Received: 11 September 2024 | Revised: 14 February 2025 | Accepted: 19 February 2025

DOI: 10.1111/csp2.70017

Conservation Science and Practice
A journal of the Society for Conservation Biology
Open Access

WILEY

REVIEW

A climate adaptation menu for North American grasslands

Jacy S. Bernath-Plaisted[1] | **Stephen D. Handler**[2,3] | **Marissa Ahlering**[4] | **Leslie A. Brandt**[5] | **Scott B. Maresh Nelson**[1] | **Neal D. Niemuth**[6] | **Todd Ontl**[5] | **Courtney L. Peterson**[3,7] | **Christine A. Ribic**[1] | **Delane Strohmeyer**[8] | **Benjamin Zuckerberg**[1]

[1]Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, Madison, Wisconsin, USA

[2]USDA Forest Service Northern Research Station, and USDA Northern Forests Climate Hub, Houghton, Michigan, USA

[3]Northern Institute of Applied Climate Science, Houghton, Michigan, USA

[4]The Nature Conservancy, Moorhead, Minnesota, USA

[5]USDA Forest Service, Office of Sustainability and Climate, Washington, District of Columbia, USA

[6]US Fish and Wildlife Service, Habitat and Population Evaluation Team, Bismarck, North Dakota, USA

[7]Forest & Rangeland Stewardship Department, Colorado State University, Fort Collins, Colorado, USA

[8]USDA Forest Service, Midewin National Tallgrass Prairie, Wilmington, Illinois, USA

Correspondence
Jacy S. Bernath-Plaisted, Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, Madison, Wisconsin, USA.
Email: bernathplais@wisc.edu

Funding information
USDA Forest Service and USDA Northern Forests Climate Hub, Grant/Award Number: 23-CS-11242306-056; U.S. Geological Survey Midwest Climate Adaptation Science Center

Abstract

North American grasslands are climate-vulnerable biomes that provide critical ecosystem services and support biodiversity. However, grasslands are often not included in climate policy and treaties, and they are underrepresented in ecological climate-adaptation literature. We synthesized existing knowledge on climate adaptation in North American grasslands to provide resources and guidance for grassland managers facing increasing climate change impacts. We leveraged data from a systematic review and solicited input from management professionals at workshops to create a Grassland Adaptation Menu—a referenced, hierarchical list of specific grassland management tactics nested under broader climate adaptation strategies. Our review revealed that although the number of published studies examining grassland-climate topics is increasing, relatively few provide actionable recommendations for adaptation. Among studies that did make recommendations, landscape-planning principles such as conserving grasslands in future climate refugia and enhancing connectivity were the most frequently recommended practice types, but there were also suggestions for site-level management such as adjustments to fire and grazing, improved seed sourcing and restoration practices, increased heterogeneity and biodiversity, use of assisted migration, and management of microclimate conditions. The Grassland Adaptation Menu incorporates eight general strategies and 32 approaches in a structured format designed to help managers translate concepts into actions.

KEYWORDS

climate adaptation, climate change, conservation planning, ecosystem services, fire, grassland, grazing, Great Plains, management, restoration

1 | INTRODUCTION

Grasslands currently occupy approximately 40% of the world's land surface (Gibson, 2009; White et al., 2000). In North America, grasslands are continentally distributed and encompass a diversity of natural and planted habitats. Globally, grassland biomes provide trillions of dollars in ecosystem services that are both critical to the maintenance of biodiversity and to sustaining human well-being (Bengtsson et al., 2019; Liu et al., 2022; Zhao et al., 2020). Key ecosystem services provided by grasslands include food, fiber, and animal production (Jackson, 2022; O'Mara, 2012; White et al., 2000), erosion control and soil production (Saviozzi et al., 2001; Wu et al., 2020), water quality and runoff reduction (Bengtsson et al., 2019; Zhao et al., 2020), pollination services (Holland et al., 2017; Sexton & Emery, 2020), and wildlife habitat and biodiversity (Bernath-Plaisted, Correll, et al., 2023; Davidson et al., 2012; Hanberry et al., 2021; Leipold et al., 2025; Werling et al., 2014). Currently, grasslands store ∼30–35% of the world's terrestrial carbon stock (Ahlström et al., 2015; White et al., 2000) and, importantly, ∼90% of carbon in grasslands is stored belowground in soil (Bai & Cotrufo 2022), where it is protected from release during disturbance events such as fire (Briske et al., 2024; Viglizzo et al., 2019).

Despite their importance to ecosystem services, grasslands are threatened by many anthropogenic stressors and are often undervalued for their conservation and ecosystem service benefits. Globally, grasslands have been reduced to 26%–45% of historical extents (Hoekstra et al., 2005), and most remaining grasslands are highly fragmented (Augustine et al., 2021; Scholtz & Twidwell, 2022). Grasslands also tend to receive less protection (Hoekstra et al., 2005) and policy attention (Bardgett et al., 2021; Bengtsson et al., 2019) than forested systems, and they are frequently left out of international treaties and climate agreements (Gibson & Newman, 2019). In North America, ∼50% of original grasslands have been lost to threats including agricultural expansion, energy development, woody encroachment, urbanization, and deliberate afforestation (Briske et al., 2024; Lark et al., 2015; Ott et al., 2021; van Auken, 2009). This habitat loss has been exacerbated by the degradation of many grasslands by invasive species, fire suppression, and homogenization through grazing practices (Bardgett et al., 2021; Fuhlendorf et al., 2012; Grant et al., 2020; Ratajczak et al., 2016). Anthropogenic climate change now presents a further threat to grassland systems, and the biodiversity and services that they support (Gibson & Newman, 2019; Lavorel, 2019).

Global surface temperatures have increased on average by 1.1°C since the pre-industrial era, and greenhouse gas emissions have continued to rise over the last decade, increasing the likelihood that mean warming will exceed 2°C by mid-century (Calvin et al., 2023). Broadly, many grassland regions in North America are projected to experience increased intensity and frequency of summer droughts, elevated maximum temperatures, and an increase in heavy precipitation events in some areas (Calvin et al., 2023; Gibson & Newman, 2019). The Central Grasslands form a tri-national region (Figure 1) that contains the largest remaining grassland tracts in North America and was once among the largest contiguous grasslands on Earth (Scholtz & Twidwell, 2022). By 2040–2070, northern parts of this region will experience increases in average maximum temperature of at least 4°C (Figure 1a). Central and southern grassland regions will likely see reduced precipitation, while many northern areas will receive increased rainfall (Figure 1b). However, these precipitation gains may be offset by greater evaporative water loss and moisture deficits (e.g., drier soils due to high evaporation) throughout the Central Grasslands region (Figure 1c). Grasslands may be especially vulnerable to increasing temperatures associated with climate change because they lack the buffering capacity of forest canopy to moderate microclimate extremes (Suggitt et al., 2011), and because they often (with the exception of montane grasslands) occur in areas of little topographic relief, where the velocity of climate change may be greater (Dobrowski et al., 2013; Loarie et al., 2009).

Climate change may affect the ecology and functioning of grassland systems in numerous ways and will likely create new management challenges, as well as exacerbate existing ones (Gibson & Newman, 2019; Lavorel, 2019). Changes in temperature extremes, as well as the timing and intensity of precipitation, will fundamentally alter the productivity and phenology of grassland plants (Fraser, 2019), nutrient cycling, and ecosystem processes (Henry, 2019). For example, elevated temperatures and drought may reduce forage quality and grazing capacity (Holechek et al., 2020), shift fire seasons (Yurkonis et al., 2019), and reduce carbon sequestration (Felton & Goldsmith, 2023). Greater climate variability and occurrence of extreme events (particularly concerning precipitation), elevated CO_2 levels, and earlier growing seasons may favor the dominance of invasive species and facilitate woody encroachment—invasive species may be better able to capitalize on longer growing seasons, and woody plants can put on biomass more rapidly with higher CO_2 concentrations, and both groups may also benefit from intense precipitation events (Catford & Jones, 2019; Goodale & Wilsey, 2018; Kulmatiski & Beard, 2013; Morgan et al., 2007). Increased drought and evaporative water loss may also result in the

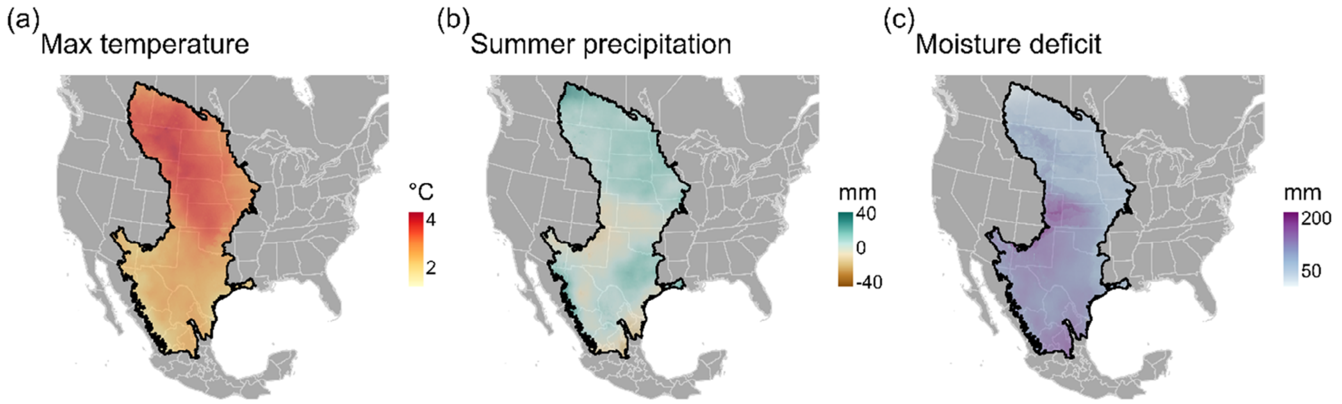

FIGURE 1 Projected changes between current climate normals and normals by 2040–2070 under a moderate emissions scenario for the North American Central Grasslands region. The largest maximum temperature increases are projected to occur in the Northern Great Plains (a). Mean summer precipitation may increase through much of the Northern Great Plains, while parts of the south and central plains will become increasingly dry (b). Nearly the entire Central Grassland region will experience greater climatic moisture deficits (a measure of evaporation potential and soil drying) likely resulting in more arid conditions (c). Climate data are generated from CMIP6 (ensemble models for SSP245 emissions scenario) models and sourced from the AdaptWest Project (adaptwest.databasin.org). The Central Grasslands boundary file is available from the US Fish and Wildlife Service at https://gis-fws.opendata.arcgis.com/datasets/fws::north-american-central-grasslands/explore.

drying of grassland-embedded wetlands and subsequent loss of wetland habitat and ecosystem services (Londe et al., 2024; Zhang et al., 2021), though strong regional variability in these trends may also occur (Niemuth et al., 2014). Finally, the management of grassland wildlife and biodiversity will also be affected by climate change, with many species experiencing range shifts and losses (Wilsey et al., 2019), elevated demographic stress and disease risk (Conrey et al., 2016; Poje et al., 2020), altered movement patterns (Bateman et al., 2015), and phenological mismatches (Freimuth et al., 2022).

Given these diverse challenges and the threats they pose to the functioning of grassland ecosystems, there may be a growing need for actionable management recommendations that can help grassland managers adapt to a changing climate (Miller Hesed et al., 2023). Climate adaptation can be defined as any adjustment to the management of systems intended to reduce the risks and impacts of climate change (Handler et al., 2022; Swanston et al., 2016). While there is an increasingly wide array of broad principles available to managers to help guide climate adaptation, information on specific adaptation practices is often sparse, and many recommendations made in the literature are not locally actionable (Cady et al., 2023; Handler et al., 2022). In particular, grassland biomes are underrepresented in the literature (Cady et al., 2023; LeDee et al., 2021).

Our goal was to synthesize current recommendations about climate adaptation in grassland ecosystems and create an adaptation menu to address the unique and pressing adaptation needs of North American grasslands. There were three objectives involved in the development of this menu: (1) Conduct a systematic literature review to provide a synthesis of recommended climate adaptation practices in grasslands and assess the current state of research on this topic; (2) Combine recommendations extracted from our review with expert opinion and input from management professionals to produce a structured Grassland Adaptation Menu; and (3) Demonstrate a real-world application of the menu through a case study with grassland managers.

2 | METHODS

2.1 | Systematic review

We used the ISI Web of Science (WOS) database (https://www.webofscience.com/) to conduct a systematic literature review. To target articles that researched the effects of climate change in North American grasslands or discussed topics broadly relevant to grassland climate adaptation, we constructed a search string using Boolean operators. Our review was intended to synthesize literature from all North American grassland regions. We constructed our search to link key terms describing climate change, habitat, and topics related to the ecological response and management of grasslands (including restoration). Thus, our search used the following structure on WOS: TS = (first climate term OR second climate term) AND TS = (first habitat term OR second habitat term…) AND TS = (first ecological term OR second ecological term…). Using this structure, any article that contained at least one term from each argument in any of the title, abstract, or keywords would be returned. Our climate terms included only "climate change" and "global warming" as we wanted to identify not simply articles that related climate variables to grassland ecology (e.g., temperature, precipitation), but rather those that examined, discussed, or acknowledged the impacts of change in these climate conditions on grasslands. Our habitat terms included grassland, old field, parkland, pasture, prairie, rangeland, and savanna as these are the most widely used terms to describe grassland habitats in North America. Finally, our ecological topic keywords included terms describing possible response taxa (e.g., plants, birds, invertebrates, etc.), grassland ecosystem services (e.g., ecosystem functioning, hydrology, soil, etc.), and grassland management/adaptation topics (e.g., fire, grazing, invasive species, translocation, etc.). Several preliminary searches were conducted to inform discussion of early workshops (see Menu Development), but the final search of these terms for which we present results here was conducted on January 2, 2024. The full search string exactly as entered in WOS is available in Supporting Information, Appendix S1. WOS initially returned 8423 records when we searched these terms. Before abstract screening, we used WOS filters for country (selecting only Canada, Mexico, and USA) and record type (removing books) leaving 4201 records (Figure S1).

