Midwest Climate Adaptation Science Center

SCIENCE AGENDA (2023-2026)

MIDWEST Climate Adaptation Science Center

USGS science for a changing world

Acknowledgements

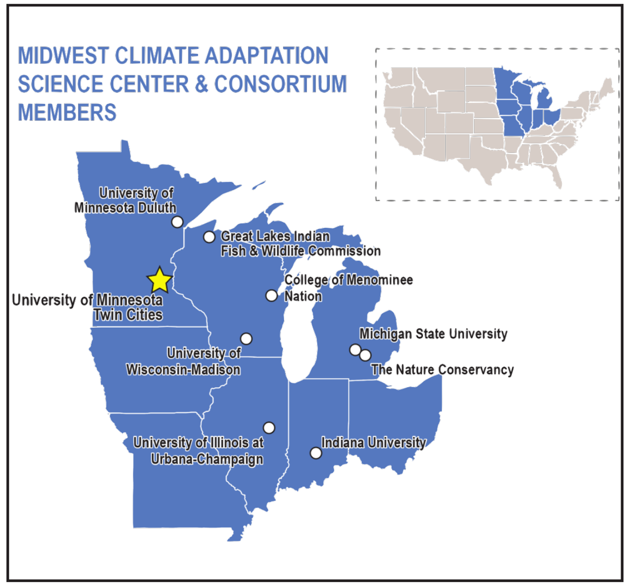
This document reflects a collaborative effort of the Midwest Climate Adaptation Science Center (CASC) community, including: U.S. Geological Survey, the Midwest CASC Consortium, the Midwest Tribal Climate Resilience Liaisons, the Midwest CASC Advisory Committee, management partners, and regional climate experts. Special thanks to Jessica Hellmann, Sue Galatowitsch, and Sarah Skikne for leading a technical assessment of our interim science priorities. Special thanks to Hugh Ratcliffe for preparing syntheses of our management challenges. Many individuals contributed to this effort in different capacities, hereby listed in alphabetical order by last name: Jess Del Fiacco, Holly Embke, Will Farmer, Gabe Filippelli, Jeremy Guest, Lucinda Johnson, Tom Kenote, Ellen Ketterson, Marta Lyons, Penelope Murphy, Owen McKenna, David Reidmiller, Ally Scott, Sara Smith, Kristen Voorhies, Elissa Welch, Jeff Ziegeweid.

Cover photo credit: Jess Del Fiacco, MW CASC

Introduction

The mission of the U.S. Geological Survey (USGS) Climate Adaptation Science Centers (CASC) is to deliver science to help fish, wildlife, water, land, and people adapt to a changing climate. Since 2010, the CASC program has cultivated regional partnerships with colleges, universities, and other non-federal organizations to share expertise, expand partnerships, produce high-quality science, increase accessibility of information, and prepare the next generation of federal scientists. In 2021, the Midwest CASC was established as the ninth member of the CASC network. For 2021-2026, the Midwest CASC Consortium is hosted by the University of Minnesota and includes the University of Wisconsin, the College of the Menominee Nation, the Great Lakes Indian Fish and Wildlife Commission, Michigan State University, Indiana University, the University of Illinois, and The Nature Conservancy.

Our vision is to advance climate adaptation science, provide indispensable resources and tools, and catalyze adaptation across the Midwest.



Our Values:

- We have **respect** for nature, for one another, and for different forms of knowledge.
- We work in **service** to our region and all the beings that live here now and in the future.
- We are **optimistic** about the future of natural and cultural resources in the Midwest.
- We have the **resolve** necessary to solve the urgent challenge of climate change.
- We prioritize **relevancy** to ensure our science will inform adaptation action.

To achieve our mission and vision, the Midwest CASC prioritizes the climate information needs of federal, state, and Tribal natural and cultural resource managers in Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. This includes organizations responsible for priority-setting, resource allocation, and/or decision-making regarding the restoration, protection, conservation, or management of fish, wildlife, plants, lands, and waters in the Midwest. To ensure relevancy, we engage the Midwest CASC Advisory Committee to provide strategic guidance on regional management challenges and climate science needs. Members include: 1854 Treaty Authority, the Bureau of Indian Affairs, Michigan Department of Natural Resources, Midwest Association of Fish and Wildlife Agencies, Minnesota Chippewa Tribe, Missouri Department of Conservation, National Oceanic and Atmospheric Administration (NOAA), National Park Service, U.S. Fish and Wildlife Service, U.S. Forest Service, USGS, Wisconsin Department of Natural Resources, and Wisconsin Tribal Advisory Council.

