower bands of new cottonwoods, and narrower floodplain forests.
Major decrease in late summer flows	Major stress. Especially in arid and semi-arid ecoregions, riparian groundwater is recharged with water from the stream during the summer. Decreasing streamflow would reduce this recharge, resulting in drought stress and consequently, xylem cavitation and branch, crown and whole tree die-back. Seedlings and saplings would be particularly vulnerable and this would further diminish reproduction that is essential for long-term forest survival.

Cottonwood-willow woodlands in the Great Plains are maintained by periodic flooding and require "the creation of new sandbars, mudflats, and other barren stretches for its continued existence" (Von Loh et al. 1999, p. 162). Cottonwoods and willows, with their life strategy of abundant seed production, seed dispersal, and fast growth to colonize newly created habitats, are well-adapted to riparian areas (Stella and Battles 2010). Without regular disturbance (at least every 20-30 years), cottonwood and willow species will be unable to regenerate and the woodlands will likely transition to a grassland plant community (Von Loh et al. 1999).

BADL woodlands are not expected to have significant adaptive capacity, due to the limited area in which suitable soil moisture conditions occur within the park. The dry coniferous woodlands, which tolerate a wider variety of moisture conditions, may display a slightly higher adaptive capacity than the riparian woodlands. With the exception of cottonwood, the common BADL tree species are not prolific reproducers, which may reduce their ability to recover from significant environmental stress. For example, Rocky Mountain juniper does not reproduce until at least ten years of age under favorable conditions, while ponderosa pine only produces good seed crops every three to eight years (Burns and Honkala 1990). Cottonwood, in contrast, can begin reproducing after five years and may produce up to 48 million seeds per year (Burns and

Honkala 1990). However, cottonwood seedling establishment requires a narrow range of environmental conditions which can lead to overall low recruitment (Stella and Battles 2010).

The ecologically influential species of the various woodland plant community types within the park are generally at the center of their ranges (NRCS 2011) and, like the woodlands overall, would not be highly vulnerable to an increase in temperature alone. However, ponderosa pine, green ash, and cottonwood are all known to be negatively impacted by dry soil conditions, especially drought (Allen and Breshears 1998, Gitzen et al. 2010, Stella and Battles 2010), and could therefore be considered especially vulnerable to climate change.

The hotter and drier conditions expected in BADL over the next century will likely exacerbate many of the current non-climate stressors of the woodland plant community. Researchers believe that drought and warmth across western North America over the past decade have already led to extensive insect outbreaks and increased mortality in many forest types (Allen et al. 2010). Higher summer temperatures typically accelerate the development and reproduction rates of insects, while drought stress may increase many tree species' (especially ponderosa pine) vulnerability to insect attack (Allen and Breshears 1998, Ayers and Lombardero 2000, Allen et al. 2010). In the Black Hills, drought lowers the resistance of ponderosa pine stands to attack, and can increase mountain pine beetle populations to "highly destructive epidemic levels" (Shepperd and Battaglia, citing Schmid et al. 1991). The impact of another biological threat, the ash heart rot *P. fraxinophila*, may also increase during droughts (Lesica et al. 2003).

Warmer, drier conditions often favor stress-tolerant invasive plants over native woodland species. One example of this is *Tamarix*, a genus of opportunistic exotic woody species that has begun to dominate many riparian corridors in the southwestern United States (Stromberg et al. 2007). Under historic hydrological conditions, this species was not able to compete with native poplar and willow species. Yet under drier soil conditions, the deep roots, prolonged seed dispersal period, drought and salt tolerance, and unpalatability of *Tamarix* species allow them to thrive on sites previously occupied by native riparian species (Stromberg et al. 2007).

Uncertainty and Data Gaps

It is widely recognized that there is less agreement between precipitation model projections than between temperature model projections (Girvetz et al. 2009, Kucharik et al. 2010). For example, individual climate models predict anywhere from a 15% decrease to a 25% increase in annual precipitation for the BADL region by the end of this century (Climate Wizard 2011b). On average, the models predict a slight increase in precipitation, although increases in evapotranspiration will likely lead to overall drier conditions. However, a slight variation in precipitation change in either direction could have a serious impact on woodlands, which are so dependent on soil moisture.

One of the largest knowledge gaps regarding woodlands is a lack of data on climate-related vegetation mortality (Allen and Breshears 1998, Allen et al. 2010). Allen et al. (2010) recognizes the need for a worldwide monitoring program to document global forest mortality patterns. The "physiological thresholds of individual tree mortality under chronic or acute water stress" is also unknown for most tree species, which makes it difficult to confidently predict patterns of regional die-off (Allen et al. 2010, p. 670).

More information is also needed on the interactions between woodlands and other organisms, particularly herbivores and pathogens. Ayers and Lombardero (2000, p. 273) found that "it is difficult to predict how climate scenarios will influence tree resistance to pathogens." Little is also known about fungi-tree interactions (both harmful and beneficial) and how fungi will respond to climate change (Allen et al. 2010). Within BADL, little is known about the impacts of pathogens in green ash draws, the effects of Dutch Elm disease in the park, and the threat that white-tailed deer browsing poses to ash regeneration (Gitzen et al. 2010). The potential effects of invasive plant species on succession within woody draws are also poorly understood. If a dense sod of Kentucky blue grass or other exotics forms, it may inhibit tree seedling establishment (Lesica 2003, as cited by Gitzen et al. 2010).

Confidence in the woodlands vulnerability assessment is moderate due to the uncertainties and data gaps discussed above. Most variables were rated moderate, with only "intrinsic adaptive capacity" receiving a low certainty rating (Table 12).

To address some of the uncertainty within this assessment, alternative scores were identified for several variables in addition to the best estimate scores (Table 12). Alternative scores create a range of likely vulnerability for the plant community. When factored in, the range of vulnerability scores for the woodland plant community is 20 to 24, all of which are still within the "highly vulnerable" category. This suggests that, despite some uncertainty in climate projections and individual community variables, the classification of woodlands as highly vulnerable is fairly certain.

Table 12. Certainty and alternative vulnerability scores for woodland plant community assessment variables.

Variable	Certainty Score*	Vulnerability Score	Alternative Scores
Location in geographical range/distribution of plant community	3	3	
Sensitivity to extreme climatic events (e.g., drought, flash floods, windstorms)	2	4	3,5
Dependence on specific hydrologic conditions	2	4	
Intrinsic adaptive capacity	1	3	4
Vulnerability of ecologically influential species to climate change	2	4	3
Potential for climate change to exacerbate impacts of non-climate stressors	2	4	
Total	**12**	**22**	**20-24**

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* For individual variables, 3 = high, 2 = moderate, and 1 = low; total ranges are 6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence.

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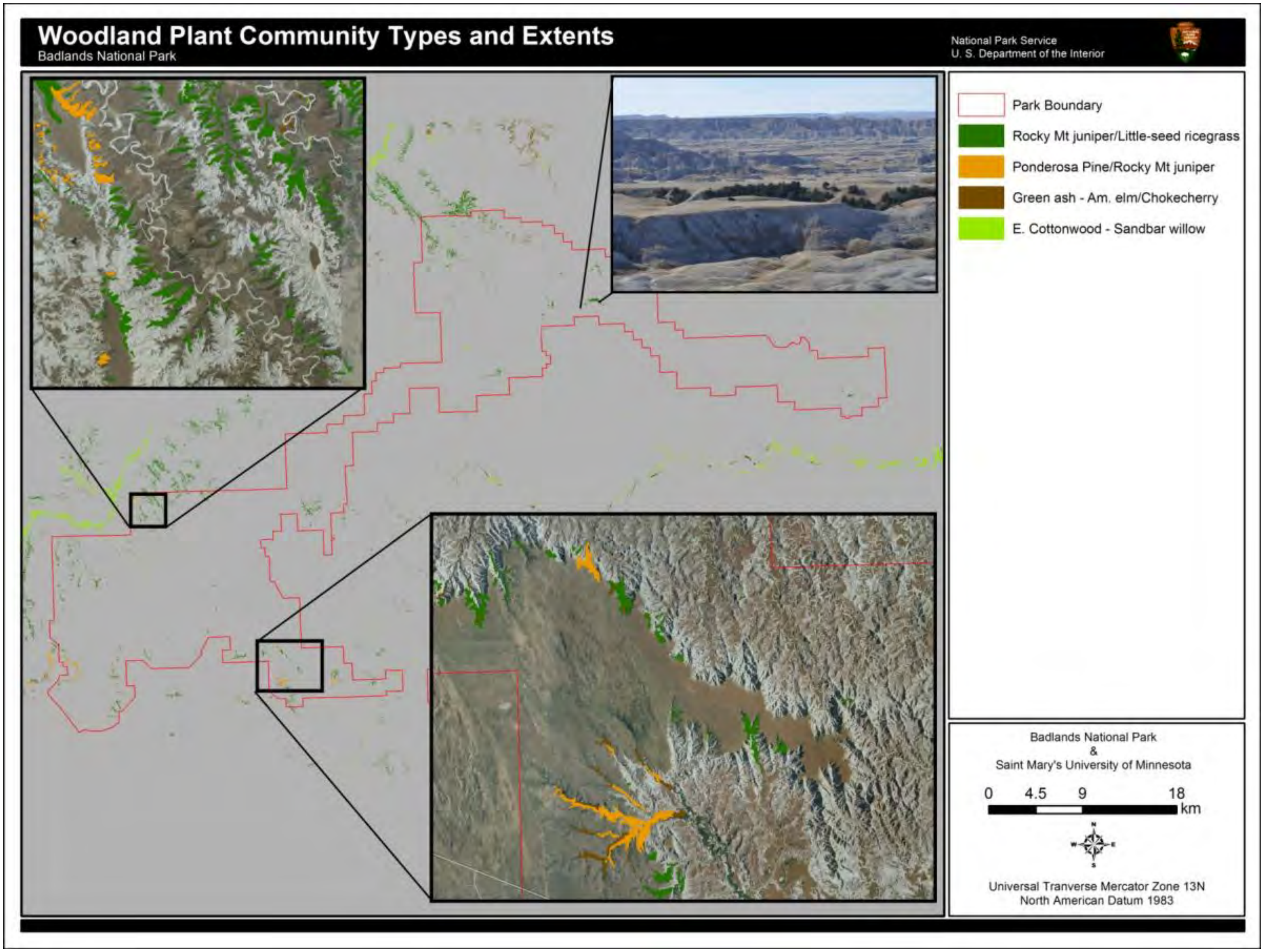

Plate 7. Distribution of woodland plant community types within BADL (USGS 1999).

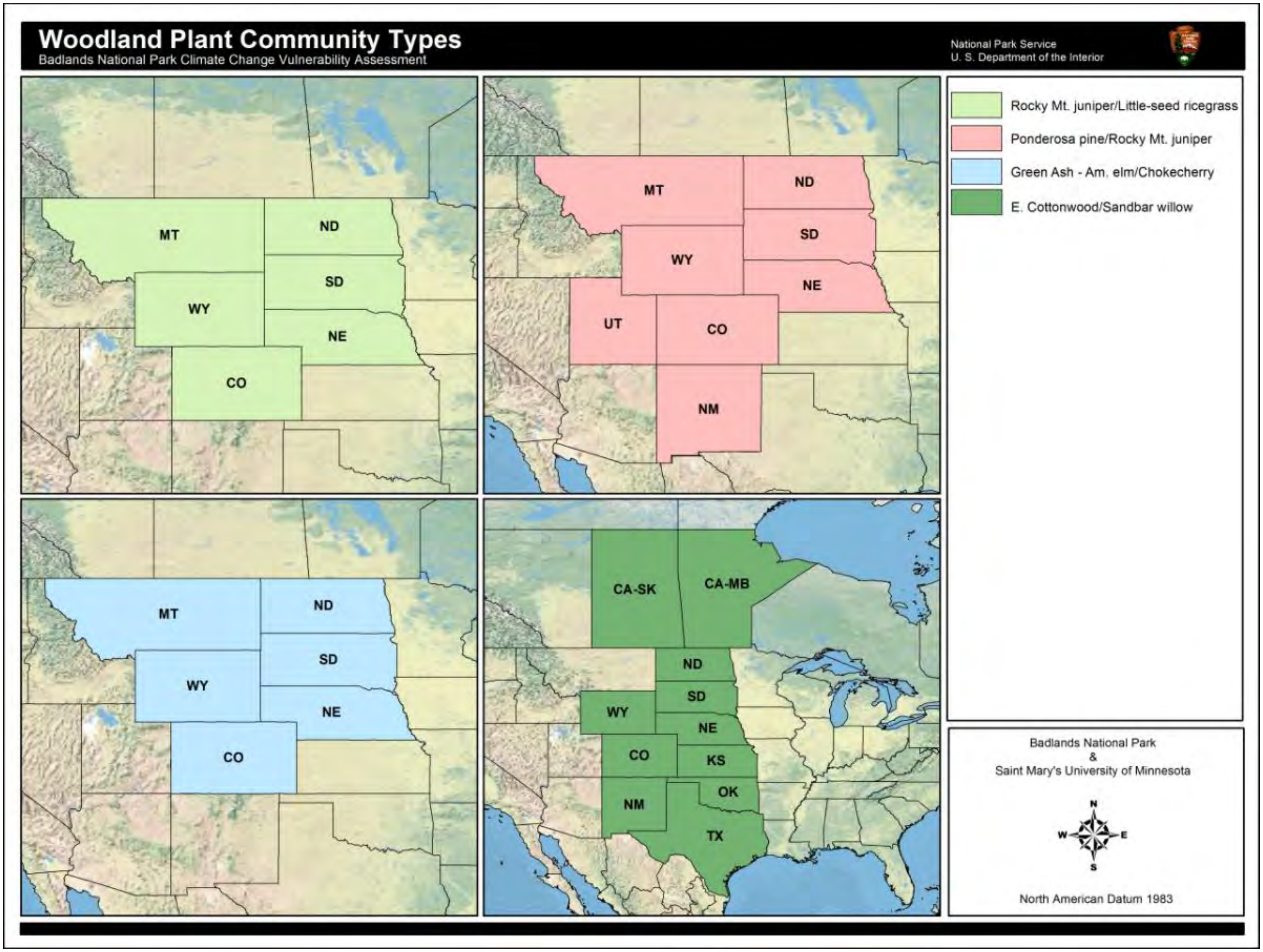

Plate 8. Distribution of the four woodland plant community types found in BADL (NatureServe 2011). Maps indicate presence/absence within a state or province rather than actual range.

4.1.2 Shrublands

Summary:

A wide variety of shrubland plant community types occur throughout BADL, primarily in mesic or sandy areas, providing critical habitat for park wildlife. Common shrub species include silver and sand sagebrush, skunkbush sumac, soapweed yucca, and chokecherry. Shrublands as a whole were rated as “moderately vulnerable” to climate change with moderate uncertainty due to limited research on the plant community. However, the factors and processes that control the distribution of each shrubland community type are quite different, so uncertainty is greater regarding the vulnerability of each type. Sandbar willow shrublands are likely more vulnerable due to their dependence on periodic flooding. Silver sagebrush shrublands may also be more vulnerable, as they tend to occur in drainage bottoms, while drier shrublands (e.g., sand sagebrush) may be less vulnerable. Climate change will likely exacerbate current threats to shrublands, particularly invasive species such as annual brome grasses.

Description

Shrublands comprise just over 6% of the BADL area, occurring mainly along floodplains and on sand deposits, mesic slopes, and in draws (Plate 9; Von Loh et al. 1999). Shrublands are limited primarily by soil moisture availability, although shrublands usually can tolerate drier conditions than woodlands (Girard et al. 1989, Gitzen et al. 2010). Shrublands provide critical habitat for many wildlife species, particularly birds and small mammals (Rowland et al. 2006, as cited by Bradley 2010). The variety of shrublands found within the park are shown in Table 1 and described in detail in Von Loh et al. (1999).

Photo 3. Silver sagebrush in BADL (photo by Milt Haar, NPS, 2011).

Table 13. Shrubland plant community types of Badlands National Park (Von Loh et al. 1999).

Dry plains shrublands	**Mesic plains shrublands**
Sand sagebrush/ Prairie sandreed Shrubland	Silver sagebrush/ Western wheatgrass Shrubland
Rubber rabbitbrush Shrubland	Chokecherry – (American plum) Shrubland
Skunkbush sumac/ Threadleaf sedge Shrub Herbaceous Vegetation	Greasewood/ Western wheatgrass Shrubland
Soapweed yucca/ Prairie sandreed Shrub Herbaceous Vegetation	Silver buffaloberry Shrubland
Riparian shrublands	Western snowberry Shrubland
Sandbar willow Temporarily Flooded Shrubland	

Silver sagebrush (*Artemisia cana*) shrublands are the most widespread shrubland plant community in BADL, found regularly in the loamy soils of floodplains and on adjacent slopes (Von Loh et al. 1999, NatureServe 2011). Other shrubs such as greasewood (*Sarcobatus vermiculatus*) and western snowberry (*Symphoricarpos occidentalis*) are often present in these stands, along with an understory of western wheatgrass (*Pascopyrum smithii*) (Von Loh et al. 1999).

Sand sagebrush (*Artemisia filifolia*) shrublands are found on sand hills and ridges, especially in the southern unit of the park (Von Loh et al. 1999). This species sometimes forms a mosaic with soapweed yucca (*Yucca glauca*) on lower ridges and near butte tops (as reviewed by NatureServe 2011). Soapweed yucca forms its own shrubland type along butte edges, on low sandy ridges, and on dry canyonsides (Von Loh et al. 1999). The herbaceous layer in both of these shrublands is characterized by prairie sandreed (*Calamovilfa longifolia*), although the understory is typically more dense and diverse in the soapweed yucca shrubland than in sand sagebrush (Von Loh et al. 1999, NatureServe 2011).

Western snowberry shrublands occur in mesic draws, swales, and drainage bottoms, as well as along the margins of woodlands (Von Loh et al. 1999). Western snowberry is also regularly found in the understory or around the edges of other less common shrub community types, including chokecherry-(American plum), silver buffaloberry, greasewood/western wheatgrass, rubber rabbitbrush, and skunkbush sumac/threadleaf sedge shrublands (Von Loh et al. 1999, NatureServe 2011). Sandbar or coyote willow (*Salix exigua*) shrubland is a rare plant community type in the park, found in small stands adjacent to creeks, rivers, and some wetlands (Von Loh et al. 1999).

Photo 4. Rubber rabbitbrush flowering (left) and sandbar willow (right) in BADL (photos by Milt Haar, NPS, 2011).

Culturally Significant Plant Species

The BADL shrublands support six plant species of cultural importance to the Oglala Lakota (Table 14).

Table 14. Culturally important plant species found in shrublands (Burnette 2006; M. Haar, written communication, 1 June 2011) and examples of their uses (White 2002). All species, with the exception of yucca and fringed sage, are also found in woodlands. This is a selection of species considered to be culturally important and is not intended to be a comprehensive list.

Scientific name	Common name	Use
Artemisia frigida	fringed sage	medicinal
Prunus americana	wild plum	food
Prunus virginiana	chokecherry	food
Rhus aromatica/trilobata	skunkbush sumac	smoked w/ tobacco
Shepherdia argentea	buffalo berry	food/ritual
Yucca glauca	yucca	medicinal/soap

Ecological Processes

Most of the dominant shrub species in BADL are tolerant of fire and will resprout even after repeated fires (Higgins et al. 1989, as cited by Gitzen et al. 2010). While frequent or hot fires may temporarily reduce the cover and abundance of many shrub species, it is highly unlikely that shrublands will be eradicated in favor of grasslands due to fire alone (as reviewed by Gitzen et al. 2010). A study of the effects of prescribed burning on silver sagebrush found that fall burning, when soils were dry, resulted in significantly higher sagebrush mortality than spring burning when soil moisture was high (White and Currie 1983). This study also found that higher intensity burns resulted in greater sagebrush mortality and less regrowth (White and Currie 1983).

Grazing has the potential to influence shrublands in BADL, but the relationships are complex and have not been studied in the park. Heavy grazing in sagebrush-dominated shrublands may benefit the shrubland community by reducing competition from grasses, or trampling may inhibit sagebrush seedling survival (Beck and Mitchell 2000, as cited by Gitzen et al. 2010). Gillen and Sims (2006, as cited by Gitzen et al. 2010) found that moderate to heavy grazing maintained or increased sand sagebrush. However, overgrazing has been found to increase the vulnerability of sagebrush shrublands to invasion by non-native annual grasses (Chambers et al. 2007). Although it has not been reported in the park, extensive ungulate browsing could negatively impact riparian willow shrublands. In the Rocky Mountains, heavy elk browsing has impacted willow seed production and likely contributed to an overall decline in riparian willow shrublands (Gage and Cooper 2005). With prolonged heavy browsing, shrub-dominated riparian areas could transition to grassland communities, “resulting in the loss of important ecological functions” (Gage and Cooper 2005).

Existing Threats and Stressors

The primary threat to shrublands in BADL is invasion by non-native species, particularly annual bromes (*Bromus* spp.). While the invasion of these grasses has been linked to historical land disturbance, the species appear capable of expanding into undisturbed areas as well (Bradley et al. 2006). The presence of cheatgrass (*Bromus tectorum*) in Idaho shrublands was found to increase fire frequency ten-fold in these communities, to as often as five years (Whisenant 1990, as cited by Bradley et al. 2006). While the impact of annual bromes on fire regime is not expected to be as dramatic in BADL, where native grasses are common in shrublands and contribute to a naturally higher frequency regime than in Idaho shrublands (USGS, Amy Symstad, Plant Ecologist, pers. comm., 15 November 2011), fire frequency may increase slightly. More frequent fires, in turn, could favor the invasive grasses over the native shrub species (Chambers et al. 2007). If vegetative cover decreases, even temporarily, as a result of increased fire frequency, it could lead to an increase in topsoil erosion (D'Antonio and Vitousek 1992, as cited by Bradley et al. 2006). Kentucky bluegrass is also present in most mesic shrublands in the northern Great Plains and may become dense enough to inhibit shrub regeneration (as reviewed by Gitzen et al. 2010). Leafy spurge (*Euphorbia esula*), although not yet confirmed in BADL, has been identified as a serious threat to silver sagebrush shrublands in other Great Plains parks (Butler and Cogan 2004). This species is capable of forming dense patches that could inhibit sagebrush seedling establishment and survival (as reviewed by Gitzen et al. 2010).

In some areas of North America, sagebrush shrublands adjacent to woodlands are threatened by woody species encroachment (Bradley 2010). However, this has not been reported as an issue in the park. Larger woody species generally require more soil moisture than is available in BADL's shrublands. The threat of shrubland conversion to native grasslands is also highly unlikely under current conditions (Gitzen et al. 2010).

Climate Change Vulnerability

Analysis shows that the shrubland plant community in BADL is moderately vulnerable to climate change with an overall score of 18 (Table 15).

Table 15. The vulnerability assessment results for the shrubland plant community of BADL.

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

* 6-13 = least vulnerable, 14-19 = moderately vulnerable, 20-25 = highly vulnerable, 26-30 = critically vulnerable

While several of the shrubland plant community types in BADL are in the central part of their current latitudinal range, others are at the southern edge (soapweed yucca/prairie sandreed, skunkbush sumac/threadleaf sedge, and rubber rabbitbrush), and the sand sagebrush/prairie sandreed shrubland reportedly occurs only in South Dakota (Plate 10 and Plate 11). Typically communities at the southern edge of their ranges are more vulnerable to climate change. However, the component shrub species within these plant community types are in the central or northern parts of their ranges (Figure 11; NRCS 2011). This suggests that the ranges of these shrublands (the unique combination of species) are limited by environmental factors other than temperature. Therefore, the shrublands of BADL, like the woodlands, are unlikely to be significantly vulnerable to an increase in temperature alone. Since shrubland distribution is limited by soil moisture, the increased seasonal variability in precipitation and increased evapotranspiration rates projected by the climate models could affect this plant community.

While some of the dry shrublands are adapted to drought, if conditions become drier with more frequent and severe droughts, riparian and mesic shrublands are likely to be seriously impacted. Seasonal changes in hydrology such as reduced summer flows, as discussed in the woodlands assessment, could also affect riparian shrublands (Rood et al. 2008).

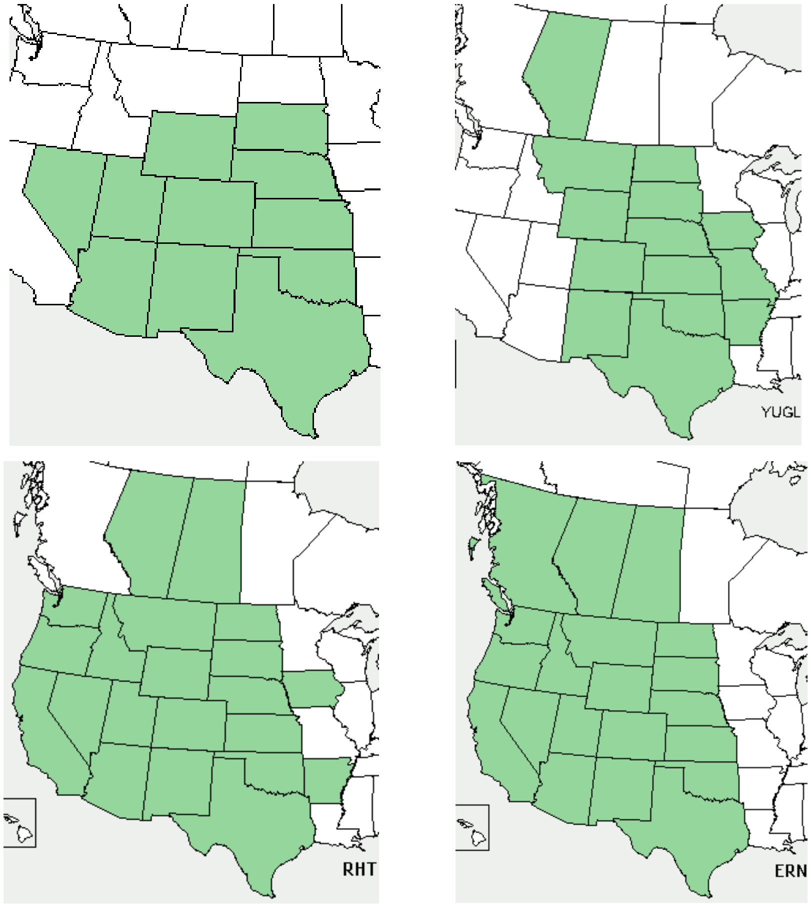

Figure 11. Distribution of sand sagebrush (upper left), soapweed yucca (upper right), skunkbush sumac (lower left) and rubber rabbitbrush (lower right) (NRCS 2011). Maps indicate presence/absence within a state or province rather than actual range.

The sandbar willow shrubland is an early successional plant community type that originates after floods deposit fresh sediment or wash away existing alluvial material (as reviewed by NatureServe 2011). They require this disturbance for regeneration and, without periodic flooding, may persist for only 10-20 years before being replaced (as reviewed by NatureServe 2011). Therefore, if the frequency or magnitude of stream flooding within BADL is reduced as a result of climate change, willow shrublands could disappear from the park.

The intrinsic adaptive capacity of shrublands was rated as fairly significant, primarily because most shrubland community types (with the exception of sandbar willow) occur within a variety of environmental conditions (soil types, elevations, etc.) within the park. Most shrub species are also able to regenerate fairly rapidly, both vegetatively and by seed (USFS 2011). Finally, the current non-climate stressors on the plant community appear to be relatively minimal.

While the vast majority of BADL's shrub species are somewhat adapted to periods of drought and are not expected to be particularly vulnerable to climate change, the one exception is sandbar willow. Rood et al. (2011, p. 31) described sandbar willow as an "obligate riparian shrub" that requires sites with shallow groundwater and abundant moisture. Due to its moisture needs and the flooding disturbance requirements discussed above, sandbar willow could be considered especially sensitive to climate change.

The warmer and drier conditions predicted for BADL are likely to benefit the non-native plants already invading the park's shrublands. Dukes and Mooney (1999) noted that most aspects of global climate change will favor invasive species over natives. A study of cheatgrass invasion in the southwestern United States found that the species was limited at higher elevations by low soil temperatures and a shorter growing season (Chambers et al. 2007). Cheatgrass was very successful on sites with highly variable precipitation and soil moisture (Chambers et al. 2007). Several of the climate changes predicted for the BADL area – increased temperatures, longer growing seasons, and more variable precipitation – would favor the expansion of annual bromes such as cheatgrass. Shrublands may become less resistant to other invasive plants such as spotted and Russian knapweed (*Centaurea maculosa* and *Rhaponticum repens)* and yellow star-thistle (*Centaurea solstitialis).*

Uncertainty and Data Gaps

Based on review of literature, it seems that less research has been done on the potential impacts of climate change on this plant community and its component species in the Great Plains than on other plant communities such as woodlands and grasslands. The greatest data gap with regard to shrublands is how they are affected by invasive plant species and, more specifically, how these responses will be impacted by climate change. As Chambers et al. (2007, p. 117) noted, "ecosystem susceptibility to invasion by nonnative species is poorly understood." One particular area of uncertainty is whether mature shrubs would be harmed by invasive herbaceous species (Gitzen et al. 2010). The idea that alteration of flow regime as a result of climate change could drive compositional shifts in riparian shrublands, perhaps favoring invasives such as *Tamarix* over natives, is also untested (Stromberg et al. 2007).

Confidence in the shrubland plant community vulnerability assessment is moderate (Table 16), primarily due to the lack of available research discussed above. All individual variables received moderate certainty scores. However, it is worth noting that the uncertainty is greater regarding the vulnerability of individual shrubland types.

Alternative scores were identified for four of the six individual variables (Table 16). Initial scores were assigned based on average vulnerability across all shrub community types within the park. However, some community types appear more vulnerable to certain variables than others (e.g., sandbar willow and dependence on specific hydrological conditions). The first two alternative scores below were chosen based on the higher vulnerability of one or two specific shrubland community types, while the third and fourth, intrinsic adaptive capacity and impacts of non-climate stressors, were largely based on uncertainty. These alternatives result in a range of scores from 17 to 21, which are slightly higher than our best estimate and extends into the highly vulnerable category. This suggests that although most shrublands in BADL are moderately vulnerable to climate change, some may in fact be highly vulnerable.

Table 16. Certainty and alternative vulnerability scores for shrubland plant community assessment variables.

Variable	Certainty Score*	Vulnerability Score	Alternative Scores
Location in geographical range/distribution of plant community	2	3	4
Sensitivity to extreme climatic events (e.g., drought, flash floods, windstorms)	2	3	
Dependence on specific hydrologic conditions	2	3	4
Intrinsic adaptive capacity	2	2	3
Vulnerability of ecologically influential species to climate change	2	3	
Potential for climate change to exacerbate impacts of non-climate stressors	2	4	3
Total	**12**	**18**	**17-21**

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* For individual variables, 3 = high, 2 = moderate, and 1 = low; total ranges are 6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence.

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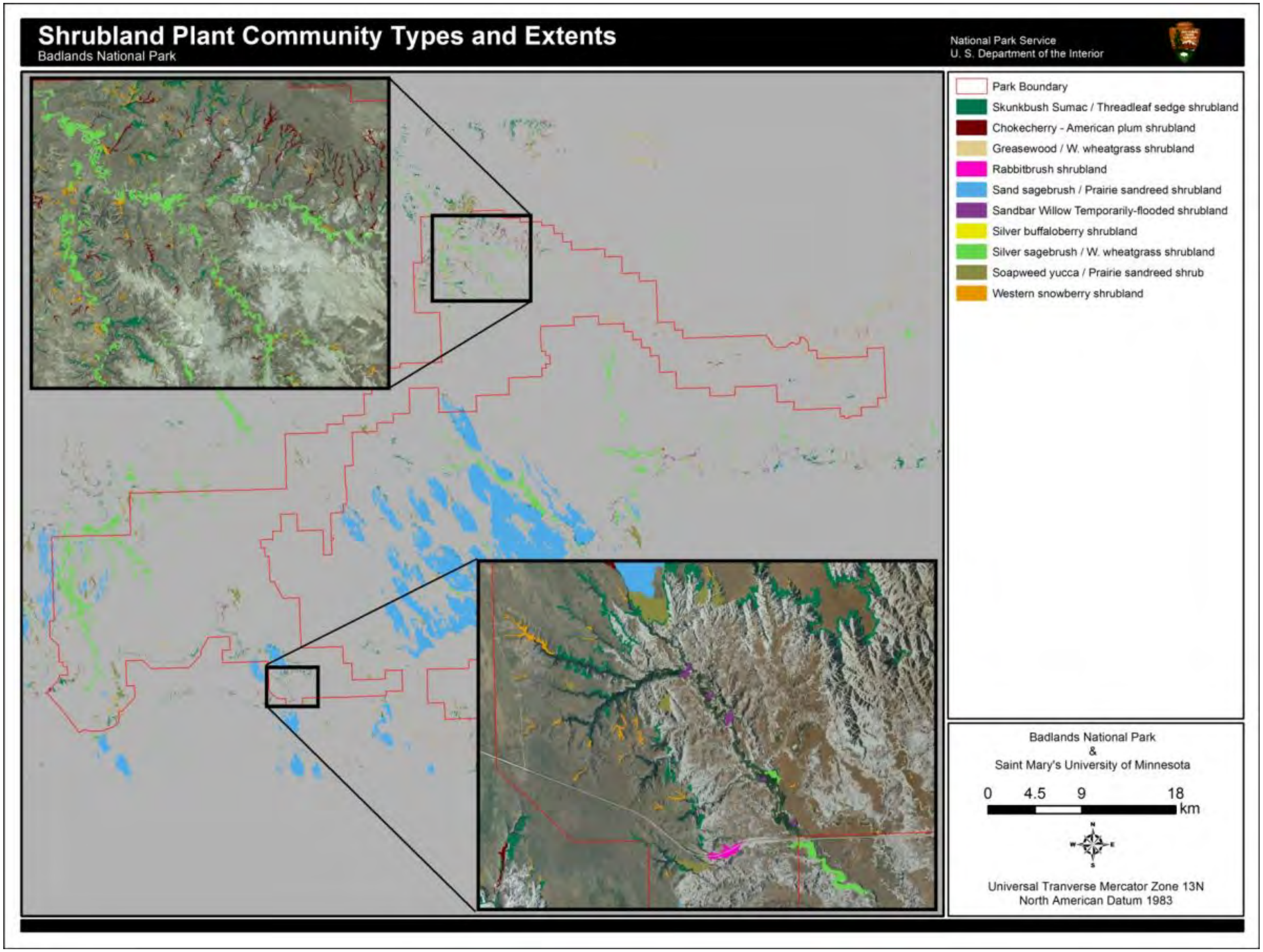

Plate 9. Distribution of shrubland plant community types within BADL (USGS 1999).

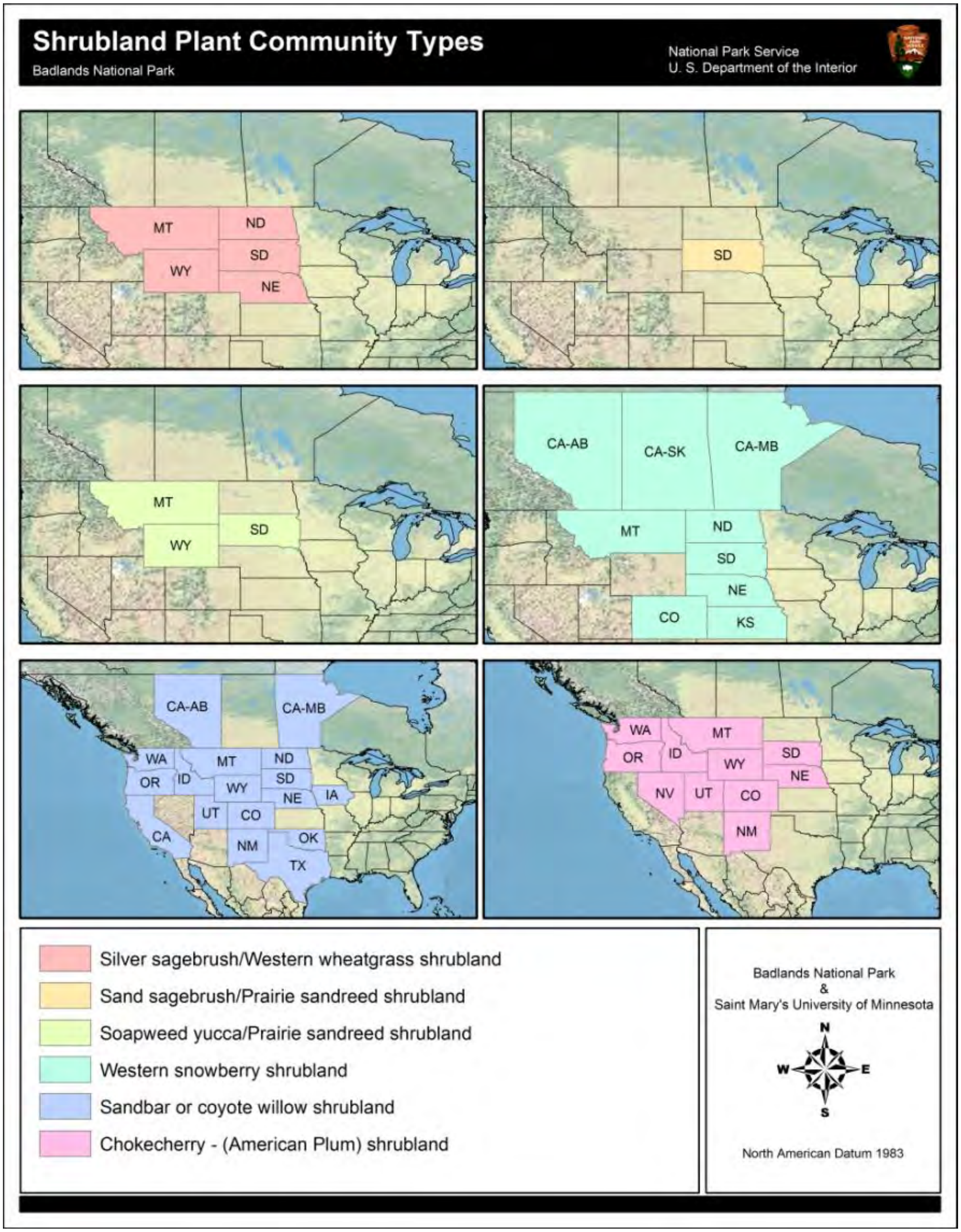

Plate 10. Distribution of six of the shrubland plant community types found in BADL (NatureServe 2011). Maps indicate presence/absence within a state or province rather than actual range.

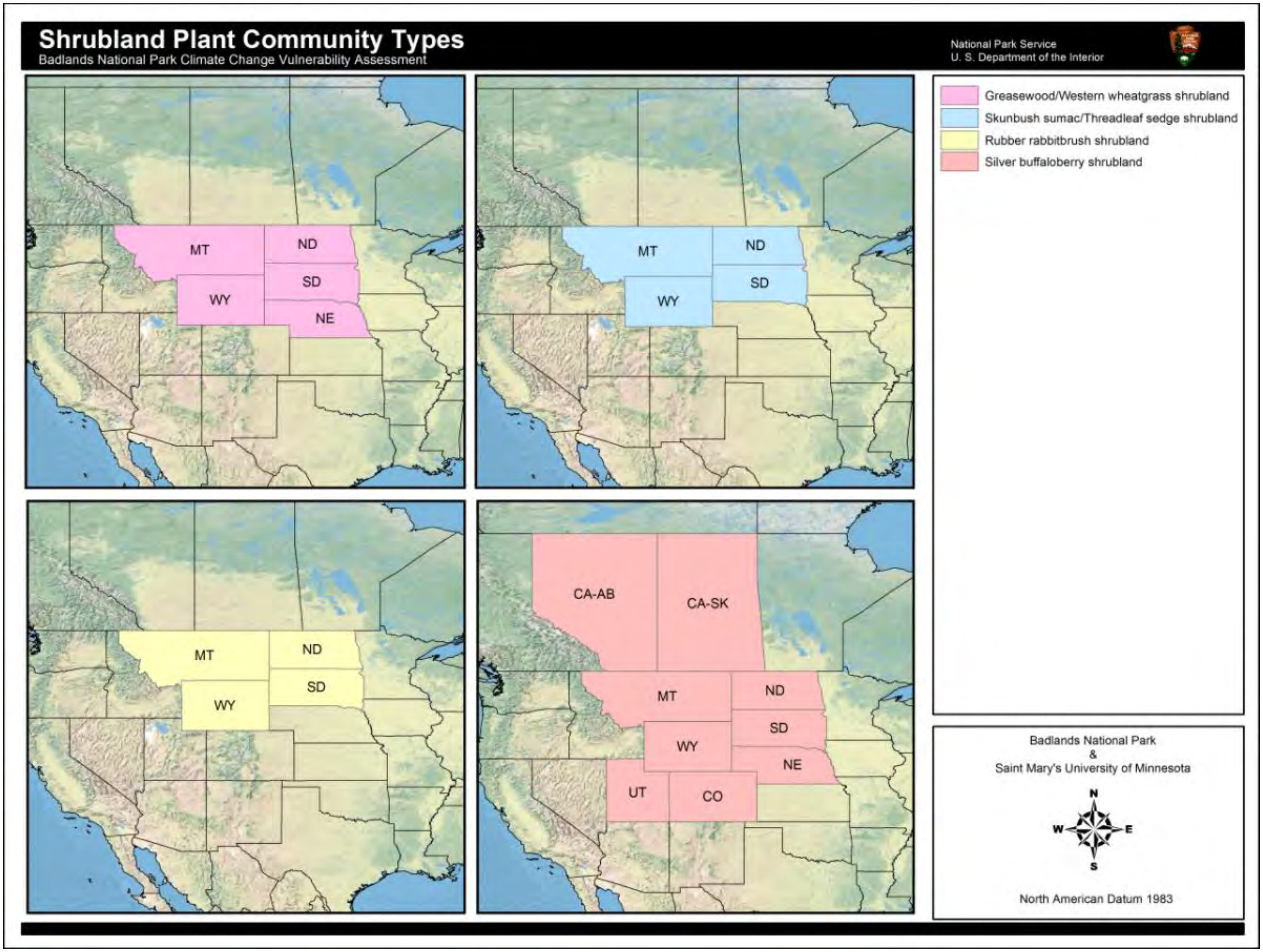

Plate 11. Distribution of the remaining four shrubland plant community types in BADL (NatureServe 2011). Maps indicate presence/absence within a state or province rather than actual range.

4.1.3 Grasslands

Summary:

A variety of mixed-height grassland types cover approximately 42% of BADL. The most common grass species include western wheatgrass, blue grama, little bluestem, and buffalograss. Grasslands are well adapted to fire and grazing and these processes play an important role in the BADL plant community today. Grasslands as a whole were rated as “least vulnerable” to climate change, with less uncertainty than other BADL plant communities based on the abundance of research conducted in grassland ecosystems. However, certainty about the vulnerability of individual grassland types is lower than for the plant community as a whole. The small emergent wetland areas in the park are likely much more vulnerable to climate change than other grassland community types, as conditions are expected to become drier in the area.

Description

Grasslands cover 42% of BADL and can be found across a variety of soil types and landscape positions (Plate 12; Von Loh et al. 1999). The species composition of the park’s grasslands is influenced by soil depth and composition, moisture levels, and disturbance history (particularly fire and grazing). The different types of grassland found within BADL, often intermingled, are shown in Table 17. Detailed descriptions of these plant community types can be found in Von Loh et al. (1999).

Photo 5. Mixed-grass prairie at BADL (photo by Shannon Amberg, SMUMN GSS, 2010).

Table 17. Grassland community types of Badlands National Park (Von Loh et al. 1999).

Dry Mixed-grass Prairie Types	**Riparian/Wet Meadow Types**
Blue grama - Buffalograss, Xeric soils	Pale spikerush
Prairie sandreed - Sun sedge	Switchgrass
Western wheatgrass - Blue grama - Threadleaf sedge	Prairie cordgrass – Sedge species
Little bluestem - (Sideoats grama, Blue grama) -Threadleaf sedge	Cattail species – Bullrush species – Mixed herbs
Needle-and-thread – Blue grama – Threadleaf sedge	**Introduced Grasslands**
Mesic Mixed-grass Prairie Type	Crested wheatgrass – (Western wheatgrass)
Western wheatgrass – Green needlegrass	Smooth brome - (Western wheatgrass)
	Kentucky bluegrass – (Western wheatgrass)

Photo 6. Western wheatgrass – green needlegrass grassland at BADL (photo by Milt Haar, NPS, 2011).

Western wheatgrass (*Pascopyrum smithii*) is the predominant grass in BADL (Von Loh et al. 1999). The species thrives in clayey soils but also grows in the loamy soils of floodplains, narrow valleys, and on rolling uplands (as reviewed by NatureServe 2011). On mesic sites with deep soils, western wheatgrass is commonly found with green needlegrass (*Nassella viridula*). On drier sites, it is associated with blue grama (*Bouteloua gracilis*) and threadleaf sedge (*Carex filifolia*). Coarser-textured deep soils also support blue grama and threadleaf sedge, but in association with needle-and-thread (*Hesperostipa comata*), which is the tallest of the mid-height grasses at one meter high (as reviewed by NatureServe 2011).

Photo 7. Little bluestem in a BADL grassland (photo by Barry Drazkowski, SMUMN GSS, 2010).

Blue grama and buffalograss (*Bouteloua dactyloides*) dominate on drier soils and in areas with regular grazing, including by prairie dogs (Von Loh et al. 1999). These include butte edges and sandy ridges or hilltops. Small stands of prairie sandreed (*Calamovilfa longifolia*) and sun sedge (*Carex inops* ssp. *heliophila*) occur along intermittent drainages with significant sand and silt deposits. Drainageways and slopes with shallow, gravelly soils also support a mix of little bluestem (*Schizachyrium scoparium*), blue grama, sideoats grama (*Bouteloua curtipendula*), and threadleaf sedge (Von Loh et al. 1999).

Riparian and other wet areas of the park support different types of grasslands but these are generally limited in extent. Switchgrass (*Panicum virgatum*) dominates in a few small drainages in the North Unit (Von Loh et al. 1999). Prairie cordgrass (*Spartina pectinata*) is also found in drainage bottoms and along perennial waterways in the park. Other wetland species present include pale or common spikerush (*Eleocharis palustris*), cattails (*Typha* spp.), and bulrushes (*Scirpus* spp.).

Forbs make up a relatively small percentage of the biomass in grasslands but are a diverse and important component of the plant community. Some of the forb species commonly found in BADL grasslands are listed in Table 18.

Table 18. Native forbs common in BADL grasslands (Von Loh et al. 1999, NPS 2006).

Scientific Name	Common Name
Artemisia ludoviciana	white sagebrush
Asclepias pumila	plains milkweed
Helianthus annuus	wild sunflower
Phlox hoodii	Hood's phlox
Psoralidium tenuiflorum	slimflower scurfpea
Ratibida columnifera	prairie coneflower
Solidago missouriensis	Missouri goldenrod
Sphaeralcea coccinea	scarlet globemallow
Symphyotrichum ericoides	white heath aster
Tradescantia bracteata	longbract spiderwort
Verbena stricta	hoary vervain
Viola nuttallii	Nuttall's violet

Prairie dog towns are widespread within BADL grasslands on the deeper soils of valleys, level drainages, sloping hillsides, and the flats of tables and buttes (Von Loh et al. 1999). They range in size from less than one hectare to several hundred hectares, with the largest occurring adjacent to the Conata Basin (Von Loh et al. 1999). The vegetation on dog towns is typically sparse and patchy but can be highly variable, depending on soil type, the age of the town, and the prairie dog density (which relates to grazing intensity) (Von Loh et al. 1999). Prairie dogs alter vegetation types through their cycle of burrow establishment, grazing, and burrow abandonment, causing the native vegetation types to revert to an earlier successional state, typically weedy and forb-dominated (Von Loh et al. 1999). Some of the most common species in or on the edges of BADL dog towns include prostrate verbena (*Verbena bracteata*), fetid marigold (*Dyssodia papposa*), purple threeawn grass (*Aristida purpurea*), western wheatgrass, and buffalograss (Von Loh et al. 1999).

Photo 8. Sparse, patchy vegetation on a prairie dog town in BADL (photo by Shannon Amberg, SMUMN GSS, 2010).

Several introduced grassland types occur in areas of the park that have been disturbed, mostly by past agricultural or transportation activities. Crested wheatgrass (*Agropyron cristatum*) and smooth brome (*Bromus inermis*) were seeded in road corridors and old fields while Kentucky bluegrass (*Poa pratensis*) has invaded former sheep pastures (Von Loh et al. 1999). These non-native species have spread into many of the native grassland community types described above.

Culturally Significant Plant Species

The BADL grassland plant community supports 15 plant species of cultural importance to the Oglala Lakota (Table 19).

Table 19. Culturally significant plant species found in grasslands (Burnette 2006; M. Haar, written communication 1 June 2011) and examples of their uses (White 2002). This is a selection of species considered to be culturally important and is not intended to be a comprehensive list.

Scientific name	Common name	Use
Achillea millefolium	common yarrow	medicinal
Amorpha canescens	lead plant	medicinal
Artemisia frigida	fringed sage	medicinal
Artemisia ludoviciana ssp.*ludoviciana*	white sagebrush	ritual
Astragalus crassicarpus	groundplum milkvetch	food/medicine
Dyssodia papposa	fetid marigold	medicinal
Echinacea angustifolia	purple coneflower/blacksamson echinacea	medicinal
Gaura coccinea	scarlet gaura	ritual
Ipomoea leptophylla	bush morning glory	medicinal
Monarda fistulosa	wild bergamot	medicinal/ritual
Pediomelum esculentum	wild turnip/Indian breadroot	food
Physalis heterophylla	clammy ground cherry	medicinal/food
Prunus pumila var. besseyi	sand cherry	food
Rosa woodsii	woods rose	food
Yucca glauca	yucca	medicinal/soap

Ecological Processes

The grasslands within the park are strongly influenced by both fire and grazing, and may rely on these processes for their continued existence. These relationships have been modeled by Gitzen et al. (2010), as shown in Figure 12 below. Fire kills or greatly inhibits competing trees and many shrub species, limiting woody encroachment into grasslands (Bachelet et al. 2000). Fire also burns built-up litter layers to provide more space, light, and nutrients to grassland species (Bachelet et al. 2000). In the absence of fire, shrubs such as snowberry may increase in both height and cover within northern Great Plains grasslands (as reviewed by Gitzen et al. 2010).

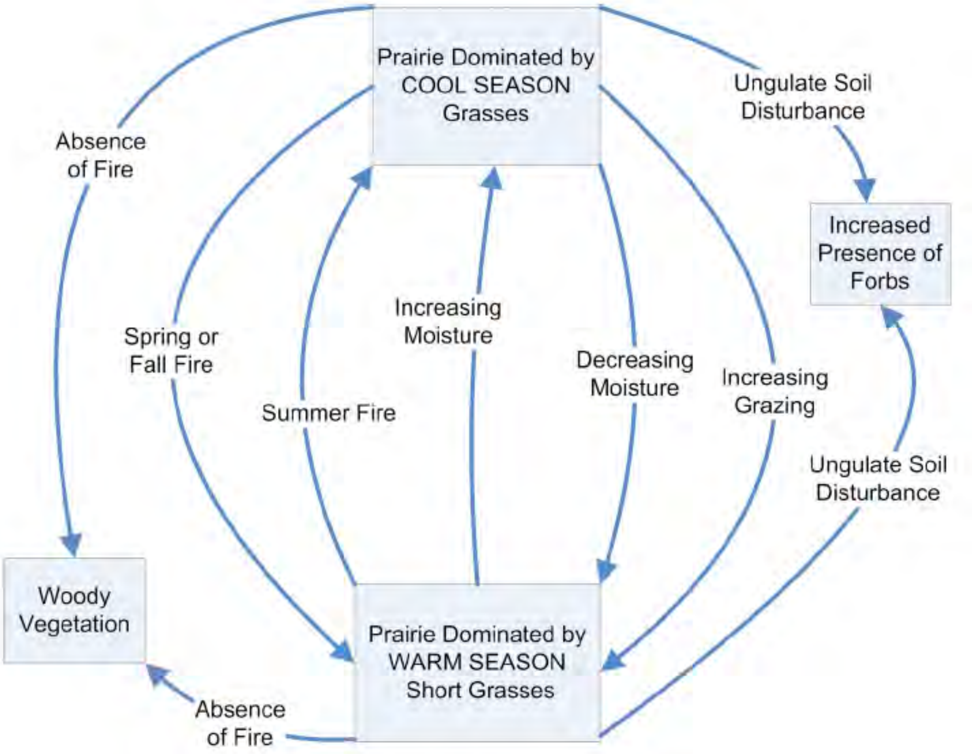

Figure 12. The general response of Northwestern Great Plains grasslands to fire, grazing, and precipitation (Gitzen et al. 2010). This is a simplified representation of the interactions; more detailed models for individual grassland types can be found in Appendix B of Gitzen et al. (2010).

Mixed- and shortgrass communities in semi-arid regions like BADL generally exhibit a neutral or negative immediate response to fire (Scheintaub et al. 2009, Symstad and Jonas 2011). In Colorado shortgrass steppe dominated by blue grama and buffalograss, net primary productivity either decreased or did not change following prescribed burning (Scheintaub et al. 2009). Decreased productivity in these water-limited environments is likely due to soil moisture loss after the litter layer is consumed by fire (Redmann 1978, as cited by Symstad and Jonas 2011). Species richness and diversity in mixed- and shortgrass prairie show little or no response to fire (Scheintaub et al. 2009; Morrison et al. 1986, Wilson and Shay 1990, as cited by Symstad and Jonas 2011).

The native grass species of BADL respond differently to fire, often depending on the season when burning occurs and postburn precipitation levels. For example, spring burning on an upland site in BADL reduced blue grama and western wheatgrass production for one to two growing seasons, while fall burning increased these species' productivity when precipitation levels were favorable during the following growing season but reduced it if the following year was dry (Whisenant and Uresk 1989, Table 20). April and October burning both reduced needle-and-thread production for two to three years, leading Whisenant and Uresk (1989) to conclude that it is intolerant of spring and fall fires. Threadleaf sedge production, in contrast, significantly increased after fall and spring burns if postburn precipitation was above average but decreased if precipitation was low (Whisenant and Uresk 1989). Production of the short grasses sand dropseed (*Sporobolus cryptandrus*) and buffalograss increased for two to four years after spring burning (Whisenant and Uresk 1990).

Table 20. Above-ground standing crops of current year's growth (g/m^2) in July 1984-1987 following burn treatments in spring or fall of 1984 or 1985 in BADL (adapted from Whisenant and Uresk 1989). Note that precipitation was above average in all years except 1985, when it was well below average. Numbers in bold indicate the first measurement following prescribed burning.

Species	**Evaluation date (July)**			
Burning date	**1984**	**1985**	**1986**	**1987**
Needle-and-thread				
None (control)	29	9	48	59
April 1984	**14**	4	8	55
October 1984	28	**5**	11	51
April 1985	27	**2**	18	45
October 1985	30	10	**13**	51
Western wheatgrass				
None (control)	5	1	4	8
April 1984	**3**	1	6	7
October 1984	5	**1**	10	8
April 1985	6	**0**	5	9
October 1985	6	1	**10**	10
Threadleaf sedge				
None (control)	30	2	6	10
April 1984	**26**	1	37	18
October 1984	30	**2**	47	28
April 1985	31	**1**	24	22
October 1985	32	3	**33**	27
Blue grama				
None (control)	16	3	5	6
April 1984	**7**	1	12	23
October 1984	19	**0**	17	18
April 1985	16	**0**	19	31
October 1985	17	2	**11**	16

Whisenant and Uresk (1989) found that the drier upland prairies at BADL took longer to recover from burning than more productive mesic areas where the majority of fire effects research has been conducted. The recovery of western wheatgrass, needle-and-thread, and threadleaf sedge in upland areas took one to three years longer than more productive sites (Whisenant and Uresk 1989). They also concluded that fall burning is preferable to spring burning in northern mixed-grass prairies, as spring burns cause more damage to cool-season grasses including western wheatgrass and needle-and-thread (Whisenant and Uresk 1989). This conclusion was later supported by Wienk et al. (2007).

Photo 9. Prescribed fire in a BADL grasslands (NPS photo, in Wienk et al. 2007).

Fire and grazing can both play a role in limiting certain invasive plant species within the park. On mesic sites, the absence of fire plus prolonged absence of grazing or heavy seasonal grazing leads to an increase in the density of Kentucky bluegrass, perhaps to the point where it becomes the dominant species (as reviewed by Gitzen et al. 2010). Litter buildup associated with a lack of fire and grazing can decrease native grass cover and increase cover of exotic brome species, particularly field brome (*Bromus arvensis*) (as reviewed by Gitzen et al. 2010). Spring burning in BADL killed field brome seedlings and reduced growth in subsequent growing seasons when burning was followed by dry weather (Whisenant and Uresk 1990). While fire and grazing are unlikely to remove brome and other exotics from the grasslands, these natural processes could greatly reduce their overall cover (Whisenant and Uresk 1990).

Bison and prairie dogs are the two grazers believed to have the greatest influence on park grasslands. Their presence and associated disturbances may maintain and facilitate plant species richness and habitat diversity within grassland ecosystems (Fahnestock et al. 2003, Forrest et al. 2004). Similar to fire, grazing does not affect all grassland plant species equally. Moderate annual grazing has been shown to reduce western wheatgrass and needlegrass while increasing shorter warm season grasses such as blue grama and buffalograss as well as threadleaf sedge (Von Loh et al. 1999, Gitzen et al. 2010). However, Gitzen et al. (2010) noted that transitions from wheatgrass to shortgrass are reversible with the reduction or cessation of grazing. Light to moderate grazing by prairie dogs and bison may also promote forb diversity, as these species prefer grasses over forbs (Fahnestock et al. 2003).

Fahnestock et al. (2003) studied the differences between prairie dog town vegetation and the surrounding grasslands in BADL. A total of 72 plant species were found in dog town sampling plots while just 36 were found in the surrounding grassland plots. Grasses comprised 82% of the vegetation in grassland plots, while forbs comprised 84% of dog town vegetation. While total live plant cover did not vary greatly, bare ground and litter cover were significantly different. Bare ground made up 26% of dog towns but just 4% of surrounding grasslands, while litter cover was much higher in grasslands than on dog towns at 49% and 14% respectively (Fahnestock et al. 2003). Some of the variation in species composition is represented in Table 21 below.

Table 21. Selected plant species and their mean canopy cover on prairie dog towns and in the surrounding grasslands (Fahnestock et al. 2003).

Species	**% Cover**	
	Off-town Grassland	**On Dog Town**
Blue grama	4.2 ± 0.8	---
Cheatgrass	17.6 ± 1.7	1.2 ± 0.7
Fetid marigold	---	3.0 ± 1.2
Pennyroyal sp.	1.7 ± 1.2	3.8 ± 2.3
Western wheatgrass	23.0 ± 1.5	2.0 ± 1.7
Exotic plant cover	20.2 ± 3.8	11.0 ± 2.1

Existing Threats and Stressors

Like other BADL communities, the primary threat to grasslands is invasive plant species. These invasive species compete for resources with native plants and “have the potential to affect fundamental ecosystem processes through alteration of wildlife foraging practices, fire regimes, and nutrient cycling” (Symstad 2008, p. 4). Invasion of native grasslands by cheatgrass, for example, has been shown to negatively impact ecosystem processes and wildlife (Evans et al. 2001, Gitzen et al. 2001, Hall et al. 2009). Table 22 lists some of the invasive plants commonly found in BADL grasslands.

Table 22. Invasive plant species reported in BADL grasslands (Von Loh et al. 1999, Symstad 2008, Gitzen et al. 2010).

Scientific Name	**Common Name**
Bromus arvensis	field brome
Bromus inermis	smooth brome
Bromus tectorum	cheatgrass or downy brome
Cirsium arvense	Canada thistle
Convolvulus arvensis	field bindweed
Melilotus officianalis	yellow sweetclover
Poa pratensis	Kentucky bluegrass

In recent years, Canada thistle has covered up to 8,000 acres in BADL, primarily associated with prairie dog colonies (Symstad 2008) and relatively moist areas such as draws (BADL, Milt Haar, Ecologist, written communication, 14 September 2011). This species is a state-listed noxious weed (SD DA 2009). Canada thistle reproduces by root and is a prolific producer of seed (up to 8,000 seeds per plant) (Sindel 1991, as cited by Symstad 2008). Canada thistle tissue, both live and dead, has been shown to have allelopathic effects on other plants, suggesting that the species might have a lasting impact on plant community composition even after it dies; however, this effect has not been observed at BADL (Symstad 2008). There is an active chemical control program for this species in BADL that has proven effective at greatly reducing targeted thistle populations in the park (Symstad 2008).

The annual grasses field brome and cheatgrass are usually present to varying degrees in all grassland community types, but especially western wheatgrass stands (Von Loh et al. 1999) where they can become the dominant species (Wienk et al. 2007). These winter annuals grow rapidly early in the growing season and may deplete soil moisture critical for native species, particularly seedlings (Upadhyaya et al. 1986, as cited by Symstad 2008). Along roadways or in previously homesteaded areas where it was historically planted, the perennial smooth brome can

Photo 10. Yellow sweetclover in BADL in 2009 (photo by Milt Haar, NPS, 2009).

form dense stands that may outcompete native grasses and are highly resistant to restoration (as reviewed by Gitzen et al. 2010). Another perennial invasive, Kentucky bluegrass, may increase its density in mesic western wheatgrass community types with prolonged wetter years or absence of fire and grazing, and "may be difficult to remove once established" (Gitzen et al. 2010, p. 41). Yellow sweetclover is also present throughout the park's grasslands, especially in the North Unit. The yellow sweetclover population in BADL fluctuates wildly. In some years it is barely present, while in other years such as 2009, yellow sweetclover covers the landscape (M. Haar, written communication, 14 September 2011).

Many native grasslands worldwide have been threatened by woody plant encroachment over the past 200 years (Morgan et al. 2007). However, this does not appear to be a serious threat in BADL (Gitzen et al. 2010). Within the park, woodlands and shrublands are limited by soil type and available moisture, and encroachment into adjacent grasslands is rare (Gitzen et al. 2010). Increased shrub density has been noted in the absence of fire, particularly in little bluestem grasslands, but grassland plant community types are expected to remain dominant in these areas (Gitzen et al. 2010).

Climate Change Vulnerability

Analysis of the grassland plant community within BADL shows that it is least vulnerable to climate change with an overall score of 13 (Table 23).

Table 23. The vulnerability assessment results for the grassland plant community of BADL.

Component	Score
Location in geographical range/distribution of plant community	2
Sensitivity to extreme climatic events (e.g., drought, flash floods, windstorms)	2
Dependence on specific hydrologic conditions	2
Intrinsic adaptive capacity	2
Vulnerability of ecologically influential species to climate change	2
Potential for climate change to exacerbate impacts of non-climate stressors	3
Total*	**13**

* 6-13 = least vulnerable, 14-19 = moderately vulnerable, 20-25 = highly vulnerable, 26-30 = critically vulnerable

Most BADL grassland community types are near the center of their latitudinal range, although many are closer to the southern edge than the northern edge, particularly prairie sandreed – sun sedge (Plate 13). However, none of the key component species of these grasslands are near the southern edge of their distributions (NRCS 2011; Figure 13 and Figure 14). Therefore, it seems that, like the park's shrublands, the ranges of these grassland plant community types are limited by environmental factors other than temperature. This suggests that grasslands as a whole in the park are unlikely to be significantly vulnerable to an increase in temperature alone. However, research suggests that warming could change the species composition, productivity, and phenology of grasslands across the Great Plains. According to Adler and HilleRisLambers (2008), an increase in mean annual temperature significantly affected forb growth rates in a Kansas tallgrass prairie. Six of the ten forb species studied responded positively to increased temperature (including BADL species *Echinacea angustifolia* and *Thelesperma megapotamicum*), while the other four (including *Solidago mollis*) were negatively affected (Adler and HilleRisLambers 2008). Adler et al. (2006) found a similar pattern among three grass species, with sideoats grama growth rates increasing in response to increased temperatures while hairy grama (*Bouteloua hirsuta*) and little bluestem growth rates were negatively affected by warming. Craine et al. (2011) forecasts that increased temperature would remove perennials at a rate 2.4 times higher than annuals in tallgrass prairie. Their research also suggests that warming could remove non-native species at a rate that was 29% higher than native species (Craine et al. 2011). Changes in spring temperatures alone altered the net primary production (NPP) of grassland species. An increase in minimum spring temperature was correlated with a decreasing NPP in the native C_4 grass blue grama while increasing the abundance and production of exotic and native C_3 forbs (Alward et al. 1999). Researchers have also found that experimental warming can decrease grassland biomass, both aboveground (-29%) and belowground (-25%) (De Boeck et al. 2008), and shift the reproductive phenology of tallgrass prairie species (Sherry et al. 2007).

