Technical Assessment of the Interim Science Agenda

Prepared by:

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

With contributions 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

December 17, 2022

This material is based upon work supported by the U.S. Geological Survey Midwest Climate Adaptation Science Center, which is managed by the USGS National Climate Adaptation Science Center.

Suggested citation: Skikne, S., J. J. Hellmann, J. Del Fiacco, E. Welch, M. Miazga, T. Kenote, S. Galatowitsch, J. Guest, G. Filippelli, & E. Ketterson. 2022. Technical Assessment of the Interim Science Agenda. Midwest Climate Adaptation Science Center. St. Paul, Minnesota.

MIDWEST Climate Adaptation Science Center

INSTITUTE ON THE ENVIRONMENT
UNIVERSITY OF MINNESOTA
Driven to Discover®

Table of Contents

Background and Objectives

The Strategic Science Agenda of the Midwest Climate Adaptation Science Center (MW CASC) guides the CASC's work through 2026, helping to identify which projects should be funded and which partnerships should be cultivated. The Science Priorities for the MW 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.

This Technical Assessment was designed to finalize the Strategic Science Agenda. We conducted a three-stage assessment to support the revision of science priorities initially identified with stakeholder consultation. In particular, we gathered input from scholars and practitioners pursuing research to help 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.

In the first stage of the technical assessment, we surveyed regional experts, which we define as university, state, Tribal and federal researchers, and others with experience and insights related to climate impacts and adaptation for natural resource management in the region. The survey questions were designed to identify topics that were missing from or underrepresented in the Interim Science Agenda, as well as emerging topics for future iterations of the Agenda. This included two questions asking respondents to list important research topics over two time frames: <5 years and 10+ years, and five questions (one for each management challenge) on topics missing from the existing science priorities. We received responses from 68 experts, which we analyzed using qualitative methods as well as a comprehensive approach to categorize all responses. Details about the survey methods and results are here.

In the second stage of the assessment, the United States Geological Survey (USGS) revised the interim list based on the survey findings to create an updated list of interim science priorities[1].

Here, we report on the third and final stage of the technical assessment. In this stage, we invited regional experts to characterize the updated science priorities along three axes: (1) state of knowledge / amount of uncertainty, (2) feasibility of addressing the science priority, and (3) potential to impact management. **Our objective in this stage is to help the USGS focus and prioritize the items pursued in funding and outreach efforts, in order to strategically advance climate adaptation science in the region.**

[1] Additional edits will be made to this version based on feedback from this report and others.

Methods

Designing the process and inviting experts

We designed this stage of the technical assessment in consultation with the University of Minnesota Office of Measurement Surveys and the Technical Assessment Working Group (made up of five members of the MW CASC Consortium Leadership Team, identified on the cover page). Here, we sought to complement our survey from Phase 1, which had a relatively large sample (breadth), with a more qualitative approach with selected experts (depth) to prioritize the identified research topics. Such a combination of surveys and focus groups is a common research approach[2].

We organized one expert session for each management challenge. For each session, our target was to include five experts, with 3+ institutions represented, 1+ non-university experts, and a range of geographical expertise. To identify experts, we solicited names from the Technical Assessment Working Group. We also asked other contacts for recommendations, allowed recommended experts to make additional recommendations, and searched online. Once identified, experts were invited via email or via phone / Zoom call. The final list of 25 expert participants is below.

We created a two-part process for soliciting their expertise. In Part 1, experts worked independently to score science priorities according to identified criteria. In Part 2, experts participated in a live Zoom session with a facilitator, in order to determine a final group score. Final group scores were determined using one of two methods: discussion in the Zoom session that led to consensus, or voting for the most common individual score submitted in the pre-work (details below).

See the Limitations section for details on how our process impacts the interpretation of our findings.

Part 1: Pre-work

Each focus group member was asked to perform an independent assessment before joining the focus group discussion. We piloted this "pre-work" with three testers and revised it based on their feedback. Pre-work assignments and instructions were sent out approximately two weeks before the focus group conversations.

The instructions provided to Group 1 are here, as an example. Experts were asked to score each science priority in the management challenge according to three variables ("individual scores", below). The colors below are used throughout this report, to aid in visualizing results.

[2] Morgan, David L. "Focus groups." *Annual Review of Sociology* 22.1 (1996): 129-152.

1. **Uncertainty**: What is the state of knowledge on this topic?

   4 options:

   Very certain - Somewhat certain - Somewhat uncertain - Very uncertain

2. **Feasibility**: How feasible is research on this topic?