To foster adaptation, we promote and support meaningful managers/stewards and stakeholder/rightsholder engagement in the complete scientific process. Key features of actionable science conducted by the Midwest CASC include:

- The work is responsive to needs identified by stakeholders/rightsholders of fish, wildlife, waters, lands, and cultural heritage

- The research team engages managers/stewards in project planning and, as desired by all, throughout the lifecycle of the project
- The research team dedicates time and attention to build trust and mutual understanding with stakeholders/rightsholders and managers/stewards
- The methods are sound and advance climate impacts and adaptation science
- The results are useful and useable in planning and decision-making

We also recognize the essential role of our partners to foster adaptation in the Midwest, especially across other sectors. Therefore, we work closely with other regional climate organizations to identify common challenges and collaboration opportunities, including: Chicago Wilderness, Great Lakes Integrated Science and Assessments, Indigenous Climate Resilience Network, Michigan Climate Coalition, Midwest Climate Collaborative, Minnesota Climate Adaptation Partnership, NOAA Midwest Regional Climate Center, NOAA National Integrated Drought Information Service, NOAA Regional Climate Services, Northern Institute of Applied Climate Science, U.S. Department of Agriculture Midwest and Northern Forest Climate Hubs, and the Wisconsin Initiative on Climate Change Impacts.

Science Priorities

Developed through extensive dialogue (Appendix A), this Science Agenda reflects the current management challenges and near-term climate science needs of our management partners. We also engaged climate experts in the region to identify major thematic gaps and key science opportunities (Appendix B). In this process, we identified five challenges to the management of natural and cultural resources in the Midwest:

1. Heavy precipitation events and drought. Heavy precipitation events, flooding, and drought alter the condition, structure, services, and management of natural resources.
2. Loss of winter. Warming winters, altered snow patterns, and increased variability affect fish and wildlife populations, habitat management, subsistence, and nature-based recreation.
3. Altered hydrological regimes. Changes in temperature, flows, and connectivity alter high-value fish populations, at-risk aquatic organisms, and culturally important resources.
4. Novel terrestrial landscapes. Shifts in vegetation and human responses to climate change alter the suitability of the landscape for priority and at-risk wildlife populations.
5. Barriers to and opportunities for adaptation. Climate change alters the feasibility of management goals and suitability of management tools.

The resultant Midwest CASC Science Agenda outlines these five challenges and 49 strategic science priorities. It will guide all climate science at the center over the next three years (2023-2026).

Core Concepts

The following ideas underlie all Midwest CASC science priorities and are integral to climate impact and adaptation science:

- Organisms, systems, and institutions may exhibit adaptive capacity and vulnerability assessments are incomplete without this consideration.
- While the direct effects of climate change are widely recognized, the indirect effects pose great threat to natural and cultural resources and require evaluation.
- Adaptation may cause harm (maladaptation) and is recognized as a management intervention with potential downstream effects across systems.
- Multiple ways of knowing, including Traditional Ecological Knowledge, Indigenous knowledges, and traditional knowledge, are honored and valued.
- Diversity, equity, inclusion, and justice are considerations in what, where, and how our science is practiced.

Photo credit: Dan Larkin, University of Minnesota

Management Challenge 1. Heavy precipitation events and drought.

Heavy precipitation events have increased substantially in the Midwest region with an associated increase in the number and intensity of flooding events (Groisman et al. 2001; Mallakpour and Villarini 2015; USGCRP et al. 2017). This trend is projected to continue with precipitation concentrated into fewer rainfall events (Easterling et al. 2017; Prein et al. 2017; Byun and Hamlet 2018; Kirchmeier-Young and Zhang 2020; Dollan et al. 2022; Zhou et al. 2022). Such heavy precipitation events can intensify stream flow, runoff, erosion, and non-point source pollution from agricultural and urban areas (Bosch et al. 2014; Ryberg et al. 2014; Swanston et al. 2018; Osei et al. 2023). The subsequent changes in water quality and quantity can degrade fish habitat, disrupt physiology, impair movement, and affect recruitment (Freeman et al. 2001; Farrell et al. 2006; Ficke et al. 2007; Zohary and Ostrovsky 2011; Gaeta et al. 2014; Wuebbles et al. 2019; Paukert et al. 2021). Flooding and fluctuating water levels also affect wetland-dependent wildlife and aquatic plants, particularly manoomin/ psiŋ/wild rice (Shealer et al. 2006; Tucker et al. 2011; Ballinger 2018).

In contrast, decreased summer precipitation and enhanced evapotranspiration may create seasonal soil moisture deficits and amplify drought conditions (Tavakoli and De Smedt 2012; Hatfield et al. 2015; Polasky et al. 2021; Berg and Sheffield). Enhanced drought stress may increase vulnerability to pests and tree mortality with subsequent declines in forest health and productivity (Dale et al. 2001; Choat et al. 2012; Gustafson and Sturtevant 2013; Worrall et al. 2013; Anderegg 2015; Hember et al. 2017). Lower water levels and greater water stress can also negatively affect amphibians and aquatic invertebrates (Rittenhouse et al. 2009; Walls et al. 2013; Wolff et al. 2016; Lannoo and Stiles 2020).