The lead author screened abstracts of all remaining records for relevance based on three criteria. First, if the study was field-based, we ensured that data collection occurred in North America (WOS country filters are often not precise). Global datasets that included North America were also included, as well as reviews on topics that could be broadly applied to any grassland system. Second, we confirmed that data collection occurred in grassland habitat or that the topic was focused on a grassland system. We excluded studies that were focused on other similar ecosystems, such as sagebrush. However, we included studies of grassland-embedded wetlands, as we felt these were highly relevant to the management of grasslands in the Prairie Potholes and Playa Lakes regions, for example. Finally, we assessed whether the analysis or topic of the study explicitly addressed the effect of climate change on some aspect of ecology or management in grasslands. Thus, we excluded studies that, for example, were concerned with climate change projections in grassland regions but did not address any kind of ecological response or context, studies that examined the relationship between climate and a grassland response but said nothing about climate change or its implications, and studies that were entirely agriculturally focused (e.g., drought tolerance of crops, cattle weight gain practices, etc.) but did not address any of the ecological consequences associated with agricultural management decisions.

Following abstract screening, the lead author and two trained assistants extracted vote count (i.e., summarizing the number of studies on given topics or making certain recommendations etc.) data from all relevant records. We extracted the following variables: publication year, country where data were collected (Canada, Mexico, or USA; reviews and global studies were classified as "multiple"), grassland topic in relation to climate change (fire, grazing, human dimensions, invasive species, organismal response, restoration, soil and nutrients, wetlands and hydrology, woody encroachment, other, or multiple), focal taxa (if the study was organismally focused; bird, herpetofauna, invertebrate, mammal, plant, soil fauna, or multiple), and grassland type (arid, grassland-embedded wetland, Mediterranean, mixed-grass, old field, planted/pasture, savanna, shortgrass, tallgrass, other, or multiple). The "other" category included systems that were difficult to categorize or for which very few studies met the criteria for our review, including coastal grasslands, montane and alpine grasslands, saltmarsh and fens, ecotones, and various experimental settings. Finally, we assessed whether each article had made what we considered to be one or more coherent management recommendations (see Textual Analysis section below) concerning climate adaptation in grassland ecosystems and assigned each record a binary "Yes" or "No." We summarized vote count data from all relevant studies to provide an overview of interest in the topic over time and breakdowns of studies by grassland type, ecological/adaptation topic, and taxonomic focus.

2.2 | Qualitative textual analysis and extraction

A primary objective of our review was to extract management recommendations for climate adaptation actions in grassland ecosystems to include in the Grassland Adaptation Menu. Thus, for each relevant article, we manually scanned the discussion, conclusion, management implications, and relevant review sections for clear statements about management in relation to climate change adaptation. We extracted and stored relevant text passages for each article, and articles could contain multiple recommendations. We considered passages to be coherent recommendations if they clearly stated specific actions that could be taken to achieve adaptation goals. However, we excluded passages that were vague or provided insufficient detail and context to be actionable. For example, many studies stated that their results had implications for

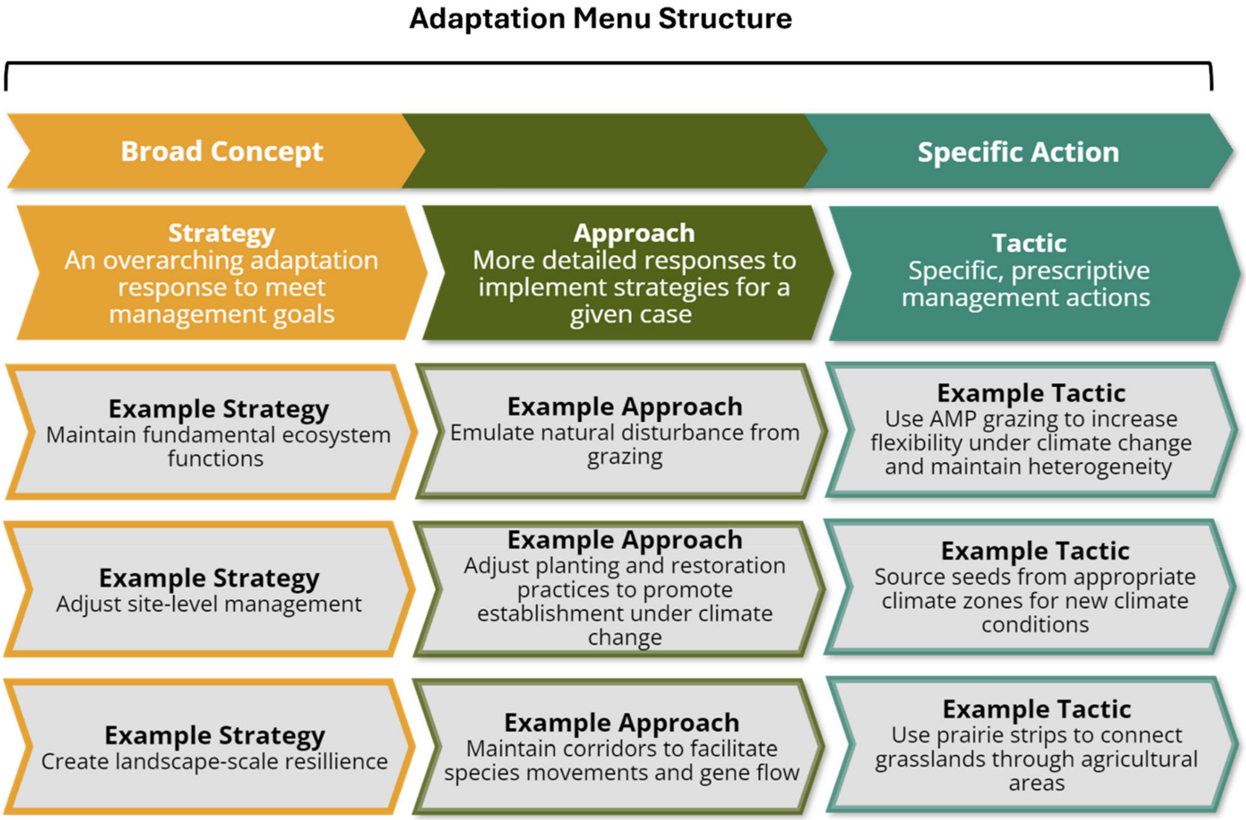

FIGURE 2 The tiered structure of the Grassland Adaptation Menu is intended to help managers move from broad concepts to specific management actions. Strategies (yellow) represent broader adaptation responses to meet general management goals, approaches (green) are more detailed ways to implement a strategy for a given site, species, or problem, and tactics (teal) are specific, prescriptive actions taken to achieve adaptation goals in a particular instance.

climate change but did not provide specific details describing how their findings could be applied. Similarly, studies often called for additional research, made vague statements about future implications, or discussed their findings in the context of advancing theory or improving certain types of models, but failed to connect these advances to management. After all recommendation passages were compiled, we assigned each passage a practice category so that we could summarize what types of recommendations are commonly made. These practice categories were not created *a priori* but rather were informed by the types of recommendations that we frequently observed during the review. Practice categories were adjustments to grazing systems, adjustments to prescribed fire, assisted migration, climate matching seeds, conservation stocking rates, future habitat refugia and connectivity, habitat heterogeneity, incentivizing conservation actions, increasing biodiversity (including richness, functional diversity, and genetics), managing invasive species, managing microclimate conditions, managing woody encroachment, providing resources to managers, restoring hydrology, soil amendments, and other. Recommendations that fell into the "other" category were often too system-specific to fit general categories or were recommended too rarely to be given a designated category.

2.3 | Menu development

We followed a similar approach to previously published adaptation menus (e.g., Handler et al., 2022; Janowiak et al., 2021; Schmitt et al., 2022; Staffen et al., 2019; Swanston et al., 2016) in developing the Grassland Adaptation Menu. After completing our literature review, we collated and synthesized both specific management recommendations extracted from textual analysis and broader adaptation concepts gleaned from the literature we reviewed into a tiered list of adaptation strategies, approaches, and tactics (Figure 2). As in previous menus, we used the terms *strategy*, *approach*, and *tactic* as defined by Swanston et al. (2016). *Strategies* are defined as broad adaptation responses that describe major management goals under climate change; *approaches* are more detailed responses that consider how a strategy could be applied in different instances; and *tactics* are

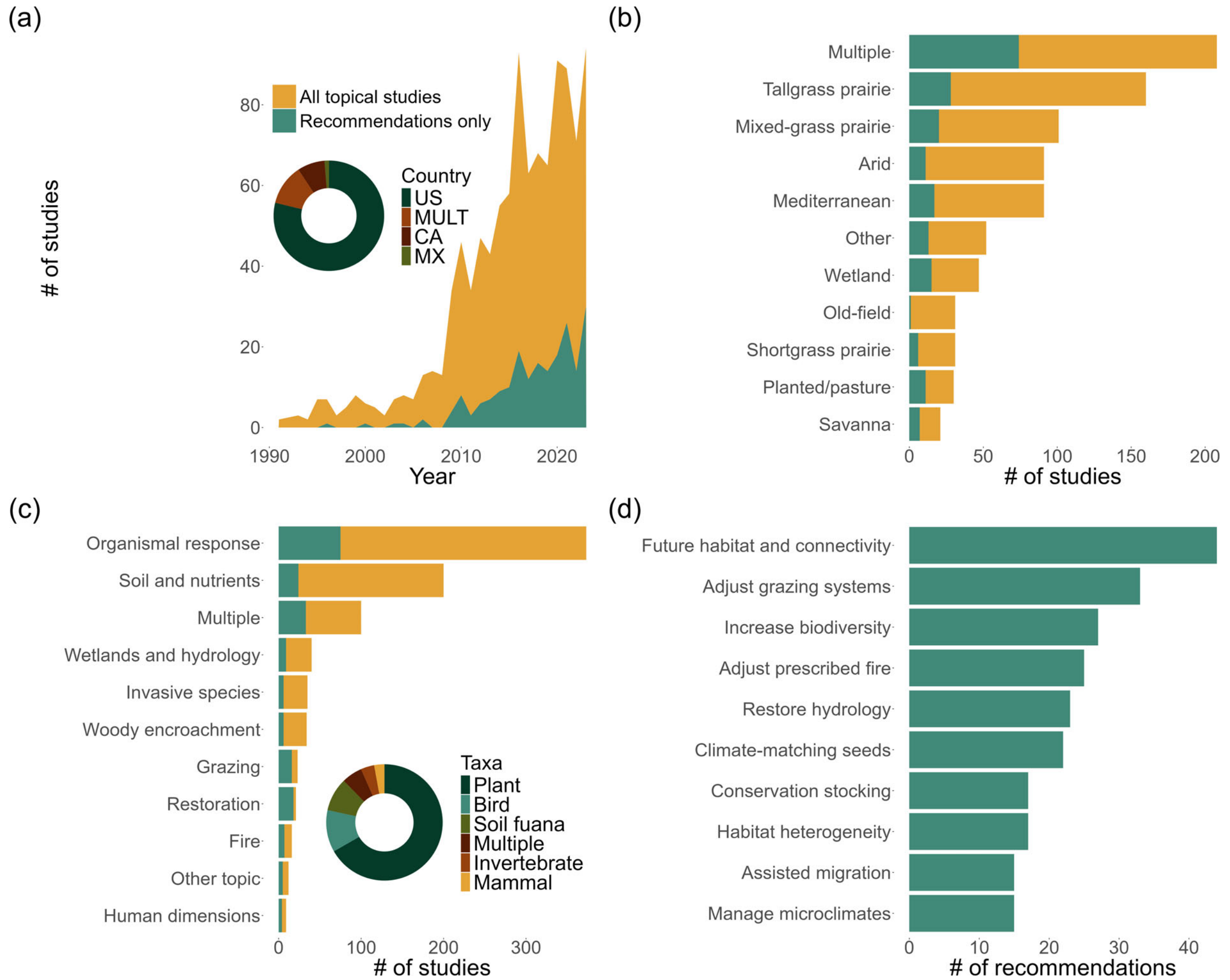

FIGURE 3 Summaries of vote-count data from a systematic review examining the effects of climate change on grassland management in North America ($n = 863$). Interest in the topic has been increasing, but only a small proportion of studies made clear management recommendations for grassland climate adaptation (a); studies have been conducted in a variety of grassland types in North America, with tallgrass prairie receiving the most research attention (b); the studies in our review focused on a range of topics, and the most frequently examined topic was the relationships between grassland organisms and climate variables ($n = 373$); among all studies, the taxonomic focus was biased toward plants, while other taxa received less attention (c); the 10 most commonly identified grassland climate adaptation practices (d).

specific, prescriptive management actions taken to implement strategies and approaches.

Following the development of an initial draft menu, we solicited input on the menu from management professionals by hosting three virtual manager workshops. The first workshop was held in February 2021, and two subsequent events were held in August 2021 and February 2022. The first workshop was attended only by USDA Forest Service staff, while subsequent workshops were attended by management professionals from a diversity of non-governmental organizations, as well as state and federal natural resource agencies. We followed Handler et al. (2022) in structuring our workshops, and participants were split into groups and asked to apply the Grassland Adaptation Menu in combination with the Adaptation Workbook—a planning process developed by the Northern Institute of Applied Climate Science (NIACS), a collaborative, multi-institutional partnership led by the USDA Forest Service—to real-life grassland management projects. The Adaptation Workbook consists of a structured five-step process that can be summarized as: (1) *Define* management objectives; (2) *Assess* vulnerability to climate change; (3) *Evaluate* objectives given vulnerability; (4) *Identify* adaptation practices; and (5) *Monitor* the effectiveness of management actions. It was during this fourth step that participants were asked to use the Grassland Adaptation Menu to identify strategies, approaches, and tactics that were appropriate for the management goals they had defined. Following these breakout sessions, we brought participants back together for a group discussion to receive general feedback and comments on the draft menu. We revised the menu in accordance with these comments using feedback from all workshops. Example meeting agenda and workshop feedback forms are available in Supporting Information, Appendix S2 and S3, respectively.