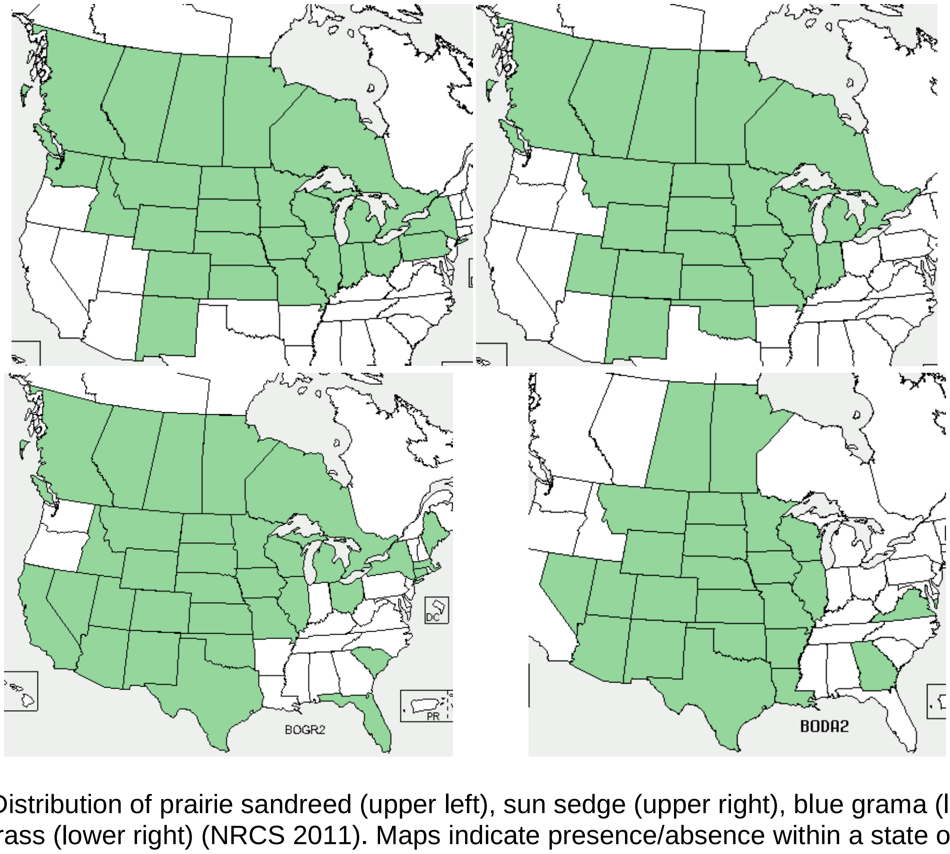

Figure 13. Distribution of prairie sandreed (upper left), sun sedge (upper right), blue grama (lower left) and buffalograss (lower right) (NRCS 2011). Maps indicate presence/absence within a state or province rather than actual range.

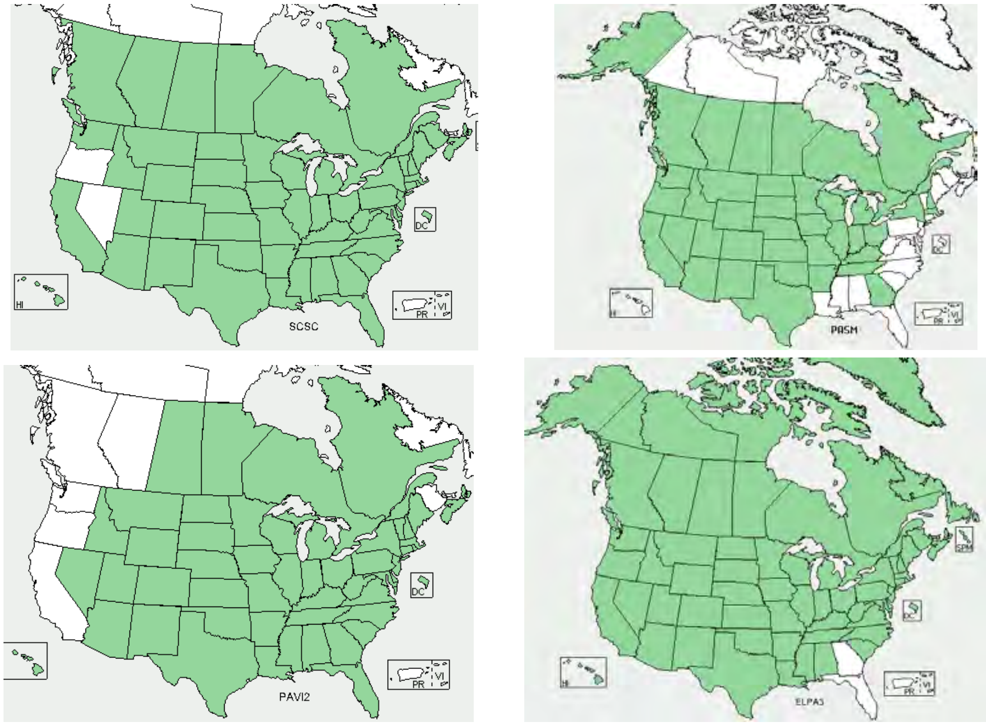

Figure 14. Distribution of little bluestem (upper left), western wheatgrass (upper right), switchgrass (lower left), and pale spikerush (lower right) (NRCS 2011). Maps indicate presence/absence within a state or province rather than actual range.

Lauenroth et al. (1999) state that a smooth west-east precipitation gradient is one of two major gradients defining the climate in the northern Great Plains grassland ecosystem (the other is temperature); mean annual precipitation ranges from greater than 100 centimeters in the east to less than 30 cm in the west. Consequently, the western portion of the Great Plains grasslands are typically categorized as semi-arid and, moving easterly, the grasslands are categorized as dry and moist subhumid where supply of moisture exceeds atmospheric demand (Lauenroth et al. 1999). This precipitation gradient, particularly the natural variation in seasonal precipitation, influences vegetation species distribution across the Great Plains grassland ecosystem, with tall-grass species more common in the east and short-grass species more common in the west. As a result, the location of a grassland community type in its east-west distribution may also be an indicator of its climate change vulnerability. The BADL grassland types and key species are primarily near the center of their east-west distributions (Plate 13, Figure 13 and Figure **14**).

Changes in precipitation may also alter grassland productivity, phenology, and nutrient cycling. Heisler-White et al. (2009) studied the effects of extreme rainfall regimes (larger individual events with longer periods between events) on three different North American grasslands: semiarid steppe, mixed-grass, and mesic tallgrass. Shifts in the frequency and magnitude of rainfall events without a change in rainfall amount could increase the severity of within-season drought, significantly alter evapotranspiration, and contribute to greater runoff from soils (Heisler-White et al. 2009). They found that a shift to fewer but larger events, with no change in total rainfall amount, significantly altered NPP in all three grasslands. Mixed-grass NPP showed the greatest change with a 70% increase, while semiarid steppe NPP increased by 30%, and mesic tallgrass NPP decreased by 18% (Heisler-White et al. 2009). A change in precipitation regime also influenced soil nitrogen availability. The shift to fewer but larger rainfall events significantly increased soil nitrogen availability in the semiarid steppe and mesic tallgrass prairie, but showed no significant effect in mixed-grass (Heisler-White et al. 2009). While Heisler-White et al. (2009) did not detect any changes in species richness or plant community structure as a result of altered precipitation regime, species-specific climate envelope analysis by Craine et al. (2011) predicts that a decrease in precipitation could preferentially remove native species at a relative rate 2.0 times higher than non-native species (the opposite effect of warming temperatures, which are predicted to remove non-native species at a higher rate, as mentioned earlier). Fay et al. (2006) found that extreme rainfall could also impact carbon cycling in the tallgrass prairie. In their experiment, longer intervals between rain events resulted in greater net ecosystem uptake of carbon (Fay et al. 2006). In European grasslands, both severe drought and heavy rain events “caused phenological shifts in plants of the same magnitude as one decade of gradual warming” (Jentsch et al. 2009, p. 837).

While the drier conditions predicted for BADL are unlikely to threaten the continued existence of grasslands in the park, they could dramatically shift species composition. Gitzen et al. (2010) notes that a prolonged shift to a much drier climate would increase the dominance of shortgrass species, potentially causing the conversion of some mixed-grass community types (for example those dominated by western wheatgrass or little bluestem) to shortgrass types, such as blue grama and buffalograss. Grasslands on sandy sites, such as prairie sandreed, could see an increase in bare ground, short grasses, and annuals (Gitzen et al. 2010). The amount of bare ground in shortgrass community types would also likely increase on shallow soils or soils high in clay content (M. Haar, written communication, 14 September 2011). Weaver and Albertson (1943) found that recurrent drought decreased grass cover while increasing drought-tolerant forbs and weedy species in the Great Plains grasslands. The authors also noticed a shift in species composition towards cool season grasses during the 1930s drought, since they better utilize early season moisture (Weaver and Albertson 1943). This may, in turn, lead to moisture deficits later in the season when warm season grasses are growing (NPS, Dan Swanson, Fire Ecologist, written communication, 6 October 2011).

The primary driver of increasing temperatures is CO_2 (IPCC 2007), which is both a greenhouse gas and a determinant of important physiological functions in plants. CO_2 concentrations have increased from approximately 280 ppm in preindustrial times to approximately 385 ppm today, and IPCC scenarios A1B and A2 project CO_2 concentrations that exceed 650 ppm in the 21st century (Meehl et al. 2007). In many ecosystems where productivity is primarily limited by water, these CO_2 concentrations may have positive effects on soil water content due to increased plant water use efficiency (Morgan et al. 2004, Morgan et al. 2011). Enhanced CO_2 concentrations typically reduce stomatal conductance and thereby reduce water loss via transpiration (reviewed by Polley et al. 2010). Unless these effects are compensated for by increased biomass and leaf area, the overall net effects are likely to include slower loss of soil moisture in mixed-grass ecosystems with rainfall patterns similar to those in BADL (Morgan et al. 2011).

Typically, the retention of soil moisture is determined in complex ways by plant cover, evaporation from bare soils, transpiration loss, the aggregate of species-level responses, and other factors. Changes at the community level will also be mediated by competition for nutrients as well as water, so it is very difficult to predict the trajectory of individual species or plant groups, including potential increases in forbs and shrubs (e.g., Morgan et al. 2007). In the shortgrass steppe, growth of *Artemisia frigida*, in particular, was greatly enhanced at higher concentrations of CO_2 (Morgan et al. 2007). While our understanding of these interactions is incomplete, these experimental results suggest several general conculsions. First, increased water use efficiency is likely in mixed-grass prairie (but not in tall or short grass) due to anticipated increases in CO_2 concentration, and this may compensate for increased evaporation due to temperature increases up to a point. Experiments that crossed CO_2 and temperature treatments suggest there may be compensation for a temperature increase in the range of 1.5^o C (Morgan et al. 2011). In the event of a sustained drought, it is possible that any compensatory effect will be largely irrelevant, as there will be severe water limitations on all vegetation. Morgan et al. (2008) provides a general review of these (and other) global change effects on Great Plains rangelands.

The vast majority of grasslands in BADL do not depend on specific hydrologic conditions. The exceptions are emergent wetlands (pale spikerush, prairie cordgrass, and cattail-bullrush vegetation) and switchgrass stands, which are rare in the park and limited to relatively small areas. Emergent wetlands occur where soils are moist for at least part of the year. Prairie cordgrass requires moist soils for at least part of the growing season, while pale spikerush stands regularly experience early season flooding but may dry out during the summer (as reviewed by NatureServe 2011). Cattail-bullrush wetlands are located in areas where soils are saturated or shallow standing water is present “on a more-or-less permanent basis” (Von Loh et al. 1999, p. 211). Switchgrass can occur in mesic mixed-grass prairies, but is considered a facultative wetland species that dominates only where soils are saturated throughout the growing season at BADL (Von Loh et al. 1999). These wetland community types are likely highly vulnerable to climate change; however, they make up a very small percentage of the park’s grassland plant community. Wetlands have not been specifically studied in the BADL region, but research suggests that they are especially vulnerable to climate warming in the prairie pothole region to the north and east of the park (Johnson et al. 2005).

The intrinsic adaptive capacity of BADL grasslands is expected to be fairly significant. Grasslands occur in a variety of environmental conditions (soils, slopes, elevations, etc.) within the park and are adapted to many environmental stressors, including fire, grazing, drought, and harsh winters. Most grassland species are capable of rapid regeneration, vegetatively as well as by seed (USFS 2011). The park’s grasslands as a whole also seem to be in relatively good condition at this time with high levels of species diversity (M. Haar, written communication, 14 September 2011). However, brome grasses are widespread and abundant in some areas, which could be considered in a lesser condition (A. Symstad, written communication, 27 September 2011).

None of the ecologically influential species of BADL’s grassland plant community types appear particularly vulnerable to climate change. Most of the grasses are near the center of their ranges (Figure 13 and Figure 14) and are tolerant of drought, sometimes going dormant in response to prolonged dry conditions (USFS 2011). Many of the grasses have extensive deep root systems (seven feet in the case of western wheatgrass) that can reach moisture deep in the soil (USFS 2011).

Climate change may exacerbate current non-climate stressors in grasslands, such as invasive species. Long-term studies suggest that an increase in annual precipitation in arid and semiarid regions of western North America (which is projected for BADL) could increase the dominance of invasive alien grasses (Dukes and Mooney 1999). Kreyling et al. (2008) also suggest that the predicted increase in variability of precipitation may decrease the resistance of grasslands to invasion. Conditions may become favorable for invasive species that are not yet a serious concern in the park, such as yellow star-thistle and Russian knapweed. However, overall drier conditions as a result of higher evapotranspiration rates could decrease the threat posed by invasive species that require wetter environments. Canada thistle, for example, tends to occur in draws within BADL and in riparian areas or wetter grasslands elsewhere in the Great Plains (Symstad 2008).

Uncertainty and Data Gaps

An abundance of research has been conducted in grasslands, including some studies on the potential impacts of climate change. This reduces the overall uncertainty with regard to grasslands, yet data gaps remain for specific aspects of climate change and plant community response. For example, more research is needed on the impacts of increased dormant-season temperatures and elevated minimum temperatures (as opposed to average or maximum temperatures) (Alward et al. 1999, Adler and HilleRisLambers 2008). The effects of multiple, simultaneous climate changes have also been understudied in the field, as most field experiments focus on a single climate variable (e.g., temperature or precipitation) (Bloor et al. 2010).

Little is known about the influence of climate change, particularly the effect of changes in annual precipitation and extreme rainfall events, on grassland species' phenology (Cleland et al. 2006, Sherry et al. 2007, Jentsch et al. 2009). According to Jentsch et al. (2009, p. 838), "an emerging research challenge is to assess whether temperature-driven shifts in phenology put the maintenance of crucial plant– animal interactions such as pollination at risk. Desynchronization of previously synchronized life cycles and a disruption of mutually beneficial interactions due to climate change appear possible."

Further study is needed to determine how species interactions and ecological processes will be affected by climate change and how this will, in turn, impact BADL's grasslands. These questions include:

- Will long-term changes in precipitation and moisture availability lead to increased shrub encroachment or shrub loss in grasslands? (Gitzen et al. 2010)

- How will grassland invasive species respond to climate change? Will they have more or less of an impact on native grasslands?

- Will the response/recovery of grasslands to fire be affected by climate change?

- Do the ecotypes of grassland species currently present at BADL have the same adaptive capacity as the species as a whole?

- How will changes in precipitation and temperature affect the extent and function of wetlands?

Confidence in this assessment is high, largely due to the amount of information available for the plant community (Table 24). Three individual variables received high certainty scores while the other three were rated moderate. However, confidence in the vulnerability of individual grassland types is lower, as the complex interactions that control vegetative composition at this finer level are not yet well understood. Mesic, mid-height grasses may be more vulnerable to the predicted climate changes than shorter grasses, which typically occur on drier sites in the park, possibly leading to a change in the structure and composition of the park's grasslands.

Only one grassland community variable was given an alternative score (Table 24), resulting in a total range of just 13 to 14. The higher score of 14 would move grasslands just inside the "moderately vulnerable" category.

Table 24. Certainty and alternative vulnerability scores for grassland community assessment variables.

Variable	Certainty Score*	Vulnerability Score	Alternative Scores
Location in geographical range/distribution of plant community	3	2	
Sensitivity to extreme climatic events (e.g., drought, flash floods, windstorms)	3	2	
Dependence on specific hydrologic conditions	2	2	3
Intrinsic adaptive capacity	2	2	
Vulnerability of ecologically influential species to climate change	3	2	
Potential for climate change to exacerbate impacts of non-climate stressors	2	3	
Total	**15**	**13**	**14**

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* For individual variables, 3 = high, 2 = moderate, and 1 = low; total ranges are 6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence.

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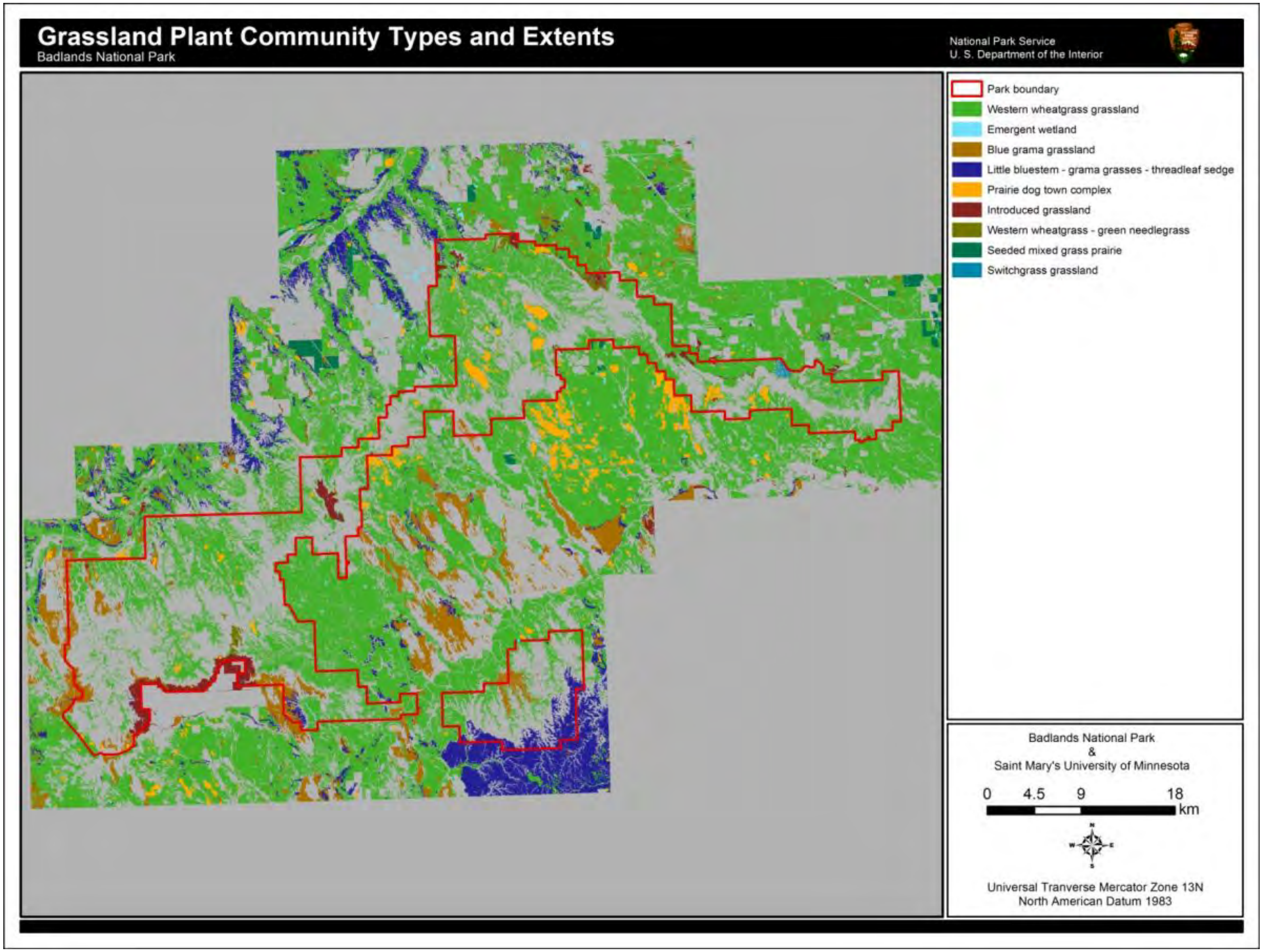

Plate 12. Distribution of grassland community types within and around BADL (USGS 1999).

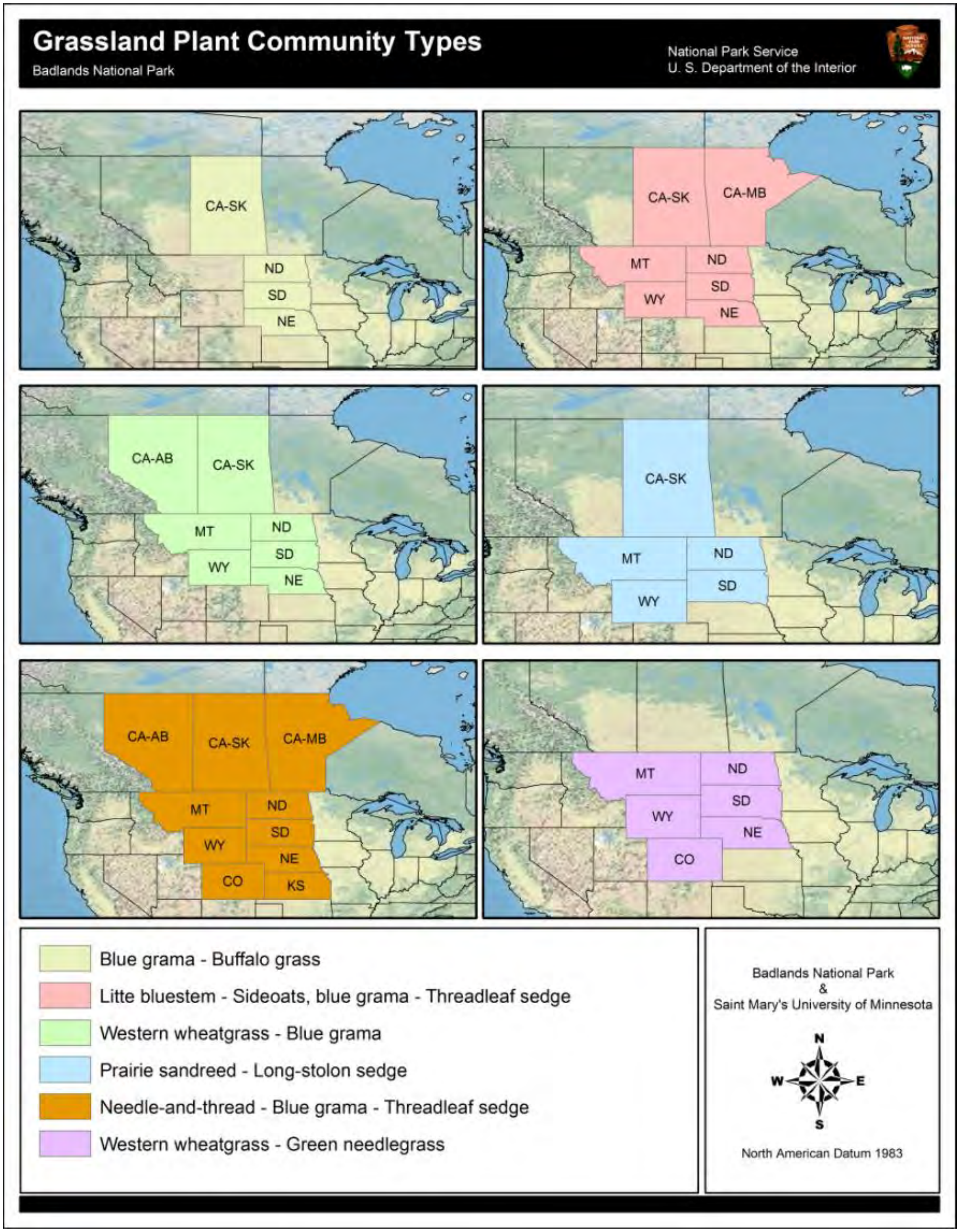

Plate 13. Distribution of the six mixed-grass grassland community types found in BADL (NatureServe 2011). Maps indicate presence/absence within a state or province rather than actual range.

4.1.4 Sparse Badlands

Summary:

Sparse badlands comprise nearly half the park, but vegetation here is thin and patchy, averaging approximately 10% total cover. Soils are highly erodible and support drought tolerant species such as small-flowered wild buckwheat (*Eriogonum pauciflorum*), broom snakeweed (*Gutierrezia sarothrae*), and long-leaf sagebrush (*Artemisia longifolia*). The community also supports several rare and endemic plant species. The sparse badlands were rated as "moderately vulnerable" to climate change, but with uncertainty in several areas due to a lack of research in this specific, localized plant community. Little is known about how both native species and invasive plants that currently threaten the community will respond to climate change in this already harsh environment. Alternative scores for the plant community extend into the "highly vulnerable" category, suggesting that a lack of research may contribute to an underestimate of vulnerability for this community.

Description

The sparse badlands community covers 46% of the total park area, a greater percentage than any other single plant community (Plate 14; Von Loh et al. 1999). The vegetation that occurs in the community is typically a mixture of low-growing shrubs, forbs, and grasses, and generally accounts for just 10% or less total cover (Von Loh et al. 1999, NatureServe 2011). This community is found on badlands ridges, slopes, and intermittent drainages with highly erodible soils derived from siltstone, claystone, volcanic ash, or chalcedony. On steep slopes and cliffs, the vegetation often grows in patches, rows, or seams (Von Loh et al. 1999). Three specific types of badlands sparse vegetation occur within BADL: Eroding Great Plains badlands sparse vegetation, Small-flowered wild buckwheat–snakeweed sparse vegetation, and Long-leaf sagebrush badlands sparse vegetation. One additional type, Shale barren slopes sparse vegetation, occurs just outside the park boundary on private land in the Cheyenne River drainage and has not been surveyed (Von Loh et al. 1999). These vegetation types are described in detail in Von Loh et al. (1999).

Photo 11. Sparse badlands vegetation in BADL (photo by Shannon Amberg, SMUMN GSS, 2010).

The Eroding Great Plains badlands sparse vegetation type is found on the most sparsely vegetated portions of badlands formations, usually with less than 1% vegetative cover (Von Loh et al. 1999). Soils are poor and loose while the topography is "somewhat sloping to vertical" (Von Loh et al. 1999, p. 231). Plant species that can be found in these areas include small-flowered wild buckwheat, broom snakeweed, and curlycup gumweed (*Grindelia squarrosa*) (Von Loh et al. 1999, NatureServe 2011).

The Small-flowered wild buckwheat - snakeweed sparse vegetation type also occurs on badlands formations throughout the park and is commonly found on silty or sandy outwash fans created by badlands erosion (Von Loh et al. 1999, NatureServe 2011). Vegetative cover may reach 10% but is often less than 5% (Von Loh et al. 1999). In addition to small-flowered wild buckwheat and snakeweed, other common species include prickly pear cactus *(Opuntia polyacantha),* silverscale saltbush (*Atriplex argentea*), and cat's eye (*Cryptantha thyrsifolia*) (VonLoh et al. 1999, NatureServe 2011). The final type, Long-leaf sagebrush badlands sparse vegetation, is rare within the park and is limited to exposed clay knobs and hillslopes. This community occurs in small patches of less than 250 square meters, typically with less than 5% cover and very low species richness (Von Loh et al. 1999).

Several plant species endemic to the sparse badlands community are considered rare and are tracked by the South Dakota Natural Heritage Program (SDGFP 2009). These species, which are all known to occur in BADL, are listed in Table 25. The known locations of several of these species in BADL are depicted in Plate 16, while photos appear below in Photo 12.

Table 25. Rare species occurring within the sparse badlands of BADL (SDGFP 2009).

Scientific Name	Common Name	State Rank
Astragalus barrii	Barr's milkvetch	S3
Chrysothamnus parryi	Parry's rabbitbrush	SU
Eriogonum visheri	Dakota buckwheat	S3
Lesquerella arenosa var. argillosa	secund or sidesaddle bladderpod	S3
Townsendia exscapa	Easter daisy	S4?

S3 - Either very rare and local throughout its range, or found locally in a restricted range
S4 - Apparently secure, though it may be quite rare in parts of its range (? indicates inexact rank)
SU - Possibly in peril, but status uncertain, more information needed.

Photo 12. Rare, endemic plants of BADL (clockwise from top left): Barr's milkvetch (photo by J. Proctor in Ladyman 2006), Parry's rabbitbrush (photo by D. Ode in Dingman 2003a), Easter daisy (photo courtesy of Smithsonian Institute, in NRCS 2011), secund bladderpod (unknown photo in Dingman 2003b), and Dakota buckwheat (photo by D. Ode in Dingman 2003c).

Culturally Significant Plant Species

Broom snakeweed (*Gutierrezia sarothrae*) is the only selected culturally important plant species found primarily in the sparse badlands plant community (Burnette 2006; M. Haar, written communication, 1 June 2011).

Ecological Processes

Fire and grazing are rare in the sparse badlands community due to the general lack of vegetation (M. Haar, e-mail communication, 20 July 2011). To date, no research has addressed the effects of fire on the sparse badlands plant community as a whole, but some of the individual plant species, such as Barr's milkvetch, are thought to be poorly adapted to survive fire (Dingman 2005). Broom snakeweed is severely damaged by fire, but due to rapid regeneration through wind-dispersed seed from adjacent areas, its density often increases after fire (Tirmenstein 1999).

No information could be found on the effects of grazing in the sparse badlands community. Dingman (2005) noted that Barr's milkvetch continues to thrive on lands used for cattle grazing in the South Unit of BADL and in the adjacent Buffalo Gap National Grasslands. The author suggests that continuation of existing bison management practices or "moderate expansion of the bison herd or bison pasture” is unlikely to have a detrimental effect on the species (Dingman 2005, p. 124). However, it is unknown if cattle were actually grazing in Barr’s milkvetch habitat in these areas or at what intensity grazing was occurring.

Erosion is a significant natural process in badlands areas. Wind and water erosion are responsible for creating the barren yet spectacular landscape where this sparse vegetation community occurs. Many sparse badlands endemic plant species are adapted to the harsh conditions here and likely could not compete in a more stable or fertile environment (Dingman 2005). However, erosion can also be seen as a threat to the plant community since it can contribute to physical habitat loss for plant species (Ladyman 2006). Cliffs and ridges have been known to break off or collapse overnight during rain storms (Graham 2008). Seedling establishment is also low, as many seeds are washed away before they can germinate, further contributing to the landscape’s low plant cover levels (Van Riper 2005).

Photo 13. Highly eroded features of the BADL landscape (photo by Shannon Amberg, SMUMN GSS, 2010).

Existing Threats and Stressors

The greatest threat to the sparse badlands community is invasive plant species (Table 26), especially yellow sweetclover (*Melilotus officianalis*). Sweetclover has the potential to alter the ecosystems it invades in many ways. It can grow in tall, dense stands that displace native plants and the litter it produces can alter habitat conditions (Van Riper 2005). It flowers abundantly and may compete with natives for pollination. Sweetclover also produces abundant amounts of seed (up to 100,000 seeds per plant) that can persist in the seed bank for over 40 years, making it difficult to eradicate (Van Riper 2005). Finally, and perhaps most importantly for the sparse badlands, sweetclover is a legume that can fix nitrogen and increase the amount of this nutrient available in the soil (Van Riper 2005). This could allow more plant species to survive in the area and potentially outcompete native badlands species.

Table 26. Invasive plant species documented in the sparse badlands community by Van Riper (2005).

Scientific Name	Common Name
Bromus arvensis	field brome
Halogeton glomeratus	saltlover or halogeton
Kochia scoparia	kochia or burningbush
Lactuca serriola	prickly lettuce
Melilotus alba	white sweetclover
Melilotus officianalis	yellow sweetclover
Poa pratensis	Kentucky bluegrass
Salsola tragus	Russian thistle
Taraxacum officinale	common dandelion
Tragopogon dubius	yellow salsify or goatsbeard

Van Riper (2005) studied the effects of yellow sweetclover on sparse badlands vegetation within BADL. First she determined that nitrogen is a limiting factor within the sparse badlands plant community. Nitrogen fertilization of experimental plots in the sparse badlands resulted in an increase in plant biomass, primarily of another non-native species, *Halogeton glomeratus* (Van Riper 2005). This invasive annual contains sodium oxalate, which can cause kidney damage when consumed by grazing animals (ARS 2006). Whitson et al. (2000) report that it can be fatal to re-introduced bighorn sheep that may turn to it for food in the winter. Van Riper (2005, p. 154) also found that sweetclover increases nitrogen levels in the sparse badlands community, a historically low nitrogen system, and is therefore "acting as a transformer of the nitrogen cycle in Badlands sparse vegetation." A transformer is a species that changes "the character, condition, form, or nature of ecosystems over substantial areas" (Richardson et al. 2000, p. 93).

Van Riper (2005) also determined that yellow sweetclover acts as a facilitator in the sparse badlands community. A facilitator is an exotic species that alters habitat in a way that promotes the invasion of other exotic species (Van Riper 2005). However, sweetclover was found to serve as a facilitator for both exotic and native plant species in the sparse badlands. The vegetative cover and species richness of exotic and native species increased in badlands plots when sweetclover was present (Van Riper 2005). Sweetclover facilitates other species not only by increasing nitrogen but also by acting as a "nurse plant." Nurse plants protect other species, especially seedlings, from desiccation, wind, and erosion (Van Riper 2005). Sweetclover plants and litter in the sparse badlands may also catch seeds from other species and prevent them from washing away.

The invasion of sweetclover, along with its facilitative effects, has the potential to alter succession within the sparse badlands plant community. The increased cover from exotics and natives can stabilize soils and reduce erosion, allowing the encroachment of other BADL plant communities such as mixed-grass prairie or invasion by a wider variety of exotic species (Van Riper 2005). There is also some concern that the rare endemic species of the sparse badlands may not tolerate the higher vegetative cover associated with sweetclover and other exotics (Van Riper 2005, Ladyman 2006). Barr's milkvetch, for example, is not tolerant of shade, and yellow sweetclover has already begun invading at least one population of this rare plant within the park (Dingman 2005).

Deposition of nitrogen from industrial emissions in the atmosphere could also influence plant community composition and production in the nutrient-poor sparse badlands environment (M.

Haar, written communication, 14 September 2011). In 2008, the National Parks Conservation Association (NPCA) identified BADL as one of ten national parks most threatened by future construction of coal-fired power plants (Baxter et al. 2008). While nitrogen deposition is likely to increase across the park landscape, it is of highest concern in the particularly low nitrogen sparse badlands communities.

Climate Change Vulnerability

Analysis of the sparse badlands plant community within BADL showed that it is moderately vulnerable to climate change with an overall score of 17 (Table 27).

Table 27. The vulnerability assessment results for the sparse badlands plant community of BADL.

Component	Score
Location in geographical range/distribution of plant community	5
Sensitivity to extreme climatic events (e.g., drought, flash floods, windstorms)	3
Dependence on specific hydrologic conditions	1
Intrinsic adaptive capacity	3
Vulnerability of ecologically influential species to climate change	2
Potential for climate change to exacerbate impacts of non-climate stressors	3
Total*	**17**

* 6-13 = least vulnerable, 14-19 = moderately vulnerable, 20-25 = highly vulnerable, 26-30 = critically vulnerable

The sparse badlands community of BADL is near the southern edge of its latitudinal range (Plate 15). This suggests that it may be more vulnerable to climate change than some of the other plant communities in the park. The plant species in this community are already adapted to warm, dry conditions and are largely drought tolerant (Von Loh et al. 1999, Van Riper 2005). This may help them cope with the even warmer and drier conditions projected for the BADL area, or it may push them ‘over the edge’ of an as yet unknown ecological threshold. Sparse badlands vegetation is also adapted to “extreme wetting” during storms and the erosion associated with these events (Van Riper 2005, p. 78), which are also predicted to increase in intensity (although frequency may decrease) with climate change. However, if the magnitude of rainfall events increases, water erosion may intensify to a point where it is a serious threat to the sparse badlands plant community (Ladyman 2006). If the frequency of rain events decreases and soils are dry for longer periods of time, wind erosion could increase as well.

The adaptive capacity of the sparse badlands plant community is expected to be low. The sparse badlands seem to be a “specialist” community, occurring only under specific environmental conditions that are too harsh for most plant species. If their current environment becomes uninhabitable, the sparse badlands species are unlikely to be able to compete with the species in other communities.

The ecologically influential species of the sparse badlands plant community do not appear to be especially vulnerable to the climate changes predicted for the BADL region. However, some of the rare endemic species (Table 25) may be vulnerable to climate change due to their restricted ranges. A report on Barr’s milkvetch in the western part of its range suggested that drought-induced stress causes reduced vigor, higher mortality, and reduced flowering (Schassberger 1990, as cited by Dingman 2005). Schassberger (1990) speculated that a shift toward a warmer and drier climate, as is projected for BADL, would negatively affect Barr’s milkvetch.

It is difficult to assess how the warmer and drier conditions predicted for BADL will affect the non-native plants already invading the sparse badlands community. While Dukes and Mooney (1999) suggested that most aspects of global climate change will favor invasive species over natives, it is unknown if this pattern will apply to already harsh environments such as the badlands. The non-native species already present in the sparse badlands (Table 26) would likely be tolerant of warmer conditions, but may not survive the even drier conditions that could become common in the community. Van Riper (2005) found that sweetclover cover increased in the sparse badlands with higher precipitation levels. The predicted drier conditions may therefore decrease sweetclover cover and reduce its impact on the plant community as a whole. Drier conditions may also make the sparse badlands unsuitable for another invasive plant, Kentucky bluegrass, which typically thrives in mesic conditions.

Uncertainty and Data Gaps

The greatest source of uncertainty for the sparse badlands comes from a lack of information about the community and how it responds to environmental variation. The sparse badlands are a very localized and specialized plant community and have therefore not attracted the attention of the larger scientific community. No information could be found on how the plant community as a whole is affected by drought or grazing, or even if grazing would be considered a stressor on the community. Also, little is known about the rare endemic plants of the sparse badlands. Other data gaps related to the sparse badlands include:

- If vegetative cover increases as a result of invasive species, will fire become a threat to the plant community?
- Could grazing pressure increase in sparse badlands as a result of climate change, and what affect would this have on the vegetation?
- If erosion increases due to climate changes, how will this affect the sparse vegetation community?
- Do the sparse badlands component species have environmental thresholds that could be exceeded as a result of climate change in this already extreme environment?
- How will invasive species respond to climate change under the harsh conditions of the sparse badlands?

Confidence in the sparse badlands vulnerability assessment is moderate (Table 28). The range of the sparse badlands plant community is known to be fairly restricted, resulting in a high certainty score for the first variable. Certainty scores are lowest for variables where information is lacking, as discussed above.

Alternative scores were identified for four of the six individual variables (Table 28). These scores reflect an ‘err on the side of caution’ approach, since so little is known about the sparse badlands plant community. The alternative scores range from 18 to 21, which crosses into the “highly vulnerable” category, suggesting that a lack of research may contribute to an underestimate of vulnerability for this plant community.

Table 28. Certainty and alternative vulnerability scores for sparse badlands community assessment variables.

Variable	Certainty Score*	Vulnerability Score	Alternative Scores
Location in geographical range/distribution of plant community	3	5	
Sensitivity to extreme climatic events (e.g., drought, flash floods, windstorms)	2	3	4
Dependence on specific hydrologic conditions	3	1	
Intrinsic adaptive capacity	2	3	4
Vulnerability of ecologically influential species to climate change	2	2	3
Potential for climate change to exacerbate impacts of non-climate stressors	1	3	4
Total	**13**	**17**	**18-21**

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* for individual variables, 3 = high, 2 = moderate, and 1 = low; total ranges are 6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence.

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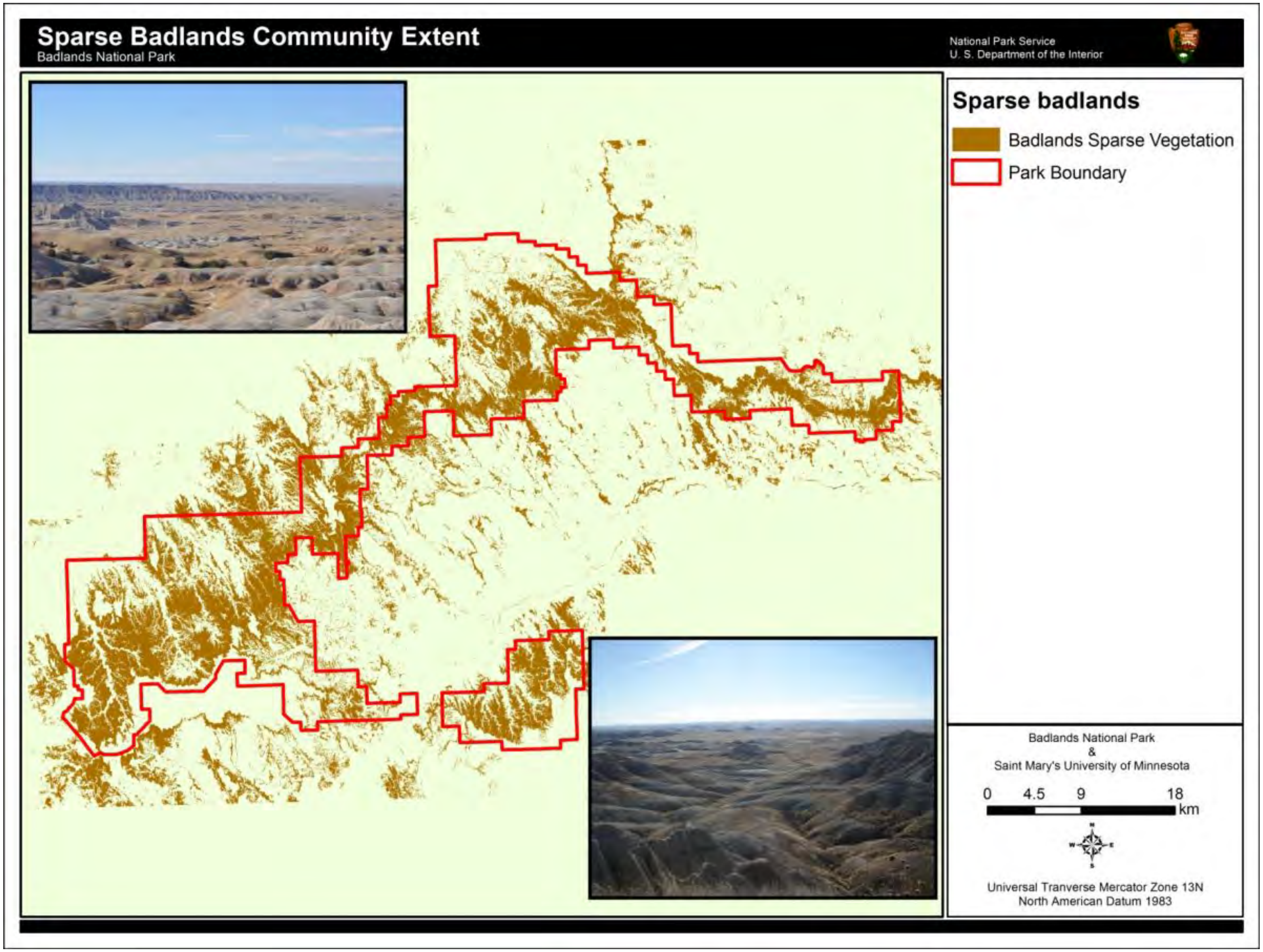

Plate 14. Distribution of the sparse badlands vegetation community within BADL (USGS 1999).

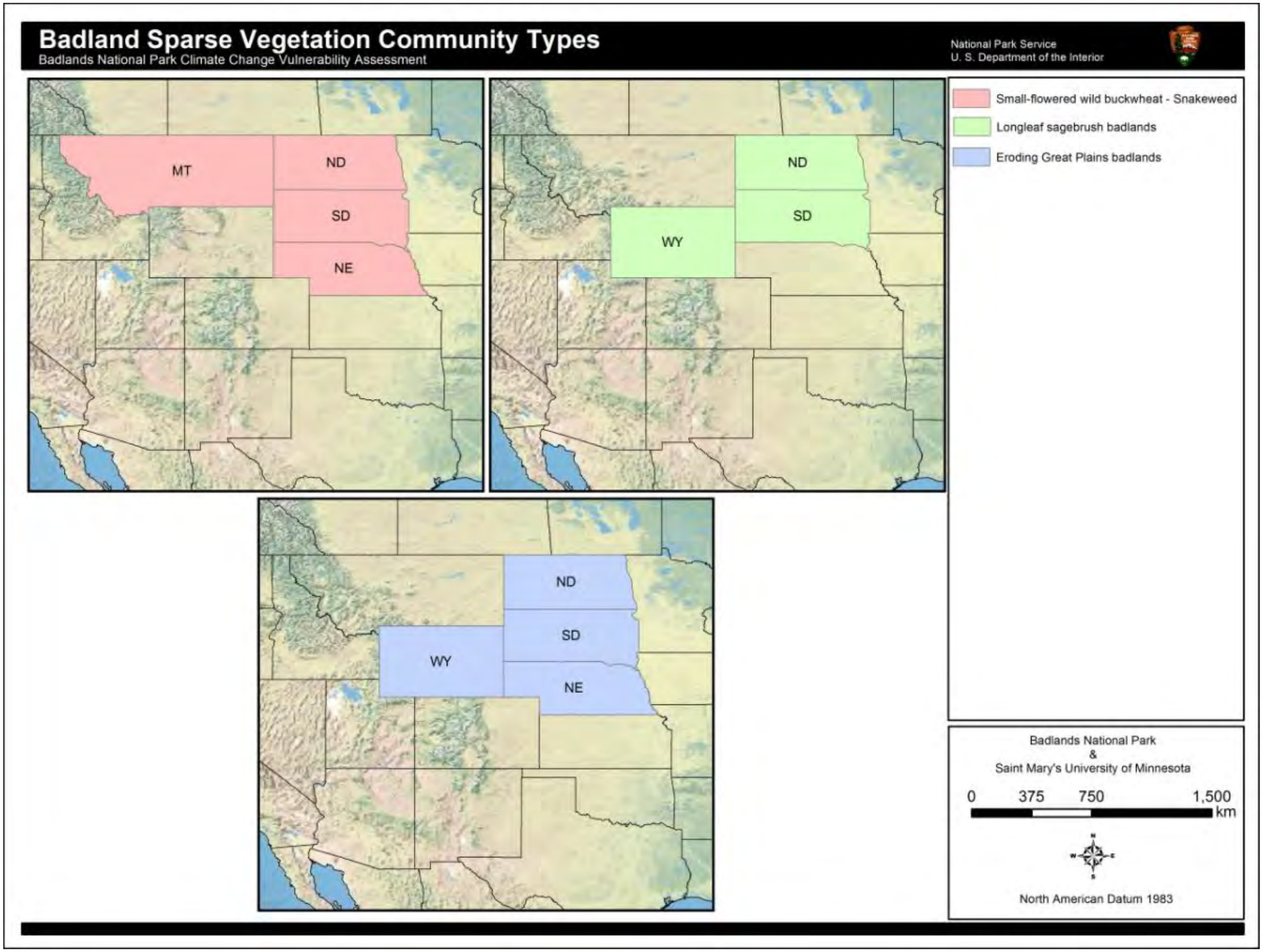

Plate 15. Distribution of sparse badlands community types in BADL (NatureServe 2011). Maps indicate presence/absence within a state rather than actual range.

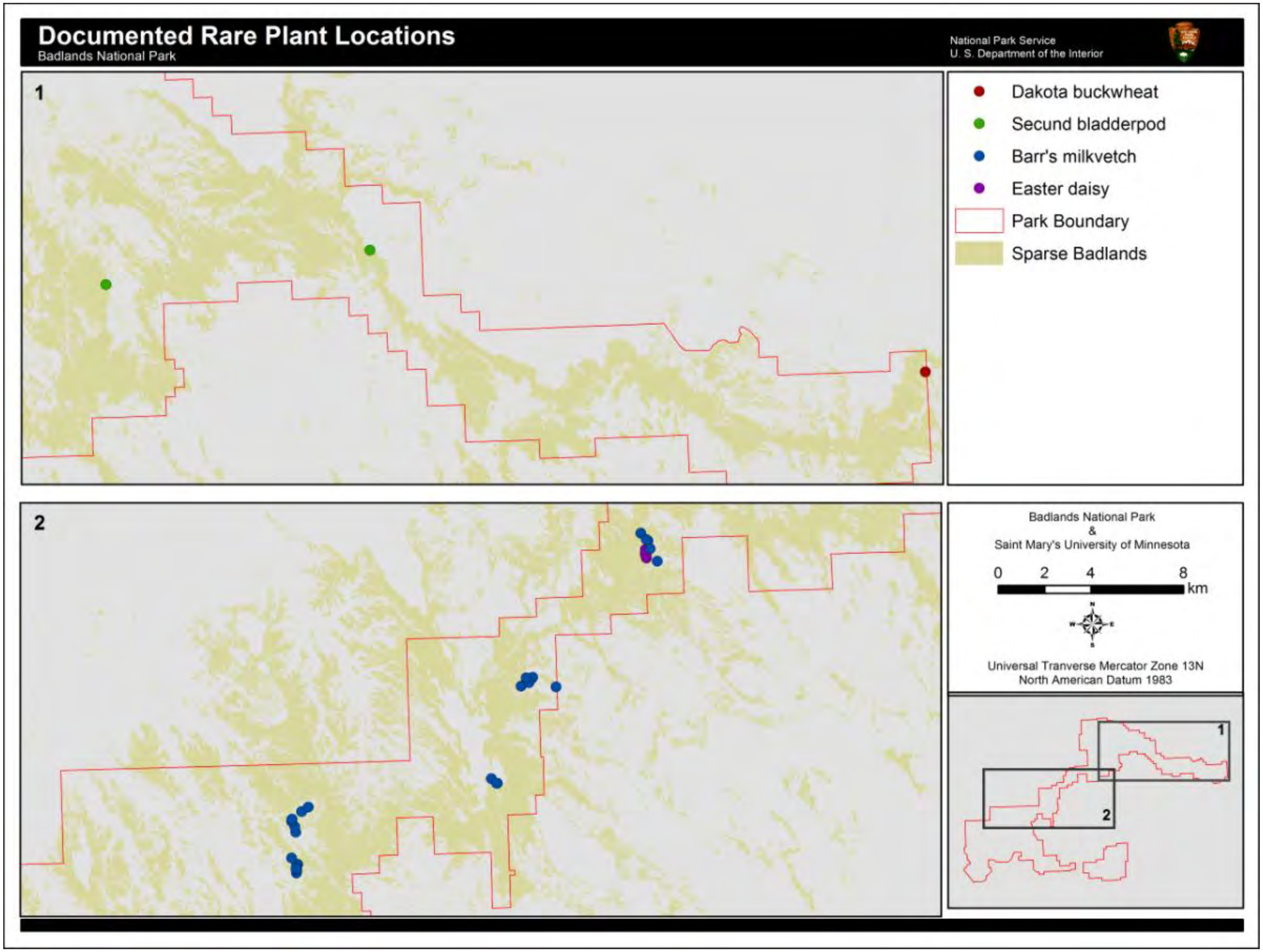

Plate 16. Known locations of rare endemic plants in BADL (NPS 2003, USGS 1999). Survey efforts have been limited and have not covered the entire park.

4.1.5 Springs and Seeps*

* Springs and seeps are defined by the presence of water or moist soils rather than vegetation types, which were used to define the previous plant communities. As a result, the assessment method used for the other plant communities was not applicable for springs and seeps. Very little information is available about these unique features. Therefore, this assessment is strictly a narrative with no quantitative scoring component.

Description

Photo 14. A spring in BADL (photo by Milt Haar, NPS, 2011).

Springs and seeps are important but rare features within the semi-arid landscape of BADL. They are an important source of water for many wildlife species in the park (Von Loh et al. 1999). Springs and seeps occur where water percolating through porous rock layers encounters a nonporous rock layer and then moves laterally until it finds an exit point. In BADL, the majority of springs occur along the eastern edge of Quinn Table (BADL, Rachel Benton, Paleontologist, e-mail communication, 3 August, 2011). Springs and seeps can also be found at the edges of sandhills where sandy soils meet clay soils (Von Loh et al. 1999). These areas support a variety of vegetative communities, ranging from woodlands to grasslands. Von Loh et al. (1999) observed the following vegetation types around springs and seeps: green ash-elm-chokecherry woodlands, cottonwood-willow woodlands, chokecherry shrublands, greasewood shrublands, and cattail-bulrush wetlands. Other vegetation likely found around springs and seeps include spikerushes and sandbar willow. Plate 17 shows the locations of known springs and seeps in BADL, as well as dams where pooling water is likely fed by a spring or seep.

Existing Threats and Stressors

Several of the threats to springs and seeps have been discussed in previous sections of this assessment. For example, springs and seeps surrounded by green ash woodland are threatened by ash pathogens (Lesica et al. 2003), while heavy ungulate browsing in cottonwood-willow bordered springs and seeps could negatively impact seedling establishment (Gage and Cooper 2005). Frequent use by wildlife may cause trampling of vegetation, soil compaction, and reduced water infiltration (Uresk 1987, as cited by Gitzen et al. 2010). Springs and seeps are also vulnerable to invasive species common on mesic or moist sites such as Russian olive, tamarisk, Kentucky bluegrass, and Canada thistle. Wildlife that frequent these areas may carry the seeds of invasive species between sites.

Some springs and seeps in BADL may be threatened by agricultural practices on adjacent lands that could leach herbicides and pesticides into the ground (USGS 2003). According to the USGS (2003), data from the CCC spring complex in the northwest part of the park indicated that its water quality is probably affected by anthropogenic activities occurring outside the park.

Climate Change Vulnerability

The warmer and drier conditions projected for BADL are likely to have a negative impact on springs and seeps. Although precipitation may increase slightly, increases in evapotranspiration will result in less available moisture overall. A warmer, drier climate may also cause an increase in wildlife use of springs and seeps, which could exacerbate the vegetation trampling, browsing, and soil compaction threats to these areas.

The projected increase in variability of precipitation will likely have a serious impact on seeps and springs. Changes in the frequency and magnitude of rain events could alter the amount of water reaching these areas. Variation in precipitation could also lead to more frequent droughts and heavy rain events. Droughts would likely lower the water levels and dry out soils around springs and seeps, which would negatively affect the surrounding vegetation and any wildlife relying on the aquatic or moist habitat. During a drought in 2003, several springs and seeps in the park dried up by July (USGS 2003). Heavy rain events could also negatively impact springs and seeps by flooding the areas or through increased sedimentation from storm runoff.

Photo 15. The Jonny Spring located in BADL (NPS BADL photo).

Data Gaps

Very little is known about the springs and seeps at BADL, and therefore it is difficult to predict how they will be impacted by climate change. Attempts to assess climate change vulnerability would greatly benefit from a park-wide survey of these features to describe the plant communities they support and any wildlife that rely on them (e.g., amphibians, reptiles, and insects). A hydrogeology survey that identified springs and seeps was conducted on the Pine Ridge Indian Reservation (covering part of what is now the South Unit of the park) in 1971 (Ellis and Adolphson 1971) and could serve as a starting point for survey efforts. Regular monitoring would also contribute to a better understanding of the ecology of these systems and how they respond to environmental variation.

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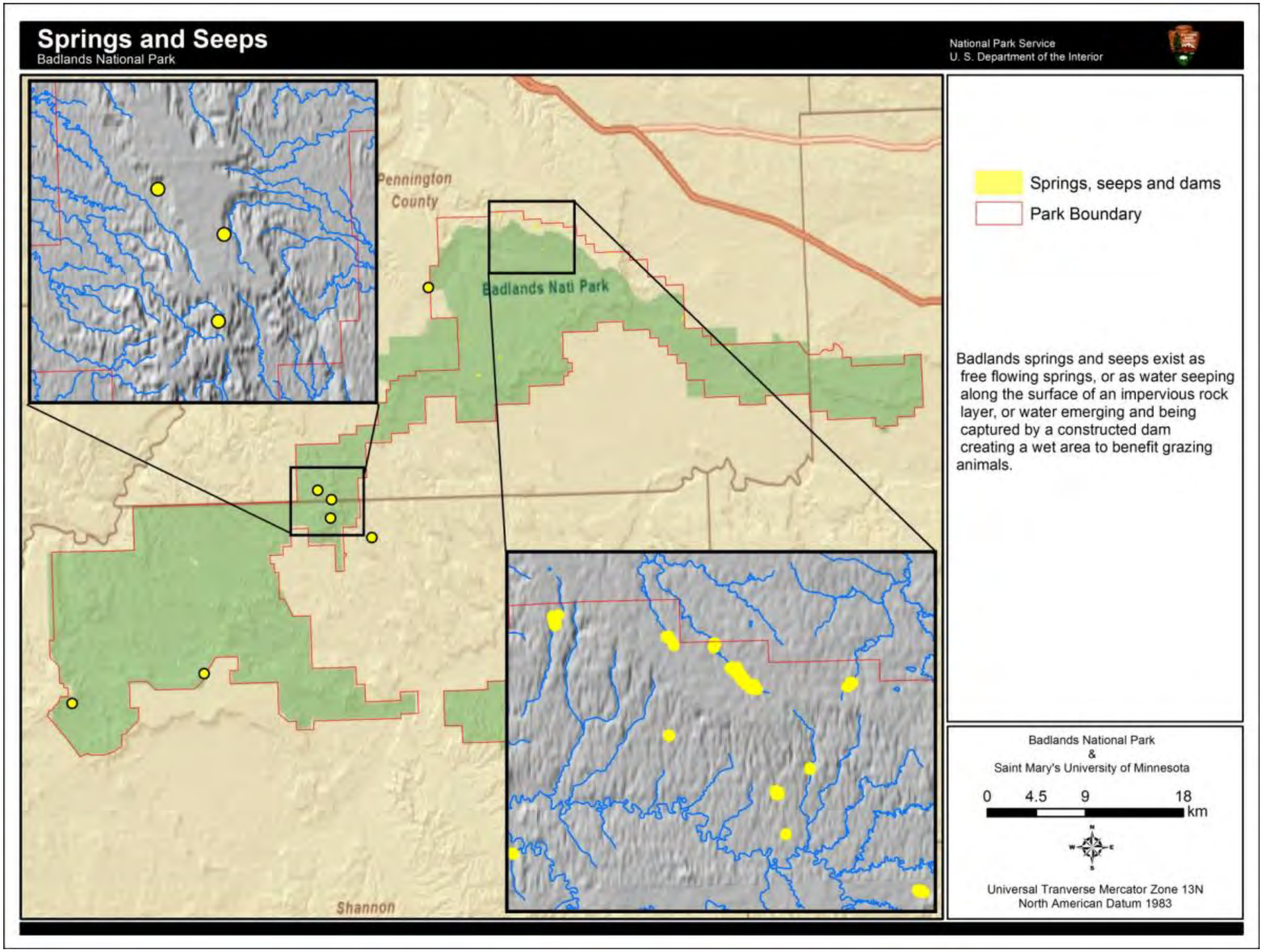

Badlands springs and seeps exist as free flowing springs, or as water seeping along the surface of an impervious rock layer, or water emerging and being captured by a constructed dam creating a wet area to benefit grazing animals.

Plate 17. Known spring and seep locations in BADL, and dams that are likely fed by springs or seeps (NPS n.d.). The upper left inset shows that springs and seeps often occur near table edges, while the lower left inset suggests that springs and seeps can be the sources of streams.

4.2 Ecological Processes

Summary:

Three ecological processes have played a major role in shaping the landscape and communities of BADL: fire, grazing, and erosion. Fire is a natural part of the disturbance regime in the Great Plains and many native plant species have evolved to benefit from its effects. Prescribed burning is often used in this ecosystem to maintain community health and integrity, not only in grasslands but in woodlands and shrublands as well. Fire influences both the species composition and structure of plant communities, which in turn impacts wildlife such as bison and grassland birds. Climate impacts fire regime both by influencing weather patterns and by influencing plant communities (fuels) through temperature and precipitation regimes. The warmer, drier conditions projected for BADL could increase fire frequency in and around the park. Increased variability in precipitation, for example, could lead to wet and dry oscillations where biomass fuel production increases during wet periods and then is more susceptible to burning during dry periods. However, extended droughts could reduce biomass, which would potentially impact the extent and persistence of fires.

Grazing creates a mosaic of habitats in Great Plains grasslands that support a wide variety of wildlife. Grazers are also an important part of the nutrient cycling process. Climate change, through its influence on vegetation, has the potential to affect forage quality, which would in turn have an impact on grazers. Changes in temperature and precipitation could shift the balance between C_3 and C_4 grasses, as well as changing the nutritional quality of the plants. If forage quality declines, grazers will need more forage to meet their nutritional needs and grazing pressure could increase.

Erosion is largely responsible for shaping the rugged landscape that characterizes BADL. The park experiences some of the highest known erosion rates in the world. Erosional processes, such as mass wasting, are influenced by climatic factors including precipitation and freeze-thaw cycles. Precipitation is expected to become more variable in the BADL region with more extreme events, which could accelerate rates of erosion. Drier conditions could decrease vegetative cover in areas where it is already low, further increasing the vulnerability of these surfaces to erosion. A study is currently underway in BADL to explore erosion rates at different sites in the park and is scheduled for completion in 2012.

4.2.1 Fire

Description

Fire has driven the adaptation and evolution of many communities and species in the Northern Great Plains (Forrest et al. 2004). It has played an important role in maintaining the species diversity and ecological processes of grasslands (Forrest et al. 2004, Schuler et al. 2006). Grasslands depend on fire to suppress encroachment by woody species, and to act as a decomposition agent and nutrient recycling path (NPS 2004, Schuler et al. 2006). Fires also generally improve and enrich mixed-grassland soils by increasing nitrification, mineral, and salt availability, as well as adding organic matter in the form of ash and charcoal residue (Vogl 1979, as cited by NPS 2004). This added organic material, in combination with dead and dying root systems, make the soil more porous, less compact, and better able to retain water while increasing needed surface area for essential microorganisms and mycorrhizae (Vogl 1979, as cited by NPS 2004). The effects of fire on grassland plant species is complex, as discussed in section 4.1.3 (Figure 12 shows the interactions among grasses and fire). Burning can increase the number of species, create monocultures, or allow invasion by aggressive non-native plants (NPS 2004). Perennials, including most non-native species, regularly survive fires since they can re-grow from underground plant parts and can reproduce vegetatively (e.g., through rhizomes). Seed production, germination, and seedling establishment of both annuals and perennials are commonly encouraged by burning (NPS 2004). Fire generally restricts shrub and tree growth, but can play an important role in regeneration in some woodland communities, such as green ash-elm-chokecherry woodlands (Girard et al. 1987, as cited by Gitzen et al. 2010). Fire can also maintain healthy stand structure in ponderosa pine woodlands, which can increase their resistance to insect and disease outbreaks (Brown 2006).

Photo 16. Prescribed fire in BADL (NPS photo, in Wienk et al. 2007).

BADL has “a classic grassland fire regime” characterized by large tracts of continuous fine fuels, frequent periods of hot, dry weather, and recurrent lightning (NPS 2004, p. 2). It is a fundamental ecological process in the park, influencing plant and animal diversity and distribution as well as abiotic processes such as erosion and nutrient cycling (NPS 2004).

Historically, low-intensity fires likely occurred every 1-25 years in this ecosystem, mostly ignited by lightning (Wright and Bailey 1980, as cited by NPS 2004). The direct impacts of fire on wildlife include dislocation of individuals or groups and occasional mortality of small mammals, reptiles, amphibians, and invertebrates (NPS 2004). Indirect effects, such as loss of potential nesting, resting, or forage habitat and increased predation, are usually short-term. Fire is generally considered to benefit bison, bighorn sheep, deer, and other mammals due to the increased forage quality in recently burned areas (NPS 2004). Fires that reduce plant cover height can also improve habitat for some grassland birds and may increase prey diversity and density for raptors (NPS 2004).

Photo 17. A grassland prescribed burn in BADL. Note how the badlands formations provide a natural firebreak (NPS photo, in Wienk et al. 2007).