To meet the challenges posed by extreme rainfall and flooding, managers are implementing innovative solutions, such as increasing vegetative cover on inactive agricultural lands, preserving wetlands, shifting the timing of prescribed burns, and translocating endangered species (Gratto-Trevor and Abbott 2011; Walters and Babbar-Sebens 2016; Hall et al. 2017; Moomaw et al. 2018; Handler et al. 2022). To reduce water demand in drought conditions, managers may focus on reducing water use in a number of ways, including but not limited to precision irrigation, forest thinning, and planting drought tolerant species (Sadler et al. 2005; D'Amato et al. 2013; Asbjornsen et al. 2019).

Management Challenge	Science Priority
1. Heavy precipitation events and drought. Heavy precipitation events, flooding, and drought alter the condition, structure, services, and management of natural resources	1.1. Assess the effects of extreme rainfall on at-risk fish, wildlife, ecosystems, and cultural resources.
	1.2. Identify aquatic fish, wildlife, and ecosystems vulnerable to the impacts of climate on water quality and quantity.
	1.3 Assess potential impacts of extreme rainfall on fish and wildlife management infrastructure.
	1.4. Determine optimal design and placement of culverts and fish passage structures to protect aquatic habitat and connectivity under future precipitation patterns.
	1.5. Evaluate the efficacy of management strategies to limit negative effects of flooding, sedimentation, and contaminants on aquatic fish, wildlife, ecosystems, and cultural resources.
	1.6. Evaluate and quantify the potential of natural lands to moderate the effects of extreme rainfall, protect natural resources, and provide co-benefits to society.
	1.7. Identify and evaluate management strategies to prepare refuges and parks for extreme rainfall and flooding.
	1.8. Identify, design, and evaluate management interventions to maintain ecological integrity and ecosystem services under future precipitation patterns.
	1.9. Identify fish, wildlife, and ecosystems vulnerable to variability in precipitation and novel drought conditions.
	1.10. Identify and evaluate methods to reduce the effects of drought on fish, wildlife, and ecosystems.
	1.11. Assess the effects of human-centric adaptation on water quality and quantity for fish, wildlife, and ecosystems.

Photo credit: National Park Service, public domain

Management Challenge 2. Loss of winter.

Warming and milder winters are key signals of climate change in the Midwest, which has experienced the largest increase in average minimum temperatures of the contiguous U.S. and a marked decrease in the severity of winter extremes (Wolter et al. 2015; Vose et al. 2017). Over the coming century, these regional trends are expected to intensify — with a lengthening of the frost-free season, more precipitation falling as rain, and a reduction in winter snowpack and ice cover (Bryan et al. 2015; Hibbard et al. 2017; Magee and Wu 2017; Hewitt et al. 2018; Ford et al. 2020). These environmental changes may initiate a complex cascade of consequences for ecosystems.

Warmer and milder winters may increase forest productivity via longer growing seasons; however, milder winter conditions may facilitate the spread of pests and invasive species that are typically limited by severe winters (Boisvenue and Running 2006; Dragoni et al. 2011). For native fish and wildlife, the effects of warmer, milder winters depend both on the magnitude of change and the species' adaptive capacity. Decreased snow cover may disadvantage species adapted to and dependent on snowy conditions for camouflage, shelter, etc. (Zimova et al. 2016; Shipley et al. 2019; Kennah et al. 2023). Changing seasonality and event timing, such as snow melt, can result in phenological and spatial mismatch, wherein a species is inadequately adapted to local conditions (Parmesan and Yohe 2003; Sultaire et al. 2016; Patterson et al. 2020). For example, warming waters may restrict suitable habitat for cold-water fish (Shuter et al. 2012; Herb et al. 2014; Fuller and Whelan 2018). Lastly, warmer and milder winters can directly alter animal physiology and vital rates (Farmer et al. 2015; Hoy et al. 2018; Kucheravy et al. 2021).

Ultimately, effective conservation of habitats and species will depend on our ability to understand species' adaptive capacity and implement local management actions (Moritz and Agudo 2013; Charmantier and Gienapp 2014; Valladares et al. 2014). In response to changing winters, adaptation practices may include: increasing surveillance and management efforts for invasive species, cultivating thermal insulation for species threatened by reduced snow cover, and establishing conservation easements to reduce nutrient applications and improve water quality for cold-water fish (Galatowitsch et al. 2009; Kovach et al. 2017; Zuckerberg and Pauli 2018; Tingley et al. 2019).

