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U.S. Geological Survey North Central Climate Adaptation Science Center

Prepared in cooperation with the University of Colorado Boulder

Grassland Management Priorities for the North Central Region

Open-File Report 2023–1037

U.S. Department of the Interior
U.S. Geological Survey

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Edited by Christine D. Miller Hesed and Heather M. Yocum

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Grassland Management Priorities for the North Central Region

Edited by Christine D. Miller Hesed[1] and Heather M. Yocum[1]

Preface

This report presents findings from the project "A Synthesis of Climate Impacts, Stakeholder Needs, and Adaptation in Northern Great Plains Grassland Ecosystems" (hereafter, the Grasslands Synthesis Project) led by the U.S. Geological Survey North Central Climate Adaptation Science Center (USGS NC CASC). Grassland ecosystems in the NC CASC region support local economies, Tribal communities, livestock grazing, diverse plant and animal communities, and large-scale migrations of ungulates and multiple bird guilds. Understanding how climate change and variability will impact grassland ecosystems is crucial for successful management of grasslands in the 21st century. The NC CASC began the Grasslands Synthesis Project in 2020 to establish a baseline of information to best serve resource managers and help meet regional grassland management goals. This project had two primary goals: (1) to synthesize management goals and challenges for grassland managers across the region and (2) to assess the state-of-the-science and identify knowledge gaps for addressing these goals and challenges within the context of climate change.

The NC CASC is a partnership between the U.S. Geological Survey, the University of Colorado Boulder, and five consortium partners—Conservation Science Partners, Great Plains Tribal Water Alliance, South Dakota State University, University of Montana, and Wildlife Conservation Society. The NC CASC is part of a network of regional Climate Adaption Science Centers (fig. Pr1) that serve resource managers by developing the science and tools needed to address impacts of climate change on the Nation's land, water, fish, wildlife, and cultural heritage resources. The NC CASC serves Federal, State, and Tribal resource managers in Montana, Wyoming, Colorado, North Dakota, South Dakota, Nebraska, and Kansas (fig. Pr1).

[1]North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder.

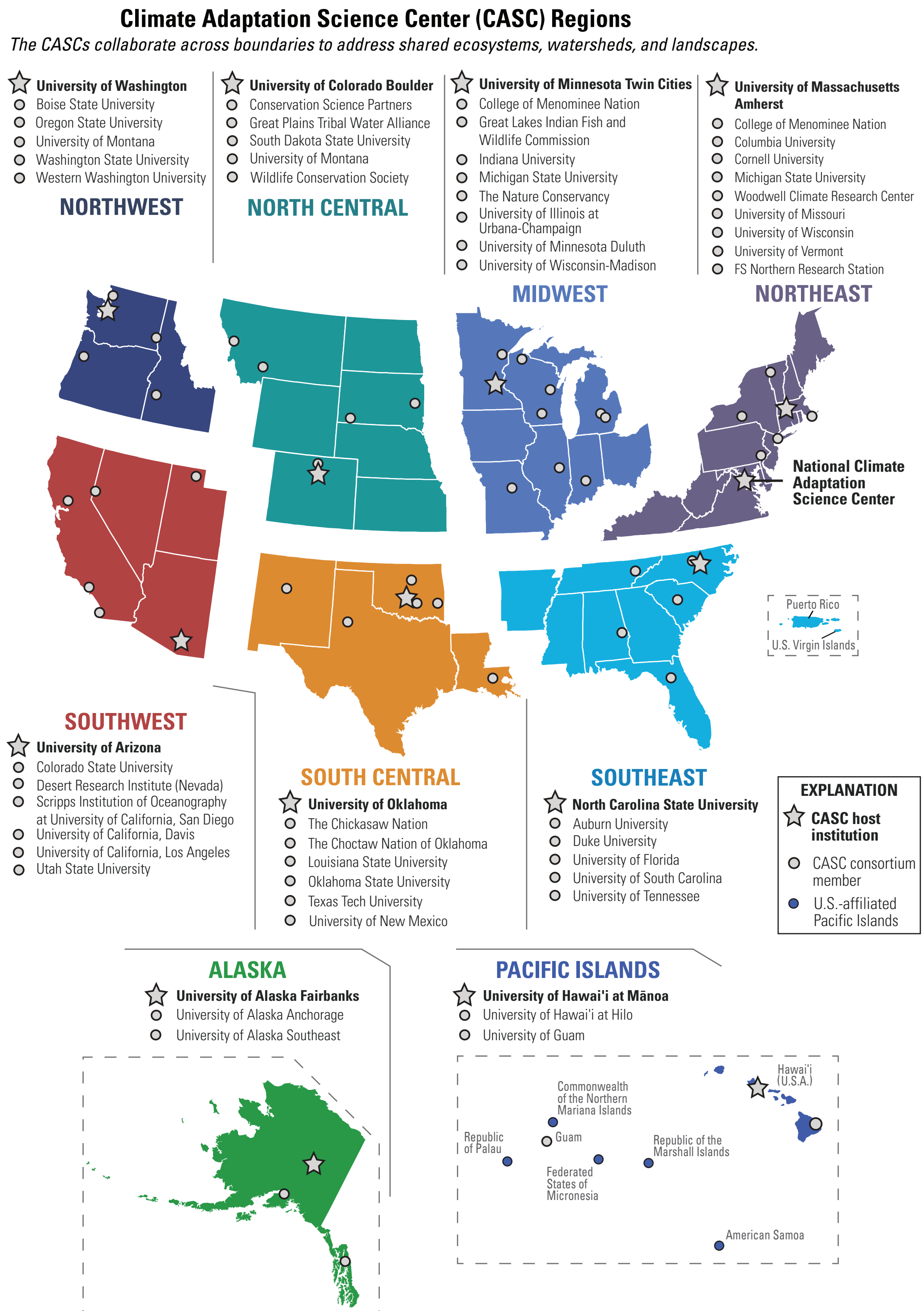

Figure Pr1. Schematic diagram showing the United States, affiliated Pacific islands, and associated territories depicting the Climate Adaptation Science Center regions overlain by the location of the National Climate Adaptation Science Center, host institutions, and consortium members.

The NC CASC recognizes the importance of private landowners for grassland conservation across the region primarily because of the proportion of land in the region held in private ownership; however, the mission of the Department of the Interior and the scope of this project limited the degree to which this report pertains to private landowners. The NC CASC indirectly serves private landowners by providing relevant climate science and tools to the Federal, State, and Tribal agencies and nongovernmental organizations that partner with private landowners on grassland conservation and management; however, the NC CASC does not directly provide technical or financial service to private landowners. Furthermore, the data collection and analysis

methods used to develop this report were not conducive to a thorough consideration of private landowners' grassland management goals, challenges, and information needs (see "Chapter A—Background and Methods" of this report). Nevertheless, we highlight the importance of working with private landowners on grassland conservation and describe ways other Federal, State, Tribal agencies, and nongovernmental organizations work with private landowners on grassland conservation.

The chapters in this report provide background information and the main findings from the synthesis of grassland management documents. "Chapter A—Background and Methods" describes the project impetus and methods and discusses project limitations. "Chapter B—Introduction to the North Central Grassland Ecoregions" introduces the North Central Grassland Ecoregions and provides a brief history of the formation of the central grasslands of North America. We then define and describe five grassland ecoregions in the North Central region and provide information on their spatial extent, vegetation, climate, and management. "Chapter C—Grassland Management Goals, Challenges, and Information Needs" presents the findings from the synthesis, including the multiple goals of grassland management and the management actions, and information needs related to direct and indirect threats (that is, contributing factors) to grassland conservation. The chapter concludes with a discussion of emerging challenges and opportunities. This discussion, unlike most of the report, drew heavily on the experience and knowledge of the working groups and feedback from the Advisory Committee rather than being primarily rooted in the review of grassland management-relevant documents. The information in "Chapter C—Grassland Management Goals, Challenges, and Information Needs" provides important context for understanding grassland management goals and the information needed to better meet those goals within the context of a changing climate. "Chapter C—Grassland Management Goals, Challenges, and Information Needs" should be of interest to anyone seeking a high-level summary of the factors most important for grassland conservation in a changing climate.

Contributors

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Acknowledgments

We are grateful to the members of the Climate and Ecology Working Group and the Advisory Committee for their feedback on an initial draft of this report. The Climate and Ecology Working Group consisted of Marissa Ahlering (The Nature Conservancy [TNC]), Kathy Chase (U.S. Geological Survey [USGS]), Shelley Crausbay (Conservation Science Partners), Ana Davidson (Colorado Natural Heritage Program), Julie Elliott (U.S. Department of Agriculture, Natural Resources Conservation Service [NRCS]), Kevin Ellison (American Bird Conservancy), Jim Giocomo (American Bird Conservancy), David Hoover (U.S. Department of Agriculture, Agricultural Research Service [ARS]), Toni Klemm (ARS), David Lightfoot (Museum of Southwestern Biology, University of New Mexico), Jeff Martin (Center of Excellence for Bison Studies, South Dakota State University), Owen McKenna (USGS), Brian Miller (USGS), Christine Miller Hesed (Cooperative Institute for Research in Environmental Sciences [CIRES], University of Colorado Boulder), Danika Mosher

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This research was funded by the Department of the Interior, U.S. Geological Survey.

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Figures

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Datums

Vertical coordinate information is referenced to the [insert datum name (and abbreviation) here; for example, North American Vertical Datum of 1988 (NAVD 88)].

Horizontal coordinate information is referenced to the [insert datum name (and abbreviation) here; for example, North American Datum of 1983 (NAD 83)].

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

AC	Advisory Committee
ARS	U.S. Department of Agriculture, Agricultural Research Service
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
CEWG	Climate and Ecology Working Group
CIRES	Cooperative Institute for Research in Environmental Sciences
CPW	Colorado Parks and Wildlife
FSA	U.S. Department of Agriculture, Farm Service Agency
FS	U. S. Department of Agriculture, Forest Service
FWS	U.S. Fish and Wildlife Service
HUC	hydrologic unit code
JV	Migratory Bird Joint Venture
JV8	JV8 Central Grasslands Conservation Initiative
KDWP	Kansas Department of Wildlife and Parks
MFWP	Montana Fish, Wildlife and Parks
MPWG	Management Priorities Working Group
NC CASC	North Central Climate Adaptation Science Center
NDGFD	North Dakota Game and Fish Department
NGO	nongovernmental organization
NGPC	Nebraska Game and Parks Commission
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
PAD-US	Protected Areas Database of the United States
SDGFP	South Dakota Game, Fish and Parks
TEK	traditional ecological knowledge
TNC	The Nature Conservancy
USGS	U.S. Geological Survey
WGFD	Wyoming Game and Fish Department
WWF	World Wildlife Fund

Executive Summary

Background

Understanding how climate change and variability will impact grassland ecosystems is crucial for successful grassland management in the 21st century. In 2020, the U.S. Geological Survey North Central Climate Adaptation Science Center (USGS NC CASC) began a project to establish a baseline of information to best serve grassland managers (that is, those who develop grassland management plans or implement those plans on the ground) at Federal, State, and Tribal agencies and nongovernmental organizations to help meet regional grassland management goals. This project "A Synthesis of Climate Impacts, Stakeholder Needs, and Adaptation in Northern Great Plains Grassland Ecosystems" (hereafter, the Grasslands Synthesis Project), had two primary goals: (1) to synthesize management goals and challenges for grassland managers across the region and (2) to assess the state-of-the-science and identify knowledge gaps for addressing the goals and challenges within the context of climate change. The findings from the Grasslands Synthesis Project are described in two volumes. This report serves several purposes, including providing (1) a synthesis of regional grassland management goals and challenges, (2) identification of information needs relevant to grassland management in a changing climate, and (3) summaries of grassland management issues by ecoregion and management organization or agency.

Methods

The identification, synthesis, and summary of grassland management priorities, challenges, and information needs were conducted by the Management Priorities Working Group (MPWG), which was composed of individuals knowledgeable of grassland management in Federal, State, and Tribal agencies and nongovernmental organizations across the region. The MPWG identified 300 grassland management-related documents—including plans, reports, summaries, peer-reviewed literature, and other documents—authored by or relevant to grassland management organizations and agencies across the North Central region (Colorado, Wyoming, Montana, North Dakota, South Dakota, Nebraska, and Kansas). The MPWG systematically reviewed documents until they reached inductive thematic saturation (that is, no new themes were emerging from the continued review of new management documents). In total, 183 documents were systematically reviewed. To supplement this review, the MPWG also worked with Tribal partners and iterated on the synthesis of information from grassland management-related documents by seeking feedback and input from the Advisory Committee, Climate and Ecology Working Group, and representatives of Federal and State agencies and nongovernmental organizations.

The North Central Grassland Ecoregions

We defined five North Central Grassland Ecoregions: Tallgrass, Northern Mixed Grass, Central Mixed Grass, Shortgrass, and the Sagebrush-Grassland Ecotone. Grasslands that characterize these ecoregions evolved under the natural and human-assisted disturbance regime of fire and grazing. From time immemorial, Indigenous people living in the Great Plains helped to promote a highly heterogeneous and biodiverse landscape by setting intentional fires and hunting large, grazing mammals. These grasslands were also differentially influenced by climate gradients. In the North Central region, temperature increases from north to south and precipitation increases from the northwest to the southeast. Precipitation and temperature limit the growth of vegetation in these ecoregions, which impacts fire and grazing by determining fuel loads and forage availability for herbivores. Today, the state of grasslands in the region varies greatly. We use the term "grassland" to refer to any grass-dominated land, whether native or reclaimed prairie, ranchland, or improved grassland (that is, seeded to provide improved forage to livestock). Grasslands in the region vary from small fragments to large undisturbed patches and exist in a background matrix of natural and modified lands.

The amount of remaining grassland acreage varies within each of the five North Central Grassland Ecoregions. Widespread conversion of grassland to cropland began with nonindigenous settlement around 1850; however, this conversion was much greater in the eastern part of the region. Although only 41 percent of the Tallgrass Ecoregion is currently intact grassland (that is, grassland that has not been converted to cropland since at least 2014—the year the World Wildlife Fund began tracking conversion of grassland to cropland), the Sagebrush-Grassland Ecotone is 87 percent intact. The spatial pattern of grassland conversion corresponds to the general east-to-west decrease in precipitation (which limits suitability for conversion to cropland) and private land ownership. Approximately 95 percent of the Tallgrass Ecoregion is privately owned and managed, whereas only 65 percent of the Sagebrush-Grassland Ecotone is privately owned and managed. In addition to private landowners, grasslands within these ecoregions are managed by a diverse group of Federal, State, and Tribal agencies; nongovernmental organizations; and formal partnerships. Management entities manage variously sized parcels of land distributed unevenly across the North Central region.

Grassland Management Goals

Grassland management entities have varying organizational structures, goals, and management actions; however, they share many of the same climate-related challenges and information needs. Grassland management goals are varied across management entities and include conservation, recreation, productive grazing of livestock, historic and cultural preservation, and energy development. Grasslands management for multiple goals in the North Central region can sometimes mean neighboring lands are managed for conflicting goals; nevertheless, conservation is a widely shared goal across all grassland management entities and is the focus of this report. This report discusses many aspects of conservation, including protection, maintenance, restoration, reconstruction, and enhancement of grassland ecosystems. Increased collaboration and coordination among various grassland management entities will be crucial for successful grassland conservation in the North Central region in a changing climate.

Direct Threats and Contributing Factors

Grasslands across the globe, including in the North Central region, have been greatly reduced over the past few centuries. In addition to direct conversion, loss of key processes and replacement of wild grazers with domestic livestock have changed the dynamics of these robust and diverse systems. Although these changes in disturbance regimes shaped diversity and management needs, the primary direct threat to grasslands in the North Central region is currently loss and fragmentation from conversion to cropland, urban and suburban development, ranchland subdivision, and energy development. Extensive portions of the North Central Grassland

Ecoregions have already been converted for cropland, urban development, energy development, and other uses. As of 2020, only 60 percent of land in the North Central Grassland Ecoregions is intact grassland and the amount of remaining native or undisturbed grassland is likely lower. Other factors directly impacting the extent and quality of grasslands include woody encroachment, herbaceous invasives, unsustainable grazing, changes in water quality and quantity, wildlife population declines, and conservation on private land.

In addition to direct threats, a number of contributing factors indirectly impact the success of grassland conservation efforts, including lack of public understanding of the value of grassland ecosystems, legal and policy drivers of use and protection of grasslands, lack of economic incentives for grassland conservation, lack of strategic coordination of conservation actions at the landscape scale, inaccessibility of relevant science and tools, and the unprecedented challenge of addressing climate change. Climate change increasingly interacts with and exacerbates threats posed by human impacts and deepens the challenge of successful grassland management.

Management Responses

To prevent or remediate grassland loss, managers may use one or multiple strategies, including land acquisition, designation of protected areas or special management areas, conservation easements, policies and nonregulatory guidance, and grassland restoration. Grassland managers also work to address sources of grassland degradation by using prescribed grazing, fire, and other tools to maintain heterogeneous and biodiverse grassland ecosystems. Importantly, many agencies, departments, and organizations work with private landowners to promote similar conservation actions on private land. Grassland managers work to address contributing factors by conducting public outreach and education, advocating for policy change, providing economic incentives for conservation, increasing coordination and collaboration across agencies and organizations, increasing access to usable tools and science, and developing and use new ways of thinking.

Information Needs

From the review and synthesis of grassland management documents, we identified information needed for grassland managers to meet multiple goals while promoting conservation in a changing climate. These information needs can be summarized in three broad questions:

1. How will climate change interact with current grassland threats and stressors?;
2. How will climate change impact the efficacy of present management actions?; and
3. How (and where) should grassland conservation and management actions be prioritized given the projected impacts of climate change?

Related to these questions, this report identifies 15 main categories of needed information, with more specific information needs listed under each category for a total of 70 questions that—if answered—could help grassland managers be more successful in meeting goals and addressing challenges in a changing climate.

Although not exhaustive, this report offers a starting point for understanding grassland management priorities across the North Central region. The review of management documents and informal consultation with managers across the region allowed the MPWG to identify an extensive range of grassland manager goals, priorities, and actions; distinguish the main threats to conservation in various grassland ecoregions; and identify information needed to help grassland managers be more successful in meeting goals while promoting conservation in a changing climate. The Climate and Ecology Working Group is reviewing and synthesizing scientific literature to answer these questions, where possible, and to identify where additional research is needed. Findings from a planned, forthcoming report, along with findings presented in this report, should serve as a baseline of information to help inform future research that will be relevant and useful for supporting grassland management aligned with conservation in a changing climate.

Chapter A.

Background and Methods

By Christine D. Miller Hesed,[1] Heather M. Yocum,[1] and Sarah Jaffe[2]

Acknowledgments

We would like to thank Windy Kelley (University of Wyoming Extension), Toni Klemm (U.S. Department of Agriculture, Agricultural Research Service [ARS]), Dannele Peck (ARS), Lauren Porensky (ARS), and Matt Reeves (U.S. Department of Agriculture, Forest Service) for their helpful suggestions and feedback in developing the maps for this report. We would also like to thank Marissa Ahlering (The Nature Conservancy), Aparna Bamzai-Dodson (U.S. Geological Survey [USGS]), Molly Cross (Wildlife Conservation Society), Kevin Ellison (American Bird Conservancy), Kimberly R. Hall (The Nature Conservancy), Brian Miller (USGS), R. Chelsea Nagy (Cooperative Institute for Research in Environmental Sciences [CIRES], University of Colorado Boulder), Amy Symstad (USGS), Ben Wheeler (Pheasants Forever and Quail Forever), and David J. A. Wood (USGS) for their edits and additions to this chapter.

Abstract

Understanding how climate change and variability will affect grassland ecosystems is crucial for successful management of grasslands in the 21st century. In 2020, the North Central Climate Adaptation Science Center began a project to establish a baseline of information to best serve grassland managers at Federal, State, and Tribal agencies and nongovernmental organizations in the region comprised of Colorado, Wyoming, Montana, North Dakota, South Dakota, Nebraska, and Kansas. This effort had two primary goals: (1) to synthesize the management goals and challenges for grassland managers across the region and (2) to assess the state-of-the-science and identify knowledge gaps for addressing these goals and challenges within the context of climate change. This project sought to synthesize existing information in order to reduce stakeholder fatigue and leverage ongoing research in grassland ecosystems. We convened subject matter experts in two working groups and an advisory committee to identify and systematically review 183 grassland-relevant management documents and provide feedback on initial findings. Although this effort was extensive, this work points to the need for additional research to understand information and research needs to support grassland management on land owned by Tribal nations and private individuals. Additional outreach to grassland managers would further enhance these findings.

Background

Importance of Grasslands

Grasslands are one of the most endangered ecosystems in the world (Samson and Knopf, 1994; Samson and others, 2004; Noss, 2013; Bardgett and others, 2021), with less than 5 percent legally protected worldwide (Hoekstra and others, 2005). For this report, grassland refers to grass-dominated landscapes, including native or reclaimed prairie and improved grasslands. Characterized by the dominance of grasses and other herbaceous species (see Allen and others, 2011), grasslands are found in temperate and tropical regions and about 31–43 percent of land globally (Gibson and Newman, 2019, p. 3–4). Grasslands provide numerous ecosystem services including stormwater management (Flynn and others, 2017), soil water conservation during drought, aquifer recharge, soil conservation, improved soil properties, and carbon storage (Gibson and Newman, 2019, p. 3–4). Grassland carbon storage may be more secure than that of forests, especially in the context of increasing wildfire (Dass and others, 2018). In addition, grasslands are crucial to global food security (O’Mara, 2012), provide habitat to species found nowhere else, and support the economies of ranching communities and pastoralists around the globe. Of the grassland types around the world, native temperate grasslands—including those in the North Central region of the United States—are particularly vulnerable to conversion to alternate land uses. These temperate grasslands formerly occupied about 8 percent of land globally (White and others, 2000; Henwood, 2010); however, conversion of temperate grasslands outpaces protection by a ratio of 8:1 (Hoekstra and others, 2005; Doherty and others, 2013).