BADL has an active fire management program “in order to preserve many of the values for which this area was set aside,” and prescribed burning has been used as a management tool since the early 1980s (NPS 2004, p. 2). Fires in the park are generally fast-moving and short in duration, with the extensive badlands formations serving as natural firebreaks that aid in control (Photo 17; NPS 2004). Since the mid-1970s, BADL has experienced an average of three fires per year, excluding prescribed burns, with approximately 60% of these caused by lightning (NPS 2004). Fire is closely monitored and managed in the BADL area. Natural and human-caused fires in the park are typically suppressed quickly and often burn less than an acre. As a result, fire does not occur to the extent that it naturally would in a grassland ecosystem. The park is divided into two Fire Management Units (FMUs): the 191,000 acre Boundary FMU and the smaller 53,400 acre Natural FMU (Figure 15). Prescribed fire and wildland fire suppression are practiced in both FMUs, but in the Natural FMU wildland fires are sometimes allowed to burn in order to maintain the natural variability of fire dependent communities in the ecosystem (NPS 2004). However, the amount of acreage burned annually in the Natural FMU is not allowed to exceed 10,000 contiguous acres for all fire types, to ensure adequate winter forage for ungulate populations (NPS 2004). The Natural FMU is located in the interior of the Badlands Wilderness Area. The Boundary FMU consists of lands adjacent to the park boundary and developed areas as well as the entire South Unit within the Pine Ridge Indian Reservation, where tribal grazing interests and other activities could be negatively affected by wildland fire use (NPS 2004). Prescribed burning in the South Unit is only conducted upon agreement with the Oglala Sioux Tribe.

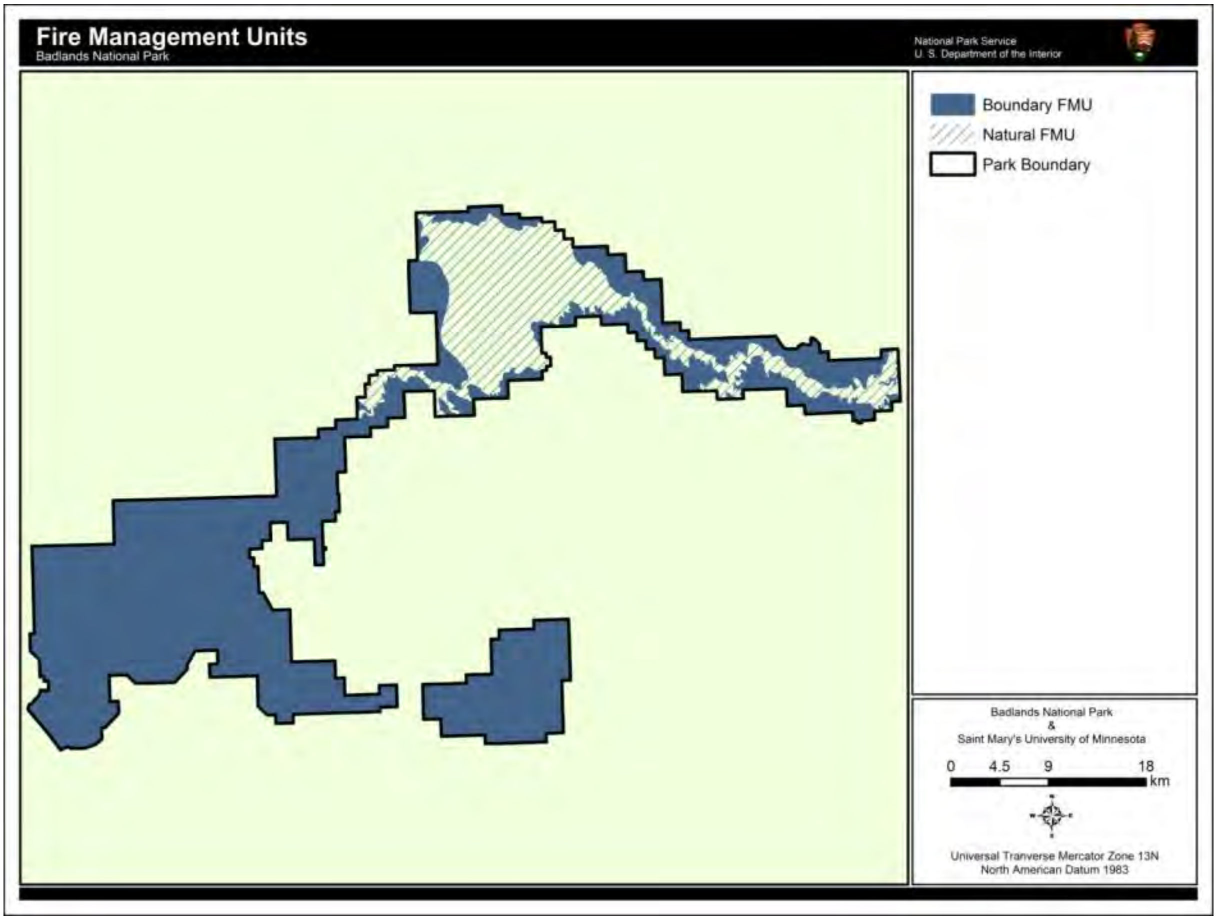

Figure 15. The two Fire Management Units (FMUs) of BADL (NPS n.d.).

In the northern mixed-grass prairie, spring burning generally benefits warm-season plants, while autumn burning usually benefits cool-season species (Whisenant and Uresk 1989). Whisenant and Uresk (1989, p. 226) concluded that fall burning is “preferable” in the northern mixed-grass prairie, due to the greater damage to cool-season grasses such as western wheatgrass and needle-and-thread caused by spring burning. Fall burning also is more effective in reducing the density and cover of some shrub species (White and Currie 1983).

The frequency and intensity of fire in the Northern Great Plains is influenced by the occurrence of two other ecological processes: drought and grazing. Short-term droughts preceded by several years of above average precipitation are likely to increase fire frequency due to abundant fine fuels (NPS, Dan Swanson, Fire ecologist, written communication, 6 October 2011). During droughts caused by long-term below normal precipitation, fire frequency will likely decrease due to low herbaceous biomass amounts. The overall drier conditions during a drought also reduce fuel moisture content, making it more flammable (Westerling et al. 2006). Grazing reduces plant biomass and reduces fuel loads, which can decrease fire frequency (Bachelet et al. 2000). Fire, in turn, influences the type and quality of forage available to grazers. This side of the relationship will be further discussed in section 4.2.2.

Prescribed burning has been explored as an option for controlling invasive plant species. Field brome and Kentucky blue grass are just two of the non-native species that can invade or increase in density in the absence of fire, partially due to litter accumulation (as reviewed by Gitzen et al. 2010). However, the long-term efficacy of burning as a management tool is still in question. In an experiment at BADL, Whisenant and Uresk (1990) found that spring burning decreased field brome density during the subsequent growing season, and reduced following generations if burning was followed by dry weather. The NPS Northern Great Plains Fire Ecology Program has established multiple monitoring plots in BADL and other parks to further explore the effects of fire on both invasive species and native vegetation. The results to date show "an undesirable trend in native and non-native cover" within the park (Figure 16; Wienk et al. 2007, p. 34). While non-native cover is often reduced in the first year after burning, it appears to recover and sometimes increase after two to five years. However, researchers suspect that this may be more an effect of ongoing drought in the park rather than fire. More information and detailed results can be found in Wienk et al. (2007).

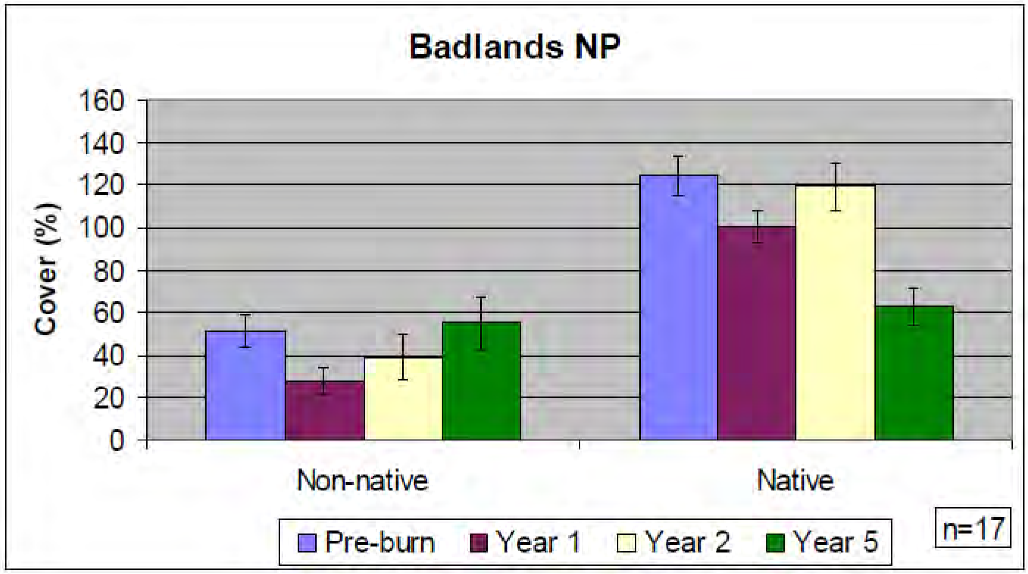

Figure 16. Percent cover of non-native and native species in seventeen monitoring plots before and up to five years after prescribed burning (Wienk et al. 2007).

Invasive species can significantly change fuel properties in an ecosystem, which can ultimately alter fire regime characteristics such as frequency, intensity, extent, type, and seasonality (Brooks et al. 2004). Whisenant (1990, in Bradley et al. 2006) showed that fire frequency in western shrublands can increase ten-fold to as often as every five years following cheatgrass invasion. Ecosystem properties that influence fire regime (e.g., nitrogen cycling, soil organic matter) may also be altered by invasive species (Brooks et al. 2004).

Climate Change Vulnerability

Climate influences fire regime both directly, by influencing weather patterns conducive to fire ignition and spread, and indirectly, by influencing plant communities through temperature and precipitation regimes (WICCI 2010). Weather parameters that strongly influence fire regime include temperature, relative humidity, wind speed, cloud cover, and time since last precipitation. On a broad time scale, climatic means and variability shape the character of vegetation, which affects fire regime. On an interannual or shorter time scale, climate variability influences the flammability of live and dead vegetation (Westerling et al. 2006). For example, oscillations between wet and dry conditions could first promote biomass growth, and then lead to the drying and burning of these increased fuels (Balling et al. 1992, as cited by Westerling et al. 2006). The spatial extent of wildfires is likely to increase during and shortly after years with above average precipitation, due to the larger amounts of fine fuel, and to decrease during drought periods (D. Swanson, written communication, 6 October 2011). Many scientists believe that increased forest wildfire activity in the western United States in recent decades can be explained by variations in climate (e.g., variability in moisture conditions, increasing drought frequency, warming temperatures) (Westerling et al. 2006). Westerling et al. (2006) found that variability in wildfire frequency was strongly associated with regional spring and summer temperatures.

Recently wildfire occurrence has also been linked to patterns in oceanic surface temperatures such as the El Niño/La Niña-Southern Oscillation (ENSO). These oceanic patterns have a strong influence on precipitation and droughts and can cause extreme weather events (Brown et al. 2006). Brown et al. (2006) found that fire occurrence in Black Hills ponderosa pine woodlands increased during La Niña (cooler) phases, cool phases of the Pacific Decadal Oscillation (PDO), and warm phases of the Atlantic Multidecadal Oscillation (AMO). These phases of the oceanic climate models are associated with drought conditions over much of the western United States (Brown et al. 2006). The opposite combination of patterns (El Niño, warm PDO, and cool AMO) was associated with years when fewer fires occurred than were expected (Brown et al. 2006).

The warmer, drier conditions projected for the BADL area could potentially increase fire frequency in and around the park. Drier conditions, due to increased evapotranspiration, would lead to drier, more flammable fuels. Warmer temperatures could lengthen the growing season, which could lengthen the fire season and provide more biomass for fuel. The projected increase in precipitation variability could lead to wet and dry oscillations, as discussed above, where biomass/fuel production increases during wet periods and is then more vulnerable to fire during dry periods. On the other hand, extended drought periods could reduce biomass/fuel levels, decreasing the likelihood of fire. If thunderstorms become more frequent (‘extreme events’ are projected to increase), the potential for lightning ignitions would increase.

Photo 18. Conducting a prescribed burn in BADL (NPS photo, in Wienk et al. 2007).

Climate change and the resulting vegetation changes may alter the effects of prescribed burning, particularly in grasslands. Whisenant and Uresk (1989) found that post-burn production of many grass species depended on post-burn precipitation levels. They also reported that drier upland grasslands took longer to recover from burning (1-3 years) than more productive mesic grasslands. If climate change causes BADL's mesic grasslands to transition into drier shortgrass prairies, prescribed burning and fire management in general may need to be adapted to these new conditions.

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4.2.2 Grazing

Description

Grazing has played a key role in the history of Northern Great Plains ecosystems and remains an important ecological process in BADL today (Gitzen et al. 2010). Grazing by native ungulates, such as bison and prairie dogs, is patchy and creates a mosaic of vegetation stages, each functioning as a unique habitat type for wildlife (Miller et al. 1994, Truett et al. 2001, as cited by Forrest et al. 2004). For example, some grassland bird species require intensively grazed areas while others rely on lightly grazed areas (Kantrud 1981, Forrest et al. 2004). The wastes excreted by grazers can also accelerate nutrient cycling, improving soil fertility and promoting plant growth (McNaughton et al. 1988, as cited by Milchunas et al. 1995). Grazing itself may increase forage quality. Several studies have found that vegetation regrowth after defoliation often has higher crude protein concentrations (Milchunas et al. 1994) and, in some grass species, increased digestibility (Milchunas et al. 2005). Additionally, vegetation cropped by grazers (particularly around prairie dog colonies) aids some wildlife species in detecting and evading predators (Von Loh et al. 1999).

Photo 19. Bison grazing in Sage Creek Wilderness Area, Badlands National Park (photo by Shannon Amberg, SMUMN GSS, 2011)

Domestic livestock have not grazed in the North Unit of BADL since it was fenced to exclude cattle in 1963 (Von Loh et al. 1999). Cattle grazing still occurs regularly in the South Unit, although stocking rates are unknown, as well as on adjacent private and U.S. Forest Service lands (Von Loh et al. 1999).

While grazing may contribute to an increase in some non-native invasive species (e.g., Canada thistle), it appears to help control others. Yellow sweetclover, for example, is more prevalent in the ungrazed North Unit of the park than in the South Unit and adjacent lands where livestock grazing still occurs (Von Loh et al. 1999). Several exotic invasive grasses currently present in the park, including crested wheatgrass and smooth brome, were introduced to BADL before it became a park in an effort to improve the range for foraging livestock (Von Loh et al. 1999).

Grazing and fire have developed an intricate ecological relationship in the grasslands of the Great Plains. Intensive grazing reduces plant biomass and fuel loads, decreasing the frequency of fire (Bachelet et al. 2000). Burning, in turn, affects plant species composition, which can influence grazing regimes. Fire burns off built-up layers of dead plant material and kills competing trees and shrubs, opening more space and improving light, water, and nutrient availability for grasses (Bachelet et al. 2000). In tallgrass prairie, spring burns increase the production of the dominant perennial grasses preferred by many grazers while summer burns favor annual grasses and forbs (Schuler et al. 2006). Bison show a strong preference for recently burned areas in both tall and mixed-grass prairies (Shaw and Carter 1990, Schuler et al. 2006), suggesting higher forage quality in these areas.

In the Great Plains, fire was often suppressed historically due to concerns about its negative impact on forage production (Launchbaugh 1964, as cited by Augustine and Milchunas 2009). However, research has shown that the effects of fire on forage quality in shortgrass vary with the timing of burning (Augustine and Milchunas 2009, Augustine et al. 2010). Augustine and Milchunas (2009) found that forage production on moderately grazed shortgrass steppe was not negatively affected by late winter burns, unless followed by a severe drought. This is likely because vegetation is mostly dormant under cooler conditions, as opposed to later burns when vegetation is “photosynthetically active” (Augustine and Milchunas 2009, p. 90, citing Wright and Bailey 1982). Burns conducted in early spring or later can have “significant negative effects”, particularly on ungrazed or lightly grazed sites due to a higher fuel load (Augustine and Milchunas 2009, p. 93, citing Brockway et al. 2002, Ford and Johnson 2006). Late winter prescribed burns also “substantially increased the nitrogen content” (i.e., forage quality) of blue grama grass early in the season (May and June), although no difference was seen later in the season (Augustine and Milchunas 2009, p. 92). Augustine et al. (2010) found that burning also increased the digestibility of blue grama sampled in late May by 11%.

Climate Change Vulnerability

Climate change will potentially affect grazing through its strong influence on vegetation, especially forage quality. An analysis of forage quality among ecologically defined areas across the U.S. showed a decrease in dietary crude protein and digestible organic matter with increasing temperature and decreasing precipitation for regions with continental climates (Craine et al. 2010). This pattern suggests that a warmer climate, like that projected for BADL, would reduce protein availability to grazing animals (Craine et al. 2010). Increases in temperature are thought to favor C_4 (warm season) grasses, which are generally considered to be of lower forage quality than C_3 (cool season) species (Ehleringer et al. 2002, as cited by Craine et al. 2010). However, warming

Photo 20. Bighorn sheep grazing in BADL (photo by Shannon Amberg, SMUMN GSS, 2010).

during fall or spring favors C_3 plants and could extend the high-quality foraging season (Alward et al. 1999, Sherry et al. 2007; Craine et al. 2010).

No research could be found regarding the effects of climate change on forage for native grazers in a mixed-grass prairie similar to BADL. Craine et al. (2009) studied the effects of changing precipitation on bison grazing in tallgrass prairie. They found that the timing of precipitation was significant, with increased late-summer precipitation increasing bison weight gain while greater midsummer precipitation decreased bison weight gain (Craine et al. 2009). No relationship was found between bison weight and air temperatures, early season precipitation, or winter precipitation. The decreased weight gain with greater midsummer precipitation was associated with increased grass stem production (Craine et al. 2009). While greater stem production increases forage quantity, it typically decreases nutritional quality since grass stems have lower protein and digestible organic matter concentrations than leaves (Jung and Vogel 1992, as cited by Craine et al. 2009). Greater late-summer precipitation could increase forage quality and bison weight gain by increasing the productivity of C_3 grasses, delaying plant senescence, or increasing nitrogen mineralization, which would increase nitrogen concentration in grasses (Craine et al. 2009). Craine et al. (2009, citing Blanchard et al. 2003, Derner and Hart 2007) suggests that in ecosystems where grazers are primarily limited by the quantity of forage, reductions in precipitation are likely to decrease herbivore performance. In contrast, when herbivores are more limited by forage quality, reductions in precipitation could increase nutritional quality and increase grazer performance despite a decrease in forage biomass (Sheaffer et al. 1992, Sanderson et al. 1997; as cited by Craine et al. 2009).

In moderately grazed shortgrass steppe, Milchunas et al. (1994) found that variability in forage production can largely be explained by variation in cool-season precipitation. An increase in cool-season precipitation is more likely to improve forage production than a warm-season increase, due to differences in “evaporative demand” and rainfall “utilization-efficiencies” between the two seasons (Milchunas et al. 1994, p. 133). Moisture extremes, high or low, may also affect forage quality in shortgrass steppe. Milchunas et al. (1994) noted that forage nitrogen concentrations were lowest during the wettest year of their study, while Milchunas et al. (2005) found that drought years resulted in only half the digestible forage yield of years with average or above average precipitation. Climate change may also alter the phenology (e.g., timing of green-up, seed production) of forage plants (Sherry et al. 2007, Jentsch et al. 2009). The impact this could have on grazing wildlife in BADL is unknown.

The projected increase in CO_2 that is driving climate change could also affect plant productivity, forage quality, and grazing. Research suggests that rising atmospheric CO_2 concentration has the potential to significantly alter grassland structure and function, possibly leading to grasslands that are more productive but less useful for grazing (Morgan et al. 2004). Morgan et al. (2004) found that growth under experimentally elevated atmospheric CO_2 concentrations reduced the digestibility of three dominant prairie grasses (blue grama, western wheatgrass, and needle-and-thread) by an average of 16%. Higher atmospheric CO_2 could also exacerbate declines in plant nitrogen concentrations and protein levels (Ainsworth and Long 2005, as cited by Craine et al. 2010). Therefore, grazers may have to consume more biomass than under present CO_2 concentrations to achieve the same nutritional results (Morgan et al. 2004).

A reduction in forage quality (e.g., lower digestibility or nitrogen content) cannot only decrease animal weight gains but also reproductive success (Owensby et al. 1996, as cited by King et al. 2004). According to Murphy and Coates (1966, as cited by Milchunas et al. 2005), a reduction in forage crude protein concentrations from 13% to 7% negatively affected the productivity and survival of female deer. A diet of 7% crude protein also dramatically reduced the body weights and antler development of male deer (Murphy and Coates 1966). Five percent crude protein content is considered a “critical point where muscle catabolism and negative apparent protein digestibility may begin” (Milchunas et al. 2005, p. 180, citing Milchunas et al. 1978). Lower digestibility, particularly in the fall when forage quality is relatively poor, “can affect rate of passage and reduce intake to a point where muscle and fat catabolism, and even death, can occur in animals with a full rumen (Milchunas et al. 2005, p. 181).

Little is known about the indirect effects of grazing (e.g., soil compaction, trampling of vegetation) in BADL or how these effects may be impacted by climate change. During wet periods on the adjacent Buffalo Gap National Grasslands, livestock can create deep footprints and their trails can reroute hydrology patterns (B. Burkhart, written communication, 5 October 2011). If extreme precipitation events become more frequent, the opportunity for these types of damage may increase.

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4.2.3 Erosion

Description

Natural erosion processes are largely responsible for shaping the BADL landscape (Graham 2008), particularly the spectacular geological formations that attract many visitors to the area. BADL experiences some of the highest known erosion rates in the world, with some surfaces reduced by 2.5 cm (1 inch) every year (Kiver and Harris 1999, Stoffer 2003; as cited by Graham 2008). Sustained erosion of the Badlands began around 500,000 years ago when the Cheyenne River captured sediment laden streams and rivers flowing from the Black Hills, starving the region of sand, silt and clay deposits. Tributaries flowing into drainage basins from the White, Cheyenne and Bad Rivers began eroding 30 million year old deposits, forming a scarp that has since become known as “the wall” (Graham 2008; R. Benton, written communication, 7 November 2011). A prominent geographic feature of BADL, the wall averages four to eight kilometers in width and is actively retreating (through continued erosion) in several directions (Churchill 1979; R. Benton, written communication, 7 November 2011). It stretches approximately 95 km, separating the ‘Lower Prairie’ and ‘Upper Prairie’ by an average elevation of 45 meters (Churchill 1979).

Photo 21. The Badlands wall (NPS photo, from NPS 2010).

Erosion is caused by three main sources: water, wind, and freeze-thaw activity. While all three occur in BADL, water erosion has received the most attention. One significant erosional process often triggered by water and/or freeze-thaw activity is mass wasting. Mass wasting is the downslope transport of soil and rock material by gravity; it is an important issue in the park (Graham 2008). Some of the park’s rock layers contain clay that swells when wet, creating instability in both soil and rock and raising the potential for mass wasting. Ridges and pinnacles in the park have collapsed overnight as a result of a single thunderstorm (Graham 2008). Cliffs in the wall periodically break loose, forming slumps and creating holes, pits, or seasonal ponds in the disturbed areas (Graham 2008). Mass wasting has occurred in the Cedar Pass Area, at Norbeck Pass, Sage Creek, Pinnacles, and along the Cliff Shelf Trail. The Badlands Loop Road (the main road into the park) is built on several active landslides and requires constant repair, occasionally becoming a public hazard (Photo 22; Graham 2008). Mass wasting also contributes sediment directly to some stream channels, including Sage Creek (Graham 2008). This could affect the water quality and aquatic habitat of these streams.

Photo 22. Damage to the Cedar Pass Road in a geological slump area after heavy rain (photo by Brian Kenner, NPS, 2011).

Erosion affects the various rock layers in the park differently. Layers composed of volcanic ash are often easily eroded, exposing the more durable formations beneath (Graham 2008). The Brule formation with its erosion-resistant, silty sediments produces many of the steep, rugged peaks and canyons in the park. Areas with sandstone caprock may erode less than one inch in 500 years (Hauk 1969). The older Chadron Formation and Pierre Shale are clay-rich and more erodible (Graham 2008). Some of these clays are likely to swell when wet and contract when dry, sometimes forming a “popcorn-like surface.” When this occurs, plant root establishment can be inhibited, further encouraging erosion (Graham 2008). In areas that lack significant vegetation, a karst-like terrain (called pseudokarst) can develop, characterized by pits or vertical piping (Graham 2008; R. Benton, written communication, 26 September 2011). Churchill (1979) noted that where fully exposed, the Chadron Formation eroded to rounded “haystack” hills whereas the Brule Formation slopes are steeper with a more rectilinear appearance.

Erosion rates can also vary across the park depending on the slope of the land, presence of vegetation, lithologic composition, and sediment moisture amounts (Stetler and Benton 2011). Gravity-related erosional movements, known as creep, increase with slope angle (Clarke and Rendell 2006). In contrast, rainsplash erosion peaks at a slope angle of 45° (given a vertical rain) and decreases as the slope angle goes up or down (Clarke and Rendell 2006). Vegetation plays an important role in protecting soils and bedrock from wind erosion (Munson et al. 2011). A lack of vegetation can also increase water erosion, particularly during intense rainfall events (Graham 2008). Plant litter alone can prevent erosion by protecting the surface from rainsplash and slowing runoff velocities (Wei et al. 2009). Long-term reductions in plant cover due to grazing or short-term reductions due to fire can create opportunities for accelerated erosion (Ryan et al. 2008).

Soil data collected by the NRCS (2011) in the BADL region were used by SMUMN GSS analysts to identify areas of the park with soils susceptible to wind and water erosion. Plate 18 shows that soils in much of the park are moderately susceptible to wind erosion or to both water and wind erosion. Small areas in the South Unit and larger areas in the adjacent Conata Basin are highly susceptible to wind erosion. Parts of the Sage Creek Basin in the North Unit and a small part of the northwest corner of the South Unit contain soils that are highly susceptible to water erosion.

Climate Change Vulnerability

Climate is an extremely important factor in erosional processes, especially in arid and semiarid regions (Kuehn 2003, Graham 2008). According to Kuehn (2003, p. 10), temperature and rainfall "are critical in the erosion and transport of sediment, and hence to the often precarious balance between deposition, erosion, and landscape stability". Climate variables also impact vegetation patterns, which in turn influence erosion across the landscape. In BADL, the combination of high summer temperatures, short intense rain events, and dry, cold winters make growing conditions difficult for most plant species (Graham 2008). Many slopes in the park are completely devoid of vegetation, exposing the surfaces to both water and wind erosion (Kuehn 2003).

According to Wei et al. (2009, p. 308), "rainfall is the initial and essential driving force for natural runoff generation and erosion variation." In a study of southern European badland formations, Clarke and Rendell (2006) found that cumulative mean erosion rates increased as cumulative rainfall amounts increased. They also predicted that a reduction in annual rainfall, which is expected in southern Europe as a result of climate change, will result in a further reduction in erosion rates (Clarke and Rendell 2010). However, a reduction in rainfall could also reduce vegetative cover, increasing the surface area exposed to rainfall and runoff (Clarke and Rendell 2010). A model run by Lee et al. (1996, as cited by O'Neal et al. 2005) predicted that a 20% increase in precipitation in the U.S. Corn Belt (just south of BADL) would increase erosion by 37%. In semi-arid badlands, the ephemeral nature of precipitation and runoff means that change is particularly associated with extreme events (Faulkner 2008). Wei et al. (2007) found that rainfall regimes with strong intensities and low frequencies induced more severe runoff and soil erosion than regimes with weak intensities and high frequencies. While annual precipitation amounts are only projected to increase by about 10% in the BADL region, precipitation is predicted to become more variable with more extreme events (see Table 8). Both of these factors have the potential to increase erosion rates in the region. Temperature is also predicted to increase and could accelerate evapotranspiration rates, which may influence infiltration and runoff amounts and rates (Pruski and Nearing 2002, as cited by O'Neal et al. 2005). The complex relationship between changes in rainfall, water erosion, and other environmental variables (as modeled by Wei et al. 2007) is shown in Figure 17.

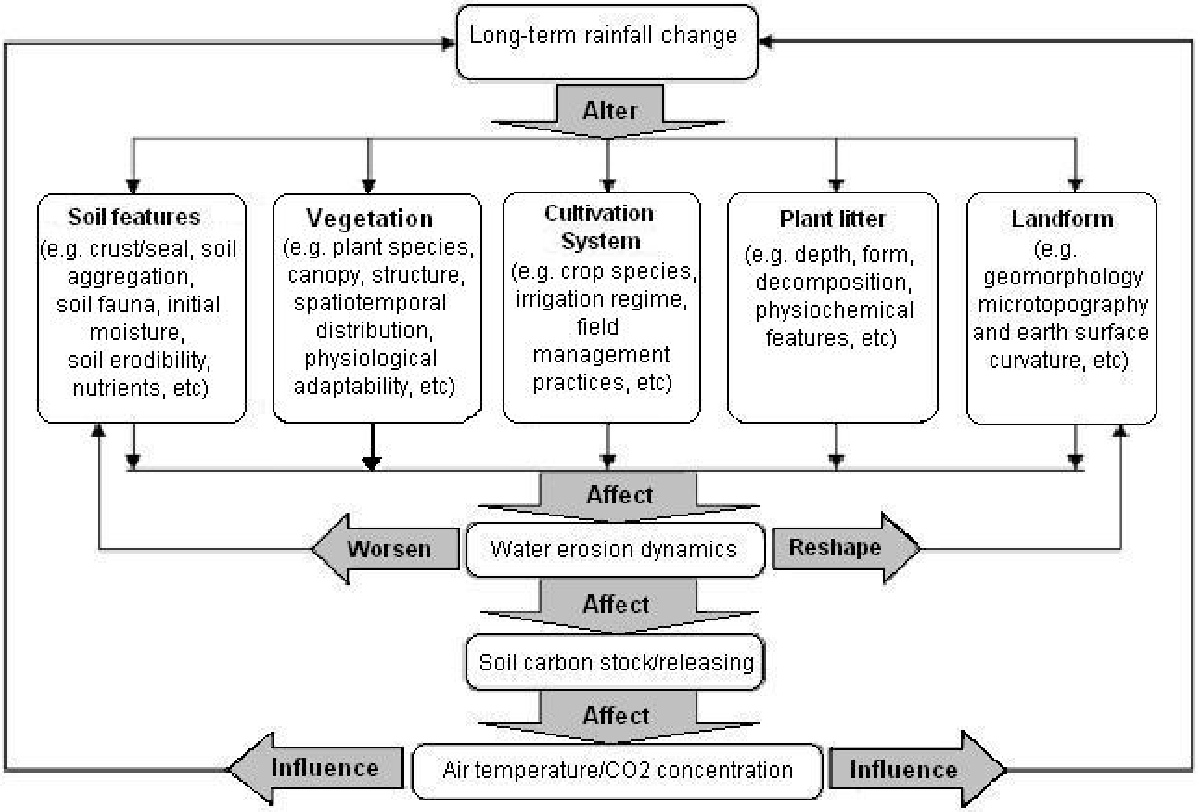

Figure 17. The relationship between rainfall change and water erosion processes in terrestrial ecosystems (Wei et al. 2007).

Semi-arid conditions in the BADL may increase the landscape's susceptibility to wind erosion (Stetler and Benton 2011). The warmer, drier conditions projected for BADL will not only dry out the soil, directly increasing its vulnerability to wind erosion, but will also impact the vegetation that can protect the ground from wind. Munson et al. (2011) found that enhanced aridity in arid regions due to climate change is likely to cause a decline in already low vegetative cover, increasing the soil's exposure to wind erosion. However, depending on the sediment's composition, it is also possible that dry conditions could cause the formation of a hard surface layer that reduces susceptibility to wind erosion (SD SMT, Larry Stetler, Professor, written communication, 12 October 2011).

Photo 23. Rilling due to fluvial erosion in BADL (photo by Shannon Amberg, SMUMN GSS, 2010.)

Churchill (1979) found that hillslope development and erosional processes in BADL differed based on the aspect of the slope. He hypothesized that this influence was due to temperature differences resulting from aspect-related variation in direct solar radiation. According to his research, north-facing slopes maintain moisture levels that are higher and less variable than south-facing slopes, due to the fact that they receive considerably less solar radiation. Higher moisture retention by north-facing slopes reduces the rate of infiltration by precipitation, which increases the volume of overland water flow and leads to more extensive fluvial erosion (e.g., rilling; Photo 23). On south-facing slopes, where direct solar radiation is much higher, moisture levels are generally lower and highly variable. There is little evidence of fluvial erosion, but periods of intense desiccation following precipitation often initiate numerous small rockfalls that erode these slopes (Churchill 1979). As a result of these differences, north-facing slopes are generally less steep with more complex topography than south-facing slopes. South-facing slopes also experience greater diurnal temperature fluctuations, which may cause a more frequent and intense cycle of freeze-and-thaw than on north-facing slopes (Churchill 1979).

Churchill (1979) also found that while both north- and south-facing slopes were subject to mass wasting, the type and frequency of these movements varied. North-facing slopes, perhaps due to their higher and less variable soil moisture content, are more susceptible to large-scale, rapid types of mass movements. South-facing slopes, in contrast, experience much smaller but more frequent failures, such as shallow rockfalls triggered by intense desiccation or seasonal freeze-and-thaw. This difference also contributes to the lower slope angles of north-facing slopes and steeper south-facing slopes (Churchill 1979).

A study is currently underway in BADL to explore erosion rates at significant fossil sites within the park. The goals of this project are:

- To establish measurement and monitoring procedures necessary to determine erosion rates for select fossil sites at Badlands National Park,
- To document the erosion rates at significant fossil sites described within the park,
- To provide park management with a paleontological monitoring schedule based on erosion rates at specific fossil sites (Stetler and Benton 2011).

The investigators are exploring the use of LiDAR (Light Detection and Ranging) imagery and photogrammetry to document surface changes and for slope stability assessment (Photo 24; Stetler and Benton 2011). A more detailed description of methods can be found in Stetler et al. 2011. Preliminary data suggest that erosion in BADL occurs in major pulses rather than gradually, and that the effects of a single rain event can be more radical than previously thought (R. Benton, phone conversation, 10 August 2011). The study is scheduled to be completed in 2012. The results will help managers better understand current erosion rates and how erosional processes will be affected by climate change within BADL.

Photo 24. Dr. Larry Stetler from the South Dakota School of Mines and Technology taking stereo pair images of an erosion study site in BADL using photogrammetry techniques (photo by Emily French, SD School of Mines and Technology, 2011).

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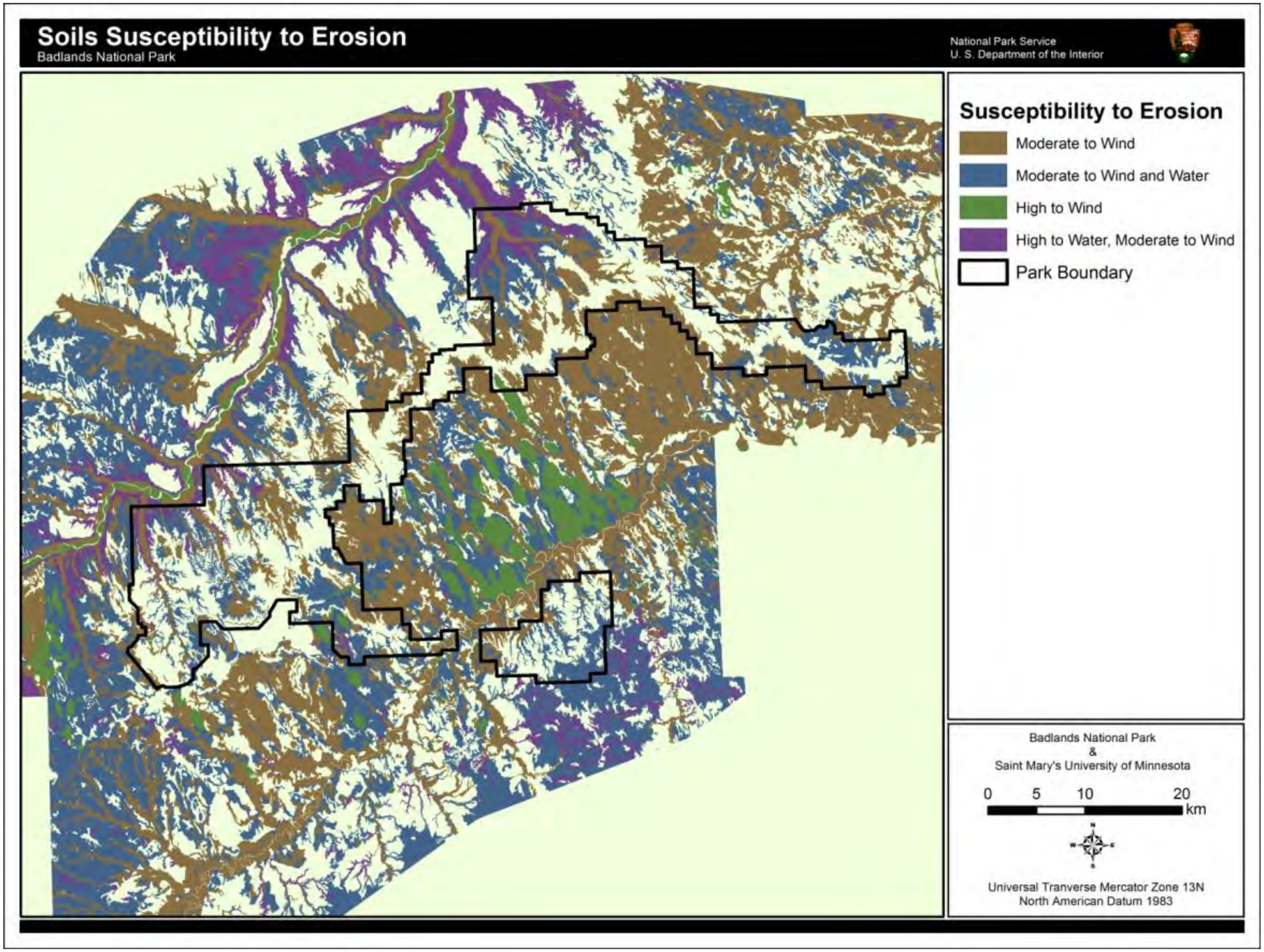

Plate 18. The susceptibility of soils in the BADL region to wind and water erosion (NRCS 2011). This map represents soils only, not bedrock exposed in the park and surrounding areas.

4.3 Species

Summary. The core project planning group selected a number of species (or groups of species) for individual vulnerability assessments (Table 29). These species were either a high priority for park managers or are viewed as indicators of ecosystem health. Species assessments use a narrative approach rather than a scoring system (as was used in plant community assessments). For a detailed description of this approach, see chapter 2.

Table 29. Species and groups of species selected for individual assessments.

Species	Groups of Species
Prairie dog	Herpetofauna
Black-footed ferret	Birds of prey
Swift fox	Grassland birds
Bighorn sheep	Culturally significant species
Bison	
Mule deer	
Bobcat	

Factors that contribute to a species' degree of vulnerability include physiological sensitivity, degree of specialization, reliance on sensitive plant communities and habitats, and the impact of climate change on current non-climate stressors. The vulnerability of a given species was also often correlated with the vulnerability of the plant communities it utilizes. For example, the bison and prairie dog populations in BADL seem least vulnerable to climate change, mainly because the vulnerability of their habitat (grasslands) is low. Prairie dogs also have little to no physiological vulnerability to climate change and, as a burrowing species, can often escape extreme weather events by going underground. Bison, however, may be impacted if the projected drier climate causes a shift in grassland species composition away from the most nutritional or preferred forage species.

The swift fox population exhibits a slight vulnerability to climate change in the BADL region due to their preference for a particular grassland plant community and their reliance on prairie dogs as prey for at least part of the year. However, the swift fox has little to no physiological sensitivity to climate changes (e.g., temperature sensitivities) and they do not rely on sensitive habitat. Birds of prey also appear to be slightly vulnerable to climate change in BADL. Most birds of prey utilize a variety of habitats and food sources, making them highly adaptable to environmental change. However, the specialized habitat needs of some species, such as the bald eagle and burrowing owl, may make them more vulnerable to climate change. The bobcat population in BADL is slightly vulnerable to climate change as well, primarily due to its reliance on woodland plant communities, which were identified as highly sensitive to climate change in and around the park.

Mule deer in BADL are moderately vulnerable to climate change, because of their extensive use of woodlands (a sensitive plant community) and a possible increase in prevalence of certain diseases and parasites with increased temperatures. Bighorn sheep are also moderately vulnerable, as climate change could impact forage quality and sheep health, increasing the species' already high susceptibility to disease.

Many grassland bird species have experienced population declines due to changes in available habitat and will likely experience further declines due to the influences of climate change in the region. Vulnerability to climate change will vary across individual species. Although most grassland birds can tolerate habitats with some intrusion of non-native grasses, the grasslands may become progressively unsuitable for some species if invasive plants begin to dominate the composition as a result of climatic changes. Likewise, the response of herpetofauna in BADL to climate change will also vary, with amphibians exhibiting higher vulnerability than reptiles. While both groups are threatened by habitat loss and fragmentation, amphibians are also stressed by their physiological sensitivities to temperature and dessication, and their dependence on sensitive wetland and aquatic habitats.

The black-footed ferret, a federally endangered species, exhibits moderate vulnerability to climate change in BADL. A specialist to grassland prairie ecosystems that support prairie dog populations, the ferret has a close dependency on prairie dog colonies for prey and dens. The ferret population would be at significant risk if climate change were to threaten the stability of prairie dog colonies in the park. These colonies are carefully managed in the park and currently populations are stable with low incidence of disease.

4.3.1. Prairie Dogs

Description

Prairie dogs are herbivorous rodents that occur throughout central North America's mixed- and shortgrass prairies (Whicker and Detling 1988). Black-tailed prairie dogs form and reside in "large social aggregates" or prairie dog towns (Cincotta et al. 1986, p. 5). As colonial burrowing rodents, black-tailed prairie dogs function as an ecosystem engineer, altering prairie ecosystems to create a unique habitat that numerous wildlife species depend on (Bowser 1993, Groom et al. 2006). Historically, black-tailed prairie dogs were the most abundant and widely spread species in the Great Plains (Whicker and Detling 1988). Ranchers viewed prairie dogs as competitors with livestock for rangeland resources. Eradication programs throughout the 1900s led to a reduction in colony sizes across the United States, from approximately 280 million total hectares to less than 1.2 million hectares (Bowser 1993).

Photo 25. Prairie dogs at BADL's Roberts Prairie Dog Town. Note the difference in vegetation between the prairie dog town and the grassland in the background (photo by Shannon Amberg, SMUMN GSS 2010).

Prairie dogs graze on graminoids, such as buffalograss, threadleaf sedge, blue grama, and western wheatgrass, and forbs such as scarlet globemallow. Their grazing often causes a vegetation shift from tall or mixed-grass prairie to shortgrasses with an increased dominance of forbs (Bowser 1993). Black-tailed prairie dogs not only regulate grassland ecosystems through their foraging habits, they are also an important prey source for several wildlife species including the black-footed ferret, swift fox, ferruginous hawk, and badger (*Taxidea taxus*) (Bowser 1993). The decline of prairie dogs in the 1900s contributed to the crash of the black-footed ferret population, an obligate predator of prairie dogs (Bowser 1993).

Existing Threats and Stressors

The black-tailed prairie dog is affected by several non-climate threats and stressors such as exotic diseases, rodent control activities, habitat loss, and predation. Sylvatic plague, a flea-borne bacterial disease that was introduced to North America from Europe around 1899 (Cully 1989, as cited by NatureServe 2011), is a major concern for prairie dog populations. Plague is caused by the bacterium *Yersinia pestis*, and has been positively identified in black-tailed prairie dogs since 1945, when plague-positive fleas (*Oropsilla hirsuta*) were found in burrows in western Kansas (Cully et al. 2000, as cited by Cully et al. 2010). Cully et al. (2010, p. 13) indicated that "highly connected" colonies are more susceptible to outbreaks when plague is present, since transmission is easier. The prairie dog is believed to be an "amplifying host for plague and a source of the disease" for wild and domestic species (Rocke et al. 2010, p. 53, citing Barnes 1993). Sylvatic plague was first identified in the Conata Basin in 2008 and in BADL in 2009 (Griebel 2009, Olson 2009). By the end of 2009, plague had eliminated over 15,000 acres of prairie dog colonies in the Conata Basin and 700 acres in BADL, killing an estimated 190,500 prairie dogs (Griebel 2009); however, it is unclear what percentage of the BADL population was affected by this event. Plague activity appeared to slow in 2010, impacting only 1,771 acres in the Conata Basin and BADL area (Griebel 2010). In the past, plague (*Y. pestis* infection) has devastated human populations and cases are still reported today in the United States and around the world (Stenseth 2006), making control of the disease particularly important.

Considered a rangeland pest species by ranchers since the introduction of cattle to the western states (Bowser 1993), prairie dog towns that expand outside park boundaries onto private lands may be subject to poisoning. The compound strychnine was first introduced into the United States around 1847 and experienced varied success as a rodenticide. It was eventually found to be hazardous to numerous non-target species such as the black-footed ferret and swift fox (Tietjen 1976, as cited by Apa et al. 1990). Zinc phosphide was then introduced in 1943 as a “pest-control agent” that caused no secondary poisoning of non-target wildlife (Apa et al. 1990, p. 107). In a study in BADL, Apa et al. (1990) found this chemical to be the most effective of three rodenticide treatments tested, reducing prairie dog populations by 95%, with treated towns requiring five or more years to recover to previous densities (Apa et al. 1990).

Climate Change Vulnerability

Physiological Sensitivity. The BADL black-tailed prairie dog population is currently in the northern part of its historical range (Figure 18). Black-tailed prairie dog colonies are found throughout the semiarid Great Plains ecosystem (as reviewed by NatureServe 2011). In BADL, summer temperatures reach up to 40° C. Living in burrows as deep as three to five meters allows prairie dogs to escape some of the heat during the hottest parts of the day (Hoogland 1996), which means they may be less vulnerable to extreme heat events predicted to increase in frequency with climate change (Karl et al. 2009).

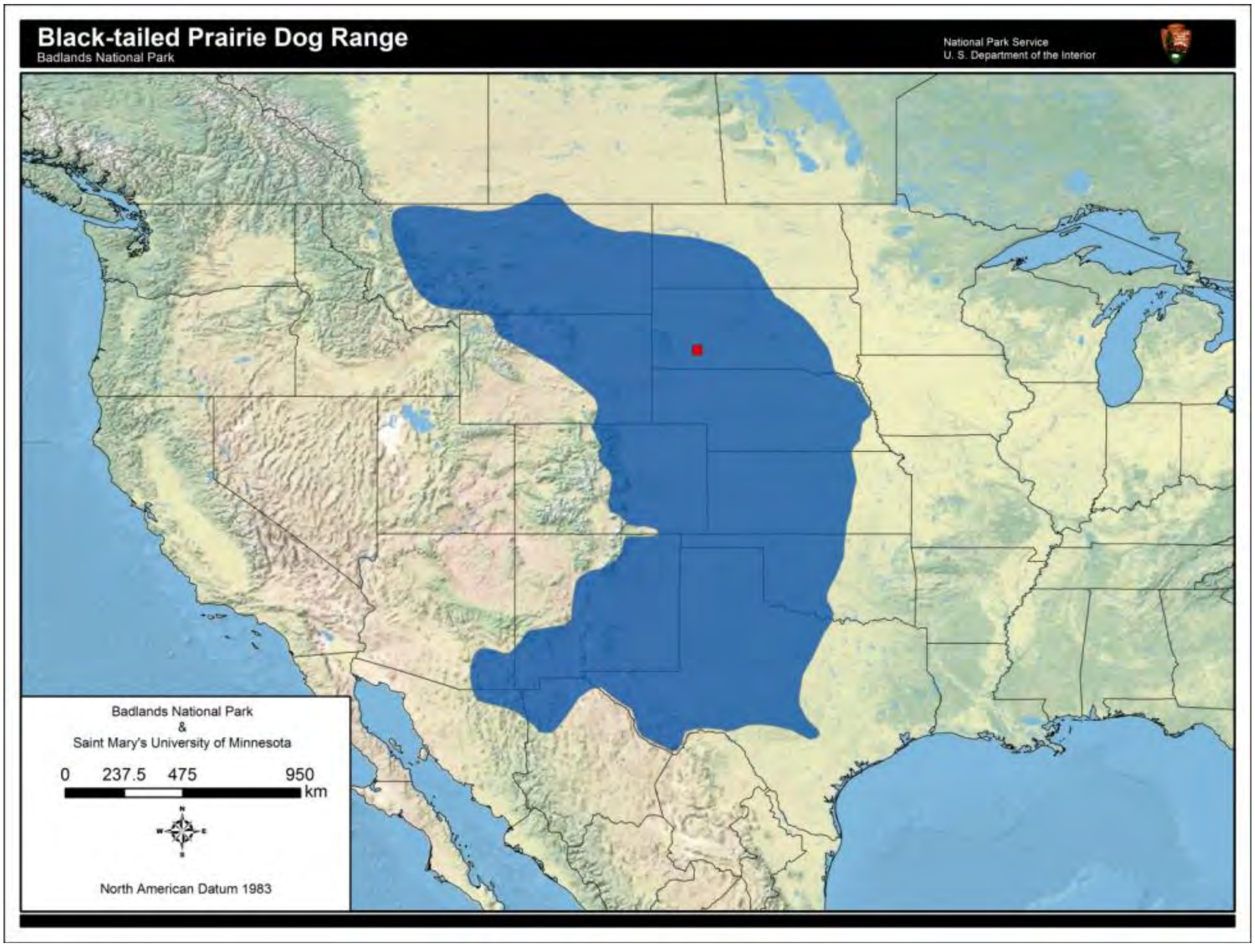

Figure 18. Current black-tailed prairie dog distribution (Patterson et al. 2007) (BADL location shown in red).

Generalist vs. Specialist. Black-tailed prairie dogs are considered highly adaptable, generalist feeders (Uresk 1984). They may prefer a few important species when available, such as sand dropseed and sunsedge (*Spharagemon equale*), because of their higher protein content (Uresk 1984). However, when resources are stressed by over-grazing, drought conditions, or herbicides, prairie dogs can quickly adjust their diet to meet their nutritional needs (Uresk 1984). In BADL, prairie dogs have been known to eat buffalograss, blue grama, needleleaf sedge, and western wheatgrass (Uresk 1984). Cincotta et al. (1986) found that prairie dog diets differ between young and old prairie dog towns and between habitat zones of the town. Western wheatgrass made up a majority of the diet in old town centers, while buffalograss and grass seeds were most abundant in the diets of individuals occupying young town areas (Cincotta et al. 1986).

Black-tailed prairie dogs tend to start colonies in mixed- and shortgrass prairies, and may be considered a specialist to grassland communities. Prairie dog towns are located on a diversity of soil types, but most typically occur in deep, loamy soils (Cincotta et al. 1986). Although they favor softer soils, especially when first developing a town, prairie dogs will dig out large rocks and dig through heavy clay soils when constructing burrows (Koford 1958, as cited by Cincotta et al. 1986).

Interspecific Interactions. Black-tailed prairie dogs are key species within the prairie ecosystem. A variety of sensitive species (e.g., black-footed ferret, burrowing owls, and ferruginous hawks) are affected by prairie dog colony expansion, decline, and movement (Bowser 1993). Prairie dogs create unique habitat by grazing and burrowing (Bowser 1996), which contributes to high bird diversity and rodent abundance inside prairie dog towns (Agnew et al. 1986). Another interspecific interaction is between bison and prairie dogs. Prairie dog colonies provide valuable forage resources for bison and other ungulates; bison forage on the nutritious plants on town edges, which inhibits tall grass growth (Cincotta et al. 1989). This in turn keeps visibility of predators high for the prairie dogs. These interactions are not expected to be seriously impacted by climate change.

Sensitive Habitat. Prairie dogs inhabit the grassland communities in and around BADL. They prefer dry, flat, or gently sloping grasslands with relatively sparse vegetation (as reviewed by NatureServe 2011). These grassland communities were rated as less vulnerable to climate change (see section 4.1.3). The grassland plant community in BADL may experience a shift in species composition with climate change, but prairie dogs are known to change to an alternate diet when necessary. A study by Krueger (1986) suggested that prairie dog towns may be resilient to climate induced plant composition shifts.

Photo 26. Black-tailed prairie dog at BADL (photo by Shannon Amberg, SMUMN GSS 2010).

Non-Climate Stressors. The black-tailed prairie dog population in BADL is carefully managed (e.g., translocations, closures to grazing to shrink towns, vegetation barriers to control expansion); this gives the population more stability due to insecticide treatments (i.e., "dusting") to reduce flea numbers, which likely reduces plague outbreaks (Olson 2009, Rocke et al. 2010). Sylvatic plague (*Y. pestis*) can become epizootic in an infected colony, resulting in 100% mortality of the colony. Projected climate changes in BADL may further alter the dynamics of this disease in the region (Snall et al. 2009). A study by Snall et al. (2009) identified a positive relationship between precipitation and plague transmission. Since BADL climate is projected to become drier with an increasing number of hot days, plague levels in prairie dogs are expected to decrease (Snall et al. 2009). A decrease in plague could mean an increase in both the number of colonies and colony size. Climate change may therefore have a positive effect on the black-tailed prairie dogs in this respect.

Reproductive Potential for Adaptation. Black-tailed prairie dogs maintain a harem-polygynous family breeding system, with most females breeding with only one male and males breeding with numerous females (Hoogland 1996). Females reach sexual maturity at two years of age, which is characterized as a moderate rate of maturity. Females are in estrous for several hours of only one day per year, and they only produce one litter per year (Hoogland 1996). Gestation lasts approximately 35 days (Hoogland 1996). Litter size typically averages three to five pups, which is characterized as moderate fecundity, and is positively correlated with precipitation during the previous summer (Hoogland 1996). In general, survival rates of first-year prairie dogs average 54% for females and 47% for males; females that survive the first year may live as long as eight years, while males seldom live longer than five years (Hoogland 1996). In BADL, reproduction rates of the females occupying the old town center were reported to be lowest in the colony (two offspring/female), with the highest rates occurring in the middle zones of the town (five offspring/female) (Cincotta et al. 1986). Overall, prairie dogs have a moderate reproductive potential for population recovery and adaptation following a population disturbance or rapid environmental changes. However, prairie dogs may be slightly more vulnerable to environmental changes associated with climate change given their significantly narrow estrous window for mating and a potentially low rate of survival in the first year of life.

Ecological Processes. Fire may be an important ecological process for prairie dog towns, though the relationship is not well understood. In general, fire in mixed- and shortgrass prairie systems discourages tree and shrub growth (Bachelet et al. 2000) that would otherwise crowd out preferred forage or significantly decrease visibility, leaving prairie dogs vulnerable to predation.

Summary of Vulnerability. Prairie dogs seem least vulnerable to climate change, primarily because the vulnerability of their habitat (grasslands) is low (Table 30). Prairie dogs have little to no physiological vulnerability to climate change and, as a burrowing species, can often escape weather extremes by going underground. Lastly, the threat of plague, according to models developed by Snall et al. (2009), is predicted to decrease if the climate becomes warmer and drier. Although their reproductive potential for adaptation is moderate (maturing early, breeding yearly, and producing multiple offspring), females have a brief period of fertility and pup survival is relatively low. These factors would make it more challenging to adapt to rapid environmental changes. However, as long as the prairie dog population in BADL is managed, the species should not be seriously impacted by climate change.

Table 30. A summary of the vulnerability characteristics of prairie dogs.

Characteristics	Displays Characteristic*	Notes
Physiological sensitivity	--	
Specialist	○	Prefer short to mixed-grass prairie
Interspecific interactions	--	
Sensitive habitat	--	
Non-climate stressors	--	
Reproductive potential to adapt	○	Reproductive success in BADL is low

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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4.3.2 Black-Footed Ferret

Description

The black-footed ferret (*Mustela nigripes*) is a small carnivore native to North America. The historic range of the black-footed ferret included the expansive prairies of the Great Plains (Wisely 2002). They depend on prairie dogs as a primary component of their diet and use prairie dog burrows for protection and rearing young (Wilkinson 1994). They once occupied colonies throughout the Great Plains, reaching from northern Mexico to southern Canada (USFWS and CDW 2011). However, the black-footed ferret experienced a dramatic population decline in the early 1900s due to prairie dog control programs, and nearly became extinct in the 1980s due to disease (Wisely 2002). The species has been federally listed as endangered since 1967 (McDonald and Plumb 1996), and populations are currently recovering.

After a 1985 outbreak of plague nearly drove the species to extinction, the entire black-footed ferret population was captured and a captive breeding program was initiated (Miller et al. 1988, as cited by Reading et al. 1996). "The first release of captive-bred black-footed ferrets into the wild occurred in 1991 in Shirley Basin, Wyoming" (Bevers et al. 1997, p. 495). Ferret reintroductions have occurred in the northern Great Plains over the past 20 years including efforts in Montana, Wyoming, and South Dakota; however, these reintroduction efforts require careful planning and so far have been difficult to carry out because ferrets require extensive prairie dog colonies to provide habitat and prey (Wisely 2002, Matchett et al. 2010). From 1994 to 2005, more than 500 captive-reared animals were released in north-central Montana, but still no successful ferret populations were established (Matchett et al. 2010). BADL was a preferred reintroduction site because it had one of the largest remaining black-tailed prairie dog populations (Bowser et al. 1993). Since fall of 1994, over 200 black-footed ferrets have been released into BADL, with the first litters sighted in late summer of 1995 (Greg Schroeder, WICA Chief of Resources, pers. comm., 26 September 2011). As of 2007, there were more than 50 ferrets residing within BADL (Uhler 2007) and at least 170 on adjacent Forest Service lands (Griebel 2009).

Photo 27. Black-footed ferret (NPS photo, from NPS 2007).

The black-footed ferret has narrow habitat requirements, living principally in prairie dog burrows and relying primarily on prairie dogs as prey (Bevers et al. 1997). Ferrets have many uses for prairie dog burrows (e.g., shelter, rearing young, escape predation, and prey abundance) (Plumb et al. 1995). While the majority of their diet consists of prairie dogs (91% in one study), they are also known to consume ground squirrels, cottontail rabbits, and deer mice if necessary (Hillman 1968, as cited by Hillman and Clark 1980).

Existing Threats and Stressors

The black-footed ferret is highly sensitive to a number of threats and stressors in the BADL region including disease, predation and indirect poisoning through consumption of poisoned prairie dogs. It is not well understood how these threats and stressors interact to influence ferret survival and abundance.

Sylvatic plague is a flea-borne bacterial disease that was introduced into North America in the late 1890s (Cully 1989, as cited by NatureServe 2011), and is believed to be one of the most significant factors in the decline of black-footed ferrets (Forrest et al. 2004). Ferrets are highly susceptible to sylvatic plague; they could be exposed by fleabite or could consume infected prey (as reviewed by NatureServe 2011). Even as little as one fleabite dose of this disease can be fatal to ferrets (Garell and Marinari 2000). The prairie dog is considered an “amplifying host” for plague, meaning they could have high enough levels of the pathogen to infect species that feed on them (Rocke et al. 2010, p. 53). The elimination of prairie dog colonies due to plague is devastating to ferrets primarily through reduced prey abundance (Matchett et al. 2010). The disease was first identified in the Conata Basin in 2008 and in BADL in 2009 (Griebel 2009, Olson 2009). By the end of 2009, plague had eliminated over 15,000 acres of prairie dog colonies in the Conata Basin and 700 acres in BADL (Griebel 2009), decreasing the amount of black-footed ferret habitat by nearly 50% (Griebel 2010). The U.S. Forest Service estimated that 1/3 of the Conata Basin ferret population (~95 individuals) was lost during this plague outbreak (Griebel 2009). No known sylvatic-plague ferret fatalities have been confirmed within BADL park boundaries; however, it is likely that several ferrets translocated to the Kocher Flats prairie dog town were lost when the town was infected by plague in 2008-2009 (USFS, Randy Griebel, Wildlife Biologist, written communication, 7 October 2011). A program to vaccinate black-footed ferrets in the area against plague is underway and, to date, has captured and treated 77 individual ferrets (Griebel 2010).

Canine distemper is another concern for the black-footed ferret population. Canine distemper virus (CDV) is an enveloped RNA virus that infects various organs and tissues including the central nervous system and lymphoid tissue; carnivores are the predominant host for this virus (Beineke et al. 2009). The black-footed ferret does not seem to have any natural immunity to CDV (Forrest et al. 2004), and the disease has played a role in the near extinction of the species in the past (Reading et al. 1996).

Additionally, intensive efforts to eliminate local prairie dog populations through chemical or physical means have led to significant reduction and fragmentation of potential black-footed ferret habitat (McDonald and Plumb 1996). Over 100 million hectares of prairie dog towns historically distributed across the Great Plains were reduced to less than two percent of their original area after eradication efforts in the early twentieth century (as reviewed by NatureServe 2011). Chemical eradication efforts not only affected habitat but also caused secondary poisoning of ferrets that preyed on poisoned prairie dogs (McDonald and Plumb 1996).

Natural predation of black-footed ferrets is also a concern for population recovery. The main obstacle for the black-footed ferret recovery in Shirley Basin, Wyoming is predation by coyotes and badgers (Godbey and Biggins 1994, as cited by NatureServe 2011). A study by Bowser et al. (1993) at potential ferret reintroduction sites in the BADL area found that the primary mammalian predator at all sites was coyote (observed in 90% of visual surveys). Other predators at these sites included foxes, badgers, and various birds of prey (e.g., great-horned and short-eared owls; ferruginous, red-tailed, and Swainson's hawks; and golden eagles) (Bowser et al. 1993).

Low genetic diversity is a major concern for black-footed ferret populations. When the black-footed ferret population dropped to 18 known individuals in 1985, the entire population was captured to initiate a captive breeding program (Reading et al. 1996). While the captive breeding program has been fairly successful, problems associated with inbreeding may develop. The current breeding pool is based on just seven genetic founders (Reading et al. 1996). The genetic and fitness consequences of such population bottlenecks in endangered taxa are unclear and understudied (Wisely 2002). No negative effects on the ferret population's fitness or reproduction have been observed, but concerns remain about inbreeding leading to problems with physical abnormalties, survivorship, and fecundity (Reading et al. 1996).

Climate Change Vulnerability

Physiological Sensitivity. The black-footed ferret population in BADL resides near the northern part of its historic range (Figure 19). No research could be found indicating that black-footed ferrets are physiologically sensitive to changes in temperature or moisture. Ferrets can escape temperature extremes by seeking shelter in their burrows.