Management Challenge	Science Priority
2. Loss of winter. Warming winters, altered snow patterns, and increased variability affect fish and wildlife populations, habitat management, subsistence, and nature-based recreation	2.1. Assess the population-level effects of warming winters on cool and cold-water fish in streams and lakes.
	2.2. Assess the vulnerability and adaptive capacity of boreal wildlife.
	2.3. Assess the effects of decreased snow cover, rain-on-snow conditions, and ice storms on terrestrial wildlife and ecosystems.
	2.4. Determine the effects of variability in winter conditions on fish, wildlife, and ecosystems.
	2.5. Determine the indicators and effects of phenological mismatch and false springs on at-risk terrestrial species.
	2.6. Assess the effects of lake ice loss on fish, wildlife, and ecosystems.
	2.7. Identify management strategies to facilitate small-scale (e.g., microclimate), short-term, or long-term refugia.

Photo credit: Jess Del Fiacco, MW CASC

Management Challenge 3. Altered hydrological regimes

Shifting precipitation and temperature regimes are driving considerable change in lakes, wetlands, streams, and rivers of the Midwest. The Great Lakes have experienced a decline in annual ice cover, nearly a 71% reduction, and sharp increases in evaporation rates (Hanrahan et al. 2010; Wang et al. 2012; Mason et al. 2016). Pronounced surface warming, as well as deep water warming during winter, have led to earlier ice loss and summer lake stratification (Austin and Colman 2007; Mishra et al. 2011; Anderson et al. 2021; Imrit and Sharma 2021; Woolway et al. 2021; Li et al. 2022). Inland systems have also experienced many of these warming-related changes (Woolway and Merchant 2017; Hanson et al. 2021; Woolway, Denfeld, et al. 2022). The number of ice-free days will likely continue to increase, leading to shifts in the amount and timing of light availability for photosynthesis, as well as shifts in the timing and length of stratification periods (Woolway, Sharma, et al. 2022). Together, increased evapotranspiration, extreme variations in lake levels and mixing patterns, and increases in salinity can alter a lake's classification along the amictic–meromictic-holomictic continuum (Woolway, Sharma, et al. 2022).

Changing flow regimes and water levels will be particularly consequential for Midwest ecosystems and habitats. Warmer temperatures and heavy rainfall events may foster harmful algal blooms (Michalak et al. 2013; Watson et al. 2016; Carpenter et al. 2022). For fish and other aquatic organisms, increased water temperatures, altered stratification periods, and the increasing prevalence of anoxic conditions can stress species' capability to find suitable habitat conditions (Stefan et al. 2001; Höök et al. 2020; Tellier et al. 2022; Woolway, Sharma, et al. 2022). Threatened and endangered species, like freshwater mussels and aquatic insects, are also affected by altered flow regimes and changes to aquatic connectivity (Strayer 2006; Staudinger et al. 2015). Waterbirds and waterfowl are at greater risk of disease as lower lake levels and warming temperatures increase the incidence of avian botulism (Ohio Sea Grant et al. 2002; Lafrancois et al. 2011). Additionally, fewer inundated ponds in early spring can adversely impact species like ducks, which depend on adequate wetland coverage (McKenna et al. 2021).

Overall, the magnitude and variety of hydrological changes in the Midwest will require substantial adaptation efforts. For instance, offsetting the increased discharge rate of nutrients into lakes and streams could require as much as a 33% (± 24%) reduction in initial nitrogen inputs (Sinha et al. 2017). However, opportunities for local climate adaptation do exist. For example, managers may establish water control structures, remove artificial barriers to movement, protect aquatic vegetation for fish habitat, and promote native plantings on private shorelands (Seavy et al. 2009; Paerl et al. 2016; Angel et al. 2018; Magee et al. 2019; Schmitt et al. 2022).

Management Challenge	Science Priority
3. Altered hydrological regimes. Changes in temperature, flows, and connectivity alter high-value fish populations, at-risk aquatic organisms, and culturally important resources	3.1. Evaluate fluctuations of water levels in stream, lake, and wetland ecosystems.
	3.2. Determine the future geophysical conditions of inland lakes.
	3.3. Determine groundwater contributions to stream refugia and potential impacts of climate-induced groundwater changes on ecosystems.
	3.4. Determine the future condition and ecological function of prairie pothole wetlands.

3. Altered hydrological regimes, *continued*	3.5. Assess changes to aquatic connectivity and the subsequent effects on wetland/aquatic ecosystems.
	3.6. Determine the climate-driven establishment, spread, impact, and effectiveness of management of aquatic invasive species.
	3.7. Assess and predict changes in future abundance and distribution of high-value fish species and at-risk aquatic organisms.
	3.8. Evaluate the efficacy of in-lake, landscape, and watershed management to protect the quality and function of wetland, stream, and lake ecosystems.
	3.9. Assess the effects of climate change on recreational angling and subsistence fisheries.
	3.10. Identify and evaluate management strategies to reduce risk and impacts from climate to particularly manoomin/psiŋ/wild rice.
	3.11. Assess the effects of climate change on current and anticipated aquatic pathogens, including transmission, ecosystem impacts, and management options.

