Technical Assessment of the Interim Science Agenda: Survey Responses

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MIDWEST Climate Adaptation Science Center

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Background and objectives

The Midwest Climate Adaptation Science Center's (MW CASC) Strategic Science Agenda will guide the CASC's work through 2026, helping to identify which projects should be funded and which partnerships need to be cultivated. Currently, the Strategic Science Agenda is at an interim stage. The Interim Science Priorities for the Midwest CASC are structured around five management challenges:

1. Heavy precipitation events and drought
2. Loss of winter
3. Altered hydrological regimes
4. Novel terrestrial landscapes
5. Barriers to and opportunities for adaptation

For each management challenge, there are approximately 10 science priorities, for a total of 51 interim science priorities.

We are conducting a technical assessment to support the revision and finalization of these science priorities. This exercise will ensure that 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. We report on the methods we used to develop and disseminate the survey and analyze responses, characteristics of the respondents, and the responses we received in relation to the interim science agenda. **Our goal was to identify topics that are missing or underrepresented from the Interim Science Agenda (as identified by experts in the region), 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 funding and outreach efforts in order to strategically impact climate adaptation science in the region.

Methods

Survey development and distribution

We designed a Google Forms survey in consultation with the University of Minnesota Office of Measurement Surveys and our Technical Assessment Working Group (made up of 5 members of the MW CASC Consortium Leadership Team, identified on p. 1 above). We piloted the survey with four test subjects and revised it based on their feedback.

The survey consisted of 4 sections:

- Section I asked about the expertise and background of the respondent
- Sections II and III constituted the main part of the survey, and consisted of seven questions:
    - Section II had two questions on important topics, without prompting, over two time frames: <5 years and 10+ years. Respondents generally answered these questions without having seen the interim science priority list. Therefore, these questions solicit research topics that were top-of-mind for respondents.
    - Section III had five questions (one for each management challenge). Respondents were instructed to read the existing science priorities and then list what was missing.
    - For each question in Section II and III, respondents could write more than one response (from here on "comments"). Both sets of questions asked respondents to include why they thought their proposed topics were important (*"For each, include the primary reason you think it is important (e.g., it is understudied, there is a lot of uncertainty, the threats are large, the target is already threatened, it is of interest to stakeholders, it will have an important impact on management, etc."*)).
- Section 4 asked for additional names of experts who should take the survey

See Appendix I for the full text of the survey. Respondents were ensured confidentiality, with results reported in aggregate in public versions of the study (e.g., published reports and papers).

Between the people identified on p. 1 of the report and the full Consortium Leadership Team, we sent the survey out to at least 100 individuals and listservs. We additionally sent the survey to ~50 experts identified by those taking the survey in Section 4. Because we encouraged recipients to invite additional contacts, we do not know the number of people that the survey invitation reached. The survey was open from June 6 to July 9, 2022.

Analysis of responses

We used R to characterize the respondents (i.e., responses to Survey Section I) and create figures.

We used MAXQDA software to analyze responses to open-ended responses in Sections II and III. We removed comments that did not have a clear relationship to climate change or natural resources / natural resource management. In order to be included, comments on agriculture had to also describe natural resources or their management.

We conducted a two-part analysis: a qualitative assessment of unrepresented themes, and a formal assessment of the relationship between existing priorities and survey 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 them or the extent to which they could be encapsulated by the existing management challenges and science priorities.

2. Formal assessment

We categorized all comments into one of three categories:

(1) comments that were encapsulated by and therefore 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 ("new topics")

At times respondents made comments in reference to a particular management challenge or priority, but we felt they better fit in another; in these cases we moved responses to the category where we felt it best fit. Some comments fit into more than one of the three categories (e.g., part of the comment suggested a new research topic while another part implied a revision to an existing science priority); in these cases we put them in both. In some cases, comments did not fit into any of the management challenges; we grouped these and include them at the end.

We provided individual responses supporting our assessment directly to the USGS; these will be held privately and not distributed.

Respondents & responses

Of 70 survey respondents, we removed two (one who is on the MW CASC external advisory board, and one whose responses did not answer the posed questions). Our final sample was N=68 respondents.

Geography
The states with the most respondents were Minnesota and Wisconsin (N=16 each). In contrast we received one response from Iowa and none from Missouri. (Fig. 1a). The overall number of respondents from Northern vs. Southern states within the region likely reflects the MW CASC consortium institutions and their networks.

Institutions and sectors
Respondents represented 20 unique institutions. The most common were University of Illinois, Indiana University, University of Minnesota and The Nature Conservancy (N=10, 9, 9, and 8 respondents each, respectively). Eight institutions had one respondent each (Table 1, Appendix 2). By sector, most respondents were from higher education (Fig. 1b).

