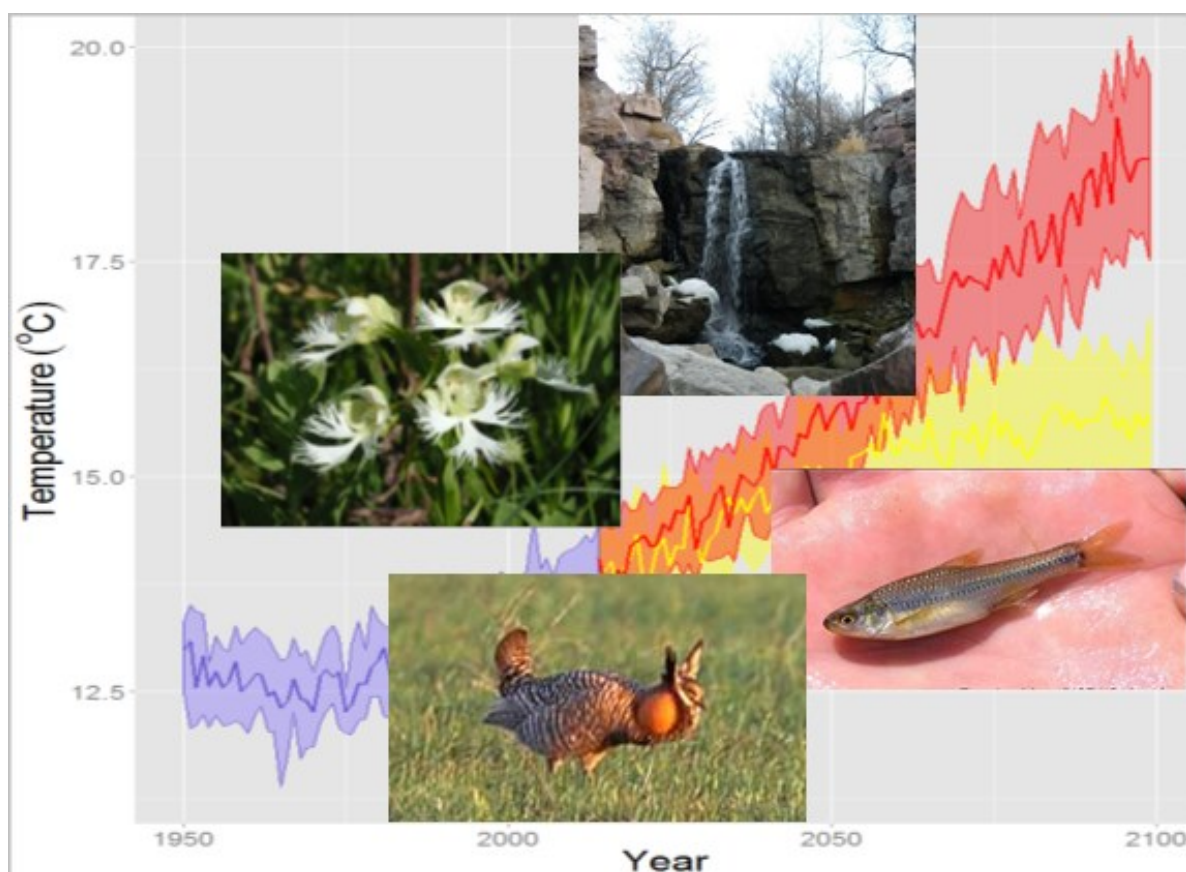




Integration of Climate Change Vulnerability with NPS Natural Resource Condition Assessments

Applying NatureServe's Climate Change Vulnerability Index Tool

Natural Resource Report NPS/NRSS/WRD/NRR—2016/1259



ON THE COVER

Clockwise from top - Winnewissa Falls at Pipestone National Monument (Dave Jones CSU photo), Topeka shiner (USWFS photo), greater prairie-chicken (NPS photo), and western prairie fringed orchid (NPS photo) superimposed on past and projected mean annual temperature for Tallgrass Prairie National Preserve, Kansas.

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National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Abstract

This project examines and evaluates integration of a climate change vulnerability assessment (CCVA) component into the natural resource condition assessments (NRCAs) currently in development by Colorado State University for Tallgrass Prairie National Preserve, Kansas (TAPR) and Pipestone National Monument, Minnesota (PIPE). This evaluation serves as a pilot effort to help demonstrate creative and cost-effective ways to include a CCVA component in the context of NRCA projects. Vulnerability to climate change is examined using the Climate Change Vulnerability Index (CCVI), a Microsoft Excel-based spreadsheet tool developed by NatureServe. The CCVI is designed as a rapid-assessment tool intended to be used primarily for practical planning purposes by natural resources managers and USFWS staff and is intended to be complementary to the NatureServe Conservation Status ranks.

The study is largely a qualitative process that applies the CCVI tool and framework to the following resources: the greater prairie-chicken (*Tympanuchus cupido*) and federally endangered Topeka shiner (*Notropis topeka*) at TAPR; and the federally endangered western prairie fringed orchid (*Platanthera praeclara*), the federally endangered Topeka shiner, and the Sioux quartzite prairie community at PIPE. Primary sources of data included climate change projections from ClimateWizard.org, literature surveys, expert opinion and previous climate change vulnerability work in the region. A suite of vulnerability factors related to exposure and sensitivity were rated to produce a 2050 vulnerability rating for each species or community at the local park scale and at a regional/state-wide scale. Two out of five resources were considered less vulnerable to climate change at the park scale than at the statewide or regional scale.

Recommendations and observations were made regarding CCVI features and use, caveats for interpreting results, and addressing information gaps and uncertainties. The results complement NRCA evaluations and inform the need or urgency to conduct more in-depth CCVAs of selected resources at individual parks. Specific recommendations for integrating vulnerability results into NRCAs include developing a *Climate Change* section within the NRCA to provide a comprehensive summary of historical and projected climate metrics that would directly support vulnerability assessment, including a discussion of the potential effects of climate change on natural processes and disturbance agents (e.g., fire regime), and using climate change vulnerability as one of many indicators of condition and/or trend for sensitive species and communities.

Although the CCVI by itself does not provide a comprehensive vulnerability assessment for species, in conjunction with other sources of information it is a relatively straightforward and useful tool for examining the relative vulnerabilities of different species with respect to basic climate change exposure, indirect exposure to climate change, and sensitivity and documented or modeled response to climate change. Integration of climate change vulnerability into natural resource condition assessments does require additional effort and expertise that may not already be present on a given NRCA development team. However, by using the approach described above, vulnerability can be both incorporated and well integrated.

1 Introduction

In the context of climate change, vulnerability refers to the degree to which an ecological system or individual species is anticipated to experience harm as a result of changes in climate (Schneider et al. 2007). Vulnerability to climate change is a function of exposure to climate change, i.e., the magnitude, intensity and duration of the climate changes experienced; the sensitivity of the species or community to these changes, and the capacity of the system to adapt to these changes (IPCC 2007,

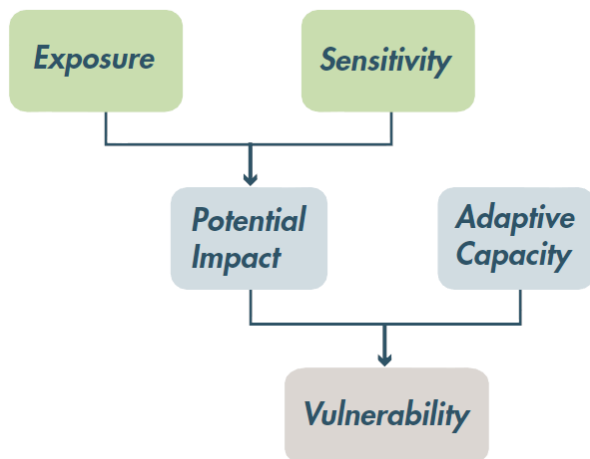


Figure 1. Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity (Glick et al. 2011).

Glick et al. 2011) (Figure 1). Climate change vulnerability assessment (CCVA) is an emerging science, drawing on a variety of sources to estimate the relative impact of CC on species and ecological systems/habitats. Primary sources of information contributing to the analysis include published information in books, reports and the scientific literature; professional opinion by recognized experts; spatial and non-spatial data; and modeled climate change data for specific geographic locations. There is currently much emphasis on integrating CCV into state wildlife action plans and endangered species recovery planning.

Vulnerability assessment is a critical component of climate adaptation planning

(Figure 2), and is most useful when considered as a process that leads to an understanding of which resources appear to be vulnerable and why (Glick et al. 2011). Two general approaches to evaluate the vulnerability of species are: (1) index-based assessments that often combine multiple information types; and (2) model-based assessments that often rely on spatially explicit analyses (Stein et al. 2014). Two commonly used indices are the NatureServe Climate Change Vulnerability Index (CCVI) (Young et al. 2011), which applies to both plant and animal species and is intended for use in conjunction with NatureServe conservation status ranks, and the U.S. Forest Service System for Assessing Vulnerability of Species (SAVS) (Bagne et al. 2011), which applies to terrestrial vertebrates. The SAVS tool (<http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/>) uses an online questionnaire with 22 criteria to predict vulnerability or population response of species to provide a framework for assessing vulnerability to future climate change. The 22 multiple-choice questions are grouped into four categories by theme: habitat, physiology, phenology and biotic interactions. The questionnaire is completed using information gathered from published materials, personal knowledge, or expert consultation. The SAVS has been developed and applied mainly in the southwestern U.S., whereas the CCVI has been applied extensively across the continental U.S. and Alaska.

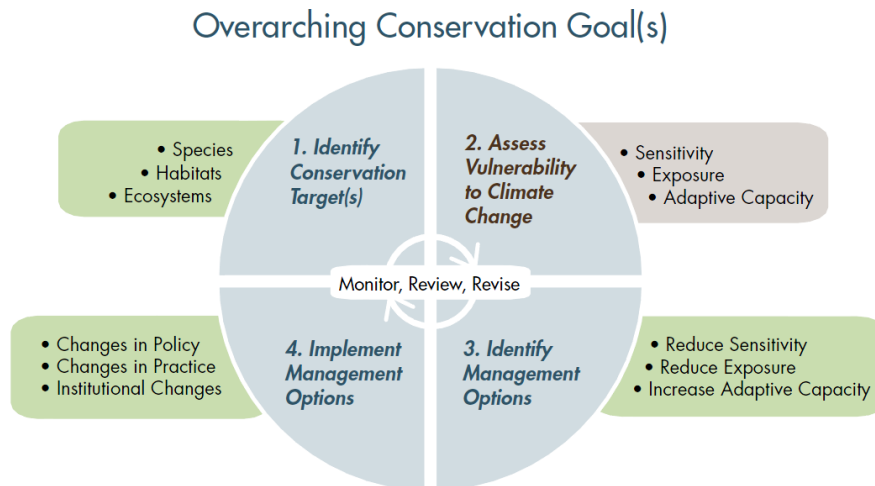


Figure 2. Framework for developing climate change adaptation strategies (Glick et al. 2011)

This assessment examines climate change vulnerability for selected species and communities in Tallgrass Prairie National Preserve (TAPR) and Pipestone National Monument (PIPE) using the CCVI tool, and makes recommendations to broaden the scope of the park NRCAs to accommodate a more comprehensive examination of climate change vulnerability analysis. The CCVI is a Microsoft Excel-based spreadsheet tool developed by NatureServe to evaluate vulnerability of species to climate change. It is designed as a rapid-assessment tool intended to be used primarily for practical planning purposes by natural resources managers and USFWS staff. It is designed to be complementary to the NatureServe Conservation Status ranks, but it does not duplicate information in those ranks such as the size of a specific population. The intended application scale of the tool is up to the state or province level. The primary purpose of the CCVI is to produce a relative ranking or priority list for species of concern with respect to climate change vulnerability. NatureServe and state Natural Heritage staffs are the most common users of the tool.

Relatively few habitat or community-scale evaluations of climate-change vulnerability have been completed. The Climate Change Vulnerability Index for Ecosystems and Habitats (HCCVI) was developed by NatureServe, federal, state, and non-governmental organization partners to develop an index to serve as a habitat-based companion to the species-centric CCVI. The HCCVI aims to implement a series of measures addressing climate change sensitivity and ecological resilience for each community type for its distribution within a given ecoregion. Since quantitative estimates may not be feasible for all measures, both numerical index scores (normalized 0.0-1.0 scores) and qualitative expert categorizations may be used in the HCCVI. The combined relative scores for sensitivity and resilience determine the categorical estimate of climate change vulnerability by the year 2060 (i.e., 50 years into the future) for a community type (Comer et al. 2012). Index measures are organized within categories of direct effects, indirect effects, and adaptive capacity. The pilot example of the HCCVI approach applied in the southwestern United States is described by Comer et al. (2012). The pilot work draws upon voluminous data from Bureau of Land Management rapid ecoregional assessments and other recent research efforts and geospatial data, and requires a much higher level of available information and analysis compared to the species-based CCVI. Other

documented approaches emphasizing a combination of scoring tools, workshops and expert elicitation for evaluating habitat or community-scale vulnerability have been developed and applied by the Manomet Center for Conservation Sciences (Manomet Center for Conservation Sciences and Massachusetts Division of Fisheries and Wildlife 2010, Whitman et al. 2013).

1.1 Study Objectives

The purpose of this project is to examine and evaluate integration of a climate change vulnerability assessment (CCVA) component into the natural resource condition assessments (NRCAs) currently in development by Colorado State University (CSU) for Tallgrass Prairie National Preserve (TAPR) and Pipestone National Monument (PIPE). This evaluation complements and extends aspects of the ongoing project work, and serves as a pilot effort to help demonstrate creative and cost-effective ways to include a CCVA component in the context of NRCA projects. The study is largely a qualitative process that applies the CCVI tool and framework to the following resources: the greater prairie-chicken and federally endangered Topeka shiner at TAPR; and the federally endangered western prairie fringed orchid, the federally endangered Topeka shiner, and the Sioux quartzite prairie community at PIPE. The results complement NRCA evaluations and other reports, and are intended to inform the need or urgency to conduct more in-depth CCVAs of selected resources at individual parks.

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2 Approach

2.1 General Approach

Most of the published CCVI work is for state-level assessments in the eastern continental U.S. Published reports include an evaluation of 157 plant and animal species for the coastal zone of Michigan (Lee et al. 2011), 162 species in Illinois (Walk et al. 2011), 85 species in Pennsylvania (Furedi et al. 2011), over 250 species in Nevada (Szabo 2012), 156 rare plant species in California (Anacker et al. 2011), 30 plant and animal species in the Great Plains (Zack et al. 2010), and 185 animal and plant species in West Virginia (Byers and Norris 2011). Most species examined in these state-level CCVI assessments were selected based on their status as Species of Greatest Conservation Need within the state wildlife action plans. Additional CCVIs have been completed for an unknown number of species but are generally unpublished and available only via distribution from the authors or agencies. Sources containing the most comprehensive list of completed CCVIs and related reports are the NatureServe CCVI web page (<http://www.natureserve.org/conservation-tools/climate-change-vulnerability-index>) and the Climate Adaptation Knowledge Exchange (Cakex.org) web site.

The general approach is as follows:

1. Select species and communities for assessment: Species may be selected for any reason, but are most commonly evaluated based on their NatureServe Conservation Rank status as vulnerable, imperiled or critically imperiled (Faber-Langendoen et al. 2012); Federal or state status as endangered, threatened, candidate or species of concern; or status as *Species of Greatest Conservation Need* within a state wildlife action plan. Some species may be selected based on their distribution, value as game species, or perceived vulnerability to the effects of climate change. Common species may be selected because they are important habitat foundation species upon which many other species depend (Byers and Norris 2011).

For the species and community we examined, the Topeka shiner is federally endangered; the western prairie fringed orchid is federally threatened; and the Sioux quartzite prairie has a restricted distribution with a NatureServe Global Status of G3 – Vulnerable, and often harbors a variety of rare plants; and the greater prairie-chicken at TAPR is not rare but is considered an iconic prairie species and desirable from a visitation and ecological perspective.

2. Assemble natural history and distribution information: Federal and state agencies, state Natural Heritage programs and other non-profits, and academic institutions have developed published and unpublished information about the distribution, natural history, and conservation status of species and habitats. Following a review of the existing information for each species, data gaps were identified and a literature search and/or expert consultation were conducted as needed.

3. Gather modeled future climate information: Historical data and future modeled projections for climate was obtained from the Climate Wizard online web tools (Girvetz et al. 2009) or using the national-level maps distributed with the software to support CCVI data requirements for exposure (risk factor A) and sensitivity (risk factor C). Historical climate data for the United States (Lower 48 and Conterminous) past 50 years (1951-2006) is based on 4km resolution PRISM data (PRISM

Group 2007). United States (Lower 48 and Conterminous) mid-century climate projections use data downscaled by Maurer et al. (2007).

For our analysis, changes in temperature were estimated using data from ClimateWizard.org. For moisture, the departure of future (2050) available moisture compared to the baseline 1960-1991 period for the park, state or region of interest was estimated using the Hamon AET:PET metric generated by ClimateWizard web-based tools (Girvetz et al. 2009) (Figure 3, Figure 4). The percentage of the area of interest falling within each CCVI moisture category was then calculated using GIS software or estimated visually. ClimateWizard does not currently display the Hamon AET:PET moisture metric, but the data is distributed with the CCVI software and is available for download (<http://www.natureserve.org/climatechange>). Climate data available from ClimateWizard are also used to support the following species sensitivity factors: historical thermal niche, current physiological thermal niche, historical hydrological niche, and current physiological hydrological niche. An example of national data supporting historical thermal niche is shown in **Figure 5**.

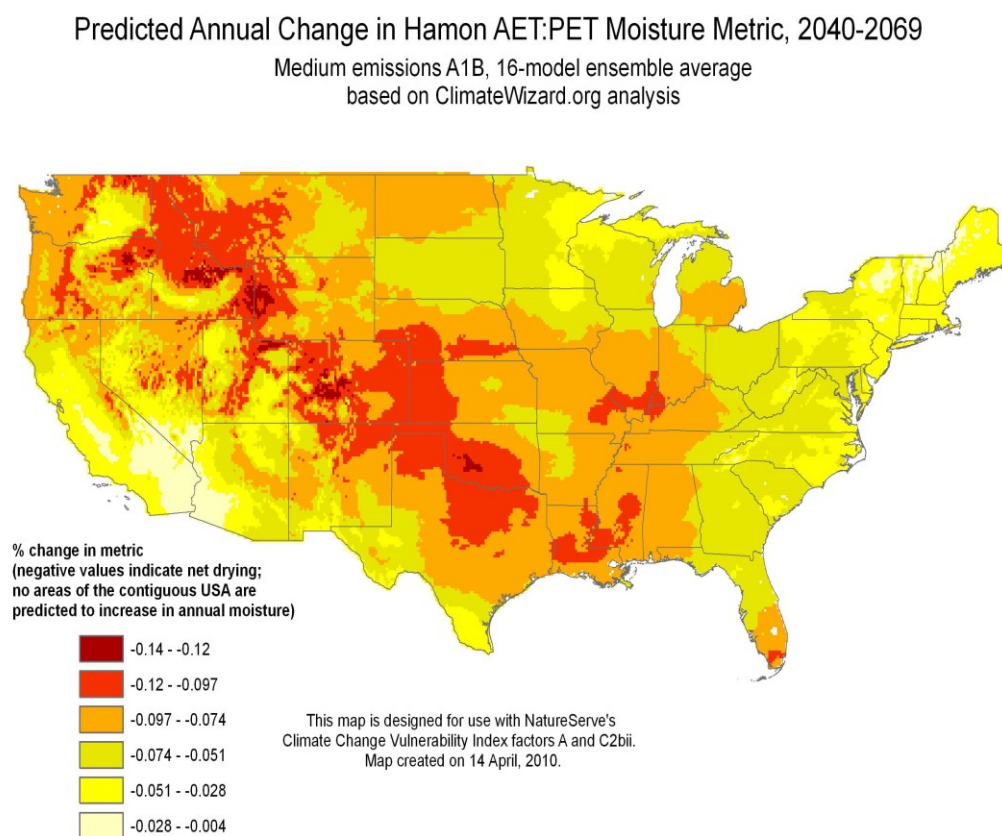


Figure 3. Map of modeled Hamon AET:PET mid-century moisture metric results for the contiguous United States. These data are published with the CCVI spreadsheet tool (source: ClimateWizard, University of Washington and NatureServe (2010).

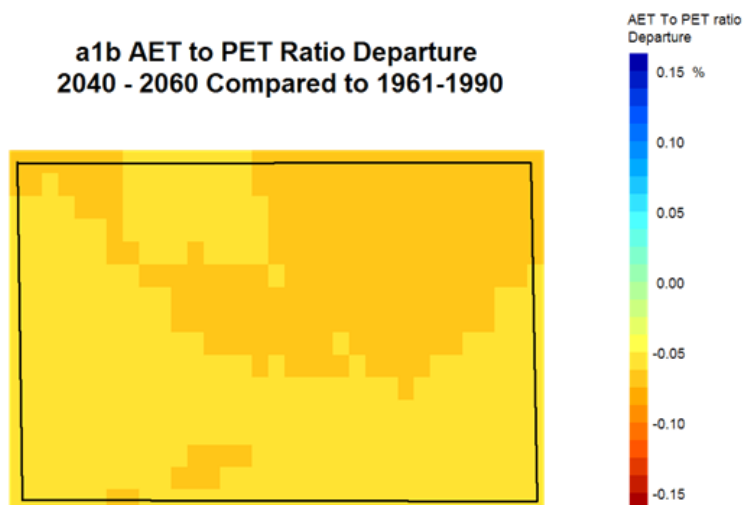


Figure 4. Hamon AET:PET moisture metric results generated using ClimateWizard.org custom analysis tools (Girvetz et al. 2009) based on downscaled climate projections for a roughly 180 x 120 mile area surrounding Pipestone National Monument, which is in the southwest corner of Minnesota.

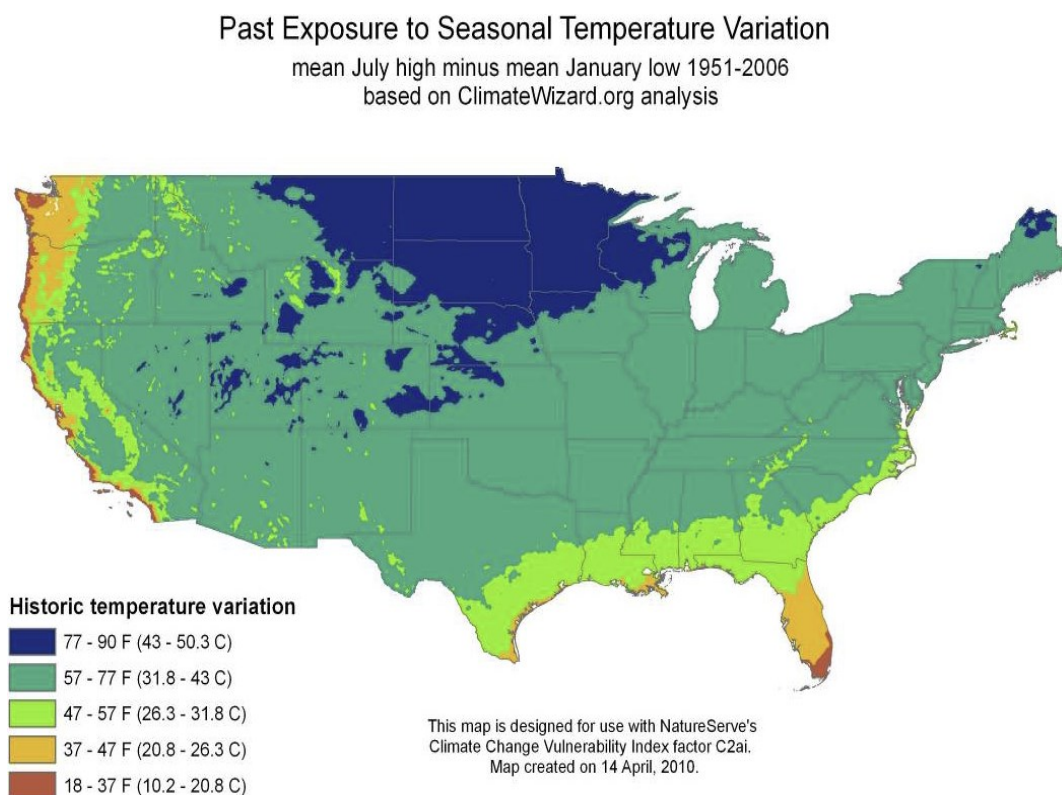


Figure 5. Past exposure to temperature variation for factor C2ai, historical thermal niche (Young et al. 2011).

4. Assess the relative vulnerability of selected species and communities: Climate change vulnerability is assessed using the CCVI tool. Results are reviewed by biologists most familiar with the species under evaluation. The factors considered in evaluating species response may be divided

into general categories of direct exposure, indirect exposure, sensitivity, documented response, and modeled response. Complex interactions such as shifts in competitive, predator-prey, or host-parasite interactions may be important as well, but they are beyond the scope of the CCVI tool (Byers and Norris 2011).

5. Analyze results and make management recommendations: Vulnerability assessments help managers understand which species may require greater or less climate change-related emphasis. If a species is found to be vulnerable to climate change, the factors responsible for the rating can be identified and integrated with management plans and actions. The results can also be analyzed to identify groups of species with similar susceptibility.

6. Examine integration of results within Natural Resources Condition Assessments: The integration of CCVI results with NRCAs was examined and specific recommendations are made.

2.2 Overview of NatureServe Climate Change Vulnerability Index (CCVI)¹

The CCVI workbook tool provides an easy-to-use interface for evaluating climate change vulnerability. For a particular species and geographic area, the user enters specific information and choices within the *Calculator* tab, which generates a CCVI rating from Not Vulnerable/Increase Likely to Extremely Vulnerable and a confidence rating for the species information used. When the user is satisfied with the entries, the results are copied to a new row in the *Results Table* tab. Results rows can be imported to the *Calculator* tab to make changes if desired, and can also be deleted. Documentation is provided in the CCVI Excel workbook and in Young et al. (2011).