Photo credit: Christina Packard, Unsplash

Management Challenge 4. Novel terrestrial landscapes

Changes in precipitation and temperature patterns will result in novel ecological communities and large ecosystem shifts across the region, including an overall loss of boreal forest habitat, northward expansion of temperate forests, and expanded suitability for grasslands (Kucharik et al. 2010; Janowiak et al. 2014; Toot et al. 2020; Iverson and Taft 2022). Climate-driven alterations of the terrestrial landscape of the Midwest also occur in the context of broad changes in land use, creating synergistic challenges for Midwestern ecosystems. Over the past several decades, in the Midwest, the largest change in land use has been an increase in urban and developed areas (Sleeter et al. 2018). Further, since the mid-2000s, agriculture has been increasing in extent, largely via the conversion of grasslands (Wright and Wimberly 2013; Hendricks and Er 2018). These changes are expected to continue over the coming years with implications for native ecosystems and protected areas (Haim et al. 2011; Lawler et al. 2014; Ordonez et al. 2014). Climate change may dictate the regional pattern of land use change in the Midwest in part by shifting conditions necessary for corn and soy production northwards (Cunningham 2022).

Decreases in the extent and quality of native ecosystems like grasslands and wetlands may negatively affect species that depend on these habitats, such as grassland birds, waterfowl, pollinators, and dispersal-limited amphibians and reptiles (Meehan et al. 2010; Crawford et al. 2016; Jarzyna et al. 2016; Koh et al. 2016; Kovács-Hostyánszki et al. 2017; Struecker 2017; Hamilton et al. 2018). Land use change in the Midwest will also likely reduce habitat connectivity (Radeloff et al. 2005). For example, due to urbanization, buffer zones around protected areas in the Midwest will continue to shrink (Wade and Theobald 2010). By increasing fragmentation and creating other physical barriers, land use change will hinder species' ability to shift their range in response to climate (Scheller and Mladenoff 2008; Schloss et al. 2012; Carroll et al. 2015; Caplat et al. 2016; Swanston et al. 2018). This fragmentation not only impacts the quantity of accessible habitat, but also its quality, such as through altering suitable microclimates in forests for bird species (Latimer and Zuckerberg 2017). Land use changes can also negatively impact ecosystem services; expanding suburban areas in the Midwest exacerbate the effect of extreme heat waves on forests and diminish their capacity to store carbon and supply water (Kicklighter et al. 2023).

Because large, intact landscapes tend to provide greater adaptative capacity to climate change, significant attention to this issue is warranted (Watson et al. 2018). Nevertheless, opportunities to work in partnership for local adaptation exist, such as enhancing invasive species management, promoting new plant communities in restoration practices, facilitating species translocation, and increasing habitat and green space in urban and suburban areas (Galatowitsch et al. 2009; Lerner and Allen 2012; Magee et al. 2019; LeDee et al. 2021; Handler et al. 2022).

Management Challenge	Science Priority
4. Novel terrestrial landscapes. Shifts in vegetation and human responses to climate change alter the suitability of the landscape for priority and at-risk wildlife populations	4.1. Determine changes in the composition, structure, disturbance regimes, ecological function, and distribution of forests.
	4.2. Determine changes in the composition, structure, disturbance regimes, ecological function, and distribution of grasslands.
	4.3. Determine the climate-driven establishment, spread, impact, and effectiveness of management of terrestrial invasive species.
	4.4. Advance climate knowledge for under-studied terrestrial species.
	4.5. Assess climate-driven changes in the abundance and distribution of priority wildlife species.
	4.6. Identify optimal future habitat (e.g., refugia, connectivity to) for at-risk or priority species.
	4.7. Assess the potential for range shifts to or from Tribal lands, or local extirpation of focal species from Tribal lands.
	4.8. Evaluate the effects of climate-induced changes in land use on aquatic and terrestrial fish, wildlife, and ecosystems.
	4.9. Evaluate the social and economic effects of climate change on hunting, gathering, fishing, and wildlife viewing opportunities, outdoor recreation, and Tribal livelihoods.
	4.10. Determine climate vulnerability in the non-breeding season for priority wildlife (e.g., migratory species).
	4.11. Assess the effects of climate change on current and anticipated terrestrial pathogens, including transmission, ecosystem impacts, and management options.