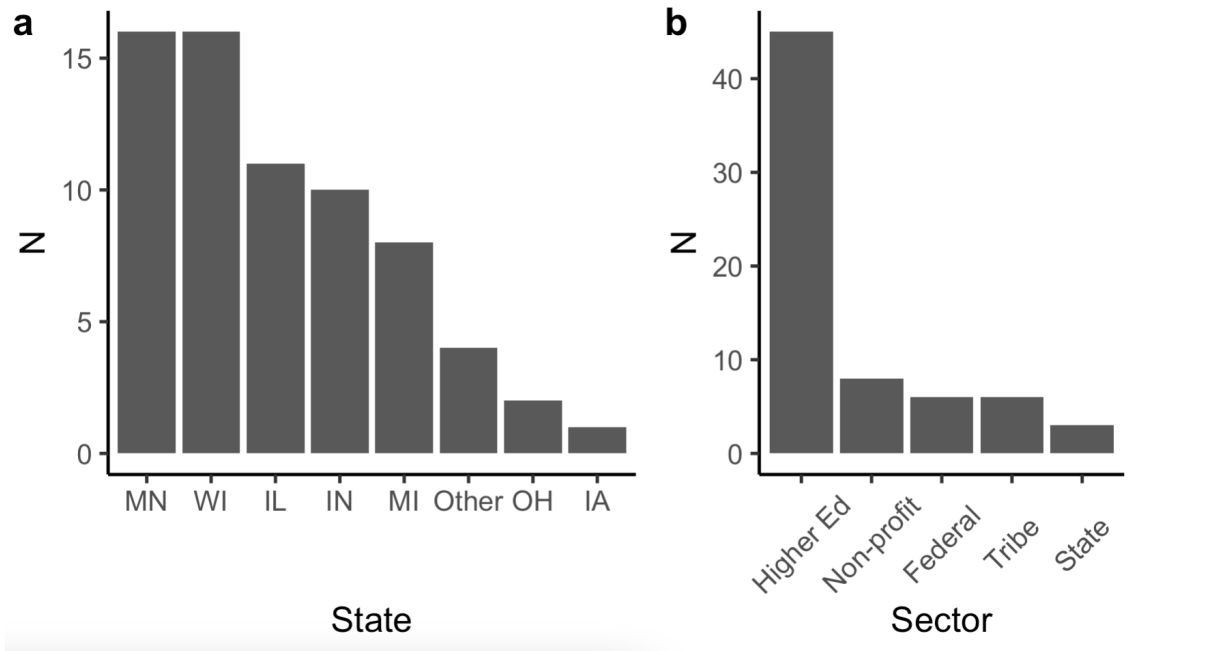

Fig. 1: Number of respondents from each (a) state and (b) sector.

Expertise and experience
Respondents reported a mean and median of 20 years of experience working in or involvement in their field.

The two most common areas of expertise were “terrestrial species / habitats” and “management / restoration” (N= 35 and 29, respectively). There was relatively less expertise in “aquatic species

/ habitats" (N=15) compared to "terrestrial species / habitats" (Fig 2a); this may reflect the fields as a whole, or our networks. Similarly, respondents had the least expertise in agriculture and recreation (N=9 and 5, respectively, Fig 2a). We don't think this will impact our overall analysis, because we did not count "votes" or otherwise quantify responses. However, it may mean that we received less detailed feedback on these topics than others.

Respondents most often gained their expertise via field research (N=54), as well as data analysis / modeling, study of the literature, and time spent in Midwest ecosystems (N=49, 48 and 47, respectively, Fig 2b).

25% of respondents reported expertise in "tribal communities" AND/OR gained expertise via "native stewardship or traditional ecological knowledge". Responses from experts with Tribal experience are salient given the importance of Tribal concerns, and related science questions, in the Midwest CASC.

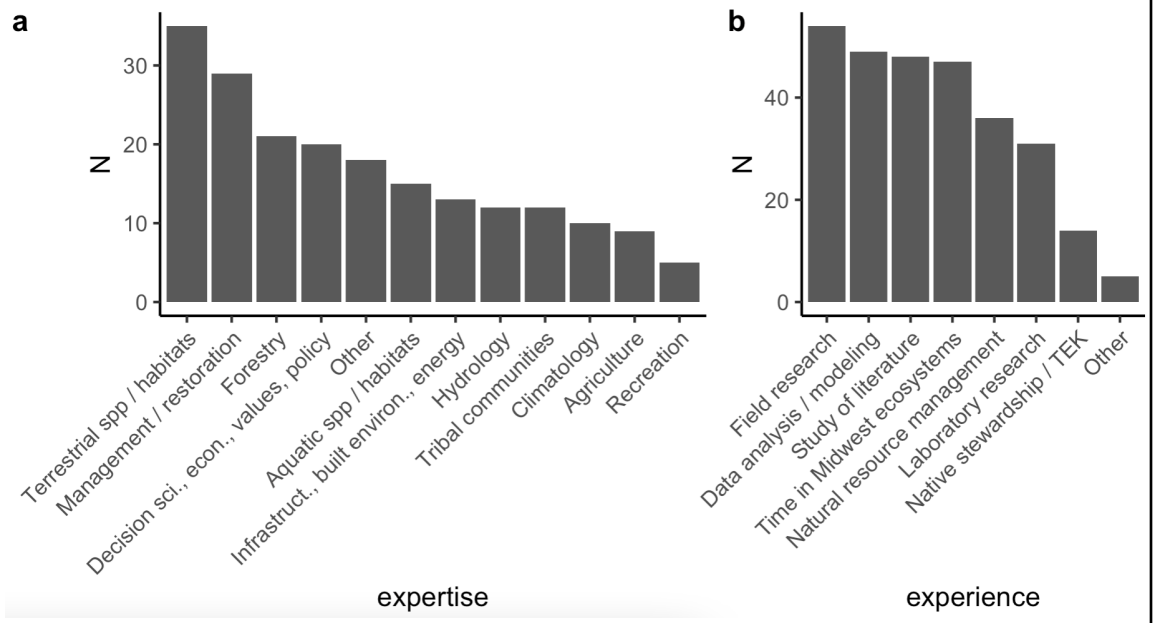

Fig. 2: Responses to questions asking respondents (a) to list their areas of expertise and (b) "How did you gain your expertise?". For both, respondents could check multiple categories, so results add up to more than the total sample size.

Responses

Respondents provided 264 unique, usable answers in response to the 7 main questions in the survey (Table 2, Appendix 2). Each answer could be composed of >1 comments, which were separately coded.

Results: Summary

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

In a few cases we quantify the number of comments supporting the revision to illustrate that the topic was a focus of responses. Those not listed received no comments.

Management Challenge 1

1.1. Assess the population-level effects of extreme rainfall and increased variability on at-risk aquatic and terrestrial species and their habitats.

1.2. Identify ~~aquatic~~ habitats and ecosystem functions vulnerable to impacts on water quality and soil health, including erosion, sedimentation, contaminants, ~~and~~ debris influx, ~~or~~ and infrastructure failure.

1.4. Determine optimal ~~culvert~~ design and placement of culverts and other interventions 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, contaminants and debris influx on aquatic species, ~~and~~ habitats, biodiversity, and water quality and quantity.