   4 options:

   Very unfeasible – Somewhat unfeasible – Somewhat feasible – Very feasible

3. **Potential impact**: To what extent could addressing this research topic change management?

   4 options:

   Low potential – Somewhat low potential – Somewhat high potential – High potential

For each score, experts were also asked two additional questions:

1. What is the justification for your score*?* In other words, describe why you came to this score.
2. How confident are you about your score?

   4 options:

   Not at all confident – Somewhat unconfident – Somewhat confident – Very confident

Pre-work was expected to take two hours, and experts were encouraged to consult with colleagues who might have complementary expertise when deciding on their scores.

Each expert came into the focus group conversations having completed an Excel spreadsheet of these individual scores (example blank scoresheet here). These were submitted to the facilitator via email approximately four days before the focus group discussion (Part 2).

Facilitator's Internal Preparation for Part 2

The facilitator collated responses from Part 1 and sent them to participants so they could read others' responses ahead of the Zoom session.

The facilitator also used the collated individual scores to determine the extent of agreement or disagreement in each science priority and variable. We refer to this combination of priority × variable as a "case" (Fig. 1). The facilitator determined which of three "tiers" (described below) that each case fell into. Tier 1 was the *highest priority* to discuss with the greatest amount of disagreement among individual scores; Tier 3 was the *lowest priority* to discuss with the least amount of disagreement.

Tier 1: Cases that were discussed in order to come to consensus during the session:

(a) ties (Fig. 1a)

(b) cases where individual scores span three or more levels, which represent a wide range of opinions and therefore a need for discussion to come to agreement. (Fig. 1b)

Fig. 1a

Uncertainty			
Science priority	**Expert**	**Individual scores**	**Confidence**
1.3 Assess potential impacts of extreme rainfall on fish and wildlife management infrastructure.	1	Somewhat certain	Somewhat confident
	2	Somewhat certain	Somewhat confident
	3	Somewhat uncertain	Somewhat unconfident
	4	Somewhat uncertain	Somewhat confident

Fig. 1b

Potential Impact			
Science priority	**Expert**	**Individual scores**	**Confidence**
1.6. Evaluate and quantify the potential of natural lands to moderate extreme rainfall, protect natural resources, and provide co-benefits to society.	1	High potential	Very confident
	2	Somewhat low potential	Somewhat unconfident
	3	Somewhat high potential	Somewhat confident
	4	Somewhat low potential	Somewhat confident

Fig. 1: **Example "Tier 1" cases.** Such cases were discussed in zoom sessions in order to come to consensus. We refer to each combination of variable and science priority (e.g. uncertainty 1.3; potential impact 1.6) as a "case".

(a) This case is a tie between "somewhat certain" and "somewhat uncertain", so discussion is needed because there is no way to decide on a final group score by voting for the most common score

(b) This case has individual scores spanning three levels (e.g. "high potential", "somewhat high potential", "somewhat low potential"), representing a wide range of opinions and a need for discussion to come to agreement.

Tier 2: Cases that were discussed during the sessions if there was remaining time, including:

(a) cases where voting for the most common individual score would result in more confident experts being out-voted by less confident experts. (Fig. 2a)

(b) cases where individual scores span three or more levels (as in Tier 1 (b) above), but scores were symmetrical around a more common, central score, suggesting that the extreme scores could "cancel" each other out. (Fig. 2b)

(c) cases where individual scores were split two-to-three between adjacent levels, which is close to a tie and therefore might warrant discussion. (Fig. 2c)

If the session ended before all Tier 2 cases were discussed, remaining Tier 2 cases were decided by voting for the most common individual score.

Fig. 2a

Feasibility			
Science priority	**Expert**	**Individual scores**	**Confidence**
1.10. Identify and evaluate methods to reduce the effects of drought on fish, wildlife, and ecosystems.	1	Somewhat feasible	Somewhat confident
	2	Somewhat feasible	Somewhat confident
	3	Somewhat feasible	Somewhat unconfident
	4	Somewhat unfeasible	Very confident

Fig. 2b

Uncertainty			
Science priority	**Expert**	**Individual scores**	**Confidence**
1.10. Identify and evaluate methods to reduce the effects of drought on fish, wildlife, and ecosystems.	1	Very uncertain	Very confident
	2	Somewhat certain	Somewhat confident
	3	Somewhat uncertain	Somewhat unconfident
	4	Somewhat uncertain	Somewhat confident

Fig. 2c

Uncertainty			
Science priority	**Expert**	**Individual scores**	**Confidence**
2.6. Assess the effects of lake ice loss on fish, wildlife, and ecosystems.	1	Very uncertain	Somewhat confident
	2	Somewhat uncertain	Somewhat unconfident
	3	Somewhat uncertain	Not at all confident
	4	Very uncertain	Very confident
	5	Very uncertain	Somewhat unconfident

Fig. 2: Example "Tier 2" cases. Such cases were discussed in zoom sessions in order to come to consensus if there was time. If time ran out, remaining Tier 2 cases were decided by voting for the most common individual score.