The CCVI divides vulnerability into two components:

- **exposure** to climate change within the assessment area (e.g., a highly sensitive species will not suffer if the climate where it occurs remains stable).
- **sensitivity** of the species to climate change (e.g., an adaptable species will not decline even in the face of significant changes in temperature and/or precipitation).

Exposure to climate change is measured by examining the magnitude of predicted temperature and moisture change across the species' distribution within the study area. CCVI guidelines suggest using the downscaled data from Climate Wizard (<http://climatewizard.org>) for predicted change in temperature. Projections for changes in precipitation are available in Climate Wizard, but precipitation estimates alone are often an unreliable indicator of moisture availability because increasing temperatures promote higher rates of evaporation and evapotranspiration. Moisture availability, rather than precipitation per se, is a critical resource for plants and animals and therefore forms the other part of the exposure measure within the CCVI, together with temperature. The Hamon AET:PET moisture metric was selected by CCVI developers as the modeled soil moisture metric to be used for the CCVI.

¹ Primary source: Young et al. (2011)

Sensitivity is assessed using 20 factors divided into two categories: 1) indirect exposure to climate change; and 2) species specific factors (including dispersal ability, temperature and precipitation sensitivity, physical habitat specificity, interspecific interactions, and genetic factors). For each factor, species are scored on a sliding scale from greatly increasing vulnerability, to having no effect on, to decreasing vulnerability. The CCVI accommodates more than one answer per factor in order to address poor data or a high level of uncertainty for that factor. The scoring system integrates all exposure and sensitivity measures into an overall vulnerability score that indicates relative vulnerability compared to other species and the relative importance of the factors contributing to vulnerability. Exposure and sensitivity risk factors assessed in the CCVI are described briefly below (adapted from Byers and Norris (2011) and Young et al. (2011)):

Risk Factor A: Direct exposure

- Temperature change: predicted change in annual temperature by 2050, calculated over the range of the species in each state using the medium emissions scenario A1B or similar.
- Moisture change: predicted net change in moisture based on the Hamon AET:PET moisture metric, calculated over the range of the species in the state or region of analysis using the medium emissions scenario A1B or similar.

Risk Factor B: Indirect Exposure

- Exposure to sea level rise: not a factor in this region
- Distribution relative to natural and anthropogenic barriers. This factor assesses the degree to which natural (e.g., topographic, geographic, ecological) or anthropogenic barriers limit a species' ability to shift its range in response to climate change. Barriers are defined here as features or areas that completely or almost completely prevent movement or dispersal of the species (currently and for the foreseeable future). The geographic features of the landscape where a species occurs may naturally restrict it from dispersing to inhabit new areas. Dispersal may be hindered by intervening anthropogenically-altered landscapes such as urban or agricultural areas for terrestrial species as well as discrete barriers such as dams or culverts for aquatic species. Agricultural cropland and lack of natural disturbance agents such as grazing and fire are the primary barriers for terrestrial species and stream impoundments and low flows are the primary barrier for fish. The distinction between a barrier and unsuitable habitat sometimes may be unclear; in these cases assume the feature or area is unsuitable habitat (habitat through which the species can disperse or move but that does not support reproduction or long-term survival). Sources of spatial data to support evaluation of this factor include American Farmland Trust (2014), SILVIS (2010), and NPS NPScape (2014) web sites.
- Predicted impact of land use changes resulting from human responses to climate change. Strategies designed to mitigate greenhouse gases, such as creating large wind farms, plowing new cropland for biofuel production, or planting trees as carbon sinks, have the potential to affect large tracts of land and the species that use these areas in both positive and negative ways.

Risk Factor C: Sensitivity

- Dispersal and movements. Species with poor dispersal abilities may not be able to move/migrate with shifting climate envelopes favorable to their requirements.

- Predicted sensitivity to temperature and moisture changes. This factor pertains to the breadth of temperature and moisture conditions, at both broad and local scales, within which a species is known to be capable of reproducing, feeding, growing, or otherwise existing. Species with narrow environmental tolerances/requirements may be more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions. Species requiring specific moisture and temperature regimes may be less likely to find similar areas as climates change and previously-associated temperature and precipitation patterns uncouple.
 - Predicted sensitivity to changes in temperature, based on current/recent past temperature tolerance.
 - Historical thermal niche - exposure to past variations in temperature (Figure 3). This factor measures large-scale temperature variation that a species has experienced in the past 50 years, as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature) for occupied cells within the assessment area. It is a proxy for species' temperature tolerance at a broad scale.
 - Current physiological thermal niche. This factor assesses the degree to which a species is restricted to relatively cool or cold above-ground terrestrial or aquatic environments that are thought to be vulnerable to loss or significant reduction as a result of climate change.
 - Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.
 - Historical hydrological niche. This factor measures large-scale precipitation variation that a species has experienced in the past 50 years, as approximated by mean annual precipitation variation across occupied cells within the assessment area. Vulnerability is determined by overlaying the species' range on a map of mean annual precipitation 1951-2006 produced using the ClimateWizard tool.
 - Current physiological hydrologic niche.
 - Dependence on a specific disturbance regime likely to be impacted by climate change. Species dependent on habitats such as native prairie, floodplain forests, and riparian corridors that are maintained by regular disturbances (*e.g.*, fires or flooding) are vulnerable to changes in the frequency and intensity of these disturbances caused by climate change.
 - Dependence on ice, ice-edge, or snow-cover habitats. The extent of oceanic ice sheets and mountain snow fields are decreasing as temperatures increase, imperiling species dependent on these habitats.
- Restriction to uncommon geological features or derivatives. This factor pertains to a species' need for particular substrates, soils, or physical features that may become vulnerable to climate change if their favored climate conditions shift to areas without these physical elements. It focuses on the commonness of suitable conditions for the species on the landscape, as indicated by the commonness of the features themselves combined with the degree of the species' restriction to them. Climate envelopes may shift away from the locations of fixed (within at least a 50 year timeframe) geological features or their derivatives, making species tied to these uncommon features potentially more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions. For example, the distribution of Sioux quartzite prairie in the Upper Midwest is tightly linked to specific geologic features and associated hydrologic conditions.

- Reliance on interspecific interactions. Because species will react idiosyncratically to climate change, those with tight relationships with other species may be threatened.
 - Dependence on other species to generate habitat.
 - Dietary versatility (animals only).
 - Pollinator versatility (plants only).
 - Dependence on other species for propagule dispersal.
 - Forms part of an interspecific interaction not addressed above.
- Genetic factors. A species' ability to evolve adaptations to environmental conditions brought about by climate change is largely dependent on its existing genetic variation.
 - Measured genetic variation.
 - Occurrence of bottlenecks in recent evolutionary history.
- Phenological response to changing seasonal temperature and precipitation dynamics. Recent research suggests that some phylogenetic groups are declining due to lack of response to changing annual temperature dynamics (*e.g.*, earlier onset of spring, longer growing season), including some bird species that have not advanced their migration times, and some temperate zone plants that are not moving their flowering times.

Risk Factor D: Documented or Modeled Response to Climate Change (optional, if available)

- Documented response to recent climate change. Although conclusively linking species declines to climate change is difficult, convincing evidence relating declines to recent climate patterns has begun to accumulate in a variety of species groups. This criterion incorporates the results of these studies when available, and is rarely available to include in the assessment.
- Modeled future change in range or population size. The change in area of the predicted future range relative to the current range is a useful indicator of vulnerability to climate change.
- Overlap of modeled future range with current range. A spatially disjunct predicted future range indicates that the species will need to disperse in order to occupy the newly favored area, and geographical barriers or slow dispersal rates could prevent the species from getting there.
- Occurrence of protected areas in modeled future distribution. For many species, future ranges may fall entirely outside of protected areas and therefore compromise their long-term viability.

2.3 Interpreting Results

For each factor, species are scored on a sliding scale from *greatly increasing vulnerability* to *decreasing vulnerability*. The CCVI framework is designed to accommodate missing data and uncertainty by ignoring missing input information and assigning a confidence level to the component factor scores. Accordingly, responses are not required for all factors. The index will calculate a score with as few as 13 responses, although CCVI developers recommend estimating as many factors as possible, even if more than one category is selected for factors associated with sparse data or high uncertainty (Young et al. 2011).

The Index treats exposure to climate change as a modifier of sensitivity. If the climate in a given assessment area will not change much, none of the sensitivity factors will weigh heavily, and a species is likely to score at the Not Vulnerable end of the range. A large change in temperature or moisture availability will amplify the effect of any related sensitivity, and will contribute to a score

reflecting higher vulnerability to climate change. In most cases, changes in temperature and moisture availability will combine to modify sensitivity factors. However, for factors such as sensitivity to temperature change (factor 2a) or precipitation/moisture regime (2b), only the specified climate driver will have a modifying effect. The Index therefore combines information on exposure and sensitivity to produce a numerical sum, which is converted into a categorical score by comparing it to threshold values. Separately, the Index calculates a numerical sum and corresponding categorical score for four factors relating to documented or modeled response to climate change if any of these factors are scored. The final Index score represents just the exposure/sensitivity result if there is no information on documented/modeled responses, and an average of the two sections if documented/modeled response information is available. The Index produces a climate change vulnerability score for each species along with a measure of confidence or uncertainty related to the species information used. Confidence scores range from low to very high. Further details of how the vulnerability score is generated are presented in Young et al. (2011). Vulnerability rating scores and abbreviations used within the CCVI are:

Extremely Vulnerable (EV): Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

Highly Vulnerable (HV): Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

Moderately Vulnerable (MV): Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

Not Vulnerable/Presumed Stable (PS): Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

Not Vulnerable/Increase Likely (IL): Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

Insufficient Evidence (IE): Available information about a species' vulnerability is inadequate to calculate an Index score.

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3 Results – Rangewide/State and Park-Scale Assessments of Climate Change Vulnerability

3.1 Climate Change Vulnerability of Topeka Shiner (*Notropis topeka*), Pipestone National Monument

Regionally-focused Climate Vulnerability Score: Moderately Vulnerable by 2050.

Pipestone National Monument-focused Vulnerability Score: Moderately Vulnerable by 2050.

Confidence in Species Information: Very High. Most ranked assessment categories were based on published literature or modeled environmental variables.

3.1.1 Introduction

The Topeka shiner (*Notropis topeka*) is a member of Family Cyprinidae (carp, true minnows, and their relatives) and was historically found throughout the central prairie regions of the United States within portions of Iowa, Kansas, Minnesota, Nebraska, South Dakota, and Missouri (USFWS 2009). Currently the species exists in portions of its historical distribution in northern Iowa, eastern Kansas, southeastern Minnesota, north-central Nebraska, eastern South Dakota and northern Missouri. The species was listed as a special concern species by Minnesota in 1984, and as a federally endangered species by the U.S. Fish and Wildlife Service (USFWS) in 1998 (USFWS 1998). In southwest Minnesota, the species is near the northern edge of its range. Topeka shiner are intolerant of certain human-caused disturbances and habitat alterations including stream impoundment; channelization; increased sedimentation from cultivation and building projects; water diversion; overgrazing; and increased nutrient loading from agriculture within the watershed and in the region. Predation by introduced nonnative game fish has been one of many factors resulting in the decline of Topeka shiner populations (Prophet et al. 1981).

3.1.2 Sources of Information, Data and Expertise

Konrad Schmidt, James Ford Bell Museum of Natural History Fish Collection and Lyn Bergquist, Fisheries GIS Coordinator, Minnesota Department of Natural resources supplied map documents and GIS files for the Topeka shiner distribution in Minnesota. Konrad Schmidt and Jay Hatch, research Associate, James Ford Bell Museum of Natural History Fish Collection are both experts on the Topeka Shiner in Minnesota. The peer reviewed scientific literature on the Topeka shiner was searched and information from that literature was used to determine ratings for the factors used in the climate change assessment.

3.1.3 CCVI Factor Inputs and Rationale

Because the shiner is associated with and is dependent on groundwater-fed streams and pools (USFWS 2004), it was considered a groundwater-obligate species in the CCVI analysis. Groundwater-fed aquatic systems are to some degree buffered from aboveground climate. By checking the box at the top of the *Calculator* worksheet for these species within the CCVI tool, the exposure weightings for the indirect exposure and sensitivity factors are moderated, resulting in a lesser vulnerability rating (Young et al. 2011).

Risk Factors Section A: Exposure to Local Climate Change

Temperature – Mean ensemble mid-century temperature change from baseline (scenario A1B) for the region (~150 mile x 150 mile area) and park is approximately 5.4 °F, which falls within the 5.1-5.5 °F CCVI class for mean temperature change.

Moisture – For the mid-century period, the difference in available moisture compared to the baseline 1960-1991 period for this region of Minnesota was estimated using the Hamon AET:PET metric generated by ClimateWizard web-based tools (ClimatWizard.org). The region (~150 mile x 150 mile area) and park falls within the CCVI Hamon metric class of -5.1 to -7.3% change.

Risk Factors Section B: Indirect Exposure to Climate Change

B1) Exposure to sea level rise. Regional Range/PIPE: Neutral. Not applicable to this species.

B2a) Distribution relative to natural barriers. Regional Range/PIPE Somewhat Increase.

Climate change is predicted to lower ground and surface water flows (Melillo et al. 2014), thus reducing instream flows and impacting movement abilities of this fish (USFWS 2009). Those impacts may affect the ability of the Topeka shiner to shift its range to track movement in its habitat as climate changes (USFWS 2009). Topeka shiners occupy smaller, lower order tributary streams and the mainstem of larger streams with naturally lower surface flows (USFWS 2004), so any reductions in already low flows will have an impact. These impacts are expected to be the same for both the regional range and the PIPE-specific CCVI models.

B2b) Distribution relative to anthropogenic barriers. Regional Range/PIPE: Increase-Somewhat Increase. To support agriculture and urbanization, groundwater withdrawal, tributary impoundments and mainstem reservoirs are predicted to increase in response to reduced water availability due to climate change (USFWS 2009). These barriers will artificially divide stream networks, reducing stream connectivity, and detrimentally affect the ability of Topeka shiner populations to shift their range in response to climate change (Edberg 2009). The fragmentation of stream systems resulting from water use and barriers noted above is a regional phenomenon that is expected to be less severe in the northern portion of the Topeka shiner's distribution (USFWS 2009). These impacts are expected to be the same for both the regional range and the PIPE-specific CCVI analyses.

B3) Impact of land use changes resulting from human responses to climate change. Regional Range/PIPE: Increase. Increased water demand from agriculture and urbanization, combined with reduced availability due to climate change, is expected to increase impoundments having negative effects on Great Plains fish (Perkins et al. 2010). Additionally, the conversion of grassland to cropland is expected to expand to meet increased demand for corn used in ethanol production (USFWS 2009). This will increase sedimentation and alter stream hydrology, reducing habitat suitability for the Topeka shiner. Increases in wind farm development may be partially driven by climate change concerns, and are anticipated for the region and area surrounding the park. These developments are not anticipated to directly affect the Topeka shiner, although associated construction and infrastructure may have nominal impacts to streams. These impacts are expected to be the same for both the regional range and the PIPE-specific CCVI models.

Risk Factors Section C. Sensitivity, or Species-Specific Factors

C1) Dispersal and movements. Regional Range/PIPE: Somewhat Increase. Rangewide genetic analyses of different populations of Topeka shiner suggest that successful migration, even between adjacent populations, is rare and that movement over long distances is unlikely (USFWS 2004). However, individuals may migrate variable distances between spawning areas and nonspawning habitats (NatureServe 2014). Additionally, in its natural environment, the Topeka shiner was able to disperse downstream or off-channel to areas with suitable waters during dry periods associated with drought (USFWS 2009). These impacts are expected to be the same for both the regional range and the PIPE specific CCVI models.

C2ai) Predicted sensitivity to temperature: historical thermal niche. Regional Range/PIPE: Somewhat Decrease. Historical mean seasonal temperature variation throughout the range assessed and at PIPE was 77-90 °F.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Regional Range/PIPE: Increase. The Topeka shiner is characteristic of small, low order (headwater), prairie streams with good water quality and cool temperatures. Although Topeka shiners can tolerate a range of water temperatures, cooler, spring-maintained systems are considered optimal (Cross and Collins 1995, Pflieger 1997). Climate projections suggest that summer temperatures across the range of the Topeka shiner will increase 6 °F by the end of the century under a lower emissions scenario, with increases of more than 10 °F by the end of the century under a higher emissions scenario (Karl et al. 2009). Additionally, extreme heat events (a one in twenty-year event) are projected to occur every 2 to 3 years across the Topeka shiner's range under a higher emissions scenario by the end of the century (Karl et al. 2009). If these projections prove accurate, the long-term impacts to Topeka shiner could be substantial. Impacts in summer are of particular concern. Streams could be dewatered during the summer, both from less water in aquatic systems and increasing demands of irrigation (Melillo et al. 2014). Stream dewatering will cause low water quality and crowding of Topeka shiners in pools that remain during periods of reduced flows (Mammoliti 2002). Fewer pools and higher water temperatures in remaining pools will reduce the availability of suitable habitat (USFWS 2009). These impacts are expected to be the same for both the regional range and the PIPE-specific CCVI models.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Regional Range/PIPE: Greatly Increase. Examination of mean annual precipitation variation within the assessment areas indicates a mean annual precipitation variation of <100mm, which is described as a very small precipitation variation over the past 50 years.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Regional Range/PIPE: Increase. Topeka shiners occur in low order stream channels and are dependent upon instream pools and off-channel habitat. Off-channel sites may represent important habitat for the species within the floodplains of occupied streams (USFWS 2009). In their natural habitat the Topeka shiner is able to disperse downstream or off-channel to areas with suitable waters during periods of reduced seasonal flows or during dry periods resulting from drought. Increased periods of protracted drought, potentially resulting from climate

change, could reduce surface and ground water flows in the region, dewatering these instream and off-channel pools and reducing the Topeka shiner's ability to persist in some areas (USFWS 2009). Increased water extraction (both groundwater and surface water) during drought periods for public consumption and agriculture will exacerbate this problem (USFWS 2009). These impacts are expected to be the same for both the regional range and the PIPE-specific CCVI models.

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.

Regional Range/PIPE: Neutral. The Topeka shiner does not depend on any specific disturbance regime such as flooding, but does require aspects of a natural hydrologic regime including the timing, frequency, and level of seasonal flows and floods that replenish and reconnect off-channel habitat (Mammoliti 2002).

C2d) Dependence on ice, ice-edge, or snow-cover habitats. Regional Range/PIPE: Neutral. The Topeka shiner is not dependent on habitats with ice, snow, or on snowpack for maintaining downstream water temperatures.

C3) Restriction to uncommon geological features or derivatives. Regional Range/PIPE: Neutral. The Topeka shiner is dependent on instream pools and off-channel habitat, but those factors are addressed under Factor C2bii: Physiological Hydrological Niche.

C4a) Dependence on other species to generate habitat. Regional Range/PIPE: Neutral. The spawning activity of Topeka shiners is dependent upon the use of sunfish or fathead minnow nests (Kerns and Bonneau 2002), but it is unlikely that these species will be vulnerable to climate change. If water impoundments increase in the range of the Topeka shiner as a result of climate change and decreasing water availability, sunfish habitats and populations may increase. Impacts are expected to be the same for both the regional range and the PIPE-specific CCVI models.

C4b) Dietary Versatility. Regional Range/PIPE: Neutral. The Topeka shiner is an opportunistic omnivore, feeding on aquatic insects, microcrustaceans, larval fish, algae, and detritus (Hatch and Besaw 2001).

C4c) Pollinator versatility. Not applicable

C4d) Dependence on other species for propagule dispersal. Regional Range/PIPE: Neutral. The Topeka shiner is a self-disperser.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Regional Range/PIPE: Neutral. The Topeka shiner does not rely on any interspecific interaction for its persistence

C5a) Measured genetic variation. Regional Range/PIPE: Somewhat Increase. Research on the genetic diversity of Topeka shiner populations is limited, but research that has been completed on Topeka shiner populations in South Dakota, Minnesota, and Missouri indicates lower genetic diversity compared to other freshwater fishes. This lower genetic diversity is reflected by lower numbers of alleles per loci and lower gene diversity (nuclear-encoded loci). The number of alleles per loci in the Topeka shiner averaged 4.5 while mean heterozygosity was 0.31, lower than those of

other freshwater fishes (7.5 and 0.46, respectively) (Anderson and Sarver 2008, DeWoody and Avise 2000).

C5b) Occurrence of bottlenecks in recent evolutionary history. Regional Range/PIPE: Not applicable

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Regional Range/PIPE: Unknown. No data available.

Risk Factors Section D. Documented or Modeled Response to Climate Change

D1) Documented response to recent climate change. Regional Range/PIPE: Unknown. No data available.

D2) Modeled future change in population or range size. Regional Range/PIPE: Unknown. No data available.

D3) Overlap of modeled future range with current range. Regional Range/PIPE: Unknown. No data available.

D4) Occurrence of protected areas in modeled future distribution. Regional Range/PIPE: Unknown. No data available.

3.1.4 CCVI Results

Each component was scored and results were compiled into an overall CCVI rating (Table 1). By 2050, within its current range within an approximate 150 X 150 mile area centered on Pipestone National Monument, the species was considered Moderately Vulnerable. Within PIPE, the species is also considered Moderately Vulnerable by 2050 (Table 1). There are aspects of Topeka shiner biology that can make it susceptible to climate alterations. In particular, the Topeka shiner is dependent upon instream pools and off-channel wetlands that could be reduced in number and distribution within the streams that the fish inhabits within the region and at PIPE. This is particularly true during drought, which is predicted to increase in the region under climate change. Dependence on and connections to groundwater may help buffer the adverse effects of climate change on this species, and are accounted for in the CCVI analysis. It is particularly important for Topeka shiner to access these wet refugia during times of drought. With water withdrawal and impoundment predicted to increase in the future, shiner habitat may become more fragmented, making it difficult for population to access these refugia and to persist.

Table 1. Summary of CCVI factor ratings for the Topeka shiner, Pipestone National Monument.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Exposure to local climate change	Temperature	5.1-5.5 °F – 100% of range	5.1-5.5 °F – 100% of range
	Hamon AET:PET Moisture Metric	-5.1 to -7.3% - 100% of range	-5.1 to -7.3% - 100% of range
Indirect exposure to climate change	1) Exposure to sea level rise	Neutral	Neutral
	2a) Distribution relative to natural barriers	Somewhat Increase	Somewhat Increase
	2b) Distribution relative to anthropogenic barriers	Increase-Somewhat Increase	Increase-Somewhat Increase
	3) Predicted impact of land use changes resulting from human responses to climate change	Increase	Increase
Sensitivity to climate change	1) Dispersal and movements	Somewhat Increase	Somewhat Increase
	2ai) Predicted sensitivity to changes in temperature: historical thermal niche	Somewhat Decrease	Somewhat Decrease
	2aii) Predicted sensitivity to changes in temperature: physiological thermal niche	Increase	Increase
	2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche	Greatly Increase	Greatly Increase
	2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche	Increase	Increase
	2c) Dependence on a specific disturbance regime likely to be impacted by climate change	Neutral	Neutral
	2d) Dependence on ice, ice-edge, or snow-cover habitats	Neutral	Neutral
	3) Restriction to uncommon geological features or derivatives	Neutral	Neutral
	4a) Dependence on other species to generate habitat	Neutral	Neutral
	4b) Dietary versatility (animals only)	Neutral	Neutral
	4c) Pollinator versatility (plants only)	Not applicable	Not applicable
	4d) Dependence on other species for propagule dispersal	Neutral	Neutral
	4e) Forms part of an interspecific interaction not covered by 4a-d	Neutral	Neutral

Table 1 (continued). Summary of CCVI factor ratings for the Topeka shiner, Pipestone National Monument.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Sensitivity to climate change (continued)	5a) Measured genetic variation	Somewhat Increase	Somewhat Increase
	5b) Occurrence of bottlenecks in recent evolutionary history	Not applicable	Not applicable
	6) Phenological response to changing seasonal temperature and precipitation dynamics	Unknown	Unknown
Documented or modeled response to climate change – unknown/no data for all subfactors	Overall CCVI Rating	Moderately Vulnerable	Moderately Vulnerable

3.1.5 Notes on Applying the CCVI Framework and Tool

The Topeka shiner is federally endangered under the ESA and a great deal of attention has been devoted to researching the species. Consequently, there is a great deal of information in the peer reviewed literature on the Topeka shiner, but finding the pertinent data is time consuming and for species with little research or information it may be difficult to find the data necessary for rating the CCVI factors. Also, even with a moderate amount of applicable information available for rating the CCVI factors the process is still inherently subjective. Relatively few responses were received by the authors for requests for additional information from researchers publishing on the Topeka shiner in the peer-reviewed literature.

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3.2 Climate Change Vulnerability of Topeka Shiner (*Notropis topeka*), Tallgrass Prairie National Preserve

Kansas-focused Climate Vulnerability Score: Highly Vulnerable by 2050.

Tallgrass Prairie National Preserve-focused Vulnerability Score: Moderately Vulnerable by 2050.

Confidence in Species Information: Rangewide in Kansas - Low; TAPR - Very High. Most ranked assessment categories were based on published literature or modeled environmental variables.

3.2.1 Introduction

The Topeka shiner (*Notropis topeka*) is a member of Family Cyprinidae (carp, true minnows, and their relatives) historically found throughout the central prairie regions of the United States within portions of Iowa, Kansas, Minnesota, Nebraska, South Dakota and Missouri (USFWS 2009). Currently the species exists in portions of its historical distribution in northern Iowa, eastern Kansas, southeastern Minnesota, north-central Nebraska, eastern South Dakota and northern Missouri. The species was listed as a threatened species by Kansas in 1978 and as a federally endangered species by the U.S. Fish and Wildlife Service (USFWS) in 1998 (USFWS 1998). Topeka shiner are intolerant of certain human-caused disturbances and habitat alterations including impoundment; channelization; increased sedimentation from cultivation, building projects, water diversion projects, and heavy and continuous grazing; and increased nutrient loading from cropland cultivation. Predation by introduced native and nonnative game fish in the region and in the park has resulted in reduced shiner numbers and the loss of Topeka shiner populations (Prophet et al. 1981).