1.6. Evaluate and quantify the potential of natural lands, biodiversity, restoration, and other nature-based solutions to moderate extreme rainfall, ~~and~~ flooding, runoff and erosion.

1.8. Use decision science techniques to identify, design and evaluate optimal ~~Conduct cost-benefit analysis of management interventions~~ management interventions that are robust to uncertainty, support multiple benefits, and maintain ecological integrity under future precipitation patterns.

1.9. Predict novel drought conditions and impacts, and identify vulnerable ecosystems, ~~and~~ species, and habitats. ~~vulnerable to novel drought conditions~~

1.10. Identify and evaluate methods to reduce the effects of drought on fish, ~~and~~ wildlife, and carbon storage.

1.11. Assess the effects of human adaptation and potential maladaptation risks to aquatic systems and resources, including water availability for fish and wildlife

Management Challenge 2

2.3. Assess the effects of decreased snow cover, ~~and~~ rain-on-snow conditions, and ice storms on wildlife and plant species and communities, soils, and ecosystem functions.

2.4. Determine the effects of variable winter conditions on fish and wildlife populations and habitat, aquatic and terrestrial plant communities, and ecosystem function.

2.5. Assess 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 and plant species and communities

2.7. Identify the locations of, ~~and~~ assess the adequacy of, and evaluate management strategies to facilitate short-term, small-scale (e.g., microclimate), or long-term refugia.

2.8. Evaluate the ecological, social and economic effects of warming winters on ~~hunting, fishing, and wildlife viewing opportunities,~~ outdoor recreation, tourism, tribal livelihoods, transportation, natural resource management activities, and other winter activities, and identify relevant adaptation strategies.[1]

Management Challenge 3

3.1. Evaluate fluctuations of water levels in and other hydrological impacts to stream, lake, and wetland systems, and the plant communities they contain.

3.3. Determine impacts of climate change on groundwater, impacts of climate-induced groundwater changes on ecosystems, and groundwater contributions to stream refugia

3.5. Assess changes to aquatic connectivity, and the effects of those changes ~~in connectivity~~ on wetland/aquatic ecosystems.

3.6. Predict the climate-driven establishment and spread of aquatic invasive species and their impacts.

3.7. Predict and assess changes in ~~the~~ sex ratios, development, abundance and distribution of high-value fish species and at-risk aquatic organisms, the resources they use, and their habitats, communities, and ecosystems.

3.8. Evaluate the efficacy of in-lake, landscape, and watershed management to protect fish and aquatic plant communities and freshwater features and ecosystems, and to enhance hydrology.

3.9. Assess the effects of climate change on recreational angling, ~~and~~ subsistence fisheries, and watercraft use.

3.10. Identify climate impacts to manoomin and evaluate management strategies to reduce climate risk ~~to manoomin~~.

3.11. Assess the effects of climate change on current and novel aquatic pests and pathogens and their transmission, resulting impacts on species and human health, and management options.[2]

Management Challenge 4

4.1. Determine recent and future changes in the ~~future~~ demography, disturbance, composition, structure, ecological function, ecosystem services, and distribution of forests and other terrestrial systems.

4.2. Determine the effects of mesophication on grassland and other habitats

4.3. Predict the climate-driven establishment, ~~and~~ spread and impact of terrestrial invasive species

4.5. Assess climate-driven changes in the abundance and distribution of priority ~~wildlife~~ species, the resources they use, and their habitats, communities and ecosystems.

4.7. Assess the potential for range shifts to or from Tribal lands, or local extirpation of focal species from Tribal lands

4.8. Assess the maintenance of and determine the potential for microclimates to buffer or exacerbate regional climate conditions

4.9. Evaluate the effects of climate-induced changes in agriculture (including climate-adapted

[1] Respondents included 17 comments supporting this revision.

[2] Respondents included 21 comments supporting this revision.

agriculture) on wildlife habitat, natural resources, the environment, and agricultural production.

4.12. Assess the effects of climate change on current and novel ~~wildlife~~ pests and pathogens and their transmission, resulting impacts on species and human health, and management options.[3]

Management Challenge 5

5.3. Conduct assessments to reduce the risks and understand the benefits of assisted migration activities, and measure their impacts.

5.4. Assess climate impacts on restoration success and provide climate-informed decision support in the selection and application of restoration tools (e.g., prescribed burning, water control, grazing, plantings) and locations.

5.5. Determine perceptions of and social values and acceptance for climate adaptation for fish, wildlife, natural resources and ecosystems, including by indigenous people and local communities.

5.6. Identify regulatory tools for fish, ~~and~~ wildlife, and other natural resources that may be inadequate or have unintended or maladaptive consequences under climate change

5.7. Identify management practices and policies that are maladaptive or exacerbate the effects of climate change on fish, wildlife, and ecosystems

5.8. Identify climate adaptation practices that yield co-benefits or trade-offs (e.g., carbon mitigation, economic gain, social resilience, biodiversity, food production)

5.9. Inform the design of monitoring programs and early warning systems to detect and respond to climate change impacts and monitor adaptation progress, including monitoring under extreme conditions.

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

[3] Respondents included 24 comments supporting this revision.

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
- 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

Results: Qualitative assessment

Based on our qualitative assessment, themes that are missing or underrepresented in the interim science priorities are described here. Themes that were especially prominent in responses (15+ supporting comments) are underlined.

Adaptation Effectiveness
Respondents suggested the need for research that tests the effectiveness and impacts of adaptation actions on-the-ground. This is related to science priorities 1.5, 1.7, 1.10, 2.7, 3.8 and 3.10, which call for "evaluating" various strategies, but specifically suggests on-the-ground implementation and then evaluation. This was the only theme where comments were noticeably prominent in the 10+ year time period relative to other parts of the survey, presumably because respondents reasoned this was enough time for deployed efforts to be measurable.

Climatology and hydrology
In addition to groundwater (below), numerous respondents noted a need for more research on climate and hydrological processes that will be impacted by climate change. Topics included cold air pooling, thunderstorms, wind events, flooding, precipitation, ice, water flow paths, water balances and evapotranspiration. Given the number of comments in the <5 year time period compared to the lack of comments in the 10+ year time period, respondents presumably see this as a theme in need of more immediate attention.