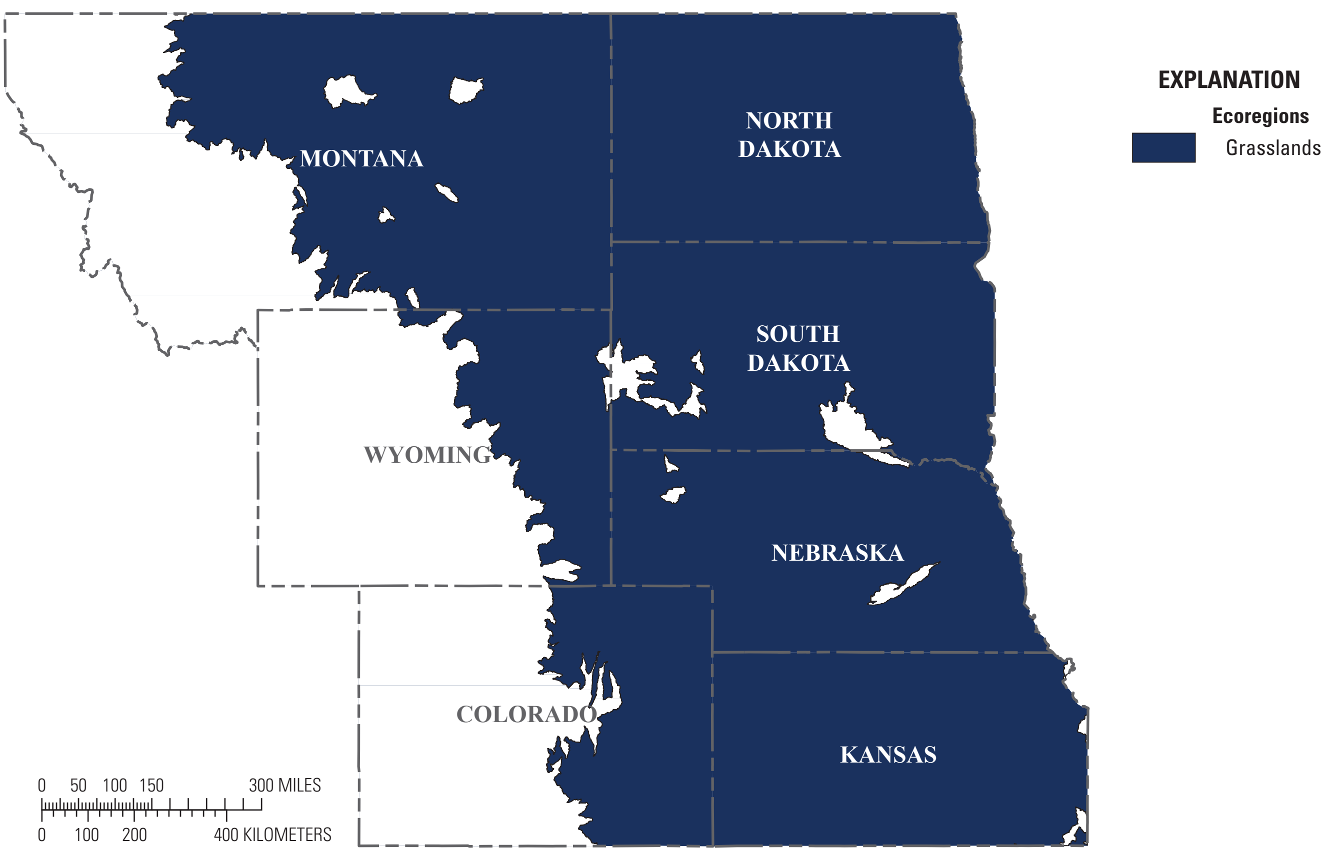
[1]North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder.

[2]Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder.

The North Central Climate Adaptation Science Center—Grasslands Synthesis Project

Understanding how climate change and variability will affect grassland ecosystems is crucial for successful management of grasslands in the 21st century. Grassland ecosystems exist in each of the seven States in the region serviced by the North Central Climate Adaptation Science Center (NC CASC): Colorado, Wyoming, Montana, North Dakota, South Dakota, Nebraska, and Kansas. Throughout the report, we referred to the seven States as the “North Central region,” whereas we referred to areas in States where biophysical characteristics support grassland ecosystems as the “North Central Grassland Ecoregions” (fig. A1). The grassland ecosystems within these ecoregions included embedded wetlands and waterways and support local economies, Tribal communities, livestock grazing, diverse plant and animal communities, and large-scale migrations of ungulates and several bird guilds. Climate change affects all these parts of the grassland ecoregions.

In 2020, the NC CASC began a project to establish a baseline of information to best serve grassland managers (that is, those who develop grassland management plans or implement those plans on the ground) at Federal, State, and Tribal agencies and nongovernmental organizations (NGOs) and to help meet regional grassland management goals. The findings from the Grasslands Synthesis project are described in two volumes. This report, “Grassland Management Priorities for the North Central Region,” serves several purposes, by providing (1) a synthesis of regional grassland management goals and challenges; and (2) identification of important questions relevant to grassland management in a changing climate. The synthesis and identification of climate change questions presented in this report helped guide the development of the companion to this report, “Synthesis of Climate and Ecological Science to Support Grassland Management Priorities in the North Central Region.” This companion report builds on the findings presented here by reviewing the existing scientific literature to identify where these information needs are already addressed and where additional research is needed.



Base from Esri and its licensors, copyright, 2023
Web Mercator (auxiliary sphere)
World Geodetic System of 1984

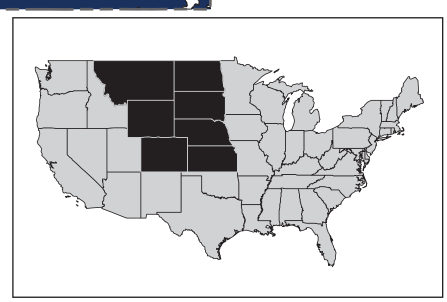


Figure A1. Map showing areal extent of grasslands within the North Central region of the United States. This report considered only the area shown in navy on this map.

Methods

Recruitment of Project Team

The NC CASC served as the administrative lead for the preparation of this report. In November and December of 2020, individuals knowledgeable in grassland management and research were recruited from Federal, State, and Tribal resource management agencies and NGOs to serve on one of three project groups.

Management Priorities Working Group

The Management Priorities Working Group (MPWG) included 11 individuals with knowledge of grassland management from Federal, State, and Tribal agencies and NGOs across the region (table A1). The MPWG synthesized grassland management goals and challenges and identified questions and information needed to allow grassland managers to meet their goals within the context of climate change. Two graduate research assistants supported the MPWG by: creating the maps for the report, calculating management and ecoregion areas, and providing input on Tribal Nations

Climate and Ecology Working Group

The Climate and Ecology Working Group (CEWG) included 24 scientists with various specialties relevant to climate change and grassland management (table A2). The CEWG assessed the state of knowledge in climate science relevant to grasslands, including trends in climate variability and projections of future climate change and extremes. This group also examined how climate shapes grassland ecosystems and identified ecological responses to climate variability and change across the grasslands, including but not limited to tipping points, droughts, fire regimes, invasive species, shifting species distributions, interactions with land use and fragmentation, and changes in ecological communities.

Table A1. Management priorities working group members.

Name	Institution
Marissa Ahlering	The Nature Conservancy
Aparna Bamzai-Dodson	U.S. Geological Survey, North Central Climate Adaptation Science Center
Jon P. Beckmann	Kansas Department of Wildlife and Parks
Emily Boyd-Valandra	Rosebud Sioux Tribe
Molly Cross	Wildlife Conservation Society
Kimberly R. Hall	The Nature Conservancy
Brian W. Miller	U.S. Geological Survey, North Central Climate Adaptation Science Center
Christine D. Miller Hesed	North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder
Danika Mosher	National Park Service Research Assistant, Student Contractor to U.S. Geological Survey, North Central Climate Adaptation Science Center
James Rattling Leaf, Sr.	Great Plains Tribal Water Alliance
Ian Tator	Wyoming Game and Fish Department
Ben Wheeler	Pheasants Forever, Quail Forever
Heather M. Yocum	North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder

Table A2. Climate and ecology working group members.

Name	Institution
Marissa Ahlering	The Nature Conservancy
Katherine J. Chase	U.S. Geological Survey, Wyoming-Montana Water Science Center
Shelley Crausbay	Conservation Science Partners
Ana D. Davidson	Colorado Natural Heritage Program, Department of Fish, Wildlife and Conservation Biology, Colorado State University
Julie Elliott	U.S. Department of Agriculture, Natural Resources Conservation Service and Northern Plains Climate Hub
Kevin Ellison	American Bird Conservancy
Jim Giocomo	American Bird Conservancy
David Hoover	U.S. Department of Agriculture, Agricultural Research Service
Toni Klemm	U.S. Department of Agriculture, Agricultural Research Service
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Christine D. Miller Hesed	North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder
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Alexander V. Zale	U.S. Geological Survey, Montana Cooperative Fishery Research Unit

Advisory Committee

The Advisory Committee (AC) consisted of 22 volunteers, including grassland resource managers, researchers, scientists, decision makers, and members of relevant NGOs and boundary organizations (table A3). The AC assisted working groups by helping to identify information and providing feedback on the written syntheses.

Review of Grassland Management Literature

In January 2021, the MPWG began collecting—including plans, reports, summaries, and peer-reviewed literature—authored by or relevant to grassland management organizations and agencies across the North Central region. This collection included documents that directly addressed grassland management (for example, State wildlife action plans) and documents more tangentially related to grassland management (for example, fire management plans). The MPWG shared an initial compilation of documents with the AC and CEWG in February 2021 for recommendations for additional documents that should be included in the MPWG review. In total, the MPWG collected 300 grassland-relevant management documents.

Table A3. Advisory committee members.

Name	Institution
David Augustine	U.S. Department of Agriculture, Agricultural Research Service
Katie Bills Walsh	U.S. Department of Agriculture, Agricultural Research Service
Alice Boyle	Division of Biology, Kansas State University
Anthony Ciocco	Bureau of Indian Affairs
Lisa Dilling	North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder
Laura Edwards	South Dakota State University Extension
Brad Guhr	Dyck Arboretum
Brice Hanberry	U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station
Chris Helzer	The Nature Conservancy
Rachel Keen	Division of Biology, Kansas State University
Doug Kluck	National Oceanic and Atmospheric Administration
Brian Obermeyer	The Nature Conservancy, Tallgrass Prairie Preserve
Kim O'Keefe	Department of Botany, University of Wisconsin Madison
Graeme Patterson	JV8 Central Grasslands Conservation Initiative
Dave Pellatz	Thunder Basin Grasslands Prairie Ecosystem Association
Ronald Pritchert	U.S. Fish and Wildlife Service
Geri Proctor	U.S. Department of Agriculture, Forest Service, Thunder Basin National Grassland
Madeleine Rubenstein	U.S. Geological Survey, National Climate Adaptation Science Center
Alden Shallcross	Bureau of Land Management, Montana/Dakotas Office
Stefan Gabriel Tangen	Great Plains Tribal Water Alliance and North Central Climate Adaptation Science Center
Alisa Wade	U.S. Geological Survey, North Central Climate Adaptation Science Center
Catherine Wightman	Northern Great Plains Joint Venture
Ben Zuckerberg	Department of Forest and Wildlife Ecology, University of Wisconsin Madison

During February and March 2021, the MPWG systematically reviewed the collection of grassland management-relevant documents by (1) noting aspects of scale, methodology, jurisdiction, State, ecoregion, primary use or goal, stressors and threats, management methods, climate change, and science needs in a table and (2) using a template to write annotated notes for each document. The MPWG met by means of video conference every 2 weeks to refine the review process and discuss the themes present in the management documents. By the end of March 2021, the MPWG had systematically reviewed 183 grassland-relevant management documents (see fig. A2) and was no longer finding new grassland management goals and challenges. These reviewed documents spanned 39 years, with most documents dated between 2010 and 2019.

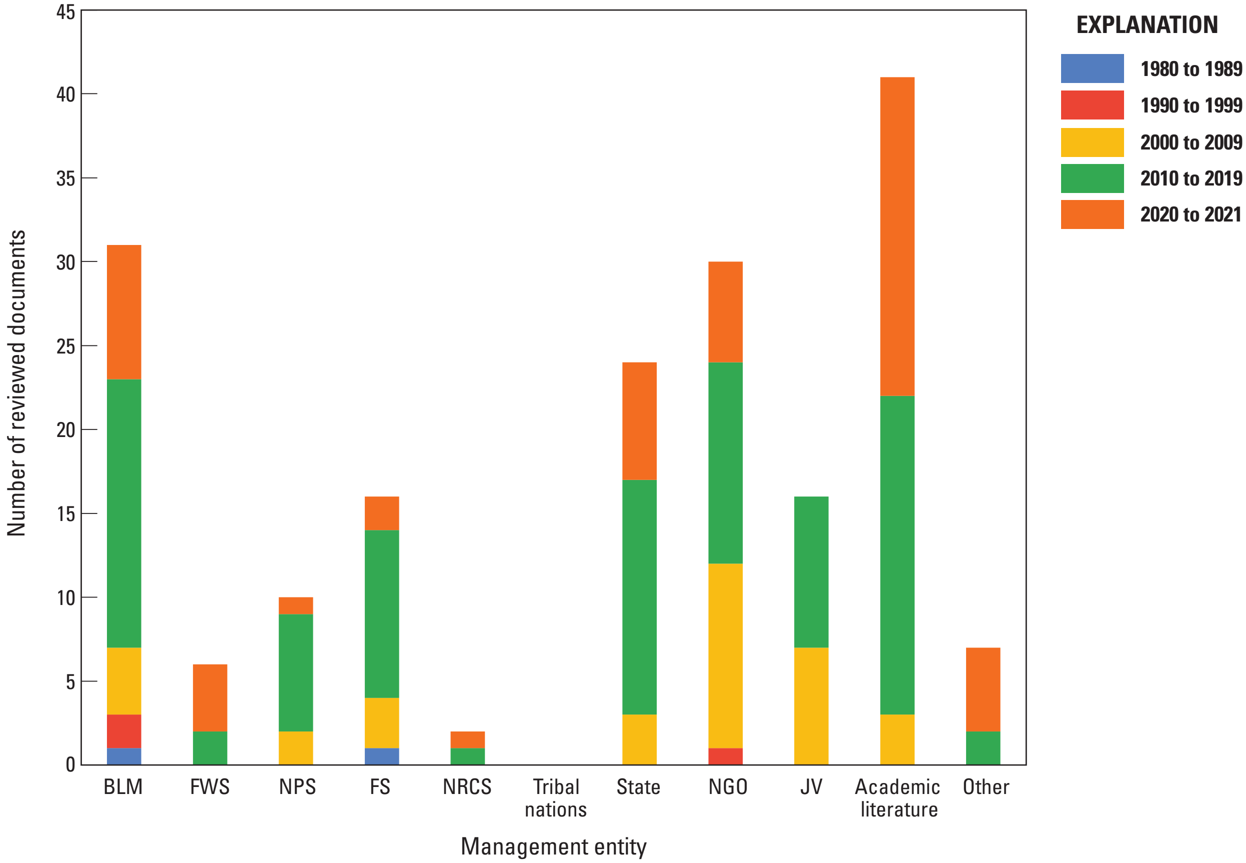

Figure A2. Distribution of reviewed documents by decade and management category. Academic literature documents pertained to general grassland management issues. The other category includes government reports or management plans that did not fit in other categories. Documents pertaining to Tribal nations were not able to be obtained for the systematic review; however, Tribal nations' grassland management goals and information needs were incorporated into the synthesis using informal consultation. BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, Natural Resources Conservation Service; NGOs, nongovernmental organizations; JVs Migratory Bird Joint Ventures.

Having reached inductive thematic saturation (that is, no new themes were emerging from the continued review of new management documents; see Guest and others, 2020), the MPWG prepared an outline of its synthesis and presented it to the AC and CEWG for feedback during a 90-minute video conference on April 9, 2021 to elicit feedback. The MPWG used responses to revise and refine the synthesis in this report and shared a subsequent draft of the report with the AC and CEWG for review prior to submission to peer reviewers.

As part of the synthesis, the authors compiled tables to summarize main findings regarding management entities' grassland management actions (see tables C3, C5, and C13) and information needs (see tables C4, C6–C12, and C14–C19). Initial estimations of importance ratings in these tables were based on our review of the grassland-relevant management documents. Specifically, the MPWG ranked management actions as follows:

1. Major: MPWG assigned this rating if the relevant, reviewed documents mentioned the action frequently or indicated that considerable resources were dedicated to that action.

2. Minor: MPWG assigned this rating if relevant documents mentioned it as a management action, but to a lesser degree.

Similarly, the MPWG ranked the synthesized information needs as follows:

1. Highly relevant: MPWG assigned this rating when the synthesized information need supported a management entity's major activities or closely aligned with information needs either directly stated in or inferred from relevant management documents.

2. Somewhat relevant: MPWG assigned this rating when the synthesized information need indirectly supported a management entity's major activities, supported only "minor" management activities, or was indirectly related to information needs directly stated or inferred from relevant documents.

3. Not relevant: MPWG assigned this rating when a synthesized information need primarily informed management activities outside of the scope of the management entity in question.

Although the MPWG rankings were informed by extensive review of management documents, we recognized some priorities for agencies may be internal, and therefore, not well represented in the documents we reviewed.

We also reached out to a representative from each management entity to make sure our estimations accurately reflected the actions and information needs of each agency and organization. The values in the tables regarding grassland management actions (tables C3, C5, and C13) and information needed (tables C4, C6–C12, and C14–C19) should be interpreted as approximations because a single value cannot adequately represent the nuances of management actions or information priorities, which may differ across offices and geographies and even within a single agency.

Limitations of Literature Review

The NC CASC chose to assess the climate-relevant science needs of grassland managers by synthesizing existing grassland management plans, reports, and other literature rather than conducting original research using interviews and surveys for three reasons. First, resource managers in the North Central region have many demands on their time and energy and the NC CASC did not wish to further burden them with interviews and surveys. Second, the emergence of the Coronavirus Disease 2019 pandemic at the start of this project further discouraged the NC CASC from using methods like interviews and workshops that are most effectively conducted in person, especially with Tribal resource managers and Tribal communities. Third, the number of previous and ongoing grassland-relevant management projects—with accompanying documents—is numerous, and the NC CASC perceived a need to assess shared issues and opportunities across these efforts to help inform priorities for research at the NC CASC and support decision-making among grassland managers. A synthesis is appropriate and useful for meeting these goals (Wyborn and others, 2018).

Although our review of was quite extensive, it nevertheless had limitations. First, we were almost entirely limited to publicly available documents, which meant that our review of documents relevant to various grassland management entities was somewhat uneven. Notably, we were unable to locate and review any documents related to grassland management by Tribal nations. This limitation was in part because of the complications in contacting Tribal offices during the disruptions of the Coronavirus Disease 2019 pandemic. In addition, many Tribal nations have not yet developed formal resource management plans, whereas others have developed plans but have elected not to make them publicly available.

Similarly, our approach was somewhat limiting for understanding the goals, challenges, and information needs of private landowners. Private landowners manage the majority of grasslands in the North Central region; however, management practices are quite diverse, and documents specific to private grassland management are difficult to obtain. In some cases, private landowner perspectives were at least partially represented in documents in the NGO and Migratory Bird Joint Venture categories (Neely and others, 2006; D.J. Case and Associates, 2014). In general, conservation groups (who may also privately own land) and collaboratives focused on grassland conservation assigned high priority to partnering with individual private landowners to achieve common goals. We also reviewed one example of a strategic plan developed by an NGO and land trust led by ranchers, the Sandhills Task Force (2014). This group seeks to "enhance the Sandhill wetland-grassland ecosystem in a way that sustains profitable private ranching, wildlife and vegetative diversity, and associated water supplies" (Sandhills Task Force, 2014, p. 5). Thus, although we have some representation of this key group, we recognized our sample is limited and other successful conservation management by individual, private landowners and private landowner cooperative groups is likely underrepresented in this document.

Because of capacity constraints, the MPWG focused its review and synthesis on documents pertaining to the management of terrestrial aspects of grassland ecosystems. Thus, this report does not consider in detail the management of wetlands and waterways embedded within the grassland ecosystems. Finally, we recognized our approach was limited by the fact that publicly available documents do not always include emerging issues, concepts, or tools most salient in internal resource management discussions and planning. These emerging issues may be excluded from publicly available reports because of the time it takes for a new issue or idea (for example, climate change) to become broadly accepted by the management team and then incorporated into their strategic planning.

The MPWG used several strategies to address these limitations in our document review. First, the core research team worked closely with Shelby Ross, a graduate student at University of Colorado Boulder and a member of the Oglala Sioux Tribe, and Emily Boyd-Valandra, a Tribal resource manager and member of the Rosebud Sioux Tribe to assist us in incorporating general information about Tribal grassland management goals and challenges across the NC CASC region. Stefan Tangen, regional Tribal Climate Resilience Liaison, and Anthony Ciocco, Bureau of Indian Affairs Environmental Protection Specialist and member of the Muscogee Creek Nation, also helped include information from Tribal nations in the region. James Rattling Leaf, also a member of the Rosebud

Sioux Tribe and the MPWG, facilitated introductions to members of other Tribal nations who were informally consulted for feedback on this report.

Second, we attempted to include the concerns of private landowners in this report by highlighting the ways in which government and NGOs engaged with private landowners through their programming. Third, we emphasized the importance of wetlands and waterways for grassland ecosystems in the section “Change in Water Quality and Quantity” of “Chapter C—Grassland Management Goals, Challenges, and Information Needs.” We also highlighted structural barriers to a more holistic understanding of grassland ecosystems that incorporates the complex interlinkages between terrestrial and aquatic systems in the section “Frameworks for Conceptualizing Problems and Solutions” of “Chapter C—Grassland Management Goals, Challenges, and Information Needs.” Finally, the MPWG iterated on its synthesis of information from documents by seeking feedback and input from the AC and CEWG to address the possibility that reviewed documents omitted important emerging issues. In addition, representatives of agencies and departments were consulted for targeted feedback on summary tables to ensure their priorities and management activities were accurately represented.

This report provides starting point for understanding grassland management priorities across the North Central region. Through review of management documents and informal consultation with managers, the MPWG identified a wide range of grassland manager goals, priorities, and actions; distinguished the main threats to conservation in various grassland ecoregions; and identified information needed to help grassland managers be more successful in meeting their goals while promoting conservation in a changing climate.

Development of Maps and Acreage Determinations

New maps developed for this report (1) depicted the five general grassland ecoregions assessed by the MPWG in their review of documents, (2) illustrated the diversity of management agencies and organizations across the North Central region, and (3) facilitated the calculation of acreages for ecoregions and management jurisdictions. A forthcoming report to provide a full description of the methods used for creating these maps is planned. Key points necessary for understanding the maps and acreage calculations in this report are highlighted in this chapter.

The MPWG wanted to define general grassland ecoregions to synthesize how threats and management challenges might be similar or different across the North Central region. Although many different ecoregion maps exist (for example, Environmental Protection Agency Ecoregions [U.S. Environmental Protection Agency, 2022], Natural Resources Conservation Service Major Land Resource Areas [Natural Resources Conservation Service [NRCS], 2022], and NatureServe’s Terrestrial Ecological Systems of the United States [NatureServe, 2021]), they have too many ecoregional categories for the MPWG to accurately and efficiently consider when synthesizing documents. In addition, in consultation with the CEWG and AC, the MPWG learned grassland managers in eastern Wyoming and southeastern Montana had unique management challenges related to being in the transition zone between grassland and sagebrush ecoregions. This transition zone—what we call the Sagebrush-Grassland Ecotone throughout the report—is not represented in the ecoregional maps the MPWG identified.