(a) In this case, voting for the most common individual score ("somewhat feasible") would mean that the most confident expert (expert 4) would be out-voted by less confident experts.

(b) In this case, individual scores span three or more levels (as in Tier 1 (b) above), but scores are symmetrical around a more common, central score (one "somewhat certain" score, two "somewhat uncertain" scores, one "very uncertain" score). Here, discussion might be warranted because of the wide range of individual scores, but if there was not enough time, a final group score based on voting for the most common score ("somewhat uncertain") could be warranted given that the two extreme scores ("somewhat certain", "very uncertain") "cancel" each other out.

(c) In this case, there is a two-to-three split between adjacent levels (two "somewhat uncertain" scores, three "very uncertain" scores), which is close to a tie and therefore might warrant a discussion rather than voting for the most common individual score.

Tier 3: In two situations, we automatically used the most common individual score submitted in pre-work as the final group score, without discussion:

(a) cases where individual scores were split four-to-one between adjacent levels, unless a given case was also in Tier 2(a) above. (Fig. 3a)

(b) cases where participants all submitted the same individual score; consensus had already been achieved. (Fig. 3b)

Fig. 3a

Feasibility			
Science priority	**Expert**	**Individual scores**	**Confidence**
2.3. Assess the effects of decreased snow cover, rain-on-snow conditions, and ice storms on terrestrial wildlife and ecosystems.	1	Somewhat feasible	Not at all confident
	2	Somewhat feasible	Somewhat confident
	3	Somewhat unfeasible	Somewhat unconfident
	4	Somewhat feasible	Somewhat confident
	5	Somewhat feasible	Somewhat confident

Fig. 3b

Potential Impact			
Science priority	**Expert**	**Individual scores**	**Confidence**
1.7. Identify and evaluate management strategies to prepare refuges and parks for extreme rainfall and flooding.	1	High potential	Somewhat confident
	2	High potential	Somewhat confident
	3	High potential	Somewhat unconfident
	4	High potential	Very confident

Fig. 3: Example "Tier 3" cases. In such cases, we determined the final group score by voting for the most common individual score, without discussion.

(a) In this case, there is a four-to-one split between adjacent levels (four "somewhat feasible" scores, one "somewhat unfeasible" score) and thus consensus has almost been achieved using individual scores.

(b) In this case, all individual scores are in agreement (all "high potential"), and so consensus has been achieved before the expert session.

Ahead of Part 2, the facilitator prepared summaries and prompts based on pre-work submissions, to facilitate discussion for each Tier 1 and 2 case. For each session, the types of cases in each tier varied based on the number of participants and potential cases, since some groups had fewer participants, fewer science priorities to discuss, or came to consensus on more cases in their pre-work. For example, management challenge 2 had fewer science priorities than other groups and management challenge 1 had an even number of participants and so several ties had to be discussed.

Part 2: Expert sessions

The facilitator began each session with brief introductions, followed by a short presentation on housekeeping, expectations, objectives, and plan for coming to consensus (i.e. tiers described above). Each session was scheduled for 2 - 2.5 hours, and included 1 or 2 scheduled breaks. An assistant to the facilitator was present to keep notes and track time.

The bulk of the sessions were spent on discussing and agreeing on scores for Tier 1 cases, and sometimes Tier 2 cases, time permitting. The facilitator began each case with a summary of pre-work and/or a discussion prompt, often directed at a particular expert. In general, groups discussed Tier 1 uncertainty cases, then feasibility cases, then potential impact cases, before moving to a similar progression for Tier 2. The number of cases discussed in each session ranged from 12 to 19. The method used to decide final group scores (i.e. discussion, voting based on individual scores) is listed for each case in the “score justification” section.

In seven cases, the group had two interpretations of the science priority, or distinct factors that divided their scores. In these cases, both scores were recorded, and the reasoning was included in their justification.