Connectivity & Fragmentation
Respondents were interested in research on improving landscape connectivity as an adaptation strategy, including the use of land protection and restoration to improve connectivity, and links between the midwest and other regions. Conversely, respondents mentioned landscape fragmentation as an interacting stressor with climate change. Given the number of comments in the <5 year time period compared to the lack of comments in the 10+ year time period, respondents presumably see this as a theme in need of more immediate attention.

Ecosystem functions

> **Carbon storage**
> Respondents were interested in research on measuring, preserving and enhancing the carbon storage potential of forests, grasslands, wetlands, soils and agroecosystems in the face of climate impacts (e.g. droughts, flooding) and climate adaptation strategies.
>
> **Nutrient storage and cycling**
> Respondents noted that the impacts of climate change on nutrient cycling, movementment and retention, and downstream effects on soils and water quality, were largely missing from the priorities.
>
> **Productivity**

Respondents noted that the impacts of climate change on ecological productivity was largely missing from the priorities.

Generic ecosystem functioning
In addition to the specific ecosystem functions described above, several respondents listed "ecosystem functions" or other similar broad terms as important and/or missing from the priorities. These comments referred to both measuring impacts on ecosystem function, and restoring lost functions.

Great Lakes
Respondents mentioned impacts of climate change to the Great Lakes, including climate projections, water temperature, cold water upwelling, hydrological cycles, water levels and quality, flooding, erosion, aquatic species, and trophic status. Some also mentioned the need for research on solutions to adapt to these impacts.

Groundwater
Respondents noted that the impacts of climate change on groundwater and groundwater recharge, and resulting impacts on resources and ecosystems, was missing from the science priorities, as was policy analysis related to these changes.

Impacts of other sectors on natural resources

Agriculture
Numerous respondents suggested research on several aspects of agriculture in relation to natural resources and natural resource management:
- How to balance the needs of food production, security and profitability with natural resource management in the face of climate change
- The impacts of agricultural adaptation (e.g. new crops and pesticides, increased livestock concentrations, flood control, land use change) and mitigation (i.e. ethanol production) on natural resources
- New opportunities for natural resource management (e.g. restoring former agricultural land, agroforestry), and the policies and socioeconomic conditions needed to realize them

Carbon emissions / mitigation in other sectors
Respondents suggested research about the impacts of carbon mitigation strategies in other sectors (e.g. biofuels, solar) on natural resources and their management.

Human resettlement
Respondents were concerned about climate-induced human resettlement into and within the upper Midwest, resulting impacts on natural resources, and strategies to prepare.

Impacts of and responses to other sectors adapting
In addition to the impacts of adaptation in agriculture (above), respondents were also concerned about responses to climate change in other sectors (e.g. timber, municipalities)

Interactions between multiple stressors

Respondents expressed the need for research on interacting stressors. This includes both the interactions between multiple climate and non-climate stressors (e.g. fragmentation, deer browsing. logging, biodiversity loss) and between different climate impacts (e.g. simultaneous changes in precipitation, temperature and CO_2). Given the number of comments in the <5 year time period compared to the relative lack of comments in the 10+ year time period, respondents presumably see this as a theme in need of more immediate attention.

Interactions between terrestrial and aquatic systems
Respondents noted missing connections between changes in terrestrial and aquatic systems. Most of these responses focused on management challenge 3 (e.g., the impact of aquatic pathogens on terrestrial wildlife, and the effects of changing hydrological regimes on soils and forests).

Pests and pathogens
While somewhat included in 3.11 and 4.12, numerous respondents described a need for more research on the causes and consequences of climate-mediated changes in pests, pathogens and diseases to both plants and wildlife (this is *in addition* to those that mentioned impacts to human health, which are included under "public health" below).

Public health
Respondents suggested research on the interaction between climate change, natural resources and public health. Most commonly, they referenced changes in wildlife pathogens and transmission, disease vectors and antimicrobial resistance, livestock densities, and downstream changes in wildlife and human disease. While already implied in 3.11 and 4.12, they described an expansion of and additional nuance to these research topics. Once a better understanding was achieved, they suggested a need for research to improve conservation practices to prevent pathogen transmission.

Social science

Decision science
Respondents suggested a need for more decision science, including reframing some existing priorities (e.g. 1.8), ensuring that science priorities were relevant to decisions, dealing with uncertainty, balancing multiple objectives, quantifying tradeoffs, and integrating adaptive management principles.

Environmental justice and equity
Respondents suggested research on environment justice and equity, both in terms of climate impacts and adaptation responses.

Policy analysis
Numerous respondents suggested a need for policy analysis. Here, we use "policy" broadly, to include procedures, regulations, laws, incentives and governance structures. Comments included policies related to water resources and management, forestry, and electrification. Many described research to:

- Identify policies that are inadequate or maladaptive in the face of change

- Identify new policies or policy changes that would remove barriers and/or enable adaptive practices.

Behavior, identities, perceptions, acceptance
Respondents listed research needs related to individual and societal behavior in response to climate change and how behaviors can be changed. They also described research on natural resource manager's beliefs and perceptions, and social acceptance of adaptation practices. Many of these questions could usefully be framed as psychology and sociology research.

Social and economic impacts
Respondents were concerned with the impacts of climate change on cultural resources and practices (e.g. winter recreation) and associated economic impacts (e.g. loss of tourism). These social and economic impacts are in addition to the impacts described in "impacts of other sectors on natural resources" and "public health", above.

Collaboration, coordination and engagement
Respondents suggested research on best practices for collaboration, building partnerships, and engagement. These suggestions included multiple communities (e.g. tribal communities, researchers, the public, land and resource managers), were across several scales (e.g. large landscapes, other regions, international) and were for numerous purposes (e.g. co-management, using Traditional Ecological Knowledge, improving research cohesion, addressing large-scale impacts, influencing management, understanding the consequences of adaptation). Given the number of comments in the <5 year time period compared to the relative lack of comments in the 10+ year time period, respondents presumably see this as a theme in need of more immediate attention.