Because existing maps did not meet the MPWG’s needs, new maps were created by drawing on data from LANDFIRE’s biophysical settings (LANDFIRE, 2020), The Nature Conservancy’s Terrestrial Ecoregions (The Nature Conservancy [TNC], 2019), and the sagebrush biome defined by Jeffries and Finn (2019). We selected LANDFIRE’s biophysical settings dataset instead of LANDFIRE’s existing vegetation dataset because we wanted to define ecoregions based on the potential grassland type; the existing vegetation dataset instead showed the altered, anthropogenic vegetation (for example, pastures). Because the LANDFIRE data are in raster format (that is, pixelated) and we wanted to define the outlines of the ecoregions, we mapped the raster data onto hydrologic units (HUC 10; NRCS, 2020) and then classified each HUC 10 according to the predominant type of LANDFIRE pixel. Modification of the resulting shortgrass region was determined to be necessary by experts on the MPWG familiar with the historical and current extent of shortgrass prairie. To address this, HUCs that fell completely within the TNC (2019) Terrestrial Ecoregion for shortgrass were reclassified as “shortgrass.” We then merged HUC 10s with the same classification to define initial outlines of Tallgrass, Northern Mixed Grass, Central Mixed Grass, and Shortgrass Ecoregions.

To define the boundaries of the Sagebrush-Grassland Ecotone, we identified where the sagebrush biome (Jeffries and Finn, 2019) overlapped with our initial grassland ecoregions (described above). Where they overlapped, any HUC with more than 0 percent sagebrush cover was reclassified as part of the Sagebrush-Grassland Ecotone. At this point, we had our map defining five grassland ecoregions. (Because we used the HUCs to help define boundaries between ecoregions, the shape of ecoregional borders may not be familiar to those who are accustomed to other maps.) Variously sized circles represented the percent of sagebrush cover within each HUC, with each circle size separated into five Jenks natural breaks buckets (rounded to the nearest five; Jenks, 1967). Note these ecoregions defined where particular grassland ecosystems could exist; however, in reality, much of the grasslands in the North Central region has been converted to other land cover and land uses. To identify where intact grasslands (that is, grasslands that have not been converted to cropland since at least 2014—the year the World Wildlife Fund began tracking conversion of grassland to cropland) currently exist, we superimposed the World Wildlife Fund's interactive Plowprint report map (World Wildlife Fund, 2021) on the North Central Grassland Ecoregions (see fig. B2).

The MPWG also wanted to understand which agencies, nations, departments, and organizations manage grasslands across the North Central region. We used the U.S. Geological Survey's Protected Areas Database, otherwise referred to as "PAD-US" (U.S. Geological Survey [USGS], 2020), to map land management across the North Central region. This dataset was updated in 2020, though some data still date back to 1994. Land is usually managed and owned by the same entity, but there are exceptions. Because we were primarily interested in grassland management, we used the management data embedded in the PAD-US dataset. We reclassified the PAD-US data to represent eight publicly managed land categories and four privately managed land categories. Publicly managed lands were defined as any Federal, Tribal, State, district, local, or jointly managed land as defined by PAD-US. Federally managed lands were further identified as being managed by the Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, or U.S. Department of Agriculture, Forest Service. Lands managed by any other Federal agency were lumped together and classified as "other Federal agencies". Public lands managed by district, local, or joint government efforts (for example, county and city collaborative management) were all classified in our map as "regional" and "local".

We categorized private lands in several ways. All lands listed as managed by NGOs were classified as NGO. Likewise, all protected areas listed as privately managed were classified as protected private lands. Determining how to classify lands with easements was much more challenging because we had to determine (1) what types of easements prevented grassland conversion, (2) what easements were permanent, and (3) who actually managed the lands under easement. In figure B5, the areas classified as "Conservation and Ranchland Easements" is a conservative estimate because we included only easements that are accounted for in the PAD-US database that we could verify as permanently preventing grassland conversion.

Acreages were determined using ArcGIS Map's Calculate Geometry tool in the USA Contiguous Albers Equal Area Conic USGS version projection. One challenge in calculating acreages from the PAD-US dataset was that management areas were sometimes overlapping. Wherever possible (that is, for State and grassland ecoregion data only), we calculated acreage without using the PAD-US dataset. When calculating other acreages, including redundant acreage was unavoidable because of the overlapping areas inherent in the large, aggregated PAD-US dataset. Therefore, where possible we reported proportions of grassland ecoregions managed by various entities rather than number of acres. Measures of proportions and acreage held by management entities should be considered a rough estimate.

Please note that the maps presented in this report were reviewed by the MPWG and CEWG to verify appropriate representation of grassland ecoregions and management in the North Central region. The maps presented are limited by the source data available and generated through a sincere effort from a team of interested parties and experts in their fields. These maps provide a general representation of ecoregion and management patterns across the North Central region.

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Chapter B.

Introduction to the North Central Grassland Ecoregions

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Abstract

This chapter defines and describes five grassland ecoregions of the North Central Region: Tallgrass, Northern Mixed Grass, Central Mixed Grass, Shortgrass, and the Sagebrush-Grassland Ecotone. We describe the spatial extent, vegetation, climate, and management for each ecoregion. The Tallgrass Ecoregion encompasses nearly 44.6 million acres across the eastern edge of North Dakota, South Dakota, Nebraska, and Kansas. The Northern Mixed Grass Ecoregion encompasses more than 83 million acres across northern Montana, central North and South Dakota, and smaller areas in Wyoming and Nebraska. The Central Mixed Grass Ecoregion encompasses nearly 57 million acres in central Nebraska and Kansas with small areas in southern South Dakota, eastern Wyoming, and eastern Colorado. The Shortgrass Ecoregion encompasses more than 44 million acres in eastern Colorado and western Nebraska and Kansas, with small areas in Wyoming and South Dakota. The Sagebrush-Grassland Ecotone is a transition area between the arid high deserts of the Wyoming Great Basins and the grasslands of the Great Plains and encompasses more than 67 million acres primarily in Montana and Wyoming, with small areas in North Dakota, South Dakota, and Nebraska.

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Introduction

The grasslands in the North Central region are part of the central grasslands of North America—often referred to as "the Great Plains"—that stretch from Canada to Mexico (fig. B1). The western edge of the Great Plains is defined by the Rocky Mountains (Inter-university Consortium for Political and Social Research, 2018). The eastern edge—where grasslands transition to woodland—is harder to define (see Rossum and Lavin, 2000; Hanberry, 2020). The Great Plains eastern boundary put forward by Dixon and others (2014) was used in this report; that boundary includes Iowa, Illinois, and parts of Minnesota and Missouri, but otherwise, generally follows the eastern edge of the North Central States (see fig. B1). This chapter first describes the formation of the central grasslands of North America. Then defines the five grassland ecoregions of the North Central region and describe the grassland ecosystems that characterize them: Tallgrass, Northern Mixed Grass, Central Mixed Grass, Shortgrass, and the Sagebrush-Grassland Ecotone. For each ecoregion, the spatial extent, vegetation, climate, and management are described.

Formation of the Central Grasslands of North America

The Great Plains were influenced by the legacy of multiple episodes of periodic glaciation and retreat during the Pleistocene and Holocene. During glacial maximums (when ice sheets are at their maximum extent), the northern parts of the Great Plains region were under ice, whereas regions close to the ice sheet edge and more southerly would have experienced different climates because of effects of the ice sheets on weather patterns (Bartlein and others, 1998; Ruddiman, 2014). At the last glacial maximum, the parts of the northern Great Plains not under ice were largely covered by *Pinus* L. (pine) or *Picea* A. Dietr. (spruce) forests (Barnosky, 1989; Yansa, 2006; Grimm and others, 2011). As the ice sheets melted, they left behind glacial till (unsorted sediment derived from the erosion of material by glaciers) and a smoothed topography, which created distinctions marking differences in soils and hence spatial ecosystem aggregations (Omernik, 1987; U.S. Department of Agriculture, 2022). Newly exposed soils from

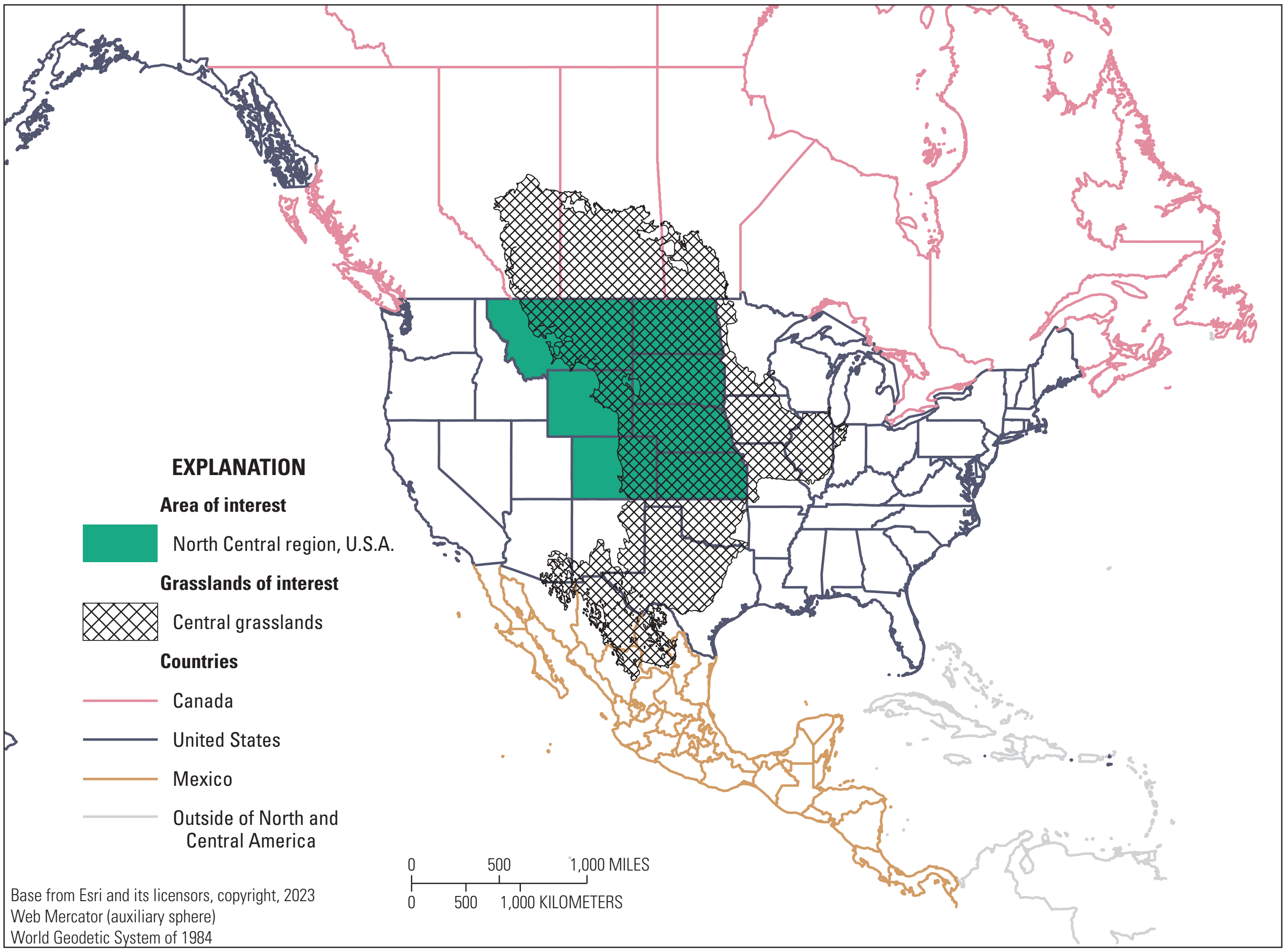

Figure B1. Central grasslands of North America. Modified from Dixon and others (2014).

glacial retreat underwent primary succession, whereas changes in the climate patterns caused vegetation community changes in the Great Plains. Furthermore, ice blocks were left buried in glacial till following glacial retreat and their slow melting (over hundreds or thousands of years), along with poor stream development (causing many closed watersheds) led to depressional wetlands known as prairie potholes (Johnson and others, 2008). Found across northern Montana, North Dakota, South Dakota, and into Nebraska, Minnesota, and Iowa, prairie potholes are important for waterfowl.

Since the last glacial maximum, the Great Plains shifted from woodlands to grasslands. During glacial retreat from 20,000 to 12,000 years ago, pine and spruce moved northward, and were replaced by grasslands with scattered trees in formerly glaciated regions (Yansa, 2006; Grimm and others, 2011). As temperatures continued to warm, *Ulmus* L. (elm) and *Quercus* L (oak) deciduous parklands followed, establishing from south to north (Yansa, 2006). Further warming and continued drying at 10,000 years ago led to the loss of evergreen and deciduous tree parklands, leaving the existing grasses and shrubs, species which could persist with increased fire and limited moisture (Axelrod, 1985; Yansa, 2006; Nordt and others, 2008; Williams and others, 2010; Grimm and others, 2011). Grass species also shifted during this time as warm season grasses moved northward (Fredlund and Tieszen, 1997; Nordt and others, 2008). Over the entire Great Plains, during the period of 12,000 to 6,700 years ago, the presences of warm season grasses increased, but with local variation mediated by site-specific factors (Nordt and others, 2008; Williams and others, 2010). A significant dry period began between 10,000 and 8,000 years ago in the interior of the Great Plains and moved outward (Williams and others, 2010) characterized by increases in the presence of warm season grasses along with higher elevation pine woodlands shifting to more grasses (Barnosky, 1989; Fredlund and Tieszen, 1997). The end of this dry period started shifts in species communities towards what is seen today. The pollen record showed wetter conditions started between 6,000 and 4,400 years ago, starting earlier on the western side of the Great Plains and more recently on the eastern side (Barnosky, 1989; Grimm and others, 2011). The distribution of grasses shifted with more cool season species at northern latitudes and more warm season species at southern latitudes, with the balance point at about 46° N (Fredlund and Tieszen, 1997; Nordt and others, 2008). Around 2,700 years ago, plant communities in the Great Plains became similar to those nonindigenous settlers would have encountered in the 1850s (Baker and others, 2000). Interactions among climate, fire, and grazing continued to shape these plant communities for thousands of years.

From time immemorial, Indigenous peoples helped shape the central grasslands by setting fires and hunting (The Nature Conservancy and the Osage Plains/Flint Hills Prairie Ecoregional Planning Team, 2000, p. 7). Indigenous peoples have been living on the Great Plains hunting prehistoric species of mammoth, *Camelus* (camels), *Equus caballus* (horse), and *Ovibos moschatus* (musk oxen), and later, *Bison bison* (bison), *Cervus elaphus* (elk), *Odocoileus virginianus* (white-tailed deer), and *Antilocapra americana* (antelope; Treuer, 2019, p. 85). From these early Indigenous peoples emerged the Crow, Cheyenne, and Arapaho, who organized into highly mobile family groups that followed bison across the plains (Treuer, 2019, p. 86). By the 1400s, the number of Tribes on the Great Plains increased to include the Mandan, Arikara, Hidatsa, Lakota, Dakota, Crow, Cheyenne, Arapaho, Blackfeet, Assiniboine, Cree, Saulteaux, and Plains Ojibwe (Treuer, 2019, p. 84). These Tribes depended on the resources the Great Plains provided and maintained cultures that emphasized the importance of human relationships with nonhuman beings in the natural environment (Tribal Adaptation Menu Team, 2019, p. 8). Central to many of these Tribes was the bison. It was used not only for food, but also for clothing, shelter, tools, and ceremonial purposes (National Park Service, 2018). These Indigenous peoples helped to promote a highly heterogeneous and biodiverse landscape across the Great Plains, particularly by setting intentional fires to prompt fresh growth to lure the grazing animals they hunted (Roos and others, 2018). With nonindigenous settlement of the North Central grasslands around 1850, the natural and human-assisted disturbance regime of fire and grazing was disrupted, and widespread conversion of grassland to cropland began (Mann, 2005, 2012).

The pattern of cropping across the region corresponded with the precipitation gradient and prevalence of private land management, with extensive agricultural conversion of grassland in the east where private landowners could rely on precipitation to provide adequate water for crops. Today, moving west, cropping decreases along with precipitation, and the percentage of public lands increases. The state of grasslands in the North Central region varies from small fragments to large undisturbed patches (fig. B2). As of 2020, only 60 percent of the land in the North Central Grassland Ecoregions is intact grassland (that is, grassland that has not been converted to cropland since at least 2014; fig. B2; see also Gage and others, 2016; Olimb and Lendrum, 2021). The amount of remaining native or potentially undisturbed grassland (that is, grassland that has never been developed or tilled) is likely much lower (see, for example, Fields and Barnes, 2019); however, it was beyond the scope of this project to estimate those amounts for the North Central region.

North Central Grassland Ecoregions

In the North Central region, biophysical characteristics vary to support grassland ecosystems that differ in their predominant vegetation (that is, the relative abundance of tall grasses, short grasses, and sagebrush). For this report, we defined five general North Central Grassland Ecoregions (fig. B3), each of which is characterized by a type of grassland ecosystem: Tallgrass, Northern Mixed Grass, Central Mixed Grass, Shortgrass, and Sagebrush-Grassland Ecotone.

Spatial Extent and Vegetation

The Tallgrass Ecoregion encompasses nearly 44.6 million acres across the eastern edge of North Dakota, South Dakota, Nebraska, and Kansas and is bordered by mixed grass to the west and temperate woodland to the east (see fig. B3). The Tallgrass Ecoregion includes the Flint Hills in Kansas, which is the largest intact, contiguous tract of tallgrass prairie left in North America (and the third most intact grassland remaining on the planet; Duncan, 1978; The Nature Conservancy and the Osage Plains/Flint Hills Prairie Ecoregional Planning Team, 2000, p. 3). The Flint Hills remain intact partly because of their shallow, gravelly soil that overlays bedrock and is therefore unsuitable for cropping (Rohweder, 2015). Ranching and the use of prescribed fire are common in the Flint Hills, which helps to maintain the prairie's biodiversity and ecological functioning (The Nature Conservancy and the Osage Plains/Flint Hills Prairie Ecoregional Planning Team, 2000, p. 5). Dominant grasses in the tallgrass prairie include *Andropogon gerardii* Vitman (big bluestem), *Sorghastrum nutans* (L.) Nash (Indiangrass), *Schizachyrium scoparium* (Michx.) Nash (little bluestem), and *Panicum virgatum* Linnaeus (switchgrass; Ratajczak and others, 2011). These grass species can reach six feet in height (Schneider and others, 2011). Tallgrass prairie also contains many species of wildflowers and other forbs, including *Solidago erecta* Pursh (showy goldenrod), *Liatris pycnostachya* Michx. (prairie blazing star), *Symphyotrichum oolentangiense* (Riddell) G.L. Nesom (skyblue aster), and *Echinacea pallida* (Nutt.) Nutt. (purple coneflower; Schneider and others, 2011).

The Northern Mixed Grass Ecoregion encompasses more than 83 million acres, extending across northern Montana, down through central North and South Dakota with small areas in Wyoming and Nebraska. The Northern Mixed Grass Ecoregion is bordered by the Sagebrush-Grassland Ecotone to the west, Shortgrass Ecoregion to the south, and Tallgrass Ecoregion to the east (see fig. B3). Dominant grasses in the Northern Mixed Grass Ecoregion include *Bouteloua gracilis* (Kunth) Lag. ex Griffiths (blue grama), *Schizachrium*

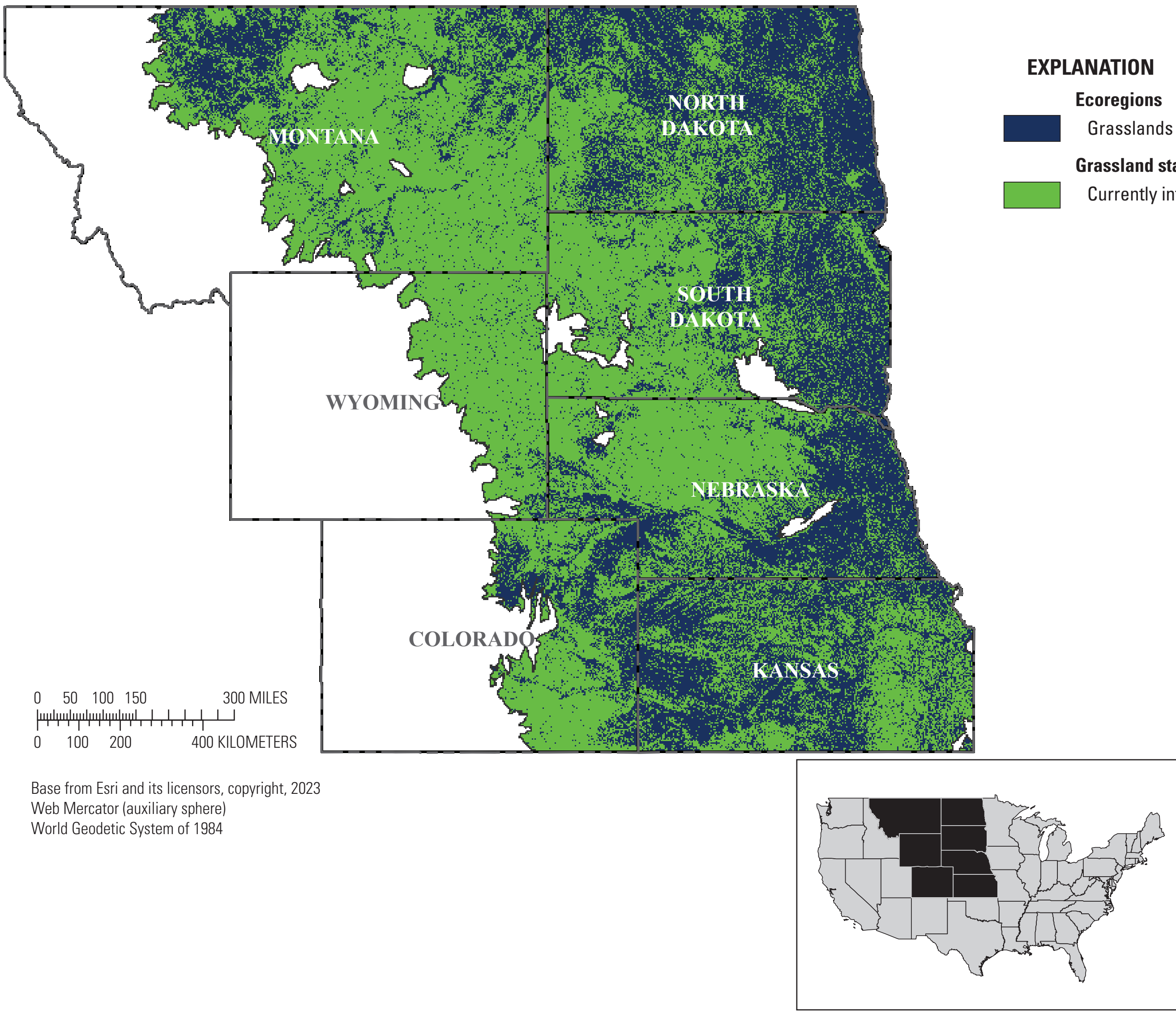

Figure B2. Intact grassland remaining in the North Central Grassland Ecoregions. Currently intact grassland areas are from the World Wildlife Fund (2022) Plowprint 2020 dataset (see also Gage and others, 2016; Olimb and Lendrum, 2021) and includes all grassland that has not been cropland since at least 2014. See also "Chapter A—Background and Methods."

scoparium (Michx.) Nash (little bluestem), *Hesperostipa comata* (Trin. & Rupr.) Barkworth (needle and thread grass), *Pascopyrum* Á. Löve (wheatgrass genus), *Carex filifolia* Nutt. (threadleaf sedge), *Koeleria macrantha* (Ledeb.) Schult. (junegrass), and *Poa secunda* J. Presl (big bluegrass). The northern and eastern portions of these grasslands are interspersed with many seasonal, temporary, semipermanent, and permanent wetlands, also called prairie potholes, which support a wide variety of aquatic and terrestrial species, including some of the most productive migratory waterfowl breeding habitat in the world (see Johnson and others, 2010; South Dakota Game, Fish and Parks, 2014; Dyke and others, 2015; Prairie Pothole Joint Venture, 2017a, b; McKenna and others, 2021).