After the sessions, the facilitator wrote a summary of the group’s justifications for each case. For those cases decided based on the most common individual score, this consisted of a summary of the justifications submitted with pre-work. For those decided based on discussion, this consisted of a summary of the main discussion points, based on session notes and/or the session recording. Group justifications were then sent to participants to confirm that they accurately captured the conversation. Group justifications are included for each case in the “Final Group Score Justifications” section below.

Finally, specific feedback from the expert groups has been submitted to the USGS and we expect that they will make some edits to the science priorities to account for these comments.

Limitations

While providing a prioritization method that was complementary to our surveys from Phase 1, focus groups have known limitations[3]. Our methods were qualitative and we did not attempt to

3 Morgan, David L. "Focus groups." *Annual Review of Sociology* 22.1 (1996): 129-152.

uncover an objective measurement (e.g., published in an established and well-cited publication(s) or measured from field studies). Our experts were knowledgeable and based their evaluation in objective science, but our assessment pursued that knowledge through subjective categorization. The justifications (documented below) help trace the thinking behind each score, but nevertheless, scores depend upon each groups' unique combination of experts, which themselves depended upon the network of people we asked to recommend participants. One area of potential bias is geographical; we did not have any experts based in Iowa or Ohio (although some participants likely had regional expertise that covered these states). Finally, because each management challenge had its own expert group that developed its own internal sense of the levels in each variable, **we advise against comparing scores *between* management challenges.**

Expert Participants

1. Heavy precipitation events and drought November 3, 2022

- **Kim Hall**, North America Science, The Nature Conservancy
- **Alan Hamlet**, Department of Civil and Environmental Engineering and Earth Sciences, University of Notre Dame
- **Diana Karwan**, Department of Forest Resources, University of Minnesota
- **Stephen Sebestyen**, Northern Research Station, U.S.D.A. Forest Service

2. Loss of winter October 14, 2022

- **Zach Feiner**, Center for Limnology, University of Wisconsin and Wisconsin Department of Natural Resources
- **Jonathan Gilbert**, Great Lakes Indian Fish and Wildlife Commission
- **Stephen Handler**, Northern Institute of Applied Climate Science
- **Ted Ozersky**, Large Lakes Observatory, University of Minnesota Duluth
- **Benjamin Zuckerberg**, Department of Forest and Wildlife Ecology, University of Wisconsin-Madison

3. Altered hydrological regimes October 21, 2022

- **Rob Croll**, Great Lakes Indian Fish and Wildlife Commission
- **Dana Infante**, Department of Fisheries and Wildlife, Michigan State University
- **Mary Khoury,** The Nature Conservancy
- **Owen McKenna**, Northern Prairie Wildlife Research Center, U.S. Geological Survey
- **Joe Nohner**, Michigan Department of Natural Resources

4. Novel terrestrial landscapes October 18, 2022

- **Alexandra Bohman**, Great Lakes Indian Fish and Wildlife Commission
- **Jeff Brawn**, Department of Natural Resources and Environmental Sciences, University of Illinois Urbana-Champaign
- **Sue Galatowitsch**, Department of Fisheries, Wildlife and Conservation Biology, University of Minnesota
- **Kim Novick**, School of Public and Environmental Affairs, Indiana University
- **Xinyi Qian**, University of Minnesota Tourism Center, University of Minnesota Extension
- **John Shuey**, The Nature Conservancy Indiana

5. Barriers to and opportunities for adaptation October 11, 2022

- **Emily Biesecker**, The Nature Conservancy Indiana
- **Meredith Cornett**, The Nature Conservancy in Minnesota, North Dakota and South Dakota
- **Gabriel Filippelli**, Environmental Resilience Institute, Indiana University
- **Jessica Hellmann**, Institute on the Environment and Department of Ecology, Evolution and Behavior, University of Minnesota
- **Jodi (Joanna) Whittier**, School of Natural Resources, University of Missouri

Overview of Final Group Scores for Each Management Challenge

The following tables list the final group score for each case, which were determined either by discussion in the expert sessions or by voting for the most common individual score submitted in pre-work.

We advise against directly comparing scores between management challenges, because the makeup of each group was different and experts brought their own diverse experiences to the process (see Limitations above). Yet, it is possible to extract some general observations and findings within and among groups.

Uncertainty: Expert groups did not score any science priority as "very certain". They scored five science priorities as "very uncertain":

- 2.6. Assess the effects of lake ice loss on fish, wildlife, and ecosystems.
- 3.8. Evaluate the efficacy of in-lake, landscape, and watershed management to protect the quality and function of wetland, stream, and lake ecosystems.
- 3.11. Assess the effects of climate change on current and novel aquatic pests and pathogens, including transmission, ecosystem impacts, and management options.
- 4.4. Advance climate knowledge for under-studied terrestrial species.
- 5.3. Conduct assessments to reduce the risks and measure the effectiveness of assisted migration activities.