Soil
Several respondents noted that climate impacts to soils were largely missing from the science priorities. This included changes in soil deposition, erosion, temperatures, freezing, and nutrient cycles, and the benefits of creating resilient ecosystems to these factors.

Traditional Ecological Knowledge
Respondents suggested research on Traditional Ecological Knowledge, its potential for improving climate adaptation science, and how to incorporate it and indigenous communities in climate adaptation.

Tribal concerns and partnerships
In addition to research regarding Traditional Ecological Knowledge (above), respondents also raised numerous concerns of interest to and regarding tribal communities. Topics included climate change impacts on treaty rights and the USA's tribal trust responsibilities, research into developing partnerships with and supporting tribes, assessing the climate-induced loss of tribal livelihoods and cultural resources, and research on tribal interest in adaptation solutions.

Results: Formal assessment

Our formal assessment resulted in two types of results:
(1) Suggested revisions to existing science priorities. We list these above, in the summary of results.
(2) New topics which could not be readily encapsulated by revising existing science priorities. Below we list these new topics for each management challenge. At the end, we also list broad topics that did not fit into any single management challenge.

New topics for management challenge 1: Heavy precipitation events and drought

Ecosystem functioning, including in terrestrial (as well as aquatic) systems: Respondents noted that ecosystem functions including nutrient cycling and retention, soil deposition, carbon storage, were missing from management challenge 1. These included functions relevant to terrestrial systems (e.g. in soils and forests).

Impacts on environmental justice, communities, cultural resources, and recreation: Respondents noted a need for research on the impact of heavy precipitation events and drought on environmental justice, culture resources, and recreation.

Physical science, climatology and hydrology: Respondents noted a need for projections of extreme events (e.g. thunderstorms) and risks of shoreline erosion and flooding. One noted that the interim priorities lacked hydrological research, even though the underlying hydrology of precipitation and drought in the region is relatively unknown.

Impacts to plants (including terrestrial) and forests: Respondents suggested research on how native plants and trees would be impacted by (or tolerant to) these challenges.

Impacts of flooding on human communities: Respondents suggested research on flooding impacts to people, including flood risk mapping, and the potential for relocating infrastructure and human settlements.

Climate refugia: One respondent suggested a need for a more explicit treatment of refugia in this management challenge.

Ecosystem responses: One respondent suggested research on ecosystem responses to altered precipitation regimes (a unit of analysis not explicitly included in this set of priorities).

Species interactions that provide resistance or resilience: One respondent suggested research on species interactions that could provide resistance or resilience to extreme events.

Wastewater discharge during droughts: One respondent noted that wastewater discharge may become the primary flow to receiving waters during droughts, and the need for an analysis of water re-use policies and practices in these systems.

Directing ecological transformation: One respondent suggested a companion to 1.8 focused on management interventions to direct ecological transformation towards preferred new conditions.

New topics for management challenge 2: Loss of winter

Impacts on ecosystem functions: In addition to comments categorized under 2.4, respondents noted that ecosystem functioning was absent from these science priorities. Examples included nutrient cycling and retention and water quality.

Impacts on connectivity: One respondent suggested research on how changes in snow would impact movement potential and landscape connectivity.

Physical science / climatology / hydrology: One respondent noted that hydrological and hydrogeological processes were missing, including impacts on vegetation productivity and resulting changes in the water supplies and groundwater recharge.

Southern species migrations: One respondent suggested research on winter imitations on Southern species migrations.

New topics for management challenge 3: Altered hydrological regimes

Physical science / climatology / hydrology: Respondents described a need for more physical science research on hydrological cycles, including flood, precipitation, wind and ice modeling, changing water-flow paths and ecological flows, and changes in evapotranspiration.

Hydrological impacts on terrestrial systems: Respondents suggested more research on hydrological impacts to terrestrial ecosystems (e.g. riparian systems, floodplain forests) and species (e.g mammals, birds).

Impacts on the Great Lakes: Respondents noted a need for research on climate impacts to the Great Lakes, including their hydrological cycles, trophic status and aquatic species.

Impacts to ecosystem function: Respondents noted that ecosystem functioning was absent from these science priorities (except for being mentioned in 3.4) but of interest.

Water policy and management: Respondents suggested studying the impact of changes in water management in other sectors on natural resources. They also suggested policy analysis to understand which water policies and regulations are inadequate or maladaptive in the face of climate change, and potential amendments.

Drinking water: One respondent suggested research on changes to drinking water supply in rural areas, and potential impacts on human wellbeing and settlement.

Conditions needed to restore peatlands: One respondent suggested research on improving the resilience of peatlands via restoration, and the biophysical and socio-political conditions needed to achieve this.

Conservation prioritization of fish species and habitats: One respondent noted the need for research on methods for prioritizing the management of fish species and habitats, incorporating both ecological and socio-economic approaches.

Ecological mechanisms by which climate change will impact aquatic systems: One respondent suggested the need for research on the ecological mechanisms underlying climate-induced changes in aquatic systems.

New topics for management challenge 4: Novel terrestrial landscapes

Forest management, reforestation and restoration, including policy: Respondents suggested several research needs related to this topic. These included research on policies and management strategies that could enhance forest adaptation and resilience, including a focus on commercially valuable tree species and southern forests. They also included assessing the extent to which natural regeneration can meet reforestation potential.

Management and restoration (non-forest or generic): Respondents suggested several research topics related to management and restoration in non-forest ecosystems. These included strategies to regain ecosystem functions, restore rare and remnant habitats, and improve their adaptability, and the role of directing novel ecosystems into desirable conditions

Agriculture: In addition to the suggestions under 4.9, respondents noted several additional research topics related to agriculture. These included strategies to balance natural habitats and their restoration with food security and profitability while building climate resilience, the impacts of adaptation in agricultural systems on natural resources, and opportunities for changes in agriculture to promote adaptation for multiple goals (e.g. ecological benefits)

Natural / evolutionary adaptation: One respondent suggested research on genetic diversity in prairie communities, and whether it was sufficient for natural adaptation.