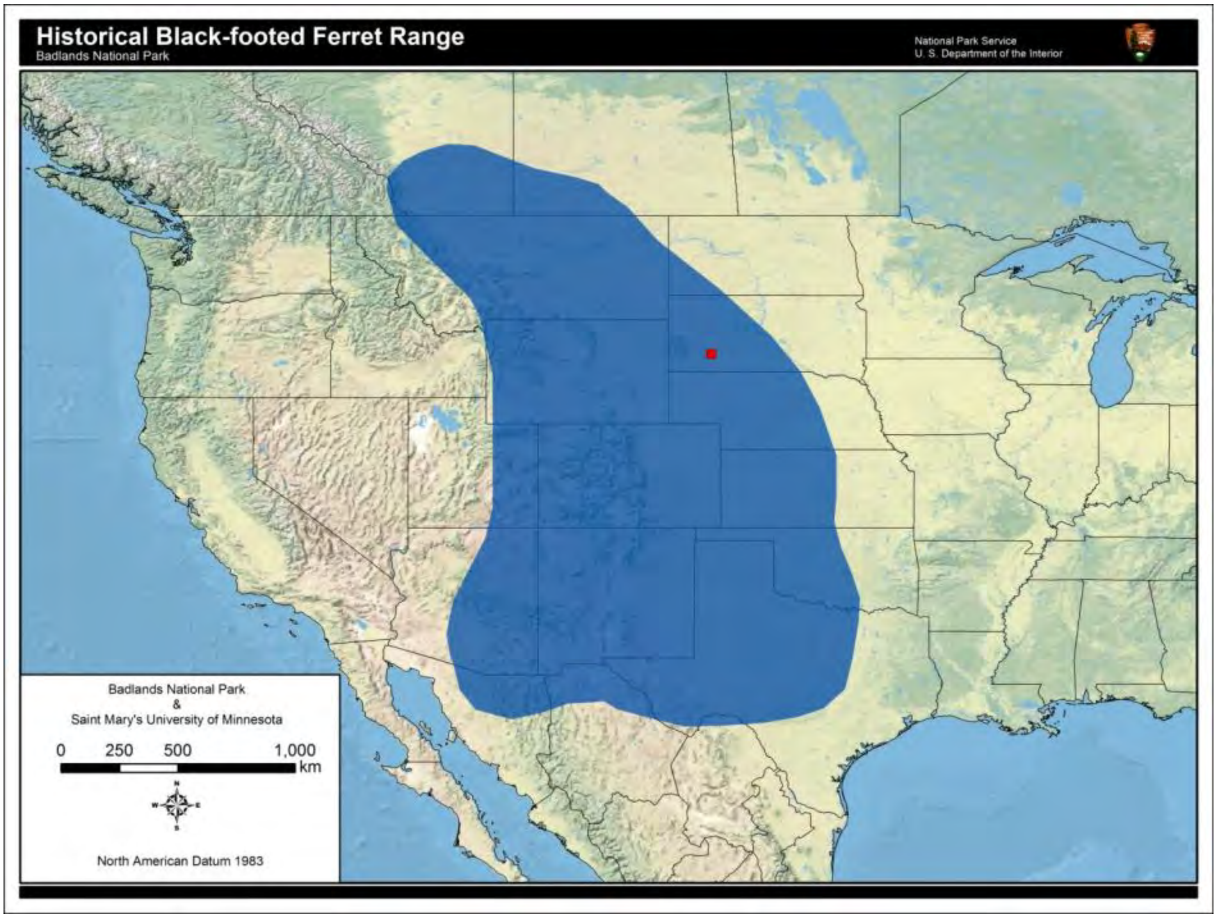

Figure 19. Historical black-footed ferret distribution (Patterson et al. 2007) (BADL shown in red).

Generalist or Specialist. The black-footed ferret is a habitat and prey specialist. They have an "obligate relationship" with prairie dogs in grassland communities, in that ferrets rely on prairie dog colonies for food, habitat, and protection from predators (Wilkinson 1994, p. 38). The prairie dog population in BADL is not expected to be particularly vulnerable to projected climate shifts in the BADL region. Thus, if prairie dog populations remain stable, the ferret population will likely remain stable as well.

Interspecific Interactions. Black-footed ferrets rely heavily on prairie dogs to survive, as ferrets depend almost exclusively on prairie dog colonies for habitat and food. Thus, the predator/prey relationship between the two species is crucial for ferret survival (Bowser et al. 1993). If the prairie dog colonies fail in a specific region, the associated black-footed ferret population would also fail. Management of prairie dog numbers in BADL is vital in order for the ferret population to persist and grow. Prairie dogs are less vulnerable to climate change, and as long as BADL continues to manage the population, they should not be seriously impacted (see section 4.3.1).

Sensitive Habitat. The black-footed ferrets in BADL depend exclusively on prairie dog colonies in the short and mixed-grassland communities for burrows and prey. The grasslands community in BADL is not expected to be particularly sensitive to the projected climatic shifts for the region (see section 4.1.3). If prairie dog colonies become smaller or the distance between colonies increases (perhaps due to plague outbreaks or persistence of disease), the probability of successful ferret dispersal among colonies would decrease and the total ferret population that the area can support will be reduced (Bevers et al. 1997).

Non-Climate Stressors. Climate change will inevitably affect environmental conditions for plague-infected flea populations, which would directly influence ferret survival. However, given the projected warmer, drier conditions for BADL, extreme sensitivity to plague may become less of a concern with climate change. A study by Snall et al. (2009) found a correlative relationship between precipitation and plague transmission; as precipitation decreases and conditions become drier, plague transmission was found to decrease as well. Snall et al. (2009) found, through climate model projections, that the projected drier and warmer conditions for BADL were expected to contribute to a decrease in plague levels in prairie dog populations. As a result, this could lead to decreased incidences of plague in black-footed ferrets.

Photo 28. Black-footed ferret and kit (Photo by Mehgan Murphy, Smithsonian's National Zoo 2010).

Reproductive Potential for Adaptation. Female black-footed ferrets are sexually mature by one year of age (as reviewed by NatureServe 2011), which is characterized as rapid reproductive maturity. Gestation period lasts approximately 42-45 days (Hillman and Clark 1980). Females produce one litter per year, with each litter having one to seven offspring (averaging 3.5) (Linder et al. 1972, as cited by Hillman and Clark 1980), which is characterized as moderate fecundity. Kits are completely blind for the first month of life (BFFRP 2011). Overall, black-footed ferrets have a moderate reproductive potential to adapt to climatic shifts; however, the reduced genetic diversity of the ferret population could hinder successful recruitment and population stability.

Ecological Processes. Currently there is no scientific evidence that highlights the direct effects of various ecological processes on black-footed ferrets. Fire is generally considered to benefit grasslands by stimulating plant growth and reducing encroachment of woody shrubs (Bachelet et al. 2000); thus, fire would likely benefit ferrets by maintaining suitable ferret and prairie dog habitat. Future studies on the impacts of ecological processes on black-footed ferrets and their habitat may prove useful.

Summary of Vulnerability. The black-footed ferret is a critically endangered species that may be moderately vulnerable to climate change due to several factors (Table 31). As a specialist species, the black-footed ferret likely has little tolerance for changes in habitat due to climate change. The ferret's close relationship with prairie dogs also makes the species more vulnerable if climate change were to threaten the health of the prairie dog colonies. In BADL, prairie dog colonies are carefully managed and relatively stable with regard to population growth and disease prevention, which provides some stability for the ferret population in the park. Disease remains a concern, but controlling flea numbers and managing prairie dog colonies decreases the risk of outbreak in the park. Reproduction in the wild can be relatively slow; however, reintroduction programs can supplement ferret populations. The recovery of this species is still dependent on captive breeding and continued reintroduction efforts (as reviewed by NatureServe 2011).

Table 31. A summary of the vulnerability characteristics of the black-footed ferret.

Characteristics	**Displays Characteristic***	**Notes**
Physiological sensitivity	--	
Specialist	●	Prairie dog towns used for prey and habitat
Interspecific interactions	●	Obligate relationship with prairie dogs
Sensitive habitat	--	
Non-climate stressors	--	
Reproductive potential to adapt	○	One annual litter, kits completely helpless for one to two months after birth

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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4.3.3 Swift Fox

Description

The swift fox (*Vulpes velox*) is a small omnivore whose native range historically extended throughout the North American Great Plains from northern Texas to southern Canada (Egoscue 1979, WWF 2010). During the 19th and the early 20th centuries, at the height of settlement of the Great Plains, swift fox populations experienced a widespread decline in distribution and abundance, primarily due to conversion of prairie to agricultural land, overgrazing by livestock, predator and rodent control programs (poisoning campaigns), and trapping and hunting (Hillman and Sharps 1978, Egoscue 1979). The American Fur Company collected 10,614 swift fox pelts between 1835 and 1838 alone (Sharps 1984). By 1900 the species was uncommon in the northern part of its range, with zero sightings of swift foxes in South Dakota between 1914 and 1966 (Hillman and Sharps 1978). Since the early 1900s, the species has occupied roughly 40% of its historic range (Kahn et al. 1997, as cited by WWF 2010).

Populations are currently recovering in the Northern Great Plains due to efforts to protect the species and its habitat. An attempt to reintroduce swift foxes to BADL and the adjacent grasslands began in the fall of 2003 (Russell 2006). Swift fox numbers within BADL are currently low, as the species seems to prefer the habitat immediately adjacent to the park boundary in the Conata Basin (BADL, Eddie Childers, Wildlife Biologist, e-mail communication, 15 August 2011).

Photo 29. Swift fox family (photo by Diane Hargreaves, hargreavesphoto.com).

Habitats of the swift fox in the Great Plains have been described as relatively flat or gently rolling short and mixed-grass prairies, dominated by such plant species as buffalograss, sunsedge, blue grama, western wheatgrass, scarlet globemallow, and rush skeletonplant (*Lygodesmia juncea*) (Hillman and Sharps 1978, Uresk and Sharps 1986). The optimal habitat for the swift fox populations in the northern Great Plains consists of these prairie communities, but interspersed with prairie dog towns (Russell 2006); prairie dog towns offer a prey base and foxes have been observed modifying and using the burrows as den sites (Kilgore 1969, as cited by Egoscue 1979). The short and mixed-grass prairie plant communities also offer the best visibility and, thus, protection against predation (Ausband and Moehrenschlager 2009). Agriculture, grazing pastures, and roads fragment the prairie habitats in the northern Great Plains, and swift foxes avoid crossing land cultivated for agriculture due to the threat of predation (Ausband and Moehrenschlager 2009), primarily by coyotes (Russell 2006). A study by Sharps (1984) found most swift fox dens were located on hillsides to ensure proper drainage, while Uresk et al. (2003) found that swift foxes often locate dens where vegetation is higher and more dense, presumably to offer screening cover for burrow entrances and resting or basking activities. Swift foxes are highly dependent on dens as a daytime retreat on the open prairies and as a way to avoid predation by coyotes (Egoscue 1979).

Like other North American canids, swift foxes are opportunistic foragers, known to eat a variety of small mammals, including black-tailed prairie dog and rabbits, ground-nesting and foraging birds, small rodents (such as voles and shrews), plants (grasses and cactus fruits), and insects (beetles and grasshoppers) (Sharps 1984, Uresk and Sharps 1986, Sovada et al. 2001). Carrion originating from cattle remains also has been found in swift fox scat (Sharps 1984). Bird species occasionally found in their diet include western meadowlark (*Sturnella neglecta*) and mourning dove (*Zenaida macroura*) (Hillman and Sharps 1978).

Existing Threats and Stressors

Swift foxes in BADL face a number of existing threats and stressors including disease, predation, and loss of habitat due to development. Additionally, threats to the swift fox differ depending on location (whether or not the fox remains inside the park or travels to adjacent lands). Little is known about how these threats and stressors currently interact to influence fox survival, abundance, fitness, and reproduction.

Swift foxes in BADL are susceptible to certain diseases and parasites. Canine distemper virus (CDV) is an enveloped RNA virus that infects various organs and tissues including the central nervous system and lymphoid tissue, with the most natural host range comprised predominantly of carnivores (Beineke et al. 2009). Exposure to CDV has been reported in some populations of swift foxes in Colorado, where serologic surveys show serum antibodies to be prevalent in 18% of adult swift foxes, suggesting exposure to the virus at some point (Miller et al. 2000). Rates of infection are higher in juveniles due to lower prevalence of antibodies than in adult foxes (Miller et al. 2000). The relatively low prevalence of CDV in swift foxes captured in Colorado may be due to the short survival time of the virus in the environment, and the need for close contact for disease transmission (Miller et al. 2000). Since the swift fox population in BADL is still recovering, CDV and other pathogens could threaten population recovery efforts (Miller et al. 2000).

Ectoparasites are another threat to the recovering swift fox population. In a study done in Texas by Pence et al. (2004), the human flea (*Pulex irritans*) was the most abundant ectoparasite discovered on the foxes examined. The human flea is commonly found on various coarse fur-coated mammals, as well as humans (Pence et al. 2004). Pence et al. (2004) found ectoparasites on all 23 and 34 swift foxes examined in 1999-2000 and 2000-01, respectively. A concern for swift fox management related to ectoparasites is den location. Swift foxes often establish their dens near black-tailed prairie dog colonies. The majority of the swift fox diet consists of black-tailed prairie dogs in the spring and summer months. Fleas tend to be common parasites of prairie dogs as well; this is a concern because these fleas could be a potential vector of sylvatic plague (Pence et al. 2004). If swift fox were to encounter infected prairie dogs, they may become a carrier and spread the virus to other colonies. This could lead to higher prairie dog mortality and reduced prey availability for the swift fox.

In general, coyotes appear to be a significant cause of juvenile and adult fox mortality and are a primary threat to swift fox numbers (Kitchen et al. 1999). In a study by Kitchen et al. (1999) at the Pinon Canyon Maneuver Site in Colorado, coyotes were found to be the cause of more than 65% of fox deaths; it is believed these fox mortalities generally constitute interference competition rather than predation (Kitchen et al. 1999). Evidence of this competition was also found by Kamler et al. (2004) at Rita Blanca National Grasslands and on properties enrolled in the Conservation Reserve Program (CRP) in northwestern Texas, where 14 foxes were killed, but not eaten, by coyotes. Russell (2006) found that swift foxes in the BADL area were choosing locations with greater visibility to avoid coyote predation, which was the leading cause of adult swift fox mortality near BADL. During a fall 2005 survey, live fox locations were observed to have greater visibility than locations where foxes had been killed by coyotes (Russell 2006). A study during the 2009 pup-rearing season in BADL revealed that female swift foxes favored shortgrass habitats, most likely to allow for easy detection of canid predators, such as coyotes (Sasmal et al. 2011).

When swift foxes travel outside park boundaries they face a variety of different threats that can negatively impact them. The historic swift fox decline has been attributed to conversion of native prairie to agriculture and a related decline in prey species, rodent control programs, and predator control programs targeting larger carnivores (Russell 2006). The pesticide “Compound 1080” was developed for large carnivore and rodent control, but its use may result in the poisoning of swift fox when applied near fox dens (Uresk and Sharps 1986).

Climate Change Vulnerability

Physiological Sensitivity. The BADL swift fox population is currently in the northern part of the species’ range (Figure 20). Although the temperature and moisture changes projected for the BADL region do not have direct impacts on the physiology of the swift fox, the species may still be sensitive to climatic shifts.

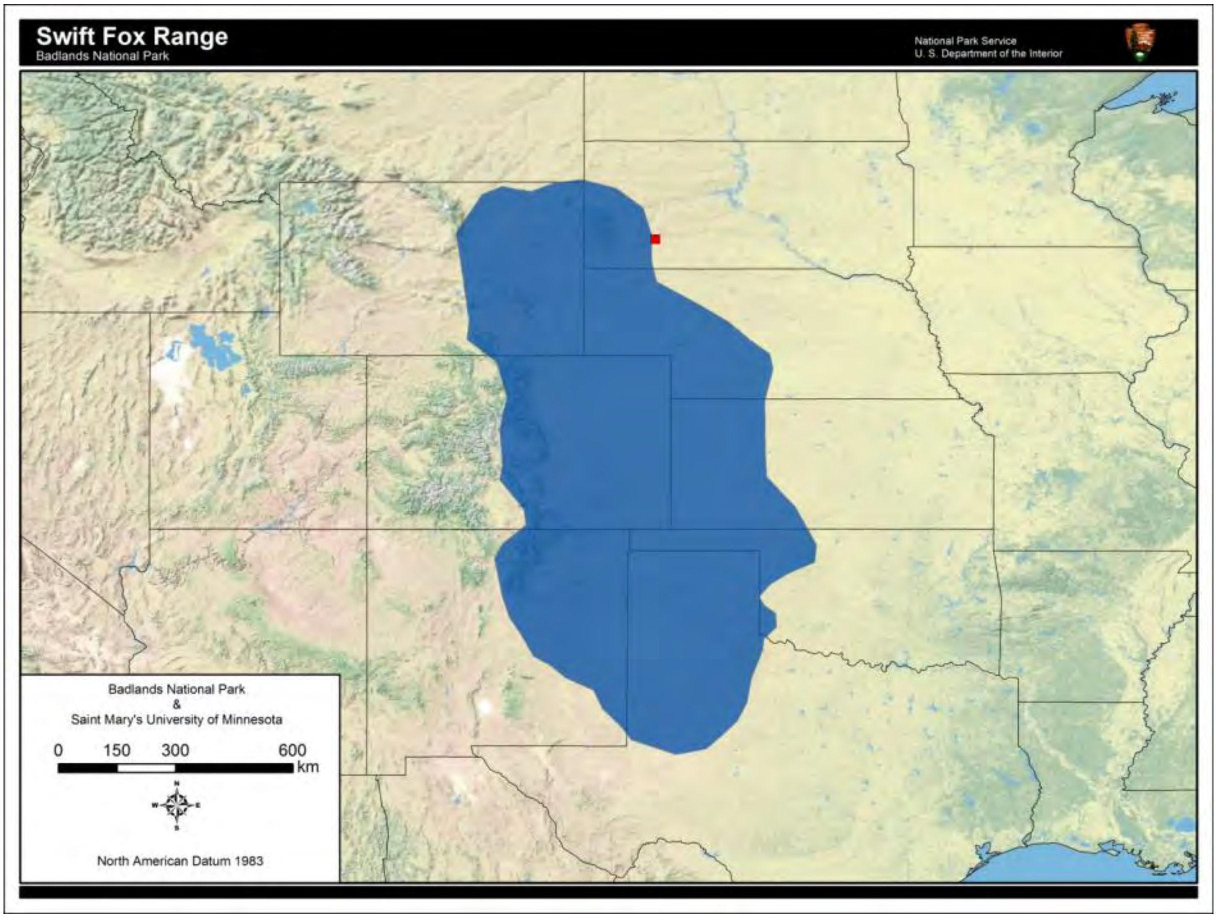

Figure 20. Current swift fox distribution (Patterson et al. 2007) (BADL shown in red). Map does not include experimental or reintroduced populations

Generalist vs. Specialist. The swift fox is typically a generalist predator, feeding opportunistically on a variety of prey items from small mammals to insects; however, they may also specialize in a prey item locally if it is abundant and alternative prey are scarce (Nicholson et al. 2006). Hillman and Sharps (1978) and Uresk and Sharps (1986) found that prairie dogs were an important majority of the swift fox diet in South Dakota, especially in the spring and summer months. In addition to a food source, prairie dog colonies also provide habitat and protection. The swift fox is a specialist species regarding habitat preference and requirements in that it almost exclusively uses short and mixed-grass prairie interspersed with prairie dog colonies for denning and forage habitat in the Northern Great Plains (Egoscue 1979, Sasmal et al. 2011). A study of swift fox habitat selection in BADL during the 2009 pup-rearing season found that female swift foxes were more likely to use shortgrass prairie and grasslands, sparse vegetation, and prairie dog town habitats than other types of habitat in or adjacent to the park such as woodlands, shrublands, or agricultural/pasture lands (Sasmal et al. 2011). In the absence of prairie dog (due to plague or predation) and ungulate grazing in the park, as well as cattle grazing in surrounding areas, shortgrass prairie in the BADL region could return to taller grasses with increased shrub cover, potentially causing the predation rate on swift fox to increase.

Interspecific Interactions. Climate change may affect the inter-specific interaction between the swift fox and the prairie dog, depending on the shift in hot days and precipitation amounts. The rates of infection by ectoparasites will increase if climate change causes increased annual precipitation and fewer hot days, which will cause prairie dog colonies to shrink and the distance between colonies to increase (Snall et al. 2009). This will put stress on the swift fox during the summer months since the prairie dog is an important prey species. However, climate models generated by Snall et al. (2009) predict increased hot days and less precipitation for BADL, which will negatively affect fleas. This will likely have a positive effect on prairie dog colony size and could lead to higher prey abundance for the swift fox. In addition, an inverse relationship has been observed in the park between swift fox and coyote population numbers. However, it is unclear how climate change will affect this relationship (B. Kenner, pers. comm. 15 November 2011).

Sensitive Habitat. The swift fox is primarily reliant on grassland plant communities. It excavates its dens in short and mixed-grass prairies or utilizes old prairie dog burrows. The grasslands are less vulnerable to climate change (see section 4.1.3), and will likely experience a plant species shift rather than a range contraction. Invasive plant species may also expand, but this may not impact fox numbers unless the shift alters the predator-prey relationships between the fox and prairie dog (Hillman and Sharps 1978).

Reproductive Potential for Adaptation. Swift foxes tend to form monogamous pairs which remain together for most of the year (EWC 2011). They reach sexual maturity at ten months of age, which is characterized as rapid maturity. Females give birth, in the safety of their dens, after seven to eight weeks of gestation (EWC 2011). Females bear one litter annually (average 4-5 pups/litter) in April or May (USFWS 2010), which is characterized as moderate fecundity. Adult females appear to be the limiting factor to successful rearing of litters; adult males generally were needed only for breeding and possibly protection of pups. However, in BADL, male swift foxes have been observed hunting for the family group (Joshua Delger, Biological Science Technician, BADL, written communication, 28 September 2011). Overall, the swift fox has a moderate to rapid reproductive potential for adaptation which increases the species' ability to effectively adapt to climate shifts and associated environmental changes.

Photo 30. Swift fox pups (photo by Diane Hargreaves, hargreavesphoto.com).

Non-Climate Stressors. Climate change could reduce the impact of current stressors on the swift fox population. According to a study done by Snall et al. (2009), the chance of sylvatic plague outbreaks will decrease if the number of hot days increases and precipitation decreases. The hotter, drier climate projected for the BADL area could negatively influence the fleas and bacteria that cause the disease.

Ecological Processes. The alteration of disturbance regimes due to climate change may have a minimal effect or even benefit the swift fox. They are a denning species, so there is a possibility that flooding could negatively affect the population. They could benefit from drought because drier conditions have a negative effect on tallgrasses and encourage growth of shortgrasses, which could increase the visibility of predators (Russell 2006). Fire may improve habitat in the grassland plant community for the swift fox by limiting growth of taller plant species such as shrubs; however, altered fire frequencies and intensities due to changes in plant composition (particularly an increase of exotic plant species) could influence the presence or abundance of fox prey items.

Summary of Vulnerability. The swift fox population in BADL exhibits slight vulnerability to climate change due to their specialist tendencies in selecting grassland habitats and inter-specific interactions with prairie dogs for at least part of the year (Table 32). However, the swift fox has little to no physiological sensitivity to climate changes and they do not rely on sensitive habitat. They have a moderate to rapid reproductive potential to adapt to environmental changes. If coyote populations are managed, vegetation changes associated with climate change could reduce the swift foxes' non-climate stressor of predation. Thus, based on existing literature and data, climate change is unlikely to cause major stress to the swift fox population in BADL.

Table 32. A summary of the vulnerability characteristics of the swift fox.

Characteristics	Displays Characteristic*	Notes
Physiological sensitivity	--	
Specialist	●	Uses grassland habitat almost exclusively
Inter-specific interactions	○	Relies on prairie dogs for part of year
Sensitive habitat	--	
Non-climate stressors	--	
Reproductive potential to adapt	--	

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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4.3.4 Bighorn Sheep

Description

Bighorn sheep are an “ecologically fragile” species (Childers and Zimmerman 2005, p. 1). Bighorn sheep numbers declined dramatically during the late 1800s and early 1900s, and the Audubon’s bighorn sheep subspecies (*Ovis canadensis auduboni*) native to South Dakota was driven to extinction (Moses et al. 1998, Childers 2002). Factors contributing to the decline included overgrazing and diseases introduced by livestock, urban expansion, competition with mule deer and elk, and fire suppression (Childers and Zimmerman 2005). Many bighorn populations still have not recovered to historical levels (Moses et al. 1998). In January of 1964, with the help of the South Dakota Game, Fish and Parks Department, Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) were reintroduced to BADL (Mattison and Grom 1968). The population in the park expanded and peaked at more than 140 individuals in three distinct populations, but a series of diseases reduced the population to fewer than 60 individuals by 2000 (Childers 2002, Childers and Zimmerman 2005). As of 2011, the park-wide population estimate is approximately 100 animals (E. Childers, written communication, 15 November 2011).

Bighorn sheep occur in mesic to xeric habitats, which include alpine and desert grasslands as well as shrub-steppe in mountains, foothills, and river canyons (Shackleton et al. 1999, Krausman et al. 1999). Suitable escape terrain (cliffs, side slopes, talus slopes, etc.) is an important feature in bighorn sheep habitat. The wintering areas of northern bighorn populations are relatively snow-free due to light snowfall, steep south aspect, and/or high winds; sheep generally avoid snow deeper than 30 centimeters (Stelfox 1975).

Photo 31. Bighorn ram and ewe at BADL (NPS photo from NPS 2010).

Bighorn sheep have a diverse and seasonally variable diet. They are primarily grazers of grasses and forbs, but they may also browse on shrubs. Mineral licks may be important for bighorns, particularly in spring (Shackleton et al. 1999). Northern sheep populations are not typically dependent on standing water, but get it instead from vegetation in the summer and snow or ice in the winter (Van Dyke 1978).

<u>Existing Threats and Stressors</u>

There are a number of threats and stressors to bighorn sheep, particularly diseases, parasites and human activities. Lungworm infection is one disease that affects Rocky Mountain bighorn sheep.

Prostrognylus stilesi and *P. rushi* are two lungworm species often prevalent in bighorn sheep populations (Rogerson et al. 2008). The adults, larvae, and eggs of lungworms can accumulate in the sheep's lungs and cause serious pulmonary problems (Foreyt et al. 2009). Heavy lungworm infestations can result in low recruitment and high lamb mortality due to pneumonia (Benzon and Halseth 1999).

Stress from lungworm infection reduces sheep resistance to other diseases such as *Pasteurella*, a bacterium known to cause a fatal respiratory disease in bighorn sheep (Moses et al. 1998). Bighorn sheep are highly susceptible to pneumonic pasteurellosis, which they can contract from domestic sheep (Gross et al. 2000); several domestic sheep herds are kept near BADL (SDGFP, John Kanta, Regional Wildlife Manager, written communication, 18 October 2011). *Pasteurella* can cause bronchopneumonia, which has had "a far more profound impact on bighorn sheep populations than any other disease" (Gross et al. 2000, p. 28). Many herd die-offs have been reported as a result of infection over the last century (Risenhoover et al. 1988, Gross et al. 2000). Historically, more extensive seasonal movements and wider dispersal likely reduced disease and parasite loads in bighorn populations (Risenhoover et al. 1988, as cited by Moses et al. 1998). The current sedentary nature of many bighorn populations increases their susceptibility to disease transmission, particularly lungworms (Risenhoover et al. 1988). More recently, Moses et al. (1998) found a higher relative parasite infection rate in the BADL North Unit herd than in the South Unit, which may be explained by higher bighorn density in the North Unit.

Bighorn sheep are also vulnerable to epizootic hemorrhagic disease (EHD). EHD is a fatal viral disease transmitted by biting flies in the genus *Culicoides*, commonly known as biting midges (SCWDS 2000). Hemorrhagic disease is seasonal and occurs in late summer and early fall. The virus, however, cannot survive outside the host animal or vector (SCWDS 2000). In BADL, outbreaks of EHD were documented in the 1990s and 2000, and were found to be uncontrollable even when sheep were immunized (Childers 2002).

Bighorn sheep are also affected by human activities. Visitors to BADL commonly encounter bighorn sheep while hiking or traveling throughout the park (Childers 2002). Human disturbance through recreation has been implicated in the decline of several bighorn sheep populations in North America, with hikers causing the greatest behavioral response (measured in total distance fled when encountering a hiker) (Papouchis et al. 2000, as cited by Childers 2002). Other observed effects of human recreation include causing sheep to vacate suitable habitat enough to reduce the population's carrying capacity or rate of growth; frequent vehicle activity that may cause sheep to reduce or abandon their use of water sources; and energetic losses that may affect physiology, amount of fat reserves, and reproductive success (Childers 2002).

Another concern for the BADL bighorn sheep population is lack of genetic diversity due to a population bottleneck. Based on the estimated population size and analysis of genetic data, biologists determined that the bighorn sheep at BADL experienced a population bottleneck at founding (Ramey et al. 2000, Childers and Zimmerman 2005). The initial reintroduction to the park consisted of just 14 sheep (Ramey 2000). A study of 31 translocated bighorn populations showed that population size was significantly associated with founding population size and diversity of founder population sources (Singer et al. 2000, as cited by Ramey 2000). In order to increase genetic diversity, 23 bighorn sheep from a New Mexico population were brought to the park in 2004 (Childers and Zimmerman 2005).

Climate Change Vulnerability

Physiological Sensitivity. The BADL bighorn sheep population is currently at the central and eastern part of the species' overall range (Figure 21; Patterson et al. 2007). The historic range of the bighorn sheep has contracted and still remains unstable due to the sensitivities of bighorn to many types of environmental change. Bighorn sheep appear to be quite physiologically sensitive to temperature and precipitation changes. In a study by Epps et al. (2004) in southern California, desert bighorn sheep (*Ovis canadensis nelsoni*) at lower mountain elevations, where temperatures are typically warmer, were much more likely to be extirpated (locally extinct); this was particularly true of populations at elevations less than 1500 meters. Populations in regions with the lowest annual precipitation, especially less than 200 mm annually, were also more likely to become extinct (Epps et al. 2004). The authors suggest that desert bighorn sheep are not only vulnerable to climate change, but that warming has already affected their distribution in California (Epps et al. 2004). Rocky Mountain bighorn sheep in BADL may experience similar effects as the climate becomes warmer and drier. The link between extirpation and precipitation likely results from both the dynamics of water availability and also forage quality (Epps et al. 2004). In arid regions, the slightest decrease in forage moisture content, through increased temperature and evapotranspiration or through decreased precipitation, could have "drastic effects" on diet quality (Epps et al. 2004). Climate change may cause a plant species composition shift in BADL grassland communities and may decrease forage quality and quantity for bighorn sheep (Craine et al. 2010). This could, in turn, increase their vulnerability to infections and disease (Moses et al. 1998).

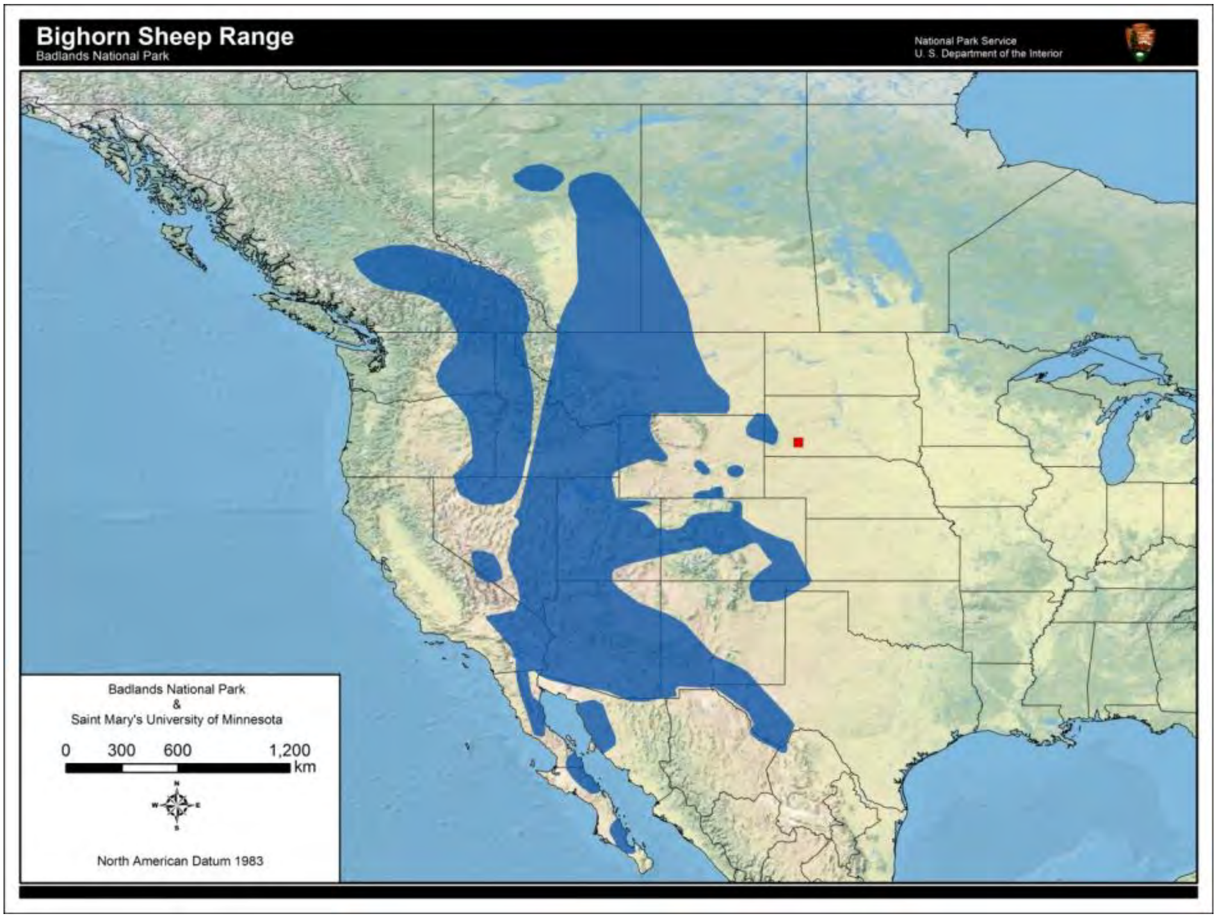

Figure 21. Current bighorn sheep distribution (Patterson et al. 2007) (Location of BADL is shown as red square). The BADL population is considered a small, disjunct species occurrence and is not shown on this map.

Generalist vs. Specialist. Bighorn sheep, as grazers, have a widely varied diet but are dependent upon escape terrain, particularly during lambing (Moses et al. 1998). They typically select open grassland habitat near these steep, rocky areas that offer protection from predators and shade during the hot BADL summers (Risenhoover et al. 1988, Moses et al. 1998). Risenhoover and Bailey (1985, in Moses et al. 1998) found a positive association between bighorn sheep foraging efficiency and proximity of escape terrain.

Interspecific Interactions. Little is known about the interspecific interactions that exist for the BADL bighorn sheep population. There is no documentation that either resource competition or predation is a serious threat to the park's bighorn population.

Sensitive Habitat. Epps et al. (2004) found that desert bighorn sheep in many California mountain ranges make extensive use of springs and water holes, and remained close to water during the summer months. The absence of dependable natural springs was also correlated with extinction of bighorn sheep populations in these ranges (Epps et al. 2004). If conditions in BADL become warmer and drier as predicted, bighorn sheep may become more reliant on the park's springs and seeps. Precipitation is also predicted to become more variable across the seasons. This may lead to increased drought that will affect the amount and consistent availability of water in the park's springs and seeps. These important features could therefore be considered especially sensitive to climate change.

Non-Climate Stressors. Bighorn sheep may become increasingly vulnerable to disease with projected changes to climate. Disease, especially EHD, will continue to negatively impact the bighorn sheep population (Moses et al. 1998). BADL appears to provide environmental conditions for outbreaks of EHD in the fall when dry conditions produce mud-flats throughout the park (Childers 2002). These conditions are favorable for outbreaks of midges, which can transmit the virus to bighorn sheep (Childers 2002).

Photo 32. Bighorn sheep ewe and lamb at BADL (NPS photo, from NPS 2010).

Reproductive Potential for Adaptation. Females in the northern part of the species' range usually breed for the first time in their third year, which is characterized as a moderate rate of sexual maturity. Fecundity generally declines only slightly after eight years of age (Caughley 1977). Gestation period lasts approximately five to six months (150-180 days). Females produce 1-2 lambs per year, though two lambs are rare (Shackleton 1985); this is characterized as low fecundity. Overall, bighorn sheep have a low to moderate reproductive potential to adapt to a disturbance or environmental changes. The longer generation time and the few offspring per breeding effort may limit the species' capacity to adjust or adapt to climatic changes in the region, particularly if they occur rapidly.

Ecological Processes. Bighorn sheep populations benefit from burning in most forested habitats (Moses et al. 1998). Fire suppression, and its effects on vegetatitive succession (e.g., encroachment of shrubland and trees), has been a major cause of habitat loss for bighorn sheep in some areas (Wakelyn 1987). Bighorn foraging efficiency is greater and forage quality is higher after burning (Hobbs and Spowart 1984, Hurley and Irwin 1986; as cited by Moses et al. 1998). Forage on burned areas within bighorn ranges greened up earlier and green-up lasted longer, in some cases through an entire winter following spring burning. Spring burning may have more benefits than fall burning since re-growth occurs sooner (Moses et al. 1998). Burning may also reduce lungworm rates and increase the area used by bighorns (Seip and Bunnell 1985, as cited by Moses et al. 1998). Prescribed fire, an active management practice, has been found to benefit bighorn sheep populations in mountain areas by removing woody vegetation that provides cover for predators of young bighorn sheep (Childers 2002). However, burning just prior to a drought period can decrease grass production and lengthen the vegetation recovery period (Whisenant and Uresk 1989), which could have a short-term negative effect on bighorn.

Summary of Vulnerability. Rocky Mountain bighorn sheep are a fragile species in BADL. Bighorn sheep rely on stable environments because they are physiologically sensitive to changes in temperature and moisture (Table 33). Temperature and moisture affect the species composition and forage quality of grasslands, which could impact the diet and nutritional health of grazing animals like the bighorn. Changes in diet quality and overall bighorn health could increase their susceptibility to disease and parasites such as lungworm, which are already a major concern. Bighorn sheep have a low reproductive potential, giving birth to few offspring each season. Successful recruitment and maintaining a stable population size may prove more difficult if climatic changes affect forage quality in primary sheep habitats. However, bighorn sheep do not have any known inter-specific interactions that will be significantly altered due to climate warming.

Table 33. A summary of the vulnerability characteristics of bighorn sheep.

Characteristics	Displays Characteristic*	Notes
Physiological sensitivity	●	Warmer, drier conditions associated with greater likelihood of bighorn population extinction
Specialist	○	Dependent upon escape terrain found on badlands formations
Interspecific interactions	--	
Sensitive habitat	--	
Non-climate stressors	○	Could become more susceptible to disease if climate change decreases diet quality
Reproductive potential to adapt	○	One, rarely two, lambs per year

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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4.3.5 Bison

Description

Free-ranging bison are limited by the fragmented prairies that once covered the North American Great Plains. The species is one of the best-known examples of a mammal rescued from the brink of extinction in North America (Berger and Cain 1999). Thirty to sixty million bison existed at the time of European settlement, yet by 1903, the species was nearly hunted to extinction. Only 1,644 reportedly survived in zoos, private herds, and Yellowstone National Park (Meagher 1986). Bison are considered an ecologically influential or keystone species that regulate many important aspects of grasslands (Knapp et al. 1999); thus, an effort to reintroduce bison into the BADL grassland ecosystems began in 1963 (Pyne et al. 2010). As of 2011, the BADL bison population was approximately 1100 animals (E. Childers, written communication, 15 November 2011). The park's goal is to maintain a herd of 600-800 animals, the number needed to have a balanced grassland ecosystem during dry conditions (Kenner and Childers 2007). Since there are no natural predators in the park, when the population grows too large, the surplus animals are rounded up and donated to the Oglala Sioux and other Native American tribes through the Intertribal Bison Cooperative located in Rapid City (Kenner and Childers 2007).

Photo 33. Bison at Badlands National Park (NPS photo, from NPS 2010a).

Bison are primarily grazers with the majority of their diet consisting of grasses, sedges, and occasionally forbs (Meagher 1986). They spend a large portion of time grazing on the edges of prairie dog towns and on recently burned areas in the spring. Gogan et al. (2010) found that bison exploit variations in forage quantity and quality, from selecting small highly nutritious patches on prairie dog towns, to travelling long distances in response to drought or heavy snowfall. Recent studies have found that bison forage "in a highly efficient manner", actively selecting more nutritious forage that satisfies their nutritional needs (Gogan et al. 2010, p. 43).

<u>Existing Threats and Stressors</u>

The BADL population is limited to lands inside the park by extensive fencing, which protects them from threats outside the park (Forrest et al. 2004). However, bison in BADL are still susceptible to a number of non-climate threats and stressors, primarily diseases. Bovine brucellosis is caused by the bacterium *Brucella abortus*. Bison, cattle and other bovid species are the primary hosts for this disease (Aune and Gates 2010). It is transmitted through oral contact with aborted fetuses or contaminated birth membranes and fluids. In most cases, the infection causes greater than 90% of female bison to abort during their first pregnancy. Infected males, in the most advanced cases, become sterile (Aune and Gates 2010). Both sexes may experience inflammation and arthritis caused by concentrations of bacterium in the joints, which increases vulnerability to predation (Tessaro 1989, as cited by Aune and Gates 2010). However, due to federal livestock regulations to control the disease, it is not likely a serious threat to BADL bison (NPS, Rick Wallen, Wildlife Biologist, e-mail communication, 17 October 2011).

Anthrax is another infectious bacterial disease that bison can contract. Caused by the endospore-forming bacterium *Bacillus anthracis*, the disease can cause septicemia and death (Dragon and Rennie 1995, as cited by Aune and Gates 2010). It is transmitted by inhaling or ingesting *B. anthracis* endospores, which then replicate in the bloodstream and release toxins. The disease is made more threatening by the fact that the endospores from a decaying carcass can remain viable in the soil for decades before infecting new hosts (Dragon and Rennie 1995, as cited by Aune and Gates 2010). Several climatic factors play a role in the prevalence of this disease. Season (summer), high ambient temperature, high densities of insects, congregation around diminished water and food supplies, and drought can promote anthrax outbreaks (Aune and Gates 2010). Captive animals can be vaccinated against the disease and treated with antibiotics if they become infected, but there is currently no treatment for free ranging bison (Aune and Gates 2010).

Bovine anaplasmosis, an infectious, non-contagious disease caused by the bacterium *Anaplasma marginale*, is a threat to the re-established bison population in BADL. It is best known as a disease of domestic livestock; however, it can also affect bison (Davidson and Goff 2001). The bacteria are transmitted between hosts by blood-sucking insects, such as ticks; infection may cause anemia, emaciation, and jaundice (Radostits et al. 2000, as cited by Aune and Gates 2010). Naturally occurring infections have been reported in western Montana on the National Bison Range (NBR) and in northern Oklahoma on the Tall Grass Prairie Preserve (TGPP). In the TGPP, 42 of 50 bison culled tested positive as carriers of *A. marginale* (De la Fuente et al. 2003, as cited by Aune and Gates 2010). In experiments performed by Zaugg and Kuttler (1985, as cited by Aune and Gates 2010), infected bison calves demonstrated a higher resistance to the bacteria than cattle.

One final disease of concern is malignant catarrhal fever (MCF). This virus, commonly carried by domestic sheep and goats in the U.S., is one of the most infectious diseases of bison, particularly at high densities (Li et al. 1996, Heuschele and Reid 2001; as cited by Aune and Gates 2010). Infection is typically lethal and herd mortalities of up to 100% have been reported (Schultheiss et al. 2001, as cited by Aune and Gates 2010). There is currently no vaccine or effective treatment for the disease; the best management approach is to avoid contact with natural hosts such as domestic sheep (Aune and Gates 2010).

A lack of genetic diversity is also a concern for the BADL bison population and the species as a whole (Boyd 2003, as cited by Gross et al. 2006). The historic decline from millions of animals to just over 1,000 around the turn of the century "represents a genetic bottleneck of epic proportions" (Gross et al. 2006, p. 4). In addition, the BADL population was founded by just 53 individual bison (Mattison and Grom 1968), supplemented by an additional 20 bison from a different genetic source in 1984 (Berger and Cunningham 1995). Low genetic diversity and inbreeding can reduce the overall fitness of individuals, making them more vulnerable to environmental changes, and increase a population’s risk of extinction (Keller and Waller 2002).

Climate Change Vulnerability

Physiological Sensitivity. The bison population is currently found in the central part of its historical range (Patterson et al. 2007); most of the population within the historical range consists of managed herds (Figure 23; Forrest et al. 2004). The original range of the species included hot, dry desert grasslands of northern Mexico, where a small population still survives today (Gogan et al. 2010). Bison are physiologically adapted for temperature extremes because they can alter their metabolism and are protected by their insulated coat (Peters and Slen 1964, Rutley and Hudson 2000, as cited by Gogan et al. 2010). However, in the past, bison also undertook extensive seasonal movements between summer and winter ranges (Seton 1927, as cited by Gogan et al. 2010), presumably to find favorable seasonal habitat. Currently, the BADL bison population is limited to park land and could not easily migrate to escape severe climate shifts or to seek more optimal habitat. Bison within BADL often rely on stock dams and ponds for drinking water during drier periods. With increased average temperatures, evapotranspiration, and variability in precipitation, the amount of surface water available for use by bison and other animals, even that which is retained in stock dams, may be significantly limited. This, combined with the fact that bison are restricted to seeking water sources within park boundaries, may increase their exposure to climate change’s effects.

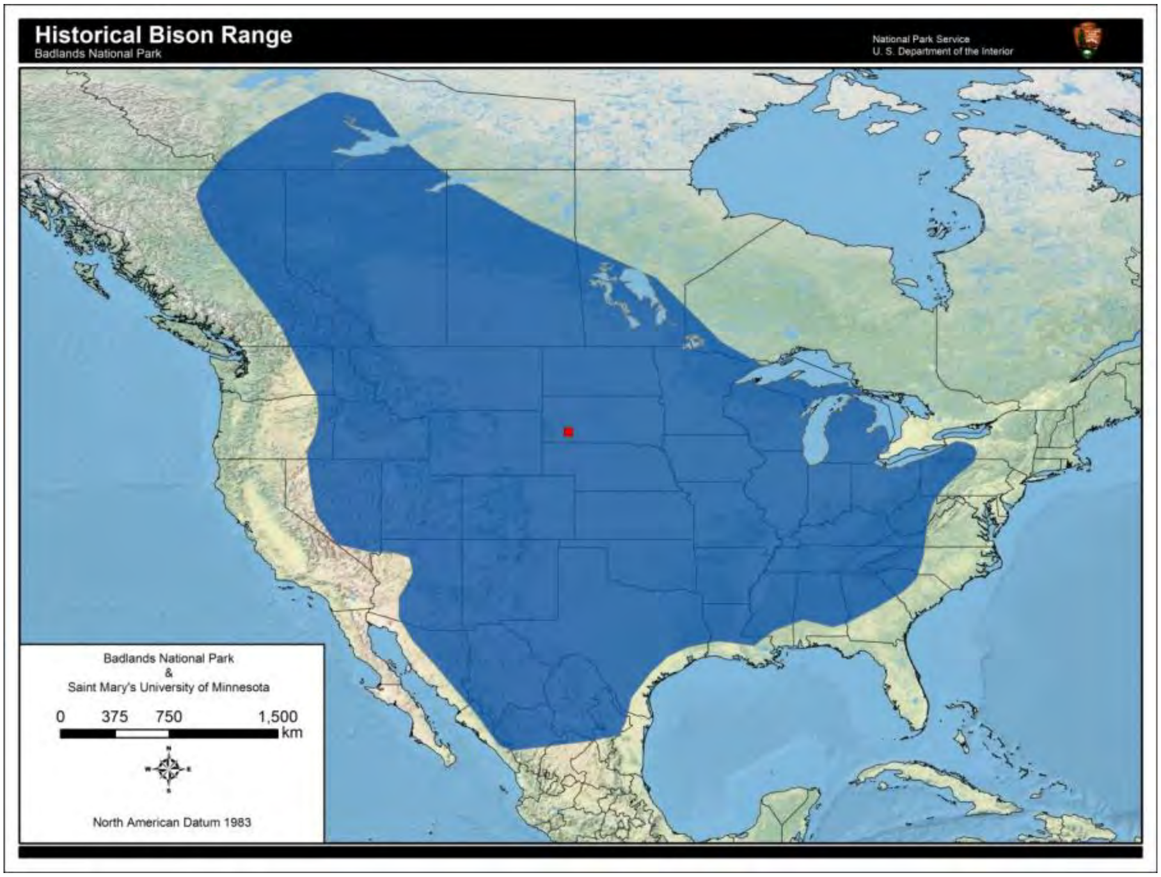

Figure 22. Historical range of bison (Patterson et al. 2007) (Location of BADL shown as red square).

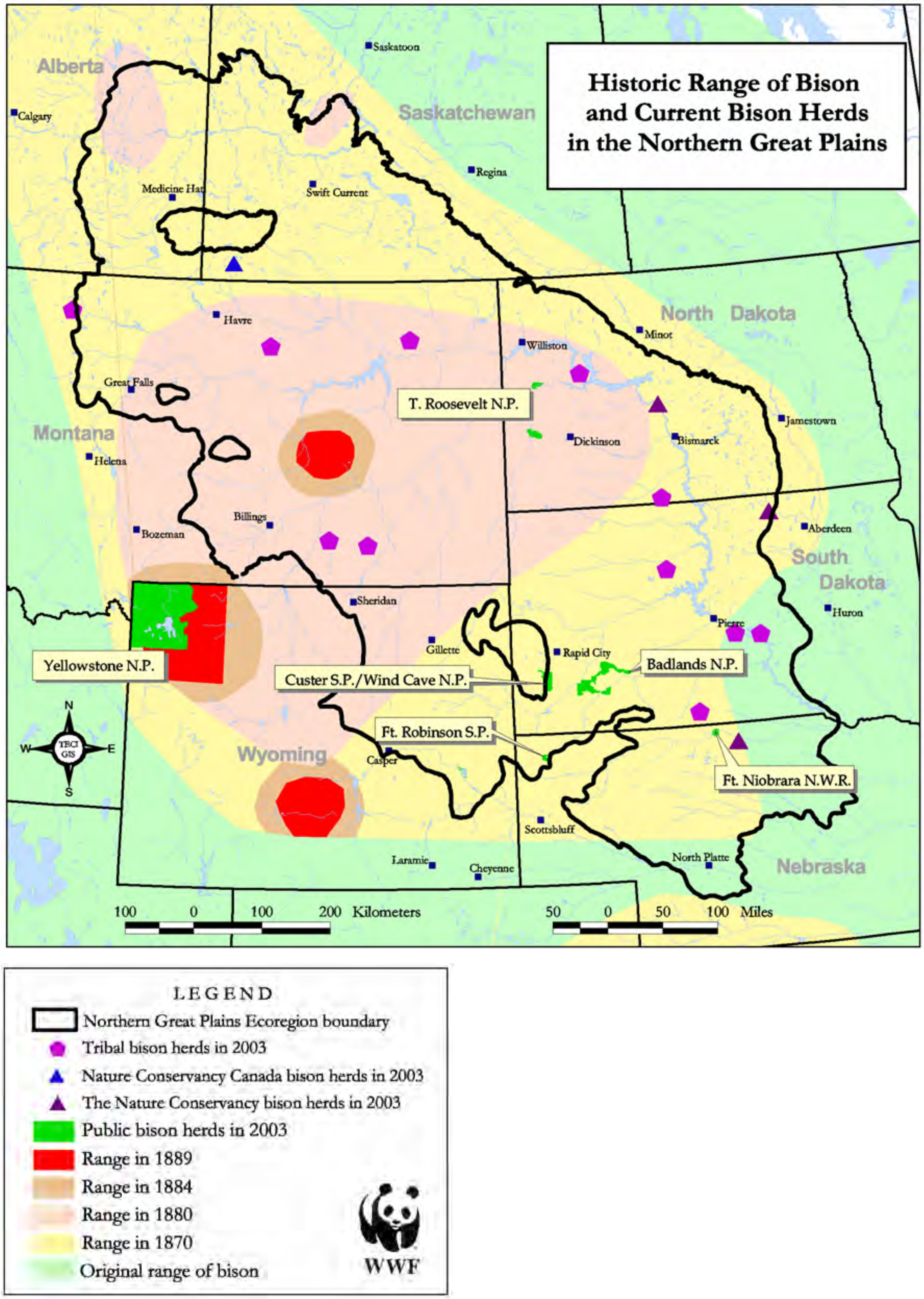

Figure 23. Bison herds by management agency/organization in the Northern Great Plains Ecoregion as of 2003 (Forrest et al. 2004).

Generalist vs. Specialist. Bison, as grazers, are a grassland specialist. They consume a variety of graminoids and forbs and forage in many different grassland communities. However, they tend to graze near prairie dog colonies and in tallgrass prairie when it is available (Krueger 1986). During a study at Wind Cave National Park in western South Dakota, Krueger (1986) found that bison fed primarily on both active and abandoned prairie dog towns, using forested areas mainly during travel to other open areas. Krueger (1986) suggested that prairie dog towns are the best areas for bison foraging because prairie dog grazing generally increases the nutritional quality of graminoids. Research also indicates that bison grazing preference is influenced by season and burn history (Schuler et al. 2006).

Interspecific Interactions. As an ecologically influential species in the Great Plains, bison have a marked influence on the patterns of occurrence, distribution, and density of other species (Figure 24; Gitzen et al. 2010). Their grazing, wallowing, and the movement of herds were instrumental in shaping the prairie landscape and enhancing grassland heterogeneity. This heterogeneity is necessary for providing suitable nesting sites for several obligate grassland nesting birds, such as upland sandpipers (*Bartramia longicauda*) and grasshopper sparrows (*Ammodramus savannarum*) (Gogan et al. 2010). Bison wallows also provide important breeding habitat for the plains spadefoot toad (*Spea bombifrons*) and the Great Plains toad (*Anaxyrus cognatus*), as temporary pools of standing water have been known to persist in wallows for many days following rainstorms or spring snow melt (Bragg 1940, Corn and Peterson 1996, as cited by Gogan et al. 2010). Bison may also play a role in the establishment of prairie dogs (Forrest et al. 2004). Results from Krueger (1986, p. 760) indicate “a mutually positive relationship between bison and prairie dogs” on town edges; bison foraging encourages growth of shortgrasses, which keeps visibility high for prairie dogs, and the acceleration of nutrient cycling processes by prairie dogs may influence bison habitat use and nutrition (Fahnestock 1995).

The lack of natural predators for bison can have a negative influence on an ecosystem. The most significant predators of bison, wolves (*Canis lupus*) and grizzly bears (*Ursus arctos*), no longer occur in BADL or the surrounding area, and the park “is not large enough to support an unmanaged herd of bison” (Pyne et al. 2010, p. 1463). The target number of bison is approximately 600-800 animals, depending on climate conditions (Kenner and Childers 2007). Without predators, reintroduced ungulates can experience overpopulation and severe resource depletion; thus, management of herd size is a key factor in maintaining ecosystem balance (Pyne et al. 2010).

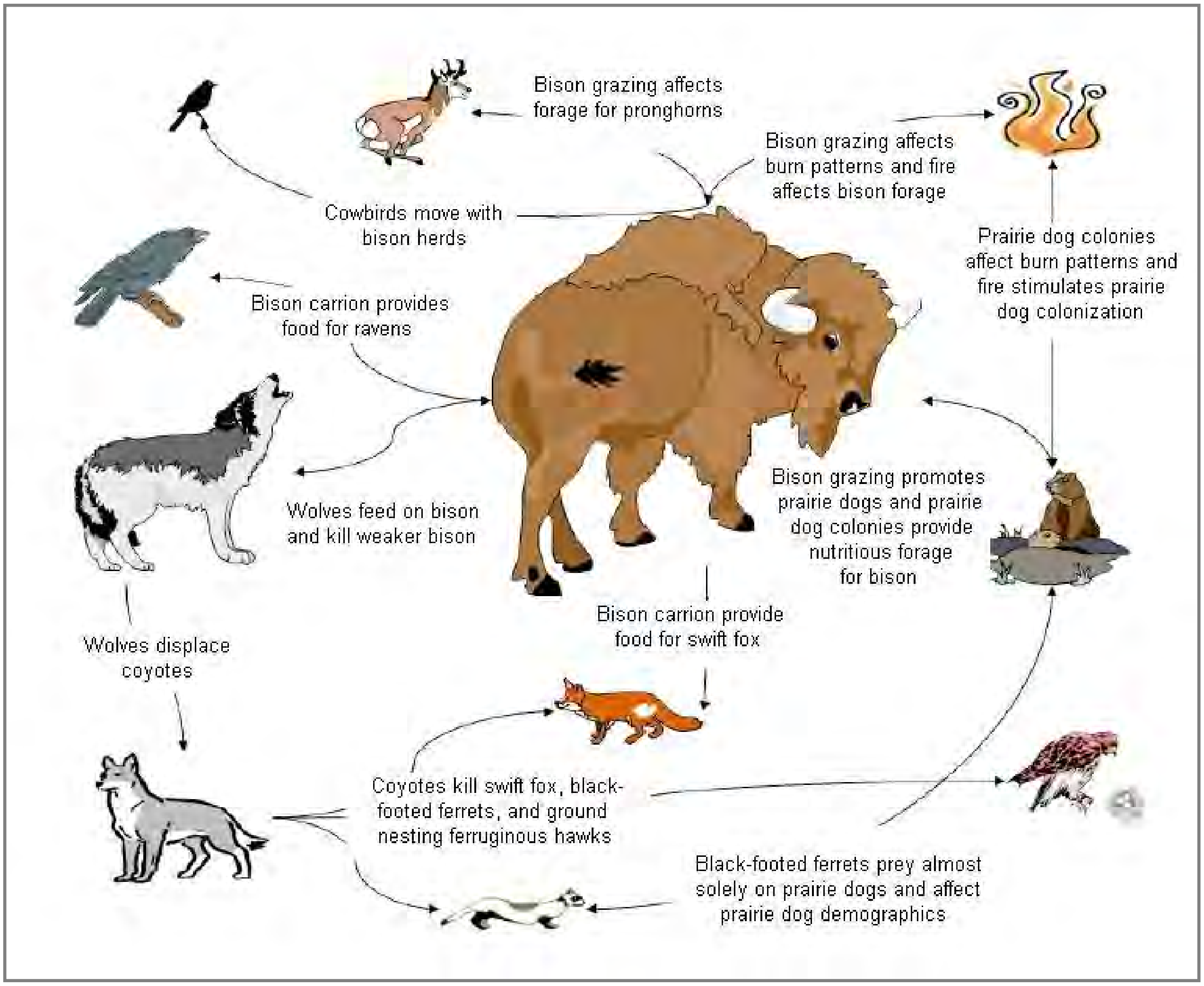

Figure 24. Historical interactions of bison and other wildlife in the Northern Great Plains (Gitzen et al. 2010).

Sensitive Habitat. Bison frequently inhabit BADL's grasslands. The grasslands are least vulnerable to climate change (see section 4.1.3), but may face a shift in composition due to climate change. This may affect forage quality, which could influence bison foraging behavior or health (Craine et al. 2009, 2010). If precipitation were to increase, invasive species may become more dominant (Dukes and Mooney 1999), which could also affect forage quality. Within the grasslands, bison forage substantially on the edges of prairie dog towns because of the composition of vegetation there. Prairie dog towns do not seem to be particularly vulnerable to the climate changes predicted for BADL.

Photo 34. Bison cow and calf (NPS photo, from NPS 2010b).

Reproductive Potential for Adaptation. Female bison become sexually mature by 2-4 years of age, which is characterized as a moderate rate of sexual maturity. Sexual maturity for male bison is similar; however, males at least six years of age do most of the breeding in a population (Meagher 1986). Gestation lasts approximately 9.5 months (285 days), longer than most large mammal species. Females typically have only one calf each year (Meagher 1986), which is characterized as low fecundity. Bison in general have low to moderate reproductive potential, meaning it may take a bison population a long time to recover from a major decline. In having a longer generation time and producing few offspring with each reproductive effort, bison may be limited in their capacity to adjust or adapt as a species to rapid environmental changes. However, the BADL bison population has so far shown high rates of survival and reproduction (Pyne et al. 2010). During a five-year period in the late 1980s, the bison population at BADL more than doubled from about 300 to 775 individuals (Berger and Cunningham 1995)

Non-Climate Stressors. Berger and Cain (1999) indicated that managed bison populations tend to have lower disease rates, likely because they are not limited by nutrition, allowing the managed bison to maintain a stronger immunity than free-roaming bison that experience periodic nutritional stress. However, if BADL experiences hotter days and a drier climate as predicted, forage quality may decrease and nutrition could be limited.

Ecological Processes. Bison, through their grazing and wallowing habits, are an important component of grassland disturbance regimes. Changes in other components of the disturbance regime (e.g., fire and drought) should not severely impact bison, but may influence their foraging behavior. While fire may cause bison to temporarily abandon grazing areas near burns, burning grasslands generally benefits bison, which preferentially select recently burned areas (Shaw and Carter 1990, Craine et al. 2009). Spring burns encourage an increase in biomass production of the dominant prairie grasses while decreasing plant litter, thus attracting bison (Schuler et al. 2006). Bison graze on little bluestem more frequently after burning, probably due to the removal of dead or decaying grass by fire (Pfieffer and Hartnett 1995, as cited by Gogan et al. 2010).

Herbivore growth is frequently limited by plant nutritional quality (e.g., concentrations of available energy and protein in plants) (Craine et al. 2009). If climate change causes extended droughts, the plant species consumed by bison may become significantly stressed, decreasing their nutritional quality. This will likely affect the nutrition and health of bison.

Summary of Vulnerability. The bison population in BADL seems less vulnerable to climate change, mainly because the vulnerability of their primary habitat (grasslands) is low (Table 34). They tend, in most cases, to favor fire as an ecological process because it increases forage quality. Since the park closely manages both bison numbers and prairie dog towns, their interspecific interaction remains balanced. Bison may be impacted if the projected drier climate causes a shift in grassland species composition away from the most nutritional or preferred forage species. Their low to moderate reproductive potential for adaptation may also limit their ability to cope with rapid changes to climate; however, bison are at an advantage as they already possess physiological adaptations that allow them to tolerate extreme temperatures (warmer average temperatures being the primary climate change projection for the region). Overall, the BADL bison population is stable and should remain so as long as management of the species continues.

Table 34. A summary of the vulnerability characteristics of bison.

Characteristics	Displays Characteristic*	Notes
Physiological sensitivity	--	
Specialist	○	Relies primarily on grasslands for food
Interspecific interactions	--	
Sensitive habitat	--	
Non-climate stressors	--	
Reproductive potential to adapt	○	One offspring per year; slower to sexual maturity

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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4.3.6 Mule Deer

Description

Mule deer (*Odocoileus hemionus*) occupy a variety of habitats throughout North America, including various forests and woodlands, forest edges, shrublands, grasslands with shrubs, and residential areas (as reviewed by NatureServe 2011). Deer browse on a wide variety of woody plants, graze on grasses and forbs, and may feed on agricultural crops. They also commonly consume mushrooms, especially in late summer and fall (as reviewed by NatureServe 2011). Mule deer predators include mountain lions, coyotes, bobcats, eagles, and domestic dogs (Anderson and Wallmo 1984).

In South Dakota and the BADL region, deer concentrate heavily within drainages and woody draws in BADL and adjacent areas (Carter 1979). Fawns tend to choose bedsite habitat consisting of chokecherry, common snowberry (*Symphoricarpos albus*), and skunkbush sumac. Data from Carter (1979) show deer moved in and out of the park, both on a daily and seasonal basis. Movement of two miles or less out of the park to adjacent alfalfa and winter wheat fields or to stacked alfalfa hay was recorded (Carter 1979). Stacked alfalfa hay attracts deer during dry seasons, cold temperatures, and deep snows (Carter 1979, Putnam et al. 2001).

Photo 35. Mule deer in BADL (photo by Shannon Amberg, SMUMN GSS, 2011).

<u>Existing Threats and Stressors</u>

Several diseases and parasites threaten mule deer in BADL. Bovine anaplasmosis is an infectious non-contagious disease. Although best known as a disease of domestic cattle, mule deer and other wild ruminants are also susceptible to infection (Davidson and Goff 2001). A majority of infections are due to a bite from a tick carrying the anaplasma bacteria (Davidson and Goff 2001). The most common species of anaplasma is *Anaplasma marginale*. This infection may cause anemia and icterus, otherwise known as jaundice. The presence of an efficient vector, tick species for example, can result in a high prevalence of infection. There are 18 species of ticks known to serve as vectors to *A. marginale*, 17 of which are found in South Dakota (USFS 2011); thus, there are a number of possible vectors for disease transmission.

Bovicola tibialis is an exotic louse native to fallow deer of Europe that was discovered in BADL mule deer in April of 2007 (E. Childers, written communication, 7 September 2011). From 28 February to 7 April 2009, 35 mule deer were found dead in BNP. Seven of these mule deer were examined at the Colorado State University Veterinary Disease Laboratory in Fort Collins, Colorado. Visible lesions in these mule deer seemed to result from both emaciation and mild to moderate alopecia. These seven mule deer were positively identified as infected with *B. tibialis.*

Future research is planned to determine if *B. tibialis* is contributing to mule deer mortality at BADL (E. Childers, written communication, 7 September 2011).

Chronic Wasting Disease (CWD), caused by an abnormal protein called a prion, is a brain disease that affects deer, elk, and moose and is fatal in 100% of cases (SDGFP 2010). This disease was first found in captive mule deer, but later surveillance proved that wild cervids were also infected (SDGFP 2010). Miller et al. (2004) reported that CWD can be transmitted to susceptible animals indirectly through contaminated animal wastes and decomposed carcasses, contaminated water sources, and contaminated forage. Typical symptoms of animals infected with CWD include progressive loss of weight and body condition, changes in behavior, excessive salivation, increased drinking and urination, loss of muscle control, and eventual death (SDGFP 2010). Additionally, Miller et al. (2004) noted that CWD has been found to persist in contaminated environments for up to two years or more, which increases the potential for transmission and spread of the disease. Southwestern South Dakota represents one of several recently identified geographically distinct foci of CWD (Jacques et al. 2003). Although the disease has not yet been found in BADL, several cases have been reported in and around Wind Cave National Park to the west (SDGFP 2010).