3 | RESULTS AND DISCUSSION

3.1 | Literature review findings

Our systematic review of literature examining the effects of climate change on North American grasslands and their management identified 863 studies spanning the years 1990–2023 (Figure 3a). Consistent with a recent review on climate change in grasslands globally (Hager & Newman, 2019), we found that interest in the topic appears to have increased substantially over the last two decades. Yet, only 23% of studies (Figure 3a) on grasslands and climate change included in our review made management recommendations for climate adaptation. These results may speak to a broader need for specificity in management and increased awareness by researchers of how conservation is delivered in a climate change context (Cady et al., 2023; Heller & Zavaleta, 2009; LeDee et al., 2021). Many of the studies identified in our review made vague or general statements about climate change but did not provide sufficient detail or specificity to inform management, while others emphasized the general importance of their work but made little attempt to link results to management. However, there are many reasons that researchers may choose not to provide explicit management recommendations. For example, some researchers associated with government agencies may be prohibited from doing so, others may not wish to be perceived as "telling managers what to do", and others still may be hesitant to make recommendations until their work is replicated. These considerations are valid and represent important nuances that inform our findings. Still, we encourage authors of future work on climate change adaptation to provide clear interpretation of how their work might apply to management when possible and appropriate. Doing so may ease the burden on managers with limited time and research background saving them from having to interpret complex results themselves. Such information may also benefit researchers seeking to provide synthesis for management applications, and create decision tools like adaptation menus, which rather than handing out top-down recommendations are intended to provide managers with a diversity of options to select from based on their own assessment of needs (e.g., Swanston et al., 2016).

Our review also identified geographic and taxonomic differences in the existing grassland climate-change literature that highlight potential information gaps. First, although we gathered studies from across North America, including Canada, Mexico, and the USA, as well as global datasets that included North America, most existing studies (78%) we identified were conducted in the USA (Figure 3a). Similarly, not all grassland ecosystems were evenly represented in the literature, and the effects of climate change were most studied in tallgrass prairie, accounting for 19% of studies (although studies examining multiple grassland types were the most common), while systems like shortgrass prairie (which is geographically more extensive) were more poorly represented at 4% (Figure 3b). The proportion of studies that made recommendations was generally similar by grassland type and averaged 23%, but ranged from 3% to 37% (Figure 3b). Finally, among all studies for which a focal taxon could be identified ($n = 668$), 67% were focused on plants, while, for example, 9%, 3%, and 2% examined climate change effects on grassland birds, invertebrates, and mammals, respectively (Figure 3c). Studies that focused on the management of grassland herpetofauna under climate change were almost completely absent from the literature. Filling these taxonomic knowledge gaps and increasing our understanding of how climate change affects a diversity of grassland species will be important for informed adaptation planning, as species groups may have unique needs and respond differently to both climate and management practices.

The studies included in our review focused on a diversity of climate adaptation topics in grasslands, and the relationship between grassland organisms and climate variables was the most common subject, while the effects of climate on various management issues were less frequently addressed (Figure 3c). The proportion of studies that made recommendations varied widely among topics (Figure 3c) and nearly all studies (85%) on grassland restoration under climate change made adaptation recommendations, while by contrast, studies on soil and nutrient cycling seldom did (12%). The studies that we considered to provide coherent or clear adaptation guidance ($n = 203$) collectively presented 335 recommendations, which we classified into practice categories (Figure 3d). The most recommended practice types comprised landscape-level planning activities such as conserving grasslands in regions where climate is likely to remain suitable for grassland species (Bateman et al., 2020; Rana et al., 2025) and improving habitat connectivity to facilitate range shifts and gene flow (e.g., Perkins et al., 2019). Recommendations were also made for site-level management. For example, alternative grazing schemes to increase ecosystem services (e.g., Döbert et al., 2021), enhancing resilience through

TABLE 1 A tabular summary of strategies, approaches, and example tactics from the Grassland Adaptation Menu.

Adaptation strategies	Adaptation approaches and example tactics
1. Restore and maintain the extent of grasslands across the landscape	1.1 Conserve existing intact grasslands. *Example*: *prioritize grasslands based on conversion risk* (Stephens et al., 2008) 1.2 Address major mechanisms of grassland conversion. *Example*: *regulate new energy leases on undeveloped grasslands and work with energy companies to minimize impacts* (Ott et al., 2021) 1.3 Create or maintain grassland habitats that include heterogeneity and redundancy in site types and environmental conditions *Example*: *implement site-level management that promotes heterogeneity, such as patch-burn grazing* (Fuhlendorf et al., 2012) 1.4 Restore or establish grasslands in locations expected to remain suitable under future climate conditions. *Example*: *incorporate climate priorities into government permanent cover programs* (Cunningham, 2022)
2. Increase landscape-scale resilience under future climate conditions	2.1 Maintain or create movement corridors. *Example*: *use prairie strips to enhance grassland connectivity through agricultural areas* (Schulte et al., 2017) 2.2 Reduce fragmentation and create habitat steppingstones. *Example*: *consider landscape context when prioritizing conservation investment* (Herse et al., 2020) 2.3 Protect habitat along species range edges. *Example*: *focus conservation efforts on the northern edge of species distributions in anticipation of range shifts* (Nixon et al., 2016)
3. Maintain fundamental ecosystem functioning	3.1 Maintain or restore nutrient cycling. *Example*: *apply soil amendments like biochar to increase soil organic matter and productivity* (Mayer & Silver, 2022) 3.2 Emulate natural disturbance processes from grazing. *Example*: *protect remaining native grazers such as prairie dogs* (Haun et al., 2024) 3.3 Emulate natural disturbance processes from natural and indigenous fire. *Example*: *allow prescribed fire to burn with varying intensity to mimic wildfire and create heterogeneity* (Hill et al., 2017) 3.4 Maintain or restore hydrology. *Example*: *exclude cattle from riparian areas to prevent bank erosion and maintain water quality* (Krall et al., 2021) 3.5 Maintain pollination services. *Example*: *strengthen pollination networks by increasing floral diversity* (Guzman et al., 2021)
4. Increase biodiversity and heterogeneity in grassland communities	4.1 Maintain or enhance genetic diversity of ecological communities. *Example*: *overseed grassland restorations with seed mixes from multiple collection zones* (Havens et al., 2015) 4.2 Maintain and restore a diversity of native plants and functional groups. *Example*: *diversify tame pasture and planted forage with greater functional diversity (e.g., legume/grass mixes) and consider plant tolerances for future climate conditions when selecting forage* (Rojas-Downing et al., 2018) 4.3 Maintain and restore heterogenous vegetation structure. *Example*: *create refugia by leaving taller patches of vegetation unburned* (Steenvoorden et al., 2019) 4.4 Maintain or restore grassland-embedded wetland vegetation and hydrology. *Example*: *remove legacy sediments to control weedy and invasive species* (Beas et al., 2013)
5. Reduce the impacts of ecological and climate stressors	5.1 Reduce the impact of climate on ecosystem functioning. *Example*: *restore grassland-embedded wetlands to regulate flooding and provide moisture refuiga* (Ferreira et al., 2023) 5.2 Reduce the impact of climate on grassland wildlife. *Example*: *maintain and deploy natural and artificial water sources for grassland wildlife to mitigate drought* (Rich et al., 2019)

TABLE 1 (Continued)

Adaptation strategies	Adaptation approaches and example tactics
	5.3 Control woody encroachment. *Example*: *implement prescribed fire with higher intensities than natural fire regimes to control invasions* (Scholtz et al., 2022) 5.4 Control invasive species. *Example*: *manipulate timing and intensity of grazing to target invasive species* (Firn et al., 2013) 5.5 Promote beneficial management practices on agricultural lands. *Example*: *Support incentives to reduce or delay mowing and haying activities in agricultural grasslands to avoid destroying grassland bird nests* (Tews et al., 2013)
6. Adjust site-level management to align with new climate conditions	6.1 Adjust the timing, frequency, and intensity of management actions (such as fire, grazing, and mechanical treatments, etc.). *Example*: *adopt flexible burn schedules that can accommodate shifting fire windows such as winter burns* (Yurkonis et al., 2019) 6.2 Adjust planting and restoration practices to promote establishment of grassland vegetation under climate change. *Example*: *create "safe sites" for seed establishment and enhance diversity by restoring microtopography and stone cover* (Biederman & Whisenant, 2011) 6.3 Adjust the management of grassland-embedded wetlands to account for changing precipitation and hydroperiods. *Example*: *install infrastructure and vegetation features that control the flow of water and sediments* (e.g., *one-rock dams, swales*) (Pierce et al., 2012)
7. Facilitate transitions under climate change	7.1 Promote climate-tolerant plant genotypes and facilitate community shifts to better align with future climate conditions. *Example*: *facilitate transition of plant communities by seeding restorations with all climate-viable species theoretically within dispersal distance* (McKone & Hernández, 2021) 7.2 Engage in assisted migration to facilitate species range shifts. *Example*: *prioritize species for assisted migration based on expected range loss and dispersal capability* (Barber et al., 2016) 7.3 Convert non-grassland systems to grassland where climate can no longer support current land use. *Example*: *identify locations where forest-ecotones are shifting to savanna and facilitate this shift through prescribed burns* (Kodero et al., 2024) 7.4 Identify where investment in grassland conservation is a poor use of resources. *Example*: *elect not to pursue adaptation where ecological value is low and management costs are high* (Bottrill et al., 2008)
8. Engage human communities in grassland conservation and adaptation	8.1 Respect and incorporate indigenous knowledge and values in grassland management. *Example*: *Partner with indigenous-led natural resources agencies to develop joint adaptation practices and co-stewardship projects on issues of cultural importance to indigenous peoples* (Mucioki, 2024) 8.2 Invest in outreach and support for landowners and producers. *Example*: *explicitly include climate adaptation practices* (e.g., *payments for carbon sequestration and pasture rest* etc.) *in programs and ensure that agency staff are trained to advise landowners on climate topics* (Wiener et al., 2020) 8.3 Develop and promote economic incentives for grassland climate adaptation on private lands. *Example*: *create branding and markets for sustainably produced grassland products, such as the Audubon Society's Bird Friendly Land label* 8.4 Involve communities in management activities. *Example*: *engage communities in regional invasive species monitoring and prevention campaigns* (Goodwin et al., 2012)

Note: Strategies characterize broad goals for the management of grasslands in a climate change context, while approaches describe more specific ways a strategy might be implemented for a given project or management site. Tactics are prescriptive practices nested under each approach and need not be limited to the examples we provide. A full narrative version of the menu, including all example tactics and references, is available in Supporting Information, Appendix S4.

FIGURE 4 Depictions of example adaptation tactics for each of the eight broad strategies (a–h) identified in the Grassland Adaptation Menu. Artwork by V. Doebley at Wild Earth Lab.

increased biodiversity (e.g., Catford et al., 2020), restoring grasslands with seed mixes that are better matched to future climate (e.g., Galatowitsch et al., 2009), conservation stocking as drought mitigation (e.g., Fritts et al., 2018), and managing for heterogeneity (e.g., Bachelet et al., 2011) and thermal diversity (Patterson et al., 2020) were all consistently suggested. We incorporated these types of practices, and many others, into the Grassland Adaptation Menu presented below.

3.2 | Grassland adaptation menu and practices

We developed a menu of strategies (overarching management goals), approaches (more detailed responses for a given project or site), and example tactics (specific management practices) intended to support managers in implementing climate adaptation in North America's grassland ecosystems. Like previously published adaptation menus for other ecosystems (e.g., Handler et al., 2022; Janowiak et al., 2021; Schmitt et al., 2022; Staffen et al., 2019; Swanston et al., 2016), the Grassland Adaptation Menu is hierarchical and designed to help managers translate broad management goals into specific actions (Figure 2). We created the menu using a synthetic approach and combined data from a systematic review and input from management professionals to create a detailed list of adaptation practices tailored for grasslands. The resulting Grassland Adaptation Menu includes eight general strategies (Table 1 and Figure 4) and 32 targeted approaches (Table 1). We also provide 145 example tactics to illustrate how adaptation strategies could be implemented in specific contexts (Appendix S4). The version of the menu found in Supporting Information, Appendix S4 includes referenced narrative text for each strategy, approach, and example tactic. Here, we present a tabular summary of the menu (Table 1) and provide a brief discussion of practices associated with each strategy.

Strategy 1. Restore and Maintain the Extent of Grasslands Across the Landscape. Despite the importance of climate change, habitat loss remains the greatest threat to ecosystems and species globally (Caro et al., 2022). In the Great Plains, roughly 6500 km^2 of grassland are converted to agriculture annually (WWF, 2024), and in the USA more broadly, approximately 10,000 km^2 of grassland are lost each year (NGBI, 2024). Climate change and land-use change can have synergistic effects on species and ecosystems (Northrup et al., 2019), and continued investment in the conservation and restoration of grasslands is a prerequisite to any successful climate adaptation. Targeting investments in large and intact grasslands is one approach that may provide good returns, as not only do these areas support high biodiversity and stable metapopulation structures (Augustine et al., 2021; Scholtz & Twidwell, 2022), but intact landscapes also display greater resilience to climate perturbations (Martin & Watson, 2016). However, recent work suggests that often these larger grasslands are at a lower risk of conversion to begin with, and prioritizing mid-sized grasslands at high risk and of high ecological value can be a more optimal tactic in some cases (Barnes et al., 2024; Niemuth et al., 2022; Olimb & Robinson, 2019). Identifying regions where future climate is likely to be suitable for target species (Grand et al., 2019; Rana et al., 2025), or prioritizing grasslands that support greater heterogeneity and resilience, such as topographically complex areas (Anderson et al., 2023; Duquette et al., 2022a), are also tactics that can delineate climate-informed priorities. Mitigating future habitat conversion is also important. For instance, as increased precipitation in some grassland areas may incentivize future crop expansion (King et al., 2018), removing crop-insurance subsidies for converted native grasslands can help discourage conversion (Lark, 2020). Proactive land-use planning around energy leases is also critical, particularly as future solar expansions throughout North America may drive massive land-use shifts (Ott et al., 2021). Regulating where these leases can go and incentivizing new installations in previously disturbed landscapes (agricultural and urban areas, landfills, old lease sites) rather than intact native grassland could help reduce habitat losses. Efforts to create products that identify where proper wind conditions and low-habitat impact areas overlap may be helpful in conservation planning (Boggie et al., 2023). The U.S. Fish & Wildlife Service has worked with energy companies to avoid the placement of wind turbines on easement properties by requiring protection of additional grasslands to offset any losses.