Expert groups scored the rest of the science priorities as "somewhat certain" or "somewhat uncertain."

Feasibility: Expert groups did not score any science priority "very unfeasible". They scored the following as "somewhat unfeasible":

- 3.8. Evaluate the efficacy of in-lake, landscape, and watershed management to protect the quality and function of wetland, stream, and lake ecosystems.
- 5.8. Inform the design of monitoring programs and early warning systems to detect and respond to climate change.[4]
- 5.9. Identify barriers to and opportunities for the integration of climate adaptation in existing natural resource policies, programs, and practices.[5]

The rest of the science priorities were scored as "somewhat feasible" or "very feasible."

[4] The group distinguished between an early warning system (which they scored "somewhat unfeasible") and a monitoring system (which they scored "very feasible"); a description of their reasoning and justification is here.
[5] The group distinguished between two aspects of feasibility: the resources it would take to address this science priority (which they scored as "somewhat unfeasible") and the availability of appropriate methods (which they scored "very feasible"); a description of their reasoning and justification is here.

Potential impact: Expert groups did not score any science priority as having "low potential" for impact. They scored the following as having a "somewhat low potential" for impact:

- 2.1. Assess the population-level effects of warming waters on cool and cold-water fish in streams and lakes.
- 2.3. Assess the effects of decreased snow cover, rain-on-snow conditions, and ice storms on terrestrial wildlife and ecosystems.
- 3.11. Assess the effects of climate change on current and novel aquatic pests and pathogens, including transmission, ecosystem impacts, and management options.
- 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.[6]

The rest of the science priorities were scored as having a "somewhat high potential" or "high potential" for impact.

[6] The group decided on two scores for two kinds of species: species of conservation concern ("somewhat low potential" for impact) and harvested species ("high potential" for impact); a description of their reasoning and justification is here.

1. Heavy precipitation events and drought

The final group scores below were determined either by discussion in the expert sessions, or by voting for the most common individual score submitted in pre-work. The number of each priority links to a description of the method used to determine each final group score, and justifications for each. We advise against comparing scores between management challenges.

Science priority	Uncertainty	Feasibility	Potential impact
1.1. Assess the effects of extreme rainfall on at-risk fish, wildlife, ecosystems, and cultural resources.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
1.2. Identify aquatic fish, wildlife, and ecosystems vulnerable to the impacts of climate on water quality and quantity.	Somewhat certain	Somewhat feasible	Somewhat high potential
1.3 Assess potential impacts of extreme rainfall on fish and wildlife management infrastructure.	Somewhat certain	Somewhat feasible	Somewhat high potential
1.4. Determine optimal design and placement of culverts and fish passage structures to protect aquatic habitat and connectivity under future precipitation patterns.	Somewhat uncertain	Very feasible	High potential
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.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
1.6. Evaluate and quantify the potential of natural lands to moderate extreme rainfall, protect natural resources, and provide co-benefits to society.	Somewhat certain	Somewhat feasible	Somewhat high potential
1.7. Identify and evaluate management strategies to prepare refuges and parks for extreme rainfall and flooding.	Somewhat certain	Somewhat feasible	High potential
1.8. Identify, design, and evaluate management interventions to maintain ecological integrity under future precipitation patterns.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
1.9. Identify fish, wildlife, and ecosystems vulnerable to variability in precipitation and novel drought conditions.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
1.10. Identify and evaluate methods to reduce the effects of drought on fish, wildlife, and ecosystems.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
1.11. Assess the effects of human adaptation on water quality and quantity for fish, wildlife, and ecosystems	Somewhat uncertain	Very feasible	Somewhat high potential

2. Loss of winter

The final group scores below were determined either by discussion in the expert sessions, or by voting for the most common individual score submitted in pre-work. The number of each priority links to a description of the method used to determine each final group score, and justifications for each. We advise against comparing scores between management challenges.