Carbon sequestration: Respondents were interested in research to measure the carbon sequestration, and to ensure and enhance forests' carbon sequestration potential, including of commercially valuable tree species.

Interactions between multiple stressors: Respondents expressed the need for research on the interactions between climate and non-climate stressors (e.g. deer browsing, logging, biodiversity loss, fragmentation).

Impacts of changes to pollinators / insects: One respondent noted a need for research on the impacts of changing pollinator/insect populations.

Fire: Respondents suggested research on the future fire regimes, their impacts on forests, and the use of fire as a management tool in terrestrial systems.

Range shifts *into* the region and management responses: Respondents noted a need for research on species likely to arrive in the region, and strategies for promoting or preventing those processes. This is related to, but not explicitly addressed in 4.5

Determinants of range limits: Somewhat related to 4.5, one respondent suggested research on the impacts of climate extremes on species range limits.

Projections and impacts of windstorms: Respondents noted a need for research to project changes in wind events and their impacts.

Seed and plant material sourcing: Respondents suggested a need for research on the creation and effectiveness of climate-informed seed collections and plant material sourcing.

New topics for management challenge 5: Barriers to and opportunities for adaptation

Landscape connectivity: Respondents were interested in research on improving landscape connectivity as an adaptation strategy, including the use of land protection and restoration to improve connectivity, and links between the midwest and other regions.

Decision science: Respondents suggested a need for more decision science, including dealing with uncertainty**,** balancing multiple objectives, quantifying tradeoffs, and integrating adaptive management principles.

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Rural and urban impacts and solutions: Respondents suggested a need for research on the role of urban areas in wildlife health, carbon balances, heat islands, and strategies to increase trees in urban and rural areas.

Adaptation effectiveness: Respondents noted the need for research to test the effectiveness of adaptation actions on-the-ground. Several science priorities (e.g. 1.5, 2.7, 3.8) call for "evaluating" various strategies, but these comments specifically suggest evaluation of deployed efforts.

Adaptation sufficiency and portfolios: Respondents suggested research on the sufficiency of the full portfolio of available adaptation strategies, the efficacy on small-scale actions, and identifying what can and cannot be adapted to.

Tribal concerns and supporting tribes: Respondents noted a need for research on climate impacts to treaty rights, treaty resources, and the USA's tribal trust responsibilities. They also suggested research on best practices for supporting tribal communities and their adaptation.

Policy, governance and socioeconomic barriers to and facilitation of adaptation: Respondents noted a need for policy analysis. Here, we use "policy" broadly, to include procedures, regulations, laws, incentives and governance structures. Many described research to identify policies that hinder adaptation, and new policies or policy changes that would enable adaptive practices. Other respondents suggested research on the social structures and socioeconomic systems that promote adaptation success.

Environmental justice of impacts and adaptation: Respondents suggested a need for research on environment justice and equity, both in terms of climate impacts and adaptation responses.

Traditional Ecological Knowledge: Numerous respondents suggested research on Traditional Ecological Knowledge, its potential for improving climate adaptation science, and how to incorporate it and indigenous communities in climate adaptation.

Collaboration, coordination and engagement: Numerous respondents suggested research on best practices for collaboration, building partnerships, and engagement. These suggestions included multiple communities (e.g. tribal communities, researchers, the public, land and resource managers), were across several scales (e.g. large landscapes, other regions, international) and were for numerous purposes (e.g. co-management, improving research cohesion, addressing large-scale impacts, influencing management, understanding the consequences of adaptation).

Impacts of other sectors mitigating: Respondents suggested research about the impacts of carbon mitigation strategies in other sectors (e.g. grid development, biofuels, solar) on natural resources and their management.

Impacts of other sectors adapting or reacting to climate change, and potential responses: Respondents noted a need for research about the impacts of climate adaptation in other sectors (e.g. changes in timber, municipal water use, land use) on natural resources. They also suggested research on strategies to mitigate potential negative impacts. This was in addition to

the impacts of adaptation in agriculture (management challenge 4) and human settlements (below).

Impacts of human resettlement: Respondents suggested a need for research on the impacts of climate-induced human resettlement into and within the upper Midwest on natural resources, and strategies to prepare.

Workforce: Respondents suggested research on the need for an increased workforce for conservation and management in the face of climate change, and the impacts of climate change on natural resource workers (e.g. via heatwaves, wildfire).

Alternative future climates: Respondents noted the need for research on the resiliency of adaptation actions to alternative future climates (e.g., extreme warming, reversal of climate change / geoengineering)

Protected areas and range shifts: Respondents suggested research to determine the extent to which protected areas could maintain native species and/or support range shifts.

Learning: Respondents noted a need for research on the potential for and barriers to human learning about adaptive responses, and how we can learn from other species' adaptive responses.

Comments not fitting into five management challenges

We loosely grouped comments that didn't fit into the five management challenges. Many such comments were given to the questions involving the most important science questions to address (Survey Section II), which respondents answered before seeing the existing interim science priorities. Thus, some respondents may not have realized the specificity of the interim science priorities, and provided what are often somewhat general comments.