Strategy 2. Increase Landscape-scale Resilience Under Future Climate Conditions. Landscape-level processes such as connectivity play an important role in climate resilience (Anderson et al., 2023). However, North America's grasslands are highly fragmented (Augustine et al., 2021; Wimberly et al., 2018). This fragmentation may exacerbate climate change by inhibiting species movements and range shifts (Bateman et al., 2015; Nixon et al., 2016) and preventing gene flow of adaptive climate phenotypes (Cullingham et al., 2023). For species with good dispersal abilities, steppingstones may be sufficient, while for others, structural corridors may be important (Brudvig et al., 2009). In grasslands, structural connectivity (Figure 4b) can be improved through tactics such as maintaining native vegetation buffers throughout riparian corridors (Cole et al., 2020), implementing prairie strips in agricultural areas (Schulte et al., 2017), managing powerline rights-of-way for native vegetation (Garfinkel et al., 2023), and using wildlife-friendly fencing to reduce ungulate movement barriers (Jones et al., 2018). Alternatively, strategic investment in patches that can serve as steppingstones between larger grasslands can also be effective (Herrera et al., 2017; Wimberly et al., 2018). Such steppingstones may even act as climate refugia depending on their locations (Grand et al., 2019), and these patches might buy time for species to adapt or continue shifting their ranges (L et al., 2014). Restoring grasslands through government incentive programs such as the Conservation Reserve Program (CRP) may provide one mechanism to introduce additional grassland habitat patches on the landscape and increase functional connectivity (Niemuth et al., 2021; Spencer et al., 2017).

Strategy 3. Maintain Fundamental Ecosystem Functioning in Grasslands. In general, North American grasslands today are highly degraded ecosystems (Augustine et al., 2021; Bardgett et al., 2021; Samson et al., 2004), and although they still provide many critical ecosystem services, these services are sensitive to management decisions (Sollenberger et al., 2019). Thus, a focus on maintaining the fundamental functions of grasslands will likely be compatible with current goals while helping to increase resilience to future climate threats. For example, transitioning from continuous to rotational and adaptive multi-paddock (AMP) grazing systems can enhance soil quality and carbon sequestration, particularly at lighter stocking rates (Bai & Cotrufo 2022; Teague & Kreuter, 2020; Zhou et al., 2017), and rest-rotation systems may also provide forage reserves for producers to use during droughts (e.g., Raynor et al., 2022). In other cases, soil amendments such as biochar may be appropriate to mitigate reduced productivity and forage quality from increases in temperature and CO_2 concentrations (Augustine et al., 2018; Mayer & Silver, 2022). Maintaining grassland structure and function by emulating natural disturbances is another major focus of grassland management. For example, increasing the frequency of prescribed fire to match natural regimes (Ratajczak et al., 2016) and conducting burns with higher intensities (Scholtz et al., 2022) can help prevent ecosystem state shifts from increasing woody encroachment. Intentional management of grassland hydrology is also important, and tactics like removing legacy drain tiles (Becker et al., 2021; Biebighauser, 2007; Figure 4c), controlling woody plant species with high water uptakes (Acharya et al., 2017), and retaining agricultural wetlands on private lands (Swartz et al., 2019) can help to sustain ecosystem services in grassland-embedded wetlands under increasing drought.

Strategy 4. Increase Biodiversity and Heterogeneity in Grassland Communities. Biodiversity is known to promote resilience and stability in grassland ecosystems (Tilman et al., 2006; Wang et al., 2019) and, in a climate context, biodiversity can be viewed as a portfolio effect by which genetically and functionally diverse communities have increased adaptive capacity under climate variability (Catford et al., 2020; Cowles et al., 2016; Whitney et al., 2019). The use of diverse seed mixes from multiple climate zones, as well as the introduction of locally adapted phenotypes from areas that better resemble future climates across species' ranges, are widely recommended tactics to increase biodiversity and drought tolerance in grassland plant communities (Havens et al., 2015; Nolan et al., 2023; Phillips-Mao et al., 2016). Similarly, the selection of plants with specific functional traits such as different carbon pathways (e.g., C4 plants), nutrient cycling roles (e.g., legumes), and leaf morphologies (e.g., narrow-leafed species for drought) is often recommended (Craine et al., 2013; Havrilla et al., 2023; Volaire et al., 2014; Figure 4d). Managers may also seek to enhance grassland biodiversity by managing for structural heterogeneity through alternative fire and grazing schemes, variable stocking rates, and variable burn intensities (Duquette et al., 2022a; Duquette et al., 2022b; Hill et al., 2017; Hovick et al., 2015).

Strategy 5. Reduce the Impacts of Ecological and Climate Stressors. Many grassland organisms are already threatened by the loss of grasslands and various sources of habitat degradation (e.g., Bernath-Plaisted, Correll, et al., 2023; Hanberry et al., 2021). The increasing frequency and intensity of extreme climate events will likely compound these stressors and further threaten grassland communities (Maresh Nelson et al., 2023; Murali et al., 2023; Ratajczak et al., 2019). Managers can take steps to lessen these impacts both by actively addressing climate effects and reducing background stressors. For example, increasing grassland-embedded wetlands on the landscape to moderate precipitation extremes (Ferreira et al., 2023), installing Zeedyk structures (e.g., simple rock infrastructure) to reduce erosion and increase water infiltration (e.g., Martyn et al., 2022; Norman et al., 2022), and deploying artificial water sources for wildlife (Rich et al., 2019) can help reduce the impacts of severe drought. In the western USA, maintaining Playas Lakes in grassland landscapes may contribute to aquifer recharge (McKenna & Sala, 2018) and support biodiversity (Haukos & Smith, 1994). The effects of extreme heat can be reduced for some organisms by retaining taller vegetation to support microclimate refuges through enhanced shade and evaporative cooling (Bernath-Plaisted et al., 2025; Bernath-Plaisted, Ribic, et al., 2023). In some cases, management can also address grassland phenology changes driven by climate change. For example, seeding grassland sites with plants that have diverse flowering phenologies may help to prevent timing mismatches for pollinators (Guzman et al., 2021; Figure 4e). Finally, addressing other ecological stressors with management actions, such as fire and herbicide for woody encroachment (Scholtz et al., 2018), targeted grazing to reduce invasive plants (Firn et al., 2013), and reduced pesticide use on agricultural lands to protect pollinators and birds (Main et al., 2021; Stanton et al., 2018) can also help species persist under increasingly challenging climate conditions.

Strategy 6. Adjust Site-level Management to Align with New Climate Conditions. Grasslands are disturbance-maintained ecosystems, and they often require intensive management (e.g., Samson et al., 2004). However, changing climate conditions could make it increasingly challenging to implement traditional management regimes. Therefore, adaptive shifts in the timing, intensity, and types of management activities may be required. For example, in many regions, prescribed burns are typically conducted during relatively cool and wet spring periods. As springs become hotter and earlier, these activities may need to shift to fall and even winter (Yurkonis et al., 2019). Similarly, rangeland productivity and forage quality may decline with increasing drought and CO_2 levels, creating challenges for grazing (Holechek et al., 2020). Thus, producers and managers may wish to consider conservation stocking rates to avoid financial risk and rangeland degradation during droughts (Briske et al., 2015; Joyce et al., 2013; Figure 4f). The management of grassland-embedded wetlands may also be affected by climate change, and increased variability in precipitation could alter hydroperiods in wetlands that are important for waterfowl and amphibians. One tactic managers can use to address this issue is to maintain wetlands of different sizes at grassland sites, as these may have different hydroperiods (Tsai et al., 2007). Grassland restoration practices may also need to change as seed establishment becomes more difficult under greater climate variability (Lyons et al., 2023). Practices such as restoring microtopography and stone cover to create "safe-sites" for plant establishment (Biederman & Whisenant, 2011), climate-informed seed sourcing (Bower et al., 2014), and inoculating propagules with beneficial microbes (Docherty & Gutknecht, 2019) could help to foster better establishment. Finally, phenological shifts associated with climate change could worsen existing management conflicts. For instance, mowing in agricultural grasslands is a major source of nest mortality for grassland birds (Tews et al., 2013), and earlier greening of vegetation will increase the overlap of nesting and haying activities—a conflict that may require management adjustments to resolve (McGowan et al., 2021).

Strategy 7. Facilitate Transitions Under Climate Change. It is generally accepted that many grassland species in the Northern Hemisphere will shift their ranges northward to track suitable climate space (e.g., Hovick et al., 2016)—though not all species will (e.g., McCauley et al., 2017). Managers can help facilitate such transitions when appropriate, especially for species that may be limited by disjunct ranges or poor dispersal capability, through approaches such as assisted migration (Cullingham et al., 2023; McKone & Hernández, 2021). Using procedures to identify species with high exposure and poor dispersal can help managers to select priority species for intervention (Barber et al., 2016). In grassland plant communities, managers can also facilitate transitions by observing native grassland species that perform well under extreme droughts and supporting the expansion of these species locally and regionally (Griffin-Nolan et al., 2019; Figure 4g). In other cases, transitions will occur at the ecosystem rather than species level. Although some grasslands will be lost to woody encroachment and sea-level rise (Crosby et al., 2016; M. B. Jones, 2019; e.g., saltmarsh habitat), opportunities for grassland conservation may also emerge. For instance, there may be an incentive to return marginal croplands to permanent cover as changing climate conditions require increasing inputs for lower yields in some regions (Lark et al., 2020). Finally, situations may arise where the best decision is simply to avoid spending resources on poor conservation investments. Managers can use so-called conservation triage frameworks to decide when it is better to allocate resources elsewhere (Bottrill et al., 2008).

Strategy 8. Engage Human Communities in Grassland Conservation Adaptation. There has always been a strong connection between grasslands and human communities, and many of the services that grasslands provide are cultural and economic (Nowak-Olejnik et al., 2020; Zhao et al., 2020). North American grasslands are working landscapes, and they have played important roles in food production in both pre-colonial and modern times (O'Mara, 2012; Roos et al., 2018). In Canada and the USA, 80% of remaining grasslands in the Great Plains are privately managed (Bernath-Plaisted, Correll, et al., 2023). Therefore, efforts to support private landowners in grassland management continue to be important (Morgan et al., 2019), and there is an opportunity for producers and landowners to benefit from carbon credit exchanges that incentivize beneficial management practices for carbon sequestration (Schofield et al., 2024). Grassbank strategies (e.g., forage reserve) that allow emergency grazing by local producers during forage shortfalls in exchange for conservation practices may also be effective (Gripne, 2005). Indigenous tribes also engage in grassland management, and several Tribal Nations have already made climate adaptation plans involving grasslands (e.g., https://cskt.org/climate/#work). Engaging tribes in discussions about grassland climate adaptation can help ensure that Indigenous Knowledge and values are represented in management actions. Outside of economic incentives and programs, human communities of all kinds can also be engaged to participate in active management that supports climate adaptation. For example, both woody encroachment and invasive species challenges may be exacerbated by climate change, but communities can participate in local burn cooperatives and regional invasive species monitoring and prevention campaigns to combat these threats (Goodwin et al., 2012; Twidwell et al., 2013; Figure 4h).

3.3 | Menu use

We developed the Grassland Adaptation menu to be flexible, and it can be used both for the management of local sites and broader landscape planning, as it contains a mix of approaches and example tactics that operate at different spatial scales. The menu is intended to be used in conjunction with a structured planning process, such as the Adaptation Workbook (https://adaptationworkbook.org/), but it can also stand on its own for some uses. The menu has a well-defined hierarchical structure intended to help managers bridge the gap between broad adaptation goals and specific actions (Figure 2). Strategies are the broadest tier of the menu and can be thought of as statements of intent describing overarching management goals (e.g., increase biodiversity and heterogeneity of grassland communities). Approaches are more detailed and describe methods for the implementation of a broader strategy. For example, an approach to implementing our example strategy of increasing grassland biodiversity could be to enhance functional diversity in grassland restorations and plantings. Tactics, the final tier of the menu, describe prescriptive management practices that can be taken to help achieve the management goals identified in previous steps. For this example, overseeding restorations with high-diversity mixes could be an appropriate tactic. Importantly, while strategies and approaches are somewhat broad and apply to many situations, tactics can be very specific and need not be limited to the examples we list. In many cases (such as in the case study discussed below), managers will use the menu structure to aid in articulating their own tactics. An important limitation of this menu is that we were not able to evaluate relative differences in evidence of effectiveness among practices that are recommended in the literature, or provide sufficient detail for managers to implement all tactics without reference to additional materials. Thus, we view the menu as a starting place where managers can leverage a structured framework to clearly articulate strategies and identify approaches and tactics that may be suitable for their adaptation goals.