Science priority	**Uncertainty**	**Feasibility**	**Potential impact**
2.1. Assess the population-level effects of warming waters on cool and cold-water fish in streams and lakes.	Somewhat certain	Very feasible	Somewhat low potential
2.2. Assess the vulnerability and adaptive capacity of boreal wildlife.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
2.3. Assess the effects of decreased snow cover, rain-on-snow conditions, and ice storms on terrestrial wildlife and ecosystems.	Somewhat certain: *biological impacts* Somewhat uncertain: *climate projections*	Somewhat feasible	Somewhat low potential
2.4. Determine the effects of variable winter conditions on fish, wildlife, and ecosystems.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
2.5. Determine the indicators and effects of phenological mismatch and false springs on at-risk terrestrial species.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
2.6. Assess the effects of lake ice loss on fish, wildlife, and ecosystems.	Very uncertain	Somewhat feasible	Somewhat high potential
2.7. Identify management strategies to facilitate small-scale (e.g., microclimate), short-term, or long-term refugia.	Somewhat uncertain	Somewhat feasible	High potential

3. Altered hydrological regimes

The final group scores below were determined either by discussion in the expert sessions, or by voting for the most common individual score submitted in pre-work. The number of each priority links to a description of the method used to determine each final group score, and justifications for each. We advise against comparing scores between management challenges.

Science priority	Uncertainty	Feasibility	Potential impact
3.1. Evaluate fluctuations of water levels in stream, lake, and wetland ecosystems.	Somewhat uncertain	Very feasible	Somewhat high potential
3.2. Determine the future geophysical conditions of inland lakes.	Somewhat certain	Somewhat feasible	High potential
3.3. Determine groundwater contributions to stream refugia and potential impacts of climate-induced ground water changes on ecosystems.	Somewhat uncertain	Somewhat feasible	High potential
3.4. Determine the future condition and ecological function of prairie pothole wetlands.	Somewhat uncertain	Very feasible	Somewhat high potential
3.5. Assess changes to aquatic connectivity and the subsequent effects on wetland/aquatic ecosystems.	Somewhat certain: *existing lack of connectivity* Somewhat uncertain: *climate-driven changes to connectivity*	Somewhat feasible	High potential
3.6. Predict the climate-driven establishment and spread of aquatic invasive species and the implications for ecosystems.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
3.7. Assess and predict changes in future abundance and distribution of high-value fish species and at-risk aquatic organisms	Somewhat uncertain	Very feasible	High potential
3.8. Evaluate the efficacy of in-lake, landscape, and watershed management to protect the quality and function of wetland, stream, and lake ecosystems.	Very uncertain	Somewhat unfeasible	High potential
3.9. Assess the effects of climate change on recreational angling and subsistence fisheries.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
3.10. Identify and evaluate management strategies to reduce risk and impacts from climate to manoomin.	Somewhat uncertain	Somewhat feasible	High potential
3.11. Assess the effects of climate change on current and novel aquatic pests and pathogens, including transmission, ecosystem impacts, and management options.	Very uncertain	Somewhat feasible	Somewhat low potential

4. Novel terrestrial landscapes

The final group scores below were determined either by discussion in the expert sessions, or by voting for the most common individual score submitted in pre-work. The number of each priority links to a description of the method used to determine each final group score, and justifications for each. We advise against comparing scores between management challenges.

Science priority	**Uncertainty**	**Feasibility**	**Potential impact**
4.1. Determine changes in the composition, structure, disturbance, ecological function, and distribution of forests.	Somewhat certain	Very feasible	High potential
4.2. Determine the effects of mesophication on grassland ecosystems.	Somewhat certain	Very feasible	High potential
4.3. Predict the climate-driven establishment, spread, and impact of terrestrial invasive species.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
4.4. Advance climate knowledge for under-studied terrestrial species.	Very uncertain	Somewhat feasible	Somewhat low potential
4.5. Assess climate-driven changes in the abundance and distribution of priority wildlife species.	Somewhat uncertain	Somewhat feasible	High potential: *harvested species* Somewhat low potential: *species of conservation concern*
4.6. Identify optimal future habitat (e.g., refugia) for at-risk or priority species.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
4.7. Assess the potential for range shifts to or from Tribal lands, or local extirpation of focal species from Tribal lands.	Somewhat uncertain	Very feasible	Somewhat high potential
4.8. Evaluate the effects of climate-induced changes in agriculture on aquatic and terrestrial fish, wildlife and ecosystems.	Somewhat certain	Somewhat feasible	Somewhat high potential
4.9. Evaluate the social and economic effects of climate change on hunting, gathering, fishing, and wildlife viewing opportunities, outdoor recreation, and Tribal livelihoods.	Somewhat uncertain	Somewhat feasible	High potential
4.10. Determine climate vulnerability in the non-breeding season for priority wildlife (e.g., migratory waterfowl, pollinators).	Somewhat uncertain	Somewhat feasible	Somewhat high potential
4.11. Assess the effects of climate change on current and novel terrestrial pests and pathogens, including transmission, ecosystem impacts, and management options.	Somewhat certain: *pests / pathogens that impact human health* Somewhat uncertain: *pests / pathogens that impact non-human health*	Somewhat feasible	Somewhat high potential

5. Barriers to and opportunities for adaptation

The final group scores below were determined either by discussion in the expert sessions, or by voting for the most common individual score submitted in pre-work. The number of each priority links to a description of the method used to determine each final group score, and justifications for each. We advise against comparing scores between management challenges.