3.2.2 Sources of Information, Data and Expertise

Vernon Tabor, U.S. Fish and Wildlife Service, Kansas Ecological Services Field Office supplied GIS files for the Topeka shiner in Kansas and is the point of contact at the USFWS for the Topeka shiner. Peer-reviewed scientific literature on the Topeka shiner supported ratings for the factors used in the vulnerability assessment.

3.2.3 CCVI Factor Inputs and Rationale

Because the Topeka shiner is associated with and somewhat dependent on groundwater-fed streams and pools, it is considered a groundwater-obligate species in the CCVI analysis. Groundwater-fed aquatic systems are to some degree buffered from aboveground climate. By checking the box at the top of the Calculator page for these species within the CCVI tool, the exposure weightings for the indirect exposure and sensitivity factors are moderated, resulting in a lesser vulnerability rating (Young et al. 2011).

Risk Factors Section A: Exposure to Local Climate Change

Temperature – Kansas Rangewide/TAPR. Mean ensemble temperature change from baseline for 2050s (scenario A1B) is +5.3 °F for the eastern 2/3 of Kansas and +5.2 °F for the western 1/3 of the state, so the entire state also falls within the +5.1 to +5.5 °F CCVI class.

Moisture – Kansas Rangewide. Within Kansas, the percentage of the range falling within each Hamon metric category is as follows: -5.1 to -7.3% (10%), -7.4 to -9.7% (55%), and -9.7 to -11.9% (35%). **TAPR.** TAPR proper falls within the -7.4 to -9.7% map class and CCVI class.

Risk Factors Section B: Indirect Exposure to Climate Change

B1) Exposure to sea level rise. Kansas Rangewide/TAPR. Neutral. Not applicable to this species.

B2a) Distribution relative to natural barriers. Kansas Rangewide/TAPR. Somewhat Increase. Climate change is predicted to lower ground and surface water flows (Melillo et al. 2014), thus reducing instream flows and impacting movement abilities of this fish (USFWS 2009). Those impacts should affect the ability of the Topeka shiner to shift its range to track movement in its habitat as climate changes (USFWS 2009). Topeka shiners occupy smaller, lower order tributary streams and the mainstem of larger streams with naturally lower surface flows (USFWS 2004), so any reductions in already low flows will have an impact.

B2b) Distribution relative to anthropogenic barriers. Kansas Rangewide. Greatly Increase. To support agriculture and urbanization groundwater withdrawal, tributary impoundments and mainstem reservoirs are predicted to increase in response to reduced water availability due to climate change (USFWS 2009). These barriers will artificially divide stream networks, reducing stream connectivity, and detrimentally affect the ability of Topeka shiner populations to migrate in response to climate change (Edberg 2009). The fragmentation of stream systems resulting from water use is expected to be greater in the southern portion of the Topeka shiner's distribution (USFWS 2009). **TAPR.** Somewhat Increase. The large area protected within the boundary of TAPR includes multiple stream reaches suitable for Topeka shiners. The amount of suitable habitat protected within TAPR where impoundments, diversions, and water withdrawals are managed or eliminated will somewhat buffer the park's Topeka shiner population from increased rates of water usage and decreased rates of water supply expected under scenarios of climate change.

B3) Impact of land use changes resulting from human responses to climate change. Kansas Rangewide. Increase. Increased water demand from agriculture and urbanization, combined with reduced availability due to climate change, is expected to increase impoundments having negative effects on Great Plains prairie fish, particularly in the southern portion of the Great Plains (Perkins et al. 2010). Additionally, the conversion of grassland to cropland is expected to expand to meet increased demand for corn used in ethanol production (USFWS 2009). This will increase sedimentation and alter stream hydrology, reducing habitat suitability for the Topeka shiner. **TAPR.** Neutral. Protection of the area occupied by the Topeka shiner at TAPR will prevent changes to the land resulting from climate change, protecting the Topeka shiner population at TAPR from such impacts.

Risk Factors Section C. Sensitivity, or Species-Specific Factors

C1) Dispersal and movements. Kansas Rangewide/TAPR. Increase. Rangewide genetic analyses of Topeka shiner populations suggest that successful migration, even between adjacent populations, is rare and that movement over long distances is unlikely (USFWS 2004). Nonetheless, individuals may migrate variable distances between spawning areas and nonspawning habitats (NatureServe

2014). Additionally, in its natural environment, the Topeka shiner appears able to disperse downstream or off-channel to areas with suitable waters during seasonally dry periods and dry periods of drought (USFWS 2009).

C2ai) Predicted sensitivity to temperature: historical thermal niche. Kansas Rangewide/TAPR. Somewhat Increase. Annual Temperature Variation Map 1951 - 2006 for the range of the Topeka shiner in Kansas and at TAPR indicates a mean seasonal temperature variation of between 57 and 77 °F.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Kansas Rangewide/TAPR. Increase. The Topeka shiner is characteristic of small, low order (headwater) prairie streams with good water quality and cool temperatures. Although Topeka shiners can tolerate a range of water temperatures, cooler spring-maintained systems are considered optimal (Cross and Collins 1995, Pflieger 1997). Climate projections suggest that summer temperatures across the range of the Topeka shiner will increase 6 °F by the end of the century under a lower emissions scenario, with increases of more than 10 °F by the end of the century under a higher emissions scenario (Karl et al. 2009). Additionally, extreme heat events (a one in twenty-year event) are projected to occur every 2 to 3 years across the Topeka shiner's range under a higher emissions scenario by the end of the century (Karl et al. 2009). If these projections prove accurate, the long-term impacts to Topeka shiner could be substantial. Impacts in summer are of particular concern. Streams could be dewatered during the summer, both from less water in aquatic systems and increasing demands of irrigation (Melillo et al. 2014). Stream dewatering will cause low water quality and crowding of Topeka shiners in pools that remain during periods of reduced flows (Mammoliti 2002). Fewer pools and higher water temperatures in remaining pools will reduce the availability of suitable habitat (USFWS 2009).

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Kansas Rangewide/TAPR. Increase. The historical (1951-2006) mean annual precipitation varies between 100 - 254mm. TAPR. Greatly Increase. Annual Precipitation Variation Map 1951 - 2006 for the range of the Topeka shiner in TAPR indicates a mean annual precipitation variation of < 100mm, which is described as a very small precipitation variation over the past 50 years.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Kansas Rangewide/TAPR. Increase. Topeka shiner occur in low order stream channels and are dependent upon instream pools and off-channel habitat. Off-channel sites may represent important habitat for the species within the floodplains of occupied streams (USFWS 2009). In their natural habitat the Topeka shiner is able to disperse downstream or off-channel to areas with suitable waters during dry periods resulting from drought. Increased periods of protracted drought, potentially resulting from climate change, could reduce surface and ground water flows in the region, dewatering these instream and off-channel pools, and reducing the Topeka shiners ability to persist in some areas (USFWS 2009). Increased water extraction (both groundwater and surface water) during drought periods for public consumption and agriculture would exacerbate this problem (USFWS 2009).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.

Kansas Rangewide/TAPR. Neutral. Topeka shiner do not depend on any specific disturbance regime such as flooding, but rather are dependent upon maintenance of the natural hydrology of a stream including the timing, frequency, and level of seasonal flows including floods that replenish and reconnect off-channel habitat (Mammoliti 2002).

C2d) Dependence on ice, ice-edge, or snow-cover habitats. Kansas Rangewide/TAPR.

Neutral. The Topeka shiner is not dependent on habitats with ice, snow, or on snowpack for maintaining downstream water temperatures.

C3) Restriction to uncommon geological features or derivatives. Kansas Rangewide/TAPR.

Neutral. The Topeka shiner is dependent on instream pools and off-channel habitat, but those factors are addressed under Factor C2bii: Physiological Hydrological Niche.

C4a) Dependence on other species to generate habitat. Kansas Rangewide/TAPR.

Neutral. The spawning activity of Topeka shiners is dependent upon the use of sunfish or fathead minnow nests (Kerns and Bonneau 2002), but it is unlikely that these species will be vulnerable to climate change. If water impoundments increase in the range of the Topeka shiner as a result of climate change and decrease water availability, sunfish habitat and populations could increase.

C4b) Dietary Versatility. Kansas Rangewide/TAPR.

Neutral. The Topeka shiner is an opportunistic omnivore, feeding on aquatic insects, microcrustaceans, larval fish, algae and detritus (Hatch and Besaw 2001).

C4c) Pollinator versatility (plants only).

Not applicable.

C4d) Dependence on other species for propagule dispersal. Kansas Rangewide/TAPR.

Neutral. The Topeka shiner is a self-disperser.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Kansas

Rangewide/TAPR. Neutral. The Topeka shiner does not rely on any interspecific interaction for its persistence.

C5a) Measured genetic variation. Kansas Rangewide/TAPR. Somewhat Increase. Research on the genetic diversity of Topeka shiner populations is limited, but research that has been completed on Topeka shiner populations in South Dakota, Minnesota, and Missouri indicates lower genetic diversity compared to other freshwater fishes. This lower genetic diversity is reflected by lower numbers of alleles per loci and lower gene diversity (nuclear-encoded loci). The number of alleles per loci in the Topeka shiner averaged 4.5 while mean heterozygosity was 0.31, lower than those of other freshwater fishes (7.5 and 0.46, respectively) (Anderson and Sarver 2008, DeWoody and Avise 2000).

C5b) Occurrence of bottlenecks in recent evolutionary history. Kansas Rangewide/TAPR. Not applicable.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Kansas Rangewide/TAPR. Unknown. No data available.

Risk Factors Section D. Documented or Modeled Response to Climate Change

D1) Documented response to recent climate change. Kansas Rangewide/TAPR. Unknown. No data available.

D2) Modeled future change in population or range size. Kansas Rangewide/TAPR. Unknown. No data available.

D3) Overlap of modeled future range with current range. Kansas Rangewide/TAPR. Unknown. No data available.

D4) Occurrence of protected areas in modeled future distribution. Kansas Rangewide/TAPR. Unknown. No data available.

3.2.4 CCVI Results

Each CCVI factor was scored and results were compiled into an overall CCVI rating (Table 2). By 2050, within its current range in Kansas the species is considered Highly Vulnerable. Within TAPR, the species is considered to be Moderately Vulnerable by 2050. There are factors of the Topeka shiner's biology that can make it susceptible to climate alterations. In particular, the Topeka shiner is dependent upon instream pools and off-channel wetlands that could be reduced in number and distribution within the streams that the fish inhabits at TAPR. This is particularly true during drought, which is predicted for the region under climate change. It is particularly important for Topeka shiner to access these wet refugia during times of drought. With water withdrawal and impoundment predicted to increase in the future their habitat may become more fragmented, making it difficult for current populations to access these refugia and persist.

3.2.5 Notes on Applying the CCVI Framework and Tool

The Topeka shiner is federally endangered under the ESA and a great deal of attention has been devoted to researching the species. Consequently, there is a great deal of information in the peer reviewed literature on the Topeka shiner, but finding the pertinent data is time consuming and for species with little research or information it may be difficult to find the data necessary for ranking the CCVI factors. Also, even with a moderate amount of applicable information available for ranking the CCVI factors the process is still inherently subjective. Pursuit of additional information from researchers publishing on the Topeka shiner in the peer reviewed literature also proved to be a hit-or-miss endeavor with some experts responding and others ignoring requests.

Table 2. Summary of CCVI factor ratings for the Topeka shiner, Tallgrass Prairie National Preserve.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Exposure to local climate change	Temperature	5.1-5.5 OF – 100% of range	5.1-5.5 OF – 100% of range
	Hamon AET:PET Moisture Metric	-5.1 to -7.3% (10%), -7.4 to -9.7% (55%), and -9.7 to -11.9% (35%)	-7.4 to -9.7% (100%)
Indirect exposure to climate change	1) Exposure to sea level rise	Neutral	Neutral
	2a) Distribution relative to natural barriers	Somewhat Increase	Somewhat Increase
	2b) Distribution relative to anthropogenic barriers	Greatly Increase	Somewhat Increase
	3) Predicted impact of land use changes resulting from human responses to climate change	Increase	Neutral
Sensitivity to climate change	1) Dispersal and movements	Increase	Increase
	2ai) Predicted sensitivity to changes in temperature: historical thermal niche	Somewhat Increase	Somewhat Increase
	2aii) Predicted sensitivity to changes in temperature: physiological thermal niche	Increase	Increase
	2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche	Increase	Greatly Increase
	2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche	Increase	Increase
	2c) Dependence on a specific disturbance regime likely to be impacted by climate change	Neutral	Neutral
	2d) Dependence on ice, ice-edge, or snow-cover habitats	Neutral	Neutral
	3) Restriction to uncommon geological features or derivatives	Neutral	Neutral
	4a) Dependence on other species to generate habitat	Neutral	Neutral
	4b) Dietary versatility (animals only)	Neutral	Neutral
	4c) Pollinator versatility (plants only)	Not applicable	Not applicable
	4d) Dependence on other species for propagule dispersal	Neutral	Neutral

Table 2 (continued). Summary of CCVI factor ratings for the Topeka shiner, Tallgrass Prairie National Preserve.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Sensitivity to climate change (continued)	4e) Forms part of an interspecific interaction not covered by 4a-d	Neutral	Neutral
	5a) Measured genetic variation	Somewhat Increase	Somewhat Increase
	5b) Occurrence of bottlenecks in recent evolutionary history	Not applicable	Not applicable
	6) Phenological response to changing seasonal temperature and precipitation dynamics	Unknown	Unknown
Documented or modeled response to climate change – unknown/no data for all subfactors	Overall CCVI Rating	Highly Vulnerable	Moderately Vulnerable

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3.3 Climate Change Vulnerability of Western Prairie Fringed Orchid (*Platanthera praeclara*) at Pipestone National Monument (PIPE)

Minnesota/Rangewide-focused Climate Vulnerability Score: Extremely Vulnerable (EV)

Species abundance and/or range extent within the geographical area assessed are extremely likely to substantially decrease or disappear by 2050. **Confidence in Species Information:** Moderate. Most ranked assessment categories were based on published literature or modeled environmental variables.

PIPE-focused Climate Vulnerability Score: Moderately Vulnerable (MV) Species abundance and/or range extent within the geographical area assessed are likely to significantly decrease by 2050. **Confidence in Species Information:** Very High. Most ranked assessment categories were based on published literature or modeled environmental variables, and were more precisely categorized at the park scale.

3.3.1 Introduction

The western prairie fringed orchid (*Platanthera praeclara*) is a long-lived perennial with a showy open raceme holding as many as two dozen white to creamy white flowers, with a fringed lip or lower petal on each flower. The single smooth stem is up to 85 cm (34 in.) tall, with 1 to 3 smooth, elongate basal leaves (MNDNR 2014). The species was listed as federally-threatened in the United States in 1989. At Pipestone National Monument (PIPE) it is also protected by Minnesota's Endangered Species Statute (84.0895) administered by the Department of Natural Resources (MNDNR 2014). The species has a NatureServe conservation rank of Globally Vulnerable (G3).

Historically, the western prairie fringed orchid was once found in mesic to wet tallgrass prairie, from southern Canada to northern Oklahoma (USFWS 1996, 2009). Conversion of native prairie to agricultural use has eliminated most of the species' habitat. The western prairie fringed orchid is now found almost exclusively in essentially undisturbed remnant native prairies and sedge meadows in Minnesota, North Dakota, South Dakota, Nebraska, Iowa, Kansas, Missouri, and Manitoba, Canada (USFWS 2009).

Regional threats affecting western prairie fringed orchid (WPFO) to varying degrees within its range include conversion of habitat to cropland, overgrazing, intensive hay mowing that may reduce primary productivity and seed dispersal and facilitate invasion of exotic cool season grasses, lack of prairie management leading to woody plant invasion, competition and invasion by exotic plants including cool season grasses, herbicide and pesticide impacts on western prairie fringed orchid and its pollinators, mechanical plant management, hydrologic alterations that directly or indirectly lower water levels in the *P. praeclara* rooting zone, and low seed set in small and isolated populations (USFWS 1996, 2009). Where populations are on unprotected sites, multiple threats and stressors are likely at work. Threats that may be affecting the orchid population at PIPE include:

- competition from invasive woody plants, grasses and forbs;
- reductions in insect pollinators;
- hydrologic alterations that may reduce available water to plants during dry years;
- herbicides use in and around the park; and

3.3.2 Sources of Information, Data and Expertise

U.S. Fish and Wildlife Service Environmental Conservation Online System (ECOS) is a key resource for candidate, threatened and endangered species information. The site provides information and literature synthesis regarding species occurrences, conservation and recovery planning, life history and critical habitat.

Rick Schneider and Gerry Steinauer of the Nebraska Natural Heritage Program, who have completed a CCVI analysis for WPFO in Nebraska, provided comments and feedback on species-specific CCVI inputs.

Jennifer Haack-Gaynor, NPS Inventory and Monitoring Heartland Network. Ms. Haack provided information about WPFO ecology and monitoring efforts at the park.

Nancy Sather, Botanist/Ecologist, MN Biological Survey, Minnesota Department of Natural Resources. Ms. Sather provided valuable comments on the intricacies and uncertainties associated with evaluating potential effects of climate change on the orchid. She emphasized caution when presented with incomplete data or knowledge, and emphasized the need for collaboration and communication among WPFO experts.

3.3.3 CCVI Factor Inputs and Rationale

Risk Factors Section A: Exposure to Local Climate Change

Temperature – Rangewide: Temperature change during June-August was used, based on the assumption that the reproductive season (latter part of growing season) was the most crucial time period for species viability. Rangewide the species is expected to be exposed to temperatures 5.1-5.5 °F (2.8-3.1 °C) warmer by mid-century.

Temperature – PIPE: Climate Wizard data for ensemble average, medium emission scenario (A1B), mid-century timeframe, average change over growing season (Jun-Aug) were obtained, based on the assumption that the reproductive season was the most crucial time period for species viability. Within PIPE the species is expected to be exposed to temperatures 5.1-5.5 °F (2.8-3.1 °C) warmer by mid-century.

Moisture – Rangewide: The annual average for the Hamon AET:PET moisture index was used. Rangewide the species is expected to be exposed to drier conditions with a predicted annual change in Hamon AET:PET Moisture Metric of -5.0 to -11.9%, with 89% of the species range experiencing a -5.1 to -9.6% change PET. This index integrates projected temperature and precipitation changes to provide an index of available soil moisture compared to the baseline period.

Moisture – PIPE: Within PIPE the species is expected to be exposed to drier conditions with a predicted annual change in the Hamon AET:PET Moisture Metric of -5.1 to -7.3%.

Risk Factors Section B: Indirect Exposure to Climate Change

B1) Exposure to sea level rise. Rangewide/PIPE: Neutral, not applicable to this species.

B2a) Distribution relative to natural barriers. Rangewide: Neutral. There are no significant natural topographic or hydrological features that would preclude rangewide movement of the species northward. However, barriers may exist at local scales. **PIPE:** Neutral. There are no significant natural topographic or hydrological features that would preclude local movement of the species northward with the park.

B2b) Distribution relative to anthropogenic barriers. Rangewide: Greatly Increase-Increase. A major threat to this species is habitat conversion to cropland, which is widespread and prevalent throughout the species' range (Minnesota DNR 2014, USFWS 2009). Agriculture and urban development are barriers to northward movement of the species throughout a majority of the species range (SILVIS 2010). Conversion of the tallgrass prairie to agriculture and other land uses creates a barrier to northward migration. In the immediate vicinity of PIPE (3 km buffer) over 66% of land acreage is used for agriculture, nearly 20% is developed and 11% remains as grasslands or herbaceous cover. However, these grassland areas are small and very fragmented. Within a 30 km buffer, over 82% of the acreage is agricultural, 5% is developed and approximately 10% remains as grassland. Land cover of the contributing upstream watershed of Pipestone Creek is over 83% agriculture, 10% is developed and approximately 5% is grassland/pasture (Jones et al. in review). **PIPE:** Somewhat Increase. Agriculture and low density housing surrounding the Monument are barriers to northward movement of the species outside PIPE (American Farmland Trust 2014, SILVIS 2010). Additional land cover and land use analysis for the region is presented in Jones et al. (in review). However, within the park there are no notable anthropogenic barriers to movement of the species and this is not anticipated to change under climate change.

B3) Impact of land use changes resulting from human responses to climate change. Rangewide: Somewhat Increase. Numerous wind energy developments exist within the species range; there is high potential for increased growing of corn for ethanol production in Nebraska, South Dakota, Minnesota and Iowa; and some solar facilities are planned for southern Minnesota (NRDC 2011, Schneider and Steinauer pers. comm. 2014). **PIPE:** Neutral. Although the WPFO occurs within 1 mile of the proposed Aurora Solar facility at Pipestone, the project site is located on cropland. The WPFO is not likely to occur within the described solar project site (Aurora Solar 2014).

Risk Factors Section C: Sensitivity or Species-Specific Factors

C1) Dispersal and movements. Rangewide/PIPE: Neutral. Seed is dispersed by wind; with at least 5% of seeds dispersed 100-1000 meters. Seed may also be dispersed by water (USFWS 2009).

C2ai) Predicted sensitivity to temperature: historical thermal niche. Rangewide: Neutral-Somewhat Decrease. Historical temperature variation throughout the species' range was between 57 °F and 90 °F (NatureServe 2012). **PIPE:** Somewhat Decrease. Historical temperature variation within PIPE was between 77 °F and 90 °F (NatureServe 2012).

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Rangewide/PIPE: Neutral. No documentation of cool micro-habitat preference. (MDNR 2014)

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Rangewide/PIPE: Somewhat Increase. The species has experienced slightly lower than average (11-20 in/255-508 mm) precipitation variation in the past 50 years.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Rangewide/PIPE: Increase. 50-90% of occurrences is moderately dependent on a specific wetland habitat and localized moisture regime that is highly vulnerable to loss or reduction with climate change. The expected change in moisture is likely to reduce habitat quality and species abundance. Orchids utilize C3 or CAM photosynthetic pathways, and soil moisture is a critical determinant of growth for this species (USFWS 2009).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Rangewide/PIPE: Neutral. Per USFWS (2009), "Persistence of WPFO is dependent on periodic disturbance by fire, mowing or grazing...but these practices may also cause adverse effects and must be carefully implemented." Although WPFO may have some dependence on fire, within PIPE periodic prescribed burns are conducted. Fire is highly managed in the park and the regime is not anticipated to change significantly under climate change. Krawchuk et al. (2009) also indicate there is expected to be little or no change in the fire regime within the species range.

C2d) Dependence on ice, ice-edge, or snow-cover habitats. Rangewide/PIPE: Neutral. The species is not dependent on ice-edge or snow-cover habitats.

C3) Restriction to uncommon geological features or derivatives. Rangewide/PIPE: Neutral. WPFO is found primarily on sandy soils or calcareous till.

C4a) Dependence on other species to generate habitat. Rangewide/PIPE: Neutral. WPFO is not dependent on other species to generate habitat.

C4c) Pollinator Versatility. Rangewide/PIPE: Somewhat Increase. There are seven documented pollinators and two potential pollinators in Canada. Of these, one is uncommon near orchid populations and another has fluctuating populations. In North Dakota, the leafy spurge hawkmoth was found to be the predominant moth in orchid pollination study (USFWS 2009). Minnesota (location of largest populations) documented four pollinators (USFWS 2009, MDNR 2014). Given some level of uncertainty, we assigned more conservative rating of Somewhat Increase for this factor (n.b., down ranking this factor to Neutral doesn't change overall score).

C4d) Dependence on other species for propagule dispersal. Rangewide/PIPE: Neutral. WPFO disperses on its own.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Rangewide/PIPE: Somewhat Increase. Requires soil mycorrhizae for seed germination (USFWS 2009).

C5) Measured genetic variation. Rangewide/PIPE: Unknown.

C5b) Occurrence of bottlenecks in recent evolutionary history. Rangewide: Neutral. Given that the occupied area has been reduced by 30-70% at some point in the last 500 years, and the decline in

the population over the past 100 years, WPFO may be in the middle of a bottleneck now. There is no evidence for a bottleneck between 100 and 500 years ago (Schneider and Steinauer pers. comm. 2014). However, the CCVI Guidelines state that only species that have declined and then rebounded can qualify for Somewhat Increase or Increase, so a Neutral rating has been applied. **PIPE:** Unknown. Despite monitoring of orchid populations (flowering plants) at PIPE since 1993, accurate monitoring of the taxon is complicated by its erratic aboveground growth pattern and variable lifespan. In some years an orchid may produce a tall, visible flower stalk, while in others it produces only one to three basal leaves or no aboveground growth (Willson and Akyuz 2010). Only flowering orchids are monitored at PIPE (J. Haack-Gaynor, personal comment Dec 2014). Although summary metrics for WPFO at PIPE appear to indicate an increasing population, there are several years during which no or very few plants were observed. Therefore we have ranked this factor as unknown because confidence in population data is low due to difficulties in monitoring this taxon and large differences in population estimates from year to year.

C6) Phenological response to changing seasonal temperature and precipitation dynamics.

Rangewide/PIPE: Unknown.

Risk Factors Section D. Documented or Modeled Response to Climate Change

D1) Documented response to recent climate change. Unknown. No data available.

D2) Modeled future change in population or range size. Unknown. No data available.

D3) Overlap of modeled future range with current range. Unknown. No data available.

D4) Occurrence of protected areas in modeled future distribution. Unknown. No data available.

3.3.4 CCVI Results

Throughout its current range in the United States, the western prairie fringed orchid was found to be extremely vulnerable to climate change. The primary factors driving this score are: 1) moderately-high increases in mean temperature and reduced soil moisture by midcentury (exposure), 2) the presence of significant anthropogenic barriers to movement throughout the species' range (indirect exposure), and 3) physiological hydrological niche (species sensitivity) (Table 3). The orchid survives in a small number of locations within the region and is dependent on wetland habitat. Occurrences are generally small and surrounded by agricultural cropland and pasture, limiting potential habitat for the species as well as suitable migration corridors. The orchid also relies on a small number of moth species for pollination and requires specific mycorrhizae for seed germination, thus further reducing its resiliency to climate change.