If mule deer leave the park, hunting becomes a threat. Deer move in and out of the park freely, so pressure from hunters is possible. Carter (1979) found major deer concentrations in the west and east ends of the park. Many times deer adjacent to the park would move into the park once hunting commenced. Forty-three of 153 deer tagged in the park by Carter (1979) were legally harvested outside the park. Carter (1979) concluded from hunter harvest data that over-harvest on lands adjacent to the park was unlikely. This remains true today, as the South Dakota Department of Game, Fish, and Parks monitors the mule deer population and controls the number of deer harvested by holding a limited draw for hunting licenses (E. Childers, e-mail communication, 15 August 2011).

Climate Change Vulnerability

Physiological Sensitivity. The BADL mule deer population is located in the latitudinal center of the species' overall range (Figure 25; Patterson et al. 2007). Mule deer do not seem to have a physiological sensitivity to temperature or moisture. Steigers et al. (1981) noted that mule deer fawns and adults exhibit a physiological adaptation that allows a certain increase in core body temperature during extremely hot temperatures. However, the plants they forage on are directly impacted by climate and seasons. On a landscape scale, climate change is expected to alter community composition and distribution of many plant species, many of which are used as forage by herbivores (Monteith et al. 2011). In some regions, mule deer populations migrate seasonally between higher elevation summer ranges and lower elevation winter ranges, often occupying mid-elevation transitional ranges (deVos and McKinney 2007). Mule deer may be capable of adjusting the timing of their seasonal movements in order to obtain the largest nutrient gain (Monteith et al. 2011). In a study by Monteith et al. (2011) in Round Valley, California, deer adjusted their seasonal migration to correspond with changing climate conditions, so long as that change was not too severe. However, deer in plains ecosystems generally are not migratory (as reviewed by NatureServe 2011).

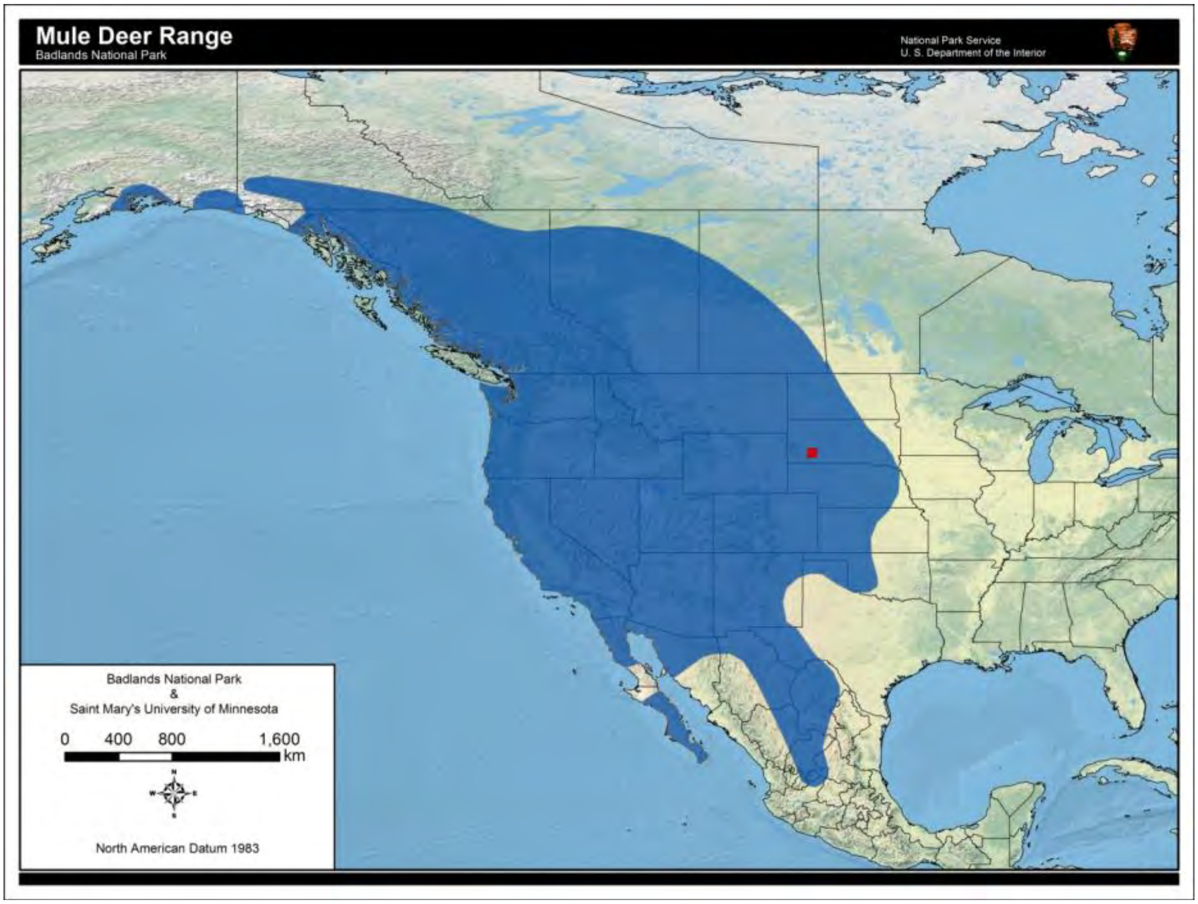

Figure 25. Current mule deer distribution (Patterson et al. 2007) (BADL location shown in red).

Generalist vs. Specialist. Mule deer are opportunistic feeders, choosing habitat based on forage type and quality (deVos and McKinney 2007). Mule deer browse on woody plants and graze on grasses and forbs. Precipitation is a key to forage quality, and changes to precipitation will likely change the capacity of the land to support populations of these plant species. Both the timing and amount of precipitation and frequency and intensity of droughts affect plant growth, which in turn influences forage availability and quality (Steigers 1981, deVos and McKinney 2007). Climate change may alter precipitation patterns, or increase the frequency and intensity of droughts in the region, potentially causing mule deer to alter their foraging strategies.

Interspecific Interactions. There are no prominent interspecific interactions for mule deer in BADL that would be affected by climate change. In Idaho and other northwestern states, elk are thought to compete with mule deer over forage (IDFG 2011); however, elk are only found occasionally in BADL.

Sensitive Habitat. Mule deer in BADL rely on habitats that are sensitive to climate change. A study by Steigers (1981) found that most fawn bedsites were located in woody draws, dominated by plant species such as chokecherry, snowberry, skunkbush sumac, silver sagebrush, and juniper-overstory. Carter (1979) and Steigers (1981) considered riparian habitat types to be the most critical habitats for mule deer in the Northern Great Plains. The vulnerability of riparian areas may make mule deer, in turn, vulnerable to climate change as a result of habitat loss.

Non-Climate Stressors. According to deVos and McKinney (2007, p. 19), the parasite "growing season" (the period when temperatures are suitable for the development of larva) has increased in some regions over the past 50 years. The authors state that "Further climate warming and extension of the seasonal window for transmission may lead to amplification of parasite populations and disease outbreaks in host populations" (deVos and McKinney 2007, p. 19; citing Jenkins et al. 2005).

Photo 36. Mule deer doe and fawn (NPS Photo, from NPS 2010).

Reproductive Potential for Adaptation. Female mule deer typically first breed at 2 years of age (Anderson and Wallmo 1984); males breed at 3-4 years of age (as reviewed by NatureServe 2011). This is characterized as moderate sexual maturity. Gestation lasts approximately seven months (190-210 days) (Anderson and Wallmo 1984). Litter size is 1-2 fawns, depending on the age and condition of the mother; females in their first and second breeding season often produce a single fawn (Anderson and Wallmo 1984, NatureServe 2011). This is characterized as low to moderate fecundity. Inadequate nutrition during gestation, possibly due to changes in type of plants and shrubs available for grazing and browsing (potentially shifts in composition due to climate change), can result in the loss of a fetus, low birth weight, and reduced probability of survival of young (Monteith et al. 2011). Overall, mule deer have a low to moderate reproductive potential to adapt to disturbance or environmental changes associated with climatic shifts. Though mule deer have a moderate rate of sexual maturity, females typically produce only one to two offspring each year (twins are uncommon). This may limit the species' capacity to adjust or adapt to environmental changes, particularly if they occur rapidly.

Ecological Processes. Long periods of drought can directly lead to mule deer mortality because it has negative effects on plant species used for cover and forage. Steigers (1981) states that high deer populations, extended drought (which decreases forage quality and abundance), and competition for habitat, result in higher rates of mortality. Another concern for mule deer would be fire suppression. Fire has been the strongest factor in shaping mule deer habitat, and has had the greatest positive influence (MDWG 2003). Historically, fire has contributed to high quality and quantity of browse for mule deer; the forage regrowth is nutritious, palatable, and easy to digest, and maintaining healthy body condition is critical to mule deer survival and reproduction (MDWG 2003). However, with fire suppression, older plants are browsed and do not re-grow as vigorously as newer plants. Fire suppression can also change the intensity and rate at which fires burn, resulting in a shift in plant communities and sometimes invasive species encroachment. Fires, when they do occur, may be hotter and can burn minerals from the soil, which slows plant regeneration (MDWG 2003). This decrease in plant productivity can negatively affect mule deer nutrition, health, and habitat.

Summary of Vulnerability. The mule deer population is moderately vulnerable to climate change due to a low to moderate reproductive potential to adapt, a possible increase in prevalence of certain diseases and parasites with increased average temperatures, and a reliance on the riparian woodlands plant community (a sensitive habitat) for cover and migration (Table 35). On the other hand, mule deer seem to be physiologically well adapted to warmer temperatures, already occur across a wide range of habitats and climates, are relatively opportunistic grazers and browsers, and have no known inter-specific interactions that would be impacted by climate change.

Table 35. A summary of the vulnerability characteristics of mule deer.

Characteristics	Displays characteristic*	Notes
Physiological sensitivity	--	
Specialist	--	
Interspecific interactions	--	
Sensitive habitat	○	Rely on riparian woodlands
Non-climate stressors	○	Range of disease-causing organisms and vectors may expand.
Reproductive potential to adapt	○	Long gestation and few offspring per litter

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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4.3.7 Bobcat

Description

The bobcat (*Lynx rufus*) is a medium-sized felid that is native to North America. Thought to be the most broadly distributed felid in the United States, its distribution ranges across North America (Brockmeyer and Clark 2007). Historically, bobcats were considered a nuisance in South Dakota due to predation on domestic livestock; a three-dollar bounty was offered on the species from 1929 to 1939 (Frederickson 1981, as cited by Mosby 2011). Between 1947 and 1972, approximately 15,000 bobcats were turned in for a five-dollar per pelt bounty. Bobcats were designated as a protected furbearer in 1975, and hunting in South Dakota was limited to managed seasons (Frederickson 1981, as cited by Mosby 2011). In 1979, the U.S. signed the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which prevented the harvest and trade of endangered species including the pelts of spotted felids such as cheetahs (*Acinonyx jubatus*), leopards (*Panthera pardus*), and ocelots (*Leopardus pardalis*) (Mosby 2011). The thick, spotted fur of bobcats became an increasingly popular alternative to these species, which subsequently led to a dramatic rise in harvest rates in the United States (McMahan 1986, Kitchener 1991; as cited by Mosby 2011). At present, bobcat furs are one of the most heavily traded pelts worldwide (CITES 2004, as cited by Mosby 2011).

Photo 37. Bobcat in BADL (NPS photo, from NPS 2010).

Bobcats are known to occupy a wide variety of habitats that range from forests to deserts (Brockmeyer and Clark 2007). In BADL, bobcats are commonly found near wooded riparian areas and drainages that provide woody vegetation for hunting, concealment, and cover for travel (Mosby 2011). Bobcats may also use tallgrass prairie habitats for hunting (Mosby 2011), although the shortgrass prairies in BADL are less suitable overall due to the lack of cover for hunting and concealment from larger predators (Mosby 2011). In BADL, female bobcats are known to generally prefer rough terrain or badland formations for safe denning habitat; on the other hand, males tend to frequent riparian areas (Mosby 2011).

Bobcats prey on a variety of species, preferring small mammals such as hares, rabbits, mice, and voles, but also eat birds, reptiles, insects, and occasionally deer as carrion (Riley et al. 2003, Brockmeyer and Clark 2007). Mosby (2011) found that the majority of the bobcat diet consists of hares and rabbits (lagomorphs); however, deer and other ungulates have been found in stomach samples. In BADL, Licht (2010, p.1) observed bobcats successfully hunting prairie dogs, and speculated that the rodents may make up a large portion of the cat's winter diet "in landscapes where prairie dog colonies exist in close proximity to badlands or woody cover." By analyzing stomach contents, Mosby (2011) discovered that juvenile bobcats ingest vegetation (found in 27% of stomach samples analyzed). He reasoned that the vegetation may have been used to purge endoparasites that were consumed (Rollings 1945, Story et al. 1982; as cited by Mosby 2011).

Existing Threats and Stressors

There are several threats and stressors to the bobcat population in BADL including disease, predation and interference competition, hunting, and habitat fragmentation and modification. Cytauxzoonosis is a fatal disease endemic to the southeastern and south-central U.S. that affects both domestic and wild cats (Snider et al. 2010). Transmission is caused by the tick-borne apicomplexan parasite *Cytauxzoon felis* (Meinkoth and Kocan 2005, Greene et al. 2006, Reichard et al. 2008, as cited by Snider et al. 2010). Studies have found that bobcats are "natural reservoir hosts" of the disease (Blouin et al. 1987, p. 499, citing Kier et al. 1982, Glenn et al. 1983) and the wide natural range of bobcats increases the probability of the disease spreading to other areas of the U.S. (Snider et al. 2010). In areas where the disease is endemic, the disease manifests itself as cases of sudden death (Meinkoth and Kocan 2005, Greene et al. 2006; as cited by Snider et al. 2010); other clinical signs include fever, jaundice, shortness of breath, anorexia, and lethargy. Sylvatic plague, which affects prairie dogs and black-footed ferrets, is also known to infect and kill felids (Jeffrey Manning, Wildlife Biologist, BADL, written communication, 15 September 2011). The presence of plague in prairie dog and ferret populations in BADL is expected to eventually affect bobcat populations in BADL (J. Manning, written communication, 15 September 2011.). Little is known about how these diseases influence survival and abundance of bobcats in the region, or how these diseases interact with other known stressors.

Another threat to bobcats is predation from increasing coyote populations. The occurrence of bobcats is usually low in areas where the coyote population is high, even when there is ample suitable habitat; this is due primarily to the reduction of prey abundance by coyotes (Toweill 1979, Litvaitis and Harrison 1989, as cited by Lariviere and Walton 1997). Bobcats are more of a habitat specialist than coyotes; thus, a rapidly expanding coyote population would threaten bobcat populations (Dibello et al. 1990, as cited by Lariviere and Walton 1997). In a Kansas study, Kamler and Gipson (2004) reported that the one bobcat killed by a coyote was not consumed. Because bobcats and coyotes are similar in size and typically select the same prey species, it is believed that interference competition rather than traditional predation is the cause for most coyote induced mortality in bobcats (Toweill 1986, as cited by Kamler and Gipson 2004).

Bobcats typically occupy large home ranges (72 km^2 for males in BADL, Mosby 2011) and are known to travel outside the BADL boundaries. Major threats outside the park include over-hunting and fragmentation of habitat due to commercial, residential, and agricultural growth (McCord and Cardoza 1982, as cited by NatureServe 2011). The hunting/trapping season for bobcat in South Dakota ranges from December to February with no harvest limit; hunting and trapping are allowed in Buffalo Gap National Grasslands adjacent to BADL (SDGFP 2011). Habitat quality is also important for the bobcat; thus, habitat modification as a result of development or land conversion can limit the habitat value of an area (Riley et al. 2003). Bobcats can tolerate a low degree of habitat disturbance but usually avoid areas of intensive development or with dense human populations (as reviewed by NatureServe 2011). Bobcats that encounter developed areas more often are expected to have lower survival rates, since several mortality sources are connected with urbanization and fragmentation (e.g., vehicle accidents, animal trapping, and contaminant build-up) (Riley et al. 2003). While most poisoning occurs in human-occupied areas, even predators in large natural zones may die from consuming prey that has ingested poison (Riley et al. 2003).

Climate Change Vulnerability

Physiological Sensitivities. Bobcats occurring in BADL are currently in the northern part of their range (Figure 26; Patterson et al. 2007). This species is a "highly adaptable carnivore" and still occupies most of its historical range (Mosby 2011, p. 8, citing Anderson and Lovallo 2003). Since bobcats are widely distributed in the United States, the species seems to tolerate a variety of habitats and climates. Adaptive capacity is expected to be relatively high due to the ability to travel throughout their home range to find suitable habitat and prey sources.

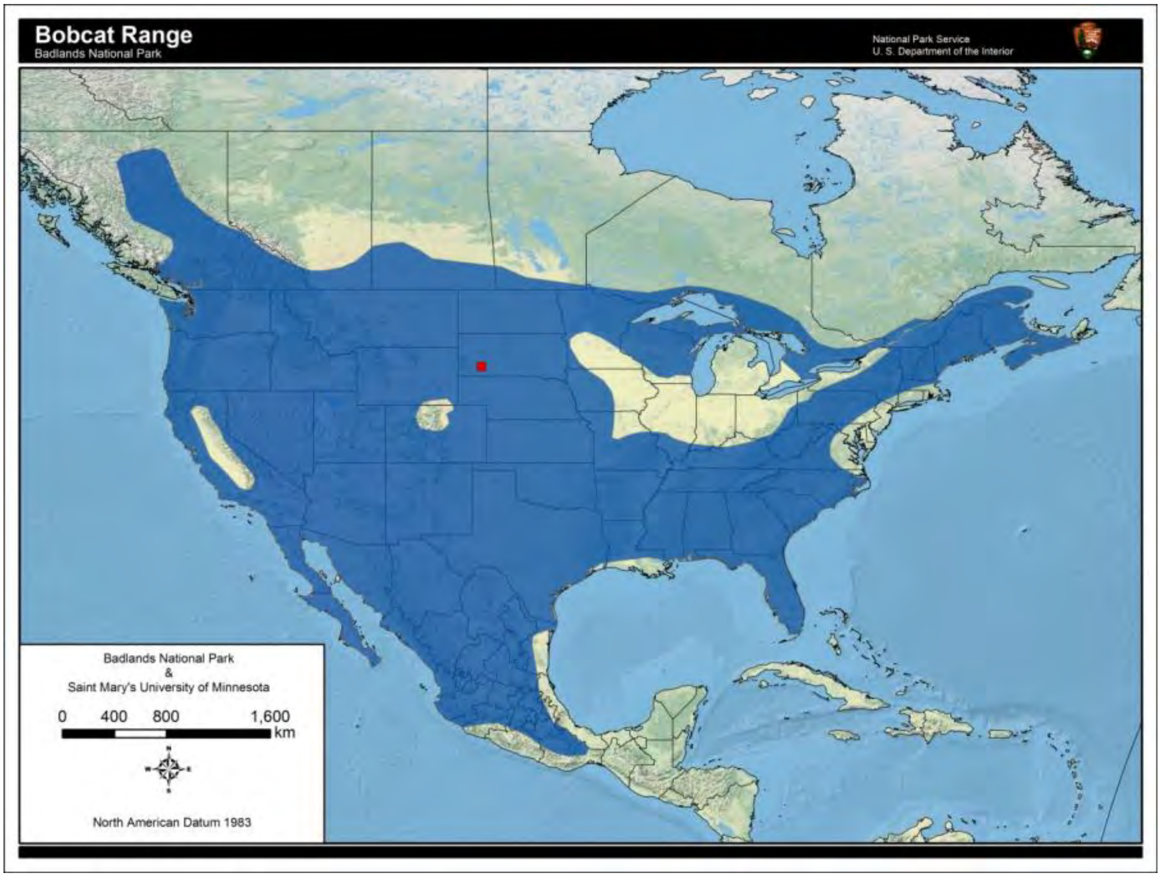

Figure 26. Bobcat distribution in North America (Patterson et al. 2007) (BADL shown as red square).

Generalist vs. Specialist. Bobcats are considered generalist predators (Hansen 2007, as cited by Brockmeyer and Clark 2007). They exhibit a preference for certain prey species, but can also prey on others if necessary (Mosby 2011). For example, bobcats typically prey on lagomorphs (rabbits and hares) most often, but when densities of these are low, bobcats will consume a greater percentage of other small mammals and birds (Bailey 1981, Knick 1990; as cited by Mosby 2011). This diversity in diet would make bobcats in BADL less sensitive to shifts in prey abundance (should they occur) due to climate change in the region.

Bobcats occur in a variety of habitats throughout their range, but in BADL male bobcats are primarily found near woodland areas whereas female bobcats are found closer to steep badlands formations (Mosby 2011). Identified as important bobcat habitat features, woody vegetation and shrublands likely provide the understory vegetation and cover required for resting, while rugged terrain provides the necessary escape terrain and resting sites (Mosby 2011).

Interspecific Interactions. Inter-specific interactions, specifically interference competition, can play a significant role in structuring a biological community (Schoener 1982, as cited by Neale and Sacks 2001), particularly at higher trophic levels (Hairston et al. 1960, Oksanen et al. 1981; as cited by Neale and Sacks 2001). In general, the interference competition between bobcats and coyotes appears to be low; however, this may be more significant in regions that experience seasonal changes, such as the western U.S. (Neale and Sacks 2001). Neale and Sacks (2001) indicated that bobcats and coyotes in California used food and habitat resources independently of each other. The coyotes appeared to prey on ungulates and other large prey, while the bobcat consumed mostly small mammals (Neale and Sacks 2001). Competitive interactions may decrease in areas where suitable habitat is varied and abundant, as this would afford a greater abundance of prey (Sanchez-Cordero et al. 2008). Competition may increase if climate change alters prey abundance, causing both predators to target the same species, or if urban expansion continues to decrease suitable habitat. Likewise, if prevalence of sylvatic plague in bobcats increases, this may give coyotes an added competitive advantage over bobcats in the region.

Sensitive Habitats. Although bobcats occupy a variety of habitats, they are still vulnerable to habitat loss and fragmentation (Riley et al. 2003). In BADL, Mosby (2011) found that bobcats tended to frequent riparian areas with increased understory vegetation that provide cover for hunting, resting, and escape. Climate models predict warmer average temperatures and drier conditions (through increased evapotranspiration) for BADL, which could decrease the extent of riparian and wooded drainage habitats in BADL. This would constitute a significant reduction of suitable habitat for bobcats in BADL.

Non-Climate Stressors. Two tick species (*Dermacentor variabilis* and *Amblyomma americanum*) are known to transmit the bacteria *C. felis*, which causes cytauxonosis (Shock et al. 2011). A study by Shock et al. (2011) in thirteen states across the country found that infections of *C. felis* were more prevalent when both species of tick were present. The study showed a rather low infection rate (2%) in North Dakota where only *D. variabilis* has been found. In Missouri, where both species of tick are present, infection rate was much higher at 79% (Shock et al. 2011). The onset of a warmer, drier climate may allow for northward expansion of *A. americanum* in the future (Shock et al. 2011), increasing the vulnerability of bobcats in the northern Great Plains. Tick prevalence in BADL coincides with the growth and production of vegetation as a function of rainfall in the region (J.

Photo 38. Young bobcat (NPS photo by Mike Laycock, in NPS 2008).

Manning, written communication, 15 September 2011); as temperatures increase and rainfall becomes more variable due to climate change, tick prevalence may increase in the park and, thus, lead to increased likelihood of disease transmission to bobcats.

Reproductive Potential for Adaptation. Bobcats are polygamous breeders, with no pair bonds established between mating pairs (Ohio DNR 2010). Females become sexually mature at nine to twelve months, while male bobcats mature around 18 months of age (Ohio DNR 2010). This is characterized as a rapid rate of sexual maturity. Bobcats may breed at any time during the year (Ohio DNR 2010). Gestation lasts about 2 to 2.5 months (approximately 63 days) (Young 1958, Hemmer 1976), and litter size can range from 1-6 kits with an average of 2-3 kits per litter (Lariviere and Walton 1997). Litter size is generally larger for adults and smaller for yearlings (Knick et al. 1985, as cited by Lariviere and Walton 1997). This is characterized as moderate fecundity. Known to be spontaneous ovulators, female bobcats that lose a litter may produce another litter in the same year (Ohio DNR 2010). Overall, the ability to spontaneously ovulate, in addition to early sexual maturation and having multiple offspring per litter, afford bobcats a moderate reproductive potential to adapt to environmental changes.

Ecological Processes. Fire may influence bobcats and their habitats in BADL. Regular burning of the grasslands and woodlands may improve forage quality, which could increase abundance of prey species favored by bobcats. The warmer, drier conditions projected for the BADL area could potentially increase fire frequency in and around the park. On the other hand, drier conditions could reduce biomass/fuel levels, decreasing the likelihood of fire (see section 4.2.1 for more details). This could, in turn, decrease forage quality for herbivores, therefore reducing prey abundance. Droughts are expected to increase in the region as average temperatures become warmer and precipitation is more variable. Droughts affect the height and thickness of vegetation, which may negatively affect the bobcat population by reducing cover for hunting. Erosion has also helped shape suitable habitat for bobcats. This process has formed caves, alcoves, and ledges that create good locations for dens and escape terrain for bobcats and their young (Mosby 2011).

Summary of Vulnerability. The bobcat population in BADL seems to be only slightly vulnerable to climate change (Table 36). Bobcats are widely distributed across North America, which implies little physiological sensitivity to temperature and moisture conditions. The bobcat, as a generalist predator, has a variety of prey options, which keeps resource competition low. The adaptation of spontaneous ovulation may be an advantage to reproductive success in light of environmental changes associated with climate shifts. However, the species may be slightly vulnerable if climate change causes wooded draws and drainage areas to disappear. Non-climate stressors, such as disease (*C. felis* and sylvatic plague), may become a concern, although little is known about the impact of plague on bobcats in the BADL. If warmer temperatures allow vector tick species, such as *A. americanum*, to spread north, the prevalence of tick-borne diseases will likely increase.

Table 36. A summary of the vulnerability characteristics of bobcat.

Characteristics	**Displays Characteristic***	**Notes**
Physiological sensitivity	--	
Specialist	--	
Interspecific interactions	--	
Sensitive habitat	○	Uses drainage areas regularly
Non-climate stressors	○	Disease may increase if tick range expands
Reproductive potential to adapt	--	

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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4.3.8 Herpetofauna

Description

The herpetofauna in BADL include at least six amphibian and six reptile species (Table 37). Some of the common amphibians are the tiger salamander (*Ambystoma tigrinum*), Great Plains toad (*Anaxyrus cognatus*), and northern leopard frog (*Lithobates pipiens*) (NPS 2011a). Common reptiles in BADL include the plains garter snake (*Thamnophis radix*), painted turtle (*Chrysemys picta*), and prairie rattlesnake (*Crotalus viridis*) (NPS 2011b). Amphibians and reptiles are ectothermic; their body temperature varies with environmental conditions.

Table 37. The herpetofauna of BADL (Smith et al. 1997, NPS 2011a and b); three additional amphibians and six reptile species are thought to occur in the park but have not been confirmed, and therefore are not listed here.

Common Name	Scientific Name
Amphibians	
Tiger salamander	*Ambystoma tigrinum*
Great Plains toad	*Anaxyrus cognatus*
Woodhouse's toad	*Anaxyrus woodhousii*
Northern leopard frog	*Lithobates pipiens*
Plains spadefoot	*Spea bombifrons*
Boreal chorus frog*	*Pseudacris maculata*
Reptiles	
Racer	*Coluber constrictor*
Western hog-nosed snake	*Heterodon nasicus*
Gopher snake	*Pituophis catenifer*
Plains garter snake	*Thamnophis radix*
Painted turtle	*Chrysemys picta*
Prairie rattlesnake	*Crotalus viridis*

* Formerly known as the western chorus frog

Photo 39. The plains spadefoot and tiger salamander (photos by Suzanne Collins in Fischer et al. 1999), and gopher or bullsnake (NPS photo, in NPS 2010).

Amphibians are among the most threatened organisms in the world, with about one-third of the approximately 6,500 documented species considered at risk of extinction by the IUCN Red List of Threatened Species (Gascon et al. 2007, Stuart et al. 2008, as cited by Rodder et al. 2010). Due to their permeable skin, amphibians are more sensitive to environmental changes than most other animals (Rowe et al. 2003, as cited by Hopkins 2007). This characteristic makes them good environmental indicators (Collins and Storfer 2003), meaning that the health of amphibian populations may offer critical clues to overall ecosystem health.

Photo 40. Prairie rattlesnake (photo by Steve Thompson, in SDGFP 2011).

Herpetofaunal habitat varies between reptiles and amphibians, as well as among species in each group. Most are primarily terrestrial as adults, although amphibians rely on temporary and seasonal wetlands for reproduction (Fischer et al. 1999). Semi-permanent wetlands tend to support the highest amphibian species diversity in South Dakota (Fischer et al. 1999). The most aquatic of the amphibians in this area is the northern leopard frog, which lives in upland areas, lakes, ponds, streams, springs, or near semi-permanent water (Smith and Keinath 2007). Painted turtles, although they are reptiles, also live in slow moving or shallow waters that are typically permanent. The prairie rattlesnake, in contrast, is completely terrestrial and can occupy a variety of habitats. However, in BADL they show a clear preference for mixed-grass prairie (Smith et al. 1997). During the winter, prairie rattlesnakes den in caves, rocky crevices, or mammal burrows (SDGFP 2011).

The herpetofauna in BADL have diverse food preferences. Amphibians such as the northern leopard frog are opportunistic insectivores that eat a variety of small invertebrates and occasionally consume small vertebrates (Smith and Keinath 2007). As tadpoles, frogs and toads mainly eat free-floating algae and plant tissue, but sometimes scavenge on dead animals (Smith and Keinath 2007). Reptiles vary in their eating habits; while the painted turtle is an opportunistic feeder, eating various plants and animals, living or dead (Bandas and Higgins 2004, NatureServe 2011), most snakes forage on small mammals, but may also consume birds, lizards, smaller snakes, and sometimes even amphibians (as reviewed by NatureServe 2011, SDGFP 2011). Plains garter snakes are more selective, relying primarily on amphibians as prey (Tuttle and Gregory 2009).

Photo 41. Northern leopard frog (photo by Royce Ballinger in Fischer et al. 1999).

Existing Threats and Stressors

The herpetofauna population in BADL is threatened by several stressors, including diseases. Chytridiomycosis, an emerging infectious disease caused by the chytrid fungus *Batrachochytrium dendrobatidis* (*Bd*), has received particular attention (Rodder et al. 2010), but its origin remains unknown (Weldon et al. 2004). In aquatic systems, chytrid fungi are usually found growing on algae or plankton (James et al. 2006). *Bd* is the only chytrid species known to feed on living animals, affecting primarily the skin of amphibians (Longcore et al. 1999). While it is still unclear exactly how the fungus causes mortality, research suggests its effects on the skin may disrupt electrolyte transport, causing a fatal imbalance (Voyles et al. 2009). Infected frogs may become lethargic, lose their righting response (turning back over when put on their backs), and remain in the hot sun when healthy amphibians would seek shade or water (Berger et al. 2000). Much of North America, southern Asia, western Europe, and the southernmost portions of the Southern Hemisphere are within the potential distribution of this chytrid fungus (Rodder et al. 2010), and it has been documented in South Dakota (Brown 2010). The rapid spread of this pathogen has been suggested as "the proximate cause of rapid decline and extinction of amphibian species across the globe" (Rodder et al. 2010, p. 201).

Another type of pathogen that has caused a decline in amphibian populations is iridovirus. Iridoviruses in the genus *Ranavirus* are primary pathogens associated with amphibian mortalities in North America (Jancovich et al. 2003). In a survey of 44 amphibian mortality events in North America over six years, Green et al. (2002) found that iridovirus was the cause in 57% of events. Tadpoles are most susceptible to the virus, with up to 100% mortality reported by Hyatt et al. (1998, as cited by Daszak et al. 1999).

Habitat loss and fragmentation are other increasing concerns for herpetofaunal species. Climate change can alter the annual hydrological cycle, increasing already rapid pond desiccation, which can in turn cause lack of recruitment, eventually leading to local extinctions (McMenamin et al. 2008). McMenamin et al. (2008) found the loss of pond habitat to be catastrophic to Yellowstone amphibian populations. Reptiles and amphibians are also negatively impacted by roads, mostly due to direct mortality (Smith et al. 1997, Fahrig and Rytwinski 2009). Outside of BADL, prairie rattlesnakes are often viewed as a dangerous species and may still be killed by local residents on private land (Smith et al. 1997).

Climate Change Vulnerability

Physiological Sensitivities. Most herpetofaunal species of BADL are near the latitudinal center of their ranges (Plate 19-Plate 25) and therefore would not likely be impacted by changing temperatures alone. However, herpetofauna have a range of physiological sensitivities to other aspects of climate change. Warmer temperatures combined with a lack of water may cause the most negative effects on amphibians. Brodkin et al. (1992, as cited by NatureServe 2011) found that mortality rates increased when frogs were subjected to crowding and higher temperatures. McMenamin et al. (2008) found amphibians in Yellowstone to be particularly vulnerable to climatic changes in early spring and late summer.

Reptiles are generally more adaptable to changes in climate than amphibians. However, extremely hot or cold conditions are particularly challenging for these animals (NPS 2011b). During the summer, snakes and lizards are generally active during the cooler parts of the day, seeking shade in the afternoon hours (NPS 2011b). In BADL the weather extremes may include temperatures ranging from over 38° C (100° F) in the summer to -29° C (-20° F) or colder in the winter (NPS 2011b), which can stress herpetofauna. Most snakes cannot tolerate prolonged exposure to direct sunlight with temperatures over 38° C (100° F) (SDGFP 2011).

Some reptiles, including the painted turtle, exhibit temperature-dependent sex determination. This means that the ratio of males to females in a clutch of young is determined by the temperature of the nest. For the western painted turtle, soil temperatures greater than 30° C result in all female young while soil temperatures from 20-27° C yield all male young (Ernst et al. 1994, as cited by Bandas and Higgins 2004). Both sexes are produced only if temperatures are below 20° C or between 28 and 30° C (Ernst et al. 1994, as cited by Bandas and Higgins 2004). Therefore climate change has the potential to skew sex ratios and influence the effective population size of painted turtles.

Generalist or Specialists. Most amphibians and reptiles are opportunistic feeders, but some species may have specific habitat requirements. Amphibians are primarily found in wetland areas and require water to reproduce. In a survey of Theodore Roosevelt National Park in southwest North Dakota, Hossack et al. (2005) found that many Great Plains amphibians breed in ephemeral pools. The climate changes projected for BADL may reduce wetland communities and other aquatic habitats (e.g., springs and seeps), which in turn shrinks suitable habitat for amphibians and some reptiles.

Interspecific Interactions. There are currently no known interspecific interactions involving herpetofauna in BADL that are likely to be negatively affected by climate change. However, bullfrogs (*Lithobates catesbeianus*) are encroaching on the park and, if they become established, could outcompete or prey on other amphibian species (Kats and Ferrer 2003, Smith and Keinath 2007).

Sensitive Habitat. Amphibians found in BADL typically rely on seasonal pools and springs. It is likely that climate change will have a negative effect on springs and seasonal pools, so amphibians that rely on ephemeral pools or permanent water sources fed by springs may be more vulnerable than reptiles. McMenamin et al. (2008) found that climatic change significantly altered the landscape of Yellowstone, resulting in a decline of wetlands and the disappearance of over half of the associated amphibian populations.

Frogs and some turtles overwinter in the sandy or muddy bottoms of ponds and streams (Bandas and Higgins 2004, Smith and Keinath 2007). There are currently very few bodies of water in the BADL region deep enough to not freeze to the bottom during winter (M. Haar, e-mail communication 19 October 2011). The drier conditions projected for BADL could reduce water volume in these bodies, increasing the likelihood that they would freeze all the way to the bottom, making overwintering more difficult for herpetofaunal species.

Non-Climate Stressors. Warmer temperatures may make conditions in BADL more suitable for *Batrachochytrium dendrobatidis* (*Bd*). Optimal temperatures for *Bd* growth are from 17-25° C (Piotrowski et al. 2004, as cited by Muths et al. 2008). Current minimum summer temperatures in the park average 14.4° C. If summer minimum temperatures (or fall and spring temperatures) increase, as predicted, conditions may become more favorable for the chytrid fungus. However, this infectious disease also has a thermal limit. The growth of *Bd* is inhibited at 28° C, and prolonged periods above 30° C are fatal to the fungus (Rodder et al. 2010). The current average maximum summer temperature in BADL is 29.6° C, and summer temperatures are projected to increase at least 2° C by 2050 and approximately 6° C by 2100. Studies have shown that *Bd*'s transmission efficiency is likely to decrease with rising temperatures, as warmer conditions reduce both fungal spore fertility and the time that zoospores are infectious (Rodder et al. 2010).

Another increasing threat to herpetofauna in BADL is habitat loss. Warmer temperatures and overall drier conditions can dry up aquatic habitats necessary for breeding (McMenamin et al. 2008). Climate change may alter the habitats in which amphibians are found, making them unsuitable for survival.

Photo 42. A newly hatched painted turtle (USFWS photo, in USFWS 2009).

Reproductive Potential for Adaptation. Herpetofaunal reproductive strategies are diverse in BADL. Amphibian breeding times are usually associated with certain water temperatures. The northern leopard frog will mainly lay eggs in early to mid-spring, but breeding peaks when water temperatures are at or above 10° C (Smith and Keinath 2007, NatureServe 2011). Female frogs may become sexually mature at one year, but most do not become mature until two to three years of age (Smith and Keinath 2007), which is characterized as a moderate rate of maturity. Clutch size varies widely, even within a population, ranging anywhere from 1,000 to 7,000 eggs depending on the size of the female (Smith and Keinath 2007), which is characterized as high fecundity. This may afford a high capacity to adapt to a changing climate. Painted turtle clutch size is approximately ten eggs, and adult female turtles will often produce up to two clutches a year (Gibbons 1967, Bandas and Higgins 2004); this is characterized as moderate fecundity. The average age for turtles to reach sexual maturity is four to six years of age; however, size is also a factor. Painted turtle males with plastron lengths over 81 mm and females with plastron lengths over 117 mm were found to be sexually mature (Gibbons 1967). This is characterized as a slow rate of sexual maturity. In many areas, eggs and hatchlings experience high mortality rates due to predation (Bandas and Higgins 2004), but the ability to lay more than one clutch per year gives painted turtles a moderate adaptability to environmental changes associated with climate change. For prairie rattlesnakes, litter size increases with the female's size (the average litter size is 15) (as reviewed by NatureServe 2011); this is characterized as moderate fecundity. However, adult females may not give birth every year, likely depending on nutritional status (Graves and Duvall 1993, as cited by NatureServe 2011). Survival tends to be low in first-year young (as reviewed by NatureServe 2011). Low survival of young and failing to reproduce in some years may decrease the ability of prairie rattlesnakes to recover from a population disturbance or to quickly adapt to rapid environmental changes associated with climate shifts.

Ecological Processes. Reptiles and amphibians respond differently to ecological processes. Of the ecological processes, fire will likely be most affected by climate change. Fire creates opposite effects in these two groups. The relatively impermeable skin of reptiles increases their tolerance to hot, dry conditions (Moseley et al. 2003), while amphibians' skin must remain moist to respire, making them extremely vulnerable to dry conditions (Moseley et al. 2003). Fires often remove debris and litter that create moist microhabitats within an ecosystem necessary for amphibian survival. Herpetofaunal species have the ability to avoid fire if needed; some amphibians can burrow into moist soils, while most reptiles will use mammal burrows for shelter (Moseley et al. 2003, NRCS 2005). Reptiles usually increase in diversity and abundance following application of prescribed fire; the increased bare ground cover in burned areas results in "greater thermoregulatory opportunities" (i.e., more ground surfaces receiving solar radiation) (Moseley et al. 2003, p. 475). Fire decreases the leaf litter layer, which reduces the amount of moist substrate used by amphibians (Moseley et al. 2005). Most salamander species will not return to an area until litter accumulates for several years after a burn (NRCS 2005). Moseley et al. (2003) found that low intensity prescribed fires do not affect most herpetofaunal populations. Herpetofaunal communities, in general, responded positively to fire over the long-term, showing increased species richness on sites that had burned within the past decade (NRCS 2005). A hot, high intensity burn, on the other hand, will reduce organic matter, resulting in elevated soil temperatures that are intolerable even for burrowing animals (NRCS 2005). Fire in BADL may increase in intensity if invasive plant species expand across the landscape, which could increase the vulnerability of some herpetofauna, particularly amphibians.

Summary of Vulnerability. Herpetofauna in BADL may experience different levels of stress due to climate change. Amphibians are and will remain severely stressed due to many factors including physiological sensitivities to temperature and their dependence on sensitive wetland and aquatic habitats (Table 38). The factors threatening reptiles include habitat fragmentation and low reproductive potential for adaption. The amphibians in BADL will likely be more vulnerable to climate change than the reptiles.

Table 38. A summary of the vulnerability characteristics of herpetofauna.

Characteristics	Displays Characteristic*	Notes
Physiological sensitivity	○	Leopard frogs show sensitivity to pH levels at and below 5.5.
Specialist	--	
Interspecific interactions	--	
Sensitive habitat	○	Amphibians require water sources for breeding
Non-climate stressors	○	Warmer temperatures may provide more favorable conditions for amphibian pathogens
Reproductive potential to adapt	○	The prairie rattlesnake may not produce a litter every year

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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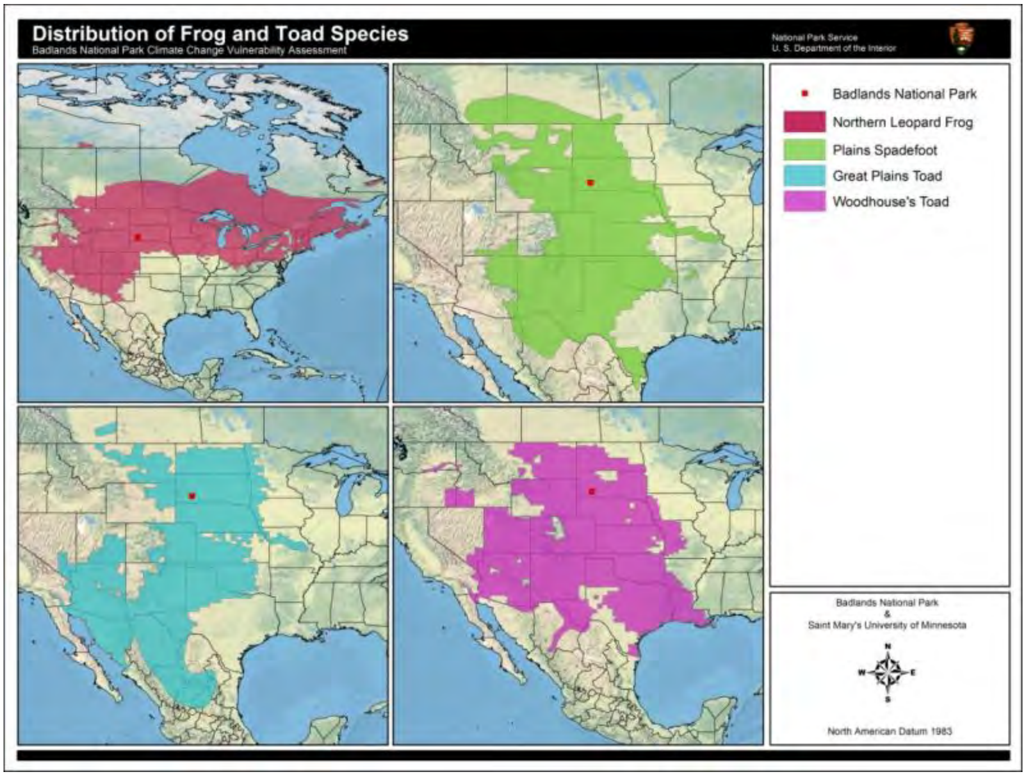

Plate 19. Distribution of four frog and toad species found in BADL (IUCN 2010).

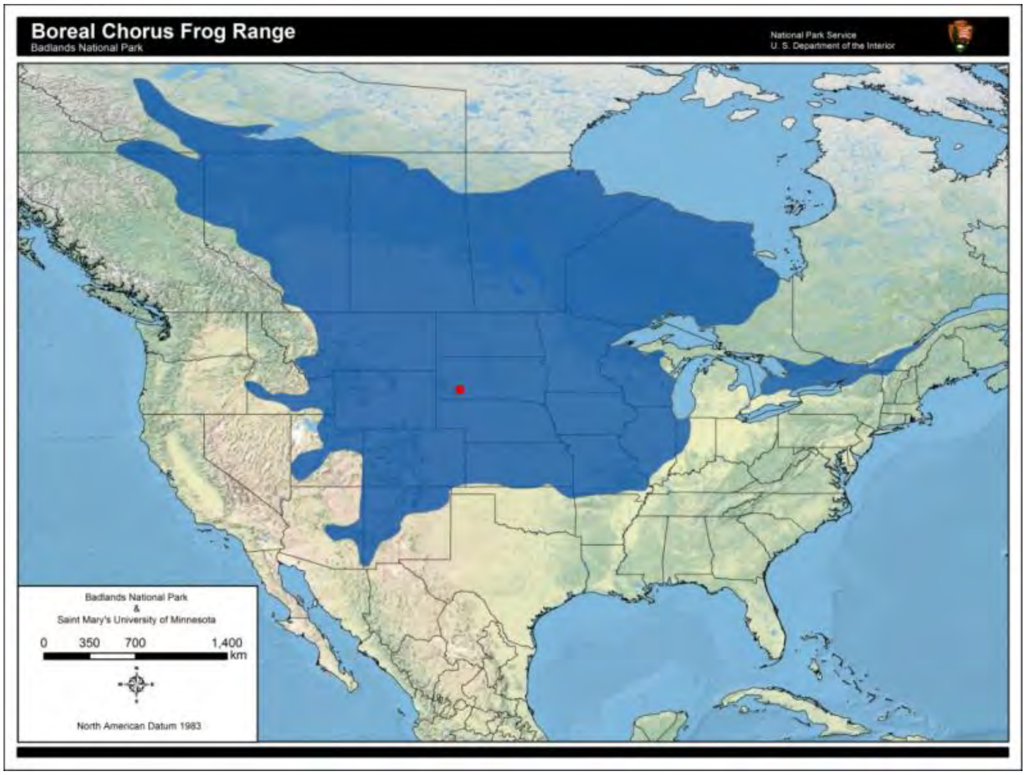

Plate 20. Boreal chorus frog distribution (IUCN 2010) (Location of BADL shown in red).

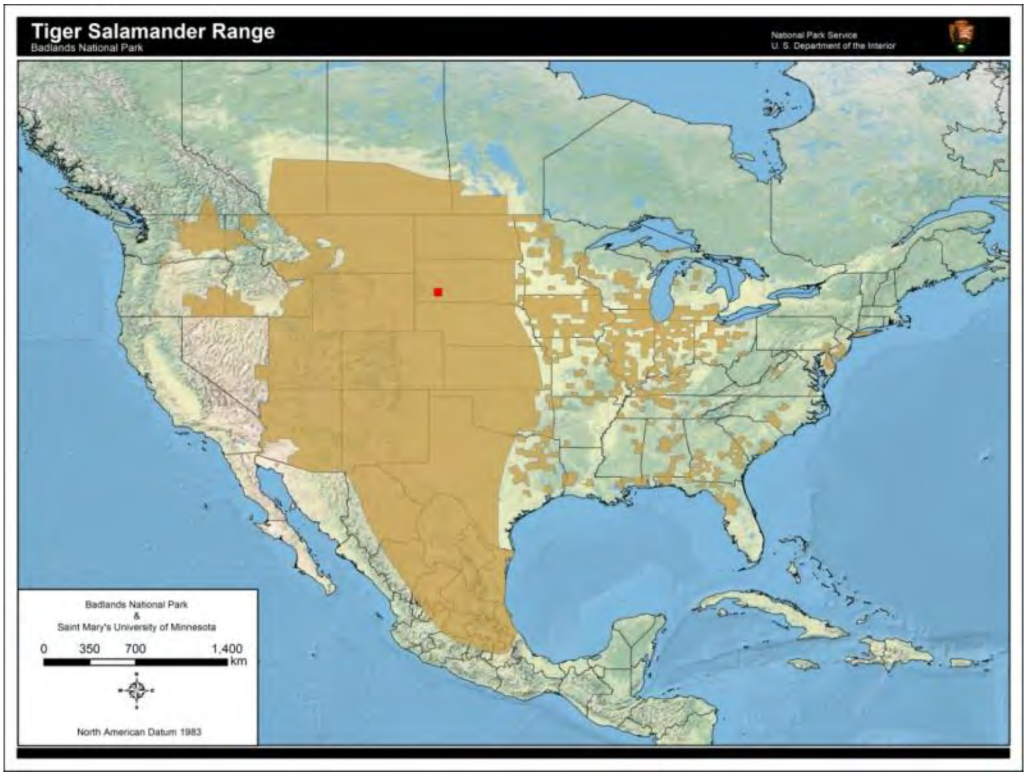

Plate 21. Tiger salamander distribution (IUCN 2010) (Location of BADL shown in red).

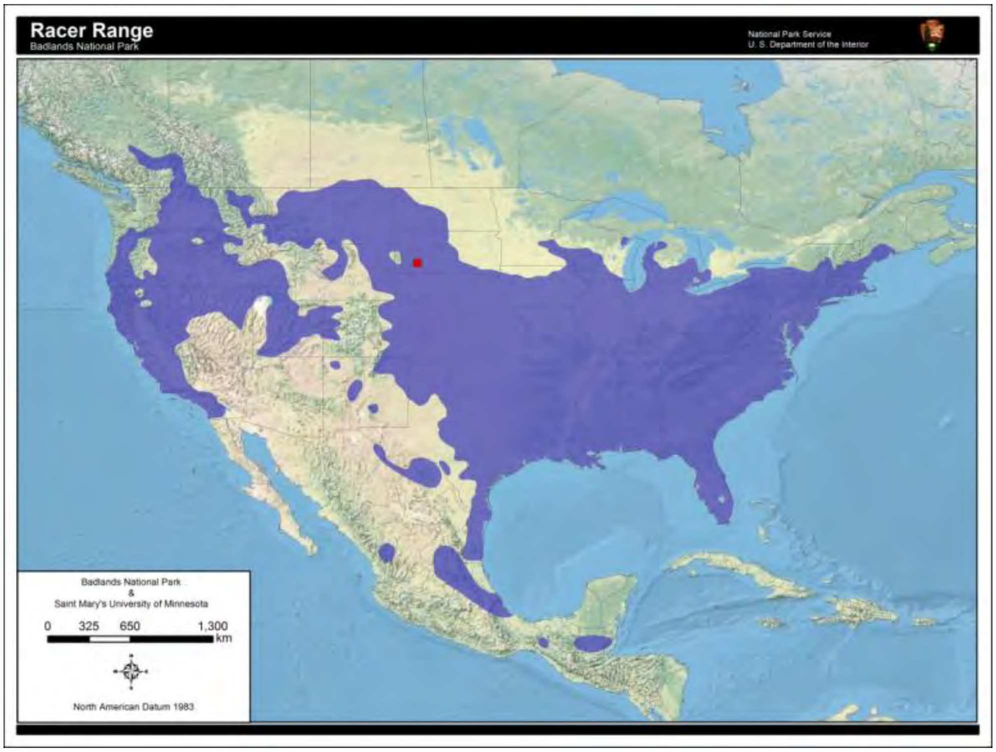

Plate 22. Racer distribution (IUCN 2010) (BADL shown in red).

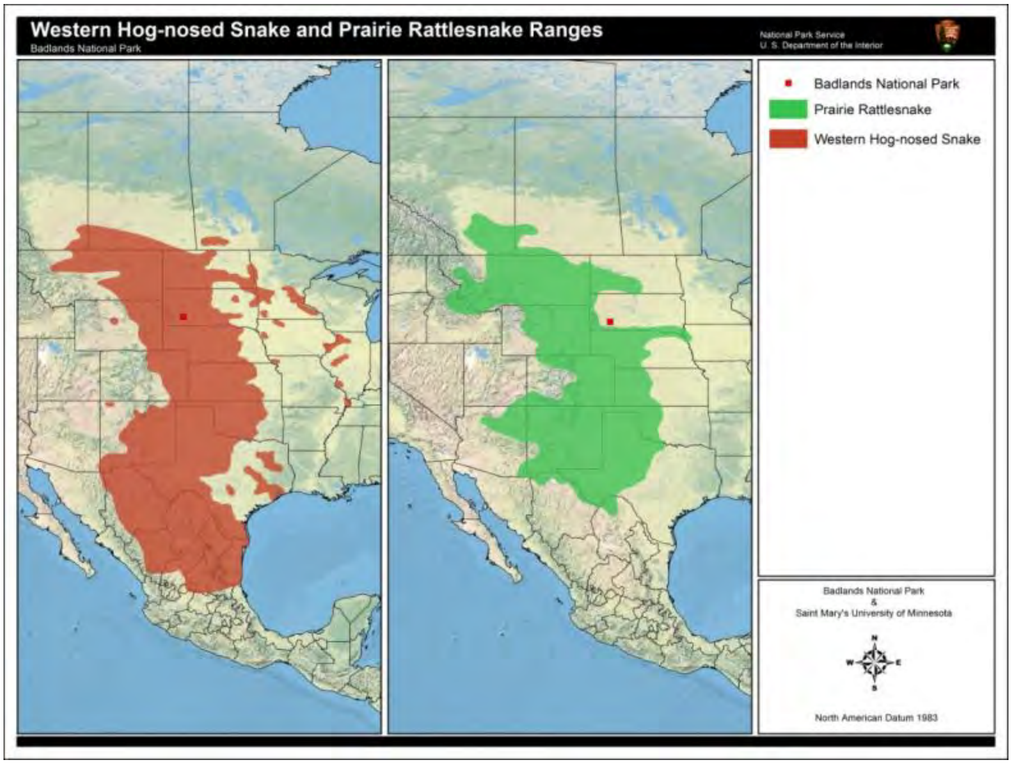

Plate 23. Distribution of the western hog-nosed snake and the prairie rattlesnake (IUCN 2010). Data are incomplete for prairie rattlesnake, as this species is common in the park and confirmed in all South Dakota counties west of the Missouri River (SDGFP 2011).

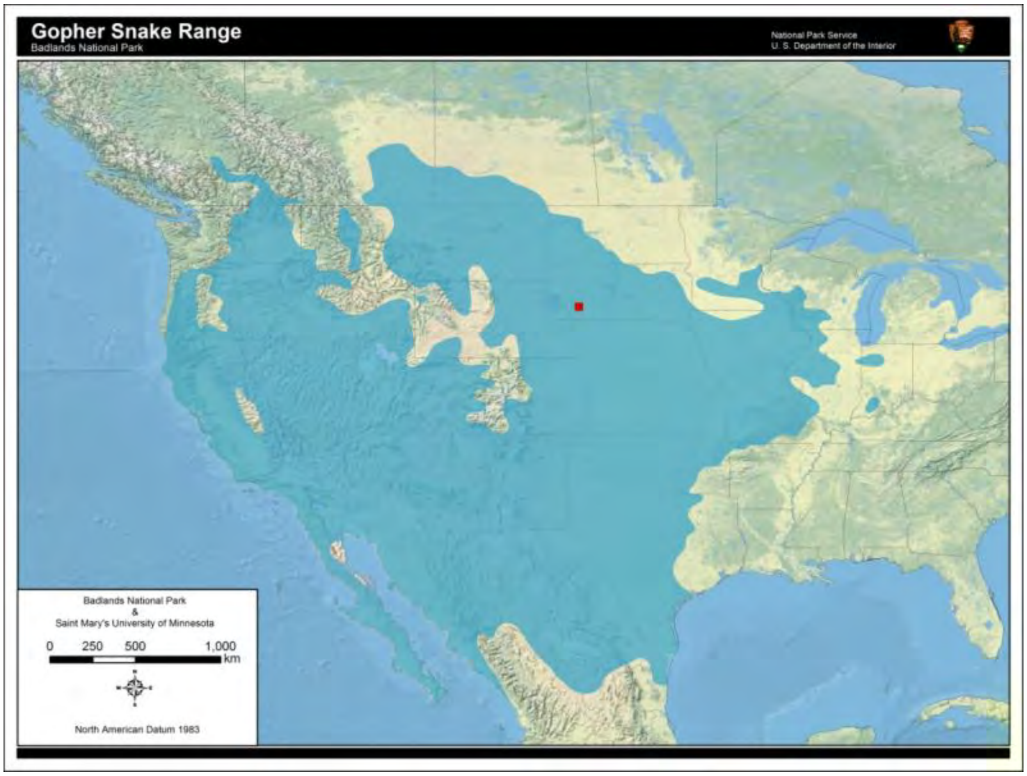

Plate 24. Gopher snake distribution (IUCN 2010) (BADL shown in red).

Plate 25. Plains garter snake distribution (IUCN 2010) (BADL shown in red).

4.3.9 Birds of Prey

Description

Birds of prey are natural predators that primarily hunt on the wing in BADL. Birds of prey such as the bald eagle (*Haliaeetus leucephalus*), peregrine falcon (*Falco peregrinus*), and burrowing owl (*Athene cunicularia*) were once widely distributed in the United States (Martell et al. 1993; as reviewed by NatureServe 2011), but rapid population declines warranted protection of the bald eagle and peregrine falcon through federal Endangered Species listing. In South Dakota, the bald eagle is currently on the state list of Threatened species (although it has been removed from the Federal Threatened and Endangered list), while the peregrine falcon is listed as Endangered in the state (SDGFP 2010). Although burrowing owls were a candidate for protection as a federally threatened species, they were never listed and are not listed as a threatened or endangered species within South Dakota (Klute et al. 2003). All three species are protected throughout North America by the Migratory Bird Treaty Act and have been recovering, supported by reintroductions in some areas of the U.S. (USFWS 2011a). The eagle population began to increase after DDT was banned in the early 1970s; the number of nesting territories nearly tripled between 1980 and 1990 (Kjos 1992). In North America, reintroduction efforts for peregrines have dated back to at least 1970 (USFWS 2003). Birds of prey found in BADL and their ecological affinity (preferred habitat) are shown in Table 39. This assessment will focus on the bald eagle and peregrine falcon, since they are designated T & E species in South Dakota, and the burrowing owl, which is a species of special concern for BADL management.

Table 39. Birds of prey of BADL and their ecological affinities (preferred habitats) (NPS 2010, Forrest et al. 2004). Species in bold were listed as "Birds of Conservation Concern" by USFWS (2008). All of these species are protected under the Migratory Bird Treaty Act (USFWS 2011a). The bald eagle and peregrine falcon are listed by the state of South Dakota as threatened and endangered, respectively.

Common Name	Scientific Name	Abundance	Residency	Ecological Affinity
Cooper's hawk	*Accipiter cooperii*	Uncommon	Migratory	Woodland
Northern goshawk	*Accipiter gentilis*	Rare	Migratory	Woodland
Sharp-shinned hawk	*Accipiter striatus*	Uncommon	Migratory	Woodland
Golden eagle	*Aquila chrysaetos*	Common	Breeder	Broad
Red-tailed hawk	*Buteo jamaicensis*	Common	Breeder	Broad
Rough-legged hawk	*Buteo lagopus*	Common	Resident	Broad
Broad-winged hawk	*Buteo platypterus*	Rare	Migratory	Woodland
Ferruginous hawk	*Buteo regalis*	Uncommon	Resident	Grassland
Swainson's hawk	*Buteo swainsoni*	Uncommon	Resident	Grassland
Northern harrier	*Circus cyaneus*	Uncommon	Resident	Grassland
Bald eagle	*Haliaetus leucocephalus*	Common	Resident	Broad
Turkey vulture	*Cathartes aura*	Common	Breeder	Broad
Prairie falcon	*Falco mexicanus*	Common	Breeder	Grassland
Peregrine falcon	*Falco peregrines*	Uncommon	Migratory	Misc.
American kestrel	*Falco sparverius*	Common	Breeder	Woodland
Short-eared owl	*Asio flammeus*	Uncommon	Resident	Grassland
Long-eared owl	*Asio otus*	Uncommon	Breeder	Woodland
Burrowing owl	*Athene cunicularia*	Common	Breeder	Grassland
Great horned owl	*Bubo virginianus*	Common	Resident	Woodland
Eastern screech-owl	*Megascops asio*	Uncommon	Resident	Woodland

Photo 43. Peregrine falcon (photo by Craig Koppie, USFWS, in SDGFP 2011) and bald eagle (USFWS photo, USFWS 2011b).

Birds of prey are found in various habitats in North America. For example, bald eagles commonly nest in cottonwoods in South Dakota, but have been known to nest in pines, spruce, firs, cottonwoods, oaks, poplars, and beech trees (Aron 2005; as reviewed by NatureServe 2011). Large trees with strong, level branches and in close proximity to water are often selected (Aron 2005). Ideal habitats for peregrine falcons include undisturbed tall cliffs with an extensive view that also offer protection from severe weather and predators (Sergio et al. 2004, Haskell and Kreitinger 2010). The burrowing owl is native to the short, open grasslands in western North America (Martell et al. 1993). Prairie dog towns are a significant feature necessary for ideal burrowing owl habitat; the owls also utilize old badger burrows for nests and protection (MacCracken et al. 1985, Martell et al. 1993).

Birds of prey also show great variety in their diets. Bald eagles feed opportunistically on fish, waterfowl, various mammals, and carrion (Terres 1980). Burrowing owls found in southwestern South Dakota also have an assorted diet, which includes mammals (e.g., deer mice), insects, and sometimes reptiles and small birds (MacCracken 1985). Peregrine falcons feed primarily on birds “up to the size of small geese” (SDGFP 2011, p. 2).

Existing Threats and Stressors

Birds of prey face a number of threats and stressors including environmental contaminants, secondary poisoning, predation and habitat loss. Environmental contaminants have caused major declines in bald eagle and peregrine falcon populations across the United States. The recovery of the eagle population in recent years is largely due to successful reproduction following the ban of the chemical compound DDT; since the ban, DDT’s effects have decreased significantly and are expected to continue declining (Aron 2005). However, environmental contaminants still affect eagles in some areas, such as the Great Lakes region, where these birds are experiencing eggshell thinning, decreased hatching success, and documented cases of lead poisoning (Davis 2011). Peregrine falcons were also greatly affected by DDT and PCB contaminants. Organochlorine pesticides, including DDT, have been the main cause for the decline of peregrine falcons (Ambrose et al. 2000). Even after DDT was banned, eggshell thickness remained a concern. A study by Ambrose et al. (2000), conducted from 1991-1995, found that eggshells were still thinner than pre-DDT era eggs by 10-12%; this indicates that DDT and its metabolite DDE are still present in eggs years after the ban (Ambrose et al. 2000). Peregrine falcon and bald eagle populations increased in the U.S. after the ban of DDT and the initiation of species reintroduction efforts (Ambrose et al. 2000, Aron 2005). While reproductive failure due to pesticide contamination is now rare in most peregrine populations, there are still high levels of organochlorine in some areas (Ambrose et al. 2000).

Secondary poisoning is another threat to birds of prey. Bald eagles have died because they consumed contaminated carcasses that were meant to poison other predators (Aron 2005). Burrowing owls sometimes died after consuming poisoned prey when strychnine and compound 1080 were used to poison prairie dog towns (MacCracken 1985). Eagles often get lead poisoning from lead shot used to hunt waterfowl, rabbits, and deer. In the fall of 2004 and winter of 2005, wildlife rehabilitators in Iowa noticed an increase in the number of bald eagles admitted for treatment, and most of the cases were associated with lead poisoning or exposure (Neumann 2009). Thirty-nine of 62 bald eagles tested for lead in Iowa from 1 January 2004 to 30 April 2008 showed potentially lethal lead levels (Neumann 2009).

Predation may also affect the population success of various birds of prey. Adult bald eagles do not have natural predators, but raccoons (*Procyon lotor*) and great horned owls (*Bubo virginianus*) may be a threat to fledglings in the nest (USFWS 1999). Great horned owls are also considered a nest predator of peregrine falcons in the U.S. (as reviewed by NatureServe 2011). In BADL, burrowing owl predators include badgers, coyotes, bobcats, hawks, and falcons (Haug and Didiuk 1993, Leupin and Low 2001; as cited by Klute et al. 2003).