Photo credit: Dana Hernandez, MW CASC

Management Challenge 5. Barriers to and opportunities for adaptation

A complex assortment of socio-political, economic, and scientific barriers hinders the capacity of natural systems and their stewards to respond to climate change (Adger et al. 2009; Biesbroek et al. 2013). Climate change threatens management goals, like conserving endangered species, preserving unique communities, and protecting wilderness areas (Bellard et al. 2012; Hall 2012; Maxwell et al. 2019; Parks et al. 2020). In turn, land managers may either prioritize conservation targets for resistance and resilience, or facilitate transitions to new states (Toot et al. 2020; Gilbert et al. 2022; Palik et al. 2022). Balancing these contrasting management decisions in the context of considerable uncertainty remains a critical challenge in adaptation science (Ahlering et al. 2020). Moreover, climate change may limit the feasibility and efficacy of traditional management tools (Staudt et al. 2013).

Implementation of adaptation strategies remains limited. For natural resource professionals, primary concerns include uncertainty, perceived relevance to unique site conditions, and inadequate research foci relative to management needs (Sarewitz and Pielke 2007; Kalafatis et al. 2015; Anhalt-Depies et al. 2016). In turn, this may result in a perception of risk that climate adaptation may be ineffective or maladaptive (Bertana et al. 2022). For natural resource agencies, the willingness to implement climate adaptation is also influenced by how stakeholders, such as hunters, anglers, and farmers, perceive the negative impacts of climate change (Hagell and Ribic 2014; Anhalt-Depies et al. 2016; Carlton et al. 2016). Lastly, implementation can be limited by the overwhelming amount of climate information available, which makes selecting and translating new studies into management actions difficult (Dilling and Berggren 2015; Kemp et al. 2015).

Despite these myriad challenges to climate adaptation, effective strategies and solutions exist and are in continuous development, including adaptation strategies that may generate co-benefits for diverse stakeholders. Examples of these win-win solutions include restoration and land-management strategies which promote fish and wildlife resilience, carbon sequestration, water quality improvements, and flood risk reduction (Johnson et al. 2016; Angel et al. 2018; Fargione et al. 2018; Jager et al. 2020; Handler et al. 2022). Climate adaptation will require meaningful, sustained exchange between scientists, managers, and the public to identify future goals and overcome technical, socio-economic, and organizational barriers to change (Kalafatis et al. 2015; Angel et al. 2018).

Management Challenge	Science Priority
5. Barriers to and opportunities for adaptation. Climate change alters the feasibility of management goals and suitability of management tools	5.1. Assess the feasibility and effectiveness of current and potential ecological restoration goals under future conditions.
	5.2. Advance climate-informed optimization of protected lands for fish, wildlife, ecosystems, and cultural resources.
	5.3. Conduct assessments to reduce the risks and measure the effectiveness of assisted migration activities.
	5.4. Provide climate-informed decision science in the selection, application, and siting of restoration and ecosystem management (e.g., prescribed burning, water control, grazing, siting, and seed selection/planting).
	5.5. Determine perceptions of and acceptance for climate adaptation for fish, wildlife, and ecosystems, including by private landowners and Indigenous communities.
	5.6. Identify and assess the risks of laws, policies, regulations, and practices that are maladaptive or exacerbate the effects of climate change on fish, wildlife, and ecosystems.
	5.7. Identify climate adaptation practices for fish, wildlife, and ecosystems that yield co-benefits (e.g., carbon mitigation, economic gain, social resilience, well-being of at-risk communities).
	5.8. Inform the design of monitoring programs and early warning systems to detect and respond to climate change.
	5.9. Identify barriers to and opportunities for the integration of climate adaptation in existing natural resource policies, program, and practices.

Implementation

This Midwest CASC Science Agenda will guide the work of the Midwest CASC— the U.S Geological Survey and the Consortium—for the next three years (2023-2026).

The U.S. Geological Survey will work with the Midwest CASC Advisory Committee to review the Technical Assessment and refine the set of 49 priorities for near-term action. In observation of Federal trust responsibilities, the U.S. Geological Survey will also work with the Bureau of Indian Affairs, Branch of Tribal Climate Resilience, and the Midwest Tribal Climate Resilience Liaisons to engage Tribal Nations to understand climate challenges, promote knowledge exchange, and gather information needs. These efforts will inform an annual call for science projects from members of the Consortium or principal investigators from U.S. Geological Survey. Over the next three years, we will expand our research portfolio, currently comprised of 39 projects, to yield responsive, high-quality science and information that advances climate adaptation across the Midwest. At the expiration of this Science Agenda, we will complete a comprehensive evaluation of the MW CASC research portfolio to include: stakeholder/rightsholder engagement, collaboration, productivity, accessibility, outreach, and societal impacts.