The Central Mixed Grass Ecoregion encompasses nearly 57 million acres primarily in central Nebraska and Kansas with small areas in southern South Dakota, eastern Wyoming, and eastern Colorado and bordered by the Tallgrass Ecoregion to the east, the Northern Mixed Grass Ecoregion to the north, and the Shortgrass Ecoregion to the west (see fig. B3). The sandhills region of Nebraska is considered one of the largest, remaining intact mixed grass prairie ecosystems in North America (Schneider and others, 2011; Sandhills Task Force,

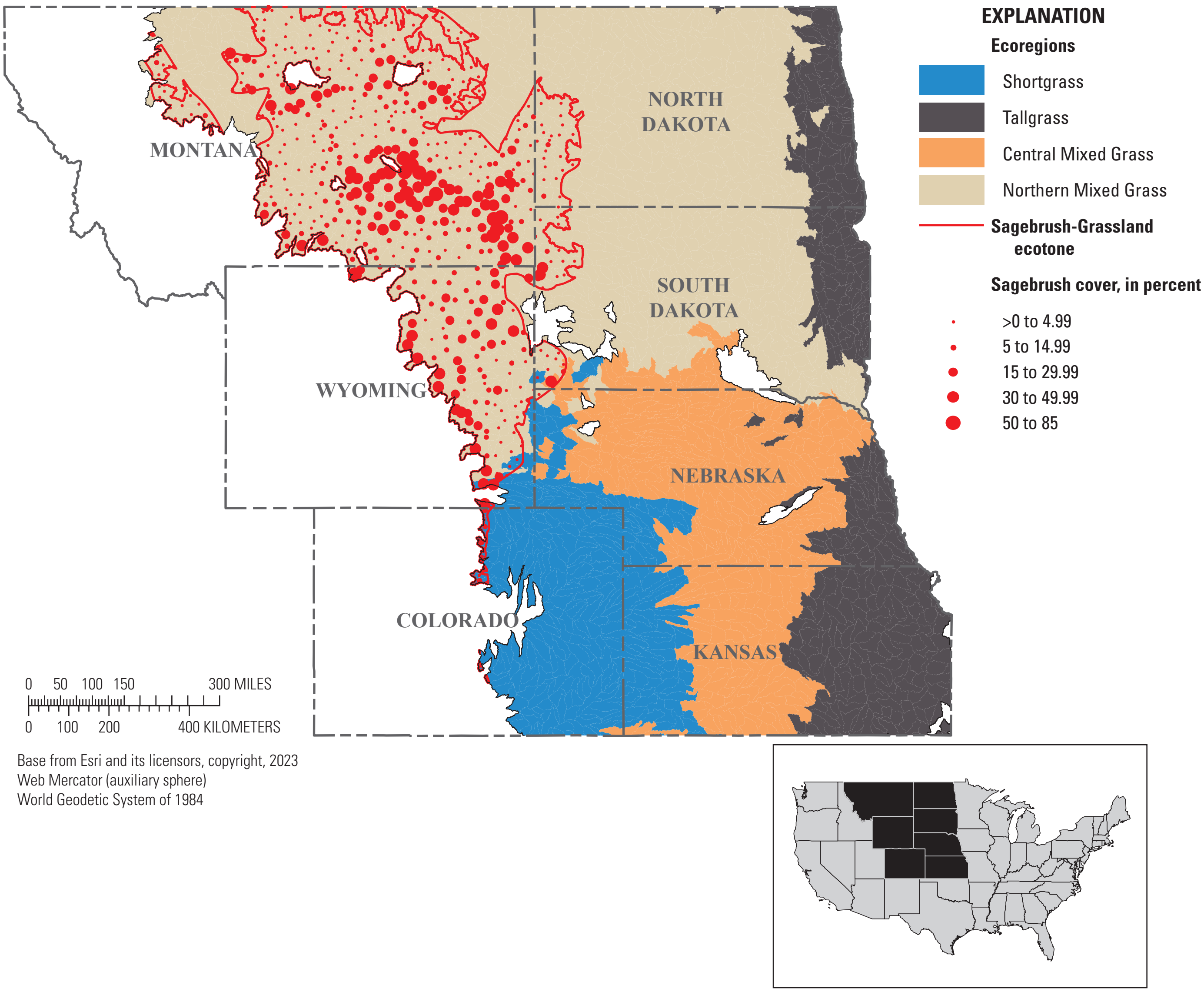

Figure B3. The five North Central Grassland Ecoregions considered in this report. This map was created using LANDFIRE's biophysical settings (LANDFIRE, 2020), The Nature Conservancy's terrestrial ecoregions (The Nature Conservancy, 2019), and the U.S. Geological Survey sagebrush biome data (Jeffries and Finn, 2019). See also "Chapter A—Background and Methods."

2014). Dominant vegetation throughout the central mixed grass prairie includes tall and midheight native grasses, including *Bouteloua curtipendula* (Michx.) Torr. (sideoats grama), *Schizachyrium scoparium* (Michx.) Nash (little bluestem), *Andropogon gerardii* Vitman (big bluestem), *Hesperostipa comata* (Trin. & Rupr.) Barkworth (needle and thread grass), *Pascopyrum smithii* (Rydb.) Barkworth & D.R. Dewey (western wheatgrass), and *Sporobolus cryptandrus* (Torr.) A. Gray (sand dropseed), and drought-resistant, short-grass species such as *Bouteloua gracilis* (Kunth) Lag. ex Griffiths (blue grama) and *Urochloa mutica* (Forssk.) T.Q. Nguyen (buffalo grass) and other associated grasses and forbs (Schneider and others, 2011, p. 105; Colorado Parks and Wildlife, 2015, p. 48). Deciduous and coniferous woodlands are featured along riparian systems and in upland pockets, and complexes of precipitation-driven playa wetlands and subirrigated wet meadows occur throughout the ecoregion.

The Shortgrass Ecoregion encompasses more than 44 million acres, primarily in eastern Colorado and western Nebraska and Kansas, with small areas in Wyoming and South Dakota and is bordered by the Rocky Mountains to the west, the Sagebrush-Grassland Ecotone to the northwest, and central mixed grass to the east (see fig. B3). The shortgrass prairie is characterized by *Urochloa mutica* (Forssk.) T.Q. Nguyen (buffalo grass), *Bouteloua gracilis* (Kunth) Lag. ex Griffiths (blue grama), *Pascopyrum smithii* (Rydb.) Barkworth & D.R. Dewey (western wheatgrass), and other short to medium height grass and forb species (Neely and others, 2006; Colorado Parks and Wildlife, 2015). Playa lakes, salt-desert shrublands, and their associated vegetation occur in small patches whereas riparian shrublands and woodlands occur along streams and rivers in this ecoregion.

The Sagebrush-Grassland Ecotone encompasses more than 67 million acres primarily in Montana and Wyoming, with small areas in North Dakota, South Dakota, and Nebraska and is an area of transition between the Great Plains and more arid high deserts like the Wyoming and Great Basins (see fig. B3). As such, it contains varying proportions of *Artemisia* spp. L. (sagebrush) and grassland plants. Most of the ecotone in the North Central region contains mixed-grass prairie species, including *Hesperostipa comata* (Trin. & Rupr.) Barkworth (needle and thread grass), *Pascopyrum smithii* (Rydb.) Barkworth & D.R. Dewey (western wheatgrass), *Bouteloua gracilis* (Kunth) Lag. ex Griffiths (blue grama), *Poa secunda* J. Presl (Sandberg's bluegrass), *Koeleria macrantha* (Ledeb.) Schult. (prairie Junegrass), *Achnatherum hymenoides* (Roem. & Schult.) Barkworth (Indian ricegrass), and upland sedges. The far southeastern edge of the ecotone also includes shortgrass prairie species, including *Urochloa mutica* (Forssk.) T.Q. Nguyen (buffalo grass) and *Bouteloua gracilis* (Kunth) Lag. ex Griffiths (blue grama; Knight, 1994).

Climate

Because of their interior location, the North Central Grassland Ecoregions experience large variability in climate over the year, from cold winters to warm summers (see fig. B4) and low precipitation and humidity. In 1936, North Dakota recorded 121 °F (July 6) and −60 °F (February 15) as its hottest and coldest temperature, respectively, setting a record for highest annual temperature range across the world within a single year. High winds are a frequent feature of the climate and the free movement of air masses with different characteristics (for example, cold and dry or warm and moist) creates irregular fronts, which can cause a sudden change in temperature (Rosenberg, 1987). The plains are also sensitive to large-scale atmospheric circulation processes, which result in large variability in climate, including wet and dry extremes, from one year to another and from one decade to another.

In the North Central region, temperatures decrease from south to north, but the temperature gradient is small, spanning only 6 °F for the summer maximum, and 12 °F for the winter minimum (fig. B4). There is, however, a strong east-west precipitation gradient with precipitation totals decreasing from east to west (table B1). To a lesser degree, there is also a north-south gradient in precipitation with precipitation decreasing from south to north. The primary source of moisture to the Great Plains is the Gulf of Mexico and much of the precipitation occurs between April and October, with more than 50 percent of annual precipitation coming between April and July (fig. B4). Precipitation in spring and early summer is critical for vegetation growth and ecosystem productivity. The precipitation gradient affects plant distribution and abundance across the region, limiting the expansion of tallgrass prairie to the west (Neely and others, 2006). The precipitation gradient has also driven land-use patterns across the North Central grasslands. In particular, the conversion of grasslands to cropland has followed the precipitation gradient, with widespread cropping in the east transitioning to livestock pasturing in the west (Gutmann and others, 2005).

Grassland Management

The grasslands in the North Central region are managed by a diverse group of Federal and State agencies, Tribal nations, nongovernmental organizations, private landowners, and formal partnerships. Federal agencies with a significant role in grassland management in the region include the Bureau of Land Management, U.S. Fish and Wildlife Service, and National Park Service in the U.S. Department of the Interior, and the U.S. Department of Agriculture Forest Service. The Natural Resources Conservation Service and Farm Service Agency in the U.S. Department of Agriculture are also important for the role they play in influencing grassland management on private land. Grassland management in the region also includes 27 federally recognized Tribal nations (in conjunction with the Bureau of Indian Affairs to varying degrees, see Chapter K), State fish and wildlife departments, NGOs, formal partnerships such as the Migratory Bird Joint Ventures, and a vast number of private landowners including farmers and ranchers. These management entities manage variously sized parcels of land distributed unevenly across the North Central region, with most land in the eastern portion of the region managed by private landowners (fig. B5). Federal policies such as the 1862 Homestead Act and the land buybacks by the Federal government during the period of drought and dust storms in the 1930s (see Hurt, 1986) resulted in complex land ownership patterns that raise challenges for coordinated management across the region today.

Conclusion

The North Central Grassland Ecoregions have been shaped by complexly interacting physical, biological, ecological, and human processes since time immemorial. Together, these processes led to the development of highly heterogeneous, biodiverse grassland systems; however, the rapid land-use change initiated with the arrival of nonindigenous settlers around 1850 vastly diminished the extent and quality of grassland ecosystems. Climate change will interact with these anthropogenic stressors to create additional challenges

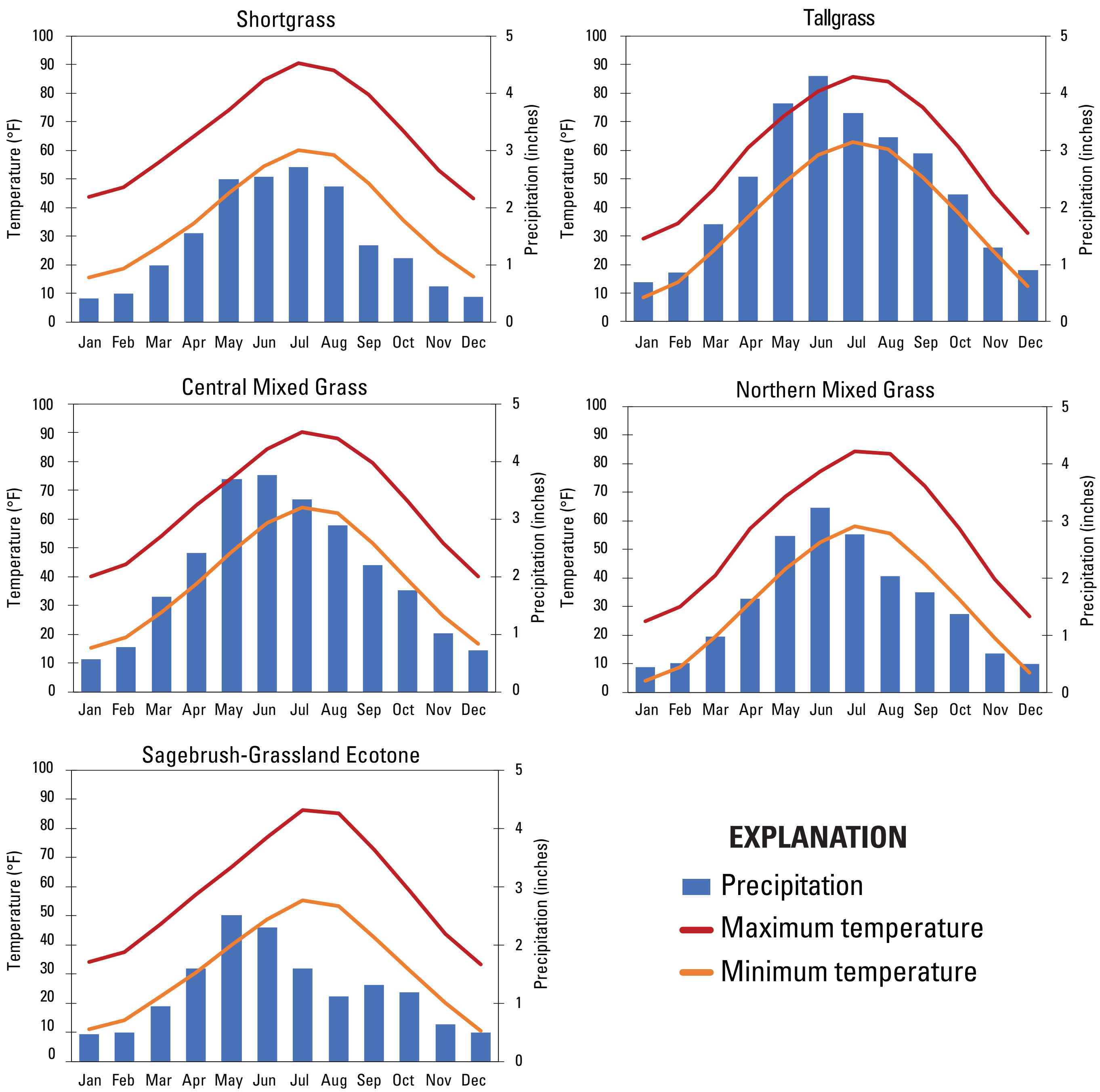

Figure B4. Climographs for the North Central Grassland Ecoregions showing averages of monthly diurnal minimum and maximum temperatures and precipitation totals between 1981 and 2010. Data are from gridMET (2022). °F, Fahrenheit; Jan, January; Feb, February; Mar, March; Apr, April; Jun, June; Jul, July; Aug, August; Sep, September; Oct, October; Nov, November; Dec, December.

Table B1. Average annual precipitation for the North Central Grassland Ecoregions between 1981 and 2010.

[Data sourced from gridMET (2022).]

Ecoregions	Annual precipitation (inches)
Tallgrass	28
Northern Mixed Grass	19
Central Mixed Grass	25
Shortgrass	17
Sagebrush-Grassland Ecotone	15

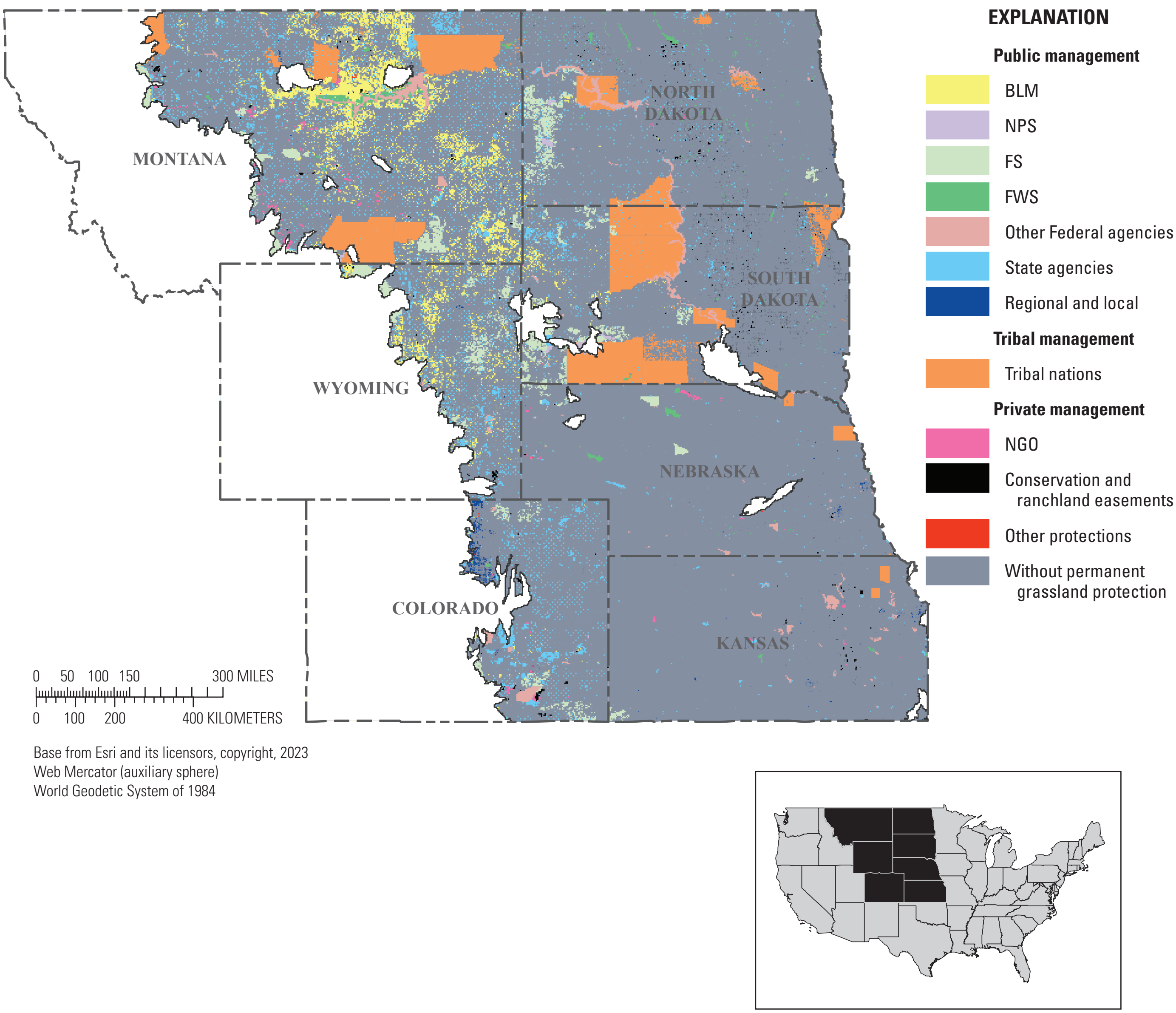

Figure B5. Land management in the North Central Grassland Ecoregions. Colors on the map indicate which entity manages the land. Although the landowner is often also the land manager, this is not always the case. This map was created using PAD-US data (USGS, 2020; see also "Chapter A—Background and Methods"). BLM, Bureau of Land Management; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; FWS, U.S. Fish and Wildlife Service; NGO, nongovernmental organization.

for grassland management and conservation. The next chapter discusses grassland management goals, direct threats and contributing factors to grassland conservation, and the information needed to support grassland management in a changing climate.

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Chapter C.

Grassland Management Goals, Challenges, and Information Needs

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Abstract

This chapter presents the main findings from our synthesis of grassland-related management documents. This chapter describes grassland management goals, direct threats and contributing factors to grassland conservation, and the information needed to support grassland management in a changing climate. The Management Priorities Working Group identified 70 specific research questions organized into 15 main categories of information needs that, if answered, would support grassland managers in meeting their management goals and to address management challenges related to climate change. We received informal feedback from grassland management entities to indicate the relevance of each question for various grassland managers across the region. This report does not describe the extent to which these information needs are already addressed by the existing scientific literature; however, a second, complementary report is planned to summarize climate and ecological information and point to remaining research needs.

Introduction

This chapter presents the main findings from our synthesis of grassland-related management documents (see “Chapter A—Background and Methods”), which addresses the climate change-related information needs that are broadly shared across grassland managers in the North Central region. This chapter begins by providing context for the identified information needs by summarizing the goals of grassland management entities. This chapter also discusses direct threats to grasslands conservation, and contributing factors, which indirectly impact grasslands and are largely shaped by social, historical, cultural, economic, and political factors. For each direct threat and contributing factor, the issue is described, examples of relevant management responses are given, and the information needed to help grassland managers address these threats and contributing factors and meet their goals within the context of climate change are highlighted. This report does not describe the extent to which these information needs are already addressed by the existing scientific literature. That assessment will be carried out by the Climate and Ecology Working Group and described in a forthcoming report (Miller Hesed and others, 2023). This chapter concludes with a discussion of emerging challenges and opportunities.