Table 3. Summary of CCVI factor ratings for the western prairie fringed orchid.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Exposure to local climate change	Temperature	5.1-5.5 0F – 100% of range	5.1-5.5 0F – 100%
	Hamon AET:PET Moisture Metric	-9.7 to -11.9% (6%), -7.4 to 9.6% (50%), -5.1 to -7.3% (39%), -2.8 to -5.0% (5%)	-5.1 to -7.3% - 100%
Indirect exposure to climate change	1) Exposure to sea level rise	Neutral	Neutral
	2a) Distribution relative to natural barriers	Neutral	Neutral
	2b) Distribution relative to anthropogenic barriers	Greatly Increase-Increase	Somewhat Increase
	3) Predicted impact of land use changes resulting from human responses to climate change	Somewhat Increase	Neutral
Sensitivity to climate change	1) Dispersal and movements	Neutral	Neutral
	2ai) Predicted sensitivity to changes in temperature: historical thermal niche	Neutral-Somewhat Decrease	Somewhat Decrease
	2aii) Predicted sensitivity to changes in temperature: physiological thermal niche	Neutral	Neutral
	2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche	Somewhat Increase	Somewhat Increase
	2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche	Increase	Increase
	2c) Dependence on a specific disturbance regime likely to be impacted by climate change	Neutral	Neutral
	2d) Dependence on ice, ice-edge, or snow-cover habitats	Neutral	Neutral
	3) Restriction to uncommon geological features or derivatives	Neutral	Neutral
	4a) Dependence on other species to generate habitat	Neutral	Neutral
	4b) Dietary versatility (animals only)	Neutral	Neutral
	4c) Pollinator versatility (plants only)	Somewhat Increase	Somewhat Increase

Table 3 (continued). Summary of CCVI factor ratings for the western prairie fringed orchid.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Sensitivity to climate change (continued)	4d) Dependence on other species for propagule dispersal	Neutral	Neutral
	4e) Forms part of an interspecific interaction not covered by 4a-d	Neutral	Neutral
	5a) Measured genetic variation	Neutral	Neutral
	5b) Occurrence of bottlenecks in recent evolutionary history	Neutral	Unknown
	6) Phenological response to changing seasonal temperature and precipitation dynamics	Unknown	Unknown
Documented or modeled response to climate change – unknown/no data for all subfactors	Overall CCVI Rating	Extremely Vulnerable	Moderately Vulnerable

Within Pipestone National Monument the WPFO was scored as moderately vulnerable to climate change. The primary factors driving the park-scale score are severe increases in mean temperature by midcentury (exposure), and physiological hydrological niche (species sensitivity). The difference in vulnerability from the range-wide score may be due to somewhat less exposure to drying within the confines of PIPE versus the entire range, which includes much habitat to the south where greater changes in available moisture are predicted. Additionally, the WPFO has experienced greater temperature variations at PIPE compared to the species' range making it potentially more resilient to the effects of temperature changes at a local scale. Anthropogenic barriers to WPFO movement within PIPE are negligible, compared to significant expanses of agricultural lands within the species' range. Moreover, rangewide habitat for WPFO is expected to be subject to more pressure from energy development than at the local scale.

Notes on Considerations Affecting Vulnerability Not Captured Here

While the CCVI results for WPFO provide some understanding of the risk factors contributing to its vulnerability to climate change, it does not address other factors influencing species vulnerability. Listed as threatened by the U.S. Fish and Wildlife Service and endangered by Minnesota, the orchid is already suffering population declines due to conversion of habitat to crop land, hydrologic alterations, inter-seeding of non-native species, overgrazing, and intensive haying (USFWS 2009). These factors should be considered together with the CCVI results to more fully address the species' vulnerability.

3.3.5 Notes on applying the CCVI Framework and Tool

One of the main obstacles in conducting climate change vulnerability analysis for any rare species is a general lack of knowledge of life history characteristics. Even though the orchid is a federally-listed threatened species for which much life history data has been collected, there are still information gaps. Some of the existing data are old and often based on observations at a small number of sites using varying levels of monitoring intensity. Therefore, existing data may not fully represent WPFO reproduction and biology traits. Rangewide, only county-level presence-absence data were available, which tends to overestimate the actual geographic range of the species. To accommodate these information gaps we consulted regional experts for critical review of the CCVI results, and provided comments in the assessment notes when appropriate.

We used the year 2050 for analysis of climate change scenarios. Given the positive feedback mechanisms that are expected to intensify precipitation variability and warming temperatures, along with potential changes to complex species interactions (pollination and soil mycorrhizae), long-term climate change effects (e.g., 2100 and beyond) may be considerably different for WPFO from the short-term ones predicted here.

Information on genetic variation is not available for this species (or most species in general), so this category was generally rated as 'unknown'. Most species were rated as 'neutral' for the Occurrence of Bottlenecks in Recent Evolutionary History.

The CCVI spreadsheet design was at times cumbersome when entering and viewing data. For future iterations of the tool, developers should consider having the entire row become highlighted when the

user places the cursor within the appropriate scoring box, so the user can avoid marking the wrong box. The tab function within *Section A* skips between Temperature and Moisture Metric cells, instead of continuing down within one of the two columns.

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3.4 Climate Change Vulnerability of Sioux Quartzite Prairie at Pipestone National Monument

Rangewide Climate Vulnerability Score: Extremely Vulnerable (EV). Abundance and/or range extent within geographical area assessed are extremely likely to substantially decrease or disappear by 2050. **Confidence in Species Information:** Moderate. Most ranked assessment categories were based on published literature or modeled environmental variables.

Pipestone National Monument Climate Vulnerability Score: Extremely Vulnerable (EV). Abundance and/or range extent within geographical area assessed are extremely likely to substantially decrease or disappear by 2050. **Confidence in Species Information:** Very High. Most ranked assessment categories were based on published literature or modeled environmental variables, and were more precisely categorized at the park scale.

3.4.1 Introduction

Sioux quartzite prairie lies within the historical range of the Tallgrass Prairie in the Prairie Coteau region of the upper Midwest. Distribution is limited to a very restricted area that is tightly associated with outcrops of Sioux quartzite that occur within southwestern Minnesota, southeast South Dakota and northwest Iowa. In this region, Sioux quartzite occurs as sporadic outcrops in a narrow band trending generally east to west over a distance of about 185 miles (300 km). Mapped community occurrences occupy approximately 75 to 100 miles of the potential 185 mile range of quartzite outcrops. This prairie community is distinguished from other more northern rock outcrop communities by the presence of several Minnesota-rare plant species such as buffalo grass (*Buchloe dactyloides*), tumble grass (*Schedonnardus paniculatus*), slender plantain (*Plantago elongata*), prairie quillwort (*Isoetes melanopoda*), and hairy waterclover (*Marsilea vestita*) (MNDNR 2013). Sioux quartzite prairie communities are found on rocky, relatively level or hilly regions and are tightly associated with rock outcrops and shallow substrates composed primarily of Sioux quartzite, granite and gneiss - environments that are characterized by extreme temperature fluctuations and are generally dry, open, and somewhat sparsely vegetated with thin soils that retain little moisture for plant growth (NatureServe 2014).

Tallgrass prairie historically covered more than 220,000 square miles in central North America. Nearly the entire original tallgrass prairie has been converted to cultivated fields or other agricultural use, and only a few isolated tracts of intact native prairie remain. In Minnesota, approximately 1.3% (110,000 acres) of the original, unplowed native prairie remains (Glaser 2012). The Minnesota County Biological Survey have mapped a total of 814 acres of intact (native-dominated) rock outcrop plant communities on exposed Sioux quartzite bedrock surfaces on the Prairie Coteau west of the Bemis Moraine in Pipestone and Rock counties. Pipestone National Monument (PIPE) preserves a small remnant of the original unplowed tallgrass prairie ecosystem. Within the Monument, 240 acres of tallgrass prairie is managed to promote native species diversity, composition and prairie function. Within PIPE, three prairie community types are present: tallgrass prairie, restored tallgrass prairie, and the rare Sioux quartzite prairie.

Sioux quartzite rock outcrop communities can be characterized as mosaics of microhabitats organized along soil and moisture gradients. Exposed bedrock is typically dominated by lichens and

bryophytes; small depressions and crevices on sloping rock faces may collect shallow (<1 inch deep), dry soils which provide microhabitats for specialized vascular plants such as brittle prickly pear (*Opuntia fragilis*), small-flowered fameflower (*Talinum parviflorum*), false pennyroyal (*Isanthus brachiatus*), buffalo grass, tumble grass, and popcorn flower (*Plagiobothrys scouleri*); areas between bedrock exposures have deeper soil and greater plant biomass (MNDNR 2014), and typically support many prairie species including typical prairie grasses such as big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), blue grama (*Bouteloua gracilis*), Indian grass (*Sorghastrum nutans*), and prairie dropseed (*Sporobolus heterolepis*) (MNDNR 2014). Woody cover is generally absent or sparse with characteristic native species such as sand cherry (*Prunus pumila*) and blackberries (*Rubus* spp.) (NatureServe 2014). Animal species using these outcrops include the common nighthawk (*Chordeiles minor*), which lays and incubates its eggs directly on the rock surfaces, and the five-lined skink (*Eumeces fasciatus*) (Harris 2008).

Ephemeral rainwater pools sometimes form in the late spring in small depressions in rock outcrops. Ephemeral rock pools suitable for aquatic/semiaquatic plant life are rare, and the rare plants of ephemeral pools are among the rarest plants in the state (Harris 2010). Sioux quartzite pools do not persist nearly as long as those in the Minnesota River valley rock outcrop system (Harris 2010) and provide habitat for a group of plant species not found in other, more permanent wetlands in the region (Harris 2009). At Pipestone National Monument all of the documented state-listed plant species are associated with the Sioux quartzite prairie (NPS 2008). Aquatic pool species include disk water hyssop (*Bacopa rotundifolia*), water mudwort (*Limosella aquatic*), prairie quillwort (*Isoetes melanopoda*), hairy watercress, mud plantain (*Heteranthera limosa*) and slender plantain (Harris 2008).

The community has a NatureServe conservation status rank rounded Global Status of G3 – Vulnerable (NatureServe 2014). The Sioux quartzite prairie community has a restricted distribution, and may always have been relatively scarce. At least four A-B ranked element occurrences are known in western Minnesota and none are known from eastern South Dakota (NatureServe 2014).

Many of the Sioux quartzite prairie communities have been altered. Most of the rock outcrop sites on private land are grazed by cattle, with some sites so severely trampled that very little of the native flora survives. (Harris 2010). The Sioux quartzite prairie community at PIPE represents one of the least disturbed examples of a globally significant and endangered plant community and is one of only several examples of a regional mesic subtype recognized by the State. The landform is intact and historical disturbance is relatively low due to lack of cultivation.

3.4.2 Stressors and Management Concerns

Changes in temperature, precipitation amount, and carbon dioxide concentrations can have different effects across species and ecological communities leading to ecosystem disruption and reorganization as well as movement or loss (IPCC 2014). Primary threats to Midwest natural ecosystems ensue from the combined effects of climate change, land-use change, and increasing numbers of invasive species (Pryor et al. 2014).

Stressors such as altered fire regimes and human land uses may have reduced the natural expression of the community. Fire is an essential process in the creation and maintenance of Tallgrass prairie ecosystems. The Monument has a prescribed burn program that aims to burn most prairie areas every 3-5 years. However, for a number of reasons there have been no burns since 2010. Continued lack of fire or an increase in the fire return interval may degrade this community and the surrounding tallgrass prairie resulting in accelerated establishment or spread of invasive exotic plants. Altered fire regimes and other drivers have resulted in historic land cover and land use changes at PIPE. During the 1940s-1960s period significant areas of pasture were converted to cropland and urban areas. Additionally, analysis of aerial photography from 1938 showed no forested acreage while during the 1960s-1990s period, 60% of the open oak woodlands became mixed deciduous forest. At the same time pasture areas continued to lose ground mainly through conversion to cropland and/or degraded prairie/pasture and increases in urbanization continued (Jones et al. in review).

New and recurring threats to this community include conversion of native grassland to cropland, herbicides, rock mining, invasive exotic plants and unsustainable grazing practices. Although the prairie community is relatively well-protected within the Monument, site hydrology and seasonal flooding of ephemeral pools may be impacted by drain tiling east of the outcrop, the historic lowering of Pipestone Creek at and above Winewissa Falls, and major hydrologic alterations within the watershed. Some invasive exotic plants and other non-natives are present and may increase over time. Outside of protected areas such as PIPE, Sioux quartzite rock outcrops are relatively uncommon and vulnerable to habitat destruction (Harris 2009). Loss of these unique and rare habitats diminishes the potential for dispersal, migration and colonization. In southwestern Minnesota many pastures undergo heavy broadleaf herbicide applications for thistle control which can also destroy native wildflowers. Overgrazing by livestock degrades shallow outcrop soils and pools (Harris 2009).

3.4.3 Notes on *Evaluating a Plant Community Using the CCVI*

Community vulnerability to climate change was assessed by evaluating the vulnerability of those plant species that are diagnostic of the community. Communities are interacting associations of species and the loss of one or more species alters community characteristics. Sioux quartzite prairie communities can be characterized as a mosaic of microhabitats, each with a suite of species adapted to the environmental conditions in those microsites. Plant species that occupy ephemeral pool microhabitats in this prairie community both distinguish this community from other, more common outcrop communities and, because of their narrow environmental tolerances, are most vulnerable to a changing climate. The CCVI evaluation for the community was focused on seven plant species, many of which are listed as sensitive in Minnesota (Tables 4a-4c).

3.4.4 Sources of Information, Data and Expertise

Information to support this analysis was gleaned from published reports and peer-reviewed literature, information from the Minnesota Department of Natural Resources Natural Heritage and Nongame Research Program, and NatureServe. The *Natural Resource Condition Assessment for Pipestone National Monument* (Jones et al. in review) provided background information about condition and trend of the community at Pipestone National Monument.

Table 4a. Distinguishing, rare and common plant species specific to Sioux quartzite prairie.

Species	Status	Habitat/water regime	Pollination/seed dispersal	Conservation notes
Buffalo grass (<i>Buchloe dactyloides</i>)	State special concern MN	***Thin soils on bedrock outcrops/ **Wetland indicator= FACU	Wind/***Wind	*CC= 7; C4 pathway; ***Drought resistant
Tumble grass (<i>Schedonnardus paniculatus</i>)	State special concern MN	Thin soils on bedrock outcrops/terrestrial	Wind/***Wind-physical tumbleweed action	C4 pathway
Popcorn flower (<i>Plagiobothrys scouleri</i>)	None	Thin soils on bedrock outcrops/terrestrial	unknown	
Blackfoot quillwort (<i>Isoetes melanopoda</i>)	State endangered MN	***Pools on bedrock outcrops /*Wetland indicator = OBL	NA/Adhesion to birds, wind (Cousens 1990)	*CC=10
Hairy watercress (<i>Marsilea vestita</i>)	State endangered MN	***Pools on bedrock outcrops/*wetland indicator = OBL	NA/Sporocarps slightly nodding, 3.6--7.6 × 3--6.5 mm, 1.5--2 mm thick (Johnson 1993)	*CC=7; ***Threatened by land uses that alter or destroy ephemeral pools on bedrock outcrops
Blue mudplantain (<i>Heteranthera limosa</i>)	State threatened MN	***Pools on bedrock outcrops/*wetland indicator = OBL	unknown	*CC=7
Slender plantain (<i>Plantago elongata</i>)	State threatened MN	***Moist soil in bedrock cracks; pool margins/*Wetland indicator = FACW	unknown /Seeds 1.2 mm long, ca. 0.3 mm wide (SEINet 2014)	*CC= 8

Sources: * Milburn et al. 2014; ** USDA 2014; *** MNDNR 2013; ****R.W. Freckman Herbarium 2014

Table 4b. Distinguishing, rare and common plant species associated with but not specific to Sioux quartzite prairie.

Species	Status	Habitat/water regime	Pollination/seed dispersal	Conservation notes
Twistspine pricklypear (<i>Opuntia macrorhiza</i>)	Special concern MN	***Shallow soil over bedrock/***Upland	***insects/***Insect, animal	CAM pathway; ***CC= 10
Disk water hyssop (<i>Bacopa rotundifolia</i>)	Special concern MN	***Pools on bedrock outcrops/*Wetland indicator = OBL	unknown /***Dispersal strategy unknown	*CC=7
Water mudwort (<i>Limosella aquatica</i>)	Special concern MN	***Shallow pools on bedrock outcrops/ *Wetland indicator = OBL	unknown /***Water currents, after rain storms or spring snow melt; long-range dispersal is probably shore birds	*CC=6

Sources: * Milburn et al. 2014; ** USDA 2014; *** MNDNR 2013; ****R.W. Freckman Herbarium 2014

Table 4b (continued). Distinguishing, rare and common plant species associated with but not specific to Sioux quartzite prairie.

Species	Status	Habitat/water regime	Pollination/seed dispersal	Conservation notes
Water pygmyweed (<i>Crassula aquatic</i>)	State threatened MN	***Shallow water; muddy *pool margins; muck/ Wetland = OBL		*CC=5
Larger water-starwort (<i>Callitriche heterophylla</i>)	State concern MN	***Rock outcrop ephemeral pools, aquatic/*Wetland indicator = OBL	unknown /*** dispersal mechanism unknown; seeds are wingless; may be an animal vector involved; seed dispersal via wind is likely	*CC=8;*** Dependent on a healthy aquatic ecosystem community

Sources: * Milburn et al. 2014; ** USDA 2014; *** MNDNR 2013; ****R.W. Freckman Herbarium 2014

Table 4c. Distinguishing, rare and common prairie grasses in the Sioux quartzite outcrop community.

Species	Status	Habitat/water regime	Pollination/seed dispersal	Conservation notes
Little bluestem (<i>Schizachyrium scoparium</i>)	NONE	Full sun; dry to moderate moisture; prairies; in sandy, loamy soil (Steinburg 2002); *Wetland indicator = FACU-	Wind/Generally wind-dispersed only short distances from the parent plant; maximum dispersal of 5 to 6 feet was observed with wind speeds up to 18 miles per hour (Steinburg 2002)	C4 pathway: *CC=5; relatively drought tolerant; seed production is relatively consistent, except during drought years when inflorescences may fail to develop (Steinburg 2002)
Big blue-stem (<i>Andropogon gerardii</i>)	NONE	Moist to wet prairie soils throughout growing season; *Wetland indicator = FAC-	Wind/Near total absence of buried seeds suggests a high dependence on vegetative reproduction (Uchytel 1988)	C4 pathway:* CC = 4 drought reduces flowering ; Soil moisture likely the most important factor determining species importance in a community (Uchytel 1988).
Indian grass (<i>Sorghastrum nutans</i>)	NONE	Require soil moisture throughout growing season (Uchytel 1988); *Wetland indicator = FACU+	Wind/ Seed is light and has small awns attached (Owsley 2011)	C4 pathway; *CC = 5
Prairie dropseed (<i>Sporobolus heterolepis</i>)	NONE	Prairie; dry to moderate moisture; *Wetland indicator = FACU-	Wind/unknown	C4 pathway; *CC= 9

Sources: * Milburn et al. 2014; ** USDA 2014; *** MNDNR 2013; ****R.W. Freckman Herbarium 2014

Table 4c (continued). Distinguishing, rare and common rare and common prairie grasses in the Sioux quartzite outcrop community..

Species	Status	Habitat/water regime	Pollination/seed dispersal	Conservation notes
Junegrass (<i>Koeleria macrantha</i>)	NONE	Dry and mesic prairie	Wind/unknown	C3 pathway; ****CC=7
Blue grama (<i>Bouteloua gracilis</i>)	NONE	Dry prairie	Wind/Dispersed by wind up to a few meters, insects , ingestion by large herbivores and by adhesion to animal hides, fur, and feathers (Anderson 2003)	C4 pathway; high water use efficiency(Anderson 2003)
Sideoats grama (<i>Bouteloua curtipendula</i>)	NONE	****Prairie, dry to moderate moisture; does not grow well on wet soils, although it is moderately tolerant of spring flooding (Chadwick 2003)	Wind/Seeds are carried into burned sites by wind (Chadwick 2003)	C4 Pathway; ****CC = 6

Sources: * Milburn et al. 2014; ** USDA 2014; *** MNDNR 2013; ****R.W. Freckman Herbarium 2014

3.4.5 CCVI Factor Inputs and Rationale

Risk Factors Section A: Exposure to Local Climate Change

Temperature – Rangewide/PIPE: Ensemble average, medium emissions scenario (A1B), mid-century timeframe, average change over growing season (Jun-Aug), based on the assumption that the reproductive season was the most crucial time period for species viability. Rangewide the community is expected to be exposed to mean temperature increases of approximately 5.4 °F by mid-century. Historical trends regarding annual mean temperatures at PIPE over time illustrate significant changes in this variable during the recent past, with minimum temperatures for most years since 1920 and 2012 being 0.5-1.5 °C above the long term (1895 to 1980) average (Jones et al. in review).

Moisture Index – Rangewide/PIPE: Rangewide this community is predicted to be exposed to net drying of 5.1 to 7.4 percent (Hamon moisture metric). Given the varying phenologies of the plant species that comprise the Sioux quartzite prairie community we used annual average for the moisture index.

Historical trends indicate that annual precipitation increased during the past century (by up to 20% in some locations), with much of the increase driven by intensification of the heaviest rainfalls. This tendency towards more intense precipitation events is projected to continue in the future (Pryor et al. 2014). Modeled climate through the year 2100 also shows an increase in mean monthly precipitation under both moderate (RCP4.5) and high (RCP8.5) emission scenarios with both the medium and high emission scenarios producing increasing mean monthly precipitation, with an increase of approximately 3-5 mm per month or 35-60 mm (1.3 – 2.3 inches) per year by 2050. In spite of predicted increased precipitation, models indicate that moisture deficits will increase under both moderate and high emission scenarios at PIPE and rangewide in the spring and summer growing

seasons. Seasonal changes under both scenarios show relatively unchanged moisture deficits in the winter, but moderate deficits in spring, significant deficits in summer, and moderately moist autumn conditions are forecast (Jones et al. in review).

Risk Factors Section B: Indirect Exposure to Climate Change

B1) Exposure to sea level rise. Rangewide/PIPE: Neutral/not applicable.

B2a) Distribution relative to natural barriers. Rangewide: Somewhat Increase. Current distribution indicates that the species that comprise this community can successfully disperse throughout suitable habitat (Milburn et al. 2014). Historically, this habitat was an intricate mosaic of prairie, wet prairie, marshes and sloughs (Glaser 2012) that provided abundant dispersal opportunity and processes for both plants and animals. Populations of those species that define and distinguish Sioux quartzite prairie communities appear to occur as metapopulations, which suggests dispersal linkages (Hanski and Simberloff 1997). Documented occurrences of Sioux quartzite prairie show a patchy community distribution corresponding with quartzite outcrops over a distance of 75 to 100 miles of the 185 miles of quartzite outcrops. Mapped distribution and range of this prairie community (Harris 2010) indicates that few natural barriers are present to prevent dispersal and successful colonization of those plant species that characterize and distinguish this prairie community. Mapping does however show that the current distribution of Sioux quartzite communities is interrupted by a band of moraine that trends northwest dividing Pipestone and Rock Counties from Cottonwood County, both regions where known occurrences of this community type are present (Harris 2010). Given current habitat conditions, this moraine could now present a barrier to migration because conversion of the surrounding landscape has eliminated alternate migratory routes. **PIPE:** Neutral. No significant natural topographic or hydrological features are present that would preclude movement of the species northward within PIPE.

B2b) Distribution relative to anthropogenic barriers. Rangewide: Greatly Increase. Successful migration and colonization of distant habitat is dependent on numerous interacting factors. These factors include seed dispersal ability and sufficiently large and suitable dispersal habitat targets to enable arrival and establishment (Nathan and Muller-Landau 2000). Conversion of the prairie matrix habitat to cropland presents both a barrier to dispersal and migration and lowers establishment success by reducing the size and abundance of suitable habitat islands available for colonization. Conversion of the tallgrass prairie-wetland matrix to a cropland matrix has resulted in small islands of native habitat with large expanses of inhospitable intervening habitat (Glaser 2012). Migration to small, distant islands of suitable habitat across inhospitable habitat will only be successful for those select few Sioux quartzite plant species that have the ability to disperse through highly altered habitats and are lucky enough to hit small targets of suitable habitat (MacArthur and Wilson 1967). Table 4 lists dispersal modes and distances for some of those species. **PIPE:** Greatly Increase. Conversion of the Tallgrass prairie-wetland matrix creates a barrier to northward migration. In the immediate vicinity of PIPE (3 km buffer) over 66% of land acreage is used for agriculture, nearly 20% is developed and 11% remains as grasslands or herbaceous cover. However, these grassland areas are small and very fragmented. Within a 30 km buffer, over 82% of the acreage is agricultural, 5% is developed and approximately 10% remains as grasslands. Land cover of the contributing

upstream watershed of Pipestone Creek is over 83% agriculture, 10% developed and approximately 5% remains as grasslands/pasture (Jones et al. in review).

B3) Impact of land use changes resulting from human responses to climate change. Rangewide: Somewhat Increase. Bemis Moraine, a high ridge along the western margin of the Des Moines Lobe, divides the Prairie Coteau and trends from the northwest to southeast, dividing two regions of mapped Sioux quartzite prairie (MCBS 2014). Wind energy development potential is high along this ridge and existing wind energy facilities are densely developed (NRDC 2011). **PIPE:** Somewhat Increase. Areas to the north and west have fair to good wind energy production potential. Further, because the majority of these lands are privately owned and developed as farmland, Sioux quartzite prairie habitat located on these lands is not protected and may be at risk from wind tower development. Although most wind farm construction in this region occurs in highly altered agricultural landscapes, construction and operation of wind-energy facilities can directly influence ecosystem structure. Site preparation activities, large machinery, transportation of turbine elements, and feeder transmission lines that lead from the wind-energy facility to the electricity grid all can lead to removal of vegetation, disturbance, and compaction of soil, soil erosion, and changes in hydrologic features (Risser 2007). This is particularly problematic in areas that are difficult to reclaim (Risser 2007).