The Consortium will work with the U.S. Geological Survey to pursue collaborative and synthetic research in climate adaptation and build professional and research capacity for current and future natural resource challenges. Synthesis research is led by universities in the Consortium, conducted by postdoctoral associates, and guided by a working group represented by member organizations. In synthesis research, the Consortium is committed to co-production with stakeholders, communities, and governments, developing adaptation indicators and decision-support tools, investigating co-benefits and maladaptation, and/or conducting research at regional or national/continental scale. To build research capacity, the Consortium hosts an Annual Gathering, monthly science seminars, and custom trainings to expand knowledge, skills, and collaborations of both established and early-career researchers. Over the next three years the Consortium will be offering kickstarter funds for researchers or research teams to identify science needs or pilot research projects that address the Midwest CASC Science Agenda.

We look forward to working with you to advance climate adaptation science, provide indispensable resources and tools, and catalyze adaptation across the Midwest.

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Appendix A

Midwest Climate Adaptation Science Center
Process to Develop the Science Agenda (2021-2026)

Stage 1. Identify management challenges

- Solicited structured feedback from the Advisory Committee (representation from Department of the Interior, States, and Tribes)
- Conducted six listening sessions with 66 informed, engaged resource managers
- Solicited feedback from research project partners

Stage 2. Define operational space

- Reviewed guidance from President, Department of the Interior, and U.S. Geological Survey
- Reviewed strategic plans of partners (e.g., U.S. Fish and Wildlife Service, NOAA)
- Reviewed regional climate science reports and publications
- Reviewed regional climate initiatives (e.g., Wisconsin Initiative on Climate Change Impacts, Minnesota Climate Adaptation Partnership)

Stage 3. Develop interim science plan

- Reviewed science agendas from other CASC regions
- Developed a two-tier structure of management challenges and science priorities
- Solicited feedback from National and Regional Climate Adaptation Science Centers

Stage 4. Technical assessment (see also Appendix B)

- Completed brief issue summary for each management challenge
- Engage university, state, Tribal, federal/USGS researchers to:
    - Identify major climate research questions for the region
    - Review the interim science plan to:
        - Identify major thematic gaps
        - Identify key science opportunities
    - Identify emerging issues for future revisions

Stage 5. Performance indicators

- Engage Advisory Committee to develop measures of success for the center

Stage 6: Plan revision

- Review 2021 regional needs assessments, partner plans, and climate science reports
- Review findings from Stages 4 and 5—integrate key gaps and performance indicators
- Comments on revision from Consortium Leadership Team
- Comments on revision from Advisory Committee
- Review and approval from National Climate Adaptation Science Centers
- Final plan (Summer 2023)

Stage 7: Implementation

- Engage Advisory Committee in prioritization for annual call for projects
- Engage Consortium Leadership Team on prioritization for synthesis research and student research projects

Appendix B. Technical Assessment, Summary Version

Technical Assessment of Interim Science Agenda: Survey Responses – Summary version

Prepared by:

Sarah Skikne
Midwest Climate Adaptation Science Center
Institute on the Environment
University of Minnesota

With helpful feedback from:

Jessica Hellmann
Jess Del Fiacco
Elissa Welch
Midwest Climate Adaptation Science Center
Institute on the Environment
University of Minnesota

Kristen Voorhies
Midwest Climate Adaptation Science Center
U.S. Geological Survey

Mark Miazga
Office of Measurement Services
University of Minnesota

Thomas Kenote
(working group member)
Sustainable Development Institute
College of the Menominee Nation

Susan Galatowitsch
(working group member)
Department of Fisheries, Wildlife and Conservation Biology
University of Minnesota

Jeremy Guest
(working group member)
Institute for Sustainability, Energy, and Environment
University of Illinois Urbana-Champaign

Gabe Filippelli
Ellen Ketterson
(working group members)
Environmental Resilience Institute
Indiana University

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MIDWEST Climate Adaptation Science Center

INSTITUTE ON THE ENVIRONMENT
UNIVERSITY OF MINNESOTA
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Background and objectives

The Midwest Climate Adaptation Science Center's (MW CASC) Strategic Science Agenda will guide the MW CASC's work through 2026, and is currently at an interim stage.

We are conducting a technical assessment to support the revision and finalization of these science priorities. This exercise will ensure that MW CASC research priorities are informed by current scientific understanding, technical complexity, and opportunity for impact, and that they capture the full range of relevant issues and are attentive to emerging concerns.

Here, we report on the first stage of our technical assessment: a survey of technical experts from the region, including university, state, Tribal and federal researchers and other experts. Our goal was to identify topics that are missing or underrepresented from the Interim Science Agenda, as well as emerging topics for future iterations of the Agenda.

In the next stage of the assessment, the USGS will revise the interim list based on the findings reported here. In the final stage, we will invite experts to group sessions to characterize the updated list of science priorities along three axes: (1) state of knowledge / amount of uncertainty, (2) technical complexity and feasibility of answering the question, and (3) opportunity for impact. This information will help the USGS focus and prioritize their efforts to strategically impact climate adaptation science in the region.