3.4 | Case study

To demonstrate the utility of the Grassland Adaptation Menu, The Nature Conservancy (TNC) in MN, ND, and SD agreed to use the menu and the Adaptation Workbook in the development of a climate adaptation plan for Samuel H. Ordway Prairie (local management; Figure 5a) and the broader Leola Hills Conservation Area (regional landscape planning; Figure 5b) in which it is located. This area crosses the border of North and South Dakota, USA, and is an example of high-quality Prairie Potholes habitat with 64% native prairie cover comprising ~141,640 ha of grassland (Miller et al., 2022). Leola Hills is also located within TNC's Resilient and Connected Network, a designation identifying landscapes expected to have high ecological value and resilience under a

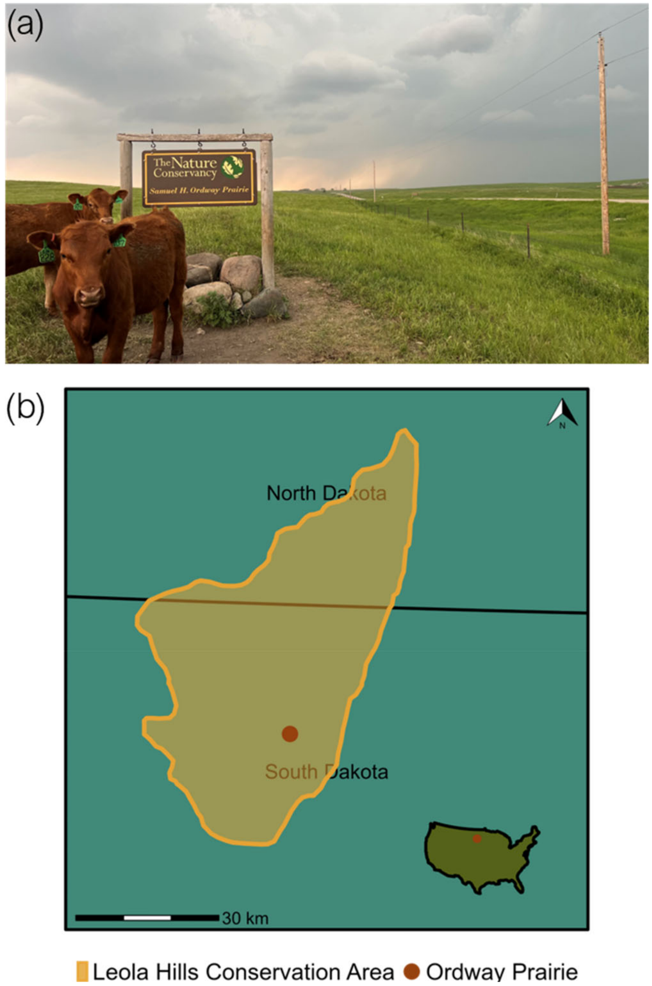

FIGURE 5 The Nature Conservancy's Samuel H. Ordway preserve (a) is located in the South Dakota portion of the Leola Hills Conservation Area, as defined by the Nature Conservancy (b). The preserve is a largely intact mixed-grass prairie characteristic of the Prairie Potholes Region and provides habitat for grassland birds, wetland-dependent birds, and pollinators, as well as grazing capacity. Samuel H. Ordway served as a case study for the Grassland Adaptation Menu, which was used to aid in creating both local and regional climate adaptation plans for Ordway and the Leola Hills Conservation Area. Photo by Nate Powazki.

TABLE 2 Example approaches and tactics selected by The Nature Conservancy staff in a case study application of the Grassland Adaptation Menu for the Samuel H. Ordway preserve (local scale), a native mixed-grass prairie property located in the Leola Hills Conservation Area (regional scale) in South and North Dakota, USA.

Climate challenges	Scale	Selected approaches	Selected tactics
Increased risk of conversion of rangeland to cropland with longer growing seasons	Regional	Mitigate major mechanisms of grassland conversion (*1.2*)	Invest in establishing more grassland and wetland easements (*1.2.2*)
Drier summers may inhibit establishment of native plants in restorations	Local	Maintain or enhance genetic diversity of ecological communities (*4.1*)	Improve seed-sourcing practices to include greater diversity of climate zones and increase adaptive capacity (*4.1.1*)
Farm Bill policies (e.g., crop insurance) have greater impact on producer decisions than climate change	Regional	Invest in outreach and support for landowners and producers (*8.2*)	Support mentoring programs for ranchers to facilitate learning and adoption of adaptation strategies (*articulated by TNC*)
Climate change and land-use changes may threaten water quality through increased agricultural runoff and sediments	Regional	Maintain or restore hydrology (*3.4*)	Use freshwater resilience maps and models to prioritize easements and riparian buffers (*articulated by TNC*)
Fewer burn days during the traditional spring burn season and more extreme weather will make prescribed fire difficult to implement	Local	Adjust the timing, frequency, and intensity of management actions (*6.1*)	Adopt more flexible burn schedules that extend into other seasons, such as fall in this case (*6.1.1*)
Precipitation increases may facilitate woody encroachment	Local	Emulate natural disturbances with fire (*3.3*)	Increase frequency and coverage of burns to better control woody species (*3.3.1*)

Note: The Climate Challenges column describes challenges to management goals driven by climate change that The Nature Conservancy team sought to address with the menu. The Scale column indicates what spatial scale example approaches and tactics were intended to address management at. The parenthetical numbers refer to the indexing of approaches and tactics in the full menu found in Data S4.

changing climate (Anderson et al., 2023). Ordway Prairie is representative of the Leola Hills Conservation Area, and TNC included both regional and site-level priorities in the adaptation plan they developed (Table 2). The Leola Hills region is projected to experience increasing annual temperatures over the coming decades with more rapid increases in nighttime and winter temperatures. Like much of the ecoregion, increased drought frequency and severity as well as extreme precipitation events are also predicted (Miller et al., 2022). Interactive maps of projected temperature and precipitation changes under various warming scenarios for the Leola Hills Conservation Area can be viewed on TNC's ArcGIS Dashboard. The region is also experiencing high rates of conversion of native grasslands, primarily to corn and soybeans, which is in part an indirect effect of increased temperature and precipitation in the region (Lark et al., 2015).

TNC has previously established three main conservation priorities for Ordway Prairie and the Leola Hills Conservation Area: (1) Managing ecosystems for biodiversity, (2) Improving and maintaining habitat connectivity, and (3) Supporting producers in improving rangeland conditions and the economic viability of their operations (Miller et al., 2022). The team used the Adaptation Workbook to formally consider how these goals might be affected by climate change and develop a climate adaptation plan for both the Ordway site and the Leola Hills region. They identified numerous potential challenges, including increased risk of conversion to cropland with longer growing seasons, loss of forage capacity with increased drought, loss of water resources from drying wetlands, water quality issues associated with increased sediments during extreme precipitation events, increased dominance of invasive species with earlier growing seasons, challenges to establishment of restorations under climate change, increased rates of woody encroachment, and narrowing windows for prescribed fire. The TNC team selected approaches from the menu that could help address such challenges and identified tactics that would best achieve their goals (Table 2). These included, for example, actions such as changing their seed-sourcing practices in restorations for the region, shifting the timing of burn schedules, and others. This case study provides a good example of menu use because it demonstrates the diversity of approaches and tactics, the use of the tool for both local and regional activities, and the flexibility for users to tailor it to their needs.

4 | CONCLUSION

North American grasslands are threatened both by past and current agricultural conversion (Lark et al., 2015, 2020; WWF, 2024) and increasingly by future climate change (Gibson & Newman, 2019). To maintain and enhance the biodiversity and ecosystem services that these biomes support, adaptation through active management and conservation planning will likely be important (Ansley et al., 2023; Miller Hesed et al., 2023; Sollenberger et al., 2019). However, actionable management recommendations for climate adaptation are often difficult to identify, particularly for grassland ecosystems (Cady et al., 2023). To assess the state of knowledge regarding climate adaptation in North America's grasslands and synthesize existing guidance for grassland managers, we conducted a systematic literature review of adaptation practices in grasslands and developed a Grassland Adaptation Menu containing potential management practices. The menu is a structured, hierarchical list of broad strategies and more specific approaches designed to help managers translate their adaptation goals into prescriptive actions. The menu contains dozens of example adaptation tactics targeted for grassland management and discusses actions widely promoted in existing literature, such as protecting future habitat and enhancing connectivity, adjusting grazing systems to increase heterogeneity and carbon sequestration, shifting the timing and intensity of prescribed fire, restoring grassland-embedded wetlands, improving seed-sourcing practices to increase diversity and climate-zone representation, assisted migration, managing microclimates to buffer organisms from extremes, and many others. Our review also revealed that, consistent with previous findings (Cady et al., 2023; LeDee et al., 2021), many studies on ecological-climate topics do not provide actionable management practices. As climate change becomes an increasingly important focus of ecological management, we draw attention to this issue in grasslands, and we suggest that researchers and ecologists who publish on climate topics in grasslands could play a greater role in helping managers to translate their findings into practice. We argue that this might be better accomplished by taking care not only to describe quantitative results and theoretical advancements associated with relevant research topics, but also by providing clear, plain language surrounding the climate change context of findings and distillation of key management implications.

AUTHOR CONTRIBUTIONS

Jacy S. Bernath-Plaisted conceptualized project, wrote manuscript text, performed literature review, and produced figures; Stephen D. Handler conceptualized menu approach and held menu workshops with managers; Marissa Ahlering contributed case study materials and management expertise; Leslie A. Brandt conceptualized menu approach and held workshops with managers; Scott B. Maresh Nelson performed initial pilot literature review and held menu workshops with managers; Neal D. Niemuth contributed grassland expertise during conceptualization and writing; Todd Ontl provided input into early versions of the menu and held workshops with managers; Courtney L. Peterson conceptualized menu approach and held workshops with managers; Christine A. Ribic contributed grassland expertise during conceptualization and writing; Delane Strohmeyer contributed to menu structure and literature review; Benjamin Zuckerberg conceptualized project and contributed climate change expertise during writing. All authors contributed meaningfully to manuscript drafts and menu development.

ACKNOWLEDGMENTS

We thank the USDA Forest Service—Northern Institute of Applied Climate Science, the University of Wisconsin-Madison, and a U.S. Geological Survey Midwest Climate Adaptation Science Center fellowship awarded to Jacy S. Bernath-Plaisted for supporting this study. We also thank the Cox Family Fund for Science for supporting the Nature Conservancy's climate adaptation planning efforts discussed in our case study. We thank all the managers who participated in menu workshops for their time and input. We thank all assistants that aided in conducting literature screening during the review process. We thank Valerie Doebley at Wild Earth Lab for scientific illustrations. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the US Fish and Wildlife Service.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

FUNDING INFORMATION

This study was supported by USDA Forest Service and USDA Northern Forests Climate Hub (23-CS-11242306-056) and the Midwest Climate Adaptation Science Center.

DATA AVAILABILITY STATEMENT

The data supporting the review conducted herein are available in a DRYAD found at https://doi.org/10.5061/dryad.8931zcs23. The Web of Science Boolean search terms used to generate these records, and a PRISMA diagram documenting how they were filtered, can be found in the Supporting Information of this manuscript.

ORCID

Jacy S. Bernath-Plaisted https://orcid.org/0000-0003-4645-8132
Marissa Ahlering https://orcid.org/0000-0002-3913-428X
Neal D. Niemuth https://orcid.org/0009-0006-9637-5588
Benjamin Zuckerberg https://orcid.org/0000-0001-7412-4354

REFERENCES

Acharya, B. S., Hao, Y., Ochsner, T. E., & Zou, C. B. (2017). Woody plant encroachment alters soil hydrological properties and reduces downward flux of water in tallgrass prairie. *Plant and Soil*, *414*, 379–391.

Ahlström, A., Raupach, M. R., Schurgers, G., Smith, B., Arneth, A., Jung, M., Reichstein, M., Canadell, J. G., Friedlingstein, P., Jain, A. K., Kato, E., Poulter, B., Sitch, S., Stocker, B. D., Viovy, N., Wang, Y. P., Wiltshire, A., Zaehle, S., & Zeng, N. (2015). The dominant role of semi-arid ecosystems in the trend and variability of the land CO2 sink. *Science*, *348*(6237), 895–899. https://doi.org/10.1126/science.aaa1668

Anderson, M. G., et al. (2023). A resilient and connected network of sites to sustain biodiversity under a changing climate. *Proceedings of the National Academy of Sciences*, *120*, e2204434119.

Ansley, R. J., Rivera-Monroy, V. H., Griffis-Kyle, K., Hoagland, B., Emert, A., Fagin, T., Loss, S. R., McCarthy, H. R., Smith, N. G., & Waring, E. F. (2023). Assessing impacts of climate change on selected foundation species and ecosystem services in the south-Central USA. *Ecosphere*, *14*, e4412.

Augustine, D., Davidson, A., Dickinson, K., & van Pelt, B. (2021). Thinking like a grassland: Challenges and opportunities for biodiversity conservation in the Great Plains of North America. *Rangeland Ecology & Management*, *78*, 281–295.

Augustine, D. J., Blumenthal, D. M., Springer, T. L., LeCain, D. R., Gunter, S. A., & Derner, J. D. (2018). Elevated CO2 induces substantial and persistent declines in forage quality irrespective of warming in mixedgrass prairie. *Ecological Applications*, *28*, 721–735.

Bachelet, D., Johnson, B. R., Bridgham, S. D., Dunn, P. V., Anderson, H. E., & Rogers, B. M. (2011). Climate change impacts on western Pacific northwest prairies and savannas. *Northwest Science*, *85*, 411–429.

Bai, Y., & Cotrufo, M. F. (2022). Grassland soil carbon sequestration: Current understanding, challenges, and solutions. *Science*, *377*, 603–608.

Barber, Q. E., Nielsen, S. E., & Hamann, A. (2016). Assessing the vulnerability of rare plants using climate change velocity, habitat connectivity, and dispersal ability: A case study in Alberta, Canada. *Regional Environmental Change*, *16*, 1433–1441.

Bardgett, R. D., Bullock, J. M., Lavorel, S., Manning, P., Schaffner, U., Ostle, N., Chomel, M., Durigan, G., L. Fry, E., Johnson, D., Lavallee, J. M., le Provost, G., Luo, S., Png, K., Sankaran, M., Hou, X., Zhou, H., Ma, L., Ren, W., … Shi, H. (2021). Combatting global grassland degradation. *Nature Reviews Earth & Environment*, *2*, 720–735.