Photo 44. Burrowing owls (USFWS photo, in USFWS 2010).

Birds of prey are also vulnerable to habitat loss and fragmentation. One of the greatest sources of habitat loss in the Great Plains is energy development (e.g., oil, natural gas, and wind) (RMBO, David Hanni, Science Division Director, written communication, 28 October 2011). Bald eagles and peregrine falcons are relatively tolerant of human activity; however, chronic disturbance, such as urban expansion, can cause the abandonment of those areas by eagles (Fraser 1985, as cited by NatureServe 2011). Prairie dog poisoning may have been responsible for the burrowing owl decline in the Great Plains (Martell et al. 1990), primarily due to a decrease in the number and coverage of suitable burrows available for habitat (Bakker 2005).

Climate Change Vulnerability

Physiological Sensitivities. Some birds of prey have large migratory ranges throughout North America. Because of these migratory tendencies, some species may be able to escape exposure to unfavorable climatic conditions and select more suitable habitats if their range is not fragmented (Matthews 2008). BADL is located in the central part of the bald eagle’s overall range and in the northern part of the burrowing owl’s breeding range (Figure 27; Ridgely et al. 2007). Climate warming may cause these two species and other similar species to shift their ranges accordingly. Peregrine falcons are occasional visitors to the park, which is near the latitudinal center of the species’ overall range (Figure 27).

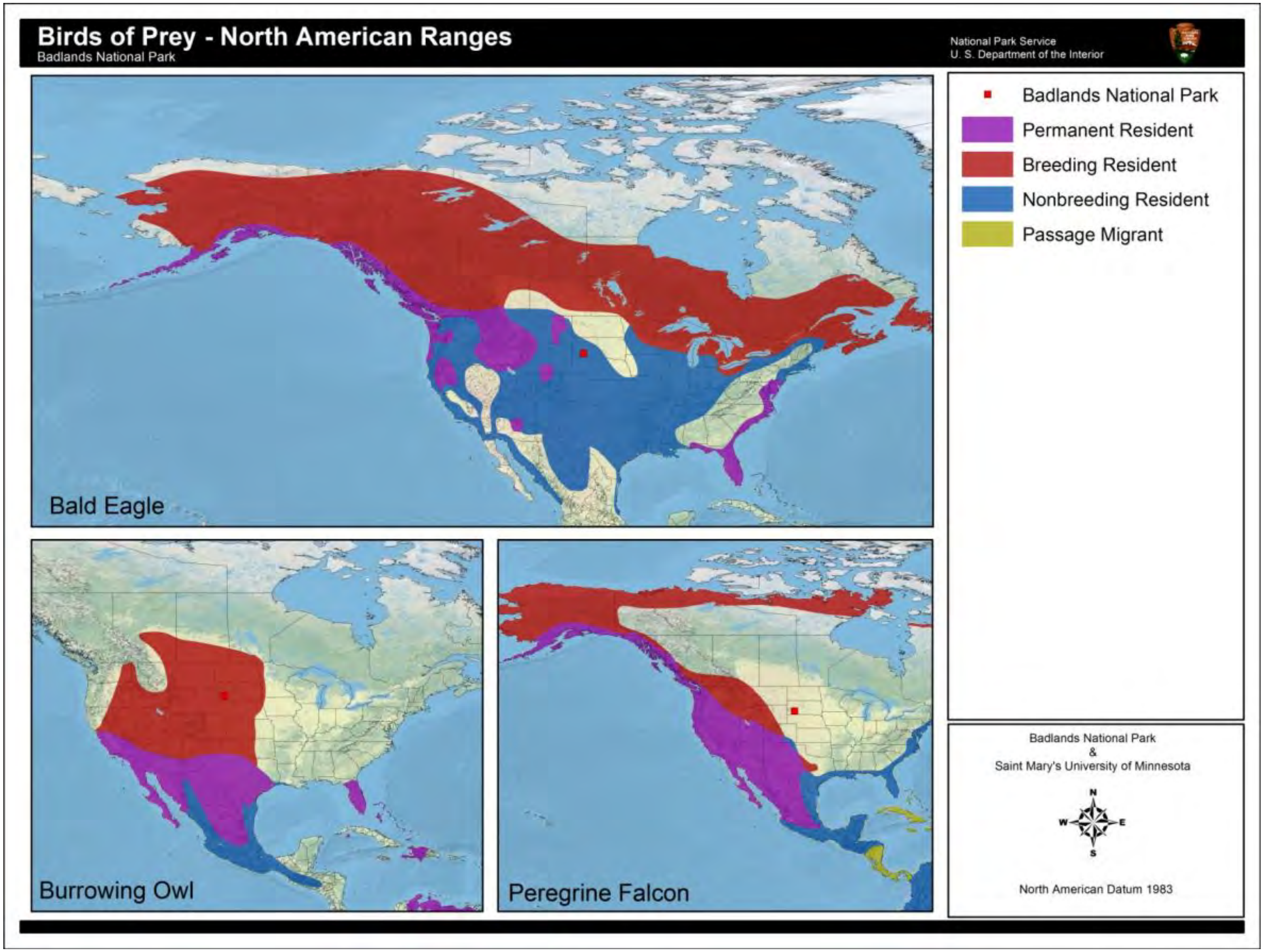

Figure 27. North American distributions of bald eagle (top), burrowing owl (bottom left), and peregrine falcon (bottom right) (Ridgely et al. 2007). Although the peregrine falcon's range does not extend over BADL on this map, the species has been observed there occasionally.

Generalist or Specialist. Birds of prey generally have a widely varied diet; however, they may require a specific habitat to hunt successfully. Peregrine falcons commonly select tall cliffs for nesting to protect their clutch from predators and for hunting opportunities (Sergio et al. 2004). Peregrines also typically nest at an intermediate elevation on cliffs away from eagles and other predators (Sergio et al. 2004). The cliffs at BADL likely are not tall enough to provide suitable peregrine falcon nesting habitat. Bald eagles have a relatively specific breeding habitat including areas close to rivers, lakes, or other bodies of water capable of supporting abundant prey (Green 1985); these breeding habitat requirements are unlikely to be met in arid regions such as BADL. Burrowing owls typically utilize a very specific habitat in the grasslands. They are commonly found in prairie dog towns, residing in old burrows, or living in old badger holes (Bent 1938, as cited by Martell et al. 1993).

Interspecific Interaction. Burrowing owls are commonly associated with prairie dog towns. The decline of the burrowing owl populations has been attributed to the large reduction in prairie dog numbers and total area of prairie dog towns (Bakker 2005). Since prairie dogs do not seem to be particularly vulnerable to climate change (see section 4.3.1), this interaction, however, should not be negatively affected by climate change.

Sensitive Habitat. Birds of prey are seen as indicator species for habitat health because of their sensitivity to “ecosystem dysfunctions” (Sergio et al. 2004, p. 818, citing Newton 1979). The burrowing owl relies on grasslands and particularly prairie dog towns; these habitats do not seem to be sensitive to climate change, which means the burrowing owl may be less vulnerable in that respect (Martell et al. 1993). Bald eagles exhibit a preference for woodlands near water, which are rare in BADL and are highly vulnerable to climate change. Peregrine falcons tend to utilize a variety of habitats, and thus may not rely on habitats in BADL that are sensitive to climate change.

Non-Climate Stressors. The non-climate stressors to birds of prey in BADL are minimal and are not expected to be exacerbated by climate change.

Reproductive Potential for Adaptation. Reproductive strategies vary slightly among birds of prey, depending on their size. Incubation periods average four to five weeks (Klute et al. 2003, Aron 2005, SDGFP 2011). The bald eagle reaches sexual maturity at about four to six years of age with an average clutch size of one to three eggs (Aron 2005); this is characterized as slow maturity and moderate fecundity. Peregrines mature at one to three years of age, and typically have clutches of three to four eggs (SDGFP 2011); this is characterized as a moderate rate of maturity and moderate fecundity. Burrowing owls mature at one year and produce a clutch of six to seven eggs (Klute

Photo 45. Burrowing owl chicks (photo by Bruce Taubert, in AZ Burrowing Owl Working Group 2007).

et al. 2003); this is characterized as a rapid rate of maturity and high fecundity. The three species have a brood annually, with the exception of the bald eagle, which may not produce a clutch every year (as reviewed by NatureServe 2011). Overall, bald eagles have a low reproductive potential to adapt to rapid changes; given the slow rate of sexual maturity, few offspring produced in each clutch, and the possibility of not breeding yearly, bald eagle populations may have difficulty rebounding after an environmental disturbance and slow generation time may not allow eagles to easily adapt to rapid changes in climate. Peregrines have a moderate reproductive potential to adapt, meaning the moderate rate of regeneration may help a population rebound more easily following a sudden disturbance or rapid climatic changes. Burrowing owls have a high reproductive potential, given a fast generation time, making it more likely that the species could evolve quickly to adapt to climatic changes.

Ecological Processes. Birds of prey are subject to several ecological processes in BADL. Burrowing owls inhabit old prairie dog burrows, and prairie dog towns experience grazing by both prairie dogs and wild ungulates. The effects of grazing likely benefit the burrowing owls by maintaining suitable habitat. Additionally, a study by Wright and Bailey (1982, as cited by NPS 2004) found that owl habitat can be maintained through prescribed burning since fire reduces vegetation height and reduces woody species invasion. The authors found that fire may increase prey abundance for burrowing owls and other birds of prey as well (Wright and Bailey 1982, as cited by NPS 2004).

Summary of Vulnerability. The birds of prey in BADL appear to be slightly vulnerable to climate change (Table 40). Birds of prey that have extensive migratory ranges may have a slight physiological sensitivity to harsh climate; however, these species may be able to shift their ranges accordingly in response to climate change. Some species, such as the burrowing owl, may have specialized habitat needs that make them more vulnerable to climate change. Most of these bird species are not year-round residents in BADL, so they do not rely solely on habitat within the park, which gives them some adaptive ability. Reproductive potential is moderate to high, with the exception of the bald eagle, which may not lay a clutch every year and sexually matures later than most bird species. Most birds of prey, in general, do not seem to rely on habitats that are particularly sensitive to climate change.

Table 40. A summary of the vulnerability characteristics of the birds of prey.

Characteristics	Displays Characteristic*	Notes
Physiological sensitivity	○	Migratory
Specialist	○	Burrowing owl is a specialist to burrows in grasslands
Interspecific interactions	--	
Sensitive habitat	○	Bald eagles prefer large trees near water
Non-climate stressors	--	
Reproductive potential to adapt	○	Bald eagles may not lay a clutch every year

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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4.3.10 Grassland Birds

Description

Photo 46. Western meadowlark, one of the common grassland birds of BADL (NPS photo, from NPS 2010b).

Grassland birds are those species naturally adapted to native grasslands and prairie ecosystems throughout North America, each with its own unique set of habitat requirements (NRCS 1999). Large blocks of undisturbed grassland allow most grassland birds to fulfill their feeding, escape, courtship, nesting, and brood-rearing requirements during the nesting season (NRCS 1999). However, many grassland birds have experienced population declines nationwide due to several factors including habitat loss (NRCS 1999, Forrest et al. 2004). The North American Bird Conservation Initiative (NABCI) found that North American grassland bird species are among the fastest and most consistently declining species on the continent (NABCI 2009). NABCI (2009) reported that 48% of grassland species are of conservation concern, and 55% are showing significant population declines. The grassland bird species found in BADL are shown in Table 41.

Table 41. Grassland birds of BADL (NPS 2010a, Forrest et al. 2004). Species in bold were listed as "Birds of Conservation Concern" by USFWS (2008). Species with a * were identified as "species of regional importance" by the Rocky Mountain Bird Observatory's Partners in Flight program.

Common Name	Scientific Name	Abundance	Residency
Sharp-tailed grouse*	*Tympanuchus phasianellus*	Common	Breeder
Upland sandpiper	*Bartramia longicauda*	Uncommon	Resident
Long-billed curlew	*Numenius americanus*	Uncommon	Resident
Common poorwill	*Phalaenoptilus nuttallii*	Uncommon	Resident
Horned lark	*Eremophila alpestris*	Common	Breeder
Sprague's pipit*	*Anthus apragueii*	Uncommon	Resident
Chestnut-collared longspur*	*Calcarius ornatus*	Uncommon	Resident
Clay-colored sparrow	*Spizella pallida*	Uncommon	Migratory
Field sparrow	*Spizella pusilla*	Common	Resident
Vesper sparrow*	*Pooecetes gramineus*	Common	Resident
Lark sparrow	*Chondestes grammacus*	Common	Breeder
Lark bunting*	*Calamospiza melanocorys*	Common	Breeder
Savannah sparrow	*Passerculus sandwichensis*	Uncommon	Migratory
Grasshopper sparrow*	*Ammodramus savannarum*	Common	Breeder
Dickcissel*	*Spiza americana*	Uncommon	Resident
Bobolink	*Dolichonyx oryzivorus*	Uncommon	Resident
Western meadowlark*	*Sturnella neglecta*	Common	Breeder
Brewer's blackbird	*Euphagus cyanocephalus*	Common	Resident

This assessment highlights two species selected by the project team as representative of the region's grassland birds: sharp-tailed grouse (*Tympanuchus phasianellus*) and lark bunting (*Calamospiza melanocorys*). Sharp-tailed grouse, considered indicators of overall grassland ecosystem health (SDGFP 2011), prefer mid-height or tallgrass prairies with sparse brush cover for nesting and brood rearing (Forde 1983; Johnsgard 1983, as cited by Hanowski et al. 2000) but also require open areas with low vegetation for lek sites and breeding (Prose 1987, as cited by Hanowski et al. 2000). The lark bunting, in contrast, prefers the open habitat of sparser short grasslands (Johnson 2000).

Photo 47. Male sharp-tailed grouse (left, NPS photo by Barb Muenchau) and lark buntings (photo by Doug Backlund from Neudorf et al. 2006).

The diets of grassland birds are "as diverse as the type of birds that inhabit grassland ecosystems" (NRCS 1999, p. 3). Sharp-tailed grouse young consume primarily insects (Kobriger 1965, as cited by Forde 1983) while adults eat primarily plant materials including seeds, berries, and buds (SDGFP 2011). The buds of trees and shrubs may be an important winter food source for some populations (Ulliman 1995, as cited by NatureServe 2011). Lark buntings feed primarily on seed (mostly grass) but also consume other plant materials and insects (Baldwin et al. 1969, Baldwin 1973, as cited by Neudorf et al. 2006). Their nestlings are fed only insects (Creighton and Baldwin 1974, as cited by Neudorf et al. 2006).

Existing Threats and Stressors

Grassland birds face several threats in BADL and across the Great Plains. The largest of these is habitat loss, fragmentation, and degradation (Neudorf et al. 2006). Loss and degradation of grassland breeding habitat has affected both the sharp-tailed grouse and lark bunting, and is "likely the largest factor contributing to the decline in many grassland bird species" (NRCS 1999, p. 2). While many grassland birds "do not require native vegetation for breeding habitat" (NRCS 1999, p. 3), others are impacted by the invasion of non-native species. For example, brome grasses and Kentucky bluegrass are thought to provide lower quality habitat for sharp-tailed grouse than native plant communities (SDGFP 2011). Norton (2005) found that grouse broods avoided smooth and Japanese brome stands. The loss of wintering habitats may also have played a role in grassland bird population declines (NRCS 1999).

Nest predation is a major stressor for some grassland bird species, including the lark bunting and sharp-tailed grouse, and can be exacerbated by habitat fragmentation and degradation (Neudorf et al. 2006, Sjogren and Corace 2006, Yackel Adams et al. 2007). Possible nest predators in the BADL area include coyote, swift fox, badger, ground squirrels, and several snake species (Yackel Adams et al. 2007). Fledglings are also preyed upon by snakes and mammals as well as birds of prey (Yackel Adams et al. 2006). Another stressor for passerine grassland birds is brood parasitism by brown-headed cowbirds (*Molothrus ater*), which can be exacerbated by habitat loss and fragmentation (Davis and Sealy 2000, as cited by Neudorf et al. 2006).

Climate Change Vulnerability

Physiological Sensitivity. Increased temperatures may cause heat stress in grassland birds, while decreased precipitation could lead to water stress (George et al. 1992). However, migratory grassland birds have the potential to shift their breeding grounds if suitable habitat is available in a less arid climate. BADL is near the southern edge of the sharp-tailed grouse's range, suggesting that populations in and around the park may be vulnerable to climate change (Figure 28). The park is near the center of the lark bunting's breeding range and in the northern portion of the species' overall range (Figure 29).

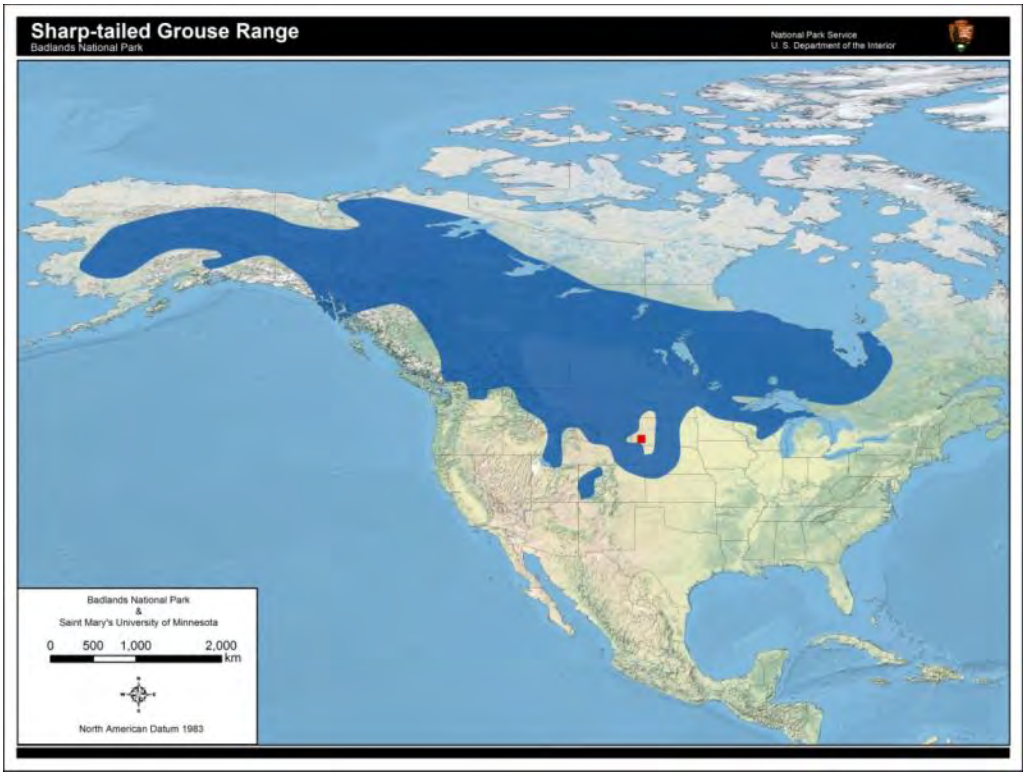

Figure 28. Distribution of sharp-tailed grouse (Ridgely et al. 2007) (BADL shown as red square). Data are incomplete for sharp-tailed grouse, as this species is common in the park (NPS 2010c).

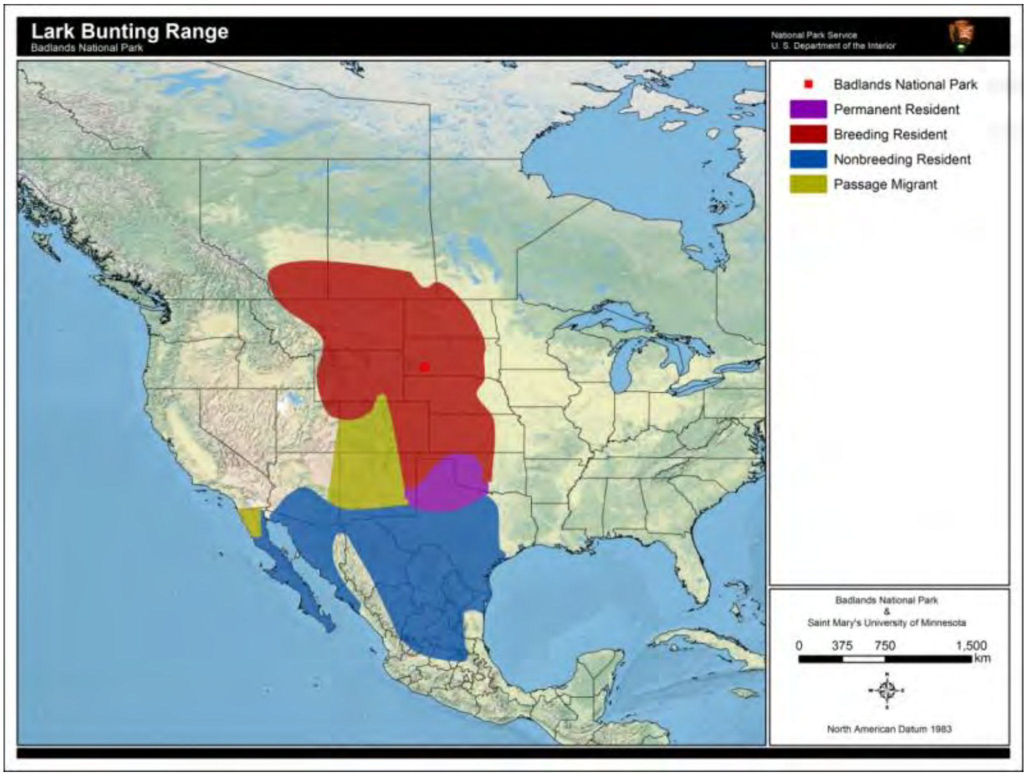

Figure 29. Distribution of lark bunting (Ridgely et al. 2007) (BADL shown as red square).

Generalist vs. Specialist. Grassland birds forage on a variety of seeds or insects, but rely to some degree on grassland communities for habitat. While some species can forage and nest in a variety of grasslands or even agricultural fields, others may have specialized habitat needs (e.g., short or tall grasses, nearby shrub coverage, litter layer thickness).

Interspecific Interactions. Many grassland birds have evolved within and adapted to the environment created by bison movements and grazing (Carter 2011). For example, bison grazing was found to enhance the abundance of birds such as upland sandpipers and grasshopper sparrows in tallgrass prairie (Powell 2006). Some grassland birds, such as the horned lark, also associate with prairie dog towns, because their grazing habits maintain a more open grassland habitat (NPS 2010a). However, there are no known interspecific interactions involving grassland birds in BADL that are expected to be negatively affected by climate change.

Sensitive Habitat. Grassland birds rely primarily on grassland habitat for nesting and breeding in BADL and the neighboring national grasslands, as well as other areas of the U.S. (NRCS 1999). Grassland communities in the park are not expected to be particularly vulnerable to climate change (see section 4.1.3). However, the potential shift in grassland plant composition (from mid-height to shorter grasses) that may occur as a result of climate shifts in the region may favor some grassland bird species over others.

Non-Climate Stressors. The conversion of native grasslands to invasive annual grasslands, which could be favored by climate change (Dukes and Mooney 1999, Kreyling et al. 2008), is likely to have a negative effect on some grassland bird species, including the sharp-tailed grouse

(SDGFP 2011). A shift from mixed-height to shorter grasslands could also increase the exposure of ground-nesting grassland birds to nest predation and brood parasitism.


Photo 48. Female sharp-tailed grouse (USFWS photo, from USFWS 2011).

Reproductive Potential for Adaptation. Grassland bird reproductive potential varies by species. The sharp-tailed grouse is a lek breeder and exhibits moderate to high fecundity. Its clutch size averages 12-14 eggs (Norton 2005). Incubation lasts about 23 days after all the eggs in the brood have been laid (SDGFP 2011). A second or third brood is possible if the initial nest is ruined; however, a renest attempt will result in smaller clutch and egg size (SDGFP 2011). Females are sexually mature by one year of age (Connelly et al 1998, as cited by Sjogren and Corace 2006), which is characterized as rapid sexual maturity.

The lark bunting has moderate fecundity levels, with average clutch sizes of four to five eggs (Terres 1980, as cited by NatureServe 2011). The lark bunting is known as a "single-brood" breeder due to early migratory departure after breeding season, but it has the ability to raise two broods if breeding begins early in the season (Shane 2000, as cited by Yackel Adams et al. 2007, p. 580). Subsequent clutches are usually smaller (Yackel Adams et al. 2007). The incubation period is about 11 days (Yackel Adams et al. 2007). Once the nestlings fledge, the mated pair split the brood to care for them separately for an additional three weeks (Yackel Adams et al. 2001, 2007), which may increase survival rates over those that only have one mate protecting the entire nest.

Ecological Processes. Ecological processes can have both negative and positive effects on grassland birds. Although fire is generally considered beneficial to grassland communities, it can negatively impact some birds if not managed. Johnson (1997) studied the effect of burning on birds in a North Dakota mixed-grass prairie. He found that some grassland bird species, such as the upland sandpiper, preferred recently burned grasslands while others (including the bobolink, grasshopper sparrow, and western meadowlark) avoided recently burned areas but increased in density 2-5 years post-burning. For sharp-tailed grouse, fire is considered "the key natural-history disturbance process" for creating and maintaining the patchy habitat that they require (Sjogren and Corace 2006, p. 11).

Grazing regimes tend to have positive effects on grassland birds and their habitat, although heavy grazing can be detrimental (Bakker 2005). Grazing bison in the western United States were once considered the "natural means of grassland management", and many grassland birds benefit from controlled grazing areas (NRCS 1999, p. 5). The sharp-tailed grouse prefers lightly grazed areas (Hillman and Jackson 1973, as cited by Roersma 2001) and avoids nesting in pastures occupied by livestock (Sedivec 1994, as cited by Natureserve 2011). Lark buntings "respond positively to moderate grazing in taller grasslands but negatively to heavier grazing in short grasslands" (Bakker 2005, p. 42).

Drought can also negatively affect grassland birds, especially the lark bunting. Researchers have found that grassland bird densities are influenced by vegetation structure and coverage, which could change drastically under drought conditions (George et al. 1992). Yackel Adams et al. (2006) found that lark bunting fledgling survival was lower during severe droughts, perhaps due to reduced food availability. Predation may also increase if vegetation is suppressed by drought conditions (Yackel Adams et al. 2006). In addition, Yackel Adams et al. (2007) observed that the lark bunting breeding season ended two weeks earlier during a severe drought, while Skagen and Yackel Adams (in review) found that clutch size was negatively affected by both decreased seasonal precipitation and higher temperatures.

Summary of Vulnerability. Many of the grassland bird species in BADL have experienced population declines and may experience further declines due to climate change. Most grassland birds can tolerate habitats with non-native grasses; however, species like the sharp-tailed grouse will likely lose suitable habitat if invasive plants begin to dominate the grasslands (Table 42). There are no known interspecific interactions involving grassland birds that seem to be negatively affected by climate change. Reproductive potential to adapt to environmental changes is moderate for most grassland birds, but may be higher for some, such as the sharp-tailed grouse. However, predation can have a serious impact on nest success for many of these ground-nesting birds.

Table 42. A summary of the vulnerability characteristics of grassland birds.

Characteristics	Displays Characteristic*	Notes
Physiological sensitivity	○	Possible sensitivity with such large migration patterns in most grassland birds
Specialist	○	Some species have specialized habitat needs within grasslands
Interspecific interactions	--	
Sensitive habitat	--	
Non-climate stressors	●	Invasives can decrease habitat quality; shift in vegetative composition may increase nest predation and brood parasitism
Reproductive potential to adapt	--	

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic, -- indicates species does not exhibit characteristic

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4.3.11 Culturally Significant Species

* The species addressed here are included in recognition of their importance to local Native American tribes. They are a diverse group, both taxonomically and ecologically, and as a result the assessment method used in previous sections was not feasible for this group. The evaluation of their vulnerability will be a more abbreviated narrative discussion.

Description

BADL is unique in that two units of the park, the Stronghold District and the Palmer Creek Unit, lie within the Pine Ridge Indian Reservation and are managed under a cooperative agreement between the National Park Service and the Oglala Lakota (Sioux) Tribe (White 2002). The cultural heritage of the Lakota and other Native American groups is connected to the lands and resources in and around BADL (White 2002). There are many faunal and floral species of cultural importance to the Lakota Sioux Tribe for traditional foods, medicine, and ceremonial use. It is therefore important to understand how climate change may affect these species, and by association, tribal heritage. Culturally significant wildlife species include, but are not limited to, bison, porcupine (*Erethizon dorsatum*), badger, golden eagle, bald eagle, rough-legged hawk, red-tailed hawk, and trumpeter swan (*Cygnus buccinator*) (Table 43). Additional information on BADL ethnographic resources will be presented in section 4.5.1.

Table 43. Culturally important wildlife species in BADL (NPS 2010a, 2010b) and their ecological affinities (preferred habitats) (Forrest et al. 2004). This is a selection of species considered to be culturally important and is not intended to be a comprehensive list.

Common Name	Scientific Name	Abundance	Residency	Ecological Affinity
Bison	*Bison bison*	Common	---	Grassland
Porcupine	*Erethizon dorsatum*	Unknown	---	Widespread
Badger	*Taxidea taxus*	Uncommon	---	Widespread
Golden eagle	*Aquila chrysaetos*	Common	Breeder	Broad
Bald eagle	*Haliaeetus leucocephalus*	Common	Resident	Broad
Red-tailed hawk	*Buteo jamaicensis*	Common	Breeder	Broad
Rough-legged hawk	*Buteo lagopus*	Common	Resident	Broad
Trumpeter swan	*Cygnus buccinator*	Uncommon	Breeder	Limnic

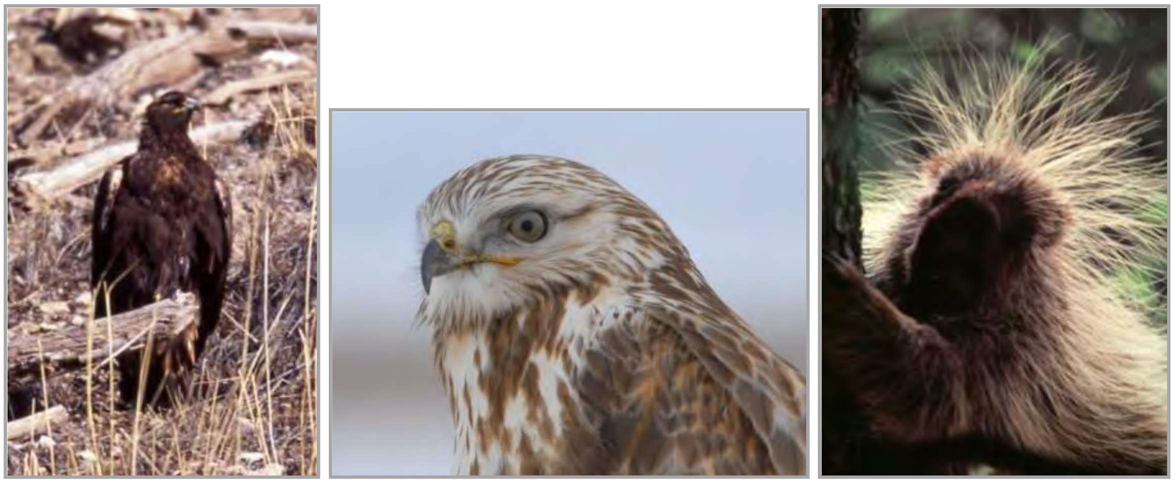

Photo 49. Golden eagle (NPS photo by J. Peaco, 2003), rough-legged hawk (USFWS photo in NPS 2010c), and porcupine (NPS photo by R. Williams in NPS 2007).

Existing Threats and Stressors

Culturally significant species in BADL face several non-climate stressors. Human disturbance in and around BADL have caused many common species' populations to decline. Urbanization has caused habitat loss and animal control efforts have led to the extirpation of some species (White 2002). Threats to the golden eagle, red-tailed hawk, and roughed-legged hawk, much like the bald eagle and peregrine falcon (see section 4.3.9), include poison (strychnine) intended for coyotes, occasional shootings, and habitat loss from conversion to agriculture and suburban land uses (as reviewed by NatureServe 2011). Golden eagles are also susceptible to electrocution due to collisions with power lines (Biosystems Analysis 1989, as cited by NatureServe 2011). Trumpeter swans are threatened by lead poisoning (from ingesting discarded lead shot or fishing gear), accidental shooting, and wetland habitat loss (Matteson et al. 1995).

Mammals such as the porcupine and badger in the areas surrounding BADL may be threatened by animal control efforts. Porcupines are sometimes considered a nuisance because of the damage they cause by gnawing on trees or wooden structures. During the winter, porcupines can damage trees by chewing through the bark (Graham 1997). When porcupine populations are high, damage can be evident at the forest level (Graham 1997). Badgers are sometimes targeted because their digging is seen as a threat to livestock (Scobie 2002) and are also affected by the poisoning of their primary prey, ground squirrels and prairie dogs (Apps et al. 2002).

Climate Change Vulnerability

The vulnerability of bison and bald eagle were addressed in previous sections of this assessment (Section 4.3.5 and 4.3.9). The vulnerabilities of the golden eagle, red-tailed hawk, and rough-legged hawk will be similar to the other birds of prey covered in Section 4.3.9.

Among the remaining culturally significant species (porcupine, badger, and trumpeter swan), no physiological sensitivities to climate were identified. The current ranges of the culturally significant wildlife species are presented in Plate 26-Plate **29**. The badger, like the prairie dog and black-footed ferret, is a burrowing animal and can avoid some weather extremes by seeking shelter underground. There is also no evidence of interspecific interactions for any of these species that may be altered by climate change.

Photo 50. Trumpeter swan and cygnets (NPS photo by J. Robbins, 1994).

While most of the culturally significant species are considered generalists (see Table 43), the trumpeter swan is a limnic specialist that relies on wetland or open water areas for food and nesting habitat (Matteson et al. 1995, Forrest et al. 2004). Given the warmer and drier conditions projected for the BADL region, these habitats could be considered particularly sensitive to climate change. If wetlands and ponds shrink or dry up in BADL and the surrounding area, it may become unsuitable for trumpeter swans. Porcupines are not considered specialists but do prefer woodlands and largely rely on trees for winter food (Woods 1973). Woodlands are already rare in BADL and were classified as highly vulnerable to climate change (see Section 4.1.1).

Most of the current threats to these species are anthropogenic and are not expected to be affected by climate change. The exception is the trumpeter swan and loss of wetland habitat, which, as mentioned above, may be exacerbated by a warmer and drier climate.

Photo 51. Badger with young (NPS photo in NPS 2010d).

The reproductive potential of culturally significant wildlife varies by species. All the bird species show both moderate maturity (first reproduce at 2-8 years of age) and moderate fecundity (average of 2-6 offspring per year) (as reviewed by NatureServe 2011). Porcupines show rapid maturity, first reproducing at less than 2 years of age, but low fecundity, producing just one offspring per year (Woods 1973). The badger also shows rapid maturity but moderate fecundity with an average litter size of three (as reviewed by NatureServe 2011).

Overall, the majority of culturally significant wildlife species are not expected to be particularly vulnerable to climate change, due primarily to their generalist tendencies. The porcupine may be slightly vulnerable to climate change, as its preferred woodland habitat is rare in the BADL area and is likely to be negatively affected by the drier conditions predicted for the region. The trumpeter swan, a limnic specialist, is also likely vulnerable to climate change, as the predicted warmer and drier conditions could reduce or eliminate wetland and aquatic habitats in the BADL region.

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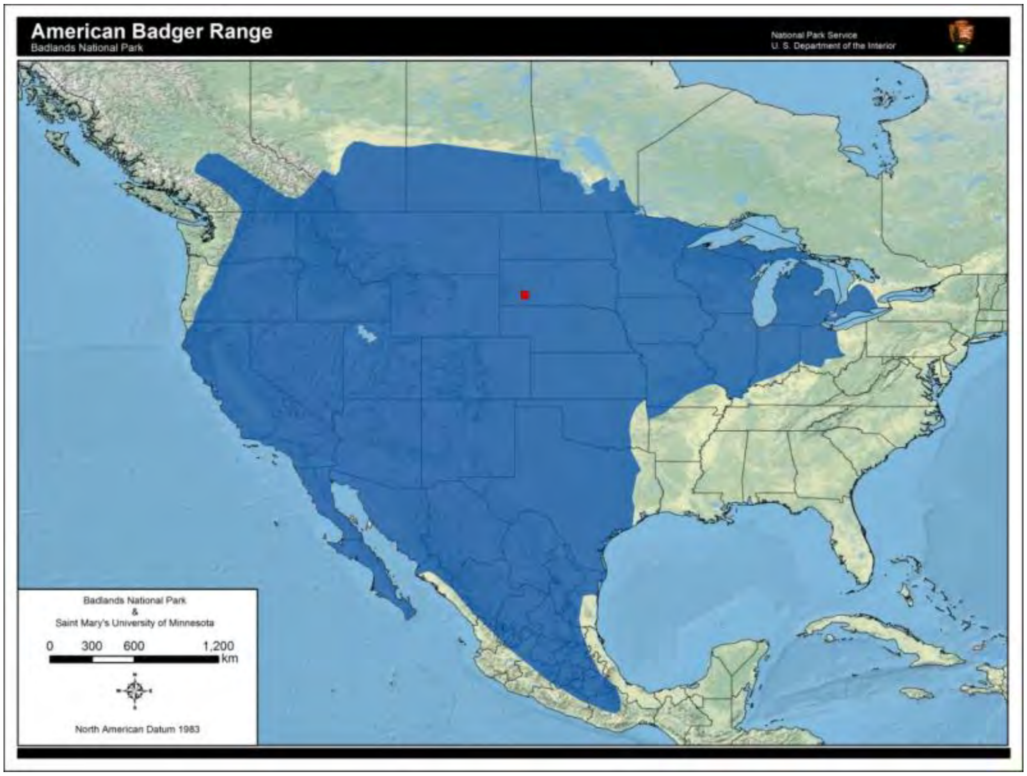


Plate 26. Distribution of American badger (Patterson et al. 2007) (BADL shown in red).

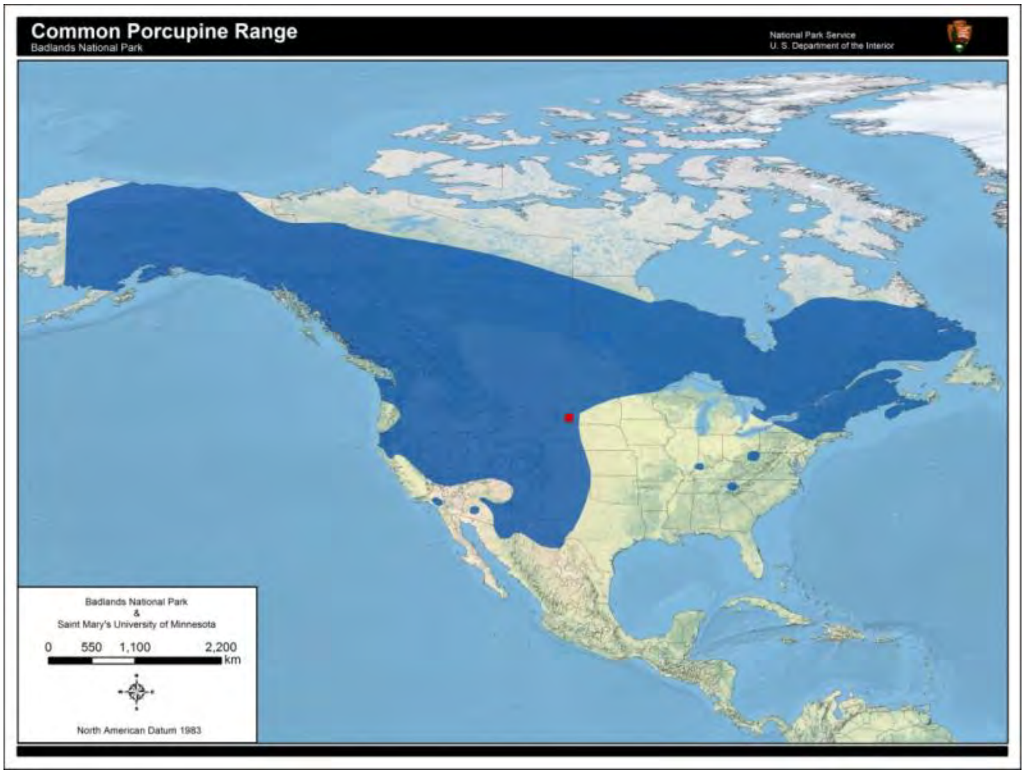


Plate 27. Distribution of common porcupine (Patterson et al. 2007) (BADL shown in red).

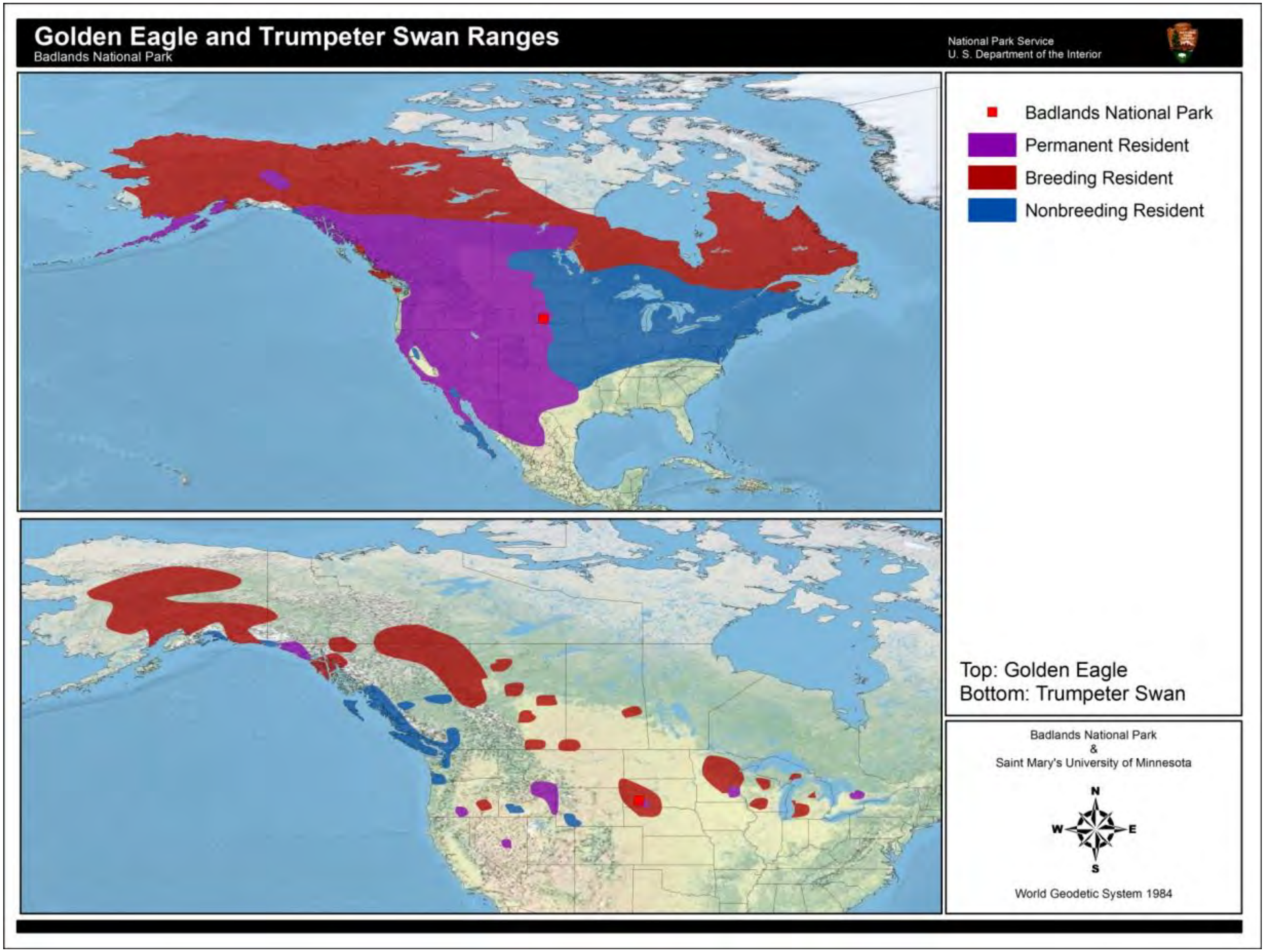


Plate 28. Golden eagle and trumpeter swan distributions (Ridgely et al. 2007) (BADL shown as red square).

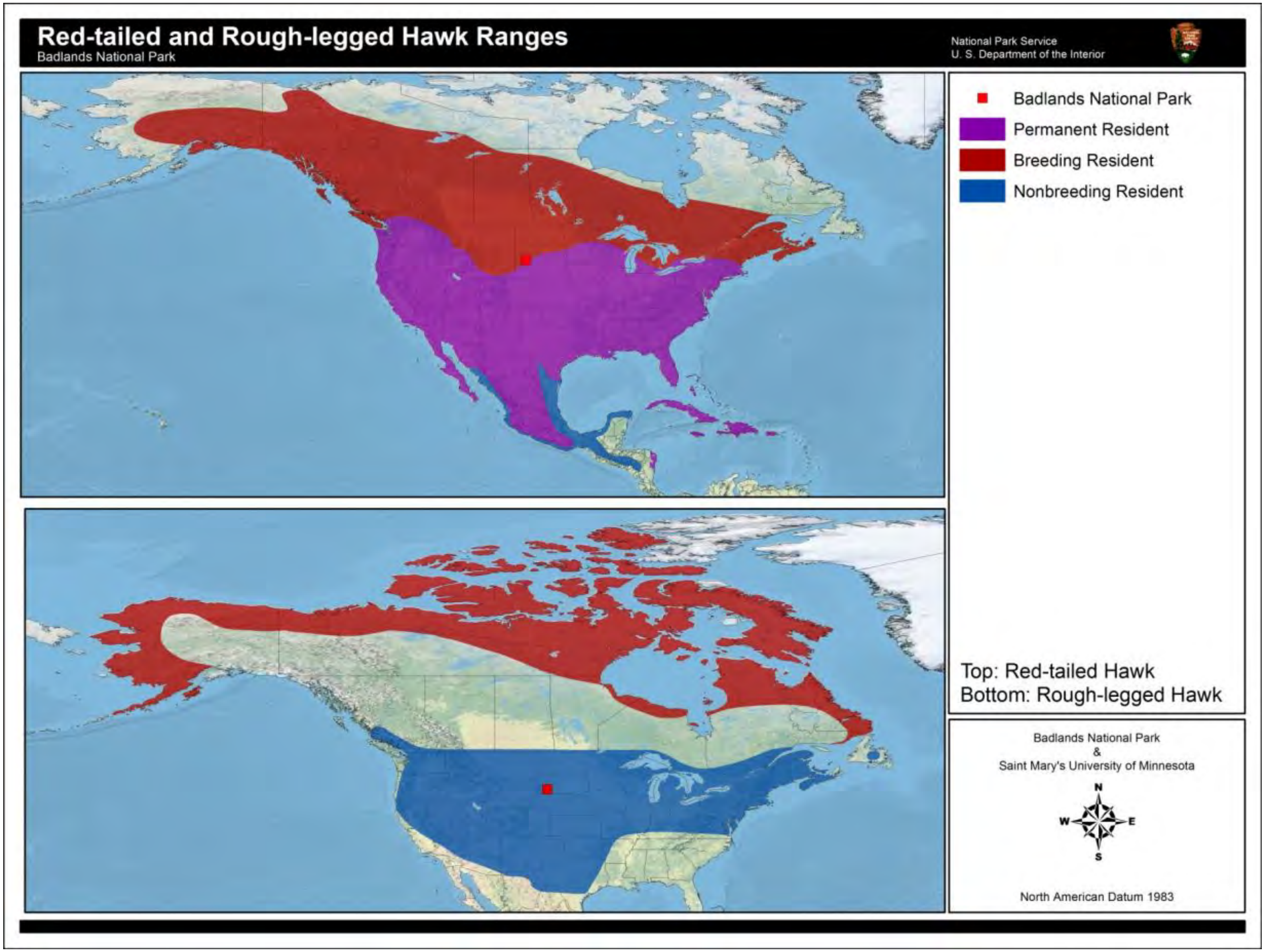


Plate 29. Red-tailed and rough-legged hawk distributions (Ridgely et al. 2007) (BADL shown as red square).

4.4 Paleontological Resources

Description

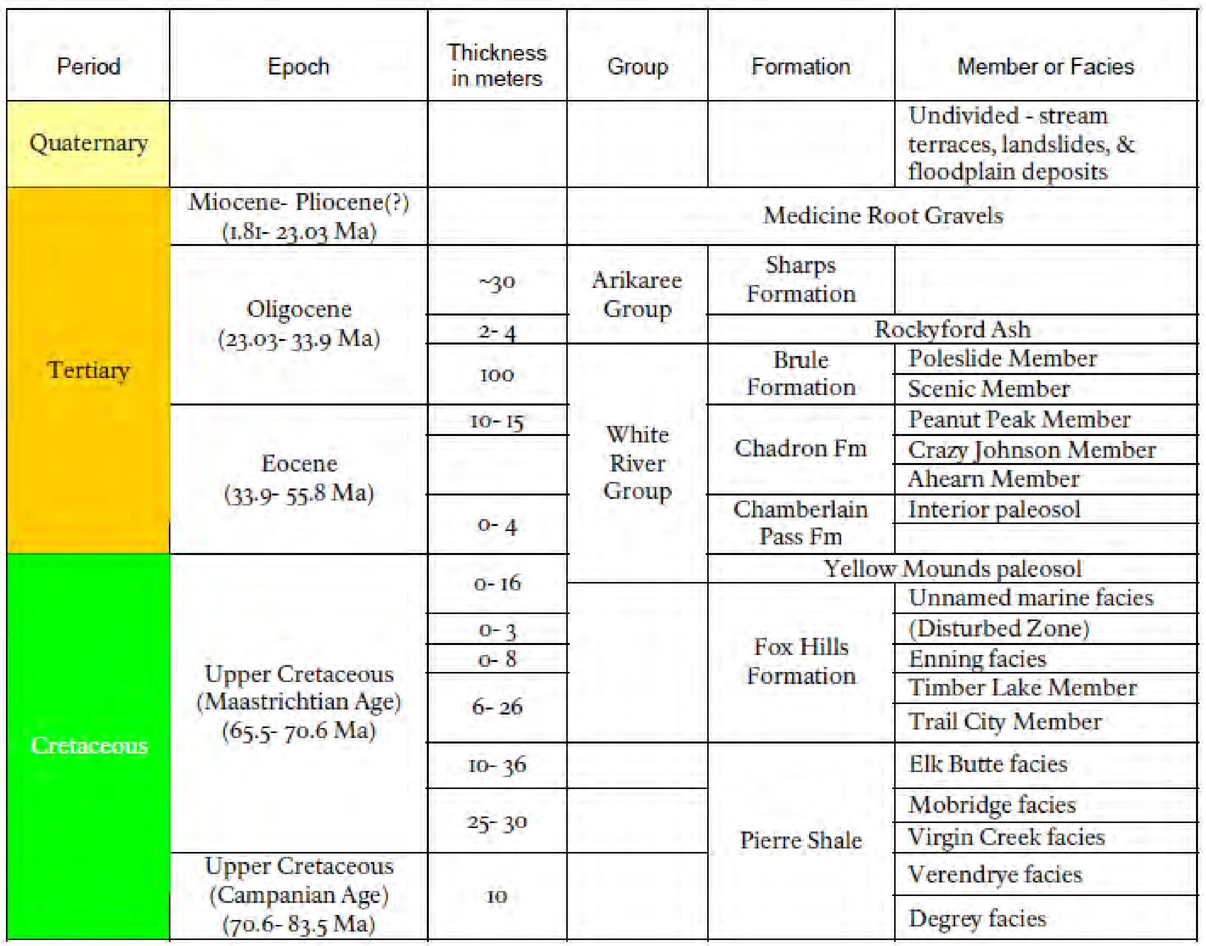
Photo 52. A saber tooth cat skull discovered by a park visitor in 2010 (NPS photo, in NPS 2011).

Paleontological resources were a major reason for the initial establishment of BADL as a National Monument and for its eventual elevation to National Park status (Graham 2008). The White River Badlands contain the largest known assemblage of late Eocene and Oligocene mammal fossils in the world (NPS 2010a). Since the mid-19th century, paleontological research in the area has contributed greatly to the science of vertebrate paleontology in North America. Fossils from the White River Badlands have been valuable in documenting climate change and how ancient mammals have adapted to major climatic events (R. Benton, written communication, 7 November 2011) Marine fossils from the Late Cretaceous are also present in the park (Graham 2008).

The oldest rocks exposed in BADL are the Upper Cretaceous marine mudstones of the Pierre Shale (Table 44). The upper portion of the Pierre Shale is exposed in the Sage Creek valley of the North Unit and along Cedar Creek in the South Unit (Graham 2008). The Pierre Shale has yielded a variety of Late Cretaceous marine fossils. Arthropods, shelled mollusks (mostly clams and ammonites), fish, and marine reptiles are preserved in these sedimentary rock beds (Graham 2008). The Fox Hills formation lies atop the Pierre Shale and contains numerous marine trace fossils (e.g., tracks, trails, burrows, fecal pellets) that can yield valuable information regarding paleoecology and environmental reconstruction (Graham 2008). Cephalopod specimens have been recovered near the Wilderness Access Trailhead area while chondrichthian (sharks and their relatives) remains have been found in the Sage Creek Basin and near the Sage Creek Basin Overlook (Graham 2008).

The Tertiary White River Group, above the Fox Hills Formation, contains the Chamberlain Pass Formation and the fossil-rich Chadron and Brule Formations (Table 44). Fossils discovered in these beds represent over 50 species of herbivores and 14 species of carnivores from the Eocene and Oligocene Epochs, 23 to 55 million years ago (Graham 2008). Common fossils in the Brule Formation include land turtles, oreodonts (herbivorous mammals), *Archaeotherium* (a large pig-like mammal), and numerous other mammals. One of the most significant sites, known as the Big Pig Dig, was first discovered by tourists near the Conata Picnic Area in 1993 (Graham 2008). This site, closed in 2008, yielded as many as 100 elements per square meter. The Chadron Formation, which underlies the Brule Formation, is known for titanotheres, elephant-sized perissodactyls (also herbivores), considered to be the largest and most impressive of the early mammals preserved at BADL (Graham 2008).

Table 44. Generalized stratigraphic column for Badlands National Park (Graham 2008).



Period	Epoch	Thickness in meters	Group	Formation	Member or Facies
Quaternary					Undivided - stream terraces, landslides, & floodplain deposits
Tertiary	Miocene- Pliocene(?) (1.81- 23.03 Ma)		Medicine Root Gravels		
	Oligocene (23.03- 33.9 Ma)	~30	Arikaree Group	Sharps Formation	
		2- 4		Rockyford Ash	
		100	White River Group	Brule Formation	Poleslide Member
					Scenic Member
	Eocene (33.9- 55.8 Ma)	10- 15		Chadron Fm	Peanut Peak Member
					Crazy Johnson Member
					Ahearn Member
		0- 4		Chamberlain Pass Fm	Interior paleosol
Cretaceous	Upper Cretaceous (Maastrichtian Age) (65.5- 70.6 Ma)	0- 16		Yellow Mounds paleosol	
				Fox Hills Formation	Unnamed marine facies
		0- 3			(Disturbed Zone)
		0- 8			Enning facies
		6- 26			Timber Lake Member
					Trail City Member
		10- 36		Pierre Shale	Elk Butte facies
		25- 30			Mobridge facies
					Virgin Creek facies
	Upper Cretaceous (Campanian Age) (70.6- 83.5 Ma)	10			Verendrye facies
					Degrey facies

The Eocene Chadron Formation and the Oligocene Brule Formation within Badlands National Park contain a detailed record of the terrestrial Eocene-Oligocene transition (Prothero 1994). The bedrock cliffs of the Big Badlands house ancient soils, plants and animals that have yielded important information on climate changes that occurred over 30 million years ago. Research into these ancient environments has concluded that regional temperatures dropped significantly and annual rainfall decreased as well (Prothero 1994). This shift in climate changed the landscape from the dense subtropical forests of the Eocene into the open woodland/grassland environment of the Oligocene (Retallack 1983). The lower vertebrate and invertebrate populations suffered great faunal turnovers, causing some snail, turtle, crocodilian and salamander species to go extinct in this area. The majority of mammal diversity, however, remained, with few exceptions, intact (Hutchison 1992).

Threats and Stressors

The natural process of erosion is constantly exposing new paleontological resources in BADL. Sudden landslides and slumps may expose new fossils but could also bury important paleontological sites (Graham 2008). Fossils are often uncovered faster than park staff and researchers can find and inventory them. Once fossils are exposed to the elements, weathering and erosion can significantly damage or even destroy them (Stetler and Benton 2011). As a result of their rapid exposure, visitors regularly discover paleontological resources in the park. Fossil theft from poachers and visitors is a constant concern for park management (Graham 2008). The number of illegal fossil collection cases investigated has increased from just one in 1998 to 32 in 2000, 72 in 2001, and 41 in 2007 (Graham 2008). In the summer of 2000, BADL staff began documenting fossil resources in the park to gain a better understanding of the park's paleontology and to identify significant sites for regular monitoring (Stetler and Benton 2011). Easily accessible fossil sites are also identified through this inventory so that management can protect them from poachers (Graham 2008). Table 45 presents the erosion resistance of each paleontologically significant geological unit in the park, along with some of the important fossils in these units.

Table 45. Geological map units of BADL with significant paleontological resources and their erosion resistance (adapted from Graham 2008).

Geological map unit (Symbol)	Erosion resistance	Paleontological Resources	Hazards
Sharps Formation (Ts)	Low	*Leptauchenia*, *Proscalops*, *Paleolagus*, *Palaeocastor*, *Heliscomys*, *Nimravus*	Fossil theft; mass wasting (slumping and rock fall)
Brule Formation (Tb)	Low	Oreodont & turtle fauna; horned sheep-sized herbivore (*Proteroceras*); aquatic rhinoceros (*Metamynodon*); camel (*Poebrotherium wilsoni*); coprolites, pollen, fossilized wood; Pig Dig fossils	Fossil theft; mass wasting (slumping and rock fall)
Chadron Formation (Tc)	Low; sandstone & conglomerate more resistant then clay	World-class Titanothere fauna (*Brontotherium, Menodus*); aquatic turtles (*Graptemys*); semi- aquatic and cursorial rhinoceros (*Trigonias , Hyracodon, Caenopus*); horses (*Mesohippus*), creodont carnivores (*Hyaenodon*), oreodonts (*Merycoidodon*), pig- like entelodont (*Archaeotherium*); fossil termite nests and other burrows	sheet wash; mass wasting (slumping); fossil theft
Fox Hills Formation (Kpi)	Variable: Sandstone more resistant than shale	Fossilized wood, arthropod parts, belemnites, ammonites, clams, fish remains, and trace fossils	None documented in Graham 2008
Pierre Shale (Kp)	Low	Baculites and scaphitid ammonites, *Didymoceras*, giant clam (*Inoceramus sagensis*)	Sage Creek Rim Road built on major landslide in Pierre Shale

Photo 53. Rock formations of BADL (from left to right): Pierre Shale (dark hillside beyond the streambed) (NPS photo provided by R. Benton), Chadron Formation, and Brule Formation (NPS photos, from NPS 2010b).

Climate Change Vulnerability

The primary influence of climate change on paleontological resources will be exposure through erosion. While many factors play a role in the dynamics of erosion, as discussed in section 4.2.3 of this assessment, rainfall has been described as the initial and essential driving force for erosion variation (Wei et al. 2009). Most studies around the world predict that projected changes in precipitation regime will accelerate erosion (O'Neal et al. 2005). The projected increase in precipitation variability could mean more extreme rainfall events, which could cause sudden landslides and slumps. These changes will likely accelerate the already high exposure rate of fossils in the park. This, in turn, could make them more vulnerable to weathering and theft. A study is currently underway (scheduled for completion in 2012) to document erosion rates at significant fossil sites in the park and to provide management with a paleontological monitoring schedule based on these rates (Stetler and Benton 2011).

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4.5 Cultural Resources

Introduction

The NPS is a leader in cultural resource preservation, managing more than 66,000 archeological sites, 27,000 structures, 115 million museum objects, and approximately 2,200 cultural landscapes (CRS 2011). A series of preservation laws and regulations including the National Historic Preservation Act (NHPA), Archaeological Resource Protection Act (ARPA), Archeological and Historic Preservation Act (AHPA), and the Native American Graves Protection and Repatriation Act (NAGPRA) mandate that the federal government preserve and maintain archeological and historic resources for the benefit of the public. As such, the agency is responsible for understanding how climate change may impact America's cultural resources. Cultural resources in the NPS fall into five categories, with a considerable amount of overlap:

- Archeological resources
- Museum collections including archives and field documentation
- Historic and prehistoric structures
- Ethnographic resources
- Cultural landscapes

Table 46 lists cultural resources in BADL that are explicitly considered in this assessment. This is a list of known resources in the park identified in BADL's Historic Resource Study (Stevens 2006), List of Classified Structures (LCS 2011), and Cultural Landscape Report (Bahr 2005). Additional cultural resources may exist that have not yet been identified, inventoried, or evaluated. Resources that are addressed in the following sections of this assessment include 278+ archeological sites, hundreds of thousands of museum objects, five historic roads, one gravesite, a visitor center, a range of ethnographically significant wildlife and plants, and one cultural landscape. The ecological vulnerability of culturally significant wildlife and plants (ethnographic resources), and biotic features of cultural landscapes, is considered throughout the natural resource sections of the report, while their cultural significance is considered below.

Table 46. List of BADL cultural resources identified in the assessment. Figure 30 shows the known locations of these resources.

Name	Type	Number
Archeological sites and artifacts	Archeological resources	278 sites
Curated archives and artifacts	Museum collections	246,484
Cedar Pass Road	Historic road	1
Cedar Pass to Northwest Entrance Road	Historic road	1
Sage Creek Rim Road	Historic road	1
Sheep Mountain Table Road	Historic road	1
Old Northeast Entrance Road	Historic road	1
Eugene Tyree Gravesite	Historic structure	1
Structures at Cedar Pass Developed Area	Historic structures	49
Cedar Pass Developed Area	Cultural landscape	1
Culturally significant plant species	Ethnographic resources	25
Culturally significant wildlife species	Ethnographic resources	8

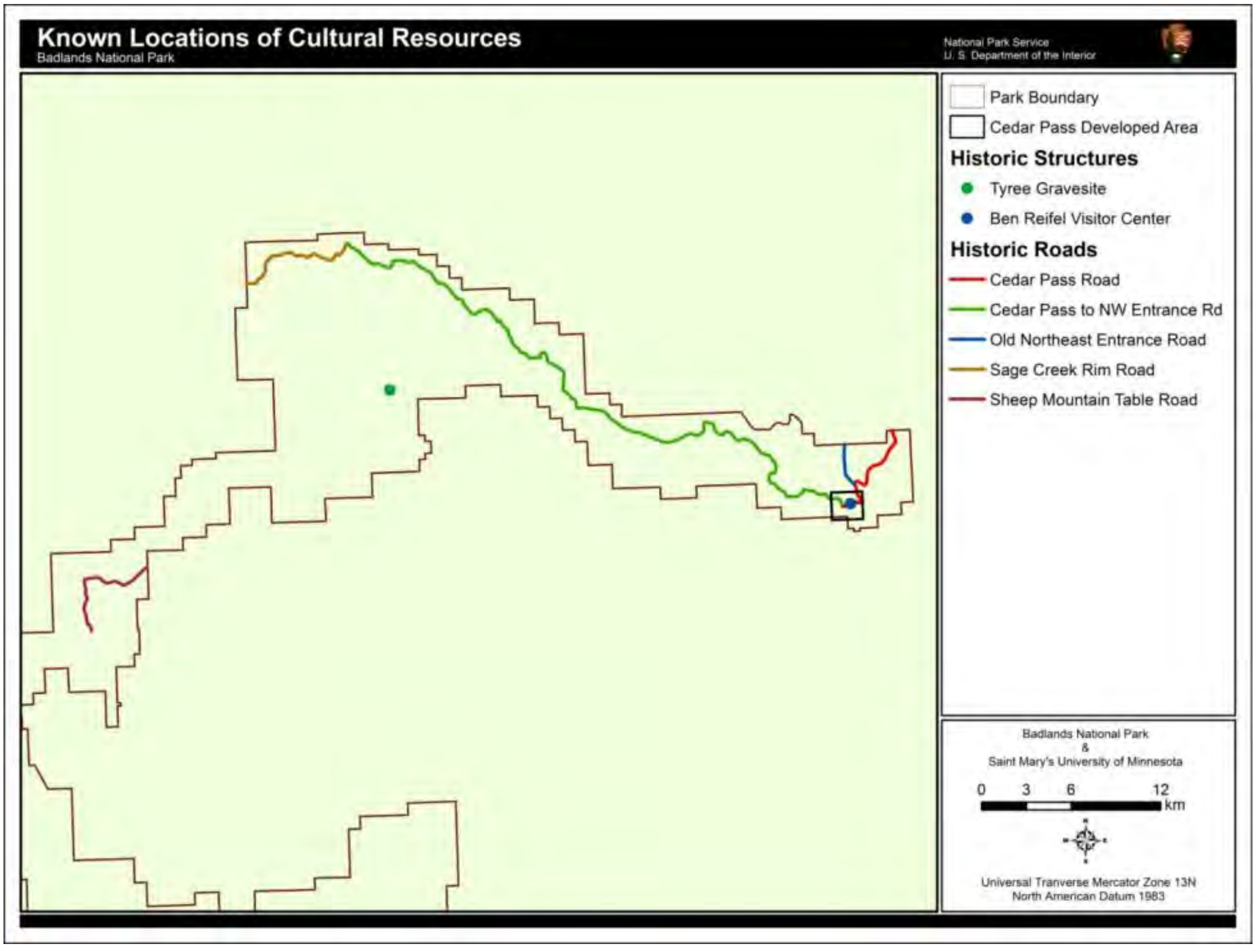

Figure 30. Map of Badlands National Park. All significant historical sites are shown in their approximate positions.