Broadly, the climate change related information needs of grassland managers in the North Central region can be summarized with three broad questions:

1. How will climate change interact with current grassland threats and stressors?;
2. How will climate change impact the efficacy of present management actions?; and
3. How (and where) should grassland conservation and management actions be prioritized given the impacts of climate change?

Answering these broad questions, however, requires more specific research questions. The Management Priorities Working Group identified 15 main categories of information needs relevant to grassland management in a changing climate (table C1). In this chapter, information needs are organized according to whether they primarily inform addressing direct threats or contributing factors to grassland conservation. Fundamental information—such as the impact climate change will have on regional temperatures, precipitation, and phenology—will be needed to answer questions across the 15 categories and particularly to address questions pertaining to the management of direct threats. Each of the 15 main categories of information needs listed in table C1 has numerous, more specific

Table C1. Organization of “Chapter C—Grassland Management Goals, Challenges, and Information Needs” sections by type of conservation challenge and information needed.

Section	Information needed
Direct threat	
Grassland loss and fragmentation	1. Where are grasslands most likely to be lost to other land uses?
Grassland loss and fragmentation	2. What are best practices for grassland restoration in a changing climate?
Disruption of historical disturbance regime	3. How will climate change affect disturbance regimes?
Woody encroachment	4. How will climate change impact woody encroachment?
Herbaceous invasives	5. How will climate change impact herbaceous invasives?
Unsustainable grazing	6. How will climate change impact grazing?
Change in water quality and quantity	7. How will climate change impact water quality, quantity, and availability?
Wildlife population declines	8. How will climate change affect animal species of conservation concern?
Conservation on private land	9. How can conservation on private grasslands be achieved?
Contributing factor	
Public understanding of grasslands	10. How can public understanding of grasslands and their importance increase?
Legal and policy drivers	11. What legal and policy changes can support grassland resilience to climate change?
Economic incentives	12. How can grassland protection, enhancement, maintenance, and reconstruction be economically incentivized?
Coordination of actions across agencies, organizations, jurisdictions, and borders	13. How can grassland management be strategically coordinated across agencies, organizations, jurisdictions, and borders?
Availability of useable science and tools	14. How can the accessibility of relevant science and tools be improved?
Frameworks for conceptualizing problems and solutions	15. What novel ways of thinking are needed to successfully manage grasslands amidst climate change?

information needs that we identified to inform more actionable and relevant research. These more specific information needs are presented in 15 tables—one for each main category of information need—throughout this chapter and together total 70 questions that could guide further research. The information needs tables also indicate the relevance of each question for various grassland managers in the North Central region. Additional research on each of these 70 questions could support grassland managers in successfully meeting management goals and addressing challenges related to climate change.

Goals for Grassland Management

Grassland management agencies have varying organizational structures, goals, and management actions; however, they share many of the same climate-related challenges and information needs. Increased collaboration and coordination among various grassland managers will be crucial for successful conservation of grasslands in the North Central region in a changing climate.

This report focuses on goals, challenges, and opportunities related to conserving grassland ecosystems. Across management entities, grassland management goals are varied and sometimes conflicting across neighboring lands (for example, *Cynomys ludovicianus* [black-tailed prairie dogs] are considered desirable within some jurisdictions but can be considered a pest on adjacent lands). The Grasslands Roadmap (https://www.grasslandsroadmap.org)—a recent trinational effort to engage Federal agencies, Indigenous communities, State and provincial agencies, private landowners, academic institutions, and industry to coordinate strategic action for North American grasslands—articulates shared goals of "diverse grasslands with thriving indigenous and rural communities; millions of acres of connected land under various types of conservation; profitable working land with livestock and regenerative agriculture; flourishing ecosystems of soil, plants, and wildlife; and rivers and wetlands supporting aquifers, wildlife, production, and people" (Grasslands Roadmap, 2021). The Grasslands Roadmap (2021) goals align with goals found throughout documents regarding grassland management in the North Central region; that is, many grassland managers are working to balance multiple goals (table C2). Managing grasslands for recreation—such as hiking, fishing, and hunting—and productive, sustainable grazing were important goals across many of the management groups. Historic and cultural preservation and energy development were also important goals for a smaller subset of grassland managers. Importantly, managing grasslands for conservation is a widely shared goal across all grassland management groups and is therefore the focus of this report.

Throughout this chapter, conservation is defined as the protection and restoration of biodiverse, heterogeneous grassland ecosystems and their ecological processes. Throughout this chapter, protection refers to efforts to prevent grasslands from being converted to other land types, such as cropland or urban development. Maintenance refers to efforts to ensure that a grassland does not become degraded. Restoration includes the reconstruction and enhancement of grasslands. Reconstruction is the process by which land that has already been converted to cropland or development is reestablished as grassland through the demolition or cessation of existing land use, replanting and reintroductions of native species, and other interventions. Enhancement refers to management efforts to improve the quality of an existing grassland, for example, by working to reduce invasive species and promote native species and biodiversity.

Direct Threats to Grassland Conservation

Grassland managers (that is, those who develop grassland management plans or implement those plans on the ground) in the North Central region face numerous, direct threats to grasslands. In this section, we highlight direct threats that emerged from our review of grassland management documents. The threats discussed here are not exhaustive and many of these threats interact in complex ways.

Table C2. Primary grassland management goals.

[Primary goals for each management entity were identified by the review of grassland-relevant management documents and by informal consultation with Tribal members (see "Chapter A—Background and Methods"). BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; U.S., United States; NGOs, nongovernmental organizations; —, not applicable]

Primary goals	BLM	FWS	NPS	FS	NRCS and FSA	Tribal nations	State agencies	NGOs	Private landowners
Conservation	X	X	X	X	X	X	X	X	X
Recreation	X	X	X	X	—	X	X	X	—
Productive grazing of livestock	X	—	—	X	X	X	—	—	X
Historic and cultural preservation	X	—	X	X	—	X	X	—	—
Energy development	X	—	—	—	—	X	X	—	—

The primary threat to grasslands in the North Central region is the loss of grassland acreage to other land uses (Lark, 2020; Lark and others, 2020; World Wildlife Fund [WWF], 2020; Olimb and Lendrum, 2021; WWF, 2021). Conversion to row crop agriculture has been a primary driver of grassland loss in the United States since nonindigenous settlement of the region began around 1850 (see, for example, Mann, 2005, 2011; Lark and others, 2015; Olimb and Robinson, 2019). Although conversion to row crops remains a threat in some regions, managers are also working to address other factors that significantly degrade grasslands, including the disruption of the historical disturbance regime, woody encroachment, herbaceous invasives, unsustainable grazing, change in water quality and quantity, and wildlife population declines. Federal, State, and Tribal agencies and NGOs are also looking to support and partner with private landowners interested in grassland conservation. Loss, fragmentation, and degradation of grasslands results in a decline of grassland biodiversity.

Threats to grasslands exist largely because of human impacts across the landscape; however, climate change increasingly interacts with these threats and deepens the challenge of successful grassland management. Direct impacts from climate change include the biophysical responses of grassland vegetation to changes in temperature, precipitation, and carbon dioxide, such as changes in grassland distribution (Jones, 2019), net primary productivity (Fraser, 2019), plant community composition (Ratajczak and Ladwig, 2019), biogeochemical cycling (Henry, 2019), and ecosystem services (Lavorel, 2019). Indirect impacts from climate change include how people choose to use or convert grasslands and their water resources to cope with and adapt to socioeconomic impacts of climate change such as shifting agricultural systems, climate refugees (for example, people retreating from areas highly impacted by climate change-related floods and fires), the development of renewable energy, and carbon storage (Joyce and others, 2013; Dove, 2019). The interaction between direct and indirect drivers may amplify the impact each would have on grassland structure and function alone, and in some cases, may lead to ecological transformation of grasslands into other ecosystem types such as savannah or forest (Hoover and others, 2020). Describing or quantifying the ways in which climate change will affect grassland loss, fragmentation, and degradation is difficult because of increasing uncertainty about social responses and feedback loops to climate change and adaptation measures (Wilby and Dessai, 2010). In this section, we describe direct threats to grassland conservation, summarize management responses, and present questions that, if answered, would help grassland managers to better meet their goals in a changing climate.

Grassland Loss and Fragmentation

Grassland loss is the conversion of grassland to another land cover and land use, whereas fragmentation is when grassland loss results in the breaking up of large tracts of grassland into smaller, more isolated tracts that are often unable to support the same degree of biodiversity (Rogan and Lacher, 2018). In the North Central region, the four main drivers of grassland loss and fragmentation are (1) conversion to cropland, (2) urban and exurban development, (3) ranchland subdivision, and (4) energy development. Climate change interacts with all these drivers of grassland loss in complex ways.

Conversion of grasslands to cropland began with nonindigenous settlement in the Great Plains and has rapidly and extensively increased the fragmentation of grassland areas. Today, about half of all grasslands in the Great Plains have been converted to agriculture or other uses (Samson and Knopf, 1996; Lark, 2020) with grassland continuing to be converted to cropland at an annual rate of about 2 percent per year (WWF, 2020, 2021). Much of the remaining prairie is in areas that are marginal for row crop agriculture (Helzer, 2010, p. xi). Conversion to row crops is driven primarily by agricultural economics and policies (Forrest and others, 2004, p. 54). In particular, U.S. Farm Bill subsidies and insurance provided by previous and the current U.S. Farm Bill (for example, 68 FR 17316–2002 Farm Bill Regulations-Loan Eligibility Provisions) along with demand for biofuels have minimized the risk of converting grasslands to cropland while increasing the potential for profit (Feng and others, 2013; Sylvester and others, 2013; Wang and others, 2017; Wright and others, 2017; Claassen and others, 2018). In addition, the advent of bioengineered crop varieties and the development of irrigation infrastructure has made it possible to profitably grow row crops in areas where it was not previously possible, further expanding the extent of grassland conversion. Watson (2020) suggested that historically, access to cheap fossil fuel energy was a key driver of crop expansion, because it allowed the intensification of center-pivot irrigation systems. Irrigation is continuing to expand, and Deines and others (2017) estimated a near doubling of irrigated land in the Republican River Basin (which covers portions of Colorado, Nebraska, and Kansas) between 1999 and 2016 based on Landsat imagery. Irrigation is having strong impacts on groundwater reserves (Scanlon and others, 2012) and is influencing the regional summer climate in some regions of the Midwest and Great Plains with high proportions of land in corn production (Alter and others, 2018). In areas where levels of grassland conversion are already high (for example, in much of the Tallgrass Ecoregion), loss of remaining grassland parcels could be especially detrimental to sensitive species and eliminate the ecological and genetic connectivity between remaining grassland areas. (See sections “Legal and Policy Drivers” and “Economic Incentives” in this chapter.)

As the climate changes, areas most suitable for cropland will also shift in the North Central region. For example, extreme temperatures because of climate change are predicted to significantly reduce yields of corn and soybeans across the North Central region, with eastern North Dakota and South Dakota particularly impacted. Conversely, yields for wheat are predicted to increase in parts of eastern Nebraska and Kansas (Rising and Devineni, 2020). As agricultural yields are impacted by climate change, there is a potential for increased conversion of grassland to cropland in some areas, which contributes significantly to carbon dioxide in the atmosphere (Sala and Paruelo, 1997). At the same time, climate change may diminish the suitability for growing crops in other areas, presenting an opportunity for reconstruction of grasslands where they had previously been converted to cropland.

Urban and suburban development is a lesser driver of grassland loss but is locally significant around existing metropolitan areas and in areas valued for their economic, environmental, and sociocultural benefits (Reeves and others, 2018). For example, the grasslands along Colorado's Front Range are being developed rapidly (Colorado Parks and Wildlife [CPW], 2015). Yet, there has been little agreement in projections across different land-use and land-cover change models (Sohl and others, 2016), making it difficult to predict when and where urban and suburban development may be significant drivers of grassland loss. Though more difficult to predict, climate change may also increase urban and exurban development in the grasslands. About 39 percent of the U.S. population lives in coastal counties (National Oceanic and Atmospheric Administration, 2013). As these areas increasingly experience flooding from sea-level rise, there may be increased migration inland from the coasts, perhaps settling in the Great Plains.

Ranchland subdivision is the breaking up of a large ranch for sale to one or more additional owners. Compared to grassland conversion to cropland, this exurban development on subdivided ranchland represents a relatively small contribution to grassland loss and fragmentation across the region, yet it is not insignificant. In the Great Plains, about 11 percent of privately owned ranchland is projected to be affected by exurban development between 2018 and 2033 (Reeves and others, 2018). Increasingly, affluent individuals from urban or suburban areas are looking to purchase "ranchettes" or "hobby farms" to enjoy the natural and cultural amenities of a more rural lifestyle (Marcouiller and others, 2002; Johnson, 2008; Abrams and others, 2012). Demand for ranchland for exurban development raises land prices, which can generate a cycle whereby traditional production on ranchland becomes more expensive, leading more ranchers to sell off pieces of their land and perpetuating the cycle (Gosnell and Abrams, 2011, p. 11). Climate change exacerbates these pressures on ranchland sale and subdivision because climate variability and the projected increase in the frequency, severity, and duration of drought will make it increasingly challenging for ranching to be profitable (Martin and Barboza, 2020).

The loss of grassland functionality that results from this fragmentation of ranchland can be significant. Homes, outbuildings, and fences are often built on the smaller parcels of ranchland (Theobald and others, 1996; Reeves and others, 2018). This infrastructure increases fragmentation, which can disrupt migration, decrease forage space, and impede gene flow for wildlife. The disturbance caused by construction also creates opportunities for invasive species to establish (Reeves and others, 2018). In addition, trees are often planted around new homes in previously unwooded areas, introducing seed sources for woody encroachment. Those individuals purchasing smaller tracts of ranchland are generally not traditional ranchers, but rather affluent individuals from cities or suburbs who may prefer environmental protection over agricultural production (Rudzitis, 1999), yet may be less likely than long-time ranchers to implement conservation practices because of lack of skill and knowledge (Sorice and others, 2014). The possibility of climate refugees moving inland from coastal areas may also increase the profitability and incidence of ranchland subdivision.

Energy development—including hydroelectric, gas, coal, nuclear, and wind—also contributes to grassland conversion and fragmentation (Ott and others, 2021). The necessary infrastructure associated with energy development—including access roads, well pads, wind turbines, storage facilities, and transmission lines—reduces habitat quality and causes species to avoid or underutilize adjacent areas (Vodehnal and Haufler, 2008, p. 22–23; Beckmann and others, 2012; Riley and others, 2012; Thompson and others, 2015a, b; Prairie Pothole Joint Venture, 2017a; Sawyer and others, 2017). Montana and Wyoming saw a coalbed methane boom at the turn of the 21st century (Forrest and others, 2004), and North Dakota and Montana saw some of the largest increases in oil and natural gas extraction (Wick and others, 2016, p. 265; Ott and others, 2021, p. 258). The number of oil wells in North Dakota increased by more than fivefold over the last 20 years, with 3,234 operating oil wells in August 2001 and 16,566 in August 2021 (North Dakota Oil and Gas Commission, 2021).

Corresponding to this growth in fossil fuel production, greenhouse gas emissions from petroleum and natural gas production in the North Central region are among the highest in the United States (Conant and others, 2018, p. 963). The development of renewable energy is likely to be a central part of the national effort to mitigate climate change, and the North Central region has some of the highest wind energy potential in the country (Elliott and others, 2011). Wind energy appears to have a relatively small footprint, yet requires more land per unit of energy produced than gas, coal, nuclear, and solar (Ott and others, 2021), and the impact wind energy development has on grassland functionality can be significant (McDonald and others, 2009; Loesch and others, 2013; Shaffer and Buhl, 2016; Trainor and others, 2016). For example, grassland birds may be displaced or avoid grasslands where wind turbines have been sited, which can lead to lower reproductive success (Leddy and others, 1999; Loesch and others, 2013; McNew and others, 2014; Shaffer and Buhl 2016; Harrison and others, 2017).

Management Responses

Grassland managers use complementary approaches to counter the threat of grassland conversion (table C3). These approaches are not mutually exclusive—a single tract of grassland may have layered protection from the application

Table C3. Management actions to prevent or counter grassland loss and fragmentation.

[For each management entity, the management action is rated as a major or a minor part of their activities. U.S., United States; NGO, nongovernmental organization; NA, management action seldom or never employed]

Organization	Preventing grassland loss					Restoration
	Land acquisition	Designation of protected areas	Designation of special management areas	Easements	Policy and nonregulatory guidance to prevent conversion	Restoring previously converted grassland
Federal						
Bureau of Land Management	Minor	Minor	Major	Minor	NA	Minor
U.S. Fish and Wildlife Service	Minor	NA	Major	Major	Minor	Minor
National Park Service	Minor	Minor	NA	NA	NA	Major
U.S. Department of Agriculture, Forest Service	Minor	Minor	Major	NA	NA	Major
Natural Resources Conservation Service	NA	NA	NA	Major	Major	Minor
U.S. Department of Agriculture, Farm Service Agency	NA	NA	NA	NA	Major	Major
Tribal						
Bureau of Indian Affairs	NA	NA	Major	NA	NA	Minor
Rosebud Sioux Tribe[1]	Minor	Minor	Major	NA	Minor	Minor
State						
Colorado Parks and Wildlife	Major	Major	Major	Major	Major	Major
Kansas Department of Wildlife and Parks	Minor	Minor	Major	Minor	Major	Major
Montana Fish, Wildlife and Parks	Minor	Minor	Minor	Minor	Minor	Minor
Nebraska Game and Parks Commission	Minor	Minor	Major	Minor	Major	Major
North Dakota Game and Fish	Minor	Minor	Major	Minor	Major	Major
South Dakota Game, Fish and Parks	Minor	Minor	Minor	Minor	Major	Major
Wyoming Game and Fish Department	Minor	Minor	Major	Major	Major	Major
Nongovernmental organizations and partnerships						
The Nature Conservancy[2]	Major	Major	Minor	Major	Minor	Major
Migratory Bird Joint Ventures[3]	NA	NA	NA	NA	Minor	NA

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the major and minor activities of the Rosebud Sioux Tribe. Further research is needed to understand grassland management actions across all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the major and minor actions of The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the major and minor actions taken by Joint Ventures as a result of the partnership, and do not necessarily represent the actions of all partners individually.

of multiple approaches. Land acquisition—the purchase of land from a willing seller—by an agency or organization can protect grassland from being developed or converted to cropland by private landowners. Easements are another way in which grasslands on private land can be protected from conversion. In exchange for monetary compensation, private landowners voluntarily agree to certain restrictions on land use such as keeping the land in grassland. The easement holder may be a Federal, State, or NGO. For example, the Grassland Conservation Reserve Program is a voluntary program jointly managed by U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) and Farm Service Agency (FSA) for soil erosion control and air or water quality protection. Conservation easements essentially reward landowners for protecting their grassland; however, because of the uncertainty about whether the grassland would have been converted regardless, easements likely contribute to only a small reduction in grassland conversion (Lark, 2020). Targeting grasslands most vulnerable to conversion for easements would improve their impact; that is, purchasing easements on grasslands that are unlikely to be converted does little to maintain overall grassland acreage across the region (Savage and others, 2014; Claassen and others, 2017).

Grassland may also be designated as a protected area by the U.S. Congress or by grassland management entities. A protected area is a clearly defined space recognized and managed through legal or other effective means for the conservation of the ecosystem services and natural values of the land (International Union for Conservation of Nature, 2008). National parks (managed by the National Park Service) and national grasslands (managed by U.S. Department of Agriculture, Forest Service) are examples of protected areas, but differ in the types of activities allowed in them. Grasslands may also be designated as special management areas, which have limits placed on their use to protect key characteristics. For example, Bureau of Land Management (BLM) land that is designated as wilderness is managed for the provision of primitive recreation or solitude by closing the area for motorized use; closing the area to salable mineral development; excluding right-of-way; and prohibiting renewable energy development, commercial woodcutting, and all other surface-disturbing activities that are not compatible with the area's natural values (see Bureau of Land Management [BLM], 2015a, 2020).

Policies and nonregulatory guidance may also be used by agencies and organizations to prevent grassland conversion. For example, the Sodsaver provision introduced in the 2014 Farm Bill (and renewed and strengthened in the 2018 U.S. Farm Bill [Public Law 115–334 (12/20/2018)] Agriculture Improvement Act of 2018) discourages landowners in the Prairie Pothole Region (including Montana, North Dakota, South Dakota, and Nebraska) from converting native grasslands and prairies to annually tilled crops by reducing the amount of Federal crop insurance and noninsured crop disaster assistance benefits the FSA can distribute for land converted in the previous 4 years (North American Bird Conservation Initiative [NABCI], 2015, p. 23).

Grassland restoration (that is, reconstruction and enhancement) of previously converted land can be used by grassland managers in some cases and can help to counter grassland loss in other areas. Grassland restoration can involve reseeding, reintroductions of grassland wildlife, and prescribed burning and grazing and is generally more expensive and less effective than protecting and maintaining existing grassland; the ecological functionality of grasslands may not be recovered after cultivation (Dodds and others, 2008; Isbell and others, 2019). However, restoration of grasslands—even if not fully recovered—can help to address fragmentation or create corridors to facilitate migration of species as an adaptation to climate change. A key focus of some of The Nature Conservancy's work around the Platte River Prairies in Nebraska is to develop and test prairie restoration strategies on abandoned croplands (Kimberly R. Hall, TNC, unpub. management plan, 2017).

Information Needed

The analysis revealed two overarching questions relevant for grassland managers as they work to address the threat of grassland loss and fragmentation amidst a changing climate: (1) where are grasslands most likely to be lost to other land uses and (2) what are best practices for grassland reconstruction in a changing climate (table C4). Within those broader questions are several subquestions. The question with highest relevance for grassland managers across the region is: What criteria can be used to designate land use (including conservation, recreation, cropping, grazing, energy development, transportation, urban development, and so forth) that will support both thriving grassland ecosystems and flourishing human communities in the midst of climate change?