Barnes, K. W., Niemuth, N. D., & Iovanna, R. (2024). Landscape-scale predictions of future grassland conversion to cropland or development. *Conservation Biology*, *39*, e14346.

Bateman, B. L., Pidgeon, A. M., Radeloff, V. C., Allstadt, A. J., Resit Akçakaya, H., Thogmartin, W. E., Vavrus, S. J., & Heglund, P. J. (2015). The importance of range edges for an irruptive species during extreme weather events. *Landscape Ecology*, *30*, 1095–1110.

Bateman, B. L., Wilsey, C., Taylor, L., Wu, J., LeBaron, G. S., & Langham, G. (2020). North American birds require mitigation and adaptation to reduce vulnerability to climate change. *Conservation Science and Practice*, *2*, e242.

Beas, B. J., Smith, L. M., Hickman, K. R., LaGrange, T. G., & Stutheit, R. (2013). Seed bank responses to wetland restoration: Do restored wetlands resemble reference conditions following sediment removal? *Aquatic Botany*, *108*, 7–15.

Becker, A. M., Becker, R. H., & Doro, K. O. (2021). Locating drainage tiles at a wetland restoration site within the oak openings region of Ohio, United States using UAV and land based geophysical techniques. *Wetlands*, *41*, 116.

Bengtsson, J., Bullock, J. M., Egoh, B., Everson, C., Everson, T., O'Connor, T., O'Farrell, P. J., Smith, H. G., & Lindborg, R. (2019). Grasslands: More important for ecosystem services than you might think. *Ecosphere*, *10*, e02582.

Bernath-Plaisted, J. S., Correll, M. D., Somershoe, S. G., Dwyer, A. M., Bankert, A., Beh, A., Berlanga, H., Boyle, W. A., Cruz-Romo, J. L., George, T. L., Herkert, J., Koper, N., Macías-Duarte, A., Panjabi, A. O., Ramírez-Flores, O. M., Robinson, B., Ruvalcaba-Ortega, I., Sibbing, J., Strasser, E. H., … VerCauteren, T. (2023). Review of conservation challenges and possible solutions for grassland birds of the North American Great Plains. *Rangeland Ecology & Management*, *90*, 165–185.

Bernath-Plaisted, J. S., Ribic, C. A., Hills, W. B., Townsend, P. A., & Zuckerberg, B. (2023). Microclimate complexity in temperate grasslands: Implications for conservation and management under climate change. *Environmental Research Letters*, *18*, 064023.

Bernath-Plaisted, J. S., Ribic, C. A., & Zuckerberg, B. (2025). Sweating the small stuff: Microclimatic exposure and species habitat associations inform climate vulnerability in a grassland songbird community. *Biology Letters*, *21*, 20240599.

Biebighauser, T. R. (2007). *Wetland drainage, restoration, and repair*. University Press of Kentucky.

Biederman, L. A., & Whisenant, S. G. (2011). Using mounds to create microtopography alters plant community development early in restoration. *Restoration Ecology*, *19*, 53–61.

Boggie, M. A., Butler, M. J., Sesnie, S. E., Millsap, B. A., Stewart, D. R., Harris, G. M., & Broska, J. C. (2023). Forecasting suitable areas for wind turbine occurrence to proactively improve wildlife conservation. *Journal for Nature Conservation*, *74*, 126442.

Bottrill, M. C., et al. (2008). Is conservation triage just smart decision making? *Trends in Ecology & Evolution*, *23*, 649–654.

Bower, A. D., St. Clair, J. B., & Erickson, V. (2014). Generalized provisional seed zones for native plants. *Ecological Applications*, *24*, 913–919.

Briske, D. D., Joyce, L. A., Polley, H. W., Brown, J. R., Wolter, K., Morgan, J. A., McCarl, B. A., & Bailey, D. W. (2015). Climate-change adaptation on rangelands: Linking regional exposure with diverse adaptive capacity. *Frontiers in Ecology and the Environment*, *13*, 249–256.

Briske, D. D., Vetter, S., Coetsee, C., & Turner, M. D. (2024). Rangeland afforestation is not a natural climate solution. *Frontiers in Ecology and the Environment*, *22*, e2727.

Brudvig, L. A., Damschen, E. I., Tewksbury, J. J., Haddad, N. M., & Levey, D. J. (2009). Landscape connectivity promotes plant biodiversity spillover into non-target habitats. *Proceedings of the National Academy of Sciences*, *106*, 9328–9332.

Cady, S. M., Londe, D. W., Fuhlendorf, S. D., Davis, C. A., Kanz, A. J., Kauffman, K. L., Knutson, J. K., Barnes, A. G., McMillan, N. A., & Neumann, L. K. (2023). Climate change literature across ecological disciplines: A review of the scope and level of specificity in management recommendations. *Global Ecology and Conservation*, *46*, e02544.

Calvin, K., et al. (2023). IPCC, 2023: Climate change 2023: Synthesis report. Contribution of working groups I, II and III to the sixth assessment report of the intergovernmental panel on climate change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. First. Intergovernmental Panel on Climate Change (IPCC). https://www.ipcc.ch/report/ar6/syr/

Caro, T., Rowe, Z., Berger, J., Wholey, P., & Dobson, A. (2022). An inconvenient misconception: Climate change is not the principal driver of biodiversity loss. *Conservation Letters*, *15*, e12868.

Catford, J. A., Dwyer, J. M., Palma, E., Cowles, J. M., & Tilman, D. (2020). Community diversity outweighs effect of warming on plant colonization. *Global Change Biology*, *26*, 3079–3090.

Catford, J. A., & Jones, L. P. (2019). Grassland invasion in the changing climate. In *Grasslands and climate change* (pp. 149–171). Cambridge University Press.

Cole, L. J., Stockan, J., & Helliwell, R. (2020). Managing riparian buffer strips to optimise ecosystem services: A review. *Agriculture, Ecosystems & Environment*, *296*, 106891.

Conrey, R. Y., Skagen, S. K., Adams Yackel, A. A., & Panjabi, A. O. (2016). Extremes of heat, drought and precipitation depress reproductive performance in shortgrass prairie passerines. *Ibis*, *158*, 614–629.

Cowles, J. M., Wragg, P. D., Wright, A. J., Powers, J. S., & Tilman, D. (2016). Shifting grassland plant community structure drives positive interactive effects of warming and diversity on aboveground net primary productivity. *Global Change Biology*, *22*, 741–749.

Craine, J. M., Ocheltree, T. W., Nippert, J. B., Towne, E. G., Skibbe, A. M., Kembel, S. W., & Fargione, J. E. (2013). Global diversity of drought tolerance and grassland climate-change resilience. *Nature Climate Change*, *3*, 63–67.

Crosby, S. C., Sax, D. F., Palmer, M. E., Booth, H. S., Deegan, L. A., Bertness, M. D., & Leslie, H. M. (2016). Salt marsh persistence is threatened by predicted sea-level rise. *Estuarine, Coastal and Shelf Science*, *181*, 93–99.

Cullingham, C., Stephens, T., Swan, K., Wilson, S., Janes, J., Matchett, M., Griebel, R., & Moehrenschlager, A. (2023). Genetic analysis reveals hidden threats and new motivation for conservation translocation of black-tailed prairie dogs at the northern limit of their range. *Global Ecology and Conservation*, *46*, e02591.

Cunningham, M. A. (2022). Climate change, agriculture, and biodiversity: How does shifting agriculture affect habitat availability? *Land*, *11*, 1257.

Davidson, A. D., Detling, J. K., & Brown, J. H. (2012). Ecological roles and conservation challenges of social, burrowing, herbivorous mammals in the world's grasslands. *Frontiers in Ecology and the Environment*, *10*, 477–486.

Döbert, T. F., Bork, E. W., Apfelbaum, S., Carlyle, C. N., Chang, S. X., Khatri-Chhetri, U., Silva Sobrinho, L., Thompson, R., & Boyce, M. S. (2021). Adaptive multi-paddock grazing improves water infiltration in Canadian grassland soils. *Geoderma*, *401*, 115314.

Dobrowski, S. Z., Abatzoglou, J., Swanson, A. K., Greenberg, J. A., Mynsberge, A. R., Holden, Z. A., & Schwartz, M. K. (2013). The climate velocity of the contiguous United States during the 20th century. *Global Change Biology*, *19*, 241–251.

Docherty, K. M., & Gutknecht, J. L. M. (2019). Soil microbial restoration strategies for promoting climate-ready prairie ecosystems. *Ecological Applications*, *29*, e01858.

Duquette, C. A., Hovick, T. J., Geaumont, B. A., Harmon, J. P., Limb, R. F., & Sedivec, K. K. (2022a). Embracing inherent and imposed sources of heterogeneity in rangeland bird management. *Ecosphere*, *13*, e4304.

Duquette, C. A., Hovick, T. J., Geaumont, B. A., Harmon, J. P., Limb, R. F., & Sedivec, K. K. (2022b). Spatially discrete disturbance processes enhance grassland floral resources. *Journal of Applied Ecology*, *59*, 1700–1708.

Felton, A. J., & Goldsmith, G. R. (2023). Timing and magnitude of drought impacts on carbon uptake across a grassland biome. *Global Change Biology*, *29*, 2790–2803.

Ferreira, C. S. S., Kašanin-Grubin, M., Solomun, M. K., Sushkova, S., Minkina, T., Zhao, W., & Kalantari, Z. (2023). Wetlands as nature-based solutions for water management in different environments. *Current Opinion in Environmental Science & Health*, *33*, 100476.

Firn, J., Price, J. N., & Whalley, R. D. (2013). Using strategically applied grazing to manage invasive alien plants in novel grasslands. *Ecological Processes*, *2*, 26.

Fraser, L. H. (2019). Production changes in response to climate change. In *Grasslands and climate change* (pp. 81–97). Cambridge University Press.

Freimuth, J., Bossdorf, O., Scheepens, J. F., & Willems, F. M. (2022). Climate warming changes synchrony of plants and pollinators. *Proceedings of the Royal Society B: Biological sciences*, *289*, 20212142.

Fritts, S. R., Grisham, B. A., Cox, R. D., Boal, C. W., Haukos, D. A., McDaniel, P., Hagen, C. A., & Greene, D. U. (2018). Interactive effects of severe drought and grazing on the life history cycle of a bioindicator species. *Ecology and Evolution*, *8*, 9550–9562.

Fuhlendorf, S. D., Engle, D. M., Elmore, R. D., Limb, R. F., & Bidwell, T. G. (2012). Conservation of pattern and process: Developing an alternative paradigm of rangeland management. *Rangeland Ecology & Management*, *65*, 579–589.

Galatowitsch, S., Frelich, L., & Phillips-Mao, L. (2009). Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America. *Biological Conservation*, *142*, 2012–2022.

Garfinkel, M., Hosler, S., Roberts, M., Vogt, J., Whelan, C., & Minor, E. (2023). Balancing the management of powerline right-of-way corridors for humans and nature. *Journal of Environmental Management*, *330*, 117175.

Gibson, D. J. (2009). *Grasses and grassland ecology*. Oxford University Press.

Gibson, D. J., & Newman, J. A. (2019). Grasslands and climate change: An overview. In *Grasslands and climate change* (pp. 1–18). Cambridge University Press.

Goodale, K. M., & Wilsey, B. J. (2018). Priority effects are affected by precipitation variability and are stronger in exotic than native grassland species. *Plant Ecology*, *219*, 429–439.

Goodwin, K., Sheley, R., Jacobs, J., Wood, S., Manoukian, M., Schuldt, M., Miller, E., & Sackman, S. (2012). Cooperative prevention systems to protect rangelands from the spread of invasive plants. *Rangelands*, *34*, 26–31.

Grand, J., Wilsey, C., Wu, J. X., & Michel, N. L. (2019). The future of north American grassland birds: Incorporating persistent and emergent threats into full annual cycle conservation priorities. *Conservation Science and Practice*, *1*, e20.

Grant, T. A., Shaffer, T. L., & Flanders, B. (2020). Patterns of smooth brome, Kentucky bluegrass, and shrub invasion in the northern Great Plains vary with temperature and precipitation. *Natural Areas Journal*, *40*, 11–22.

Griffin-Nolan, R. J., Blumenthal, D. M., Collins, S. L., Farkas, T. E., Hoffman, A. M., Mueller, K. E., Ocheltree, T. W., Smith, M. D., Whitney, K. D., & Knapp, A. K. (2019). Shifts in plant functional composition following long-term drought in grasslands. *Journal of Ecology*, *107*, 2133–2148.

Gripne, S. L. (2005). Grassbanks: Bartering for conservation. *Rangelands*, *27*, 24–28.

Guzman, L. M., Chamberlain, S. A., & Elle, E. (2021). Network robustness and structure depend on the phenological characteristics of plants and pollinators. *Ecology and Evolution*, *11*, 13321–13334.

Hager, H. A., & Newman, J. A. (2019). Methodology I: Detecting and predicting grassland change. In *Grasslands and climate change* (pp. 19–39). Cambridge University Press.

Henry, H. A. (2019). Biogeochemical cycling in grasslands under climate change. In *Grasslands and climate change* (pp. 116–130). Cambridge University Press.

Hanberry, B. B., DeBano, S. J., Kaye, T. N., Rowland, M. M., Hartway, C. R., & Shorrock, D. (2021). Pollinators of the Great Plains: Disturbances, stressors, management, and research needs. *Rangeland Ecology & Management*, *78*, 220–234.

Handler, S. D., LeDee, O. E., Hoving, C. L., Zuckerberg, B., & Swanston, C. W. (2022). A menu of climate change adaptation actions for terrestrial wildlife management. *Wildlife Society Bulletin*, *46*, e1331.

Haukos, D. A., & Smith, L. M. (1994). The importance of playa wetlands to biodiversity of the southern High Plains. *Landscape and Urban Planning*, *28*, 83–98.