Topic areas:

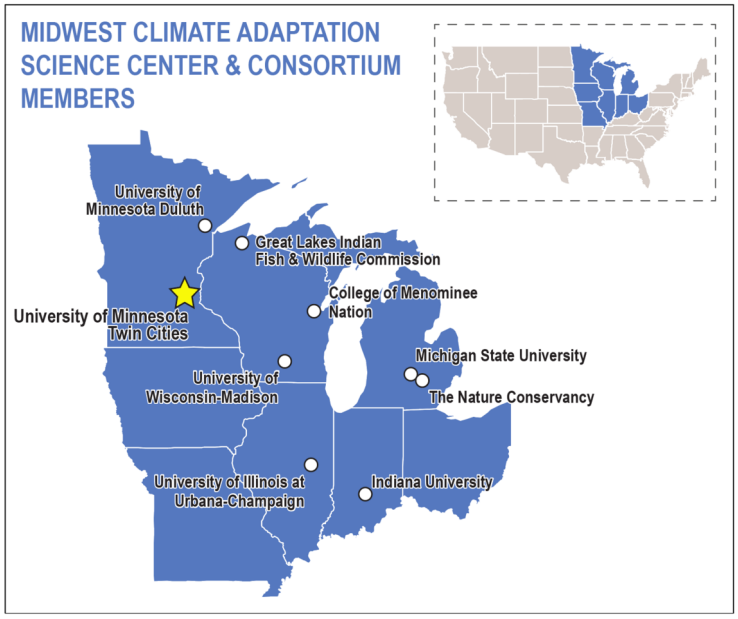
- Research methods and approaches
- Natural adaptation / evolution / tolerance
- Multiple, interacting stressors
- Social science and human dimensions
- Adaptation responses
- Climate Impacts: species functional roles and ecosystem functions
- Climate impacts: other
- Other: comments that did not suggest research topics, but instead provided constructive feedback on the research aims and approach of the CASC as a whole.

Appendix 1: Survey text

Climate Adaptation Science Needs Survey

WHO WE ARE
This survey is being administered by the Midwest Climate Adaptation Science Center (CASC), which is funded by the USGS. The mission of the Midwest CASC is to deliver science to help fish, wildlife, water, land, and people adapt to a changing climate in the Midwest*. This survey has been developed with and for the Leadership Team of the Midwest CASC Consortium, an organization that partners with the USGS to form the Midwest CASC. You can learn more about the Midwest CASC here:
https://www.usgs.gov/programs/climate-adaptation-science-centers/midwest-casc

ABOUT THE PROJECT
The goal of the project is to understand science needs for climate adaptation in the Midwest. As of May 2022, the USGS has compiled an interim list of adaptation science questions for the region, based predominantly on input from practitioners. We are now expanding that assessment to include experts from the Midwest CASC Consortium institutions, as well as others with expertise, experience and insights related to climate impacts and adaptation for natural resource management in the region. Once we have generated a list of science questions, we will begin a prioritization process. These prioritized questions will inform the Midwest CASC's Strategic Science Agenda through 2026, which will be used to guide the CASC, from programming and activities to funding priorities.



ABOUT THE SURVEY
In the survey, respondents are asked to provide their name, organization, email address and area of expertise. Individual responses will remain confidential. Results may be included in reports or peer-reviewed publications; in such cases responses will be presented in aggregate. We estimate that this survey will take approximately 25 minutes to complete. Please direct questions to Dr. Sarah Skikne, Midwest CASC postdoctoral researcher, at sskikne@umn.edu.

* For the purposes of the CASC, the Midwest region is defined as Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio and Wisconsin.

Section 1. * Required

Name*

Organization*

Email address: We ask you to provide this in case we have follow up questions, and to share the results of this project.*

Would you like to be included in the Midwest CASC email list?

Yes
No

Have you previously provided input into the development of the Midwest CASC Science Agenda?

Yes
No

If you answered "yes" to the previous question, please describe.
[open ended]

Area of expertise (check all that apply)

- ☐ Aquatic species / habitats
- ☐ Terrestrial species / habitats
- ☐ Hydrology
- ☐ Climatology
- ☐ Infrastructure / built environment / energy
- ☐ Tribal communities
- ☐ Agriculture
- ☐ Forestry
- ☐ Recreation
- ☐ Decision making / economics / social values / policy
- ☐ Management / restoration
- ☐ Other _____

How many years have you worked in or been involved in this field?
[open ended]

How did you gain your expertise?(check all that apply)

- ☐ Native stewardship or traditional ecological knowledge
- ☐ Time spent in Midwest ecosystems
- ☐ The practice of natural resource management (decision-making or implementation)
- ☐ Field research in ecology, climate impacts, or climate adaptation
- ☐ Laboratory research in ecology, climate impacts, or climate adaptation
- ☐ Data analysis or modeling in ecology, climate impacts, or climate adaptation
- ☐ Study of the climate, ecological or adaptation literature
- ☐ Other _____

Section 2.

We are hoping to refine and add to our interim list of research topics. We'd like to get your ideas about science needs before showing you this list. Later, we will show you the list and ask if you think anything is missing.

The next two questions are about research priorities for climate adaptation of natural resources in the Midwest over two time periods – the near-term (within 5 years) and longer-term (10+ years).

What do you think are the most important science questions to address in the next 5 years?

- Please list no more than ten.
- Please number topics separately.
- For each, include the primary reason you think it is important (e.g., it is understudied, there is a lot of uncertainty, the threats are large, the target is already threatened, it is of interest to stakeholders, it will have an important impact on management, etc.)

For example, if you think there are two important science questions, your answer would be formatted as follows:
1. science question A -- understudied
2. science question B -- important to stakeholders

[open ended]

What do you think will be the most important emerging science questions to address in 10+ years?

- Please list no more than ten.
- Please number topics separately.
- For each, include the primary reason you think it is important (e.g., it is understudied, there is a lot of uncertainty, the threats are large, the target is already threatened, it is of interest to stakeholders, it will have an important impact on management, etc.)

For example, if you think there are two important emerging science questions, your answer would be formatted as follows:
1. science question A -- understudied
2. science question B -- important to stakeholders

[open ended]

Section 3.

In 2020, the Midwest CASC developed a list of interim science priorities for climate adaptation in the next 5 years. This list was developed with input from natural resource managers in the region, and is organized under five management challenges.Below, we show the priorities for each management challenge, and ask if you think anything is missing.