Disruption of Historical Disturbance Regime

The grasslands in the North Central region evolved under spatially and temporally varying regimes of disturbance from wildfire, intentional fires lit by Indigenous peoples, grazing by *Bison bison* (bison) and other native herbivores, and ground disturbance by burrowing mammals. Historically, fires burned at various scales, frequencies, and intensities, creating a heterogeneous landscape of burned and unburned areas, which then influenced the grazing of native herbivores such as bison and *Cervus elaphus* (elk), who preferred forage in recently burned areas. Intermittent grazing across the landscape interacted with fire by reducing fuels available in some areas (The Nature Conservancy and the Osage Plains/Flint Hills Prairie Ecoregional Planning Team, 2000, p. 7). Extensive

Table C4. Information needed for successful grassland protection and restoration in a changing climate.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
1. Where are grasslands most likely to be lost to other land uses?	X	H	X	S	S	H	S	H	H	H	H	H	H	H	H	H	H
1.1 Where is cropland likely to expand and contract as climate changes?	X	H	X	X	H	H	H	H	S	H	H	H	H	H	S	H	H
1.2 Where is ranchland likely to be sold and subdivided as climate changes?	X	S	X	X	S	S	S	S	H	H	H	X	S	S	S	H	H
1.3 Where is urban and suburban development likely to occur as climate changes?	X	S	X	S	S	H	S	H	H	S	S	S	S	S	S	S	S
1.4 Where and how can energy be developed to minimize the extent and impact of grassland conversion?	H	H	X	H	X	X	S	H	H	H	H	H	H	H	H	H	H
1.5 What criteria can be used to designate land use (including conservation, recreation, cropping, grazing, energy development, transportation, urban development, and so forth) that will support both thriving grassland ecosystems and flourishing human communities in the midst of climate change?	H	H	X	H	H	H	H	H	H	H	S	H	H	H	H	H	H
1.6 Where can conservation funds be used most efficiently to prevent grassland conversion?	X	H	X	X	H	H	S	H	H	H	H	H	H	H	H	H	H
2. What are best practices for grassland restoration in a changing climate?	X	S	S	S	H	S	S	H	H	H	S	H	S	H	H	H	H
2.1 Where will climate change diminish the suitability of land for agriculture and present opportunities for reconstruction?	X	H	X	X	H	H	S	H	H	S	S	S	S	S	S	H	H
2.2 What areas could best be reconstructed to provide key habitat or connectivity for migration of grassland-dependent species in light of climate change?	S	H	S	S	H	H	X	H	H	S	H	S	S	S	S	H	S
2.3 What are the best sources for seeds for reseeding grasslands?	S	S	S	H	H	H	X	H	H	S	S	H	S	H	S	H	S
2.4 Where can grassland animals be successfully reintroduced?	S	S	H	H	S	S	X	S	H	S	S	H	S	S	S	H	X
2.5 How can prescribed disturbances be used to promote grassland restoration in a changing climate?	X	S	H	H	H	X	S	H	S	H	S	H	S	S	H	H	S

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation nongovernmental organizations generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Ventures we ranked that question as "H."

black-tailed prairie dog colonies combined intense grazing and clipping of vegetation with ground disturbance, and their extent likely expanded and contracted with disturbances that reduced or increased vegetation height (Augustine and others, 2007). These disturbances were crucial for creating and maintaining a landscape with a heterogeneous vegetation structure and composition (Pickett and White, 1985; Ceballos and others, 1999; Fuhlendorf and others, 2017). This heterogeneity created a mosaic of patches across the landscape that provided habitat to a wide variety of species (Warui and others, 2005; Fuhlendorf and others, 2006; Davidson and others, 2012; Ricketts and Sandercock, 2016).

Across much of the Great Plains, the ecological processes under which the grasslands have evolved have been disrupted by extensive and intensive human use (Carbutt and others, 2017). The Great Plains was one of the last regions in the United States to be colonized, with major settlement beginning after 1850 (Treuer, 2019, p. 85). With nonindigenous colonization came the near complete extermination of many native grazers and seed dispersers, which greatly diminished the extent and quality of grasslands (Carbutt and others, 2017). Unrestrained killing of bison and incidental, novel epizootic disease spread were responsible for the drastic loss of the bison population. Bison slaughter occurred for an international market for hides as a way to starve and destroy the identity of Native Americans (National Park Service [NPS], 2018; Stoneberg Holt, 2018). Approximately 10–15 million bison were slaughtered and an additional 30 million are hypothesized to have died of tick fever in the Great Plains in a little over 10 years; it is estimated that fewer than 1,000 bison remained by the 1890s (Taylor, 2011; NPS, 2018; Stoneberg Holt, 2018). The decimation of the bison devastated Native American Tribes (NPS, 2018) and disrupted the natural disturbance regime that maintained heterogenous and biodiverse grasslands. This disruption of the historical disturbance regime continues to be a substantial threat to grassland ecosystems across the North Central region.

Management Responses

Grassland managers use prescribed disturbance to try to replicate the heterogeneous landscape produced by the historical disturbance regime (table C5). For example, the Federal Wildland Fire Management Policy (U.S. Department of the Interior, 2001) directs Federal agencies to achieve a balance between fire suppression to protect life, property, and resources and fire use to regulate fuels and maintain healthy ecosystems. In addition, it directs agencies to use the appropriate management response for all wildland fires regardless of the ignition source. The Interagency Strategy for the Implementation of Federal Wildland Fire Management Policy (Wildland Fire Leadership Council, 2003) provides clarification to the fire-management policy and presents direction for consistent interagency implementation of the policy at the operational level. This guidance allows managers to use fire to improve the health, heterogeneity, and biodiversity of grasslands.

Grassland managers may also prescribe grazing to reproduce the historical disturbance of bison and other native ungulates or to target invasive plants. For example, U.S. Fish and Wildlife Service (FWS), Partners for Fish and Wildlife, promotes and cost-shares the establishment of grazing systems with private landowners (U.S. Fish and Wildlife Service [FWS], 2018) and National Wildlife Refuges use rotational grazing and prescribed fire to manage grasslands (FWS, 2013).

Grassland managers may also provide habitat for wildlife that helps increase the heterogeneity of the vegetation structure. For example, managers may choose to encourage black-tailed prairie dog colonies by using controlled burns or brush removal to reduce visual obstructions that make black-tailed prairie dogs more vulnerable to predators (Milne-Laux and Sweitzer, 2006). Black-tailed prairie dog activities then increase the amount of short-statured grassland critical to some grassland birds (Augustine and Baker, 2013). The management for heterogeneity of vegetation fostered by patchy disturbance has been shown to increase bird diversity in tallgrass, mixed-grass, and shortgrass prairies (Coppedge and others, 2008; Augustine and Baker, 2013; Augustine and Derner, 2015).

Information Needed

As grassland managers work to use disturbance to promote heterogeneous and biodiverse grasslands, it is important for them to understand how climate change will affect the disturbance regime. More specific questions are identified in table C6. The questions of highest relevance for grassland managers across the region are how climate change will affect disturbance regimes and the more specific issue of how drought (an expected outcome of climate change in most parts of the North Central region) will interact with disturbance regimes and increasing carbon dioxide to affect grassland biodiversity and resilience.

Woody Encroachment

Woody encroachment is the spread of trees and shrubs into grassland ecosystems and is one of the greatest threats to mesic grasslands in the United States today (Briggs and others, 2005, p. 243). Although woody encroachment is a threat to grasslands in all North Central Grassland Ecoregions, it is a high threat in the Tallgrass, Central Mixed Grass, and Sagebrush-Grassland Ecotone Ecoregions. Over the last century, the rate of woody encroachment was 5–7 times higher across the Central Great Plains (with 1.7 percent change per year relative to drylands outside of the Great Plains with less than 0.4 percent change per year (Barger and others, 2011).

Table C5. Management actions to address grassland degradation.

[For each management entity, the management action is rated as a major or a minor part of their activities. U.S., United States; NGO, nongovernmental organization; NA, management action seldom or never employed]

Organization	Prescribed disturbance	Managing woody invasives	Herbaceous invasives management	Domesticated grazing management	Water quality and quantity management	Management of animal species of greatest conservation concern	Promoting conservation on private land
Federal							
Bureau of Land Management	Minor	Major	Major	Major	Major	Major	NA
U.S. Fish and Wildlife Service	Major	Major	Major	Major	Major	Major	Major
National Park Service	Major	Major	Major	Major	Minor	Major	NA
U.S. Department of Agriculture, Forest Service	Major	Major	Major	Major	Major	Major	NA
Natural Resources Conservation Service	Minor	Minor	Major	Major	Major	Minor	Major
U.S. Department of Agriculture, Farm Service Agency	NA	NA	NA	NA	NA	Minor	Major
Tribal							
Bureau of Indian Affairs	Major	Major	Major	Major	Major	Major	NA
Rosebud Sioux Tribe[1]	Minor	Minor	Minor	Major	Minor	Minor	NA
State							
Colorado Parks and Wildlife	Minor	NA	Minor	NA	Minor	Major	Major
Kansas Department of Wildlife and Parks	Major	Major	Major	Major	Major	Major	Major
Montana Fish, Wildlife and Parks	Minor	Minor	Minor	Minor	Minor	Major	Major
Nebraska Game and Parks Commission	Major	Major	Major	Major	Major	Major	Major
North Dakota Game and Fish	Major	Major	Major	Major	Major	Major	Major
South Dakota Game, Fish and Parks	Major	Major	Major	Major	Major	Minor	Major
Wyoming Game and Fish Department	Major	Major	Major	Major	Major	Major	Major
Nongovernmental organizations and partnerships							
The Nature Conservancy[2]	Major	Major	Major	Major	Major	Major	Major
Migratory Bird Joint Ventures[3]	Major	Major	NA	NA	Minor	NA	Major

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the major and minor activities of the Rosebud Sioux Tribe. Further research is needed to understand grassland management actions across all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the major and minor actions of The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the major and minor actions taken by Joint Ventures as a result of the partnership, and do not necessarily represent the actions of all partners individually.

Table C6. Information needed for successful prescribed disturbance in a changing climate.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal						Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
3. How will climate change affect disturbance regimes?	S	H	H	H	H	X	H	H	H	H	H	H	S	H	H	H	S
3.1 How will climate change affect the severity and frequency of wildfire?	S	S	H	H	S	X	H	H	H	S	H	S	S	S	H	S	S
3.2 How will the effectiveness of current prescribed burn practices be affected by a changing climate and how will those practices need to be altered to be more effective in a changing climate?	H	H	H	H	S	X	H	S	S	H	H	S	S	S	S	H	H
3.3 How will the effectiveness of current prescribed grazing practices be affected by a changing climate and how will those practices need to be altered to be more effective in a changing climate?	S	S	S	H	H	X	H	S	S	H	H	S	S	S	S	H	S
3.4 How will changing drought patterns under climate change interact with fire, grazing, and increased levels of carbon dioxide to impact the resilience, biodiversity, and functioning of grasslands?	H	H	H	H	H	X	H	H	H	H	H	H	S	H	S	H	S

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as "H."

Although Barger and others (2011) do not define the geographic boundaries of the Central Great Plains, the studies that they include in their synthesis of woody encroachment in the Central Great Plains were conducted in Kansas, Nebraska, Wisconsin, and Illinois. Studies of woody encroachment in Texas were categorized by Barger and others (2011) as the Southern Great Plains. Thus, we presumed all of the North Central grasslands and grasslands extending as far east as Illinois, are part of the Central Great Plains described by Barger and others (2011).

This woody encroachment is predominantly the proliferation of *Juniperus* spp. L. (juniper) in the tallgrass and mixed grass prairies of the Great Plains (Briggs and others, 2005, p. 243; Barger and others, 2011, p. 2). Woody encroachment is caused by numerous interacting factors including changes in magnitude and seasonality of precipitation, fire and grazing frequency and intensity, concentrations of atmospheric carbon dioxide, and land use (Barger and others, 2011, p. 1; Archer and others, 2017, p. 31). However, fire suppression is the biggest driver of woody encroachment into grassland areas where woody species did not formerly exist (Briggs and others, 2005, p. 243).

Woody encroachment into grasslands leads to significant declines in species richness, threatens endemic grassland species, changes above- and below-ground biota, and alters plant productivity and carbon storage (Briggs and others, 2005; Ratajczak and others, 2012; Archer and others, 2017; Sepp and others, 2021). Conversely, in the Sagebrush-Grassland Ecotone, balancing the woody sagebrush component with grassland vegetation is important for wildlife conservation management goals (Duchardt and others, 2018). Increasing woody cover can lead to ecosystem state changes from grassland to shrubland or woodland that are difficult to reverse with reinstatement of fire or mechanical removal of woody species (Ratajczak and others, 2014). However, some ecosystem services (such as habitat for wildlife species) can be lost at very low levels of woody cover before large-scale state transitions occur. For example, female *Tympanuchus pallidicinctus* (lesser prairie chickens) select habitats, on average, at least 283 m from the nearest tree (Lautenbach and others, 2017). Thus, woody encroachment, if not properly managed, can contribute to loss of functional grasslands.

Management Responses

Woody encroachment is a major grassland management activity for many agencies and organizations in the North Central region (table C5). Grassland managers use a variety of approaches, including mechanical treatments and prescribed fire and grazing (Symstad and Leis, 2017), to prevent and reverse woody encroachment. Fire is an essential tool for preventing woody encroachment; however, its effectiveness for treating areas already invaded by woody species depends on the species, density, and age of woody plants and the burn season and intensity. For example, in a synthesis of more than 20 years of research in the tallgrass prairie in Kansas, Briggs and others (2005) found that once woody plants are established, they persist and their cover increases regardless of fire frequency. Furthermore, two studies in their synthesis (see McCarron and Knapp, 2003; McCarron and others, 2003) found that infrequent fires may actually increase the spread of some established species by increasing the availability of resources needed for vigorous sprouting (Briggs and others, 2005). Although the synergistic application of fire and grazing can help make grasslands more resilient to woody plant encroachment (Wilcox and others, 2022), prescribed fire and grazing regimes alone are often not sufficient for reversing woody encroachment especially in mesic grasslands; rather, expensive mechanical removal of woody species or high-intensity fires is required to restore grass dominance (Briggs and others, 2005, p. 243; Twidwell and others, 2013).

Information Needed

Grassland managers need to know how climate change will impact woody encroachment. Though this is somewhat relevant for nearly all grassland management agencies and organizations in the North Central region (table C7), it is highly relevant to NRCS, Kansas Department of Wildlife and Parks, and NGOs. Of the specific supporting questions related to this topic, how the effectiveness of current approaches to managing woody encroachment will be altered by a changing climate was most highly relevant to grassland managers in the North Central region.

Herbaceous Invasives

Herbaceous invasives are nonwoody plant species that lack biological and environmental controls on their establishment, growth, and reproduction, and are therefore able to spread and dominate in ecosystems (Rohweder, 2015). Gaskin and others (2021) identified 10 herbaceous invasive species in the Great Plains that have garnered substantial attention: *Agropyron cristatum* (L.) Gaertn. (crested wheatgrass), *Bothriochloa ischaemum* (L.) Keng (yellow bluestem), *Bromus arvensis* L. (field brome), *Bromus inermis* Leyss. (smooth brome), *Bromus tectorum* L. (cheatgrass), *Cynodon dactylon* (L.) Pers. (bermudagrass), *Schedonorus arundinaceus* (Schreb.) Dumort. (tall fescue; La Guardia Nave and Corbin, 2019), *Phalaris arundinacea* L. (reed canarygrass), *Phragmites australis* (Cav.) Trin. ex Steud. (common reed), and *Poa pratensis* L. (Kentucky bluegrass). Herbaceous invasives often become established in areas that have been altered and tend to spread in areas that lack grazing and fire (Cosby, 1975; Porensky and others, 2017, 2020). Herbaceous invasives can alter ecosystem processes by accelerating disturbance regimes and altering stream channel morphology. They can also impact habitat structure and function by displacing native grass and forb species, reducing

Table C7. Information needed for successful management of woody encroachment in a changing climate.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
4. How will climate change impact woody encroachment?	S	H	S	S	H	X	X	S	S	H	S	S	S	H	S	H	H
4.1 Where has climate change facilitated movement of woody species into areas that were historically grassland?	S	S	S	S	H	X	X	S	S	S	S	S	S	H	S	H	H
4.2 Where will woody species become more competitive and encroach on grasslands at a higher rate in the future?	S	S	S	S	H	S	X	S	S	H	S	S	S	H	S	H	H
4.3 How will the effectiveness of current efforts to manage woody encroachment change?	H	S	S	H	H	S	X	S	S	H	S	S	S	H	S	H	H

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as “H.”

the availability of forage required by native animals, and impacting biotic and abiotic processes belowground (Poland and others, 2021). The impacts of herbaceous invasives are a conservation concern for resource managers (see, for example, Rohweder, 2015, p. 35) and pose a high threat to all North Central Grassland Ecoregions.

Management Responses

Managing herbaceous invasives is crucial for protecting and restoring grassland ecosystems (Poland and others, 2021) and is a major activity for many agencies and organizations managing grasslands in the North Central region (table C5). Managers face many challenges in controlling herbaceous invasives because of their morphological, phenological, and physiological similarities to native plants that managers are trying to promote (Gaskin and others, 2021). Therefore, managers often employ integrated pest management, the application of biological, physical, chemical, and cultural tools to prevent the introduction and spread of invasive species and noxious weeds (see BLM, 2015b, 2019). For example, the Kansas Department of Wildlife and Parks used a combination of chemical treatments and prescribed burning and grazing to combat herbaceous invasives (Rohweder, 2015).

Information Needed

Understanding how climate change will impact herbaceous invasives is relevant for grassland managers across the North Central region (table C8). Specifically, many managers would find information about where climate change will allow herbaceous invasives to become more competitive and encroach on native grassland species at a higher rate to be highly relevant to their management goals. Of the grassland management entities we include in this report, all questions pertaining to the relationship between climate change and herbaceous invasives are highly relevant to BLM, FWS, NRCS, Tribal nations, Colorado Parks and Wildlife, and NGOs.

Unsustainable Grazing

The grasslands in the North Central region evolved under a regime of grazing by highly mobile bison and other native ungulates that moved as vegetation conditions changed within and across seasons and years. Approximately 49 percent of remaining grasslands in the North Central region are used for grazing domestic animals like *Bos taurus* (cattle; Economic Research Service, 2021). Grazing continues to play an important role in the maintenance of healthy grassland ecosystems; however, unsustainable grazing can occur when the stocking rate, timing, intensity, or duration of grazing has a lasting, negative impact on the growth, condition, ecological functioning, or biodiversity of the grazed grasslands. Unsustainable grazing is mentioned as a threat to wildlife habitat in five State wildlife action plans, which together represent all five of the North Central Grassland Ecoregions (see CPW, 2015; Dyke and others, 2015; Montana Fish, Wildlife and Parks [MFWP], 2015; Rohweder, 2015; Wyoming Game and Fish Department [WGFD], 2017). Continuous, heavy grazing can impact wildlife by reducing the forage and residual plant cover needed by many wildlife species (Forrest and others, 2004; WGFD, 2017). In areas where the stocking rate, intensity, or duration of grazing is high, livestock can cause erosion, increased sediment discharge to wetlands and waterways, and a decline in soil health (Dyke and others, 2015). Overgrazing and soil disturbance by livestock can also create opportunities for weeds and invasive plants to become well established (DiTomaso and others, 2010), which can lead to the use of broadcast herbicide that may further degrade the composition of the plant community. Even with moderate stocking rates, grazing can decrease the heterogeneity of grassland composition and structure, thereby also decreasing biodiversity (Forrest and others, 2004; Rohweder, 2015), especially if homogeneous management practices (that is, doing the same thing year after year) are used (Helzer, 2010).

Management Responses

The grasslands in the North Central region, like other temperate grasslands in the United States, are the foundation of the livestock production industry (Briggs and others, 2005, p. 243). Management of grazing livestock is a major activity for almost all the grassland management organizations in the North Central region (table C5). A primary way to manage the impact of grazing is by determining the appropriate stocking rates of cattle and other livestock. These stocking rates are based on the size of the area, drought conditions, and amount and quality of forage available. Increasingly, grassland managers are employing techniques to increase the heterogeneity of grasslands by excluding grazers from sections and implementing a variable schedule of prescribed grazing and fire. For example, the NRCS Conservation Standard for Prescribed Grazing in Kansas (Natural Resources Conservation Service, 2021) recommends that landowners adjust the intensity, frequency, timing, and duration of grazing “to provide for the development and maintenance of the plant structure, density, and diversity needed for the habitat requirements of the desired fish and wildlife species of concern” (p. 3).

There has also been interest from grassland managers in reintroducing bison herds in some areas. Not only were bison a keystone species in the region, but they are also central to the traditional culture, livelihoods, and modern economy of Tribal nations of the Great Plains region (Cheyenne River Sioux and National Wildlife Federation, 2001; Doyle, Redsteer, and Eggers, 2013; Becker and others, 2015, 2020; Martin and others, 2020).

Table C8. Information needed for successful management of herbaceous invasives in a changing climate.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
5. How will climate change impact herbaceous invasives?	H	H	H	H	H	S	H	H	H	H	S	S	S	S	H	H	H
5.1 Where has climate change facilitated the movement of herbaceous invasives into native grasslands?	H	H	H	H	H	S	H	H	H	S	S	S	S	S	H	H	H
5.2 Where will herbaceous invasives become more competitive and encroach on native grassland species at a higher rate in the future?	H	H	H	H	H	S	H	H	H	H	H	S	S	S	H	H	H
5.3 How will the effectiveness of current efforts to manage herbaceous invasives change?	H	H	H	H	H	S	H	H	H	S	S	S	S	S	H	H	H
5.4 How will management for invasives (for example, spraying), biodiversity (for example, pollinators), and water quality (for example, non-point source pollution) impact each other in a changing climate?	H	H	S	S	H	S	H	H	H	S	S	S	S	S	S	H	H

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as "H."

Information Needed

Understanding how climate change will impact grazing is highly relevant for many grassland management entities in the North Central region (table C9). Of the specific, related supporting questions, understanding which grazing management practices can help ranchers successfully adapt to climate change is most relevant to grassland managers across the region. For the U.S. Department of Agriculture, Forest Service and Tribal nations, all questions related to how climate change will impact grazing are considered highly relevant to their grassland management goals.

Change in Water Quality and Quantity

Wetlands, waterways, and water resources are an integral part of grassland ecosystems. Prairie streams provide critical habitat to wildlife (Chase and others, 2016), and the complex interactions between grassland and wetland ecosystem dynamics across the North Central region can influence where migratory birds stop to forage and breed (Pearse and others, 2022). The quantity and quality of the water resources used by migratory birds is highly sensitive to changes in climate, and the responses of those wetland and stream systems can be magnified by conversion of grassland to cropland (McKenna and others, 2019).

The proper functioning of many aquatic systems in the grasslands is already degraded and will further decline because of the impacts of climate change. Agriculture has long threatened water quality and quantity in the North Central region, especially in the northern mixed grass, central mixed grass, and shortgrass prairies. By the 1980s, the number of wetland basins had declined by 60 percent in North Dakota and 35 percent in South Dakota (Tiner, 1984). More recently, economic and climatic conditions further escalated the practice of wetland drainage on farm fields across northern Montana and eastern North Dakota and South Dakota (Dahl and Stedman, 2011). The combination of decreased grassland area and increased wetland drainage resulted in altered hydrology with higher water levels in remaining wetlands and lower streamflow in the summer and fall. This altered hydrology means that areas with high rates of wetland drainage are experiencing enduring summer and fall hydrologic droughts (Prairie Pothole Joint Venture, 2017a).