Risk Factors Section C: Sensitivity or Species Specific Factors

C1) Dispersal and movements. Rangewide/PIPE: Increase. Plant species comprising this community have variable dispersal potential and strategies (Table 4). However, the pattern of distribution is indicative of a metapopulation structure. Metapopulations can be broadly defined as a set of spatially disjunct populations linked by dispersal and periodic genetic exchange (Hanski and Simberloff 1997). Therefore, historically those species that distinguish this prairie community were linked by seed dispersal across the range of Sioux quartzite outcrops. Tolerance to climate change and ability to migrate in response to climate change varies among the species that comprise this community. For instance, many graminoid species in this community are relatively drought tolerant and have moderate dispersal ability whereas aquatic, ephemeral pool species in this community are highly vulnerable to predicted climate induced changes and have low dispersal ability. Thus while some species such as buffalo grass can likely survive in place and migrate to new sites, others such as blackfoot quillwort (*Isoetes melanopoda*) might neither survive in place nor migrate and may consequently be lost from the community. Primary migration modes include water and wind. For those species using water as their mode of dispersal their ability to migrate has been disabled by the draining of wetlands that accompanied conversion to cropland. Some plant species that occupy Sioux quartzite outcrops have high C (floristic quality index coefficient of conservatism) values while others have low values. Species assigned high C values are relatively specialized in their requirements, are more sensitive to disturbance, and will gradually decline or disappear under conditions that exceed the natural range of variation under which they evolved. Because of differential migration ability and need, entire communities of species may not shift intact. This differential response to climate change may result in the breakup of existing ecosystems and formation of new ones, with unknown consequences (USGCRP 2014). There are still significant gaps in the scientific knowledge regarding community and ecosystem response to climate change.

C2ai) Predicted sensitivity to temperature: historical thermal niche. Rangewide/PIPE:

Somewhat Decrease Vulnerability. Historical temperature variation throughout the range of the Sioux quartzite community was between 77°F and 90°F (NatureServe 2012).

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Rangewide/PIPE:

Neutral. This community is not restricted to relatively cool or cold environments.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime:

historical hydrological niche. Rangewide/PIPE: Greatly Increase. Across the range of current distribution this community has experienced very small precipitation variation (<4 in/100mm) in the past 50 years.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime:

physiological hydrological niche. Rangewide/PIPE: Greatly Increase. Sioux quartzite prairie communities are organized as mosaics of microhabitats with communities and their species organized along soil, temperature and moisture gradients. Communities include bedrock, thin soil, deep soil and ephemeral pool aquatic communities. Some of these communities are drought tolerant while others are wetland obligates. Table 4 provides a list of plant species that distinguish the Sioux quartzite prairie community and their wetland indicator status. Drought tolerant bedrock and “thin soil” communities are comprised of plant species that have historically been subjected to greater environmental extremes than species in surrounding terrestrial communities, and are exposed to fluctuations in substrate temperature and higher desiccation rates (MNDNR 2014). Four of seven plant species found only in Sioux quartzite outcrops are Minnesota Special Status wetland species. Five additional species are Minnesota Special Status wetland plant species that are not specific to Sioux quartzite prairies. These wetland species occupy pools fed by precipitation and water perched on the bedrock. These pools tend to be small and temporary and do not persist nearly as long as those in other crystalline bedrock systems (MNDNR 2014). They often support aquatic species with very narrow environmental tolerances for timing of rainfall and pool depth and duration. Depth and duration of water in pools must coincide with plant phenology and growth - deep enough to last a few weeks but not so deep that permanent wetland vegetation takes over (Harris 2008).

These environmental conditions suggest that these aquatic plants have evolved with and require a delicately timed seasonal moisture regime and minimum vegetation competition. The dynamic nature of bedrock pools (Harris 2008) renders the species that they support vulnerable to altered precipitation regimes. Drought intolerant species may be displaced by more drought tolerant species so that community composition is altered. Although precipitation is forecast to increase under climate change, these changes are anticipated to be more than offset by warmer conditions, resulting in drier environments. Modeled future changes in available moisture predict increased moisture deficits during spring and summer growing seasons. Deep-soil communities that occur in between rock outcrops may also be altered. These sites are characterized by graminoids with moisture requirements that vary from dry to moist and photosynthetic strategies that include both C3 and C4 pathways (Table 4). Competition between C3 and C4 plants is particularly sensitive to daily high temperatures and precipitation in July (von Fischer et al. 2008). In tallgrass prairie, shifts in plant species composition toward more diverse communities and towards communities more characteristic

of more xeric environments may result from changes in precipitation variability and quantity (Knapp et al. 2002).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.

Rangewide/PIPE: Neutral. Consensus view of the Intergovernmental Panel on Climate Change is that projected higher summer temperatures will likely increase the annual window of high fire risk by 10-30%, leading to a potential increase in area burned in Canada of 74-118% by the year 2100 (IPCC 2014). However, the highly agricultural and fragmented character of the landscape makes fire relatively easy to control. Within PIPE, fire is managed and only occurs as prescribed fire, thus hotter and drier conditions are not anticipated to significantly affect fire frequency.

C2d) Dependence on ice, ice-edge, or snow-cover habitats. Rangewide/PIPE: Neutral. The species is not dependent on ice-edge or snow-cover habitats.

C3) Restriction to uncommon geological features or derivatives. Rangewide/PIPE: Increase.

This community is tightly linked to areas where Sioux quartzite bedrock is exposed. The region containing these outcrops extends in a band less than 100 miles wide from north to south and less than 200 miles long from east to west, occupying portions of southeastern South Dakota, northwestern Iowa and southwestern Minnesota. This geological formation provides the template for the development of ephemeral pools occupied by several State threatened and sensitive species. Numerous rock outcrop systems occur across Minnesota, and appear to vary with geography, soil pH, and nutrient availability (MNDNR 2014). Alternatively, because of extensive habitat conversion, rare species may presently appear to be more specific to bedrock pool habitats than they once were; these bedrock pools may simply constitute the last refuge of these species in Minnesota (Harris 2010).

C4a) Dependence on other species to generate habitat. Rangewide/PIPE: Neutral. None of the species in the community are known to depend on other species to generate habitat.

C4c) Pollinator Versatility. Rangewide/PIPE: Unknown. Forb pollinators are unknown. Several species in this community are ferns or fern allies that do not require pollination. Graminoids are wind pollinated.

C4d) Dependence on other species for propagule dispersal. Rangewide/PIPE: Neutral. Community-defining species likely are not dependent on other species for propagule dispersal.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Rangewide/PIPE: Unknown.

C5) Measured genetic variation. Rangewide/PIPE: Unknown.

C5b) Occurrence of bottlenecks in recent evolutionary history. Rangewide/PIPE: Neutral. Over the last two centuries, nearly 99% of Minnesota's prairies and associated wetlands were drained and cultivated, with the result that these rare species may appear today to be more specific to bedrock pool habitats than they once were, and that these bedrock pools constitute the last refuge of these species in Minnesota (Harris 2010). Thus in Minnesota the community and its defining species may

be in the middle of a bottleneck now. However, the CCVI Guidelines state that only species that have declined and then rebounded can qualify for Somewhat Increase or Increase, therefore a Neutral rating has been applied.

C6) Phenological response to changing seasonal temperature and precipitation dynamics.

Rangewide/PIPE: Somewhat Increase. Under climate change, temperature-dependent shifts in phenology may contribute to the success of exotic species over native species. Many nonnative species are changing their flowering phenology to coincide with the longer growing season. Exotic species may succeed because they have phenologies distinct from those of native species or are able to more rapidly adjust their phenologies to a new community or climate (Wolkovich and Cleland 2014). In North American grasslands, exotic species have shifted flowering with climate change while native species, on average, have not. Exotic species appear to differ from native species primarily in responses to precipitation and soil moisture, and not temperature (Wolkovich et al. 2013).

3.4.6 CCVI Results

Each component was scored and results were compiled into an overall CCVI rating (Table 5). Sioux quartzite prairie communities were found to be extremely vulnerable to climate change throughout their current range in the United States and within Pipestone National Monument. The components of the CCVI that contributed the most to the extremely vulnerable rating included moderately high increases in modeled mean temperatures (climate change exposure); anthropogenic barriers (indirect effects); and dispersal and movements, historical hydrological niche and physiological hydrological niche, and restriction to specific geological features (species sensitivity to climate change). Some of these factors are caused by or compounded by extensive conversion of habitat from a Tallgrass prairie-wetland matrix to croplands. Impacts from habitat conversion include loss of habitat suitable for the species that characterize the community; fragmentation of native habitat into small, disconnected habitat islands where ecological functions, particularly hydrologic functions, are decoupled from environmental processes; diminished resiliency to environmental perturbations due to invasive species pressures and altered disturbance regimes; and loss of connectivity that inhibits migration enabling genetic exchange, population of new sites and migration in the face of climate change.

Table 4. Summary of CCVI factor ratings for the Sioux quartzite prairie plant community in a broad region surrounding Pipestone National Monument and for the park locality.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Exposure to local climate change	Temperature	5.1-5.5 °F – 100% of range	5.1-5.5 °F – 100% of area
	Hamon AET:PET Moisture Metric	-5.1 to -7.3% - 100% of range	-5.1 to -7.3% - 100% of area
Indirect exposure to climate change	1) Exposure to sea level rise	Neutral	Neutral
	2a) Distribution relative to barriers Natural barriers	Somewhat Increase	Neutral
	2b) Distribution relative to Anthropogenic barriers	Greatly Increase	Greatly Increase
	3) Predicted impact of land use changes resulting from human responses to climate change	Somewhat Increase	Somewhat Increase
Sensitivity to climate change	1) Dispersal and movements	Increase	Increase
	2ai) Predicted sensitivity to changes in temperature: historical thermal niche	Somewhat Decrease	Somewhat Decrease
	2aii) Predicted sensitivity to changes in temperature: physiological thermal niche	Neutral	Neutral
	2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche	Greatly Increase	Greatly Increase
	2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche	Greatly Increase	Greatly Increase
	2c) Dependence on a specific disturbance regime likely to be impacted by climate change	Neutral	Neutral
	2d) Dependence on ice, ice-edge, or snow-cover habitats	Neutral	Neutral
	3) Restriction to uncommon geological features or derivatives	Increase	Increase
	4a) Dependence on other species to generate habitat	Neutral	Neutral
	4b) Dietary versatility (animals only)	NA	NA

Table 5 (continued). Summary of CCVI factor ratings for the Sioux quartzite prairie plant community in a broad region surrounding Pipestone National Monument and for the park locality.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Sensitivity to climate change (continued)	4c) Pollinator versatility (plants only)	Unknown	Unknown
	4d) Dependence on other species for propagule dispersal	Neutral	Neutral
	4e) Forms part of an interspecific interaction not covered by 4a-d	Unknown	Unknown
	5a) Measured genetic variation	Unknown	Unknown
	5b) Occurrence of bottlenecks in recent evolutionary history	Neutral	Neutral
	6) Phenological response to changing seasonal temperature and precipitation dynamics	Somewhat Increase	Somewhat Increase
Documented or modeled response to climate change – unknown/no data for all subfactors	Overall CCVI Rating	Extremely Vulnerable	Extremely Vulnerable

Notes on Considerations Affecting Vulnerability Not Captured Here

Availability of Suitable Habitat Beyond Current Range

Conversion of the vast majority of the Tallgrass Prairie to cropland and urbanization has resulted in fragmentation and loss of ecological functions and diminished resiliency to stressors including climate change. Change in natural land cover is possibly the most basic indication of habitat condition (O'Neill et al. 1997). Landscape changes have direct impacts on ecological processes. Changes in spatial pattern in the form of fragmentation have been implicated in the decline of biological diversity and the ability of the ecosystem to recover from disturbances (O'Neill et al. 1997).

The proportion of converted acreage surrounding PIPE is high in relation to the Tallgrass Prairie ecoregion as a whole. Within the Tallgrass prairie Ecoregion approximately 33 percent of the landscape is classified as natural whereas within 30 km of the park boundary, only 12.3% of the area is classified as natural. Only 6.2% of the contributing upstream watershed is classified as natural.

In general a paucity of lands is protected in the Tallgrass Prairie ecoregion and within the area surrounding PIPE the percentage of protected lands is even less. Most protected land within the 30 km park buffer, contributing upstream watershed, and the Tallgrass Prairie ecoregion is owned by public agencies. Only 1.6% of the area within 30 km of the park is protected; of the 8.1 million acres that comprise the Tallgrass Prairie ecoregion, approximately 4.23% of the area is protected.

Potential for Continued/Accelerated Spread of Invasives

Increasing carbon dioxide concentration stimulates the growth of most plant species, and some invasive plants respond with greater growth rates than native plants. Beyond this, invasive plants appear to better tolerate a wider range of environmental conditions and, because of life history strategies, may be more successful in a warming world because they can migrate and establish themselves in new sites more rapidly than native plants.

Non-native species remain an important problem in Sioux Quartzite prairie at PIPE. Plot data for the three locations in PIPE indicates that Kentucky bluegrass (*Poa pratensis*) is the most prevalent non-native species, accounting for 17% relative cover over all plots whereas all native graminoids combined account for 23.9% of relative cover. Non-native species invasions and displacement of native species may further alter the Sioux quartzite prairie community. Because climate change may alter the timing and severity of stress and disturbance in many systems, it could provide novel opportunities for invasion (Wolkovich and Cleland 2014).

3.4.7 Notes on Applying the CCVI Framework and Tool

Published CCVI documentation provides little guidance on applying the CCVI tool to plant communities. This is understandable since the CCVI was not originally intended for examination of communities. Therefore, factor ratings and supporting rationale for evaluating communities using this tool may differ among users resulting in inconsistent vulnerability ratings. Applying the CCVI tool to evaluate impacts on a natural community as an entirety was the primary challenge. This challenge was met by first identifying those community components that distinguish the ecological system and then applying the CCVI to each of those distinguishing components to evaluate their

response to climate change. Potential changes to plant community composition and function were predicted by the response of the individual components using professional opinion. By evaluating the response of distinguishing community components to indirectly assess community response, the CCVI can be a valuable in identifying those communities that are vulnerable to climate change.

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3.5 Climate Change Vulnerability of Greater Prairie-Chicken (*Tympanuchus cupido*) at Tallgrass Prairie National Preserve

Kansas-focused Climate Vulnerability Score: Not Vulnerable/Presumed Stable by 2050.

Tallgrass Prairie National Preserve-focused Vulnerability Score: Not Vulnerable/Presumed Stable by 2050.

Confidence in Species Information: Very High. Most assessment ratings were based on published literature or modeled environmental variables.

3.5.1 Introduction

The greater prairie-chicken (*Tympanuchus cupido*), a member of Family Phasianidae (grouse and turkeys), was historically found throughout the prairielands of the central United States, with a discontinuous population along the northeastern coast (Robb and Schroeder 2005). Its population has been greatly reduced since the early 1900s, primarily due to habitat loss and conversion of prairie to agriculture.

The greater prairie-chicken (GPCH) is a medium-size, ground-dwelling bird with heavily-barred plumage of white and shades of brown. Its short tail is usually darker, rounded, and can be pitched vertically when the bird is displaying. When males are in courtship, feathers on either side of the neck are erect, unfeathered yellow/orange patches above the eyes are displayed, and unfeathered orange/red sacs along the lateral sides of the neck are inflated. The greater prairie-chicken is hunted with permits in the eastern part of the state. Although the species occurs in the western portion of the state, hunting is not permitted there due to overlap with the superficially similar lesser prairie-chicken. At Tallgrass Prairie National Preserve, Kansas (TAPR) the species is considered an iconic prairie species that is desirable from a visitation and ecological perspective.

The prairie-chicken distribution has greatly contracted since the early 1900s to remnant tallgrass and midgrass prairies of Wisconsin, Minnesota, Nebraska, Kansas, and South Dakota, with isolated populations in North Dakota, Illinois, and Iowa (Robb and Schroeder 2005). General habitat for the prairie-chicken is open, contiguous mid-to-tallgrass prairies with rolling hills and sparse or interspersed scrub or shrublands. Depending on where you are in the prairie-chicken range, the habitat can vary from tallgrass prairie to rolling sandhill prairie to grassland scrub.

As for many wildlife species, the diet for prairie-chickens is dependent on season, age, sex and availability. Common food items include grains, leaves, buds, and insects, with grains being dominant for adults and insects being dominant for juveniles (Robb and Schroeder 2005). Primary predators for adult prairie-chickens are avian raptors, including hawks and owls, and coyotes. Nest predators include skunks, badgers, raccoons, ground squirrels and opossums (Robb and Schroeder 2005).

3.5.2 CCVI Factor Inputs and Rationale

Risk Factors Section A: Exposure to Local Climate Change

Temperature – This factor was the same at the state scale and the TAPR scale. Mean ensemble temperature change from baseline for 2050s (scenario A1B) is +5.3 °F for the eastern 2/3

of Kansas and +5.2 °F for the western 1/3 of the state, so the entire state falls within the +5.1 to +5.5 °F CCVI class.

Moisture – For the mid-century period, the difference in available moisture compared to the baseline 1960-1991 period for this region of Kansas was estimated using the Hamon AET:PET metric generated by ClimateWizard web-based tools (ClimateWizard.org). Within Kansas, the percentage of the range falling within each Hamon metric category is as follows: -5.1 to -7.3% (10%), -7.4 to -9.7% (55%), and -9.7 to -11.9% (35%). **TAPR**. TAPR proper falls within the -7.4 to -9.7% CCVI class.

Risk Factors Section B: Indirect Exposure to Climate Change

B1) Exposure to sea level rise. Neutral. Not applicable to this species/location.

B2a) Distribution relative to natural barriers. Statewide range/TAPR: Neutral. There are no significant natural topographic or hydrological features that would preclude rangewide movement of the species northward. This factor was identical at the State scale and the TAPR scale.

B2b) Distribution relative to anthropogenic barriers. Statewide range: Somewhat Increase. This subspecies is limited to grassland systems that have not undergone anthropogenic habitat conversion to various high-intensity agricultural uses, which is widespread and prevalent in Kansas (Robb and Schroeder 2005). Agricultural development can be a barrier to northward movement of the subspecies. Populations separated by 10-20 km of unsuitable habitat can show limited gene flow that may limit genetic heterogeneity (Bellinger et al. 2003; Johnson et al. 2003, 2004). **TAPR:** Somewhat Increase-Neutral. At the TAPR scale, this factor is less limiting for prairie-chickens because of the shallow, rocky soils favoring grazing as the predominant land use. Such use can be more compatible for prairie-chickens than extensive converted pasture and row crops in the surrounding areas. There is some concern that areas to the north have been or can be converted to row crops and pasture.

B3) Impact of land use changes resulting from human responses to climate change. Statewide range: Somewhat increase vulnerability-Neutral. Several wind energy developments exist within the subspecies range (NRDC 2014). The area in and near TAPR has poor wind power suitability; however, portions of the species' range in central Kansas have higher wind power development potential. **TAPR:** Neutral. At and near TAPR there are fewer opportunities for large-scale wind power development.

Risk Factors Section C. Sensitivity, or Species-Specific Factors

C1) Dispersal and movements. Statewide range/TAPR: Somewhat Decrease. Juvenile GPCH are known to disperse greater than 1km (Bowman and Robel 1977). A similar subspecies (lesser prairie-chicken) is known to have juvenile males dispersing greater than 1 km and juvenile females dispersing greater than 2 km (Pitman et al. 2006).

C2ai) Predicted sensitivity to temperature: historical thermal niche. Statewide range/TAPR: Neutral. The temperature variability in this region is 55-77° over the past 50 years in Kansas.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Statewide range/TAPR: Neutral. Winter can be a time of stress for prairie-chickens (Pitman et al. 2006, Hagen et al. 2007) and prairie-chickens are not specifically adapted to cold temperatures.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Statewide range/TAPR: Somewhat Increase-Neutral. The species has experienced low to low-moderate precipitation variation in the past 50 years.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Statewide range/TAPR: Neutral. This subspecies has no dependence on hydrologic regimes.

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Statewide range/TAPR: Neutral. A mosaic of grassland and shrubland habitat types and stages are advantageous for various life stages of GPCH while expanses of stable, consistent cover are advantageous for other life stages (Horak 1985, Robb and Schroeder 2005). Various disturbance regimes such as grazing and fire can create and sustain these mosaics.

C2d) Dependence on ice, ice-edge, or snow-cover habitats. Statewide range/TAPR: Neutral. GPCH burrow into snow banks for insulation as protection from winter conditions. Snowfall and accumulation can alter habitat use and food acquisition (Robb and Schroeder 2005).

C3) Restriction to uncommon geological features or derivatives. Statewide range/TAPR: Somewhat Decrease. The GPCH is not dependent upon a particular geologic feature but tends to be tied to those soil types that allow for a variety of intermixed prairie grasslands and shrublands.

C4a) Dependence on other species to generate habitat. Statewide range/TAPR: Neutral. GPCH does not rely on other species to maintain or create suitable habitat.

C4b) Dietary Versatility. Statewide range/TAPR: Neutral-Somewhat Decrease. Young GPCH and female GPCH consume more invertebrate matter during particular seasons and age classes, but are not true omnivores.

C4d) Dependence on other species for propagule dispersal. Statewide range/TAPR: Neutral. The GPCH self-disperses.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Statewide range/TAPR: Neutral. GPCH does not require a specific interspecific interaction.

C5a) Measured genetic variation. Statewide range/TAPR: Somewhat Increase. Regional studies of GPCH have documented lower levels of genetic diversity and historic bottlenecks (Bouzat et al. 1998, Bellinger et al. 2003).

C5b) Occurrence of bottlenecks in recent evolutionary history. Statewide range/TAPR: Neutral. Not applicable because data for C5a was available.

C6) Phenological response to changing seasonal temperature and precipitation dynamics.

Statewide range/TAPR: Unknown. No data available.

Risk Factors Section D. Documented or Modeled Response to Climate Change

D1) Documented response to recent climate change. Statewide range/TAPR: Unknown. No data available.

D2) Modeled future change in population or range size. Statewide range/TAPR: Unknown. No data available.

D3) Overlap of modeled future range with current range. Statewide range/TAPR: Unknown. No data available.

D4) Occurrence of protected areas in modeled future distribution. Statewide range/TAPR: Unknown. No data available.

3.5.3 CCVI Results

Each component was scored and results were compiled into an overall CCVI rating (Table 6). By 2050, within its current range in Kansas the species was considered Not Vulnerable/Presumed Stable. Within TAPR, the species was also considered Not Vulnerable/Presumed Stable. Confidence in the species information used in the assessment was very high. Several factors relating to indirect exposure to climate change were ranked as slightly less vulnerable at the TAPR scale compared to the state-level scale. These results are similar to those published by Zack et al. (2010), whose CCVI assessment for the greater prairie-chicken in Bird Conservation Region 19 within the Great Plains determined that the species would be Presumed Stable under climate change.

Although the GPCH was not deemed especially vulnerable to climate change throughout its Kansas range, there are factors of its biology that can make it susceptible to climate alterations. In particular, GPCH's range is limited by human-based habitat modifications and does not allow the flexibility to expand northward if habitat in the south becomes less suitable. Additionally, as habitat becomes more constricted and reduces gene flow among populations GPCH loses capacity to adapt to rapidly-altered landscapes. Because GPCH has no specific thermal or physiological affinities to cold environs, has the capacity to disperse when habitat is available, is not linked to any particular geological features or other species for vital life history components, and has a relatively general diet it is not considered to be vulnerable to climate changes forecast for 2050.

Notes on Considerations Affecting Vulnerability Not Captured Here

Although the CCVI ranking can be helpful in predicting conservation priority in the face of changing climate, it could be improved by allowing incorporation of current known threats to persistence. For example, being able to focus ranking on the resources or threats of greatest concern to persistence may highlight the need for immediate conservation action. For the GPCH in TAPR, being able to weight the need for compatible habitat outside the boundary of the preserve may draw attention to the need for additional suitable habitat for population persistence.

Table 5. Summary of CCVI factor ratings for the greater prairie-chicken at Tallgrass Prairie National Preserve.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Exposure to local climate change	Temperature	5.1-5.5 °F – 100% of range	5.1-5.5 °F – 100% of area
	Hamon AET:PET Moisture Metric	-5.1 to -7.3% (10%), -7.4 to -9.7% (55%), and -9.7 to -11.9% (35%)	-7.4 to -9.7% of area
Indirect exposure to climate change	1) Exposure to sea level rise	Neutral	Neutral
	2a) Distribution relative to barriers Natural barriers	Neutral	Neutral
	2b) Distribution relative to Anthropogenic barriers	Somewhat Increase	Somewhat Increase-Neutral
	3) Predicted impact of land use changes resulting from human responses to climate change	Somewhat Increase-Neutral	Neutral
Sensitivity to climate change	1) Dispersal and movements	Somewhat Decrease	Somewhat Decrease
	2ai) Predicted sensitivity to changes in temperature: historical thermal niche	Neutral	Neutral
	2aii) Predicted sensitivity to changes in temperature: physiological thermal niche	Neutral	Neutral
	2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche	Somewhat Increase-Neutral	Somewhat Increase-Neutral
	2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche	Neutral	Neutral
	2c) Dependence on a specific disturbance regime likely to be impacted by climate change	Neutral	Neutral
	2d) Dependence on ice, ice-edge, or snow-cover habitats	Neutral	Neutral
	3) Restriction to uncommon geological features or derivatives	Somewhat Decrease	Somewhat Decrease
	4a) Dependence on other species to generate habitat	Neutral	Neutral

Table 6 (continued). Summary of CCVI factor ratings for the greater prairie-chicken at Tallgrass Prairie National Preserve.