The main environmental forces affecting historic preservation and identified in this assessment are temperature, precipitation, humidity, fire, wind, and biological infestation (Colette 2007). Climate change may alter these forces, potentially accelerating the rate of exposure and subsequent deterioration of historic and prehistoric resources. BADL cultural resources will be assessed for their sensitivity and exposure to these climate variables in order to determine their overall vulnerability to projected climatic change in BADL. It should be noted that combinations of these factors, anticipated under current climate change models, may produce impacts that are more than the sum of their parts (e.g., temperature increase, humidity decrease, and biological infestation may impact structural integrity cumulatively or exponentially).

The Oglala Lakota (Sioux) tribe resides on the Pine Ridge Indian Reservation, directly south of the North Unit of BADL, as well as the nearby Rosebud Reservation and cities throughout western South Dakota (BHBL 2011). The South Unit of the park is located on the reservation, and is co-managed by the park and the Oglala Sioux Parks and Recreation Authority (OSPRA). OSPRA staff and other tribal members were consulted in the development and review of this assessment, in order to represent tribal management priorities regarding climate change, as well as incorporate considerations regarding tribal culture and heritage values connected to the park.

This assessment focuses on tangible resources, such as roads, structures, and artifacts. But the NPS is also charged with preserving intangible resources; the cultural values embedded in these reservoirs of American history. In particular the Oglala Lakota tribe and other traditionally associated peoples in the surrounding area attribute a great deal of their cultural identity to this landscape, and all of the plants, animals, and other cultural resources found within it. Changes in tangible cultural resources can affect intangible skills, world views, traditional languages, and cultural practices. The NPS is a steward of this heritage, and therefore must be proactive in understanding how climate change may impact the future of both tangible and intangible cultural resources in BADL.

Abiotic Cultural Resource Adaptive Capacity

These assessments are based on evaluating the exposure, sensitivity, and adaptive capacity of conservation targets. Evaluating the sensitivity and level of exposure of cultural resources to projected change in BADL’s climate is a productive exercise that can produce critical information for management decisions. However, the adaptive capacity of most abiotic cultural resources is low or nonexistent. The intrinsic traits of archeological sites, historic structures, and museum collections do not allow for behavior modification – they cannot reproduce, migrate, or self-repair, not without management action. As they age, they are inherently vulnerable to deterioration. When the integrity of these resources is compromised or destroyed, the link to the history and cultural heritage of communities and the nation (their significance) may be irretrievably lost. Additionally, these resources have place-based integrity of location; they are most meaningful when managed *in situ*. When a resource is relocated for salvage, or reproduced to interpret history, the link to that place-based significance is weakened and significance declines (NPS 2006).

It is due to this lack of adaptive capacity that this assessment considers only the sensitivity and exposure of abiotic cultural resources to projected climate change. When doing this, an analyst should consider exactly what characteristics of a landscape or structure make it historically significant. For example, a Lakota sacred site in the park may be significant due to a combination of physical landscape characteristics and features including the viewshed, the shape of certain geologic formations, and the availability of white sage in the vicinity, among other things. If climate change is projected to decrease the prevalence of grasses such as prairie sandreed (see section 4.1.3) at that sacred site, it is not likely to impact the landscape characteristics and features of that cultural landscape. However, if a feature of the cultural landscape such as white sage is shown to be sensitive to climatic change, then the landscape may be vulnerable to climate change. Similarly, if a structure built in the 1990s, but situated in a landscape significant for its 1950s-era architecture, is sensitive to climate change-induced flooding, it does not increase the sensitivity of the cultural landscape because it is not a feature of that landscape. However, if the 1990s building is similar in size and color to the historic buildings, and contributes to the historic spatial arrangement, is may be considered a feature of the landscape and therefore contribute to the landscape's vulnerability.

Existing federal standards, guidelines, and park reports, including Cultural Landscape Reports and the National Register of Historic Places Criteria, and consultation with traditionally associated peoples will help determine whether cultural resource integrity and significance will be affected by climate change in BADL. In particular, the Oglala Lakota must be involved early and often in determining how projected change will impact the tangible resources described below, and whether and how those changes will affect the intangible heritage values ascribed to the badlands landscape by the tribe. The narrative below discusses sensitivity and exposure of BADL cultural resources to projected climate change.

4.5.1 Ethnographic Resources

Description

Ethnographic resources are park resources (e.g., sites, structures, objectives, landscapes, natural resources) that have cultural significance to a peoples' way of life (NPS 1998a). The NPS preserves and protects ethnographic resources for the values they hold to traditionally associated peoples. In BADL, there are wildlife and plant species that are ethnographically significant to the Oglala Lakota tribe. Based on consultation with the OSPRA and the Tribal Historic Preservation Office (THPO), a small number of these species were included in the wildlife and plant community sections of this assessment in order to represent the management priorities of the tribe. The species were also included, not because they are necessarily ecologically influential species (those that exert strong effects on the fabric of their ecological communities), but to emphasize the importance of the connection that tribal traditions and heritage values have with the park landscape and the biota within it.

The vulnerability of ethnographically significant plant and wildlife species is addressed in sections 4.1.1-4.1.4 and section 4.3.11 of this document. These sections provide brief overviews of the cultural value of these resources and examples of the ways that changes to natural resources may affect Lakota heritage values. Ethnographically significant plants and animals may be significant for medicinal, religious, and/or subsistence value, and as defining characteristics of a landscape with cultural significance. Potential shifts in native species size, distribution and associated characteristics due to climate change may result in changes regarding economic, cultural, and religious use of these species by the Oglala Lakota.

For example, a shift in some areas from mixed-grass species to shortgrass (see section 4.1.3) may impact the ability of tribal members to harvest traditional foods such as turnips. Reduced ability to harvest turnips (or other traditional foods) could impact Lakota customs and family traditions, leading to a loss of traditional knowledge, a long-established family activity, and access to a low-cost, healthy food base. The use of porcupine quills in artwork is one of the oldest known Lakota art forms and is a trademark feature of Lakota clothing, jewelry, and accessories. Porcupine quill artwork is also a high demand tourism product and can produce considerable revenue for reservation residents (Graham 2009). The projected decline of porcupine's preferred woodland habitat may make it more difficult for tribal members to harvest quills, negatively impacting an important cultural and economic activity.

Ethnographically significant plants and the vulnerability of their habitats are listed in Table 47 while wildlife species are shown in Table 48 (for more detailed information on vulnerability, see chapter 4). Vulnerability determinations are inferred based on the communities within which plants are found. These lists, compiled through conversations with OSPRA staff and staff of the Sinte Gleska University Lakota Studies Department (Burnette 2006; OSPRA, pers. comm. 2011), are far from inclusive and should be considered a sampling of some of the most important species found in or near BADL. These plants and animals have a variety of uses, from practical (e.g., food and firewood) to medicinal and ceremonial. Wild turnip is a prized food among the Lakota and is one of the most important food sources on the prairie (White 2002). Many of the woodland species produce edible fruits that are also an important food source for the Lakota people (White 2002). Many grassland species (e.g., purple coneflower, yarrow, bush morning glory, and wild bergamot) have various medicinal uses. Purple coneflower, for example, can be used to numb a toothache, while bush morning glory roots can be eaten for stomach problems (White 2002). The crushed leaves of fetid marigold, a plant found almost exclusively on prairie dog towns, have been used for respiratory problems (White 2002). Broom snakeweed, found in the sparse badlands, is made into a tea for treating coughs and colds (White 2002). Yucca roots can be used for soap and medicinal purposes while macerated leaves are a useful thread (White 2002). Cottonwood is favored as firewood for both practical and ritual purposes while ash has been used for pipestems and war bows (White 2002). Eastern red cedar has both medicinal and ritual value and is regularly burned in sweat houses or dwellings (White 2002). Sage plays a critical role in many religious ceremonies, including annual Sun Dances (White 2002).

Table 47. Culturally significant plant species, the communities where they occur, and the vulnerability of those communities. If species occur in more than one plant community, the lowest vulnerability rating is given. This list provides a sampling of some of the most significant plant species but is by no means comprehensive.

Scientific name	**Common name**	**Grasslands**	**Sparse badlands**	**Shrublands**	**Woodlands**	**Vulnerability**
Echinacea angustifolia	purple coneflower	x				least vulnerable
Artemisia ludoviciana gnaphalodes	white sage	x				least vulnerable
Amorpha canescens	lead plant	x				least vulnerable
Mentha arvensis (M. canadensis)	wild mint				x	highly vulnerable
Prunus virginiana	chokecherry			x	x	moderately vulnerable
Prunus americana	wild plum			x	x	moderately vulnerable
Populus deltoides	cottonwood				x	highly vulnerable
Prunus pumila var. besseyi	sand cherry	x			x	least vulnerable
Pediomelum esculentum (Psoralea esculenta)	wild turnip	x				least vulnerable
Achillea millefolium	yarrow	x				least vulnerable
Shepherdia argentea	buffalo berry			x	x	moderately vulnerable
Fraxinus pennsylvanica	green ash				x	highly vulnerable
Juniperus virginiana	Eastern red cedar				x	highly vulnerable
Physalis heterophylla	ground cherry	x				least vulnerable
Ipomoea leptophylla	bush morning glory	x				least vulnerable
Rosa woodsii	woods rose	x			x	least vulnerable
Dyssodia papposa	fetid marigold	x*				least vulnerable
Rhus aromatica/trilobata	fragrant sumac			x	x	moderately vulnerable
Gutierrezia sarothrae	broom snakeweed		x			moderately vulnerable
Artemisia frigida	fringed sage	x		x		least vulnerable
Monarda fistulosa	wild bergamot	x				least vulnerable
Yucca glauca	yucca	x		x		least vulnerable
Astragalus crassicarpus	ground-plum	x				least vulnerable
Gaura coccinea	scarlet gaura	x				least vulnerable
Lycoperdon gemmatum	puff ball (mushroom)				x	highly vulnerable

* = Fetid marigold occurs almost exclusively on prairie dog towns, which are found within grasslands.

Table 48. Selected culturally significant wildlife species in BADL and their ecological affinities (preferred habitats) (Forrest et al. 2004). Note: See culturally significant species assessment for explanation of vulnerability (section 4.3.11).

Scientific Name	Common Name	Abundance	Ecological Affinity	Vulnerability
Bison bison	Bison	Common	Grassland	less vulnerable
Erethizon dorsatum	Porcupine	Unknown	Widespread	moderately vulnerable
Taxidea taxus	Badger	Uncommon	Widespread	less vulnerable
Aquila chrysaetos	Golden eagle	Common	Broad	less vulnerable
Buteo jamaicensis	Red-tailed hawk	Common	Broad	less vulnerable
Buteo lagopus	Rough-legged hawk	Common	Broad	less vulnerable
Haliaeetus leucocephalus	Bald eagle	Common	Broad	less vulnerable
Cygnus buccinator	Trumpeter swan	Uncommon	Limnic	highly vulnerable

The bison (*Tatanka*) is described as “the patron of ceremonies, of health, and of provision” and “the patron of fecundity, hospitality, industry and comfort” (Walker 1983, 1991, as cited by White 2002, p. 157). Bison have a wide range of uses. In addition to providing meat, their hides can be used for clothing and shelter while skulls, heads, horns and tails have ceremonial uses (White 2002). The Lakota people use porcupine quills as hair accessories and for decorating leather, traditional clothing, and jewelry (Graham 1997). The Eagle (*Wanbli*) is also an important symbol for the Lakota Sioux tribe. The spirit of the Eagle “presided over councils, hunters, war parties, and battles” (White 2002, p. 163). Whistles made from eagle wing bones are used in the Sun Dance while feathers are used in ceremonial regalia. Eagle feathers are also widely used in the regalia of warriors (White 2002).

4.5.2 Archeological Resources

Description

Archeological resources include prehistoric and historic sites, artifacts (including museum objects), and records associated with these resources (NPS 1998a). Although archeological resources are defined by law as greater than 100 years of age (ARPA 2011), for the purposes of this assessment ‘archeological resources’ shall also include historic properties (defined by the National Register of Historic Places as resources greater than 50 years of age) found in archeological contexts or curated as archeological collections. Archeological materials provide us with a physical link to human prehistoric and historic cultural heritage. These resources contribute to our understanding of past human-environment interactions, including how human behavioral change follows climatic and environmental change. Archeology can contribute a great deal of information regarding past human adaptation to climate change (Rockman 2011).

A variety of archeological surveys have been conducted within BADL in the past century. Many surveys have focused on project-based compliance, while others are larger scale inventories of archeological materials in the park (Kuehn 2003, Hannus 2003). It is difficult to estimate archeological survey intensity and completeness (see Banning 2002), but approximately 12,000 acres (about 5%) of the park have been surveyed for archeological resources (Hannus 2003, Stevens 2006). It is important to recognize that sites are not distributed evenly across the landscape, but are often clustered in areas of similar age, site integrity and topography, which can vary greatly from other park sites (and may influence exposure and sensitivity to climate change).

The park currently has approximately 278 known prehistoric and historic sites (ASMIS 2011a). Surveys have revealed lithic scatters (mainly chert, chalcedony, and fine-grained quartzite), prehistoric ceramics, stone tools such as axes and grinding stones, projectile points, bone tools, mammal bones, and charcoal, as well as seasonal hunting camps, semi-permanent camps near water sources, and historic sites of both Native American and European American origins (Table 49) (ASMIS 2011b, Kuehn 2003, Stevens 2006, White 2002). Most sites in the park date to the last circa 2,100 years in the Plains Woodland tradition, Avonlea complex, Besant complex, Plains Village tradition, or Late Prehistoric or Protohistoric groups (Kuehn 2003). The remaining sites older than circa 2,100 years include Paleoindian projectile points and sites assigned to Early, Middle, and Late Plains Archaic (Kuehn 2003). There are currently two sites in the park that have been determined eligible for listing in the National Register of Historic Places, but all sites are considered eligible for management purposes, and are protected under the National Historic Preservation Act, the Antiquities Act, and the Archaeological Resources Protection Act (Stevens 2006). Table 49 below lists the types and number of sites recorded in BADL (ASMIS 2011b). Note that the total adds up to more than the 278 sites, because a site can have more than one site type.

Table 49. The type and number of archeological sites recorded in Badlands National Park (ASMIS 2011b).

Site type	Site count
Artifact Scatter	128
Ceramic Scatter	8
Charcoal	1
Circular Feature	3
Depression	4
Dugout	1
Farmstead	2
Foundation	2
Habitation	11
Hearth	31
Isolated Feature	2
Isolated Find	23
Lithic Scatter	163
Lithic Workshop	9
Midden	1
Occupation Site	4
Quarry	13
Sherd Scatter	4
Undetermined	2

Archeological resources are often attributed significant cultural value by traditionally associated peoples, such as the Lakota of the Pine Ridge Indian Reservation, where the South Unit of BADL is located. Archeological site location data are exempt from the Freedom of Information Act disclosure. Therefore, the location of archeological materials and sacred sites on park landscapes is confidential and kept solely by NPS and tribal staff and the individual families for whom a site is significant (NPS 2006).

Threats and stressors

BADL's highly erodible landscape is "like no other when it comes to the dynamics, complexity, synchronicity, and overall impact of geomorphic process on the archeological record" (Kuehn 2003, p. 32). The processes of wind and water erosion make the exposure and discovery of new archeological materials ever-present on the landscape. They also create major challenges for park management to identify and mitigate the risks of rapid deterioration following exposure (NPS, Pei-Lin Yu, Cultural Resource Specialist, pers. comm. 2011). Large precipitation events cause water and wind erosion, which may destabilize sites, shifting the original contextual associations between the site's objects and associated physical elements. Fallen trees from thunderstorms both directly damage archeological sites and can add to hazard fuel loading (Gauthier et al. 2010). Table 50 provides the condition of known archeological sites as provided in the 2011 fiscal year report (ASMIS 2011a).

Table 50. Condition of the 278 archeological sites in Badlands National Park (ASMIS 2011a).

Condition	Number
Good	60
Fair	124
Poor	70
Destroyed (not included in site counts)	10
Inundated-Uncertain	1
Not Relocated-Unknown	15
Unknown	8

Sixty-six percent of BADL sites are currently disturbed by general erosion, while all remaining sites are listed as threatened by erosion (ASMIS 2011b). Sufficient erosion of a site can result in data loss, loss of cultural integrity, and in some cases, the complete destruction of the site (Stevens 2006).

Wildland fire can potentially threaten archeological resources through both direct contact and through the loss of stabilizing vegetation and resulting erosion (Winthrop 2009) (for detailed information on BADL's fire regime, see section 4.2.1). Fire can cause surface lithic scatters to distort, fracture, spall (flaking off of material), or melt; ceramics may lose appliqués or painted material or become blackened (Buenger 2003). Fire can also alter the moisture content of the material, impacting long term preservation. However, the temperature duration of grassland fires is short and typically will not heat objects sufficiently to cause damage (Sturdevant et al. 2009). Organic matter, including wooden baskets, clothing, structures, leather, hide, etc., will burn at lower temperatures than the resources described above and are at risk of complete destruction from a fire. In general, however, direct contact of a grassland fire with surface artifacts is not likely to cause major damage (NPS 2004).

Indirectly, wildland fires can further increase erosion rates through the burn-off of vegetation, sometimes removing artifacts from their original location and destabilizing architectural features (Saunders 2006). Even at low temperatures, characteristics that render artifacts and other materials suitable for radiometric dating and other scientific analysis can be lost (e.g., destruction of datable organics, loss of obsidian hydration rinds, etc.) (Loyd et al. 2002). Fire may cause physical damage from fallen trees, particularly in woodland areas (Saunders 2006). Additionally, fire suppression activities performed in the course of emergency response and cleanup have enormous potential to damage sites through fireline construction, fire camps, the use of fire retardants and other chemical products, and related activities (Winthrop 2009). Additional indirect stressors resulting from fire include increased visibility following vegetation burn-off, which may expose sites to vandalism and looting. There is also a risk for exposure of Native American burials, funerary and sacred objects, and other highly sensitive items (Yu 2011).

The integrity of any archeological site is also potentially threatened by disturbance from park visitors and the public, whose knowledge of a site location may result in looting or vandalism of artifacts and other activities that compromise the integrity and cultural significance of a site (NPS 2006).

Climate Change Vulnerability

Climate change may exacerbate many existing challenges for archeological site management in BADL. A projected increase in storm intensity increases the risk of physical damage to archeological resources from wind, flooding, lightning-induced wildland fire, and tree wind throw (Cassar 2005; Gauthier et al. 2010). A projected increase in temperature may lead to higher rates of evapotranspiration, which can result in generally drier conditions. Coupled with more variable precipitation, the increased occurrence of periodic drought is possible (see chapter 3). Extended periods of heat and drought can begin a dry-out process that accelerates artifact deterioration (Adams 2007), while the same drying process can help preserve other materials, such as organic artifacts like baskets. All of these factors contribute to increasing the rate of erosion, deteriorating site stratigraphy and compromising artifact integrity (see section 4.2.3).

The combination of drier conditions and projected warmer temperatures could also extend the park’s fire season, encouraging more frequent and intense wildland fires. An increase in fire occurrence would exacerbate existing threats to archeological sites and artifacts and alter the surrounding cultural landscape (Saunders 2006). The combined effect of drier conditions, more intense precipitation events, and extended fire seasons is expected to accelerate already high erosion rates in the park, further threatening the integrity of existing archeological sites through wind, water, and fire-induced erosion (Colette 2007).

The exposure of archeological sites and materials to these climate drivers (e.g., temperature, precipitation, wind) and ecological processes (e.g., fire) depends largely upon their location on the landscape. For example, sites located in wooded areas are more vulnerable to damage from falling trees (Saunders 2006). Sites and artifacts located in areas where fires burn hotter and longer; that are vulnerable to high wind; or where encroaching vegetation may take hold, will be more sensitive to fire, wind and water-related damage. Sites located in areas prone to erosion, such as those located near former water sources (e.g., drainage basins), are more exposed to flooding, wash-out, and subsequent soil erosion (Stevens 2006).

In general, it is important to remember that archeological material is preserved in the first place because it has “reached a balance with the hydrological, chemical and biological processes of the soil. Short and long cycles of change to these parameters may result in a poorer level of survival of some sensitive classes of material” (Colette 2007, p. 24). Climate change may accelerate or exacerbate the processes that continually work to compromise this balance. Drier conditions resulting from increased rates of evapotranspiration may alter soil moisture levels, which can destabilize archeological deposits (Cassar 2005, Colette 2007). Temperature variations can also accelerate deterioration of remains (Colette 2007). For example, warmer winters increase freeze/thaw-related ground movement over winter months, which may impact the stratigraphy of archeological sites (Adams 2007).

With only 5% of park land formally surveyed, the extent of significant archeological resources distributed across the park is currently unknown. This is BADL's greatest vulnerability regarding climate change impacts to archeological resources. Without knowing where and what resources exist, managers will be unable to assess either the exposure or the sensitivity of most archeological materials to climatic change. It is likely that the exposure of new archeological sites and artifacts will increase in frequency as the climate changes. Newly exposed materials create opportunities for managers and scientists to learn new information about BADL history, but without regular surveying and the ability to immediately mitigate further damage, newly exposed materials may be lost to physical damage, loss, or theft before they can be recorded.

Table 51. A summary of the potential sources of climate change-related impacts to BADL archeological sites.

Projected cause	Projected effect	Resource impact
Increased storm intensity	Wind, flooding, lightning, tree fall	Physical damage Misplacement/data loss
Increased storm intensity + drier average conditions	Increased rates of erosion due to low soil moisture and loss of stabilizing vegetation	Destabilize deposits Misplacement/data loss
Increased temperature + drier average conditions	Increased evapotranspiration	Dry-out accelerates artifact deterioration (in some cases can preserve artifacts)
	Extended fire season	Direct physical damage Physical damage from tree fall Increased risk of vandalism from vegetation burn-off
Extended fire season	Increased erosion from loss of stabilizing vegetation	Destabilize deposits Misplacement/data loss
	Increased fire suppression techniques	Damage artifacts from retardants and water enhancers
Warmer winters	Increased freeze/thaw-related ground movement	Destabilize site stratigraphy

Summary of Vulnerability. Generally speaking, archeological resources in BADL are highly vulnerable to climate change. Sites and artifacts are sensitive to a variety of climate change-related impacts, including increased storm intensity, an extended fire season, and erosion caused by the interaction of these variables with increasingly dry conditions. All BADL sites are currently exposed to erosion, and 66% are classified as disturbed by erosional processes (ASMIS 2011a). One-third of sites are in poor condition or worse (ASMIS 2011b). The location of BADL archeological sites is not known to the analysts and therefore a site-specific assessment of vulnerability is not possible. Site-specific assessments of vulnerability may be accomplished through work with the Midwest Archeological Center. In general, however, climate change is likely to exacerbate current site stressors and further impact the integrity of BADL archeological sites.

4.5.3 Museum Collections

Description

Museum collections are groupings of material objects that have scientific, historical, cultural, or aesthetic value protected by the NPS and partners and made available to the public for educational purposes (NPS 1998a). A collection is usually made up of “material remains that are excavated or removed during a survey, excavation or other study of a prehistoric or historic resource, and associated records that are prepared or assembled in connection with the survey, excavation or other study” (NPS 2011a, p. 1). BADL collections represent the national significance of the park, and tell the story of BADL through historical archives, natural history, and through artifacts related to ethnology, archeology, paleontology, and geology. They are important to the general public, scientists, students, educators, and staff actively managing resources in the parks (PMMP 2007).

Photo 54. Examples of cultural resources that have been curated as museum objects from Badlands National Park. Left to right (first row) and left to right (second row): Oglala Lakota conch shell headdress (including eagle feathers, buffalo hide and porcupine quills); Bracted spiderwort; Saber-tooth cat; Badger; Titanothere skull and jaw with teeth.

BADL’s 246,484 museum items include 167,252 paleontological items, 53,870 archives, 11,515 archeological items, 9,684 historical items, 3,632 biological items, 437 geological items, 80 pieces of art work, and 14 ethnological items (NPS 2011b). Ninety-nine percent of BADL collections are properly catalogued as of fiscal year 2011 (NPS 2011b). Of the 711 items accessioned into collections in fiscal year 2011, 88% were paleontological items collected from the field. A total of 5 items were deaccessioned in the same fiscal year, 3 biological items due to loss of integrity, one Ghost Dance shirt deemed to no longer fit within BADL Scope of Collections and conveyed to the Oglala Lakota tribe, and human remains which were repatriated to the same tribe according to the Native American Graves Protection and Repatriation Act (NAGPRA).

BADL museum objects are located in three storage facilities. Approximately half of BADL's collections are stored in a facility in the Cedar Pass Developed Area located 1 mile south of the Ben Reifel Visitor Center near housing and maintenance facilities. The storage facility is a concrete bunker with no basement, located in a relatively flat area that is not a 100-year floodplain. The facility meets 90 percent of federal security, fire protection, proper storage equipment, emergency preparations, and environmental standards required to house NPS collections (NPS, Megan Cherry, Museum Technician, pers. comm. 2011). This is an excellent rating compared with most NPS storage facilities that meet federal standards at between 50 and 70 percent (PMMP 2007). Areas in which BADL does not meet standards include the lack of an Integrated Pest Management Plan or Emergency Operations Plan that incorporates the storage facility, missing deadbolts on facility doors, and the lack of appropriate seals on doors to prevent museum pests, such as carpet and woodboring beetles, clothes moths, and crickets, from entering the facility. Future storage plans also include the storage of Minuteman Missile NHS museum objects in BADL, as the park has been designated a multipark facility (NPS 2011c). Several articles are also housed in other park facilities in the Cedar Pass area, including several paintings, photos, and two natural history specimens at the Ben Reifel Visitor Center, administrative building and Cedar Pass Lodge. A headdress is on display at the White River Visitor Center in the South Unit of the park.

Paleontological specimens are primarily housed in Rapid City at the South Dakota School of Mines and Technology, a designated federal paleontology repository for the NPS (Shelton 2008). The facility holds 149,660 paleontological items, and meets the majority of storage standards (SD School of Mines and Technology 2011). There are also 5,624 archeological artifacts and 2,881 archival documents from BADL stored at the Midwest Archeological Center in Lincoln, NE. Of those, 93.72% are catalogued in the Interior Collection Management System (ICMS). At the end of fiscal year 2011 MWAC met 74 out of 81, or 91.35%, of museum standards (NPS, Karin Roberts, pers. comm 2011).

Climate Change Vulnerability

In the past ten years, the quantity of museum objects has increased by 63 percent nationwide. Between 2001 and 2005, 93 percent of newly accessioned collections were archeological and related archival documents (PMMP 2007). New collections may be generated by project compliance activities, or as a result of pro-active collecting efforts. It is likely that the need for collections care and storage will continue to increase with projected changes in BADL's climate. As discussed above, there is an ever-increasing likelihood that new archeological materials will be discovered in the park. In addition to these new areas, known sites are vulnerable to increases in intense storms, erosion and fire frequency, which will necessitate an increase in monitoring, mitigation and documentation activities.

In some cases, artifacts will need to be salvaged through excavation or other data recovery techniques and placed in collections. This increased need for museum property curation and records archiving at BADL may put strain on the capacity of the collection storage facility (Toothman 2008). BADL's compliance with the majority of facility standards increases the likelihood that collections will be protected from structural fire, looting and earthquakes; the lack of a basement and location in an area at low risk for flooding decreases the likelihood that collections will be exposed to flood. However, an increase in intense precipitation events projected for BADL may result in a higher occurrence of tornadoes, building codes for which facility storage standards do not currently consider.

Warmer temperatures may also precipitate humid conditions inside the building, which can encourage mold and other vegetative growth on collections that are sensitive to those conditions. Paper documents can also suffer from mold, mildew, 'foxing', and other heat and moisture related deterioration, as well as insect and rodent infestations. This is also true for photographic prints and negatives. In addition, if climate change encourages larger or new insect populations in the park, the facility may be exposed to infestations, potentially causing damage to collections through the deterioration of organic material (e.g., paper, fur, feathers, leather). Pesticides used to control infestations can also cause shrinking or stiffening of plastics, changing color of dyes, stains, and metal corrosion (NPS 1998b). Additional risks to the museum collections and records at BADL includes simple over-crowding of available space and compromised management if collections grow quickly as a result of climate change-induced excavation in the field.

There is some risk in storing collections in non-federal repositories, because it is difficult to monitor care. However, the current repository at the Rapid City School of Mines is a state-of-the-art facility, with an almost nonexistent backlog (approximately less than 100 records), and collections are likely to receive high quality care (SD School of Mines, Sally Shelton, Collections Manager, pers. comm. 2011). The same can be said for the Midwest Archeological Center in Lincoln, NE, which maintains both facility and curation standards at 90 percent or above.

Unlike place-based archeological sites and historic structures, collections are moveable, although sometimes at high cost. The fact that BADL has most of their collections in one facility increases the staff's ability to evacuate collections quickly and efficiently in the case of impending flood, fire, or other disaster. Another important consideration in maintaining the integrity of collections is the indirect effect of the damage or destruction of the site that collections came from, which can reduce the value of the collections due to a loss of context and ability to make a connection between the item and its original relationship on the landscape (NPS, Jay Flaming, Archeologist, pers. comm. 2011).

Summary of Vulnerability. BADL collections are expected to increase as new and existing sites on the landscape are compromised by climate change impacts. This will put demand on collections management staff and increase the potential for overcrowding and curation backlog at storage facilities. However, all three facilities currently maintain a reasonably high level of both curation and storage standards which minimizes this risk. The lack of an integrated pest management plan or appropriate seals on the facility doors increases the vulnerability of the BADL facility to insect and vegetative growth infestation. In general, however, BADL's compliance with collections standards, partnership with high quality repositories, and mobility of collections contribute to a low degree of vulnerability for museum collections.

4.5.4 Historic Roads and Structures

Description

The NPS defines historic structures as "constructed work[s] created to serve some human activity;" prehistoric or historic, and usually immovable (NPS 1998a, p. 1). BADL retains few traces of its pre-park agricultural and ranching history from the homestead era, due to the destruction of buildings, fences, and roads after the federal land repurchase programs of the 1930s (Stevens 2006). However, buildings and roads constructed during the early years of the park's establishment retain integrity and historic significance. Table 52 describes five historic roads in the park eligible for listing in the National Register of Historic Places (Stevens 2006, LCS 2011). Figure 31 shows the location of each historic road.

Table 52. A description of the five historic roads in Badlands National Park.

Road Name	Length	Width	Superstructure	Substructure	Runs from/to
Cedar Pass Road	5.2 mi (8.4km)	22 ft (6.7m)	Asphalt	Stone & earth	NE Entrance to Cedar Pass Junction
Cedar Pass to Northwest Entrance Road	29.4 mi (47.3 km)	22 ft (6.7m)	Asphalt & stone	Concrete & stone	End of NE Entrance Rd to Pinnacles
Sage Creek Rim Road	23.2 mi (37.3 km)	24 ft (7.3m)	Stone & earth (gravel)	Stone & earth	N.W. Entrance to West Boundary (Scenic to Wall, SD)
Sheep Mountain Table Road	8.6 mi (13.8 km)	12 ft (3.7m)	Stone & earth (gravel)	Stone & earth	Rt. 27 (Bombing Range Road) to top of Sheep Mountain Table
Old Northeast Entrance Road	2.6 mi (4.2km)	20 ft (6m)	Stone & earth (gravel)	Stone & earth	North boundary to SD240 above Cedar Pass

Each of these roads is significant because of its contribution to the establishment of Badlands National Monument in the 1930s and 1940s. Roads were critical in the early days of tourism in the area, when automobiles had become the primary transportation method for tourists and recreationalists. In addition to providing access to the park, the roads were designed to enhance viewsheds in the badlands and minimize intrusion on the landscape (Stevens 2006).

Photo 55. Historic structures in Badlands National Park. Clockwise from top: Cedar Pass to Northwest Entrance Road; Cedar Pass Road; Eugene Tyree Gravesite; Sheep Mountain Table Road; Ben Reifel Visitor Center.

The structures clustered at the Cedar Pass Developed Area possess significance between 1928 and 1966 due to their association with early tourism development, the Civilian Conservation Corps, and the NPS Mission 66 initiative (LCS 2011) (see Table 53). Cedar Pass is approximately 290 acres and includes the Ben Reifel Visitor Center (Photo 55), park administration complex, Cedar Pass Lodge, a campground and cabins, amphitheater area, park housing (Photo 56), maintenance facilities, and the beginning of the Badlands Loop Road (Bahr 2005).

Table 53. List of structures at the BADL Cedar Pass Developed Area and their condition.

Type of Structure	Condition
Lodge laundry building	Fair
Lodge maintenance building	Fair
Resource protection building	Fair
Lodge ice house	Fair
Tack room	Fair
Cabin buildings (19)	16 in fair condition; 3 in good condition
Visitor center	Good
Lodge cottage	Good
Lodge ice house	Good
Campground stations (3)	Good
Residences (7)	Good
Garages (5)	Good
Seasonal apartments (3)	Good
Maintenance shop	Good
Maintenance cold storage	Good
Flagpole	Unknown
Amphitheater benches	Unknown

The Ben Reifel Visitor Center retains 11 of 12 feature characteristics of NPS Mission 66 building type and style, and is the only remaining Mission 66-era visitor center in South Dakota to retain a substantial level of integrity (Bahr 2005, Stevens 2006). It is a one-story building made of masonry, sheet-metal, concrete, plywood, steel, and glass that was built for and still functions as the park interpretive center, gift shop, and administration building (Bahr 2005). The building is in good condition. The structural components of other buildings in Cedar Pass typically involve a concrete foundation, wood framing, stucco walls, and either asphalt or metal roof. The Lodge's laundry and maintenance buildings are in fair condition due to wood logs and rafter tails that are rotting. Wood paint, wall surfaces stucco, windows, screen doors and doors on several cabins are in fair condition. Metal frames and roofs on some structures, such as the campground stations, ice house, and tack room, are also in fair condition. The remaining structures are in good condition.

One additional historic property not located at Cedar Pass is the Eugene Tyree Gravesite, the 1910 gravesite of the infant son of a local homesteading family (Photo 55). The gravesite contains a concrete cross, plastic flowers, and metal headstone inscribed with information about the deceased. The site is surrounded by two protective barriers, one made of wooden posts linked by a single chain, the second of steel posts joined by barbed wire (LCS 2011).

Climate Change Vulnerability

Historic roads and buildings in BADL are vulnerable to destabilizing processes when located in areas prone to erosion. In BADL's already highly erodible landscape, dry conditions reduce soil moisture which can increase the risk of subsidence of roads or structures (Cassar 2005). Drought can also cause a loss of protective sediment and vegetation through wind and downslope movement that may cause subsidence or slumping of the undermined structure (Yu 2011). In addition to the stress of dry conditions, intense precipitation events accelerate erosional processes, exposing structures to damaging wind and wind-driven salt, sand, and rain, which further undermine structural integrity (Adams 2007).

Projected increases in storm intensity, coupled with warmer temperatures and drier conditions, threaten to exacerbate existing threats to historic roads, the Tyree gravesite, and the structures at Cedar Pass Developed Area. Figure 31 illustrates the location of historic roads and structures across landscapes with varying susceptibility to wind and water-induced erosion. The Sage Creek Rim Road in particular is highly vulnerable to the increased occurrence of subsidence or wash-out due to its location in an area susceptible to wind and water erosion. The Old Northeast Entrance Road (gravel) is almost entirely situated in an area susceptible to moderate wind and water-induced erosion. Sections of the Cedar Pass to Northwest Entrance Road (asphalt) are located in areas vulnerable to moderate wind erosion and some high water erosion. Parts of Sheep Mountain Table Road (gravel) and Cedar Pass Road (asphalt) are also located in areas moderately susceptible to wind and water erosion.

The porous gravel surface of Sage Creek Rim Road, Old Northeast Entrance Road, and Sheep Mountain Table Road are also sensitive to wash-out when located near washes, culverts, or steep hills. Both the Eugene Tyree Gravesite and the structures at Cedar Pass Developed Area are situated in or near areas susceptible to moderate wind erosion. In cases where the structures are in fair condition, wind may cause further damage to the previously compromised structural integrity of a building. All of these structures are located on a flat landscape and are therefore less exposed to wash-out and subsidence caused by extreme precipitation events.

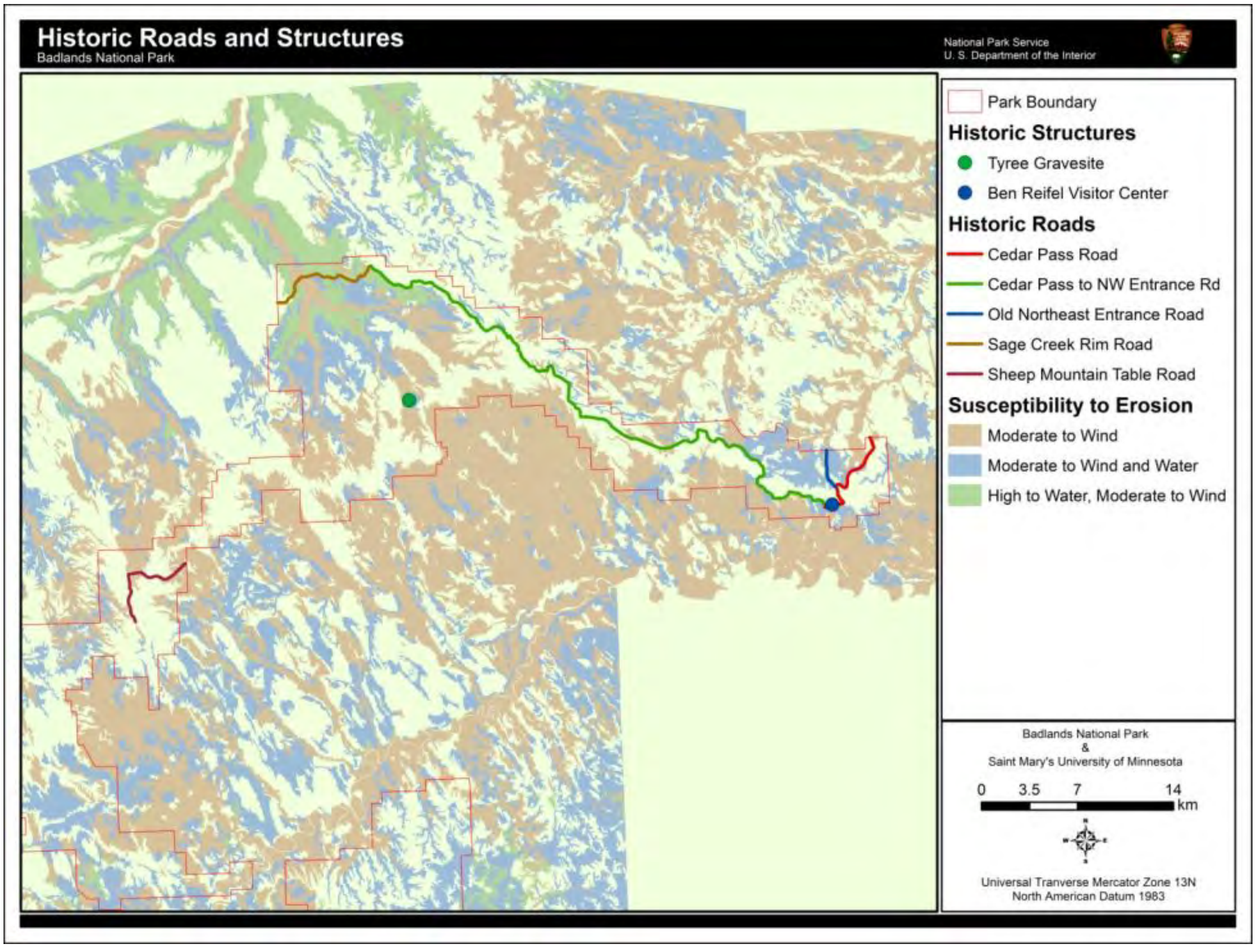

Figure 31. Locations of historic structures in areas prone to soil erosion within BADL.

Drier, warmer conditions may increase fire frequency and intensity in BADL (see section 4.2.1). Historic structures made of organic materials, metals, and some stone are extremely sensitive to fire, including wood and metals located at the Eugene Tyree Gravesite and Cedar Pass administrative buildings, housing, Cedar Lodge, and other buildings (Saunders 2006, Yu 2011). Three of the five historic roads in BADL are gravel roadbeds which burn at around 1000-1200° C (Saunders 2006, Winthrop 2009). These materials may not be as sensitive to fire damage from grassland fires, which generally range between 800-1000° C (Martell 2009). The concrete substructure on the Cedar Pass to Northwest Entrance Road is also unlikely to be impacted by fire, although asphalt used in the superstructure of both this road and the Cedar Pass Road may burn at its flash point, above 232 ^{o}C, causing damage (Marathon Petroleum Co. 2010).

Longer growing seasons and warmer winters may increase the spread and scope of opportunistic species. On landscapes like BADL that historically lack dense vegetation growth, invasive vegetation may cause some damage to roads, although drier conditions may inhibit the spread of some invasive species (see sections 4.1.3 and 4.1.4). Treatment of invasive species through mechanical removal or chemical treatments may also have unforeseen impacts to historic structures (Yu 2011). Overall, the vulnerability of historic roads in BADL to vegetation growth is low.

Summary of Vulnerability. The vulnerability of historic structures in BADL depends upon the material of the structure and its location on the landscape. Sage Creek Rim Road is highly vulnerable to climate change due to its presence on soils that are highly susceptible to water erosion and moderately susceptible to wind erosion, and its sensitivity as a gravel roadbed to subsidence. The Old Northeast Entrance Road is moderately vulnerable due to the soil's moderate vulnerability to wind and water erosion along the length of the road. Sheep Mountain Table Road is also a gravel road, however only parts of the road are susceptible to moderate wind erosion and therefore the road is less vulnerable. The two asphalt roads are also less vulnerable to climate change, as they are less sensitive to wash-out than the gravel roads and are only partly located in areas susceptible to moderate wind and some water erosion. None of these roads are particularly sensitive to fire or destabilization from invasive vegetation. Soils at the Eugene Tyree Gravesite are moderately susceptible to wind erosion and parts of the structure are very sensitive to fire; overall the site is moderately vulnerable to climate change. Historic structures located at Cedar Pass Developed Area are not particularly vulnerable to flooding or water erosion, although there is some sensitivity and exposure to wind erosion, which may be accelerated by extreme precipitation events related to climate change. The structures are somewhat vulnerable to increased fire frequency and intensity. Overall, historic structures in BADL have a low vulnerability to climate change.

4.5.5 Cultural Landscapes

Description

A cultural landscape is a geographic area that holds cultural or aesthetic value related to the way humans interact with, manipulate, and adapt to the land (Page 2009). A cultural landscape is the sum of all of its components, including the cultural and natural resources, wildlife, domestic animals, and built environments that lie therein. There are four types of cultural landscapes that are not mutually exclusive: historic sites, historic designed landscapes, historic vernacular landscapes, and ethnographic landscapes (NPS 1998a). Cultural landscapes are eligible for listing in the National Register of Historic Places as a compilation of historic components that make up a historic district, while the individual components within the landscape may be eligible as individual structures.

In BADL, there are a variety of features that interact both functionally and spatially in defining a cultural landscape (Bahr 2005): BADL topography, including the dramatic geologic formations that first established the park; vegetation (grasslands, sparse badlands, etc.); circulation (roads, parking lots, trails); water features (stock ponds, drainages); and structures (visitor centers, administrative buildings, park housing, campgrounds, picnic areas). These features combine to create a "sense" of space linked closely to a point in history, whether that of the brief homesteading era, early tourism development, or the longer history of Native American habitation.

A Cultural Landscape Inventory (CLI) is conducted to identify and describe the features that make a landscape historically significant, including use over time, development and construction, and geographic context (Bahr 2005). A Cultural Landscape Report (CLR) then provides more in-depth research and treatment recommendations for resource management. There is one cultural landscape in BADL that has been evaluated, although there may be additional cultural landscapes that are not yet evaluated. In 2005, a CLR was completed for the Cedar Pass

Developed Area of BADL to document the history and current conditions of the area. The CLR recommended a National Register historic district be established in the Cedar Pass area (Bahr 2005). Bahr (2005) asserted the Cedar Pass Developed Area possesses significance at the state level between 1928-1966 as a historic district due to its history of early tourism in the West, its involvement with the Civilian Conservation Corps and New Deal Master Planning, and the NPS’s Mission 66 initiative.

Figure 32. Badlands National Park highlighting the Cedar Pass Developed Area (in black box on map). A more detailed Cedar Pass Developed Area is shown in the inset.

The Cedar Pass Developed Area (Figure 32) is approximately 290 acres and includes the Ben Reifel Visitor Center (Photo 55), park administration complex, Cedar Pass Lodge, a campground and cabins (Photo 56), amphitheater area, employee housing (Photo 56), maintenance facilities, and the beginning of the Badlands Loop Road (Bahr 2005). These facilities are described under the Historic Structures section. It is located at the southeastern border of BADL, surrounded on the north and east by a wall formation, while opening to grasslands towards the south and west (Bahr 2005).

Important components of the Cedar Pass cultural landscape include the geology and geomorphology surrounding the built environment, particularly the wall formation. Soils range from the well-drained and silty soil found on the uplands, fans, and badlands (Badlands-Interior-Cedarpass Association) to alluvial fans and terraces along the base of the formations (Cedarpass-

Denby-Interior Association) (Bahr 2005). Surface water is extremely limited within the area, with gullies and washes forming during rainstorms and after snowmelt.

Photo 56. Components of the Cedar Pass Developed Area. Clockwise from top left: View of western wheatgrass from Cedar Pass; campground drive and picnic shelters; apartment cluster courtyard and parking; cabin area and planted central space (Bahr 2005).

The dominant plant community in the Cedar Pass area is Western Wheatgrass Alliance Grassland (Photo 56). Steeper and more barren areas host the Badland Sparse Vegetation Complex. Less abundant plant communities can be found in drainages and draws, both natural and those associated with former wastewater ponds. Turf grass, deciduous trees and shrubs, and other manicured landscapes surround Cedar Pass Lodge, campgrounds, parking medians, and other buildings. Wildlife found in Cedar Pass include Rocky Mountain bighorn sheep, “mule deer, pronghorn antelope, coyotes, bobcats, muskrats, least chipmunks, jackrabbits, desert cottontails, eastern cottontails…black-footed ferret, black-tailed prairie dog, mountain lion, and bald eagle” (Bahr 2005, p. 3-12).

Traditional Cultural Properties: For traditionally associated peoples such as the Oglala Lakota, components of a BADL cultural landscape may be linked to a sense of living community and identity as a distinct society. These components may meet the criteria of a traditional cultural property (TCP), eligible for listing in the National Register, because of their “association with cultural practices or beliefs of a living community that (a) are rooted in that community's history, and (b) are important in maintaining the continuing cultural identity of the community” (Parker and King 1998, p. 1). TCPs are typically locations and/or physical land features, with their constituent culturally significant natural resources. The landscape may be a place of ceremonial activity, the location of an origin story, hunting or harvesting space, or of another event connected to Lakota heritage values (NPS 2006). The NPS has an obligation to preserve and encourage cultural traditions, including those related to TCPs (NHPA 2011). TCPs may be hard to recognize, and so it is difficult to understand their significance and how they may be impacted by change (Parker 1998). With its dramatic landscape and proximity to the Pine Ridge Indian Reservation, areas within BADL may be linked to living Lakota culture, and may meet the criteria of TCPs. BADL staff must work with the Lakota tribe to identify and evaluate TCPs before an assessment of climate change vulnerability can be performed.

Climate Change Vulnerability

The climate change vulnerability of BADL cultural landscapes derives directly from the vulnerability of their natural and cultural components. A discussion of the vulnerability of grasslands, sparse badlands, bighorn sheep, mule deer, and other wildlife and plant communities to climate change can be found in the community- and species-level sections of this assessment. These vulnerabilities can be combined with those discussed above for cultural resources to determine cultural landscape vulnerability on a case-by-case basis. For example, if the key components of a BADL cultural landscape include a historic road situated on a badland formation that provides a view of a prairie dog town, the combined vulnerability of the road, the formation, the grassland, and prairie dog community will determine how the landscape is vulnerable to change.

In the Cedar Pass Developed Area, the CLR describes a combination of structures, plant and animal communities, and geologic formations that make up the cultural landscape. As discussed in the above Historic Structures section, increasingly dry conditions projected in BADL can reduce soil moisture, which can result in a loss of protective vegetation and sediment through intense precipitation events and wind erosion. This in turn can cause structural damage through subsidence or slumping of roads and buildings, particularly in areas prone to erosion (Cassar 2005). The historic Cedar Pass Road, Ben Reifel Visitor Center, Cedar Lodge, administrative buildings, park housing, campground, cabins, and other structures in the Cedar Pass area are located in a relatively flat area that is not a 100-year floodplain. The structures are not particularly vulnerable to structural damage caused by subsidence or flooding. The structures at Cedar Pass are on soils moderately susceptible to wind erosion, and may be subjected to increases in intense precipitation and wind, which may accelerate normal wear and tear over time, and in extreme cases cause serious damage to the structural integrity of roads and buildings (Adams 2007). Lastly, more frequent and intense wildland fires have the potential to threaten structures in the Cedar Pass area, but park management will likely be able to mitigate these impacts and prevent extensive damage.

In terms of biotic components of the cultural landscape, warmer temperatures and drier conditions may increase the dominance of shortgrass species over some mixed-grass communities like western wheatgrass. However, this grassland plant community does not appear to be particularly vulnerable to climate change (see section 4.1.3). Wildlife species identified in this assessment, such as mule deer and prairie dogs, are less vulnerable to climate change, while bald eagles are slightly vulnerable and black-footed ferrets are moderately vulnerable (see section 4.3). The presence of wildlife is a component of the Cedar Pass landscape, along with the grassland, roads, structures, and Badlands formations.

Traditional Cultural Properties: Impacts to traditional cultural properties (TCPs) derive from impacts to the characteristics that render TCPs culturally significant to descendant communities (Yu, pers. comm. 2011). In-depth consultation with traditionally associated peoples is necessary to adequately understand if and what kind of impact the range of climate change drivers and subsequent ecological processes will have on a TCP. For example, if climate change causes a shift in a grassland community along a mesa where a ceremony is performed (as mentioned previously), or if increased storm intensity causes the same mesa to rapidly erode, only the tribe for whom the site is significant will be able to determine if one or both of these changes negatively affects the heritage values associated with the site. Traditionally associated peoples play a critical role in identifying significant characteristics of a TCP and therefore must be consulted in any assessment. However, this sort of in-depth consultation process was beyond the scope of this project.

Summary of Vulnerability. The combination of all of the components of the Cedar Pass Developed Area has a low level of vulnerability to climate change (Table 54). Historic structures at Cedar Pass are not particularly vulnerable to flooding or water erosion, although there is some sensitivity and exposure to wind erosion, which may be accelerated by extreme precipitation events related to climate change. The structures are somewhat vulnerable to increased fire frequency and intensity. The western wheatgrass currently present is not likely to be vulnerable to a significant shift in grassland community. Wildlife species at Cedar Pass are largely less vulnerable, with the exception of bald eagles and black-footed ferrets.

Table 54. Summary of climate change vulnerability for the components of the Cedar Pass Developed Area in BADL.

Component of the landscape	Climate change-related impact	Vulnerability
Buildings	Extreme precipitation events increase flooding occurrence, water and wind erosion	Less vulnerable
	More frequent and intense fire	Less vulnerable
Vegetation	Drier conditions increase dominance of shortgrass species over mixed-grass	Less vulnerable
Wildlife	Bald eagles and black-footed ferrets	Less to moderately vulnerable

Uncertainty and Data Gaps for the Cultural Resource Assessment

The cultural resource section of this assessment is a first step in applying the framework outlined in Glick et al. (2011) to evaluate cultural resource vulnerability to climate change. Additional direction and case study examples are needed to evaluate the efficacy of this approach. Uncertainties abound regarding the rate, magnitude, and extent of change likely under climate change drivers and their secondary effects on the ecosystem. A more extensive assessment of cultural resource vulnerability needs to engage a variety of subject matter experts, including but not limited to engineers, maintenance specialists, curation specialists, anthropologists, archeologists, ethnographers, historians, and cultural landscape specialists.

Basic inventory and condition assessment data is needed for archeological resources and cultural landscapes in BADL. With only 5% of the park formally surveyed for archeological sites and only one evaluated cultural landscape, the data gaps regarding NPS knowledge of resources on the landscape are extremely large. The rate of “normal” resource deterioration for these unidentified resources is unknown; therefore an understanding of how climate change may alter or accelerate that deterioration is unobtainable. This lack of knowledge is a systemic issue, not just in BADL, but across the NPS. If NPS staff do not know where the cultural resources are located in the park, they cannot know the ways in which climate change will harm or destroy them.

Extensive consultation is missing from this assessment; it was outside of the project’s scope of work and a more limited consultation process was performed (see chapter 2). However, consultation with traditionally associated peoples is necessary to understand the significance attributed to Traditional Cultural Properties and other resources, and ideally to incorporate tribal and other management concerns and priorities into the assessment. Additionally, the literature surrounding climate change impacts to cultural resources, as defined by federal preservation policy, is minimal. Efforts to develop this field are currently underway both internally and in the academic community. It is expected that more information will be available in coming years.

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Chapter 5 Discussion and Conclusions

The objectives of this project were threefold: 1) to identify which natural and cultural resources were likely to be most affected by projected shifts in climate; 2) to provide an understanding of why these resources are vulnerable including providing insights on the interactions of climate changes with existing threats and stressors to resources; and 3) to serve as a pilot project for applying climate change vulnerability methodology for natural and cultural resources managers in parks and other protected areas who have a similar need for vulnerability assessment.

Based on the framework for vulnerability assessment developed by Glick et al. (2011), this CCVA is a multi-scale analysis that focuses primarily on the vulnerability of the main ecological communities in BADL (defined by vegetation types). Secondarily, it focuses on a selection of key animal species that are either a high priority for park managers or are viewed as indicators of ecosystem health, as well as park cultural and paleontological resources. A focus on the overall vulnerability of ecological communities in the park provides an umbrella under which vulnerability may be examined and inferred for key species inhabiting those communities; the degree of vulnerability for a plant community would presumably directly influence the sensitivity and vulnerability of individual animal species residing in that community. For instance, if a specific plant community is expected to change very little despite projected climate shifts (i.e., low vulnerability), it is highly probable that the animal species that rely on the community would also be less vulnerable to many of the potential stresses of climate change. Likewise, if a plant community is expected to experience dramatic changes in composition or distribution, it is highly probable that species dependent upon that community for habitat would also be greatly affected.

This assessment presents a summary of projected climate changes for the BADL region and a literature review and analysis of the vulnerability of various park natural and cultural resources to these changes. Each assessment considers the exposure of natural and cultural resources to projected climate changes, the degree of sensitivity to such changes, and the ability to cope with and adapt to these changes.

Climate

Historical conditions. Analysis of historical (1895-2010) PRISM data indicates a warming trend for both maximum and minimum average annual temperatures in the BADL region. Maximum average annual temperatures have increased 0.6° C and minimum average annual temperature increased 1.2° C over the past century. There is no apparent trend in precipitation over this period.

Projected future conditions. Temperatures in the BADL region are projected to increase an average of 2-3° C by 2050. It is estimated that average summer and fall temperatures will increase more than average winter and spring temperatures. Projected temperature changes by 2100 are significantly warmer – with projected increases in average temperatures of 4-6° C over the historical reference period. Precipitation is projected to increase slightly, but variation in model predictions makes it difficult to determine with confidence the magnitude of increase or pattern of distribution. Overall, even with an increase in precipitation, the climate in BADL is estimated to become much drier, as higher temperatures will drive increased evapotranspiration rates. The projected increase in evaportranspiration is estimated to exceed (substantially) the projected increase in precipitation, which would result in significantly reduced soil moisture. General predictions for the region also suggest an increase in extreme temperature (number of excessively hot days) and weather events (increase in strong convective storms) (Diffenbaugh and Ashfaq 2010).

Vulnerability of Natural and Cultural Resources

Plant Communities

The four main plant communities in the park were assessed for vulnerability to climate change. Vulnerability was determined by examining six variables: current location of the plant community in its known geographical range, sensitivity to extreme climatic events, dependence on specific hydrologic conditions, intrinsic adaptive capacity, vulnerability of ecologcially influential species in the community, and potential for climate change to exacerbate the influence of non-climate stressors. The plant communities range in vulnerability to climate change from least vulnerable to highly vulnerable. Table 55 summarizes the vulnerability of the plant communities examined and the confidence in these vulnerability scores based on current available science.

Table 55. Summary of plant community vulnerability to climate change in BADL.

Community	Climate Change Vulnerability*	Confidence$^+$	Alternative Vulnerability Scores
Woodlands	High (23)	Moderate (12)	21-25
Shrublands	Moderate (18)	Moderate (12)	17-21
Sparse Badlands	Moderate (17)	Moderate (13)	18-21
Grasslands	Least (13)	High (15)	14

*6-13= least vulnerable, 14-19 = moderately vulnerable, 20-25 = highly vulnerable, 26-30 = critically vulnerable

$^+$6-10 = low confidence, 11-14 = moderate confidence, 15-18 = high confidence.

The woodlands plant community was found to have high vulnerability to climate change, and is the most vulnerable of the BADL communities examined in the assessment. Wooded areas cover a very small percentage of the park landcover, but provide essential habitat for a number of species. Woodlands are concentrated in drainages and riparian areas where soil moisture is higher and surface water is available either intermittently or yearlong. Projected climate changes indicate much warmer, drier conditions overall with more variable patterns in precipitation, which could increase the likelihood of more frequent and severe drought conditions and change seasonal hydrology. If this occurs, riparian woodlands and some upland species that exist in an already semi-arid environment would likely experience drought stress, decreased resistance to pathogens and invasive species, reduced reproduction, and increased mortality. Of particular concern are the cottonwood-willow woodlands which, although somewhat drought tolerant, rely on a period of consistently wet conditions for seedling establishment.

Both the shrubland and the sparse badlands plant communities in BADL are moderately vulnerable to projected climate changes in the region. Occurring mostly in mesic or sandy areas, the distribution of many shrubland species are limited by soil moisture and, thus, occur intermittently throughout the park. While some shrubland species are adapted to drier conditions, increased average temperatures, greater variability in precipitation, and higher rates of evapotranspiration are likely to make growing conditions more challenging, particularly for riparian and mesic shrubland species. The sparse badlands plant community is a ‘specialist’ community, occurring under specific environmental conditions that include steep slopes, highly erodible soils and very warm, dry conditions. Many of the plant species in this community are largely drought tolerant, which affords them an advantage in coping with the potential warmer, drier conditions predicted for the region. The vegetation is also adapted to “extreme wetting” that occasionally occurs during heavy rainfall; however, the projected variability in precipitation for the region is likely to occur as more sporadic, convection storms with a higher magnitude of rainfall on average. This could subject the sparse badlands to more intense erosive events. Preliminary observations from ongoing research on erosion rates due to precipitation events in BADL indicate that current rates of erosion with precipitation events are greater than originally expected.

The grassland plant community was determined to be least vulnerable of the communities examined in BADL. The warmer, drier conditions projected for the region are unlikely to threaten the continued existence of grasslands in the park, as many grassland species are somewhat adapted for drier soil conditions. However, some research suggests that increased average temperatures, coupled with shifts to more varied precipitation patterns, could stimulate changes in grassland species composition, productivity, and phenology. As average temperatures become warmer and conditions become even drier, it is possible that current species composition could shift to dominance by species that are more tolerant of these conditions (e.g., shorter grasses).

Seeps and spring features in BADL were also examined for vulnerability to climate change. Very little information exists on these features, which makes it difficult to determine relative vulnerability to changing environmental conditions. These are very unique, rare water features in the semi-arid landscape of the park and, thus, serve as an important water source and habitat for many wildlife species in the park. The projected warmer, drier climate conditions and increased variability in precipitation for the region will likely impact the amount of available surface and ground water that supply the springs and seeps. More research is needed to understand the dynamics of these features with regard to available water to better determine overall vulnerability to climate change.

Overall, the majority of species that make up the plant communities in BADL are not likely to respond rapidly to the climate changes projected for the region, but instead shifts could take decades or longer to occur. It is more likely that managers will see plant communities dissociated and decoupling, depending on plant species’ sensitivities to climate changes, and reconfiguring into novel combinations. Over the next few decades, it is possible that managers will begin to see the loss of the plant species with the greatest vulnerability (highest sensitivity to climatic changes) in each community, while the plant community as a whole still retains its overall structure. For example, the grassland plant community in BADL will likely remain a grassland in structure, however, the species composition may change significantly over time.

Species

A total of seven species and three groups of species were assessed for vulnerability to climate change. Vulnerability was determined by the degree to which species exhibited six vulnerability characteristics or traits: physiological sensitivity to environmental conditions, habitat or prey specialist, dependence on interspecific interactions, reliance on habitat deemed sensitive to climate change, non-climate stressors, and reproductive potential for adaptation. Some species (and groups of species) were found to be more vulnerable to projected climate changes in the region, while other species were determined to be less vulnerable. Table 56 shows the degree to which each species or group of species exhibits vulnerability characteristics.

Table 56. Summary of climate change vulnerability characteristics exhibited by target species or groups of species in BADL.

Species	Physiological Sensitivity	Specialist	Interspecific Interactions	Sensitive Habitat	Non-climate Stressors	Reproductive Potential
Prairie dog		○				○
Black-footed ferret		●	●			○
Swift fox		●	○			
Bighorn sheep	●	○			○	○
Bison		○				○
Mule deer				○	○	○
Bobcat				○	○	
Herpetofauna	○			○	○	○
Birds of prey	○	○		○		○
Grassland birds	○	○			●	

* ○ = partially exhibits this vulnerability characteristic, ● = fully exhibits this characteristic

More Vulnerable to Climate Change

Several of the species (or groups of species) targeted for assessment were identified as being more vulnerable to climate change than some other native species found in the park. These include black-footed ferrets, bighorn sheep, mule deer, herpetofauna, and grassland bird species. Several characteristics emerged among those species found to be more vulnerable, including having physiological sensitivities to temperature, increased susceptibility to diseases, and reliance on rare, sensitive or highly vulnerable habitat.

BADL maintains a small population of the critically endangered black-footed ferret. As a specialist species, the black-footed ferret likely has little tolerance for changes in habitat due to climate change. They do not have a physiological sensitivity to temperature, but because they rely so heavily on prairie dog colonies for habitat and food, the ferret population would be at significant risk if climate change were to threaten the stability of prairie dog colonies in the park. Currently, prairie dog populations in BADL are carefully managed and remain stable. Disease remains a concern, but the warmer, drier conditions projected for the region may work to suppress outbreaks of sylvatic plague among prairie dogs and, coupled with careful management, subsequently decrease the incidence of transmission to ferrets.