In the Tallgrass Ecoregion of Nebraska, diversion and pumping of water for irrigation and municipal water supplies reduced natural streamflow and available wildlife habitat, whereas channelization lowered water tables for nearby wetlands, affecting plant composition. In addition, the proximity of agricultural fields to water bodies has increased sedimentation, which degrades habitat for waterfowl and many aquatic species. Water bodies in this region are also impacted by pollution from pesticides and urban and industrial runoff, which harms wildlife (Schneider and others, 2011).

Climate change will amplify the degradation of wetlands, waterways, and water resources by increasing the water temperature of rivers and streams (Poff and others, 2002) and, though the effects of climate change on groundwater remain uncertain, generally projections indicate climate change will reduce groundwater recharge while increasing water demand (Earman and Dettinger, 2011; Green and others, 2011; Huntington and Niswonger 2012; Taylor and others, 2013). This will impact grasslands, such as the Nebraska Sandhills, where much of the grassland vegetation is dependent on groundwater (Sandhills Taskforce, 2014).

Management Responses

The proper functioning of grassland systems depends on the availability and quality of water. Water quality and quantity management is thus a major activity for many grassland management entities in the North Central region (table C5). Grassland managers work to maintain or improve water quality by restoring free-flowing rivers (Forrest and others, 2004, p. 65) and restoring the natural hydrology of playa lakes by filling pits and removing excessive accumulated sediments (Playa Lakes Joint Venture, 2008); installing fences around water bodies to keep livestock from eroding the banks and polluting the water (Playa Lakes Joint Venture, 2008; NPS, 2019); and reconstructing destroyed wetland, wet meadow, and stream/riparian habitats (Sandhills Task Force, 2014). There are also programs to support water quality management on private land. For example, the Conservation Reserve Enhancement Program helps promote water quality by incentivizing agricultural producers to protect ground and surface water by using practices such as filter strips to protect rivers, lakes, and streams from agricultural runoff and sedimentation (NABCI, 2015, p. 37).

Grassland managers also act to modify the quantity of water available for grassland processes and species by restoring wetlands (Sandhills Taskforce, 2014; Prairie Pothole Joint Venture, 2017a), developing water management plans that improve groundwater levels while supporting sustainable grazing and native plant and animal communities (Sandhills Task Force, 2014; U.S. Department of Agriculture, Forest Service, 2017), and maintaining or improving connectivity by removing dams (Schrag, 2011).

Information Needed

Understanding how climate change will impact water quality, quantity, and availability is highly relevant for all grassland management entities in the North Central region (table C10). Of the more specific questions on this topic, the one highly relevant to the most grassland management entities is understanding how climate change will impact the health of grassland rivers, streams, and wetlands like the prairie potholes and playa lakes. In particular, grassland managers need information on water availability, stream connectivity, and

Table C9. Information needed for successful management of grazing in a changing climate.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
6. How will climate change impact grazing?	H	H	H	H	H	X	H	H	H	H	H	H	S	H	H	H	H
6.1 How will climate change impact the quantity and quality of forage?	S	S	H	H	H	X	H	H	S	S	H	S	S	H	H	S	S
6.2 How will climate change impact the variability of forage temporally and spatially?	H	S	H	H	H	X	H	H	S	H	S	S	S	H	S	S	S
6.3 How will climate change affect the viability of Bos taurus (cattle) and Bison bison(bison) herds and other native herbivores?	X	H	H	H	S	X	H	H	H	H	S	X	S	S	X	H	S
6.4 What grazing management practices can help ranchers successfully adapt to climate change and also support healthy grassland ecosystems?	S	S	S	H	H	X	H	H	H	S	H	S	S	H	H	H	H

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as "H."

Table C10. Information needed for successful management of water quality and quantity in a changing climate.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
7. How will climate change impact water quality, quantity, and availability?	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
7.1 How will climate change impact the hydrological cycle of the North Central grasslands?	S	H	S	S	H	H	H	H	H	S	H	H	H	H	H	H	H
7.2 How will climate change impact the health of grassland rivers, streams, prairie potholes, and playa lakes?	H	H	H	H	H	H	S	H	H	H	H	H	H	H	H	H	H
7.3 How will climate change impact human water use and groundwater recharge?	X	H	S	H	H	H	S	H	H	H	H	H	H	H	H	H	H
7.4 How will water quality be directly and indirectly impacted by climate change?	H	H	H	S	H	H	H	H	S	S	S	H	H	H	H	H	H
7.5 How will climate change affect the frequency and intensity of drought and floods?	S	H	H	H	H	S	H	H	H	H	H	H	H	H	H	H	H

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[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as “H.”

streamflow (Crausbay and Cross, 2019). Grassland management documents also highlighted the importance of updated wetland inventories to identify their spatial extent and distribution, evaluate restoration potential, and inform conservation work (MFWP, 2015; Prairie Pothole Joint Venture, 2017b).

Wildlife Population Declines

As the grassland habitats in the North Central region have been lost, fragmented, and degraded, associated wildlife populations have declined in all grassland ecoregions and are at high risk of declining further if extensive management for their conservation is not implemented. Bird populations across North America have declined by 29 percent since 1970, with grassland breeding birds showing the greatest decline (53 percent) and a loss of more than 700 million individuals (Rosenberg and others, 2019). The prevalence of small grassland mammals decreases with an increase in woody encroachment (Horncastle and others, 2005). Black-tailed prairie dog populations have declined by 98 percent across their range, with related declines in many associated species (Hoogland, 2006).

The decline in wildlife populations is detrimental not just for the particular species, but also because many animal species play important roles in the ecological functioning of grasslands. For example, many insect species are important for pollination (Hanberry and others, 2021), large ungulates and smaller mammals that graze on grasses and forbs are part of the natural disturbance regime (Hygnstrom and Virchow, 2002; Anderson, 2006), and *Castor canadensis* (American beaver) are important for maintaining and improving healthy riverscapes (Westbrook and others, 2011; Gibson and Olden, 2014). Thus, the decline in grassland wildlife populations is both a consequence of the direct threats described above as well as a direct threat to the health and function of grasslands.

Management Responses

Managing grasslands for animal species of greatest conservation and cultural importance is a major activity for many of the grassland management entities in the North Central region (table C5). For example, black-tailed prairie dogs and *Mustela nigripes* (black-footed ferret) have been the focus of a few Tribal grassland restoration efforts (Cheyenne River Sioux and National Wildlife Federation, 2001; Dennis Longknife, Fort Belknap Indian Community Climate Change Program, written commun., 2021). Management to promote habitat for grassland wildlife of conservation concern often overlaps with other management goals and includes actions such as restricting activities that result in habitat loss or fragmentation, developing grazing management plans compatible with wildlife habitat needs, implementing prescribed burns, minimizing introduction and spread of invasive species, avoiding and minimizing disturbances to breeding and nesting activities, avoiding direct mortality because of human activities, providing food resources, and releasing or transplanting species of conservation concern (see, for example MFWP, 2011).

Information Needed

Understanding how climate change will affect animal species of greatest conservation concern and cultural importance is highly relevant to most grassland management entities in the North Central region (table C11). In particular, grassland managers would like to better understand how climate change will shift and fragment habitat ranges. Understanding these impacts will require improved wildlife inventory and monitoring.

Conservation on Private Land

Federal, State, and Tribal agencies and NGOs are also looking to support and partner with private landowners who are interested in grassland conservation. The conservation actions of private landowners are crucial for grassland conservation since approximately 83 percent of land across the North Central Grassland Ecoregions is privately owned and managed, including 1 percent under permanent conservation or ranchland easements (fig. C1). The proportion of privately managed land in the grassland ecoregions varies by State, with the highest proportions in Kansas (98 percent) and Nebraska (97 percent). Much of this privately owned land has already been developed or converted to cropland. The privately owned land remaining in grassland is often the basis for the landowners’ livelihood. Thus, in contrast to publicly owned and managed land, conservation practices on private land often must be congruent with the economic profitability of the land.

Despite potential economic concerns, many private landowners use voluntary conservation practices on their land. Private landowners often partner with one or more of the Federal and State agencies and NGOs discussed in this report. Private landowners may also implement conservation practices on their own or in collaboration with other private landowners. Local landowner groups like the Sandhills Task Force in Nebraska (Sandhills Task Force, 2014), Grazing Lands Coalitions (National Grazing Lands Coalition, 2021) or prescribed fire associations (Weir, 2010), use strategic thinking and innovative experimentation to implement conservation practices in cost-effective ways. Private landowners also serve on boards of soil and water conservation districts and can therefore impact land beyond that which they own. Notwithstanding the notable conservation efforts of many private landowners, voluntary conservation efforts on private land are a vital component of landscape management and supporting and expanding conservation on private lands will help achieve grassland management goals across the North Central Grassland Ecoregions.

Table C11. Information needed for successful management of animal species of greatest conservation concern in a changing climate.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
8. How will climate change affect animal species of conservation concern?	H	H	H	H	S	X	X	H	H	H	H	H	H	H	H	H	H
8.1 How will climate change shift and fragment habitat ranges?	H	H	H	H	S	X	X	H	H	S	H	S	H	H	H	H	H
8.2 How will climate change affect the timing of species' lifecycles?	S	H	H	H	X	X	X	H	H	S	H	H	H	H	H	H	H
8.3 How will climate change affect the prevalence of disease?	S	H	H	H	X	X	X	H	H	H	S	S	H	H	H	S	S

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as "H."

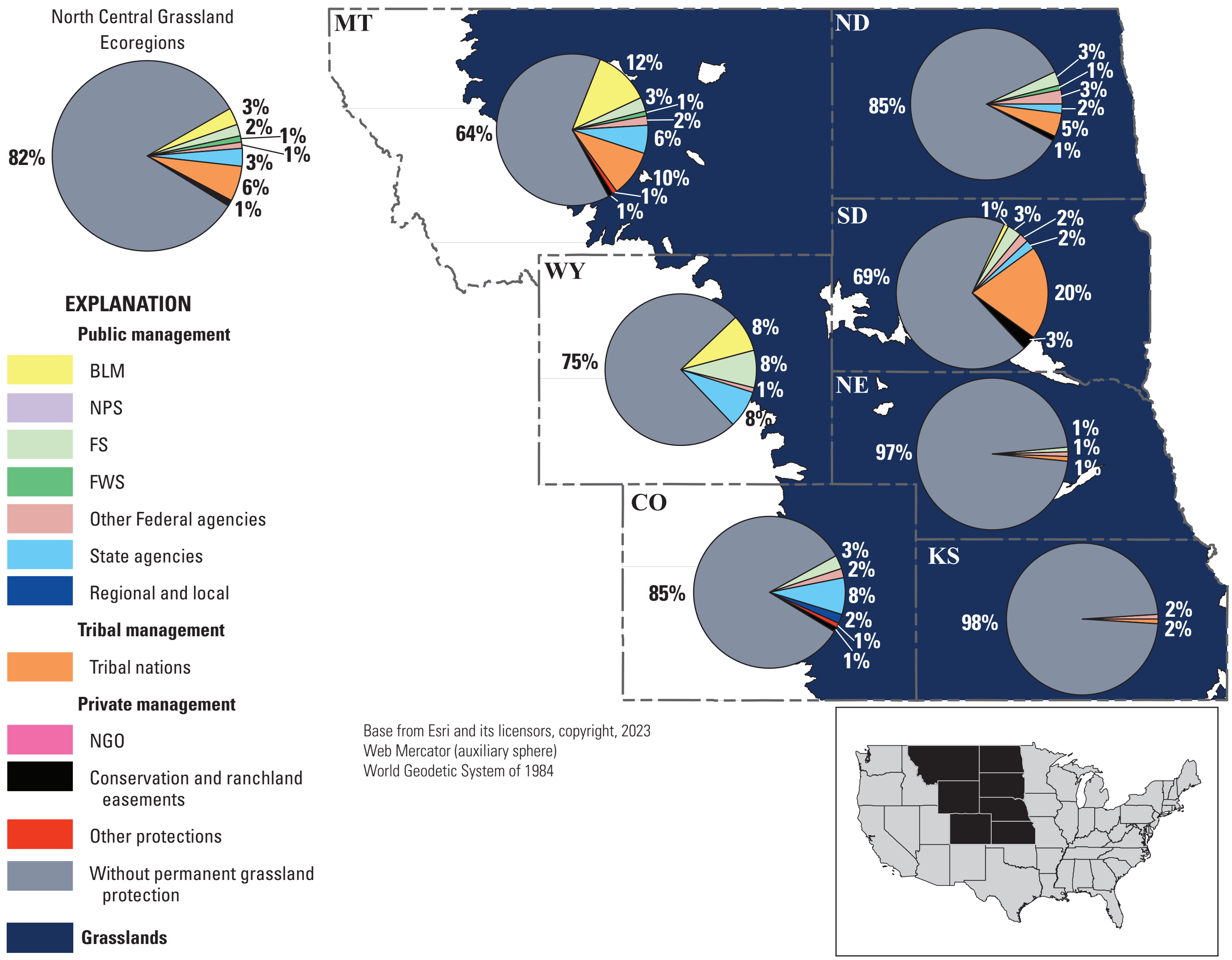

Figure C1. Proportion of North Central Grassland Ecoregions (shown in dark blue) managed by government agencies, Tribal nations, and private landowners within each State and across the region. Data from Protected Areas Database of the United States (USGS, 2020; see also fig. B5). Non-Federal entities managing less than 0.5 percent of land in the grassland ecoregions are not included here. Percentages do not add to 100 because of rounding. %, percent; BLM, Bureau of Land Management; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; FWS, U.S. Fish and Wildlife Service; NGO, nongovernmental organization; MT, Montana; ND, North Dakota; WY, Wyoming; SD, South Dakota; NE, Nebraska; CO, Colorado; KS, Kansas.

Management Responses

Working to promote conservation on privately owned grasslands is a major part of the activities of many grassland management entities in the North Central region (table C5). The NRCS and the FSA together implement the conservation title of the U.S. Farm Bill (for example, Public Law 110–246 [6/18/2008] Food, Conservation, and Energy Act of 2008; Public Law 113–79 [2/7/2014] Agricultural Act of 2014; and Public Law 115–334 [12/20/2018] Agriculture Improvement Act of 2018), which provide the most significant source of funding for private land conservation in the United States (Baier, 2020, p. 75). Specifically, the U.S. Farm Bills support conservation practices and conservation planning on private grasslands with the Environmental Quality Incentives Program and Conservation Stewardship Program and supports the maintenance of grassland with the Grassland Conservation Reserve Program and conservation easements (NABCI, 2015; Augustine and others, 2021; FSA, 2022a, b).

In addition, the FWS supports conservation on private land by providing technical and financial assistance to landowners through the Partners for Fish and Wildlife Program (FWS, 2021). Other entities, such as the U.S. Department of Agriculture, Forest Service and The Nature Conservancy, work to build relationships directly with grazing associations and may help to secure improved conservation practices on private land by allowing the grazing of livestock on national grasslands or grasslands owned by The Nature Conservancy (Casey Johnson, TNC, oral commun., 2022).

State agencies also work closely with interested landowners to promote conservation on private land. For example, Colorado Parks and Wildlife partners with private landowners to incentivize the conservation of grassland-associated wildlife through the Ranching for Wildlife Program, Colorado Wildlife Habitat Program, and Pheasant Habitat Improvement Program (CPW, 2020, p.17; CPW, 2021).

Information Needed

Understanding how conservation can be achieved on private grasslands is highly relevant to NRCS, FSA, Tribal nations, State natural resource agencies, NGOs, and partner organizations (table C12). As part of promoting conservation on private grassland, understanding what technical and financial assistance private landowners will require is highly relevant. Part of the needed technical assistance may be information on which agency or NGO private landowners should reach out to for various conservation goals. Many of the agencies and NGOs covered in this report have overlapping goals and offer similar support to private landowners for conservation practices. In many ways, this redundancy is advantageous because it allows for flexibility in meeting conservation goals in a variety of situations. However, the particular priorities and opportunities for funding at a given agency or NGO can change, and this may lead to confusion about which agency or organization is appropriate to contact for particular goals.

Contributing Factors

In addition to addressing direct threats to conservation and degradation factors, grassland managers in the North Central region also work to address the contributing factors that may serve to amplify or reduce direct threats to the grasslands. In this section, we describe contributing factors that grassland management entities are working to address.

Public Understanding of Grasslands

A general lack of understanding and appreciation for grassland ecosystems hinders the ability of private landowners to effectively manage their grasslands and diminishes public support for broader grassland conservation efforts (Dove, 2019; Hoover and others, 2020). Since explorer and cartographer Stephen H. Long described the plains as the “Great American Desert” in 1820, the myth of the region as a wasteland has influenced policy and public perception (Baltensperger, 1992). Policies dating back to the Homestead Act of 1862 (Public Law 37–64, 12 Stat. 392) framed grasslands as wastelands that became valuable only when converted to agricultural fields and planted with trees. As nonindigenous settlers moved west from the eastern, mostly forested States, they brought with them the perspective that trees are important for supporting wildlife. Even today, private landowners who desire to manage their grasslands to provide wildlife habitat often fail to understand that increasing woody vegetation will result in a loss of habitat for grassland species (Brad Guhr, Dyck Arboretum of the Plains, written commun., 2011). Furthermore, even grasslands that are locally valued and managed are often condemned as “wastelands” by nonlocals; this widespread undervaluation of grasslands limits local managers’ opportunities for conservation, development, and research (Dove, 2019, p. 276).

Another challenge is that the public is generally unaware of what has already been lost in the historical U.S. range of grassland ecosystems. What was once a thriving ecosystem with vast herds of native grazers has been radically altered, modified, and converted across a large portion of the region. In addition to promoting tree planting and the conversion of grassland to agricultural fields, the Federal Government, as part of its effort to force Native Americans from their land, systematically worked to eradicate bison herds in the plains in the 1880–90s (Taylor, 2011; NPS, 2018). The loss of grasslands and their associated wildlife has continued even in recent years (see the “Wildlife Population Declines” section above). Yet, because many of these species are small, modestly colored, or often hidden from view, the public often does not perceive or appreciate the magnitude of this loss.

Management Responses

Public outreach and education are a major part of the activities of most of the grassland management entities described in this report (table C13). There are many examples of efforts to increase public appreciation for the subtle beauty of grasslands and the value of their ecosystem services that could be more widely adopted. Dyck Arboretum of the Plains—an environmental NGO in Hesston, Kansas—is helping to increase public support of grasslands by providing education on prairie maintenance and restoration and hosting a native plant sale every spring and fall (Brad Guhr, Dyck Arboretum of the Plains, oral commun., 2021). The Nature Conservancy is also working to increase public appreciation for healthy grasslands in many States. For example, The Nature Conservancy is managing the Niobrara Valley Preserve in Nebraska as a demonstration site to show how grazing, prescribed fire, and management of woody vegetation can provide a shifting mosaic of habitat patches across the landscape to support the full range of vegetative structure and its associated species. The staff at the Niobrara Valley Preserve engaged the public by providing management demonstrations to private landowners, hosting college classes and research projects, and allowing public access for hiking on a developed trail and hunting through long-term leases for *Odocoileus*

Table C12. Information needed for achieving conservation on private grasslands in a changing climate.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
9. How can conservation on private grasslands be achieved?	X	S	X	X	H	H	S	H	H	H	H	H	H	H	H	H	H
9.1 What technical assistance will private landowners need to promote resilient and biodiverse grasslands in a changing climate?	X	S	X	X	H	H	H	H	H	H	S	S	H	H	H	H	H

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[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as “H.”

Table C13. Management actions to address contributing factors.

[For each management entity, the management action is rated as a major or a minor part of their activities. U.S., United States; NGO, nongovernmental organization; NA, management action seldom or never employed]

Organization	Public outreach and education	Advocating for policy change	Economic incentives and funding	Coordinate collaboration across agencies and organizations	Increase access to useable tools and science	Utilizing new ways of thinking
Federal						
Bureau of Land Management	Major	NA	NA	Major	Major	Major
U.S. Fish and Wildlife Service	Major	NA	NA	Major	Minor	Major
National Park Service	Major	NA	NA	Major	NA	Major
U.S. Department of Agriculture, Forest Service	Major	NA	NA	Major	NA	Minor
Natural Resources Conservation Service	Major	NA	Major	Major	Major	Major
U.S. Department of Agriculture, Farm Service Agency	Minor	NA	Major	Minor	Minor	Minor
Tribal						
Bureau of Indian Affairs	Minor	Minor	Minor	NA	NA	NA
Rosebud Sioux Tribe[1]	NA	Major	Minor	Minor	NA	Minor
State						
Colorado Parks and Wildlife	Major	NA	Major	Major	NA	Minor
Kansas Department of Wildlife and Parks	Major	Minor	Major	Minor	Major	Major
Montana Fish, Wildlife and Parks	Major	Major	Major	Major	Minor	Minor
Nebraska Game and Parks Commission	Major	Major	Major	Major	Minor	Major
North Dakota Game and Fish	Major	Major	Major	Major	Minor	Minor
South Dakota Game, Fish and Parks	Major	Major	Major	Major	Minor	Minor
Wyoming Game and Fish Department	Major	Major	Major	Major	Minor	Minor
Nongovernment organization and partnerships						
The Nature Conservancy[2]	Minor	Major	Minor	Major	Minor	Major
Migratory Bird Joint Ventures[3]	Minor	Minor	Minor	Major	Major	Major

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the major and minor activities of the Rosebud Sioux Tribe. Further research is needed to understand grassland management actions across all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the major and minor actions of The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the major and minor actions taken by Joint Ventures as a result of the partnership, and do not necessarily represent the actions of all partners individually.

virginianus (white-tailed deer) and *Meleagris gallopavo* (wild turkey). Academic institutions can also help to raise public awareness and appreciation of grasslands. For example, the Konza Environmental Education Program at Kansas State University hosts more than 2,000 school children at the Konza Prairie for prairie education each year (Nippert and others, 2018; Kansas State University, 2022).

The impact of these public outreach and education examples could be amplified by the development of additional creative approaches to further public appreciation of grasslands and support for their conservation. For example, the plains and savannas in Africa are generally valued by Americans—even children's nurseries are decorated with the animals of the African plains. Yet, Americans often think of the grasslands in the United States as "flyover country" (see Harkins, 2016). A public relations campaign to raise awareness of the uniqueness and beauty of the Great Plains could help to direct more energy and funding toward conservation efforts.

Information Needed

Knowing how to increase public understanding of grasslands and their importance is at least somewhat relevant for all the grassland management entities but the Bureau of Indian Affairs (table C14).