Type of risk	Factor influencing vulnerability	Degree to which factor influences vulnerability	
		Rangewide/state	Pipestone National Monument
Sensitivity to climate change (continued)	4b) Dietary versatility (animals only)	Neutral-Somewhat Decrease	Neutral-Somewhat Decrease
	4c) Pollinator versatility (plants only)	Not applicable	Not applicable
	4d) Dependence on other species for propagule dispersal	Neutral	Neutral
	4e) Forms part of an interspecific interaction not covered by 4a-d	Neutral	Neutral
	5a) Measured genetic variation	Somewhat Increase	Somewhat Increase
	5b) Occurrence of bottlenecks in recent evolutionary history	Unknown	Unknown
	6) Phenological response to changing seasonal temperature and precipitation dynamics	Unknown	Unknown
Documented or modeled response to climate change – unknown/no data for all subfactors	Overall CCVI Rating	Not vulnerable/ presumed stable	Not vulnerable/ presumed stable

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4 Discussion and Recommendations

4.1 CCVI Approach Lessons Learned

We applied the CCVI tool to a cross section of resources including one rare plant, one rare fish at two locations, one game bird of management concern, and one rare plant community. The scale of the analysis focused on the park environs and a larger range roughly up to the state scale. The information supporting the CCVIs consisted of NRCA resource chapters describing resource condition and trend, climate change and land cover/land use chapters, supplemental climate change information to support specific tool requirements, and additional information needed to evaluate or determine CCVI factors, primarily from peer-reviewed literature or agency reports. The information available varied across the resources, as did the number of CCVI evaluation factors supported by existing information. For some species, reviewers identified factors that were not captured in the model or were not well-defined.

A critical caveat to using the NatureServe Climate Change Vulnerability Index is that the results only consider the specific threat of climate change to a particular species in a geographic area, and are not a complete assessment of all the threats affecting that species in that area or in a larger region (Walk et al. 2011).

Published CCVI documentation provides little guidance on applying the CCVI tool to plant communities. This is understandable since the CCVI was not originally intended for examination of communities. Therefore, we feel that factor ratings and supporting rationale for evaluating communities using this tool may differ among users resulting in inconsistent vulnerability ratings.

Four biologists were involved with the CCVI evaluations presented here. Previous experience of the biologists with the CCVI tool and framework varied from considerable to none. Initial results for the vulnerability evaluations showed some differences in how CCVI factors were considered and rated or in the spatial scale being applied. For example, factor B2b “Distribution relative to anthropogenic barriers” was initially rated by most evaluators as being the same for the statewide range vs. the park scale. This factor addresses the potential for dispersal to be hindered by intervening anthropogenically altered landscapes such as urban or agricultural areas for terrestrial species or dams and culverts for aquatic species (Young et al. 2011). Upon further discussion of the ratings for this factor, it was determined that for the parks-scale assessments, species were generally less vulnerable than for the rangewide/state assessments, reflecting the positive influence of management and protection status within park boundaries. Therefore, it is important that CCVI team members establish a common understanding and interpretation of CCVI factors and ratings through examination of published CCVI guidance (Young et al. 2001), group training activities involving individual and collective evaluations and discussion of results and rationale, examination of published CCVI results for similar or the same species in other locations, and discussions with subject matter experts with experience applying the CCVI. Proper training and review of results by experts can help calibrate ratings among team members and provide more comparable results for a species with other geographic regions and over time.

4.2 Interpretation of CCVI Results

CCVI developers emphasize the need to consider other factors and information when interpreting results and examining the vulnerability of a species. This is partly because the factors contributing to the CCVI rating were intended to complement and not overlap with other information affecting vulnerability (Young et al. 2011). The CCVI is a place-based tool that may have different implications for broadly-distributed and narrowly-distributed species. The vulnerability rank for a particular species applies only within the assessment area and may not be applicable within other portions of the species range, where factors such as climate exposure, ecological dynamics, and connectivity may differ (Dubois et al. 2011). Additional vulnerability factors, many of which are interrelated, should be considered in concert with the CCVI results, e.g., population status and NatureServe Conservation rank.

Population and Demographic Information. Population size and distribution metrics are not included in the CCVI risk factors, so areas having numerous and robust populations receive the same rating as areas having few individuals or populations. Local conditions may or may not represent state or global conservation rank status.

NatureServe Conservation Ranks. CCVI ratings are intended to be used with NatureServe's conservation ranks (such as G-ranks and S-ranks) based on factors related to rarity, threats and trends (Faber-Langendoen et al. 2012). The ranking process helps determine which species and ecosystems are thriving and which are rare or declining. These ranking often form the basis for targeting conservation efforts and species prioritization. Species with NatureServe conservation ranks of concern are more likely to be evaluated for climate change vulnerability. However, rare or declining species are not necessarily vulnerable to climate change effects.

Availability of Suitable Habitat Beyond Current Range. The suitability of habitat beyond the current range or area of analysis and whether or not that habitat will remain suitable in the future as conditions change are key components of a comprehensive vulnerability analysis (Furedi et al. 2011).

Species Range Considerations. The CCVI score is based on a defined area of interest and may not represent impacts outside of that defined area of interest (Furedi et al. 2011). For most species adversely affected by the warming and drying anticipated for this region, being near the leading edge (i.e., northern part) of the species range is more advantageous compared to being near the trailing edge (i.e., southern edge) of the species range. This pattern seemed to hold true for Topeka shiner vulnerability in the TAPR region near the southern edge of its range vs. in the PIPE region near the northern edge of the range. Because of the relatively flat terrain in this region, there is little opportunity for species to occupy more moderate or cooler/wetter niches (i.e., refugia) in the landscape such as north facing slopes, sheltered ravines or higher elevations. Therefore, for the species and regions we examined, relatively large shifts in geographic range might result from relatively small changes in climate.

The CCVI tool prompts for the location of the area of interest relative to the range of the species (i.e., entire range, near northern edge of range, center of range, near southern edge of range, or near east/west edge of range) but this information does not influence the factor ratings or overall CCVI

vulnerability rating. However, in the Calculator Tab a “notes” field below the CCVI rating does change with different entries in the location of the area of interest relative to the range of the species. If the assessment area is near the southern edge of the range or encompasses the entire range and other specific vulnerability thresholds are met, the note generated states: “species range may shift and perhaps leave the assessment area”. If the area is near the northern edge of the range, the note generated states: “species may expand range in assessment area”.

Additional Threats Outside of Climate Change. Threats and stressors other than climate change affecting species include known and unforeseen threats. Habitat loss, disease, alteration of natural processes and disturbance regimes, competition from native and nonnative species, and other stressors can compound the effects of climate change and vice versa. Many of these factors are largely unaccounted for in the CCVI framework, but may be integrated to some degree into the NatureServe Conservation Rank.

Restoration and Recovery Efforts. Proactive conservation efforts such as protection from predation, nursery and translocation programs may significantly boost viable populations of species. Especially for rare species, these beneficial increases can outweigh threats associated with climate change, at least in the short term. Anticipated or real benefits associated with current or planned conservation measures are not considered in the rating.

Seasonal or Spatial Variability in Exposure. A species-level assessment may not capture differences in exposure and/or sensitivity among subspecies or populations, or where there are differences in exposure and/or sensitivity during different parts of the year or life cycle (Dubois et al. 2011).

Climate Forecast Emission Scenarios and Timeframe Used by the CCVI. The index uses climate change predictions for temperature and moisture indices representing a moderate emission scenario for the year 2050. Given the lower likelihood of moderate emissions and the temporal proximity of mid-century estimates to the present, projections extending farther out in time and using a high emission scenario may be more realistic (Furedi et al. 2011).

4.3 CCVI Features and Use

The worksheet structure is relatively easy to use and navigation is straightforward. The following specific areas for improvement were identified by the authors:

1. The Hamon AET:PET moisture index is no longer calculated using the online ClimateWizard web tools. However, NatureServe has posted the national-level map (<http://www.natureserve.org/climatechange>), which is also contained in the CCVI software V2.1. The CCVI tool specifically requires Hamon aridity index values, which are scaled to weighted values for sensitivity factors. The older published maps can be used, but ideally results for other moisture indices could be adapted to be used with CCVI. Using other indices within the CCVI would require some new guidance by CCVI authors for interpretation and categorization of results.

2. There are no fields/cells within the tool to document the rationale for decisions/selections for each CCVI factor contributing to the score. There is one location where the user can write comments for a species, but it is cumbersome and inefficient to enter text describing information sources, references, and rationale for all factors into a single spreadsheet cell. It would be easier to capture notes, sources of information, and rationale for factor decisions if there were cells allotted to each factor on a separate worksheet.

4.4 Addressing Information Gaps and Uncertainty

The CCVI tool is designed to accommodate missing data and uncertainty. The index will calculate a score with as few as 13 responses, although CCVI developers recommend estimating as many factors as possible, even if more than one category is selected for factors associated with sparse data or high uncertainty (Young et al. 2011). The emphasis seems to be on being able to generate a score despite data gaps. When running results, a confidence level associated with the species information is generated based on the number of responses/factors provided. Checking a range of values for one or more factors (e.g., Neutral and Somewhat Increase) tends to decrease the confidence level assigned to species information (Young et al. 2011).

For the species and community analyses we completed, a summary of the number of factors supported within each section for statewide/regional range results (combined) is shown in Table 7. For the resources we evaluated, the confidence level assigned to the species information ranged from moderate to very high, and was influenced by the number of factors rated, internal weights assigned to the factors that were rated and/or their ratings, and the use of multiple ratings for a single factor. In our analyses, assigning more than one value for a factor was the only apparent influence on the confidence level for species information.

Data supporting the four rating factors related to modeled responses to climate change were not available for the three species and one community we examined. Within the U.S. some comprehensive modeling of species range changes has been done. For example, the U.S. Forest Service has compiled climate change atlases for over 130 trees species and associated forest types (eastern U.S.) and for over 140 bird species (eastern U.S. and Canada) (USFS 2014). Unfortunately, anticipated changes to the ranges of many species of management concern have not been modeled. The other primary data gaps encountered in this evaluation were related to species-specific sensitivity – dietary versatility, pollinator versatility, interspecific interactions, and measured genetic variation.

Uncertainty in climate change vulnerability assessments can be linked to limited/unreliable data; unidentified or unknown interactions with non-climate stressors; unidentified or unknown interactions among different elements of climate change; unidentified or unknown interspecific interactions; unidentified or unknown thresholds; ambiguously defined concepts or terminology; scientific disagreements about what is known; or uncertain projections of human behavior (Glick et al. 2011). The CCVI generates a confidence level associated with the certainty in species information only. The tool output does not estimate or quantify uncertainties associated with climate projection data and other species information entered into the CCVI factors (Zack et al. 2010). Therefore, the results should be applied with care.

Table 6. Summary of factors supported by available information and relationship to CCVI confidence using statewide/regional range results.

Factor Group (total # of factors)	# of factors supported / # group factors				
	PIPE Western Prairie Fringed Orchid	PIPE Topeka shiner	PIPE Sioux quartzite community	TAPR Topeka shiner	TAPR Greater Prairie Chicken
A. exposure to local climate change	2/2	2/2	2/2	2/2	2/2
B. Indirect exposure to climate change	4/4	4/4	4/4	4/4	4/4
C. Sensitivity ¹	14/16	13/15	13/16	13/15	13/15
D. Documented or modeled response to climate change	0/4	0/4	0/4	0/4	0/4
# of factors supported	20	19	19	19	19
# of factors “unknown”	6	6	7	6	6
Range of values checked for some factors?	yes	yes	no	yes	yes
CCVI confidence in species information assigned	moderate	moderate	very high	moderate	very high

¹16 species sensitivity factors for plants and 15 for animals.

The application of three approaches that have been used to address uncertainty in climate change vulnerability assessments are discussed by Glick et al. (2011). The primary approaches are Monte Carlo simulations to convert uncertainties into probability distributions over output variables (this is actually incorporated to some degree into the CCVI tool where multiple vulnerabilities are selected for a factor); expert elicitation using a formal, systematic process to derive subjective judgments about uncertainties from experts; and scenario analysis, whereby uncertainties are addressed by basing vulnerability on the results of multiple scenarios. Expert elicitation using highly structured workshop settings and less formal consultation with experts are both often used, with the rigor of the approach often determined by available resources.

4.5 Level of Effort for CCVI Evaluations

Using the CCVI tool requires understanding of the guidance and intention of its developers with regard to the evaluation factors, an understanding of direct and indirect climate change stressors for the area of interest, understanding of the natural history of the species including different life stage requirements, and understanding of natural processes and disturbances. On the surface, applying the CCVI would appear to be a relatively quick and efficient means to assess vulnerabilities and priorities for a variety of species (or communities) at varying spatial scales. This is largely true, but the level of effort required to perform the evaluations accurately and consistently exceeded our initial estimations. Admittedly, the requirements of this project included a more elaborate documentation of rationale for each CCVI factor due to the reporting format used here. We initially had planned to examine the statewide range of each species/community, but ultimately decided to also include CCVI ratings for the park scale as well. We also had limited first-hand knowledge of the species of interest,

but this was partly offset by the information that had already been assembled for the NRCA chapters. More experience with the tool would help us better understand the sensitivities and robustness of the different factors.

From a planning and cost perspective, the cost per species assessment is difficult to calculate because we examined only several resources at different scales in two different regions. The Sioux quartzite prairie community CCVI process involved more effort because multiple diagnostic species were evaluated. It is most cost-effective and efficient for summaries supporting climate change, land use and conservation status to be prepared and distributed to users at the beginning of the project. Each species-level CCVI required approximately 20-30 hours for a professional biologist, including a write-up and some reviews by outside experts. Due to overlaps among some factors and among species within a smaller region, to some extent per species costs would diminish as the number of species examined in a single region of interest increased.

4.6 Integration of CC Vulnerability Assessment with NRCAs

The CCVI results are informative and complement other indicators used in the NRCAs. Overall, we found that information already assembled for focal resources, stressors and land cover and land use in the NRCA is very useful in supporting CCVI climate change vulnerability ratings. Sections that directly support CCVI data requirements and decisions include species-specific and community information related to species conservation status, threats, distribution and status/trend (monitoring data); land cover, land use and housing density data; historical climate range of variability and climate change projections; fire regime or other disturbance regimes; stream hydrology; air and water quality; and invasive exotic plants.

The NRCA land cover and land use section, consisting of Anderson land cover class data, natural vs. converted land cover, biodiversity protection status, and population and housing metrics was especially helpful. Most of the land cover summaries were derived from National Land Cover Data (NLCD) provided by the NPS NPScape Program (NPS NPScape 2014). The spatial data specifically support examination of anthropogenic barriers to migration/movement and land-use changes resulting from human responses to climate change. We feel the NRCA-assembled data was superior to the GAP/Landfire data recommended by CCVI guidance, at least for the area of analysis 30 km out from the park boundary. Conservation status derived from ownership and protected lands data provided another metric related to anthropogenic barriers to movement.

We recommend examining vulnerability at both regional and local scales, as vulnerability may differ between the two. The CCVI tool seems to be designed for scales larger than small parks such as Pipestone National Monument but appears adaptable to the park scale.

We recommend integrating climate change vulnerability into several specific areas of each NRCA document. The first area is comprehensive summary of historical and projected climate metrics that would directly support vulnerability assessment. The *Climate Change* section details climate characteristics during the past century or so, with an emphasis on range of variability, climate change trends that may already be apparent - for example starting around 1980, and projected changes in climate variables for mid and late century dates for both moderate and high emissions scenarios. An

example of said climate change section to be included in the Pipestone National Monument NRCA (Jones et al. in review) is attached in Appendix A. This summary can be tailored to support the climate change factors used by the CCVI tool. It also provides good regional context for understanding the effects of climate change on species ranges.

The second area where climate change vulnerability needs to be specifically addressed is in sections describing stressors or natural processes such as fire, hydrologic response and stream flows, and invasive exotic species. For example, we know that climate change can potentially influence some of the components driving fire regimes. Increasing temperatures and aridity generally may contribute to more frequent, larger, and/or severe fires. Our NRCA examination of the current fire regimes at PIPE and TAPR revealed that anticipated changes to climate would ordinarily alter the current regime. However, because of the highly managed nature of the burning at these parks the ability of managers to control grassland fires, it was concluded that significant changes to the fire regime are not anticipated. There may be some increases in fire severity but this would be influenced by numerous factors. An example is provided below from the *Fire Regime* section of the draft NRCA for Pipestone National Monument (Jones et al. in review.) – see box.

The third area of the document where vulnerability can be addressed is in the focal resource sections. The foundational information in the *Climate Change* section and in other sections relating to stressors and processes described above supports the evaluation of vulnerability and climate change impacts on species included in the NRCA. For example, the evaluation of condition and trends in the Topeka shiner at TAPR included Topeka shiner abundance, the relative abundance of predators, and climate change vulnerability (trend only). The evaluation of condition and trends in the western prairie fringed orchid at PIPE included population size, plant vigor (mean height and number of flowers per plant), fire regime management, and vulnerability to climate change (trend only). The CCVI-based climate change vulnerability assessments presented in section 3 of this report are examples of how vulnerability could be addressed as an indicator of condition for a focal resource. We included climate change vulnerability only as an indicator of trend for focal species and communities of interest. Climate change exposure information is crucial contextual information, but is not included in the condition rating for each resource. Including climate change vulnerability in the trend rating raises a flag where vulnerability may be high and leading to deteriorating conditions for the resource.

Pipestone National Monument: Implications of Climate Change on Park Fire Regime

The effects of changing climate on the fire regime and fire-related ecological effects at the park have not been modeled or examined in detail. A comprehensive summary of historical climate variation and climate change projections for the park and surrounding area is presented in the *Climate Change* section. Results for precipitation, temperature, aridity, and growing season vary by emissions scenario, future time period and sometimes by season. In general, the climate at PIPE is forecast to become hotter and wetter compared to the current climate, but increased temperatures are anticipated to more than offset the increase in precipitation. Both minimum and maximum temperatures are expected to increase by approximately 2.0-3.0 ° C by 2050 and by approximately 3.0-6.5 ° C by 2100, depending on the emissions scenario. Precipitation is projected to increase by approximately 3-5 mm per month or 35-60 mm per year by 2050. Very heavy rainfall events are projected to become more frequent. As an index of drought, annual summer season moisture deficits ranging from 80-90 mm compared to historical baseline conditions are forecast for medium and high-emission scenarios by 2095. It is getting significantly warmer earlier in the spring and the growing season is projected to lengthen by 10-40 days per year depending on the emissions scenario.

Specific implications of climate change on the park's fire regime and fire management cannot be predicted with a high level of confidence, but some generalizations and likely scenarios merit discussion. Wildland fire in the region surrounding the park is virtually non-existent. Small-scale prescribed burning outside the park occurs occasionally on private and public lands. The fire regime at the park is highly managed and driven by prescribed fire events planned for specific dates within burn units of defined size and location. Therefore, it seems unlikely that the fire return interval would be affected by climate change. Prescribed burns in the park are currently conducted only during fuels and weather conditions meeting a burn prescription window (i.e., acceptable range of temperature, humidity, wind and fuel conditions) to minimize the chance of fires getting out of control or producing unwanted smoke. Similar prescription windows would be applied in the future. Therefore, future fire intensity and severity would likely be similar to current fire intensity and severity. Severity of later summer burns may increase since severity is affected by soil moisture. The most significant management implication of climate change may be that prescribed burning prescription windows may become smaller and/or fewer in number as minimum and maximum temperatures rise and relative humidity declines. These changing factors would make it more difficult for the park to reach prescribed burn acreage/frequency objectives, especially when the park is scheduling burns supported by non-resident crews well ahead of the scheduled burn. Summer and late summer/fall burns may also be more difficult to schedule with smaller prescription windows, or periods meeting prescription may occur earlier or later in the year.

4.7 Conclusions

The primary purpose of the Index is to provide valuable input for key planning documents such as state wildlife action plans, and to guide management priorities so that climate change impacts can be addressed and integrated with other stressors. One strength of the CCVI is that it supports comparisons among species and factors within species. The tool is intended to “help land managers develop and prioritize strategies for climate change adaptation that lead to actions that increase the resilience of species to climate change” (Young et al. 2011). As Glick et al. (2011) emphasize, vulnerability assessment is not an end point, but a source of information to incorporate into planning

and decision making. Examining and understanding the different components of vulnerability will help optimize efforts to reduce existing stressors, manage for ecosystem function, protect refugia and improve habitat connectivity, and implement proactive management and restoration (Glick et al. 2011).

Our examples and CCVI evaluation applying the tool to just a few species of interest is informative, and highlights the components of vulnerability that are most influential for those species or communities. However, it does not speak comprehensively to park management needs from a programmatic or planning perspective. To help drive adaptation at the park level, a suite of species and community vulnerability assessments would be needed for flora and fauna. Each suite could include high priority species such as threatened and endangered species or species at risk, as well as a number of dominant species or species that are cornerstone species. Each suite could be structured for terrestrial and aquatic species. Most published vulnerability reports have addressed between a few dozen and a few hundred species, typically at the state level, and this general level of effort appears necessary for examining patterns in vulnerability related to various species assemblages.

Regional initiatives, research, workshops and recommendations supporting CCVI-type analyses are being developed by myriad groups and individuals across the globe. Results of CCVI efforts within this dynamic area of expertise trickling into the scientific and grey literature will facilitate further vulnerability assessment work at different scales. Although the CCVI by itself does not provide a comprehensive vulnerability assessment for species, in conjunction with other sources of information is a relatively straightforward and useful step towards understanding the relative vulnerabilities of different species with respect to direct and indirect exposure to climate change, sensitivity and documented or modeled response to climate change.

Integration of climate change vulnerability into NPS natural resource condition assessments does require additional effort and expertise that may not already be present on a given NRCA development team. However, by using the approach described above, vulnerability can be both incorporated and well integrated.

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Appendix A. Chapter for Climate Change, Natural Resource Condition Assessment for Pipestone National Monument (excerpted from Jones et al. in review)

Background and Importance

Climate change is increasingly recognized as a major stressor of biological taxa, communities and ecological systems. Understanding the magnitude and effects of changing climate is essential within the NPS to “manage for change while confronting uncertainty” while developing new management and adaptation strategies (National Park System Advisory Board Science Committee 2012) and a significant scientific component of the NPS *Climate Change Response Strategy* (NPS 2010).

Resources vulnerable to climate change at PIPE may include the federally endangered Topeka shiner (*Notropis Topeka*), the Western prairie fringed orchid (*Platanthera praeclara*), and the Sioux quartzite prairie community, a rare feature that includes ephemeral pools supporting many wetland species.

The climate suitable for Great Plains grasslands is expected to remain relatively stable with some expansion to the north in Canada, but the range of tallgrass prairie along the eastern boundary is expected to contract (Rehfeldt et al. 2012). This contraction would potentially affect tallgrass prairie primarily in Illinois, southwestern Minnesota, Iowa, northern Missouri, and the eastern portions of South Dakota, Nebraska, Kansas, Oklahoma and Texas. Increasing CO₂ tends to increase plant growth and water use efficiency, but may be limited by water and nutrient availability. Transpiration rates usually decline as CO₂ increases, while, in many plants, photosynthesis and growth increase. Growth response to CO₂ is usually highest in rapidly-growing plants and in plants with the C3 photosynthetic pathway (most woody plants and 'cool-season' grasses) versus the C4 pathway (most 'warm-season' grasses) (Polley 1997).

Changes in grassland composition due to the interaction of temperature, moisture, nutrient availability and CO₂ are very difficult to predict (Polley 1997, Morgan et al. 2008), but evidence increasingly suggests that rising CO₂ and temperature plus increased winter precipitation can favor herbaceous forbs, legumes, and woody plants in many Great Plains rangelands, with uncertain changes in the balance between cool-season and warm-season perennial grasses (Morgan et al. 2008). Changes in species composition will likely vary by region and by year and will depend on depth and timing of available soil water as well as disturbance factors such as grazing, fire, and disease, which can have strong influence on plant communities (Bagne et al. 2013). Long-term research at the Konza Prairie found that primary productivity NPP in tallgrass prairie is a product of spatial and temporal variability in light, water, and nutrients, driven by a combination of topography, fire history, and climate, and is not driven strongly by precipitation alone (Briggs and Knapp 1995). Dynamics shaping plant community composition will also be influenced by increasingly severe and frequent droughts, floods and fires (Bagne et al. 2013).

The synopsis of potential changes to the park climate presented here characterizes the “exposure” component of resource vulnerability, the other components being resource sensitivity and adaptive capacity. Overall climate change vulnerability for a particular resource is estimated using a

combination of exposure, sensitivity and adaptive capacity (Glick et al. 2011). Climate change is examined here using modeled future climate scenarios, but potential resource vulnerability and management implications are based on the relative amounts and directions of changes rather than specific magnitudes or thresholds of change. Although the Park can do its part to mitigate greenhouse gas emissions and optimize the efficiency of park operations vis a vis greenhouse gases, climate change and its associated effects on park resources are largely out of the control of park managers. It is happening and will require an evaluation of the vulnerability of park resources. Moreover, specific and diverse adaptation measures for some park resources may be necessary to mitigate effects of climate change and transition to future climatic conditions.

Threats and Stressors

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

Indicators and Measures

- Temperature changes from baseline – minimum, mean, and maximum temperatures (monthly)
- Precipitation changes from baseline – annual and seasonal; very heavy events
- Indices of aridity/drought – historic period of record and future vs. baseline period
- Plant phenology (baseline only) and growing season – enhanced vegetation index values for onset of spring greenup, maximum greenness (peak vegetation) and onset of minimum greenness; projected changes in frost-free period.

Data and Methods

A variety of data and analysis approaches are used to characterize the climate during the historic period of record and examine possible changes in climate for the park. A combination of site-specific and regional results is presented. Historic climate and modeled future climate change were examined for the area extending approximately 30km from the park boundary. Because the park is relatively small, geographic variation within the park is minimal and monthly values were averaged across the area of interest.