Science priority	**Uncertainty**	**Feasibility**	**Potential impact**
5.1. Assess the feasibility and effectiveness of current and potential ecological restoration goals under future conditions.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
5.2. Advance climate-informed optimization of protected lands for fish, wildlife, ecosystems, and cultural resources.	Somewhat certain	Very feasible	Somewhat high potential
5.3. Conduct assessments to reduce the risks and measure the effectiveness of assisted migration activities.	Very uncertain	Somewhat feasible	Somewhat high potential
5.4. Provide climate-informed decision science in the selection, application, and siting of restoration tools (e.g., prescribed burning, water control, grazing, seed selection).	Somewhat certain	Very feasible	Somewhat high potential
5.5. Determine perceptions of and acceptance for climate adaptation for fish, wildlife, and ecosystems, including by private landowners and Indigenous communities.	Somewhat uncertain	Somewhat feasible	Somewhat high potential
5.6. Identify laws, policies, regulations and practices that are maladaptive or exacerbate the effects of climate change on fish, wildlife, and ecosystems.	Somewhat certain	Somewhat feasible	Somewhat high potential
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).	Somewhat uncertain	Somewhat feasible	Somewhat high potential
5.8. Inform the design of monitoring programs and early warning systems to detect and respond to climate change.	Somewhat uncertain: *early warning* Somewhat certain: *monitoring*	Somewhat unfeasible: *early warning* Very feasible: *monitoring*	Somewhat high potential
5.9. Identify barriers to and opportunities for the integration of climate adaptation in existing natural resource policies, programs, and practices.	Somewhat uncertain	Very feasible: *methods* Somewhat unfeasible: *resources*	Somewhat high potential

Final Group Score Justifications

1. Heavy precipitation events and drought

1.1. Assess the effects of extreme rainfall on at-risk fish, wildlife, ecosystems, and cultural resources.

Uncertainty	
Score: Somewhat uncertain **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that while there are case studies on this topic, they were often narrow in scope. Moreover, there is considerable uncertainty regarding extreme rainfall projections; new extremes and sequences of extremes aren't captured in current projections and many studies do not incorporate these unprecedented regimes. Another area of uncertainty is ecosystem responses in systems that are heavily influenced by people.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that addressing this through review and synthesis is quite feasible and manageable. In contrast, it is challenging to directly research extreme events, unless there is sufficient investment in monitoring before and after. Therefore, one feasible area to make progress is to improve monitoring across flood risk gradients and habitat types. Participants described other challenges including the need for integrated, interdisciplinary approaches, and scaling up from individual events to larger geographic and temporal scales.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** Participants described several ways that this information could be incorporated into management, such as informing assisted migration of sensitive species, identifying flooding refugia, and prioritizing sites for restoration to absorb extreme flows, renovation of gray infrastructure, and actions to decrease agricultural erosion. However, they also noted that the potential to impact management would be more likely for highly valued targets than others. Similarly, this information would likely be overshadowed by risks to people and limited by politics, finances, and public acceptance.

See summary results for Management challenge 1: Heavy precipitation events and drought

1.2. Identify aquatic fish, wildlife, and ecosystems vulnerable to the impacts of climate on water quality and quantity.

Uncertainty	
Score: Somewhat certain **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that individual species and systems have been studied, including extensive research on the impacts of changing temperature on fish and increasingly freshwater mussels. However, while theoretical vulnerability is more certain, more field validation is needed. Other areas of uncertainty included climate projections and the combined impact of climate-induced changes and impacts caused by land use.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that individual case studies and manipulations, and focused reviews and syntheses are quite feasible. Scaling up over time and space is more challenging. One option would be to try to integrate existing state data that is inaccessible or uses differing methods. If these could be leveraged, there is potential to develop time series data on multiple species and across varying conditions to address this topic more comprehensively.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that this information could help in the establishment of management goals and the focusing of attention on the most vulnerable systems and/or species. Participants also listed potential mechanisms to use this information, such as the Farm Bill and other federal programs. However, they also stated that management changes were contingent on addressing other topics as well (e.g. 1.4, 1.5).