More details can be found in the full report of survey results.

Methods

The main part of the survey consisted of seven questions:

- Two questions asking respondents to list important research topics over two time frames: <5 years and 10+ years. These questions were meant to solicit research topics that were top-of-mind for respondents.
- Five questions on missing topics (one for each management challenge). Respondents were instructed to read the existing science priorities and then list what was missing.

We sent the survey out to >150 individuals and listservs, including ~50 experts identified by survey respondents. The survey was open from June 6 to July 9, 2022.

Respondents provided 264 unique, usable answers in response to the seven main survey questions. Each answer could be composed of >1 comments, which were separately coded.

We conducted a two-part analysis of responses:

1. **Qualitative assessment of underrepresented themes:** Many respondents listed similar themes that were missing or underrepresented in the interim science agenda. We tracked

these patterns as we noted them, but did not formally assess the extent to which they could be encapsulated by the existing science priorities.

2. **Formal assessment** of the relationship between existing priorities and survey responses: We categorized all comments into one of three categories:
   (1) comments that were encapsulated by and supported the existing priorities
   (2) comments that suggested research topics that could be included by editing or expanding existing science priorities. We suggest revisions to the existing science priorities based on these comments.
   (3) comments that suggested new research topics which could not be readily encapsulated by revisions to existing science priorities.

Respondents

We received usable responses from 68 respondents.

Geography

- Minnesota and Wisconsin had the most respondents.

Institutions

- University of Illinois, Indiana University, University of Minnesota and The Nature Conservancy were the most common institutions.

Expertise and experience

- Respondents reported a median of 20 years of experience in their field.
- The most common areas of expertise were "terrestrial species / habitats" and "management / restoration".
- Respondents most often gained their expertise via field research.
- 25% of respondents reported expertise in "tribal communities" and/or gained expertise via "native stewardship or traditional ecological knowledge".

Summary of results

Missing or underrepresented themes identified in qualitative assessment

- Adaptation Effectiveness
- Climatology & hydrology
- Connectivity & Fragmentation
- Ecosystem functions
  - Carbon storage
  - Nutrient storage & cycling
  - Productivity
  - Generic ecosystem functioning
- Great Lakes
- Groundwater
- Impacts of other sectors on natural resources
  - Agriculture
  - Carbon emissions / mitigation in other sectors
  - Human resettlement
  - Impacts of & responses to other sectors adapting
- Interactions between multiple stressors
- Interactions between terrestrial & aquatic systems
- Pests & pathogens
- Public health

- Social science
  - Decision science
  - Environmental justice & equity
  - Policy analysis
  - Behavior, identities, perceptions, acceptance
  - Social & economic impacts
  - Collaboration, coordination & engagement
- Soil
- Traditional Ecological Knowledge
- Tribal concerns & partnerships

Suggested revisions based on formal assessment

See the full report of survey results.

New topics based on formal assessment

Management Challenge 1
- Ecosystem functioning, incl. in terrestrial systems
- Impacts on environmental justice, communities, cultural resources, & recreation
- Physical science, climatology, hydrology
- Impacts to plants (incl. terrestrial) & forests
- Impacts of flooding on human communities
- Climate refugia
- Ecosystem responses
- Species interactions that provide resistance or resilience
- Wastewater discharge during droughts
- Directing ecological transformation

Management Challenge 2
- Impacts on ecosystem functions
- Impacts on connectivity
- Physical science, climatology, hydrology
- Southern species migrations

Management Challenge 3
- Physical science, climatology, hydrology
- Hydrological impacts on terrestrial systems
- Impacts on the Great Lakes
- Impacts to ecosystem function
- Water policy & management
- Drinking water
- Conditions needed to restore peatlands
- Conservation prioritization of fish species & habitats
- Ecological mechanisms by which climate change will impact aquatic systems

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Management Challenge 4
- Forest management, reforestation & restoration, including policy
- Management & restoration (non-forest or generic)
- Agriculture
- Natural / evolutionary adaptation
- Carbon sequestration
- Interactions between multiple stressors
- Impacts of changes to pollinators / insects
- Fire
- Range shifts *into* the region & responses
- Determinants of range limits
- Projections & impacts of windstorms
- Seed & plant material sourcing

Management Challenge 5
- Landscape connectivity
- Decision science
- Rural & urban impacts & solutions
- Adaptation effectiveness
- Adaptation sufficiency & portfolios
- Tribal concerns & supporting tribes
- Policy, governance & socioeconomic barriers to & facilitation of adaptation
- Environmental justice of impacts & adaptation
- Traditional Ecological Knowledge

- Collaboration, coordination & engagement
- Impacts of other sectors mitigating
- Impacts of other sectors adapting & potential responses
- Impacts of human resettlement
- Workforce
- Alternative future climates
- Protected areas & range shifts
- Learning