Two families of scenarios are generally used for future climate projections: the 2000 Special Report on Emission Scenarios (SRES) and the 2010 Representative Concentration Pathways (RCP). Results for both of these families are presented here. The SRES scenarios are named by family (A1, A2, B1, and B2) and the RCP scenarios are numbered according to the change in radiative forcing (from +2.6 to +8.5 watts per square meter) anticipated by 2100. Comparing carbon dioxide concentrations and global temperature change between the SRES and RCP scenarios, SRES A1FI is similar to RCP 8.5, SRES A1B is similar to RCP 6.0 and SRES B1 is similar to RCP 4.5 (Walsh et al. 2014b).

Consolidation of future modeled climates and comparisons with historic baseline and graphic representation of results was supported by the USGS North Central Climate Science Center (NCCSC) hosted by Colorado State University (<http://revampclimate.colostate.edu/>). Future climate

projections for the NCCSC products are presented for several scenarios of future greenhouse gas concentrations (i.e., emission scenarios); representative concentration pathway (RCP) 8.5 represents the high emissions scenario and RCP 4.5 represents a moderate emissions scenario. Examination of historic climate data used PRISM (4km) data downloaded from <http://cida.usgs.gov> (Prism Climate Group 2014). Climate projections for non-spatial graphics use CMIP5 downscaled data downloaded from the Green Data Oasis website (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html) (CMIP5 Modeling Groups 2014). CMIP5 downscaling procedures are described in Maurer et al. (2002). Approximately 35 general circulation models (GCMs) that use quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice were used for the NCCSC summaries. Because the variability in results among models makes interpreting results problematic, ensemble summaries were used to combine the simulations of multiple GCMs and quantify the range of possibilities for future climates under the different emission scenarios. Using ensemble median values based on the results from many GCMs provides a more robust climate simulation versus using results of individual models (Girvetz et al. 2009). Seasonal summaries use the following groupings: winter = December, January, and February, spring = March, April, and May, summer = June, July, and August, and autumn = September, October, and November

The Palmer Drought Severity Index (PDSI) uses temperature and precipitation data to calculate water supply and demand, incorporates soil moisture, and is considered most effective for unirrigated cropland (Palmer 1965, USDA 2014). Long-term drought is cumulative, so the intensity of drought during a point in time is dependent on the current weather patterns plus the cumulative patterns of the previous period. The Index is used widely by the U.S. Department of Agriculture and other agencies. PSDI values range between -4.00 or less (extreme drought) and +4.00 or greater (extreme moisture). The index uses a value of 0 as “normal”. The Palmer Index is most effective in determining long term drought (i.e., at least several months). Monthly PSDI values were obtained from the National Climatic Data Center (NCDC 2013a). Assumptions of the PSDI regarding the relationship between temperature and evaporation may give biased (i.e., overestimated evaporation) results in the context of climate change (Sheffield et al. 2012). However, examination of historic PSDI does appear to corroborate known drought periods and the PSDI approach is not used to model future drought.

Moisture deficit was modeled using the web-based Climate Wizard Custom tools applying 12 km downscaled climate projections for more than 15 different GCMs (The Nature Conservancy, University of Washington and University of Southern Mississippi 2014; Maurer et al. 2007). Two greenhouse gas emissions scenarios - High (A2) and Medium (A1B) were used for the Climate Wizard results. The balance between precipitation and the amount of water that an ecosystem could potentially use through evaporation and transpiration (i.e., potential evapotranspiration or PET) is the basis for the climatic moisture deficit. PET is higher with warmer temperatures and more daylight hours. PET was calculated based on monthly temperature and monthly average number of daylight hours using a modified version of the Thornethwaite equation and procedures described by Wolock and McCabe (1999). Climatic moisture deficit quantitatively estimates moisture stress in a system; a higher moisture deficit reflects higher moisture stress. A deficit (in mm) occurs only when precipitation (i.e., supply) is less than PET (i.e., demand) in a given month. If precipitation decreases

or temperature increases (increasing PET) moisture deficit increases. Deficit is calculated as monthly PET minus precipitation (in mm), and is set to zero if precipitation is greater than PET. Monthly results are summed to provide seasonal or annual values (The Nature Conservancy, University of Washington and University of Southern Mississippi 2014).

Plant phenology was examined using existing and freely available remote sensing data, specifically the NASA-funded 250 meter spatial resolution land-surface phenology product for North America. This product is calculated from an annual record of vegetation health observed by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. The land surface phenology product summarizes all the observations throughout a year into a few, key, ecologically relevant biophysical parameters or metrics. MODIS land products include two Vegetation Indexes (VI) derived from the remotely sensed fraction of photosynthetically active radiation detected every one to two days by the MODIS sensors (Gao et al. 2007). Normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI) datasets represent 8 day composites of MODIS data at the 250 meter spatial resolution scale (Tan et al, 2010). The revisit interval for any geographic point is approximately 1-2 days. The resulting land surface phenology metrics are produced from these composites using an enhanced algorithm within the TIMESAT software program (Tan et al. 2010). Phenology data for pixels within the park boundary were gathered and summarized by Kevin James of the Heartland I&M Network using procedures and tools described in James et al. (2013). It was important to keep the pixels examined within the park, since most areas outside the park are not prairie or other forms of native vegetation.

Reference Conditions

For most indices, the reference condition for this assessment is an 85-year period from about 1895, when meteorological data was first collected, to 1980, when a significant change in many climate indices roughly began. Although there may be some changes occurring during this period, the long reference period avoids bias associated with wet, dry, warm and cold periods or extreme events such as prolonged or severe drought. Some analyses of historic data use a 1950-1980 baseline because of limited dates associated with downscaled CMIP5 data. For the climatic moisture deficit projections, future values were compared to a baseline period of 1961-1980. For frost-free season length, the baseline period was 1901-1960.

Historic Conditions, Range of Variability and Modeled Changes

Temperature

Historic Trends

A linear regression model was fit to average minimum and average maximum monthly temperature for 1895-1980 and 1980 to 2012 in the vicinity of Pipestone National Monument (Figure 4.5-1). The earlier period corresponds to the period that is associated with no change in climate or a slower rate of change compared to 1980 or later. At PIPE, mean minimum monthly temperatures increased significantly over time during 1895-1980 ($p < 0.01$ but did not increase significantly from 1980-2012 ($p = 0.57$)). The model results for mean monthly maximum temperature over time were not statistically significant for either period.

Trends in monthly minimum temperatures over time are further illustrated in a graphical representation of the data for the period of record (Figure 4.5-2), which normalizes differences between a baseline period of 1895 to 1980 with individual monthly values. For example, cooler temperatures across most months are evident in the period before 1940 compared to more recent years. High temperatures associated with severe droughts that occurred in the 1930s, late 1950s, late 1980s are clearly shown in Figure 4.5-2 (bottom). An anomaly plot showing annual mean temperatures over time further illustrates significant changes in this variable during the recent past, with minimum temperatures for most years since 1920 being 0.5-1.5 deg. C above the long term average (Figure 4.5-3). Monthly data was also grouped by season into model quartiles for minimum temperature (Figure 4.5-4).

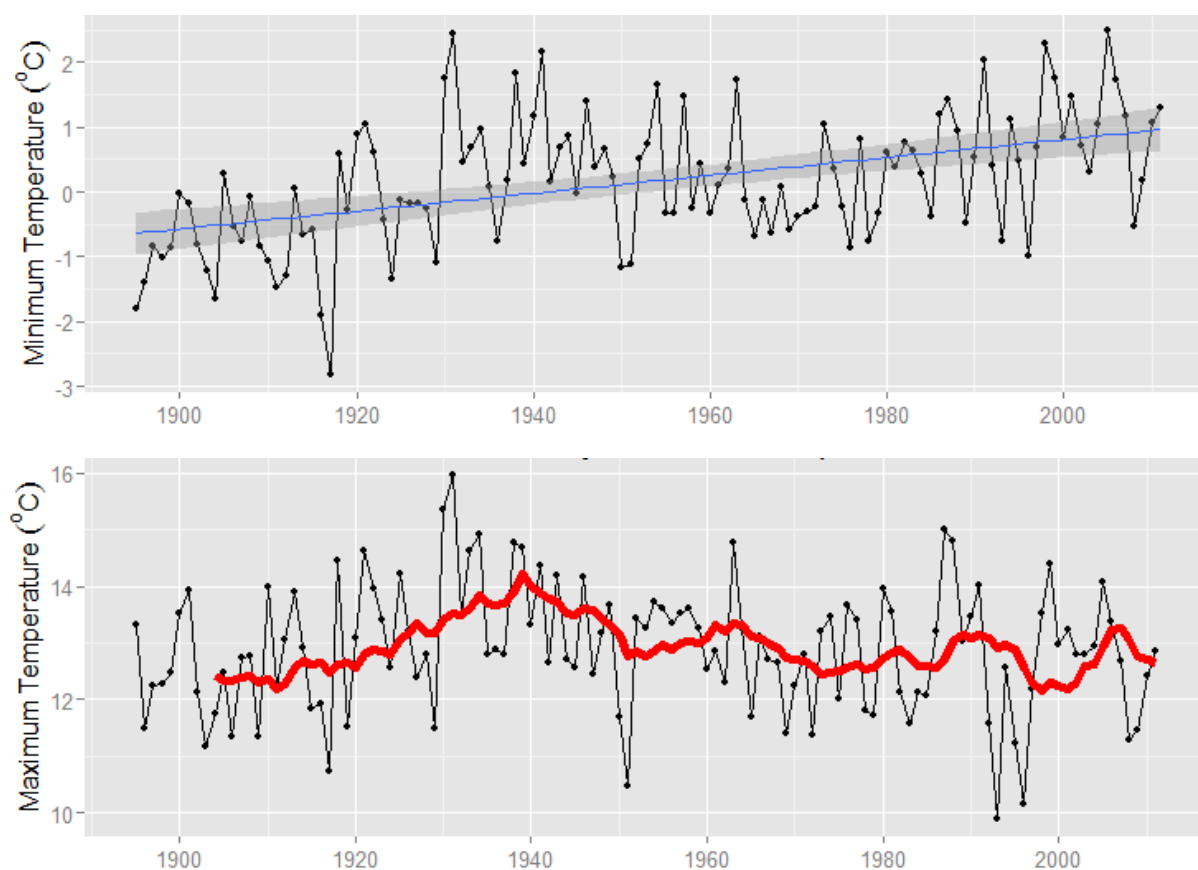


Figure A-1. Historic PRISM data for minimum temperature showing significant linear model fit (top) and maximum temperature with a five year lag running mean (bottom). (Data and graphic prepared by NCCSC)

Modeled Future Changes

Models indicate that temperatures at the park will rise significantly under climate change (Figure 4.5-5). According to median ensemble estimates, both minimum and maximum temperature are expected to increase by approximately 2-3 °C by 2050, and by approximately 3.0-6.5 °C by 2100, depending on the scenario (Figure 4.5-5).

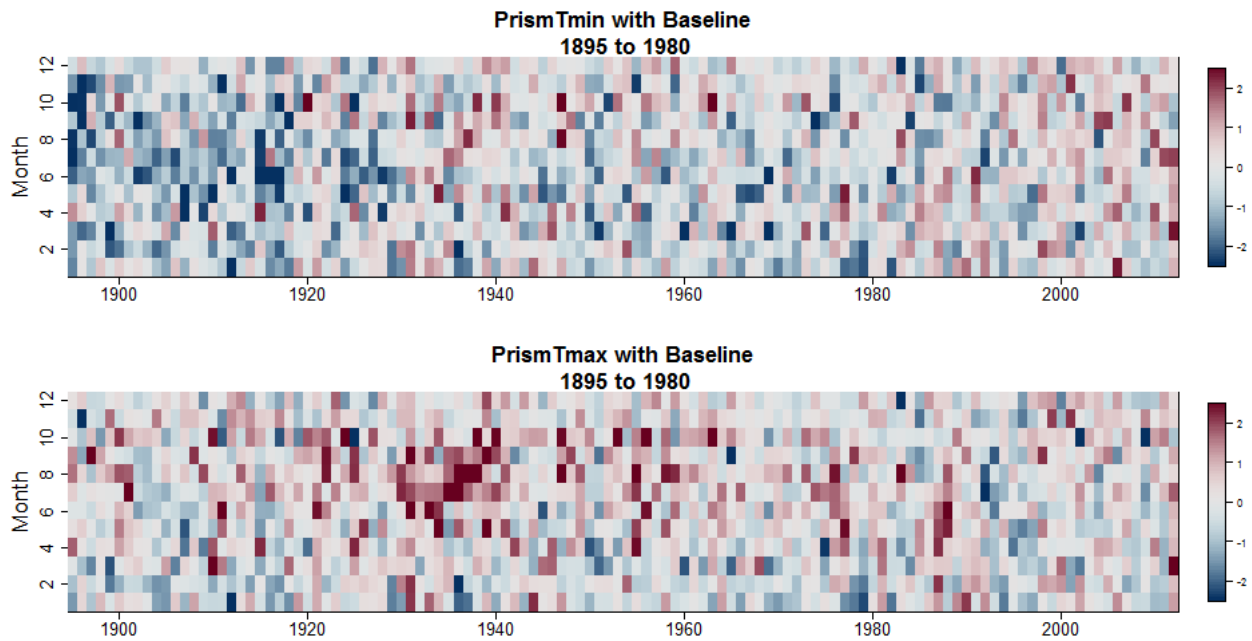


Figure A-2. Mean monthly minimum temperature (top) and monthly maximum temperature (bottom) showing the normalized difference from a baseline (1895-1980) period for each month and year for Pipestone National Monument. The baseline is calculated monthly within the specified year range. The pixels are normalized by month and colors range from +/- 2.5 standard deviations from the mean of the baseline period. (Data and graphic prepared by NCCSC)

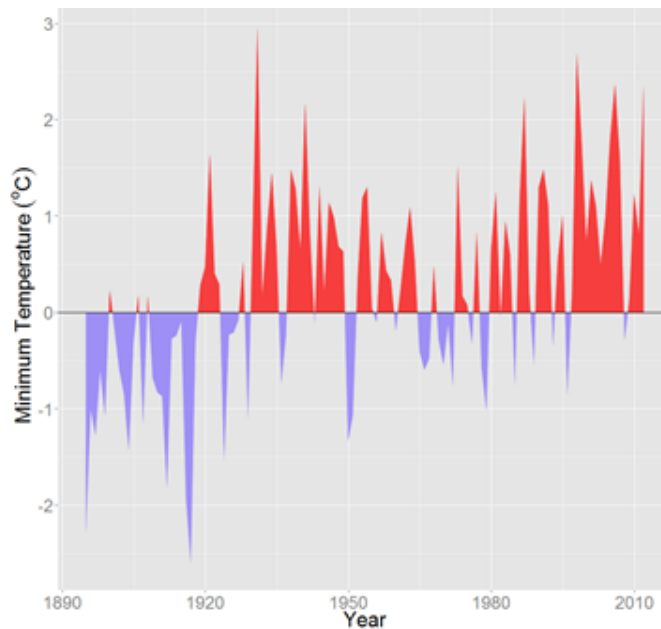


Figure A-3. Anomaly plot for mean minimum temperature showing the difference between individual years from 1895 to 2012 and a baseline (1895 to 1980 average) for Pipestone National Monument. (Data and graphic prepared by NCCSC)

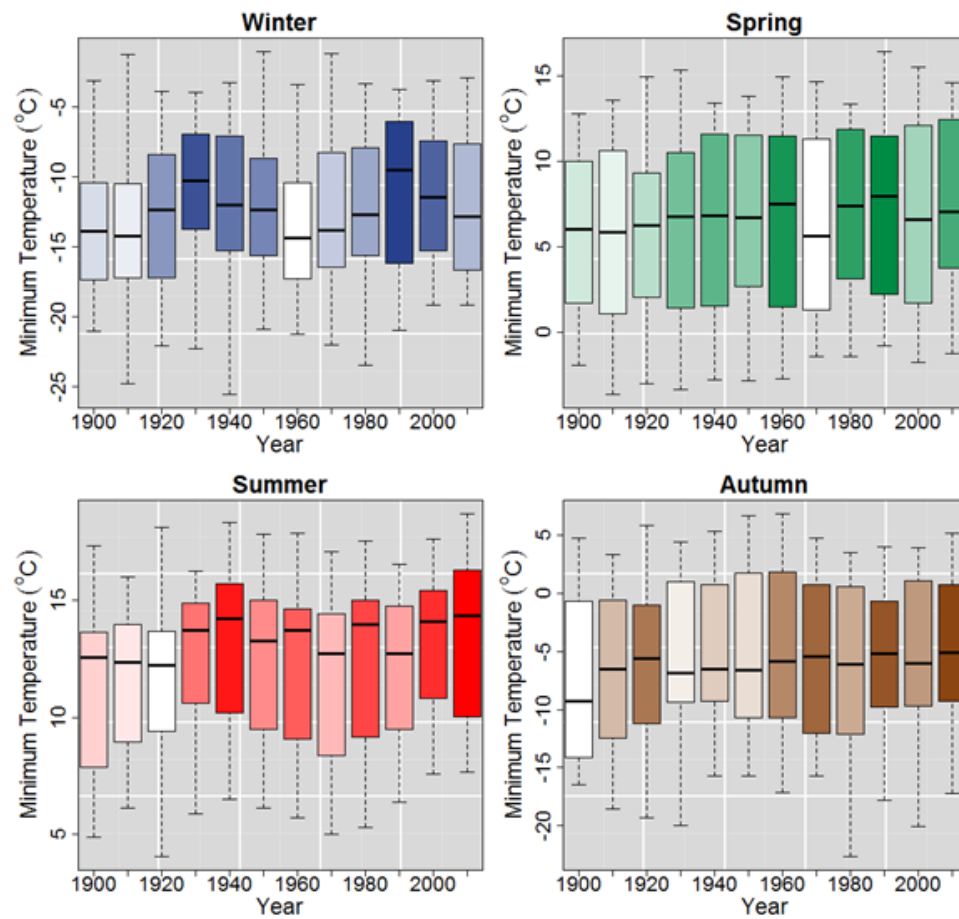


Figure A-4. Seasonal historic mean minimum temperature quartiles using PRISM data. Within a season, darker colors represent higher temperatures. (Data and graphic prepared by NCCSC)

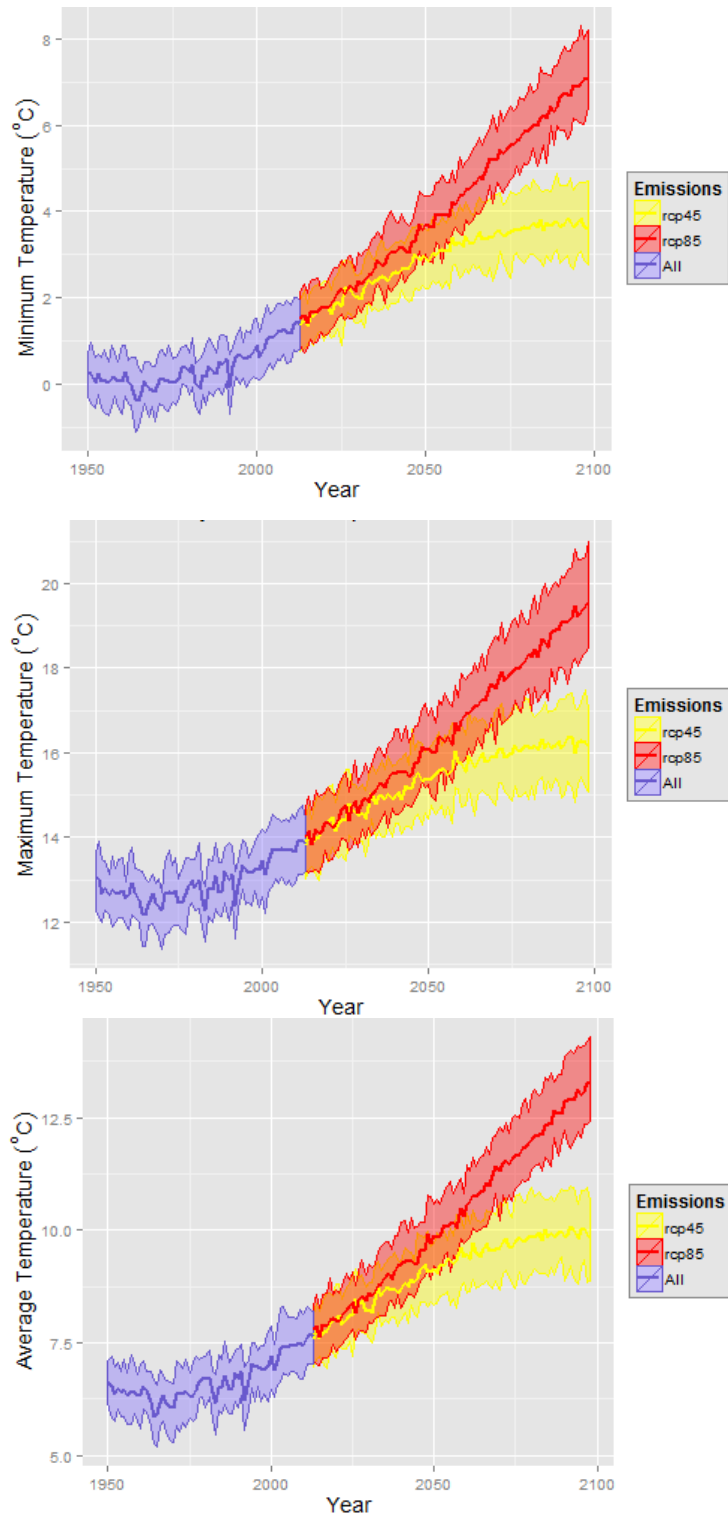


Figure A-5. Projections for annual minimum, maximum and mean temperature with median, 25 and 75% quantiles grouped by emissions scenario for Pipestone National Monument. (Data and graphic prepared by NCCSC)

Precipitation

Historic Trends

Historic trends in monthly and annual precipitation for 1895-2010 were examined to understand patterns and variability. Mean monthly precipitation appears to be increasing for some months in the latter half of the period of record, but patterns of seasonality are not clear (Figure 4.5-6). Linear regression of mean monthly precipitation with time were not significant for the 1895-1970 period ($p>0.20$) or the 1970-2012 period ($p>0.15$) (Figure 4.5-7). Variability in seasonal and annual precipitation is relatively high.

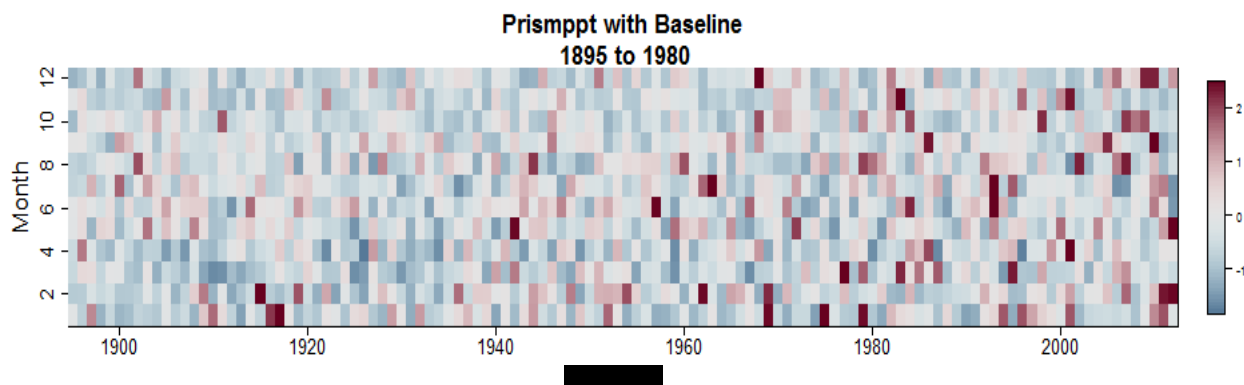


Figure A-6. Mean monthly precipitation showing the normalized difference from a baseline (1895-1980) period for each month and year for Pipestone National Monument. The baseline is calculated monthly within the specified year range. The pixels are normalized by month and colors range from ± 2.5 standard deviations from the mean of the baseline period. (Data and graphic prepared by NCCSC)

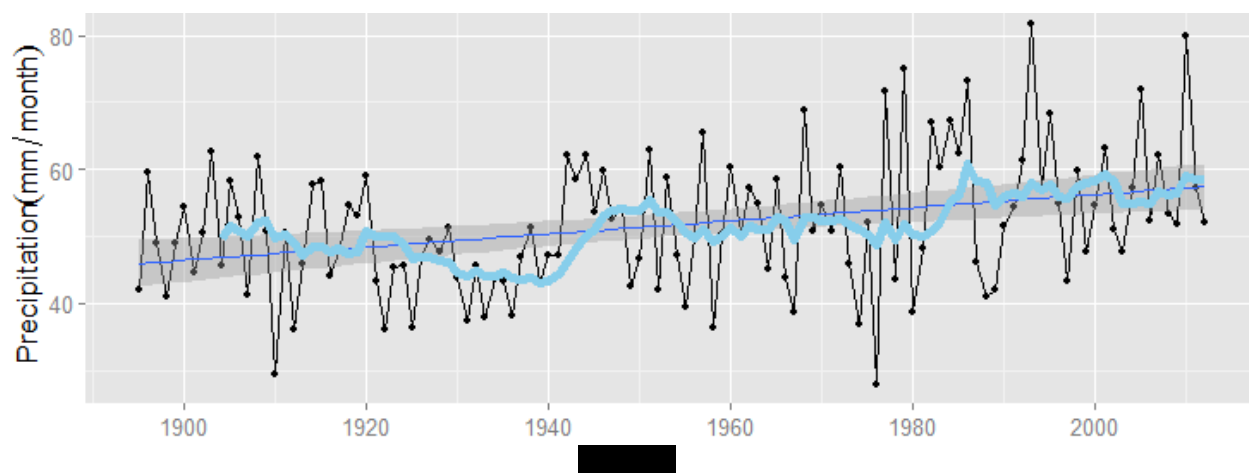


Figure A-7. Historic PRISM data for precipitation at Pipestone National Monument showing linear model fit and a five year lag running mean. (Data and graphic prepared by NCCSC)

In recent decades there have been increases nationally in the annual amount of precipitation falling in very heavy events, defined as the heaviest 1% of all daily events from 1901 to 2012. The largest regional increases have been in the Northeast, Great Plains, Midwest and Southeast regions when compared to the 1901-1960 average (Walsh et al. 2014a). Regional results for the Midwest region

including Pipestone National Monument indicate 20 to 30% or more increases in the annual amount of precipitation falling in very heavy events over the past few decades (Figure 4.5-8).