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 population-level effects of extreme rainfall on at-risk aquatic and terrestrial species
1.2. Identify aquatic habitats vulnerable to sedimentation, contaminants and debris influx, or infrastructure failure
1.3. Assess potential impacts of extreme rainfall on fish and wildlife management infrastructure
1.4. Determine optimal culvert design to protect aquatic habitat under future precipitation patterns
1.5. Evaluate the efficacy of management strategies to limit negative effects of sedimentation, contaminants and debris influx on aquatic species and habitats
1.6. Evaluate the potential of natural lands to moderate extreme rainfall and flooding
1.7. Identify and evaluate management strategies to prepare refuges and parks for extreme rainfall and flooding
1.8. Conduct cost-benefit analysis of management interventions to maintain ecological integrity under future precipitation patterns
1.9. Identify ecosystems and species vulnerable to novel drought conditions
1.10.Identify and evaluate methods to reduce the effects of drought on fish and wildlife
1.11. Assess the effects of human adaptation on water availability for fish and wildlife

Are any important research topics missing from this list?

- Please number separate topics
- For each, include the primary reason you think it is important (e.g., it is understudied, there is a lot of uncertainty, the threats are large, the target is already threatened, it is of interest to stakeholders, it will have an important impact on management, etc.)

[open ended]

2. Loss of winter

Warming winters, altered snow patterns, and increased variability affect fish and wildlife populations, habitat management, 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 and rain-on-snow conditions on wildlife species and communities
2.4. Determine the effects of variable winter conditions on fish and wildlife populations
2.5. Assess the effects of phenological mismatch and false springs on at-risk terrestrial species
2.6. Assess the effects of lake ice loss on fish species and communities
2.7. Identify and evaluate management strategies to facilitate short-term (e.g., microclimate) or long-term refugia

2.8. Evaluate the effects of warming winters on hunting, fishing, and wildlife viewing opportunities

Are any important research topics missing from this list?

- Please number separate topics
- For each, include the primary reason you think it is important (e.g., it is understudied, there is a lot of uncertainty, the threats are large, the target is already threatened, it is of interest to stakeholders, it will have an important impact on management, etc.)

[open ended]

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 systems
3.2. Determine the future geophysical conditions of inland lakes
3.3. Determine groundwater contributions to stream refugia
3.4. Determine the future condition and ecological function of prairie pothole wetlands
3.5. Assess the effects changes in connectivity on wetland/aquatic ecosystems
3.6. Predict the climate-driven establishment and spread of aquatic invasive species
3.7. Assess changes in the 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 fish communities
3.9. Assess the effects of climate change on recreational angling and subsistence fisheries
3.10. Identify and evaluate management strategies to reduce climate risk to manoomin
3.11. Assess the effects of climate change on current and novel aquatic pathogens

Are any important research topics missing from this list?

- Please number separate topics
- For each, include the primary reason you think it is important (e.g., it is understudied, there is a lot of uncertainty, the threats are large, the target is already threatened, it is of interest to stakeholders, it will have an important impact on management, etc.)

[open ended]

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 the future composition, ecological function, and distribution of forests
4.2. Determine the effects of mesophication on grassland habitats
4.3. Predict the climate-driven establishment and spread 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 for at-risk or priority species
4.7. Assess the potential for range shifts or local extirpation of focal species from Tribal lands

4.8. Determine the potential for microclimate to buffer or exacerbate regional climate conditions
4.9. Evaluate the effects of climate-adapted agriculture on wildlife habitat
4.10. Assess the effects of climate change on hunting and gathering
4.11. Determine the effects of non-breeding climate vulnerability for priority species
4.12. Assess the effects of climate change on current and novel wildlife pathogens

Are any important research topics missing from this list?

- Please number separate topics
- For each, include the primary reason you think it is important (e.g., it is understudied, there is a lot of uncertainty, the threats are large, the target is already threatened, it is of interest to stakeholders, it will have an important impact on management, etc.)

[open ended]

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 of current and potential ecological restoration goals under future conditions
5.2. Advance climate-informed optimization of protected lands for fish, wildlife, and ecosystems
5.3. Conduct assessments to reduce the risks of assisted migration activities
5.4. Provide climate-informed decision support in the selection and application of restoration tools (e.g., prescribed burning, water control)
5.5. Determine social values and acceptance for climate adaptation for fish, wildlife, and ecosystems
5.6. Identify regulatory tools for fish and wildlife that may be inadequate under climate change
5.7. Identify management practices that exacerbate the effects of climate change on fish, wildlife, and ecosystems
5.8. Identify climate adaptation practices that yield co-benefits (e.g., mitigation, economic gain, social resilience)
5.9. Inform the design of monitoring programs to detect and respond to climate change

Are any important research topics missing from this list?

- Please number separate topics
- Include the primary reason you think it is important (e.g., it is understudied, there is a lot of uncertainty, the threats are large, the target is already threatened, it is of interest to stakeholders, it will have an important impact on management, etc.)

[open ended]

Section 4.

We are looking to engage with people with expertise, experience and insights related to climate impacts and adaptation for natural resource management in the Midwest.

Can you suggest additional people we should contact to participate in this survey? We may contact your suggestions if time allows, so please include organizations and email addresses.

Your answer

Appendix 2: Respondents and responses

Table 1: Respondents by institution

Institution	N respondents
University of Illinois	10
Indiana University	9
University of Minnesota	9
The Nature Conservancy	8
US Geological Survey	4
Great Lakes Indian Fish & Wildlife Commission	3
Lac du Flambeau Band of Lake Superior Chippewa Indians	3
Michigan State	3
State of Minnesota	3
University of Michigan	3
University of Wisconsin	3
Northland College	2
Carleton College College of Menominee Nation US National Park Service Ohio State University Purdue University University of Florida University of Northern Iowa US Forest Service	1 each

Table 2: Number of respondents that provided usable comments to each of the main survey questions.

Survey section	Survey question		N respondents w. usable comments
2	What do you think are the most important science questions to address in the next 5 years?		66
	What do you think will be the most important emerging science questions to address in 10+ years?		46
3	Are any important research topics missing from this list [of research priorities]?	Management challenge 1	43
		Management challenge 2	33
		Management challenge 3	28
		Management challenge 4	25
		Management challenge 5	23
		total	**264**