Haun, A. J., Dreelin, R. A., & Boyce1, A. J. (2024). Prairie dog towns increase grassland bird diversity at the landscape scale. *The Wilson Journal of Ornithology*, *136*, 209–219. https://doi.org/10.1676/23-00067

Havens, K., Vitt, P., Still, S., Kramer, A. T., Fant, J. B., & Schatz, K. (2015). Seed sourcing for restoration in an era of climate change. *Natural Areas Journal*, *35*, 122–133.

Havrilla, C. A., Bradford, J. B., Yackulic, C. B., & Munson, S. M. (2023). Divergent climate impacts on C3 versus C4 grasses imply widespread 21st century shifts in grassland functional composition. *Diversity and Distributions*, *29*, 379–394.

Heller, N. E., & Zavaleta, E. S. (2009). Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biological Conservation*, *142*, 14–32.

Herrera, L. P., Sabatino, M. C., Jaimes, F. R., & Saura, S. (2017). Landscape connectivity and the role of small habitat patches as stepping stones: An assessment of the grassland biome in South America. *Biodiversity and Conservation*, *26*, 3465–3479.

Herse, M. R., With, K. A., & Boyle, W. A. (2020). Grassland fragmentation affects declining tallgrass prairie birds most where large amounts of grassland remain. *Landscape Ecology*, *35*, 2791–2804.

Hill, K. C., Bakker, J. D., & Dunwiddie, P. W. (2017). Prescribed fire in grassland butterfly habitat: Targeting weather and fuel conditions to reduce soil temperatures and burn severity. *Fire Ecology*, *13*, 24–41.

Hoekstra, J. M., Boucher, T. M., Ricketts, T. H., & Roberts, C. (2005). Confronting a biome crisis: Global disparities of habitat loss and protection. *Ecology Letters*, *8*, 23–29.

Holechek, J. L., Geli, H. M. E., Cibils, A. F., & Sawalhah, M. N. (2020). Climate change, rangelands, and sustainability of ranching in the western United States. *Sustainability*, *12*, 4942.

Holland, J. M., Douma, J. C., Crowley, L., James, L., Kor, L., Stevenson, D. R. W., & Smith, B. M. (2017). Semi-natural habitats support biological control, pollination and soil conservation in Europe. A Review. *Agronomy for Sustainable Development*, *37*, 31.

Hovick, T. J., Allred, B. W., McGranahan, D. A., Palmer, M. W., Elmore, D. R., & Fuhlendorf, S. D. (2016). Informing conservation by identifying range shift patterns across breeding habitats and migration strategies. *Biodiversity and Conservation*, *25*, 345–356.

Hovick, T. J., Elmore, R. D., Fuhlendorf, S. D., Engle, D. M., & Hamilton, R. G. (2015). Spatial heterogeneity increases diversity and stability in grassland bird communities. *Ecological Applications*, *25*, 662–672.

Jackson, R. D. (2022). Grazed perennial grasslands can match current beef production while contributing to climate mitigation and adaptation. *Agricultural & Environmental Letters*, *7*, e20059.

Janowiak, M. K., Brandt, L. A., Wolf, K. L., Brady, M., Darling, L., Lewis, A. D., Fahey, R. T., Giesting, K., Hall, E., Henry, M., Hughes, M., Miesbauer, J. W., Marcinkowski, K., Ontl, T., Rutledge, A., Scott, L., & Swanston, C. W. (2021). Climate adaptation actions for urban forests and human health. Page NRS-GTR-203. NRS-GTR-203. U.S. Department of Agriculture, Forest Service, Northern Research Station, Madison, WI. https://www.fs.usda.gov/research/treesearch/62807

Jones, M. B. (2019). Projected climate change and global distribution of grasslands under global warming. In *Grasslands and climate change* (pp. 67–81). Cambridge University Press.

Jones, P. F., Jakes, A. F., Eacker, D. R., Seward, B. C., Hebblewhite, M., & Martin, B. H. (2018). Evaluating responses by pronghorn to fence modifications across the northern Great Plains. *Wildlife Society Bulletin*, *42*, 225–236.

Joyce, L. A., Briske, D. D., Brown, J. R., Polley, H. W., McCarl, B. A., & Bailey, D. W. (2013). Climate change and north American rangelands: Assessment of mitigation and adaptation strategies. *Rangeland Ecology & Management*, *66*, 512–528.

King, M., Altdorff, D., Li, P., Galagedara, L., Holden, J., & Unc, A. (2018). Northward shift of the agricultural climate zone under 21st-century global climate change. *Scientific reports*, *8*, 7904.

Kodero, J. M., Felzer, B. S., & Shi, Y. (2024). Future transition from forests to shrublands and grasslands in the western United States is expected to reduce carbon storage. *Communications Earth & Environment*, *5*, 1–11.

Krall, M., Roni, P., Clark, C., & Ross, K. (2021). Effects of livestock exclusion on stream banks and riparian vegetation in Washington and Oregon. *Northwest Science*, *95*, 1–21.

Kulmatiski, A., & Beard, K. H. (2013). Woody plant encroachment facilitated by increased precipitation intensity. *Nature Climate Change*, *3*, 833–837.

L, H., L, F., AD, S., MA, M., LB, B., & IM, M. C. (2014). Fine-grain modeling of species' response to climate change: Holdouts, stepping-stones, and microrefugia. *Trends in Ecology & Evolution*, *29*, 390–397.

Lark, T. J. (2020). Protecting our prairies: Research and policy actions for conserving America's grasslands. *Land Use Policy*, *97*, 104727.

Lark, T. J., Salmon, J. M., & Gibbs, H. K. (2015). Cropland expansion outpaces agricultural and biofuel policies in the United States. *Environmental Research Letters*, *10*, 044003.

Lark, T. J., Spawn, S. A., Bougie, M., & Gibbs, H. K. (2020). Cropland expansion in the United States produces marginal yields at high costs to wildlife. *Nature Communications*, *11*, 4295.

Lavorel, S. (2019). Climate change effects on grassland ecosystem services. In *Grasslands and climate change* (pp. 131–146). Cambridge University Press.

LeDee, O. E., Handler, S. D., Hoving, C. L., Swanston, C. W., & Zuckerberg, B. (2021). Preparing wildlife for climate change: How far have we come? *The Journal of Wildlife Management*, *85*, 7–16.

Leipold, E. A., Stier, H. S., Haynam, R. T., Robison, L., Sullivan, A. R., Kaltenbach, T. L., Dykstra, L. R., Beaver, B. R., Monroe, M., Jakabosky, O. G., & McNew, L. B. (2025). An inventory of rangeland wildlife in the Western United States. *Rangeland Ecology & Management*, *98*, 170–176.

Liu, H., Hou, L., Kang, N., Nan, Z., & Huang, J. (2022). The economic value of grassland ecosystem services: A global meta-analysis. *Grassland Research*, *1*, 63–74.

Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P., Field, C. B., & Ackerly, D. D. (2009). The velocity of climate change. *Nature*, *462*, 1052–1055.

Londe, D. W., Davis, C. A., Loss, S. R., Robertson, E. P., Haukos, D. A., & Hovick, T. J. (2024). Climate change causes declines and greater extremes in wetland inundation in a region important for wetland birds. *Ecological Applications*, *34*, e2930.

Lyons, K. G., Török, P., Hermann, J. M., Kiehl, K., Kirmer, A., Kollmann, J., Overbeck, G. E., Tischew, S., Allen, E. B., Bakker, J. D., Brigham, C., Buisson, E., Crawford, K., Dunwiddie, P., Firn, J., Grobert, D., Hickman, K., Stradic, S. L. E., & Temperton, V. M. (2023). Challenges and opportunities for grassland restoration: A global perspective of best practices in the era of climate change. *Global Ecology and Conservation*, *46*, e02612.

Main, A. R., Webb, E. B., Goyne, K. W., Abney, R., & Mengel, D. (2021). Impacts of neonicotinoid seed treatments on the wild bee community in agricultural field margins. *Science of the Total Environment*, *786*, 147299.

Maresh Nelson, S. B., Ribic, C. A., Niemuth, N. D., Bernath-Plaisted, J., & Zuckerberg, B. (2023). Sensitivity of north American grassland birds to weather and climate variability. *Conservation Biology*, *38*, e14143.

Martin, T. G., & Watson, J. E. M. (2016). Intact ecosystems provide best defence against climate change. *Nature Climate Change*, *6*, 122–124.

Martyn, T. E., Barberán, A., Blankinship, J. C., Miller, M., Yang, B., Kline, A., & Gornish, E. S. (2022). Rock structures improve seedling establishment, litter catchment, fungal richness, and soil moisture in the first year after installation. *Environmental Management*, *70*, 134–145.

Mayer, A., & Silver, W. L. (2022). The climate change mitigation potential of annual grasslands under future climates. *Ecological Applications*, *32*, e2705.

McCauley, L. A., Ribic, C. A., Pomara, L. Y., & Zuckerberg, B. (2017). The future demographic niche of a declining grassland bird fails to shift poleward in response to climate change. *Landscape Ecology*, *32*, 807–821.

McGowan, M. M., Perlut, N. G., & Strong, A. M. (2021). Agriculture is adapting to phenological shifts caused by climate change, but grassland songbirds are not. *Ecology and Evolution*, *11*, 6993–7002.

McKenna, O. P., & Sala, O. E. (2018). Groundwater recharge in desert playas: Current rates and future effects of climate change. *Environmental Research Letters*, *13*, 014025.

McKone, M. J., & Hernández, D. L. (2021). Community-level assisted migration for climate-appropriate prairie restoration. *Restoration Ecology*, *29*, e13416.

Miller Hesed, C. D., Yocum, H. M., Cross, M., Bamzai-Dodson, A., Wheeler, B., Beckmann, J. P., Ahlering, M., Hall, K. R., Boyd-Valandra, E., Mosher, D., Miller, B. W., & Jaffe, S. (2023). Seventy questions of importance to the conservation of the north central grasslands of the United States in a changing climate. *Conservation Science and Practice*, *5*, e12998.

Miller, M., Losure, D., Ahlering, M. A., Alison, L.-N., Watt, D., Blann, K. L., & Lenhart, C. (2022). Leola Hills conservation and climate adaptation plan. The Nature Conservancy, South Dakota.

Morgan, J. A., Milchunas, D. G., LeCain, D. R., West, M., & Mosier, A. R. (2007). Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. *Proceedings of the National Academy of Sciences*, *104*, 14724–14729.

Morgan, J. J., Rhoden, C. M., White, B., & Riley, S. P. (2019). A state assessment of private lands wildlife conservation in the United States. *Wildlife Society Bulletin*, *43*, 328–337.

Mucioki, M. (2024). Climate and land-use change impacts on cultural use berries: Considerations for mitigative stewardship. *Plants, People, Planet*, *6*, 791–802.

Murali, G., Iwamura, T., Meiri, S., & Roll, U. (2023). Future temperature extremes threaten land vertebrates. *Nature*, *615*, 461–467.

NGBI. (2024). Press Release: US is Losing 2.5 million Acres of Grasslands Annually—National Bobwhite & Grassland Initiative. https://nbgi.org/2024/04/11/press-release-2-5-loss-acres/

Niemuth, N. D., Barnes, K. W., Tack, J. D., & Iovanna, R. (2022). Past is prologue: Historic landcover patterns predict contemporary grassland loss in the U.S. Northern Great Plains. *Landscape Ecology*, *37*, 3011–3027.

Niemuth, N. D., Fleming, K. K., & Reynolds, R. E. (2014). Waterfowl conservation in the US Prairie Pothole Region: Confronting the complexities of climate change. *PLoS One*, *9*, e100034.

Niemuth, N. D., Wangler, B., LeBrun, J. J., Dewald, D., Larson, S., Schwagler, T., Bradbury, C. W., Pritchert, R. D., & Iovanna, R. (2021). Conservation planning for pollinators in the U.S. Great Plains: Considerations of context, treatments, and scale. *Ecosphere*, *12*, e03556.

Nixon, A., Fisher, R., Stralberg, D., Bayne, E., & Farr, D. (2016). Projected responses of North American grassland songbirds to climate change and habitat availability at their northern range limits in Alberta, Canada. Avian Conservation and Ecology 11. The Resilience Alliance. https://www.ace-eco.org/vol11/iss2/art2/

Nolan, M. P., Luong, J. C., Valliere, J. M., Mazer, S. J., & D'Antonio, C. M. (2023). Rethinking local seed sourcing for the restoration of a foundational grass species in California. *Restoration Ecology*, *31*, e13992.

Norman, L. M., Lal, R., Wohl, E., Fairfax, E., Gellis, A. C., & Pollock, M. M. (2022). Natural infrastructure in dryland streams (NIDS) can establish regenerative wetland sinks that reverse desertification and strengthen climate resilience. *Science of the Total Environment*, *849*, 157738.

Northrup, J. M., Rivers, J. W., Yang, Z., & Betts, M. G. (2019). Synergistic effects of climate and land-use change influence broad-scale avian population declines. *Global Change Biology*, *25*, 1561–1575.

Nowak-Olejnik, A., Mocior, E., Hibner, J., & Tokarczyk, N. (2020). Human perceptions of cultural ecosystem services of semi-natural grasslands: The influence of plant communities. *Ecosystem Services*, *46*, 101208.

Olimb, S. K., & Robinson, B. (2019). Grass to grain: Probabilistic modeling of agricultural conversion in the north American Great Plains. *Ecological Indicators*, *102*, 237–245.

O'Mara, F. P. (2012). The role of grasslands in food security and climate change. *Annals of Botany*, *110*, 1263–1270.

Ott, J. P., Hanberry, B. B., Khalil, M., Paschke, M. W., Post van der Burg, M., & Prenni, A. J. (2021). Energy development and production in the Great Plains: Implications and mitigation opportunities. *Rangeland Ecology & Management*, *78*, 257–272.

Patterson, T. A., Grundel, R., Dzurisin, J. D. K., Knutson, R. L., & Hellmann, J. J. (2020). Evidence of an extreme weather-induced phenological mismatch and a local extirpation of the endangered Karner blue butterfly. *Conservation Science and Practice*, *2*, e147.