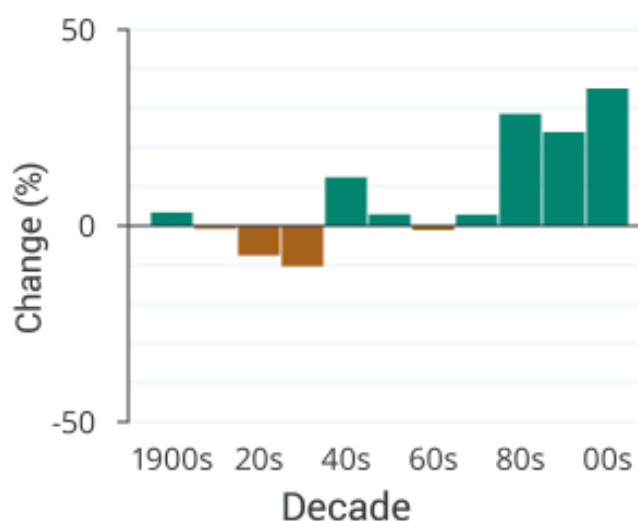


Figure A-8. Percent changes in the annual amount of precipitation falling in very heavy events compared to the 1901-1960 average for the Midwest region including Iowa and Minnesota. A very heavy event is defined as the heaviest 1% of all daily events from 1901 to 2012. The far right bar is for 2001-2012 (Kunkel et al. 2013 as presented in Walsh et al. (2014a).

Modeled Future Changes

Modeled climate through the year 2100 shows an increase in mean monthly precipitation under both moderate (RCP4.5) and high (RCP8.5) emission scenarios (Figure 4.5-9). Both the medium and high emission scenarios produce increasing mean monthly precipitation, with an increase of approximately 3-5 mm per month or 35-60 mm (1.3 – 2.3 inches) per year by 2050.

Aridity

Aridity and moisture availability is examined using the Palmer Drought Severity Index (Palmer 1965) for the historic 1940-2012 period. A climatic deficit index (The Nature Conservancy, University of Washington and University of Southern Mississippi 2014) is used to compare the 1961-1980 baseline with mid-century (2050) and end-century (2095) modeled values for medium (A1B) and high (A2) emission scenarios.

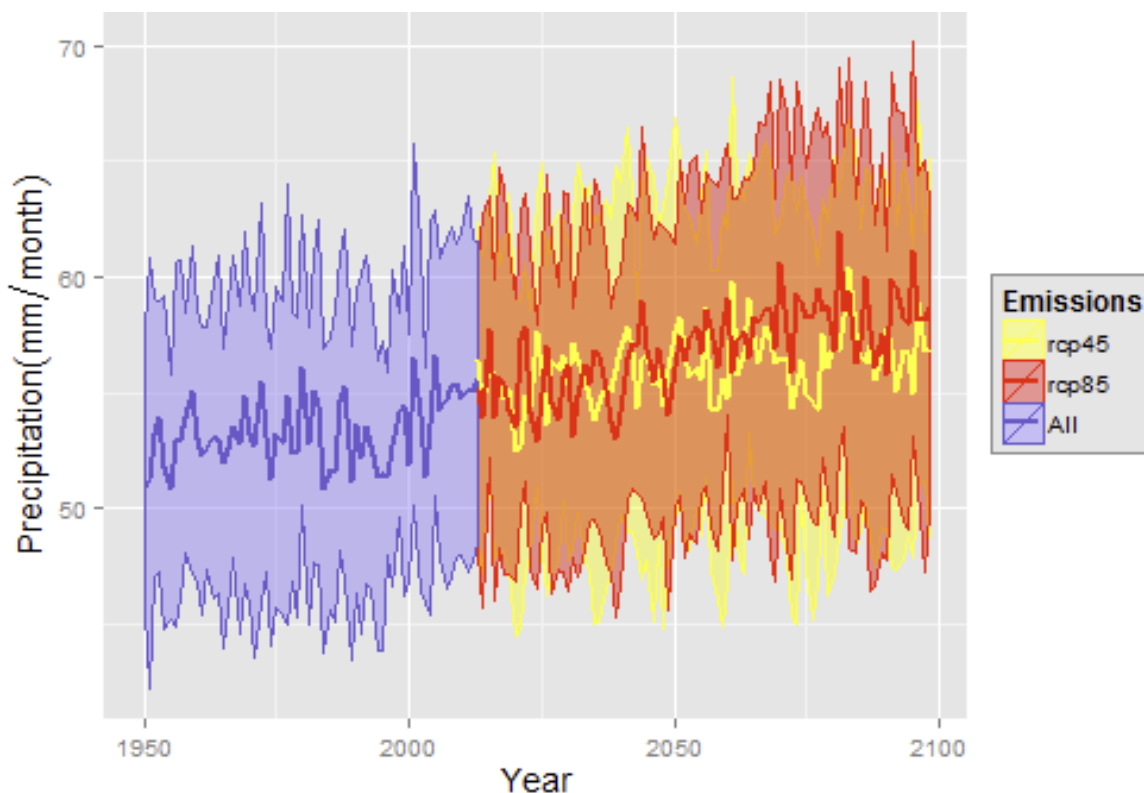


Figure A-9. Projections for precipitation/month with mean, 25% and 75% quantiles grouped by emissions scenario for Pipestone National Monument. (Data and graphic prepared by NCCSC)

Historic Trends

Palmer Drought Severity Index (PDSI) values were calculated for the period from 1940 to 2012 (Figure 4.5-10). The Palmer Index is most effective in determining long term drought (i.e., at least several months). Long-term drought is cumulative, so the intensity of drought during a point in time is dependent on the current weather patterns plus the cumulative patterns of the previous period. PSDI values range between -4.00 or less (extreme drought) and +4.00 or greater (extreme moisture). The index uses a value of 0 as “normal”, and value of -1.5 is considered drought. While drought is sometimes described as cyclic, the frequency and duration of cycles is highly unpredictable. For the period of record, PIPE PDSI data shows periodic moderate to severe drought lasting 2-4 years occurring every 5 to 15+ years since 1940.

Modeled Future Changes

Moisture deficit results for Pipestone National Monument were modeled using the Climate Wizard Custom Tools (<http://climatewizardcustom.org/>). Modeled results varied by emissions scenario and season were highly variable across global circulation models. Under the moderate and high emissions scenarios, annual moisture deficit is projected to be approximately 35-65 mm per year by 2050 and 90-120 mm per year by 2095 (Figure 4.5-11). Seasonal changes were most evident for summer and fall periods. Annual summer season moisture deficits ranging from 80-90 mm (3.3 inches) are forecast for medium and high-emission scenarios by 2095.

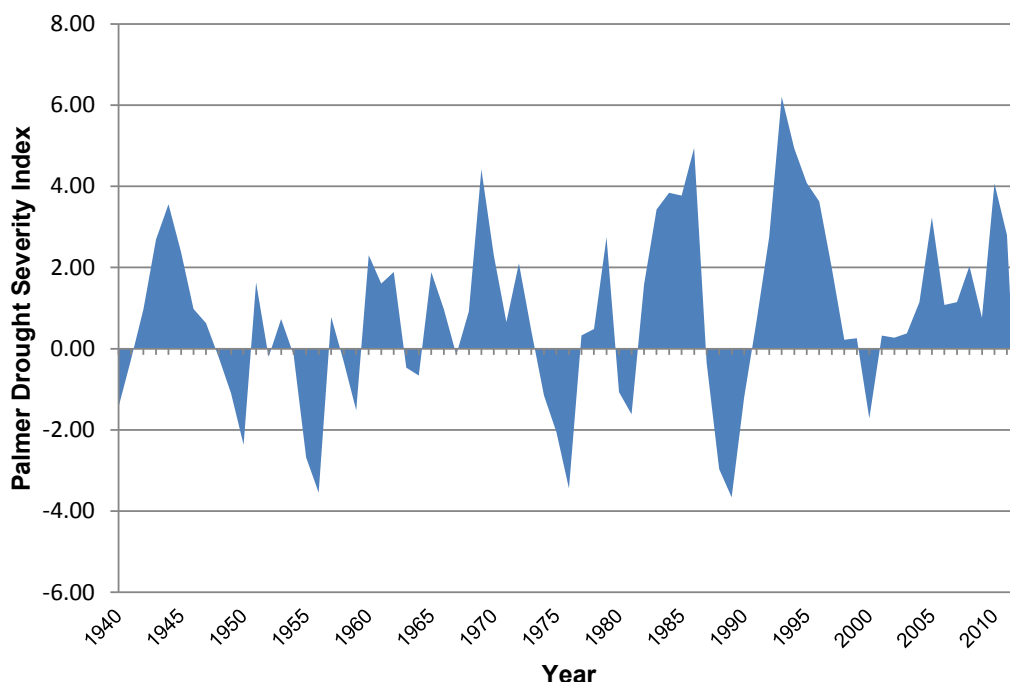


Figure A-10. Palmer Drought Severity Index from 1940 – 2012 for Pipestone National Monument. Negative values represent drought conditions and positive values represent moist conditions (NCDC 2013a).

Plant Phenology and Frost-Free Period

Plant Phenology

Plant phenology serves as an excellent global warming indicator because it is one of the most readily observable ecosystem reactions to climate change (McEwan et al. 2011). Increases in temperature are responsible for plants flowering earlier in the spring and the delayed onset of dormancy in autumn. This affects not only synchrony among plants, pollinators and complex evolutionary adaptation, but can shorten (or lengthen) a plant's growing season. Phenology also plays an important role in the amount of water released to the atmosphere via evapotranspiration, sequestration of carbon in new growth, and the amount of nitrogen utilized from the soil (Ibanez et al. 2010).

Plant phenology in the park and surrounding area is primarily governed by a combination of plant genetics and the effects of weather and day length. If plant communities change due to management, disturbance, changing climate, or other drivers, then plant phenology may also change due to those compositional changes. For example, cool-season grasses such as smooth brome (*Bromus inermis*) tend to start growing earlier in the spring, reach maximum production and flower earlier compared to warm season grasses such as little bluestem (*Schizachyrium scoparium*) and indiagrass (*Sorghastrum nutans*).

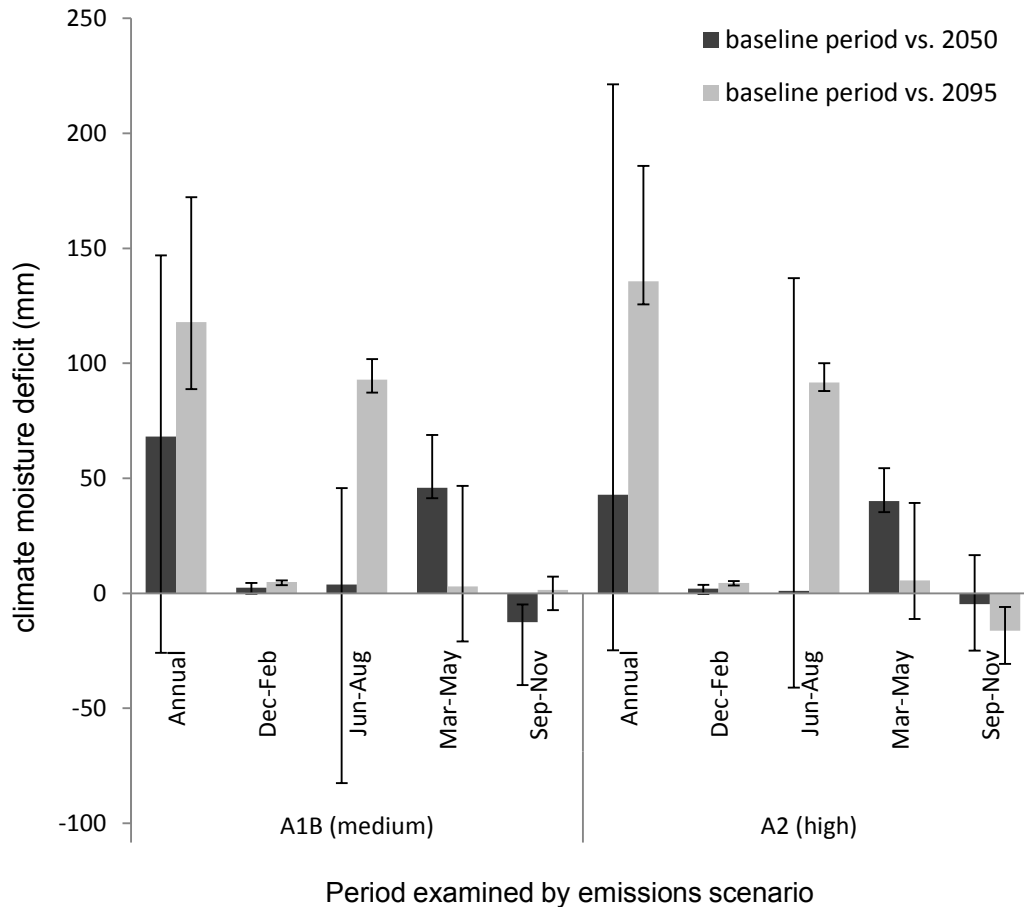


Figure A-11. Annual and seasonal climatic moisture deficit for 2040-2060 and 2090-2099 compared to the baseline 1961-1980 period under two emission scenarios for a 30 X 30km area surrounding Pipestone National Monument. Higher positive values indicate increasing aridity. Median values with 25% and 75% quartile limits. Analysis was done using the Climate Wizard Custom tools (The Nature Conservancy, University of Washington and University of Southern Mississippi 2014). High positive values reflect drier conditions.

In a study of temperature changes and plant phenology in the northern Great Plains, Dunnell and Travers (2011) found that 5% to 17% of the species observed have significantly shifted their first flowering time either earlier or later relative to the previous century. Overall, they found that as spring temperatures in the northern Great Plains have increased and the growing season has lengthened, some spring flowering species have advanced their first flowering time, some fall species have delayed their first flowering, and some species have not changed (Dunnell and Travers 2011).

Despite a plethora of collaborative scientific endeavors including the USA National Phenology Network, high resolution spatial and temporal phenology data are generally unavailable for most locations. Approaches used to investigate the influence of global change on terrestrial plant and ecosystem phenology include species-level observation networks such as the USA National Phenology Network, remote sensing such as MODIS analysis used here, Eddy-covariance monitoring of carbon fluxes using recording stations, phenology modeling and plot-scale global change

experiments. A review of the utility, limitations and temporal and spatial resolution of various methods is presented by Cleland et al. (2007).

Here we use a greenness index derived from MODIS imagery to characterize plant phenology. For the 11-year baseline period of record, the mean greenup date was April 18 (90% confidence interval of ± 5.0 days), mean vegetation greenness peaked on July 20 (90% confidence interval of ± 2.6 days) and mean onset of minimum greenness was November 15 (90% confidence interval of ± 11.8 days) (Figure 4.5-12). The onset of greenup appears to be the most consistent. Dates for maximum greenness were most consistent from year to year (i.e., had the lowest variance), followed by greenup dates and onset of minimum greenness. The distribution of annual values for the three metrics over the baseline period is show in Figure 4.5-13.

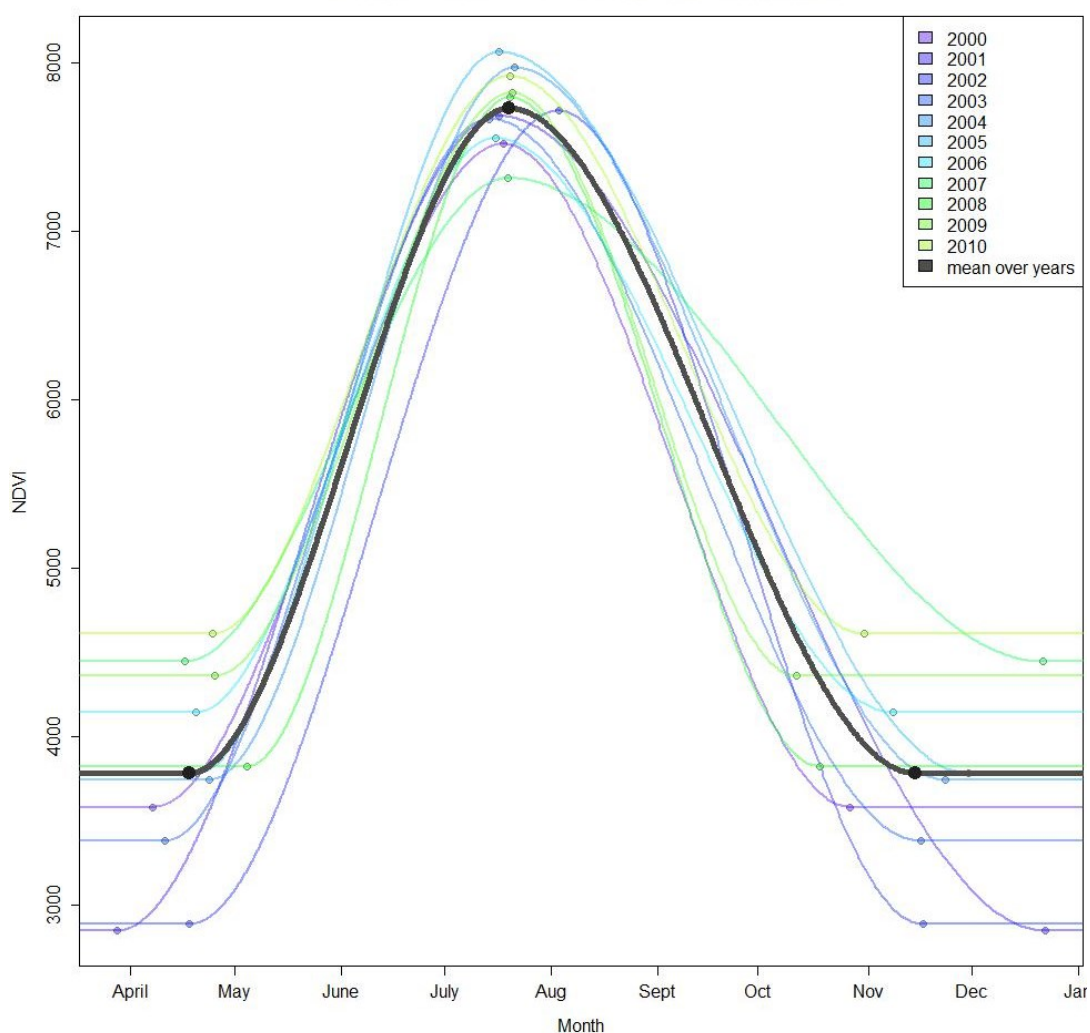


Figure A-12. Phenology curves for Pipestone National Monument based on MODIS imagery vegetation indices. The graph shows dates for greenup initiation (left), maximum greenness (center), and the end of vegetation senescence or onset of minimum greenness (browdown end) (right) for the period of record. Data visualization provided by Heartland I&M Network.

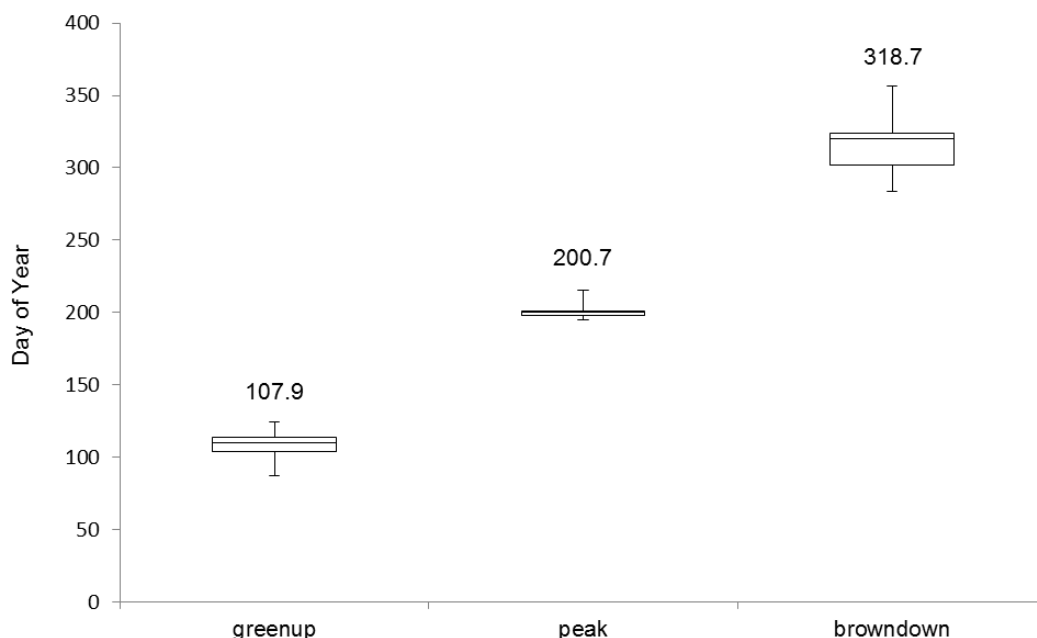


Figure A-13. Box plots for the base period for dates associated with onset of vegetation greenup, maximum greenness and onset of minimum greenness, based on MODIS EVI data. Lines represent median values, boxes represent the limits of 25th and 75th percentile values and whiskers represent remaining values. Numbers above box plots are means for each phenological period.

Frost-Free Period

The length of the frost-free season is a major determinant of the types of plants and crops that do well in a particular region. These observed climate changes are correlated with increases in satellite-derived estimates of the length of the growing season (Jeong et al. 2011). The frost-free season length, defined as the period between the last occurrence of 32°F in the spring and the first occurrence of 32°F in the fall, has been gradually increasing since the 1980s (USEPA 2012). The last frost in the spring has been occurring earlier in the year, and the first frost in the fall has been happening later. In the eastern Great Plains region, the average frost-free season for 1991-2011 was about 9-10 days longer than during 1901-1960 (Walsh et al. 2014a). A longer growing season can increase carbon sequestration in plants (Peñuelas et al. 2009) and increase the growth of both desirable and undesirable plants. In some cases where moisture is limited, greater evaporation and plant transpiration associated with the longer growing season can mean less productivity due to increased drying (Melillo et al. 2014).

By the 2070-2099 period, the frost-free season for the eastern Great Plains is projected to rise significantly as heat-trapping gas emissions continue to grow, increasing by 10-20 days under the lower emissions (B1) scenario and 30-40 days under the higher (A2) emissions scenario compared to the 1901-1976 baseline period (Melillo et al. 2014).

Overall Assessment

All indications are that the climate in this park region is already becoming drier (despite increasing precipitation), hotter, and is more prone to more frequent and extreme weather events and drought. Trends in the indicators are projected to continue or accelerate by the end of the century. Because

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

Sources of Expertise

Jeffrey Morissette, Director, DOI North Central Climate Science Center

Marian Talbert, Biostatistician, DOI North Central Climate Science Center

John Gross, Climate Change Ecologist, NPS Inventory and Monitoring Program National Office

Kevin James, Plant Ecologist, Heartland I&M Program

Uncertainty and Data Gaps

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

Management and Ecological Implications

Changing climate is anticipated to impact Great Plains grasslands in a number of ways, and is likely to compound the effects of existing stressors to potentially increase the vulnerability of grasslands to pests, invasive species and loss of native species (NFWPCAP 2012). Species ranges and ecological dynamics are already responding to recent climate shifts, and current reserves including NPS units will be unable to support all species, communities and ecosystems (Heller and Zavaleta 2009), some of which form the core of their park mission. Some of the key anticipated ecological impacts and management implications of climate change in the tallgrass prairie region and PIPE include:

- Contraction of tallgrass prairie extent along the eastern boundary (Rehfeldt et al. 2008);
- Increased plant production in northern latitude and high altitude Great Plains rangelands and decreased plant productivity in the southern Great Plains (Morgan et al. 2008);
- Increases in invasive exotic plants (Morgan et al. 2008);
- Reduced water availability – projected annual and seasonal moisture deficits indicate that any increases in precipitation in the region are unlikely to be sufficient to offset overall decreases in soil moisture and water availability due to increase temperatures, increase water utilization and aquifer depletion (Karl et al. 2009). Water dependent habitats are especially at risk due to increased evaporation resulting in altered aquifer and surface water dynamics (Bagne et al. 2013).

- More frequent extreme events such as heat waves, droughts and heavy rains (Karl et al. 2009), with heavier rainfall events likely in the northern and central areas (Kunkel et al. 2013) and increasing likelihood of flooding in the wetter, northern portions of the Great Plains (USEPA 2013);
- Limited ability for species and communities to adapt; the relatively flat terrain characterizing these grasslands increases vulnerability to climate change because species and habitats may be obliged to migrate long distances to compensate for temperature shifts. This challenge is exacerbated by the highly fragmented and altered agricultural landscape in the region (Bagne et al. 2013).
- A decrease in rainfall may lead to a net carbon loss in the system (IPCC 2007). Trees and shrubs show higher CO₂ responsiveness than do herbaceous plants, which may lead to increases in woody plants as atmospheric CO₂ rises (IPCC 2007).
- Climate change is likely to exacerbate existing stressors related to anthropogenic disturbances at landscape scales including energy development and agriculture that fragment the landscape and hinder species adaptation (Bagne et al. 2013, Shaeffer et al. 2014).

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

While climate change cannot be controlled by the park, managers can take steps to minimize the severity of exposure to these changes and help conserve sensitive resources as the transition continues. Although an in-depth analysis of the effects of climate change on park natural resources goes beyond the scope of this NRCA, a preliminary evaluation of the vulnerability of targeted park resources is being prepared to help understand how climate change vulnerability might be integrated in future assessments. Existing condition analyses and data sets developed by this NRCA will be useful for subsequent park-level climate change studies and planning efforts.

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