Already considered a fragile species in BADL because of their sensitivity to temperature and moisture conditions and susceptibility to disease, the projected climate changes for the region will likely have substantial effects on the Rocky Mountain bighorn sheep. The potential physiological impacts of warmer, drier climate on the sheep, as well as the potential for climate changes to alter species composition and availability of nutritious forage in primary grazing habitats, may make persistence of the population in and around BADL more challenging. Currently, the bighorn sheep population in BADL does not migrate. If the projected warmer, drier conditions for the region are realized, bighorn sheep may be at increased risk of disease due to malnutrition or population density. Change in conditions may also force the population in the park to seek out more suitable habitat, particularly locations that experience cooler average temperatures with more available moisture.

Although mule deer inhabit a wide range of habitats and climates in the U.S., the projected climate changes for the BADL region may have a significant influence on the persistence of the mule deer population in the park. Warmer, drier conditions in the region may increase the prevalence of certain diseases and parasites, likely through more frequent outbreaks, which would greatly affect the health and stability of the population in the park. Further, mule deer rely on riparian woodlands for cover, protection from the elements, and migration; this plant community composes only a small percentage of the park's landcover and is considered to be highly vulnerable to climate change due to the sensitivity of many of the plant and tree species to the warmer, drier conditions.

Many of the grassland bird species occurring in BADL require relatively continuous shortgrass or mixed-grass prairie habitat. A number of these bird species have experienced population declines due to changes in available habitat and will likely experience further declines due to the influences of climate change in the region. Although most grassland birds can tolerate habitats with some intrusion of non-native grasses, grasslands become less suitable for species such as the sharp-tailed grouse if invasive species begin to dominate the composition.

The various herpetofauna found in BADL will likely experience stress from climate changes in the region, though at different levels depending on life history traits. Amphibians are highly sensitive to temperature and moisture changes because the permeable skin through which they breathe needs to remain moist. Thus, amphibians depend heavily on wetlands and aquatic habitats in the park during all life stages, with these habitats being especially important for reproduction. The warmer, drier conditions projected for the region could significantly reduce available surface water and desiccate the habitats that amphibians depend on to survive in the semi-arid region, making them highly vulnerable to climate change. Reptiles are better suited physiologically to tolerate warm, dry climatic conditions, but are quite sensitive to extreme temperatures (hot and cold); extremely warm temperatures can affect reproduction (sex determination) and many reptiles must seek shelter from the sun when temperatures reach approximately 38° C or higher.

Less Vulnerable to Climate Change

A number of species were found to have low vulnerability to projected climate changes, including bobcat, bison, prairie dogs, swift fox, and birds of prey. These species, to an extent, have physiological or behavioral traits and adaptations that will allow them to better cope with the projected climatic changes in the region, including finding shelter during excessively warm periods, or having more generalized forage or prey item preferences. Although several of these species are specialists or rely on a sensitive habitat, the generalist tendencies they also posses allow for better coping with a change in environmental conditions.

Bobcats were determined to have a lower vulnerability to climate change in BADL primarily because they have little physiological sensitivity to temperature and moisture conditions, eat a wide variety of prey species, and are adapted to live in a wide range of habitats. However, in BADL, they do rely somewhat on wooded draws and drainage areas for cover and hunting, and may become more vulnerable if this plant community disappears from BADL with the onset of warmer, drier conditions. The prevalence of tick-borne disease may also increase with warmer average temperatures.

The bison, prairie dog, and swift fox population in BADL currently exhibit only a slight vulnerability to climate change. Although all are essentially grassland specialists, the grasslands plant community will likely change very little in response to the projected climate changes for the region. Some changes in plant composition away from preferred forage species may influence grazing behavior for bison. None of the species have a physiological sensitivity to temperature; bison have specially adapted pelts that help regulate body temperature during extreme cold or hot periods, and both prairie dogs and swift foxes can retreat to underground burrows to escape extreme temperatures. Swift foxes do rely on prairie dogs as prey items for part of the year and could be significantly impacted if prairie dog populations suddenly decline in the park. Sylvatic plague is a constant concern in the park and can greatly reduce prairie dog populations in a short period of time; however, this is carefully managed and the projected warmer, drier conditions for the region may actually help to reduce the spread of plague in the region.

Many of the birds of prey species in BADL are not likely to be significantly affected by the projected climate changes for the region primarily due to their migratory nature and their ability to easily seek out more suitable habitat if the need arises. Some species, such as the bald eagle which prefers large trees often found in riparian areas, may be vulnerable if climate change reduces the distribution of woodlands in the BADL region.

Non-climate Stressors and Climate Change

Most ecological communities and the species within them experience various threats or stressors simultaneously; these interactions are often quite complex and can act synergistically in that one threat intensifies or amplifies others (Myers 1987). Research on ecological communities as a whole is especially lacking and the complex interactions among species, physical parameters, and dynamic ecological processes is poorly understood. Climate change only adds to the complexity of these interactions and it is not well understood how climatic shifts will amplify or attenuate the influences of existing threats to the detriment or benefit of natural systems and wildlife. Projected shifts in climate in the region may lead to unforeseen interactions among known stressors and introductions of new stressors. For example, as a result of a changing environment, the distribution and abundance of multiple prey species may be altered, which would influence the population dynamics of larger predators in BADL.

Of the many non-climate stressors identified throughout this assessment for the plant communities and species, certain stressors repeatedly emerged as likely to have a synergistic reaction with the projected climate changes for the region. These stressors include the encroachment of non-native species into plant communities and increased susceptibility and prevalence of disease and pests for both plant communities and individual species.

Invasive Non-native Species

Non-native species are particularly threatening to natural systems because of their ability to out-compete native species for resources and alter whole communities through shifts in species composition (both plant and animal) (Wilcove et al. 1998). Stress or drought-tolerant invasive species are often better able to cope with exceedingly warmer, drier conditions than native species. Evidence also suggests that an increase in variability of precipitation may decrease grassland resistance to invasion by non-natives (Kreyling et al. 2008). As a result, some invasive plant species may become more pervasive in BADL as they will likely cope better with climatic shifts than native species. Brome grasses in particular have steadily become more prevalent in the park and projected climatic changes may create more favorable conditions for the spread of these species. Similarly, opportunistic woody species, such as tamarisk, are able to proliferate in riparian areas when drier conditions make it difficult for native species to persist. The potential shift in species composition not only has implications for native plant communities, but can also change preferred animal habitat and forage and alter ecological processes. For example, cheatgrass is highly flammable and its increased prevalence may subsequently increase the frequency and intensity of fires in BADL. While burning is considered beneficial for the health and productivity of native grasslands, invasion of cheatgrass into other habitat types, such as woodlands, increases the probability of damaging fires in communities that burn less frequently. Currently, the grasslands, shrublands, and sparse badlands ecological communities are most at risk of encroachment and invasion by non-native species.

Disease and Pests

Outbreaks of many diseases and pests will likely occur with greater frequency and severity with climate change (Harvell et al. 2002). With climate projected to become warmer and drier in BADL, wildlife and plant diseases and pests may become more prevalent as many vectors expand their ranges into new regions where conditions were previously unfavorable. If this occurs, a number of key species in BADL could be adversely affected by a myriad of disease outbreaks, including bobcat, mule deer, bison, black-footed ferrets, and bighorn sheep. Similarly, a number of key tree species that are found in the woodland community in BADL, including green ash and ponderosa pine, could experience increased incidence of disease or pest infestation, which would have significant implications for the sparsely distributed woodland plant community. Poor health or loss of these tree species would significantly affect the quality of the woody draw and riparian habitat that is used by a number of animal species for cover and migration. Conversely, some diseases that are currently an issue for some wildlife in BADL have thermal or moisture limits including sylvatic plague and chytrid fungus. Research suggests that these diseases may become less prevalent in the region with the projected warmer, drier conditions.

Paleontological and Cultural Resources

Climate change projections for BADL suggest a slight increase in precipitation and a shift to more variable precipitation patterns, which will most likely occur in the form of sporadic, strong convective storm events. High wind and heavy rain events are expected to result from these storms, which will intensify the current wind and water erosion regimes and possibly contribute to increases in landslides and slumps. Park locations with moderate to high levels of water and wind erosion currently may experience even higher rates of erosion through the end of the century. Further, the projected warmer, drier climate may create conditions that favor more frequent and intense wildfires in the park. This has implications for cultural and paleontological resources across the park landscape, as most of these resources (with the exception of culturally significant plants and animals) have no adaptive capacity or ability to cope with rapid changes in climate that would exacerbate current threats of exposure and deterioration.

Paleontological Resources

Exposure through erosion is the primary threat to paleontological resources in BADL. Rates of exposure from the soil matrix are already high for fossils in the park. Projected variability and increase in precipitation may be realized as more extreme rainfall events, which may in turn lead to increased rates of erosion or even landslides and slumping. Increased exposure also makes fossils more vulnerable to weathering and theft. Ongoing research in BADL will be essential to providing an understanding of current erosion rates at significant fossil sites with each precipitation or other weathering event. Results from this study may be combined with projections for future climate patterns to estimate future erosions rates and overall vulnerability of fossils through the end of this century.

Cultural Resources

Archeological Resources. Because BADL is a highly erodible landscape, archeological resources in general are highly vulnerable to exposure to the elements as weathering gradually uncovers artifacts. All BADL archeological sites are currently exposed to wind and water erosion, with a majority of sites experiencing disruption by erosion. Currently, approximately one-third of archeological sites are at high risk of compromise due to exposure. The projected changes in climate, including increased storm activity, warmer average temperatures and increasingly drier conditions will likely intensify the current stressors to these sites.

Museum collections. BADL collections are expected to increase as new and existing sites on the landscape are exposed through increased erosion and weathering events associated with projected climate changes. This will put demand on collections management staff and increase the potential for overcrowding and curation backlog at storage facilities. BADL currently maintains a reasonably high level of both curation and storage standards, which minimizes the potential risk to artifacts. Compliance with collections standards, partnership with high quality repositories, and mobility of collections contribute to a low degree of vulnerability for museum collections.

Historic roads and structures. Historic roads and structures in BADL range in vulnerability from low to high depending on the location on the landscape and the current stability and materials of the structures. The feature considered most vulnerable is the Sage Creek Rim Road, where soils are highly vulnerable to wind and water erosion. Soils around the Old Northeast Entrance Road are moderately vulnerable to wind and water erosion, which may increase in intensity with projected changes in climate. Likewise, the Eugene Tyree Gravesite is surrounded by soils moderately vulnerable to wind erosion, as well as parts of the structure being susceptible to damage by fire. Least vulnerable are the two asphalt roads and Sheep Mountain Table Road (which is gravel), as much of the soil along their lengths is less vulnerable to wind and water erosion than other sites.

Cultural Landscapes. The Cedar Pass Developed Area is the sum of all historic roads, structures, wildlife, plants, geologic formations, and other features located therein that contribute to the historic landscape. Overall, the Cedar Pass Developed Area is considered to have low vulnerability to the projected changes in climate for the region. The primary concerns are sensitivity and exposure to wind erosion and threat from increased fire frequency and intensity due to projected warmer, drier conditions for the region.

Ethnographic Resources. Of the cultural resources examined in this assessment, culturally significant plants and wildlife are different from the non-living resources in that they have, to some degree, the capacity to adapt or cope with environmental changes associated with climate change. Many of the culturally significant wildlife species examined in this assessment have largely generalist tendencies and are not expected to be particularly vulnerable to climate change. However, some species are viewed as much more vulnerable because they rely on plant communities in or around the park that are rare and/or likely to be adversely affected or eliminated by the overall drier, warmer conditions projected for the region. Examples of this are the porcupine, which favors the rare woodland plant communities, and the trumpeter swan, which relies on wetland and aquatic habitats in the BADL region.

Culturally significant plant species range widely in degree of estimated vulnerability depending on the main plant community in which they are found. Those species most vulnerable to climate changes in the region are found in the woodlands and/or shrubland plant communities, both of which are at-risk from the projected warmer, drier conditions and the interaction of non-climate stressors. Those species found in the grassland communities are considered least vulnerable, as the grasslands are expected to cope well with projected changes.

Uncertainty in Assessing Vulnerability

Uncertainty is inherent at every stage of a CCVA. The future scenarios for climate do not cover the entire range of possibilities and, thus, there is uncertainty in the climate models used to create regional downscaled climate projections. Uncertainty is also present in our analysis of vulnerability, resulting from a lack of definitive literature and scientific knowledge that characterizes the relationship of many natural resources to climate shifts and/or non-climate stressors and how these resources will respond to climate change. Significant data gaps exist within several plant communities in BADL. While it is possible to reduce some uncertainties by building better models or by gathering additional data, many are unavoidable and managers must learn to make decisions in the face of uncertainty.

Future Considerations

While this assessment focuses on a diversity of natural and cultural resources found in BADL, this effort was not a comprehensive assessment of all park resources or factors that may affect vulnerability to climate changes. The vulnerability of insects to climate change is not addressed in this assessment, but these organisms are acknowledged by park resource managers and outside experts as ecologically important organisms within BADL, as both a food source for other animals and pollinators to native plant communities. Insects, particularly grasshoppers, serve as a food source for many bird species and some mammals in the park; grasshopper abundance in BADL is dependent somewhat on climate conditions (B. Kenner, pers. comm., 15 November 2011). Research on many different butterfly species worldwide has shown that climate changes, such as warmer spring temperatures and variation in average precipitation, are highly correlated with earlier first appearance and first flights (reviewed in Parmesan 2006). Warmer, drier conditions have been directly linked to asynchrony of time of insect emergence and host senescence and blooming of nectar sources, contributing to butterfly population crashes and extinctions (reviewed in Parmesan 2006). Further, numerous studies in temperate climates across Europe and North America have documented a number of butterfly species shifting their ranges northward, following warmer average winter temperatures (reviewed in Parmesan 2006). Many insects play a critical role as pollinators in BADL, in particular for the native grasslands plant community. Currently, there is an on-going research effort funded by the NPS Climate Response Program to evaluate bee population responses to climate changes in critical habitats within 83 regionally distributed NPS protected areas, including BADL, and the implications for pollination of native plant communities (John Gross, Ecologist, NPS Climate Change Response Program, pers. comm., 15, November 2011. It will be important to integrate knowledge of insect and pollinator vulnerability into future conservation strategies as more data emerge.

Conclusions

Traditional conservation strategies were largely developed before climate change had become a major consideration for natural resource managers. However, recent science has increased our awareness of the ecological consequences of climate change, and managers now are tasked with adapting and refining conservation approaches that work to best protect natural resources from the influences of changing climate. Essential to the adaptation effort is identifying and, when possible, quantifying the comparative vulnerabilities of important ecological resources, such as through a CCVA. This provides natural resource managers with greater understanding of which climate influences or resources require the most immediate attention.

This CCVA defines a process for qualitative assessment of natural and cultural resources in BADL and characterizes the projected regional downscaled climate changes and the best estimates of resource vulnerabilities based on available literature and professional judgment. The project team believes the statistical downscaling approach to developing regional climate change projections is both appropriate and applicable for vulnerability assessment and the resulting assessment provides resource managers with a credible estimate of resource vulnerabilities in BADL. This CCVA shows that the physical, ecological, and cultural resources in BADL exhibit a wide range of climate change vulnerabilities and, consequently, it is likely that managers can expect to see substantial changes in the distribution of many of these resources in the next several decades. This CCVA is a very important first step in understanding how park resources may change with impending climate change. It provides managers a starting point from which to begin identifying the resources that may not cope well with climate changes and those that may be resilient to projected changes. It is our hope that this report offers insight for BADL resource managers as they begin to identify mitigative strategies for park resources.

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Appendix A: Species identified as sensitive by the U.S. Forest Service Region 2 or recognized as rare by the South Dakota Natural Heritage Program.

Common Name	Scientific Name	State Rank	USFS Reg. 2 sens. species	Tracked by SD Nat. Heritage
Regal fritillary	*Speyeria idalia*	S3	x	x
Plains leopard frog	*Rana blairi*	S3S4	x	x
Northern leopard frog	*Rana pipiens*		x	
Western box turtle	*Terrapene ornate*	S2		x
Short-horned lizard	*Phrynosoma hernandesi*	S2		x
Six-lined racerunner	*Cnemidophorus sexlineatus*	S2		x
Horned grebe	*Podiceps auritus*	S2		x
American white pelican	*Pelecanus erythrorhynchos*	S3		x
Great blue heron	*Ardea Herodias*	S4		x
Snowy egret	*Egretta thula*	S2		x
Black-crowned night-heron	*Nycticorax nycticorax*	S3S4		x
American bittern	*Botaurus lentiginosus*		x	
Trumpeter swan	*Cygnus buccinator*	S3	x	x
Bufflehead	*Bucephala albeola*	S1S2		x
Hooded merganser	*Lophodytes cucullatus*	S2		x
Common merganser	*Mergus merganser*	S1		x
Osprey	*Pandion haliaetus*	S1		x
Bald eagle	*Haliaeetus leucocephalus*	S1S2		x
Sharp-shinned hawk	*Accipiter striatus*	S3		x
Cooper’s hawk	*Accipiter cooperii*	S3		x
Northern goshawk	*Accipiter gentilis*	S2S3	x	x
Broad-winged hawk	*Buteo platypterus*	S2		x
Swainson’s hawk	*Buteo swainsoni*	S4		x
Ferruginous hawk	*Buteo regalis*	S4	x	x
Northern harrier	*Circus cyaneus*		x	
Golden eagle	*Aquila chrysaetos*	S3S4		x
Merlin	*Falco columbarius*	S3		x
Peregrine falcon	*Falco peregrinus*	SX		x
Prairie falcon	*Falco mexicanus*	S3S4		x
Loggerhead shrike	*Lanius ludovicianus*		x	
Whooping crane	*Grus americana*	SZ		x
Mountain plover	*Charadrius montanus*	SX	x	x
Long-billed curlew	*Numenius americanus*	S3	x	x
Greater prairie-chicken	*Tympanuchus cupido*		x	
Common tern	*Sterna hirundo*	S2		x
Black tern	*Chlidonias niger*	S3		x
Barn owl	*Tyto alba*	S2		x
Burrowing owl	*Athene cunicularia*	S3S4	x	x
Long-eared owl	*Asio otus*	S3		x
Short-eared owl	*Asio flammeus*		x	
Common poorwill	*Phalaenoptilus nuttallii*	S3		x
Ruby-throated hummingbird	*Archilochus colubris*	S2		x
Lewis’ woodpecker	*Melanerpes lewis*	S3	x	x
Olive-sided flycatcher	*Contopus cooperi*	SU	x	x
Brown creeper	*Certhia americana*	S2S3		x

Northern mockingbird	*Mimus polyglottos*	S3		x
Sage thrasher	*Oreoscoptes montanus*	S2		x
Spague’s pipit	*Anthus spragueii*	S2		x
Black-and-white warbler	*Mniotilta varia*	S2S3		x
Brewer’s sparrow	*Spizella breweri*	S2	x	x
Grasshopper sparrow	*Ammodramus savannarum*		x	
Mccown’s longspur	*Calcarius mccownii*	SU		x
Chestnut-collared longspur	*Calcarius ornatus*		x	
Plains topminnow	*Fundulus sciadicus*	S3		x
Plains minnow	*Hybognathus placitus*		x	
Flathead chub	*Platygobia gracilis*		x	
Sturgeon chub	*Macrhybopsis gelida*	S2	x	x
Long-eared myotis	*Myotis evotis*	S1		x
Fringe-tailed Myotis	*Myotis thysanodes pahasapensis*	S2	x	x
Northern Myotis	*Myotis septentrionalis*	S3		x
Silver-haired bat	*Lasionycteris noctivagans*	S4		x
Townsend’s big-eared bat	*Corynorhinus tonsendii*	S2S3	x	x
Spotted ground squirrel	*Spermophilus spilosoma*	S1		x
Black-tailed prairie dog	*Cynomys ludovicianus*		x	
Northern River Otter	*Lontra canadensis*	S2	x	x
Swift fox	*Vulpes velox*	S1	x	x
Mountain Lion	*Puma concolor*	S2		x
Drummond’s wild onion	*Allium drummondii*	SU		x
Barr’s milkvetch	*Astragalus barrii*	S3	x	x
Summer orophaca	*Astragalus hyalinus*	SU		x
Timber milkvetch	*Astragalus miser*	SH		x
Dakota buckwheat	*Eriogonum visheri*	S3	x	x
Spike gilia	*Ipomopsis spicata*	S4?		x
Sidesaddle bladderpod	*Lesquerella arenosa* var. *argillosa*	S3		x
One-flowered broomrape	*Orobanche uniflora*	S2		x
Hopi tea greenthread	*Thelesperma megapotamicum*	S3S4		x
Easter daisy	*Townsendia exscapa*	S4?		x

* S1 – Critically imperiled because of extreme rarity or some factor(s) making it especially vulnerable to extinction.
S2 – Imperiled because of rarity or some factor(s) making it very vulnerable to extinction throughout its range.
S3 – Either very rare and local throughout its range, or found locally in a restricted range,or vulnerable to extinction throughout its range because of other factors
S4 – Apparently secure, though it may be quite rare in parts of its range, especially at the periphery. Cause for long term concern.
S_? – Inexact rank
SH – Historically known, may be rediscovered.
SU – Possibly in peril, but status uncertain, more information needed.
SX – Believed extinct, historical records only.
SZ – No definable occurrences for conservation purposes, usually assigned to migrants

Appendix B: Analysis of Historical and Projected Climate Data for Badlands National Park

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Appendix B - Contents

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Overview

This document provides a detailed description of procedures to acquire and analyze historical climate data and climate projections to support a climate change vulnerability assessment for Badlands National Park. The detailed descriptions will allow others to relatively easily update, repeat, or modify the analyses for Badlands National Park, or (more likely), to follow these instructions and quickly generate similar results to support projects at other locations. In effect, the document will serve as a template for future use.

Historical data used in the analyses are from the PRISM archive, which provides gridded, full-coverage data for selected variables (Daly et al. 2002). Projections use downscaled, 1/8 degree spatial resolution data developed for CMIP3 (Climate Model Intercomparison Project) and downscaled as described by Maurer et al. (2007). The review and evaluation of climate models and downscaling by Barsugli et al. (2009) is particularly informative and accessible, and recommended for readers interested in these topics.

The procedures and scripts described here can facilitate an extremely broad range of data management and analysis options, but some expertise with the R statistical languages (R Development Core Team 2011) is required for many operations. Alternative ways to access historical climate data or future projections include Climate Wizard (Girvetz et al. 2009; http://www.climatewizard.org/) and the Climate Grid Analysis Toolset (CGAT; Sherrill and Frakes 2011). ClimateWizard provides a very simple interface to some very computationally intensive and extensive analyses of both historical and projected climate data, mostly at a 0.5 degree (~ 60 km) spatial resolution. Sherrill and Frakes (2011) describe procedures using Python and GIS scripts to conduct site-specific and data-specific analyses of historical to current PRISM and SNODAS climate data. ClimateWizard requires only a compatible internet browser, whereas the CGAT requires Python and ArcGIS.

This document is divided into sections that describe how to download data from the internet sites, followed by sections that describe processing and analysis of historical data and then climate projections. This work flow – acquisition of data followed by analysis – is most likely to be used, and sufficient time must be allocated to the tasks of defining the data and downloading files, and to modifying the analysis code as necessary and conducting the analysis. While this document will help streamline analyses, many user-specified options are necessary because the most useful ways to slice and dice and display climate data will vary with location and environmental conditions. A plot type or style that is informative for one region may be misleading with used in an area where climate patterns differ. Kittel (2009) provides a detailed description of important considerations when analyzing climate data (especially station data), and provides many examples of ways to analyze and present results.

Computer Requirements and Assumptions

Scripts were developed and tested with R version 2.14.0 and the then-current versions of the associated packages. These instructions assume a basic familiarity with R, and users are very likely to generate errors in R due to variations in directory structures and file names. These are easily fixed – but they do require attention on the part of users. Most users will want to modify plots and run subsets of the code repeatedly, making adjustments to labels, axes ranges, and other minor details until the final product is sufficient. The code is designed to facilitate this style of work and make it easy to produce informative and attractive graphics.

The size of data sets used in the analyses will determine hardware requirements and execution speed. Data sets smaller than about 5^o x 5^o and with less than 20 or so model-parameters combinations require fewer than 20 minutes for code execution on a reasonably fast computer, assuming data are stored on a local hard drive or very fast network. It will likely take much longer than this to refine the plot parameters.

The R scripts require installation of packages not included in the base R distribution, and in one case the ‘sourcing’ of code that is stored externally to the scripts. The required packages differ between scripts, and thus packages are always loaded in the initial section of script. Base R documents describe installation and updating of packages. R code is included in some scripts to produce files that are readily compatible with software that can embellish and enhance graphical output.

PRISM Data

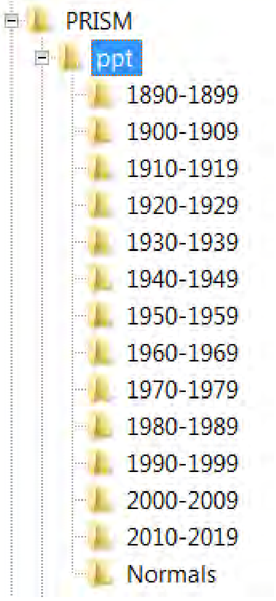
Data Acquisition

PRISM (Parameter elevation Regressions on Independent Slopes Model) climate data is produced by the PRISM climate group at Oregon State University, and subsets of data are publically available via their web site. PRISM is gridded data with complete coverage for the continental United States. Data are available from 1895 to the present, but users should recognize that older data is estimated from fewer on-the-ground observations and it is thus less reliable than more modern data. Especially in remote areas, older modeled data may be substantially less reliable.

PRISM data are available on a monthly time step, and at a 2.5 arc-minute (~4 km) spatial resolution. The four climatic variables are:

- Average maximum temperature (tmax)
- Average minimum temperature (tmin)
- Average dewpoint (tdmean)
- Total precipitation (ppt)

Create a working directory for the PRISM files and then download PRISM data for the years of interest from the PRISM web site:



http://www.prism.oregonstate.edu/   - general web interface

ftp://prism.oregonstate.edu/pub/prism/us/grids - more easily used ftp interface. This requires use of an ftp download program, such as FileZilla. I strongly recommend using an ftp client and the ftp site for any reasonably large download.

To maximize compatibility with the R files, create separate subdirectories for each variable such as:

C:\PRISM\ppt , C:\PRISM\tmax, C\PRISM\tmin, and C:\PRISM\tdmean

Download the files into these subdirectories, maintain the decade-ordered subdirectories that mimic the ftp site – e.g., c:\PRISM\tmax\1890-1899, like the figure to the right. The R script will unpack the compressed (*.gz) files to the same directory in which they reside. If you use any other file structure, you’ll need to modify the R code to accommodate this. Do not put any other files in these directories until after running the R script.

The download will consist of a large number of files - one for each month for each variable. A complete download of 1895-2010 for all four variables will be 116 * 4 * 12 = 5568 (plus the normal files, if you also download them). Hence the recommendation to use a ftp client to facilitate transfer of large groups of files.

Processing PRISM data

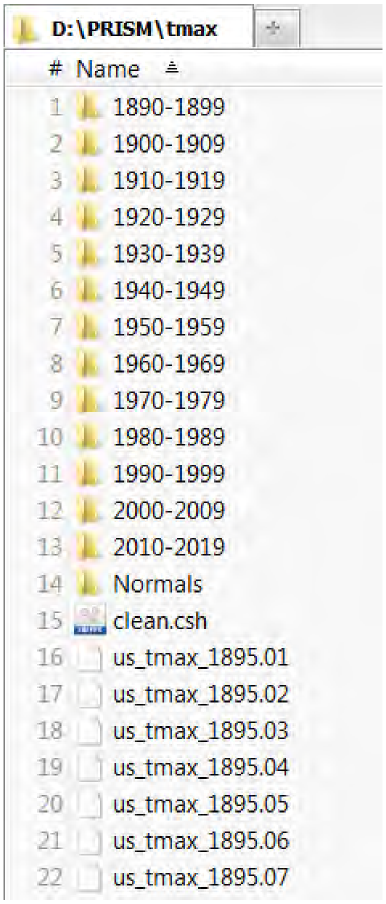
PRISM data is processed using a set of three files with R code. The first extracts and renames the downloaded data files. You should use this once. The other two files produce summary data files and plots, and you'll likely want to modify these and use them repeatedly.

R code files used for PRISM data processing:

PRISM_1_extract_files.R
PRISM_2_data_analysis.R
PRISM_3_seas_ann_avgs_plots.R
makePolys.R – this is used only for plotting, and can be "sourced" (see R help ("source") if needed)

Extracting Downloaded Files: PRISM_1_extract_files.R

This script extracts the data from the archives and, for each variable, puts the extracted files in a single directory (i.e., all ppt files in ./ppt; all tmax in ./tmax). The script names the resulting data files appropriately for further processing. After running the script, you should have a set of files like those in Figure 33. After downloading the files, ensure the directory structure and all files are what you expect. The PRISM staff may update files and put these in a 'Replaced' subdirectory. You'll need to manually deal with these – see the 'readme' file that will accompany them, and either delete the files and subdirectory, or copy and replace the older files and delete this subdirectory.



1 1890-1899
2 1900-1909
3 1910-1919
4 1920-1929
5 1930-1939
6 1940-1949
7 1950-1959
8 1960-1969
9 1970-1979
10 1980-1989
11 1990-1999
12 2000-2009
13 2010-2019
14 Normals
15 clean.csh
16 us_tmax_1895.01
17 us_tmax_1895.02
18 us_tmax_1895.03
19 us_tmax_1895.04
20 us_tmax_1895.05
21 us_tmax_1895.06
22 us_tmax_1895.07

Figure 33. Files after running script. Note all extracted files in one file.

Users may need to modify two lines in this script to loop through all the variables:

```
rootDir = "d:/PRISM/tmin"
varname <- c("tmin")
```

RootDir must be the directory in which there are decadal subdirectories, as illustrated in Figure 33. Change varname for each climate variable (i.e., replace tmin with ppt, tmax, or tdmean).

Processing the Gridded Data: PRISM_2_data_analysis.R

This script:

- Clips data to the area of analysis (AOA)
- Converts units to their actual values (PRISM data are integers 100 x actual values)

- Produces simple descriptive plots for data checking
- Calculates monthly means for the spatial extent of the park and region and writes these to a comma-separated-value (csv) file. The csv file can be used in Excel and serves as an input to the final PRISM R script. The output files name is of the format: PRISM_areas_avgs_[beginYr]_[endYr].csv.

Variables in this script that will generally need to be modified by the user are:

Section 1 (as noted in code)

- Location of the working directory. This is set in the line: > `setwd(“c:/BADL/working directory”)`. Note use of forward slashes (“/”) in directory names. This is the directory that contains the extracted PRISM data files.
- Beginning and ending year of analyses: `beginYr, endYr`
- Variable in analysis or plot: `varname`
- Extent, in decimal latitude and longitude, of areas for analysis: `parkExt, ccvaExt, regExt.` Read the comments embedded in the R scripts that describe how R handles these extents.

Producing Plots: PRISM_3_seas_ann_avgs_plots.R

The main purpose of this script is to summarize data and produce plots like those included in the Badlands climate change vulnerability analysis climate summary. Online and printed documentation of the R packages, and especially Murrell (2006) and Wickham (2009), describe the broad range of modifications that can be made to the basic plots produced by this script. Plots produced by the script include annual averages for temperatures (Tmin and Tmax) and precipitation.

As with the other scripts, users need to set the working directory (using setwd()) to the correct location, and this script requires ‘sourced’ code to produce the filled polygon plot. The source data is in the file “makePolys.R”.

Future Climates – Data from Model Projections

The analyses described here use Bias Correction followed by Spatial Disaggregation (BCSD) data available from the internet (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html). The preferred description of these files is:

"LLNL-Reclamation-SCU downscaled climate projections data derived from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset, stored and served at the LLNL Green Data Oasis."

The archived data includes the period January 1950 to December 2099. The available variables are:

- Precipitation - mean daily rate during for each month, in mm/day
- Surface air temperature, monthly mean, in degrees C

The missing value flag is: 1E+20

"Projections" from January 1950 to December 1999 are used for calibration. Yearly data for the 1950-1999 period have the same statistical properties for each year, and they thus do not reflect the same statistical trends over e.g. decades as do observations. The 'observations' file has the actual data from this period, in the same format as the projected data.

The CMIP3 downscaled archive includes data from 112 projections generated by 16 Global Climate Models (GCMs) and three emission pathways (A1B, A2, and B1). IPCC included 23 climate models in analyses for the Fourth Assessment Report (AR4). These models varied widely in resolution, age, emphasis, and sensitivity to CO_2 concentrations. Model resolution varied from approximately 7 degrees (GISS; a grid about 600 km x 600 km) to 1.5 degrees. Some models were under active development and revision, while others were more than a decade old; the processes represented in the models and the level of detail in which processes were represented varied widely. Randall et al. (2007) summarized many differences in these models (their Table 8.1).

In general, GCMs developed to forecast contemporary climates over decades to centuries performed better in the 2000-2100 period than models designed to simulate prehistoric climates over millennia, and GCMs tend to perform best near the geographical location of the laboratory in which they were developed (e.g., the Australia model works well for Australia, the NCAR model performs well for North America). Some inter-model variation is easily attributed to these traits. However, interpretations of inter-model comparisons need to account for the variables, processes, and/or periods of most interest, and there are an infinite number of permutations of these factors. Evaluations and comparisons of GCMs have been reported in many technical papers. SAP 3.1 (CCSP 2008) provides a very complete summary, but even this very detailed report does not provide assessments of model strengths and weaknesses that facilitates model selection for the Badlands region.

There are no obvious and existing comparisons or criteria for evaluating the set of CMIP3 models and then selecting models to include or exclude in the Badlands assessment. In the absence of these criteria, John Stamm (pers. comm.) suggested a conservative approach that consists of using models for which there are existing NARCCAP (North American Regional Climate Change Assessment Project) results. The underlying assumption is that participants in NARCCAP represent a wealth of experience in climate modeling and model evaluation, and these experts are capable of selecting GCMs that provide the "best" boundary conditions for driving dynamic regional downscaled climate models for North America. This is a conservative selection; it minimizes the likelihood of including a model that performs poorly for North America, but it may exclude other models that perform well in the Great Plains. Four GCMs (CCSM, CGCM3, HadCM3, and GFDL) are in use by NARCCAP. Table 57 summarizes the projections and runs available from CMIP3 for these models:

The CMIP3 downscaled data is provide at 1/8^o resolution (~ 12 km). Emissions projections for A1B and A2 are very similar up to about 2050 or 2060, and from these data we probably cannot resolve any differences in projected temperatures or precipitation until late in this century.

Table 57. Projections and runs available from CMIP3 for selected models.

Model	Number of runs A1B	A2	Model sensitivity*	Reference
CGCM3.1	5	5	3.4	Flato and Boer 2001
GFDL-CM2.0	2	2	2.9	Delworth et al. 2006
GFDL-CM2.1			3.4	
CCSM3.0	6	4	2.7	Collins et al. 2006
HadCM3	1	1	3.3	Gordon et al. 2000

* ICPP WG1, 2007, Table 8.2, p. 631

Acquiring Downscaled Data

The size of the data files will vary with the number of projections, years, spatial extent, etc. Files can be very large – easily more than 100 MB. After you submit a valid data request, the server will process the data and reply with an email that includes a URL to an ftp site with the requested data files. Reasonable-sized data requests are often produced in a matter of minutes.

Download data from LLNL site, inNETCDF format, subsetted by:

a. Area of interest, defined by decimal latitude and longitude in 1/8 degree units
b. The entire time (Jan 1950-Dec 2099).
c. One emission scenario (A1B or A2)
d. All models/runs of interest
e. Variables of interest, most likely temperature and precipitation.
f. To use the procedure described here, do not request any statistics.

Time periods used for the BADL assessment were:

Name	**Period**
1960	Jan 1957-Dec 1966
2005	Jan 2001-Dec 2010
2050	Jan 2046- Dec 2055
2100	Jan 2090- Dec 2099

The 1960 reference period (i.e., 1957-1966) is based on recommendations from Dr. John Stamm (pers. comm.), and this period is consistent with a study of trends in precipitation and runoff in several Northern Great Plains river basins. Dr. Stamm's analyses showed that this period exhibited normal precipitation, temperatures and runoff. In this context, 'normal' means there are no obvious extreme departures from the century-long patterns in these climate parameters. All definitions of reference periods are subject to debate; the R code was designed to make it easy to adjust reference periods and these can be changed to suit other needs.

Seasons were defined as winter – DJF, spring – MAM, summer – JJA, and winter – DJF.

Scenarios evaluated: A1B and A2 (Nakicenovic et al. 2000).

Spatial Extents. Note that different coordinates may be required to define the same spatial extent when using the climate data download web site or R code because different decision rules are used to define or clip areas.

Bounding coordinates for the Badlands region (latitude, longitude): 41.5625, 45.1875, -100.0625, -105.0625

Bounding box coordinates for the Badlands ecological study area: 43.125, 44.125, -103.25, -101.375,

For downloading data, it's easiest (i.e., least prone to errors, although less efficient) to request a larger bounding box and clip the files using R. The main disadvantages of this strategy are that the download size is directly related to the size of both the time and spatial dimensions, and the clipping operations in R can be time consuming. Extract the files (provided in a zip-formatted archive) and examine the metadata and other text files to confirm that your download includes all the data you requested. Check start and end dates, coordinates, scenarios, models,etc. before running analyses. It's surprisingly easy to make a mistake in the data request and some operations in R may require several hours or more to complete.

Models and runs used for the BADL assessment.

These are to be downloaded into one file for A1B runs, one file for A2 runs, and one file for observations (if you want to use the observations – see note above on their content).

Scenario A1B (14 model x run)

cccma_cgcm3_1.1.sresa1b
cccma_cgcm3_1.2.sresa1b
cccma_cgcm3_1.3.sresa1b
cccma_cgcm3_1.4.sresa1b
cccma_gcm3_1.5.sresa1b
gfdl_cm2_0.1.sresa1b
gfdl_cm2_1.1.sresa1b
ncar_ccsm3_0.1.sresa1b
ncar_ccsm3_0.2.sresa1b
ncar_ccsm3_0.3.sresa1b
ncar_ccsm3_0.5.sresa1b
ncar_ccsm3_0.6.sresa1b
ncar_ccsm3_0.7.sresa1b
ukmo_hadcm3.1.sresa1b

Scenario A2 (12 model x run)

cccma_cgcm3_1.1.sresa2
cccma_cgcm3_1.2.sresa2
cccma_cgcm3_1.3.sresa2
cccma_cgcm3_1.4.sresa2
cccma_cgcm3_1.5.sresa2
gfdl_cm2_0.1.sresa2
gfdl_cm2_1.1.sresa2

ncar_ccsm3_0.1.sresa2
ncar_ccsm3_0.2.sresa2
ncar_ccsm3_0.3.sresa2
ncar_ccsm3_0.4.sresa2
ukmo_hadcm3.1.sresa2

Example request information:
var: TP (temp precip)
yr1: 1950
mo1: Jan
yr2: 2099
mo2: Dec
lat1: 41.5625 (Note: coordinates are for 'broad region'. They will result in a large file.
lat2: 45.1875
long1: -100.0625
long2: -105.0625
analysis: no
products: bcsd, 1_8obs

NetCDF file dimensions for this request are: (months) x 30 x 41 x [14 or 12] x 2 (months x lat x long x proj x variables). I.e. for 150 years, months = 12*150 = 1800. 30 and 41 are the number of grid cells, 12 and 14 are the number of model-parameter sets (for A1B or A2, respectively), and there are 2 variables (precipitation and temperature). This request will return about 115 million data values.

Processing Downscaled Climate Projection Data

Downscaled climate projection data is processed via two scripts, with a third to process observation data. Observation data does not include a dimension for 'model'.

Read and summarize projection files

CMIP_1_clip_avg.R

This script reads the NETcdf-formatted file with monthly climate projections, clips a larger extent to a defined study area, and produces an output file with a row for each month, averaged over the spatial extent. The output file, in csv format, can be read directly by Excel and is an input for further analyses.

Variables in the output file are: scenario, year, month, average temperature, precipitation, and season.

CMIP_1.1_observ_clip_avg

This file processes observation data using the same logic as the projection data, but the observation file has only one 'level' since the file does not contain data from multiple models. This script produces a file similar to the projection output, but without a column for 'scenario'. Output variables are: year, month, average temperature, precipitation, and season.

Transform Data and Produce Tabular Output and Plots

CMIP_2_plots.R

This script reads the summary output files, transforms variables into different units, calculates averages, and produces a variety of plots. Many users will want to modify this file and run parts of it repeatedly, modifying time periods, plot labels or ranges, or otherwise changing the code to generate results for a specific purpose. This code was written to facilitate modifications to individual sections, at the cost of making the code more complex and subject to error.

Outputs from this script include the plots in the Badlands climate summary, regression model output, and tabular summaries. Plots include:

- Monthly spatial averages (very busy; mostly for data checking)
- Annual spatial averages by year
- Rolling averages (typically 10-year running means; but length can be modified)

Numerical outputs include results of linear regression of trends over time for temperature or precipitation and tabular data with decadal averages for specified periods (decadal, for the Badlands study). Beginning and ending years for ‘periods of interest’ are easily modified.

Examples of the plots and tabular output are in the Badlands climate summary (Chapter 3).

Literature Cited

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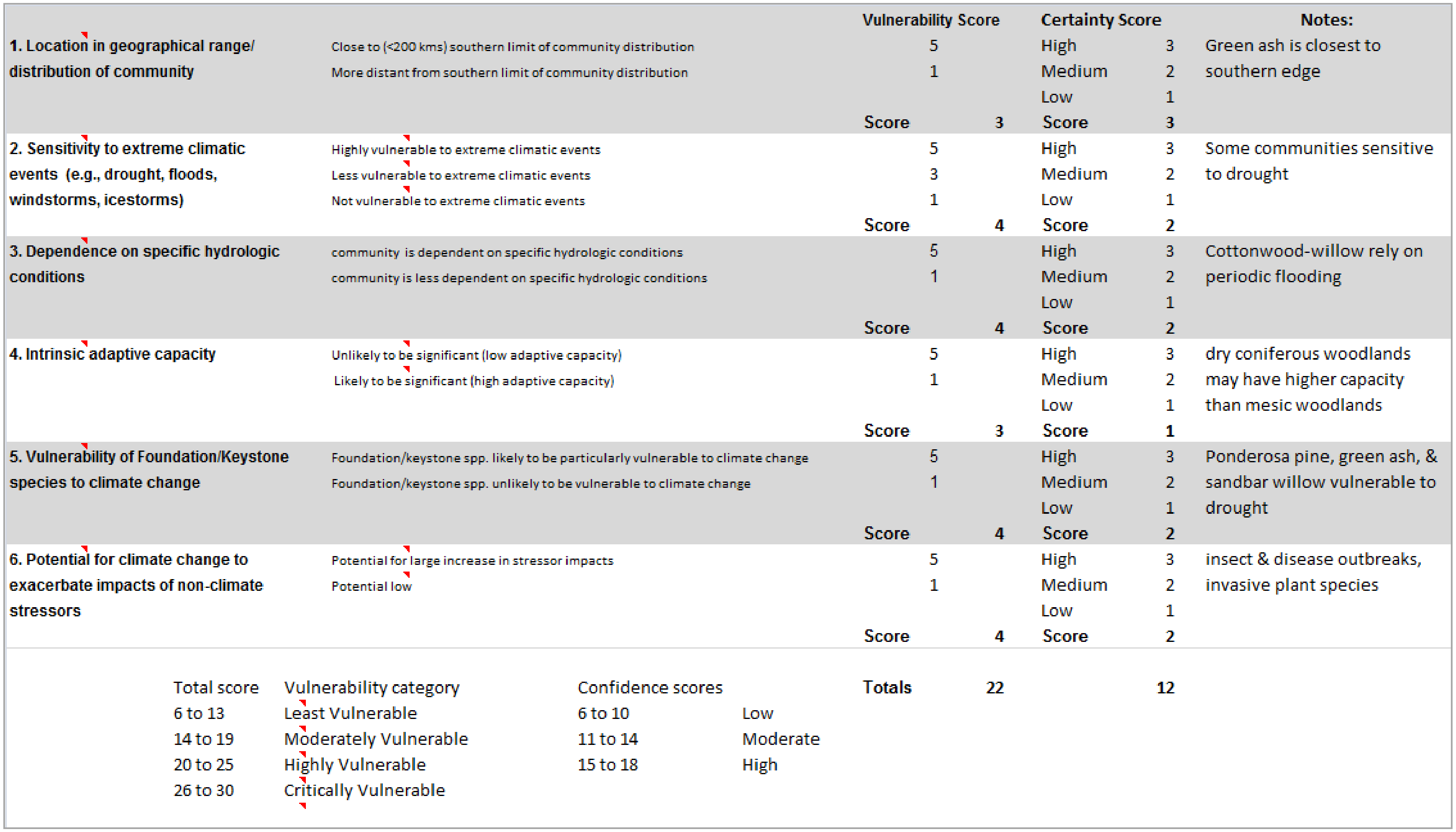
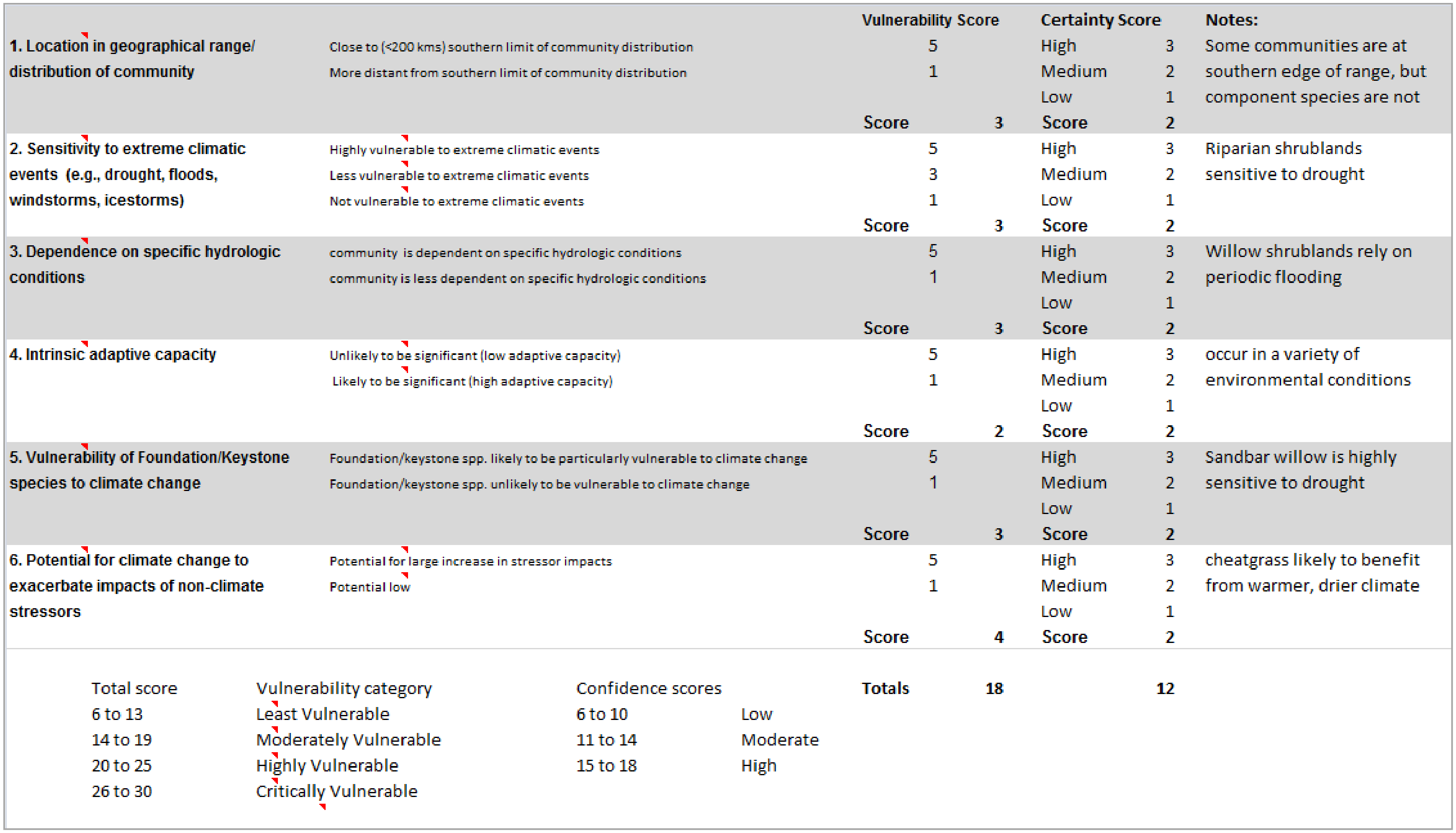
Appendix C: Plant Community Scoring Worksheets



		Vulnerability Score		Certainty Score		Notes:
1. Location in geographical range/ distribution of community	Close to (<200 kms) southern limit of community distribution	5		High	3	Green ash is closest to southern edge
	More distant from southern limit of community distribution	1		Medium	2	
				Low	1	
		Score	3	Score	3	
2. Sensitivity to extreme climatic events (e.g., drought, floods, windstorms, icestorms)	Highly vulnerable to extreme climatic events	5		High	3	Some communities sensitive to drought
	Less vulnerable to extreme climatic events	3		Medium	2	
	Not vulnerable to extreme climatic events	1		Low	1	
		Score	4	Score	2	
3. Dependence on specific hydrologic conditions	community is dependent on specific hydrologic conditions	5		High	3	Cottonwood-willow rely on periodic flooding
	community is less dependent on specific hydrologic conditions	1		Medium	2	
				Low	1	
		Score	4	Score	2	
4. Intrinsic adaptive capacity	Unlikely to be significant (low adaptive capacity)	5		High	3	dry coniferous woodlands may have higher capacity than mesic woodlands
	Likely to be significant (high adaptive capacity)	1		Medium	2	
				Low	1	
		Score	3	Score	1	
5. Vulnerability of Foundation/Keystone species to climate change	Foundation/keystone spp. likely to be particularly vulnerable to climate change	5		High	3	Ponderosa pine, green ash, & sandbar willow vulnerable to drought
	Foundation/keystone spp. unlikely to be vulnerable to climate change	1		Medium	2	
				Low	1	
		Score	4	Score	2	
6. Potential for climate change to exacerbate impacts of non-climate stressors	Potential for large increase in stressor impacts	5		High	3	insect & disease outbreaks, invasive plant species
	Potential low	1		Medium	2	
				Low	1	
		Score	4	Score	2	
		Totals	**22**		**12**	

Total score	Vulnerability category	Confidence scores	
6 to 13	Least Vulnerable	6 to 10	Low
14 to 19	Moderately Vulnerable	11 to 14	Moderate
20 to 25	Highly Vulnerable	15 to 18	High
26 to 30	Critically Vulnerable		

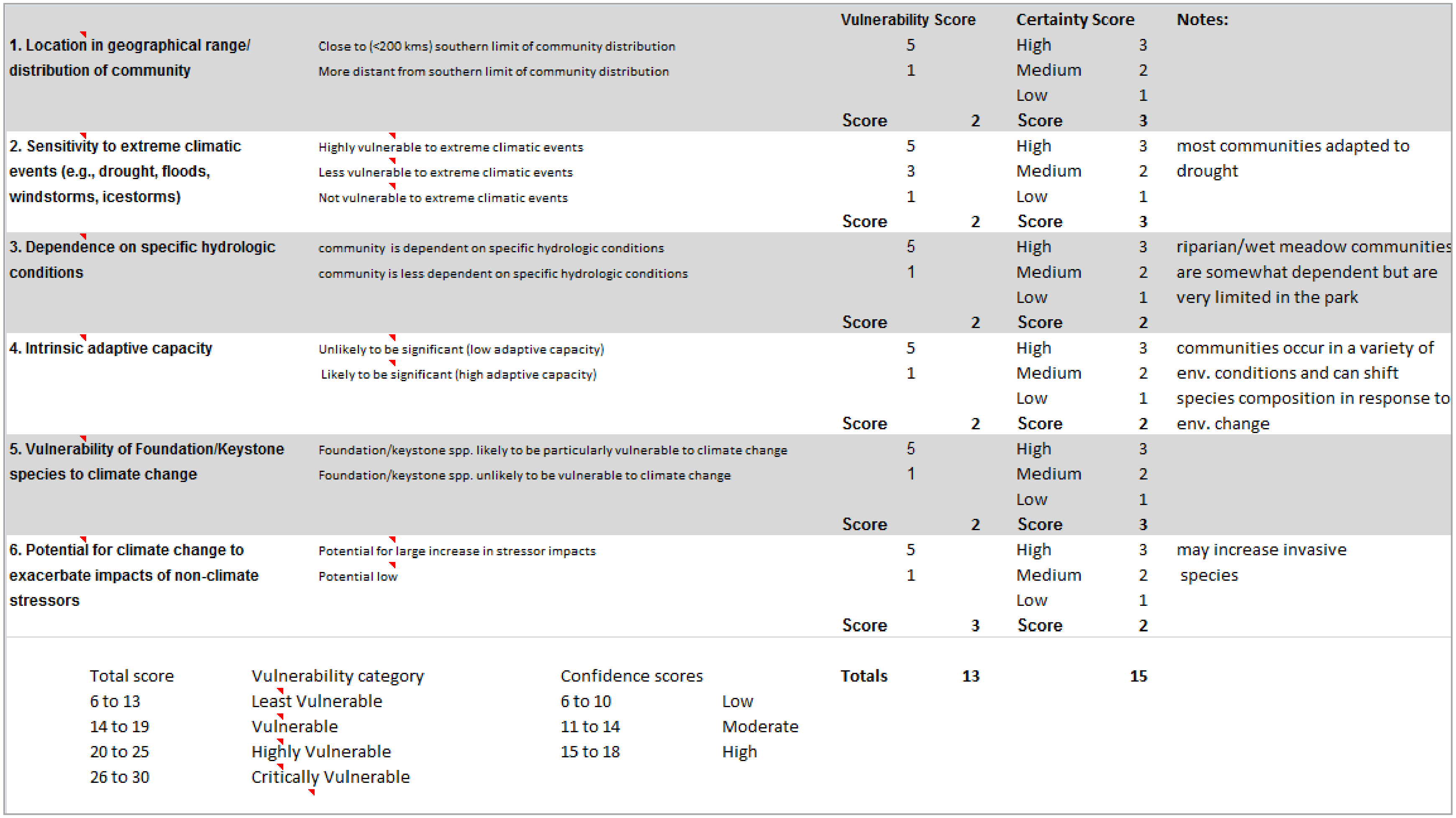
Figure 34. Scoring worksheet for the woodlands plant community.



		Vulnerability Score		Certainty Score		Notes:
1. Location in geographical range/ distribution of community	Close to (<200 kms) southern limit of community distribution	5		High	3	Some communities are at southern edge of range, but component species are not
	More distant from southern limit of community distribution	1		Medium	2	
				Low	1	
		Score	3	Score	2	
2. Sensitivity to extreme climatic events (e.g., drought, floods, windstorms, icestorms)	Highly vulnerable to extreme climatic events	5		High	3	Riparian shrublands sensitive to drought
	Less vulnerable to extreme climatic events	3		Medium	2	
	Not vulnerable to extreme climatic events	1		Low	1	
		Score	3	Score	2	
3. Dependence on specific hydrologic conditions	community is dependent on specific hydrologic conditions	5		High	3	Willow shrublands rely on periodic flooding
	community is less dependent on specific hydrologic conditions	1		Medium	2	
				Low	1	
		Score	3	Score	2	
4. Intrinsic adaptive capacity	Unlikely to be significant (low adaptive capacity)	5		High	3	occur in a variety of environmental conditions
	Likely to be significant (high adaptive capacity)	1		Medium	2	
				Low	1	
		Score	2	Score	2	
5. Vulnerability of Foundation/Keystone species to climate change	Foundation/keystone spp. likely to be particularly vulnerable to climate change	5		High	3	Sandbar willow is highly sensitive to drought
	Foundation/keystone spp. unlikely to be vulnerable to climate change	1		Medium	2	
				Low	1	
		Score	3	Score	2	
6. Potential for climate change to exacerbate impacts of non-climate stressors	Potential for large increase in stressor impacts	5		High	3	cheatgrass likely to benefit from warmer, drier climate
	Potential low	1		Medium	2	
				Low	1	
		Score	4	Score	2	
		Totals	18		12	

Total score	Vulnerability category	Confidence scores	
6 to 13	Least Vulnerable	6 to 10	Low
14 to 19	Moderately Vulnerable	11 to 14	Moderate
20 to 25	Highly Vulnerable	15 to 18	High
26 to 30	Critically Vulnerable		

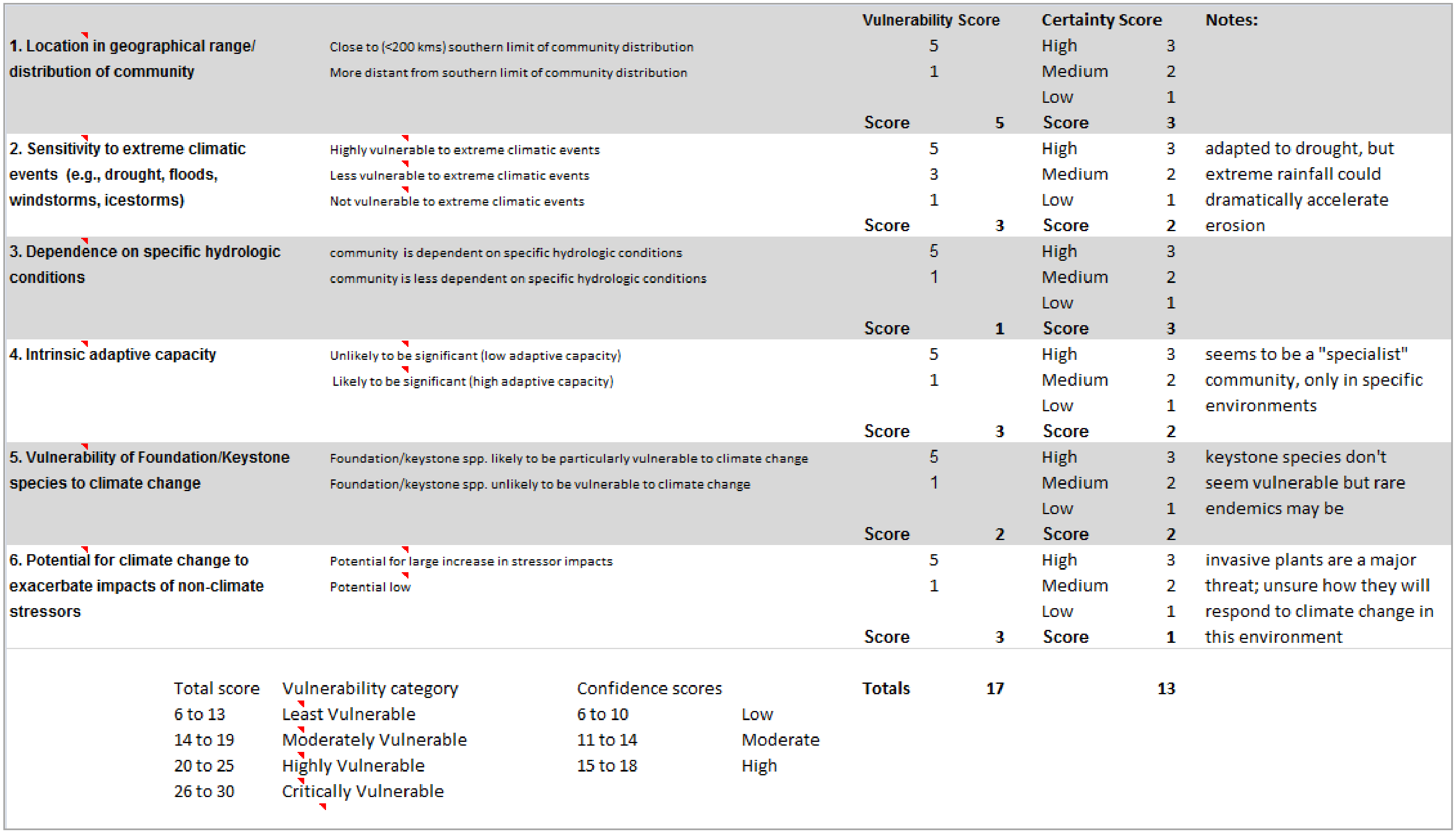
Figure 35. Scoring worksheet for the shrublands plant community.



		Vulnerability Score			Certainty Score		Notes:
1. Location in geographical range/ distribution of community	Close to (<200 kms) southern limit of community distribution		5		High	3	
	More distant from southern limit of community distribution		1		Medium	2	
					Low	1	
		Score		2	Score	3	
2. Sensitivity to extreme climatic events (e.g., drought, floods, windstorms, icestorms)	Highly vulnerable to extreme climatic events		5		High	3	most communities adapted to drought
	Less vulnerable to extreme climatic events		3		Medium	2	
	Not vulnerable to extreme climatic events		1		Low	1	
		Score		2	Score	3	
3. Dependence on specific hydrologic conditions	community is dependent on specific hydrologic conditions		5		High	3	riparian/wet meadow communities are somewhat dependent but are very limited in the park
	community is less dependent on specific hydrologic conditions		1		Medium	2	
					Low	1	
		Score		2	Score	2	
4. Intrinsic adaptive capacity	Unlikely to be significant (low adaptive capacity)		5		High	3	communities occur in a variety of env. conditions and can shift species composition in response to env. change
	Likely to be significant (high adaptive capacity)		1		Medium	2	
					Low	1	
		Score		2	Score	2	
5. Vulnerability of Foundation/Keystone species to climate change	Foundation/keystone spp. likely to be particularly vulnerable to climate change		5		High	3	
	Foundation/keystone spp. unlikely to be vulnerable to climate change		1		Medium	2	
					Low	1	
		Score		2	Score	3	
6. Potential for climate change to exacerbate impacts of non-climate stressors	Potential for large increase in stressor impacts		5		High	3	may increase invasive species
	Potential low		1		Medium	2	
					Low	1	
		Score		3	Score	2	
		Totals		**13**		**15**	

Total score	Vulnerability category	Confidence scores	
6 to 13	Least Vulnerable	6 to 10	Low
14 to 19	Vulnerable	11 to 14	Moderate
20 to 25	Highly Vulnerable	15 to 18	High
26 to 30	Critically Vulnerable		

Figure 36. Scoring worksheet for the grasslands plant community.



		Vulnerability Score		Certainty Score		Notes:
1. Location in geographical range/ distribution of community	Close to (<200 kms) southern limit of community distribution	5		High	3	
	More distant from southern limit of community distribution	1		Medium	2	
				Low	1	
		Score	**5**	**Score**	**3**	
2. Sensitivity to extreme climatic events (e.g., drought, floods, windstorms, icestorms)	Highly vulnerable to extreme climatic events	5		High	3	adapted to drought, but extreme rainfall could dramatically accelerate erosion
	Less vulnerable to extreme climatic events	3		Medium	2	
	Not vulnerable to extreme climatic events	1		Low	1	
		Score	**3**	**Score**	**2**	
3. Dependence on specific hydrologic conditions	community is dependent on specific hydrologic conditions	5		High	3	
	community is less dependent on specific hydrologic conditions	1		Medium	2	
				Low	1	
		Score	**1**	**Score**	**3**	
4. Intrinsic adaptive capacity	Unlikely to be significant (low adaptive capacity)	5		High	3	seems to be a "specialist" community, only in specific environments
	Likely to be significant (high adaptive capacity)	1		Medium	2	
				Low	1	
		Score	**3**	**Score**	**2**	
5. Vulnerability of Foundation/Keystone species to climate change	Foundation/keystone spp. likely to be particularly vulnerable to climate change	5		High	3	keystone species don't seem vulnerable but rare endemics may be
	Foundation/keystone spp. unlikely to be vulnerable to climate change	1		Medium	2	
				Low	1	
		Score	**2**	**Score**	**2**	
6. Potential for climate change to exacerbate impacts of non-climate stressors	Potential for large increase in stressor impacts	5		High	3	invasive plants are a major threat; unsure how they will respond to climate change in this environment
	Potential low	1		Medium	2	
				Low	1	
		Score	**3**	**Score**	**1**	
		Totals	**17**		**13**	

Total score	Vulnerability category	Confidence scores	
6 to 13	Least Vulnerable	6 to 10	Low
14 to 19	Moderately Vulnerable	11 to 14	Moderate
20 to 25	Highly Vulnerable	15 to 18	High
26 to 30	Critically Vulnerable		

Figure 37. Scoring worksheet for the sparse badlands plant community.

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