Perkins, L. B., Ahlering, M., & Larson, D. L. (2019). Looking to the future: Key points for sustainable management of northern Great Plains grasslands. *Restoration Ecology*, *27*, 1212–1219.

Phillips-Mao, L., Galatowitsch, S. M., Snyder, S. A., & Haight, R. G. (2016). Model-based scenario planning to develop climate change adaptation strategies for rare plant populations in grassland reserves. *Biological Conservation*, *193*, 103–114.

Pierce, S. C., Kröger, R., & Pezeshki, R. (2012). Managing artificially drained low-gradient agricultural headwaters for enhanced ecosystem functions. *Biology*, *1*, 794–856.

Poje, J. E., Rocke, T. E., & Samuel, M. D. (2020). Impacts of environmental conditions on fleas in black-tailed prairie dog burrows. *Journal of Vector Ecology*, *45*, 356–365.

Rana, S. K., Lindstrom, J., Lehrer, M. A., Ahlering, M., & Hamilton, J. (2025). Forecasting hotspots of climatic suitability for grassland restoration under climate change in North America. *Biological Conservation*, *302*, 110988.

Ratajczak, Z., Briggs, J. M., Goodin, D. G., Luo, L., Mohler, R. L., Nippert, J. B., & Obermeyer, B. (2016). Assessing the potential for transitions from tallgrass prairie to woodlands: Are we operating beyond critical fire thresholds? *Rangeland Ecology & Management*, *69*, 280–287.

Ratajczak, Z., Churchill, A. C., Ladwig, L. M., Taylor, J. H., & Collins, S. L. (2019). The combined effects of an extreme heatwave and wildfire on tallgrass prairie vegetation. *Journal of Vegetation Science*, *30*, 687–697.

Raynor, E. J., Derner, J. D., Augustine, D. J., Jablonski, K. E., Porensky, L. M., Ritten, J., Hoover, D. L., & Elliott, J. (2022). Balancing ecosystem service outcomes at the ranch-scale in shortgrass steppe: the role of grazing management. *Rangelands*, *44*(6), 391–397. https://doi.org/10.1016/j.rala.2022.05.003

Rich, L. N., Beissinger, S. R., Brashares, J. S., & Furnas, B. J. (2019). Artificial water catchments influence wildlife distribution in the Mojave Desert. *The Journal of Wildlife Management*, *83*, 855–865.

Rojas-Downing, M. M., Nejadhashemi, A. P., Abouali, M., Daneshvar, F., al Masraf, S. A. D., Herman, M. R., Harrigan, T., & Zhang, Z. (2018). Pasture diversification to combat climate change impacts on grazing dairy production. *Mitigation and Adaptation Strategies for Global Change*, *23*, 405–431.

Roos, C. I., Zedeño, M. N., Hollenback, K. L., & Erlick, M. M. H. (2018). Indigenous impacts on north American Great Plains fire regimes of the past millennium. *Proceedings of the National Academy of Sciences*, *115*, 8143–8148.

Samson, F. B., Knopf, F. L., & Ostlie, W. R. (2004). Great Plains ecosystems: Past, present, and future. *Wildlife Society Bulletin*, *32*, 6–15.

Saviozzi, A., Levi-Minzi, R., Cardelli, R., & Riffaldi, R. (2001). A comparison of soil quality in adjacent cultivated, forest and native grassland soils. *Plant and Soil*, *233*, 251–259.

Schmitt, K., Krska, R., Deloria, C., Shannon, P. D., Cooper, M., Eash, J., Haugland, J., Johnson, S. E., Johnson, S. M., Magee, M. R., Mayne, G., Nelson, C., Nigg, C., Sidie-Slettedahl, A., Brandt, L., Handler, S., Janowiak, M., Butler-Leopold, P., Ontl, T., & Swanston, C. (2022). Strategies for adapting great lakes coastal ecosystems to climate change. United States Department of Agriculture, USA. https://handle.nal.usda.gov/10113/7816961

Schofield, L. R., Pearson, M. E., Newell, S., Clackum, N., & Turner, B. L. (2024). Why aren't more landowners enrolling in land-based carbon credit exchanges? *Rangelands*, *46*, 117–131.

Scholtz, R., Donovan, V. M., Strydom, T., Wonkka, C., Kreuter, U. P., Rogers, W. E., Taylor, C., Smit, I. P. J., Govender, N., Trollope, W., Fogarty, D. T., & Twidwell, D. (2022). High-intensity fire experiments to manage shrub encroachment: Lessons learned in South Africa and the United States. In *African Journal of Range & Forage Science*, *39*, (pp. 148–159).

Scholtz, R., Polo, J. A., Fuhlendorf, S. D., Engle, D. M., & Weir, J. R. (2018). Woody plant encroachment mitigated differentially by fire and herbicide. *Rangeland Ecology & Management*, *71*, 239–244.

Scholtz, R., & Twidwell, D. (2022). The last continuous grasslands on earth: Identification and conservation importance. *Conservation Science and Practice*, *4*, e626.

Schulte, L. A., Niemi, J., Helmers, M. J., Liebman, M., Arbuckle, J. G., James, D. E., Kolka, R. K., O'Neal, M. E., Tomer, M. D., Tyndall, J. C., Asbjornsen, H., Drobney, P., Neal, J., van Ryswyk, G., & Witte, C. (2017). Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn–soybean croplands. *Proceedings of the*

National Academy of Sciences, *114*(42), 11247–11252. https://doi.org/10.1073/pnas.1620229114

Sexton, A. N., & Emery, S. M. (2020). Grassland restorations improve pollinator communities: A meta-analysis. *Journal of Insect Conservation*, *24*, 719–726.

Sollenberger, L. E., Kohmann, M. M., Dubeux, J. C. B., Jr., & Silveira, M. L. (2019). Grassland management affects delivery of regulating and supporting ecosystem services. *Crop Science*, *59*, 441–459.

Spencer, D., Haukos, D., Hagen, C., Daniels, M., & Goodin, D. (2017). Conservation reserve program mitigates grassland loss in the lesser prairie-chicken range of Kansas. *Global Ecology and Conservation*, *9*, 21–38.

Staffen, A., O'Connor, R. P., Johnson, S. E., Shannon, P. D., Fleener, J., Kearns, K., Panci, H., Sheehan, M., Volkening, A., & Zine, M. (2019). Climate adaptation strategies and approaches for conservation and management of non-forested wetlands. USDA Northern Forests Climate Hub, Houghton, MI. https://handle.nal.usda.gov/10113/8228725

Stanton, R. L., Morrissey, C. A., & Clark, R. G. (2018). Analysis of trends and agricultural drivers of farmland bird declines in North America: A review. *Agriculture, Ecosystems & Environment*, *254*, 244–254.

Steenvoorden, J., Meddens, A. J. H., Martinez, A. J., Foster, L. J., & Kissling, W. D. (2019). The potential importance of unburned islands as refugia for the persistence of wildlife species in fire-prone ecosystems. *Ecology and Evolution*, *9*, 8800–8812.

Stephens, S. E., Walker, J. A., Blunck, D. R., Jayaraman, A., Naugle, D. E., Ringelman, J. K., & Smith, A. J. (2008). Predicting risk of habitat conversion in native temperate grasslands. *Conservation Biology*, *22*, 1320–1330.

Suggitt, A. J., Gillingham, P. K., Hill, J. K., Huntley, B., Kunin, W. E., Roy, D. B., & Thomas, C. D. (2011). Habitat microclimates drive fine-scale variation in extreme temperatures. *Oikos*, *120*, 1–8.

Swanston, C. W., Janowiak, M. K., Brandt, L. A., Butler, P. R., Handler, S. D., Shannon, P. D., Lewis, A. D., Hall, K., Fahey, R. T., Scott, L., Kerber, A., Miesbauer, J. W., Darling, L., Parker, L., & St. Pierre, M. (2016). Forest adaptation resources: Climate change tools and approaches for land managers, 2nd edition. Gen. Tech. Rep. NRS-GTR-87-2 Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 161 p.

Swartz, T. M., Coon, J. J., Mattes, J. R., & Miller, J. R. (2019). Identifying opportunities to conserve farm ponds on private lands: Integration of social, ecological, and historical data. *Land*, *8*, 127.

Teague, R., & Kreuter, U. (2020). Managing grazing to restore soil health, ecosystem function, and ecosystem services. *Frontiers in Sustainable Food Systems*, *4*, 534187. https://doi.org/10.3389/fsufs.2020.534187

Tews, J., Bert, D., & Mineau, P. (2013). Estimated mortality of selected migratory bird species from mowing and other mechanical operations in Canadian agriculture. *Avian Conservation and Ecology*, *8*, art8. https://doi.org/10.5751/ACE-00559-080208

Tilman, D., Reich, P. B., & Knops, J. M. H. (2006). Biodiversity and ecosystem stability in a decade-long grassland experiment. *Nature*, *441*, 629–632.

Tsai, J.-S., Venne, L. S., McMurry, S. T., & Smith, L. M. (2007). Influences of land use and wetland characteristics on water loss rates and hydroperiods of playas in the southern High Plains, USA. *Wetlands*, *27*, 683–692.

Twidwell, D., Rogers, W. E., Fuhlendorf, S. D., Wonkka, C. L., Engle, D. M., Weir, J. R., Kreuter, U. P., & Taylor, C. A., Jr. (2013). The rising Great Plains fire campaign: citizens' response to woody plant encroachment. *Frontiers in Ecology and the Environment*, *11*, e64–e71.

van Auken, O. W. (2009). Causes and consequences of woody plant encroachment into western north American grasslands. *Journal of Environmental Management*, *90*, 2931–2942.

Viglizzo, E. F., Ricard, M. F., Taboada, M. A., & Vázquez-Amábile, G. (2019). Reassessing the role of grazing lands in carbon-balance estimations: Meta-analysis and review. *Science of the Total Environment*, *661*, 531–542.

Volaire, F., Barkaoui, K., & Norton, M. (2014). Designing resilient and sustainable grasslands for a drier future: Adaptive strategies, functional traits and biotic interactions. *European Journal of Agronomy*, *52*, 81–89.

Wang, Y., Cadotte, M. W., Chen, Y., Fraser, L. H., Zhang, Y., Huang, F., Luo, S., Shi, N., & Loreau, M. (2019). Global evidence of positive biodiversity effects on spatial ecosystem stability in natural grasslands. *Nature Communications*, *10*, 3207.

Werling, B. P., Dickson, T. L., Isaacs, R., Gaines, H., Gratton, C., Gross, K. L., Liere, H., Malmstrom, C. M., Meehan, T. D., Ruan, L., Robertson, B. A., Robertson, G. P., Schmidt, T. M., Schrotenboer, A. C., Teal, T. K., Wilson, J. K., & Landis, D. A. (2014). Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. *Proceedings of the National Academy of Sciences*, *111*, 1652–1657.

White, R. P., Murray, S., Rohweder, M., Prince, S. D., & Thomson, K. M. (2000). *Grassland ecosystems* (p. 81). World Resources Institute.

Whitney, K. D., Mudge, J., Natvig, D. O., Sundararajan, A., Pockman, W. T., Bell, J., Collins, S. L., & Rudgers, J. A. (2019). Experimental drought reduces genetic diversity in the grassland foundation species Bouteloua eriopoda. *Oecologia*, *189*, 1107–1120.

Wiener, S., Roesch-McNally, G. E., Schattman, R. E., & Niles, M. T. (2020). Ready, willing, and able? USDA field staff as climate advisors. *Journal of Soil and Water Conservation*, *75*, 62–74.

Wilsey, C., Taylor, L., Bateman, B., Jensen, C., Michel, N., Panjabi, A., & Langham, G. (2019). Climate policy action needed to reduce vulnerability of conservation-reliant grassland birds in North America. *Conservation Science and Practice*, *1*, e21.

Wimberly, M. C., Narem, D. M., Bauman, P. J., Carlson, B. T., & Ahlering, M. A. (2018). Grassland connectivity in fragmented agricultural landscapes of the north-central United States. *Biological Conservation*, *217*, 121–130.

Wu, G.-L., Liu, Y.-F., Cui, Z., Liu, Y., Shi, Z.-H., Yin, R., & Kardol, P. (2020). Trade-off between vegetation type, soil erosion control and surface water in global semi-arid regions: A meta-analysis. *Journal of Applied Ecology*, *57*, 875–885.

WWF. (2024). 2023 Plowprint report. World Wildlife Fund, Washington DC, USA. https://www.worldwildlife.org/publications/2023-plowprint-report

Yurkonis, K. A., Dillon, J., McGranahan, D. A., Toledo, D., & Goodwin, B. J. (2019). Seasonality of prescribed fire weather windows and predicted fire behavior in the northern Great Plains, USA. *Fire Ecology*, *15*(7), 1–15.

Zhang, Z., Bortolotti, L. E., Li, Z., Armstrong, L. M., Bell, T. W., & Li, Y. (2021). Heterogeneous changes to wetlands in the Canadian prairies under future climate. *Water Resources Research*, *57*, e2020WR028727.

Zhao, Y., Liu, Z., & Wu, J. (2020). Grassland ecosystem services: A systematic review of research advances and future directions. *Landscape Ecology*, *35*, 793–814.

Zhou, G., Zhou, X., He, Y., Shao, J., Hu, Z., Liu, R., Zhou, H., & Hosseinibai, S. (2017). Grazing intensity significantly affects belowground carbon and nitrogen cycling in grassland ecosystems: A meta-analysis. *Global Change Biology*, *23*, 1167–1179.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Bernath-Plaisted, J. S., Handler, S. D., Ahlering, M., Brandt, L. A., Maresh Nelson, S. B., Niemuth, N. D., Ontl, T., Peterson, C. L., Ribic, C. A., Strohmeyer, D., & Zuckerberg, B. (2025). A climate adaptation menu for North American grasslands. *Conservation Science and Practice*, e70017. https://doi.org/10.1111/csp2.70017