Legal and Policy Drivers

Policies can create incentives or disincentives for protecting and maintaining healthy grasslands; therefore, they present important opportunities for promoting grassland conservation (Lark, 2020). For example, because conversion of grasslands to agricultural cropland is one of the biggest threats to grasslands in the North Central region, policies laid out in the U.S. Farm Bill have a direct impact on the future existence and health of grasslands. Although the U.S. Farm Bill includes many programs that help to incentivize conservation on private land (see above), it also includes disincentives for protecting grasslands. For example, the U.S. Farm Bill's provision of publicly funded crop insurance incentivizes the conversion of grassland to cropland by decreasing farmers' risk of crops failing in areas of marginal suitability for those crops (Claassen, 2011; Miao and others, 2016). This effect has been somewhat mitigated by the Sodsaver program, which was first established in the 2014 U.S. Farm Bill and only applies in six States (including Montana, North Dakota, South Dakota, and Nebraska in the NC CASC region), by making cropland that has been converted from native prairie eligible for only 50 percent of crop insurance subsidies for four years before having access to 100 percent (Lark, 2020). Policies that intend to incentivize grassland conservation need adequate consideration of the best available science to ensure they meet their goals.

Management Responses

Tribal nations, State natural resource departments, The Nature Conservancy, and Migratory Bird Joint Ventures (JV) all work to advocate for policies that will support conservation of grasslands (table C13). For example, The Nature Conservancy advocated for increased resources and flexibility in the Regional Conservation Partnership Program in the 2018 U.S. Farm Bill. This program dedicates Federal funding to public-private partnerships for agricultural conservation practices. The Nature Conservancy used this funding to partner with agricultural producers to protect some of the most intact native grazing lands remaining in Kansas (TNC, 2021). By advocating for greater funding and flexibility in this program, The Nature Conservancy helped to make sure it would enable new partnerships and greater innovation for conservation going forward (TNC, 2021).

Information Needed

Understanding the legal and policy changes that can support grassland resilience to climate change is most relevant to NGOs, partnerships, and State and Tribal agencies because Federal agencies are not able to advocate for policy changes (table C15). Nevertheless, the question of how the U.S. Farm Bill can promote conservation of private grasslands is highly relevant to most grassland management entities.

Economic Incentives

Approximately 84 percent of the land in the North Central region is privately owned and managed without any permanent protection (that is, from a conservation easement or other measure), so economic incentives for landowners to protect, improve, and maintain their grasslands represent an important opportunity for grassland conservation. For example, enhanced livestock insurance and other policies to improve ranching profitability and competitiveness with crop production would help reduce conversion of grassland to cropland (Brunson and Huntsinger, 2008; Davidson, 2016; Hendrickson and others, 2019).

Management Responses

As described above, the U.S. Farm Bill offers a number of economic incentives to support grassland conservation. Other incentives include financial support or cost-sharing for conservation offered by NGOs. Such incentives may include direct payments (for example, payments for establishment of a conservation easement) or may save landowners money indirectly. An example of the latter is the grassbank that has been established on The Nature Conservancy's Matador Ranch; neighboring ranchers are allowed to graze their animals on

Table C14. Information needed for increasing public understanding of grasslands and their importance.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
10. How can public understanding of grasslands and their importance increase?	S	H	H	H	H	S	X	H	H	H	S	H	H	H	H	S	S
10.1 What are the main characteristics of grasslands and what ecosystem services do they provide?	X	H	H	H	H	S	X	H	S	S	S	H	S	S	H	H	S
10.2 How can grasslands help support community resilience to climate change?	S	S	S	S	H	S	X	H	H	S	S	H	S	H	H	H	S

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as "H."

Table C15. Information needed for legal and policy drivers to support grassland resilience to climate change.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity															
	Federal							Tribal	State						NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
11. What legal and policy changes can support grassland resilience to climate change?	X	X	X	S	S	X	S	H	S	X	S	S	H	H	S	H	S
11.1 What legal constraints need to be addressed to promote grassland resilience to climate change?	X	X	X	H	X	X	S	H	S	X	S	X	S	S	S	H	S
11.2 How can the U.S. Farm Bill promote conservation of private grasslands?	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as “H.”

The Nature Conservancy's land for a reduced fee in exchange for the establishment of conservation practices on their own land (TNC, 2021). As the United States works to address climate change, there may be opportunities to offer additional economic incentives to landowners in the form of payments for ecosystem services such as carbon storage.

Information Needed

Understanding the best ways to economically incentivize grassland protection, enhancement, and maintenance is highly relevant to most grassland management entities in the North Central region (table C16). Emerging opportunities include investigation of how landowners might receive payments for ecosystem services of carbon sequestration in grasslands.

Coordination of Actions across Agencies, Organizations, Jurisdictions, and Borders

The grasslands of the North Central region are managed in small pieces by many different grassland management entities (see fig. B5), which sometimes leads to conflicting goals. Management will need to be coordinated at the landscape level to be most effective in facilitating healthy grassland ecosystems in a changing climate (Epstein and others, 2021). There are efforts to coordinate across States, between State and Federal agencies; among Federal agencies; among national governments; and among these agencies, NGOs, and the private sector. There is a need to increase this coordination across agencies, organizations, jurisdictions, and borders. To do this, numerous structural barriers to cooperation across agencies, organizations, and borders will need to be overcome; however, a full discussion of these barriers is beyond the scope of this report.

Tribal nations face particular challenges and opportunities in coordinating a landscape approach to grassland management. The histories, cultures, and legal sovereignty of Tribal nations set them apart from other management entities discussed in this report. In many cases, Tribes share common bureaucratic challenges to management authority and capacity, often involving their unique relationship with the Federal Government through the Bureau of Indian Affairs. Tribal nations also vary widely in their internal management systems. Thus, the complex and disparate structure of Tribal management may at times add a layer of complexity to large-scale partnerships, but may also provide opportunities for new directions in grassland conservation.

Management Responses

Migratory Bird Joint Ventures offer a model for how agencies and organizations can work across jurisdictions and borders on a coordinated approach to a common conservation goal. The JVs are coordinated and supported by the FWS to plan, fund, implement, and evaluate projects deemed a priority for meeting broad migratory bird population and habitat objectives on a continental scale. The diversity of partner groups engaged in JV projects includes Federal and State agency science and management entities, county and local governments, land trusts and other NGOs, Tribal resource managers, academic researchers, private landowners, agricultural producers, and private corporations.

Bureau of Land Management ecoregional assessments offer another example of efforts to facilitate conservation of grasslands at a larger scale. The BLM currently develops and implements land management plans at the level of the field office. However, BLM has recently begun to explore a landscape approach by conducting rapid ecoregional assessments that "seek to identify important resource values and patterns of environmental change that may not be evident when managing smaller, local land areas" (BLM, 2022). Specifically, rapid ecoregional assessments look at how climate change, wildfires, invasive species, and urban and energy development will impact habitat for species of concern across the landscape. Landscape-level assessments like this have potential to provide common information across boundaries that can help inform coordinated land management decision making across the North Central grasslands.

Information Needed

Information to facilitate the strategic coordination of grassland management actions across agencies, organizations, jurisdictions, and borders is relevant to all grassland management entities in the North Central region (table C17).

Availability of Usable Science and Tools

Although grassland ecosystems have historically been understudied relative to other biomes (Bengtsson and others, 2019), there has nevertheless been increasing scholarly attention to the grasslands and the way they will be impacted by climate change (for example, Gibson and Newman, 2019). It is critical this growing body of scientific research on climate change and grasslands be focused on providing relevant information that can be used in decision making by grassland managers. In addition, many of the information needs occur at the intersection of social science and ecology, yet there is a relative dearth of social science to support grassland management decision making. Specifically, it remains unclear how

Table C16. Information needed to economically incentivize grassland protection, enhancement, maintenance, and reconstruction.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
12. How can grassland protection, enhancement, maintenance, and reconstruction be economically incentivized?	X	S	X	S	H	H	H	H	H	H	H	H	H	H	H	H	S
12.1 How might landowners receive payments for ecosystem services?	X	X	X	X	H	H	H	H	H	S	S	H	H	H	H	H	H
12.2 Are there opportunities for payments for carbon sequestration in grasslands?	X	S	X	S	S	S	S	S	S	H	S	S	S	S	H	H	S

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as "H."

Table C17. Information needed to strategically coordinate actions across agencies, organizations, jurisdictions, and borders.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal						Tribal		State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
13. How can grassland management be strategically coordinated across agencies, organizations, jurisdictions, and borders?	H	H	H	H	H	H	H	H	H	H	S	H	H	H	H	S	H
13.1 What are the structural barriers to cooperation and how can they be overcome?	H	H	H	H	H	S	H	H	H	S	S	H	S	S	H	S	H
13.2 What are the benefits and costs of a coordinated approach to grassland management in a changing climate?	H	H	H	H	H	S	H	H	S	H	S	H	S	S	H	H	H

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

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people living and working in the grassland ecoregions will respond to climate change and how those actions will, in turn, impact grassland ecosystems (Ahlering and others, 2020).

Management Responses

Translating science into usable management tools is a developing field and there is a wealth of information on how to create more actionable, usable science (Bamzai-Dodson and others, 2021). Early engagement between researchers and grassland management entities can help to make sure research is relevant to management needs (McNie, 2012). Opportunities to develop relevant, usable climate sciences can be found at institutions whose mission is to serve resource managers, such as the Department of the Interior Climate Adaptation Science Centers and U.S. Department of Agriculture Climate Hubs (see Rangwala and others, 2021). The FS has been a leader in the development of user-friendly, climate change adaptation science, planning tools, and other related resources, including the template for assessing climate change impacts and management options for the climate change response framework, the climate change adaptation library for the western United States, and the system for assessing vulnerability of species climate change tool. A growing number of FS units are using these tools.

Information Needed

All grassland management entities in the North Central region need information to help improve the accessibility and usability of relevant science and tools (table C18). A study of what information and tools are currently available to help managers respond to climate change and what tools need to be developed is highly relevant to the greatest number of grassland management entities.

Frameworks for Conceptualizing Problems and Solutions

Grassland ecosystems will be directly impacted by climate change through, for example, changes in temperature and precipitation, and indirectly impacted by the way in which people choose to alter their use of land and water resources in response to climate change. Managing grasslands within the context of climate change is further complicated by the uncertainty in the intensity, duration, spatial scale, and timing of many direct and indirect impacts. Therefore, new frameworks are needed to conceptualize problems and solutions in relation to climate change and successful management of grasslands.

Even within agencies and organizations there are structural barriers to a holistic understanding of grassland ecosystems and the way they will be affected by climate change. Within the field of ecology, terrestrial and aquatic research and management are often siloed into separate departments and offices in academia and resource management organizations. This makes it challenging to understand and manage grassland systems of which aquatic features like streams, wetlands, and potholes are integral parts. Even research and management tools make it difficult to integrate these interconnected systems. For example, when organizing information into geographic units, it is possible to choose between major land resource areas, which are defined by terrestrial ecosystems; hydrologic unit codes, which are defined by watershed; Environmental Protection Agency Ecoregions; or a host of other options, which may be more or less conducive to transdisciplinary or applied research efforts.

Beyond the challenges of bridging jurisdictional, ecological, and geographic silos is the need to incorporate an understanding of how social factors and processes will interact with grassland systems in the context of climate change. Politics, economics, and culture all influence how people will respond to the impacts of climate change, and these responses in turn will impact grassland ecosystems. The speed at which human activities can impact grasslands greatly exceeds the rate at which climate change will impact grasslands, so focusing on the latter to the exclusion of the former will severely limit our ability to meet grassland management goals. Much research is yet to be done to develop our understanding of these social factors and processes. Identifying and synthesizing the social science on economics, policy, and culture and how they will interact with climate change to impact grassland conversion, degradation, and conservation is an emerging need from this synthesis of grassland management priorities.

Another important aspect of adaptation to climate change is the inclusion of local knowledge to help ensure that scientific information, which is often presented as generalizable information that applies to large spatial scales, is thoughtfully interpreted in the local ecological and social context (National Research Council, 2009; LeDee and others, 2021). The need to bring scientific information together with local knowledge for successful adaptation highlights the importance of participatory decision making and science and the inclusion of traditional ecological knowledge (TEK) that members of Tribal nations have accumulated over generations of living on the North Central grasslands (Jantarasami and others, 2018). Central to the TEK of the Tribal nations of the North Central region is the understanding that biodiversity is crucial for the health of grassland ecosystems (Cheyenne River Sioux and National Wildlife Federation, 2001; Goodwin and LongKnife Jr., 2013; Great Plains Tribal Water Alliance and Oglala Sioux Tribe, 2020). Bringing TEK and scientific knowledge together is important for developing best management practices for grasslands in a changing climate. Furthermore, inclusion of local knowledge and TEK is also important for working toward grassland management that is equitable in its distribution of costs and benefits among communities.

Table C18. Information needed to improve the accessibility of relevant science and tools.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
14. How can the accessibility of relevant science and tools be improved?	S	H	S	S	H	S	H	H	H	H	S	H	S	S	H	S	H
14.1 What information and tools are currently available to help grassland managers respond to climate change and what tools need to be developed?	S	H	H	S	H	S	H	H	H	S	S	S	S	S	S	S	H
14.2 How could relevant grassland science and tools best be shared and communicated with interested users?	S	H	S	S	H	S	S	H	H	S	S	S	S	S	S	S	H
14.3 What kinds of technical training programs and (or) informational workshops would increase the capacity of resource managers to utilize scientific information and tools?	S	H	S	S	H	S	S	S	S	S	S	S	S	S	S	S	H
14.4 How can new technologies be employed to increase creation and sharing of relevant data for decision-making?	S	H	S	S	H	S	S	S	H	X	S	S	S	S	H	S	H

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[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

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Management Responses

Many of the grassland management entities reviewed for this report are beginning to develop and adopt some novel frameworks for conceptualizing problems and solutions related to grassland conservation in a changing climate. The National Park Service Climate Change Response Program has been instrumental in identifying adaptation options for individual NPS units through scenario planning (NPS, 2020; Miller and others, 2022) and the resist-accept-direct decision framework (Schuurman and others, 2020; NPS, 2021). The FWS is also looking to develop novel frameworks for addressing climate change. The "Advancing the National Fish, Wildlife, and Plants Climate Adaptation Strategy into a New Decade" report specifically recommends additional research on use of the resist-accept-direct framework for specific management questions, evaluation of climate adaptation projects and plans, best practices providing climate adaptation training to staff, management for future ecological conditions, identification of tipping points, and understanding social-ecological-climatological feedbacks that may result in new opportunities or challenges (National Fish, Wildlife, and Plants Climate Adaptation Network, 2021, p. 64).

Information Needed

Developing novel ways to think about grassland management in a changing climate is relevant for all grassland management entities. Of the various information needs (table C19), understanding how to manage for shifts in the frequency and intensity of extreme events is highly relevant to the greatest number of grassland management entities, followed by an understanding of what strategies can be used to promote grassland health and human community flourishing in the face of climate change.

Emerging Challenges and Opportunities

The systematic review of grassland management documents and related literature allowed us to identify, synthesize, and summarize grassland management priorities, challenges, and information needs across the North Central region (see full methods in "Chapter A—Background and Methods"). This approach enabled us to generate a baseline of information about grassland management in the North Central Climate Adaptation Science Center (NC CASC) region while not overburdening resource managers and key stakeholders. Using this approach yielded extensive findings that offered a starting point for further research and informed outreach to resource managers in the NC CASC. However, since this approach relied on available management plans and related literature, the information we synthesized may not reflect priorities and challenges that have not yet been integrated into formal planning documents or other studies. In addition, our reliance on publicly available documents means that we likely did not include issues that are an important part of internal management discussions but have not yet been integrated formally into public-facing documents.

The reliance on using available documents prevented us from thoroughly incorporating the grassland management goals, challenges, and information needs of Tribal nations in this report. Twenty-seven federally recognized Tribal nations manage grasslands within the North Central region. Each of these Tribal nations has unique grassland management goals, challenges, and activities; however, we were unable to include Tribal resource management documents in our systematic review (see "Chapter A—Background and Methods"). Instead, the core research team worked closely with Tribal members and a Bureau of Indian Affairs Tribal resilience liaison to summarize general information about Tribal grassland management goals and challenges across the North Central region. However, given the diversity in history, governmental structure, and ecological resources, each Tribal nation in the region warrants its own chapter in this report. Better understanding of the unique grassland management goals and challenges for each Tribal nation has emerged from this synthesis as a significant knowledge gap, which can be addressed by increased partnership and collaboration with Tribal nations. One opportunity for collaboration with Tribal nations in the North Central region may be in supporting the management of bison herds in a changing climate, for example, with the InterTribal Buffalo Council (https://itbcbuffalonation.org/). Scientific research and traditional ecological knowledge can help to inform adaptive bison management practices across the region.

Additional social science research could build on and further elucidate the findings from this document review and address the limitations of this approach. Given the lack of publicly available documents for Tribal nations, social science methodologies like interviews, surveys, and focus groups may be the best approach for better understanding the diversity of grassland management goals, challenges, and information needs across Tribal nations. These social science methods could also be useful for digging deeper in our understanding of other management entities as well. For example, surveys could be used to further refine the measures of relevance of the information needs identified in this report and interviews could help to identify priorities, challenges, and information needs not expressed in public documents because of their sensitive or currently emerging nature.

There is an imperative to increase timely collaboration across social, ecological, and climate science to address complex challenges and opportunities that are newly emerging. As national leaders increasingly look to address climate change through mitigation and adaptation strategies, how can resource managers be provided with the up-to-date information they need to respond quickly to executive orders (for example, initiatives like the 30 by 30 plan) and increased prioritization of carbon storage? In addition, what information will grassland

Table C19. Information needed to think in novel ways about grassland management in a changing climate.

[BLM, Bureau of Land Management; FWS, U.S. Fish and Wildlife Service; NPS, National Park Service; FS, U.S. Department of Agriculture, Forest Service; NRCS, U.S. Department of Agriculture, Natural Resources Conservation Service; FSA, U.S. Department of Agriculture, Farm Service Agency; BIA, Bureau of Indian Affairs; CPW, Colorado Parks and Wildlife; KDWP, Kansas Department of Wildlife and Parks; MFWP, Montana Fish, Wildlife and Parks; NGPC, Nebraska Game and Parks Commission; NDGF, North Dakota Game and Fish; SDGFP, South Dakota Game, Fish and Parks; WGFD, Wyoming Game and Fish Department; TNC, the Nature Conservancy; JV, Migratory Bird Joint Ventures; U.S., United States; NGO, nongovernmental organization; X, not relevant; H, highly relevant; S, somewhat relevant]

Information needed	Management entity																
	Federal							Tribal	State							NGO	
	BLM	FWS	NPS	FS	NRCS	FSA	BIA	Rosebud Sioux Tribe[1]	CPW	KDWP	MFWP	NGPC	NDGF	SDGFP	WGFD	TNC	JV
15. What novel ways of thinking are needed to successfully manage grasslands amidst climate change?	H	S	H	H	H	S	S	H	S	S	S	S	H	S	H	S	S
15.1 How can approaches and frameworks such as Resist-Accept-Direct, adaptive management, social-ecological systems, scenario planning, proactive management, landscape-level planning, drought planning, tradeoff evaluation, state-transition models, traditional ecological knowledge, local ecological knowledge, and participatory decision-making and science help contribute to the successful management of grasslands amidst climate change?	X	H	H	H	H	S	X	H	S	S	H	H	H	S	H	H	S
15.2 What strategies can be used to promote grassland health and human community flourishing in the face of climate change?	S	S	X	H	H	H	X	H	H	H	S	H	H	S	H	H	H
15.3 How can tradeoffs in climate mitigation (for example, carbon sequestration) and biodiversity be carefully considered?	S	H	H	S	X	H	S	H	S	S	S	S	H	S	H	H	H
15.4 How will human responses to climate change impact grasslands?	S	H	X	H	H	S	S	H	H	H	S	S	H	S	H	H	S
15.5 What are the feedback loops between human actions, climate change, and ecological processes?	X	H	S	H	S	S	X	S	H	H	S	H	H	S	H	H	S
15.6 What cascading or amplifying effects might be caused by the complex and interconnected reactions of various systems to climate change?	S	S	S	S	S	S	X	S	H	S	S	S	H	S	H	H	S
15.7 How can we manage for shifts in the frequency and intensity of extreme events?	H	H	H	H	H	X	H	H	H	H	H	S	H	S	H	H	S
15.8 Where will the impacts of climate change make it impossible for grasslands to continue to exist?	S	H	H	H	H	H	S	H	S	S	H	X	H	S	H	S	H

[1]Although we have attempted to broadly consider all 27 federally recognized Tribes, these values best represent the relevance of these questions to the Rosebud Sioux Tribe. Further research is needed to understand the full range of goals and information needs for grassland management among all North Central Tribal nations.

[2]Although we have attempted to broadly consider conservation NGOs generally, these values best represent the relevance of these questions to The Nature Conservancy.

[3]Migratory Bird Joint Ventures are partnership organizations and reflect the priorities of multiple partners. The values in this table reflect the relevance of questions to the priorities of the four Joint Ventures that overlap with the North Central region; where a question was highly relevant to at least one Joint Venture we ranked that question as "H."

and other resource managers need to respond effectively to rapid sociodemographic changes? These changes are difficult to predict, but may be triggered or exacerbated by climate change as global demands for food production and preferences shift, or as people move to escape sea-level rise, rising temperatures, or other harmful impacts of climate change. Although this report centers on the climate change-related information needs of grassland managers, it is imperative to remember grasslands are not isolated systems, but are interconnected with broader, social-ecological systems (see Walker and Salt, 2006) that include social, economic, cultural, environmental, and political dynamics. The need to deepen understanding of the interactions and feedback loops between the interlinked human, climate, and ecological systems will be increasingly important to generating science to support decision makers in a rapidly changing world (see National Academies of Sciences, Engineering, and Medicine, 2021).

Conclusion

Grasslands are crucial to the North Central region and provide valuable ecosystem services and support rural livelihoods. Review of the grassland management documents for the agencies and organizations that manage grasslands across this region revealed that although many are managing grasslands to meet multiple different goals, conservation is a widely shared goal across all management entities. To conserve grasslands in a changing climate, however, grassland managers need information about how climate change will interact with other social and environmental drivers to impact grassland loss and fragmentation, disruption of the historical disturbance regime, woody encroachment, herbaceous invasives, unsustainable grazing, changes in water quality and quantity, wildlife population declines, and grassland conservation on private land. In addition, grassland managers need information to address indirect threats to grassland conservation, including information to increase public understanding of grasslands; support legal and policy drivers that align with grassland conservation; develop economic incentives for conservation of private grasslands; coordinate actions across agencies, organizations, jurisdictions, and borders; increase the availability and useability of relevant science and tools; and employ novel frameworks for conceptualizing climate problems and solutions.

This synthesis of grassland management documents is an important first step in identifying where future research could be directed to best support grassland conservation in a changing climate; however, the next step is to synthesize the research literature to identify where answers to these information needs already exist and where answers are lacking. The Climate and Ecology Working Group (see "Chapter A—Background and Methods") is reviewing and synthesizing scientific literature to answer these questions, where possible, and to identify where additional research is needed. Their forthcoming findings, along with findings presented in this report, can serve as a baseline of information to help inform future research that will be relevant to grassland manager priorities, challenges, and information needs, and necessary to address scientific gaps in our understanding of grasslands and climate change.

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