See summary results for Management challenge 1: Heavy precipitation events and drought

1.3 Assess potential impacts of extreme rainfall on fish and wildlife management infrastructure.

Uncertainty	
Score: Somewhat certain **Method**: Discussion	**Justification:** The group agreed that there is existing groundwork in the region, but also uncertainty around precipitation projections and resulting impacts on flows in combination with agricultural responses. Once these are more certain, impacts to management infrastructure will be more certain as well.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group agreed this is generally feasible given available methods and precedent for this kind of work. Challenges include the need for better precipitation and hydrological models, a lack of a management infrastructure inventory, and the fact that this topic is very site specific, making it hard to address at larger scales.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group agreed that while there is potential for this information to impact management, getting information to the right people and increasing political will are often barriers. While challenging and slow, working directly with managers helps with the incorporation of such information, although whether managers have sway over infrastructure changes depends on the governance structure of the specific end user.

See summary results for Management challenge 1: Heavy precipitation events and drought

1.4. Determine optimal design and placement of culverts and fish passage structures to protect aquatic habitat and connectivity under future precipitation patterns.

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group listed several areas of uncertainty here. Like many other topics, there is uncertainty around precipitation and flow projections. In addition, the optimal placement of structures within a network is uncertain, as is the sequencing of the changes that would be most optimal. Finally, it is not clear who or what such a network would be optimized for, which is a social question that brings in other dimensions of uncertainty.
Feasibility	
Score: Very feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that if future flows and fish species ranges can be predicted, scenarios around culvert/fish passage can be developed and evaluated. Participants explained that this is highly feasible from an engineering perspective, that existing work could be updated to consider extreme events, and that there is precedent for this kind of work in other regions.
Potential Impact	
Score: High potential **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that this information was highly implementable, especially if the work is done in conjunction with managers. However, cumulative impacts are limited if implementation is piecemeal; work to inventory existing structures and coordinate where to work can have the biggest impact on management.

See summary results for Management challenge 1: Heavy precipitation events and drought

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.

Uncertainty	
Score: Somewhat uncertain **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that the knowledge of the physical processes was well founded, and that there was a lot of existing work on this in agricultural systems. However, they also described several gaps and areas of uncertainty. In addition to uncertainty around precipitation projections, existing studies tend to look at effects too narrowly and not consider unintended consequences, and many focus on gray infrastructure and only qualitatively consider green infrastructure.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group agreed that this topic is context specific, making it especially feasible at the site-scale. However, it is difficult to conduct this research at larger spatial scales, or to generalize the outcomes of management interventions to untested sites. One potential alternative is to try to synthesize across site-specific projects to understand variations in efficacy *post hoc*.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that there was good potential for restoration and infrastructure funding to be used for these purposes. Participants also stated that changes in management would depend on the quantification of specific management alternatives, a high level of adaptive management, and sophisticaed communication to capture nuanced and complicated findings.

See summary results for Management challenge 1: Heavy precipitation events and drought

1.6. Evaluate and quantify the potential of natural lands to moderate extreme rainfall, protect natural resources, and provide co-benefits to society.

Uncertainty	
Score: Somewhat certain **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that there is a fair amount of relevant work in relevant areas, including on the effects of removing natural storage, and the effects of canopy storage. However, given uncertain precipitation and hydrological projections, there are still remaining questions to address.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group agreed it is feasible to address this using observation and models, and to build off of existing long term data, case studies and frameworks. However, they also noted challenges to doing large-scale experiments and quantifying the specific societal benefits of a given action and issues arising from a lack of updated precipitation and hydrological models.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group agreed that in some settings, mechanisms for uptake of this information exist and better quantification would help accelerate management changes. In other settings, where the status quo is to use gray vs. natural infrastructure, further research is of limited use because of institutional barriers to incorporation. Finally, the group stated that this information is more likely to have an impact on promoting the protection of existing natural lands, versus efforts to restore natural lands.

See summary results for Management challenge 1: Heavy precipitation events and drought

1.7. Identify and evaluate management strategies to prepare refuges and parks for extreme rainfall and flooding.

Uncertainty	
Score: Somewhat certain **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that management strategies are generally known, but uncertainty remained about how much is enough relative to future projections.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group agreed that this topic had similar issues with feasibility as 1.6 (e.g. outdated precipitation and hydrological models, difficulties in experimentation and in extrapolating from site-specific research), and so scored it the same.
Potential Impact	
Score: High potential **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that while this topic was relatively limited in scope, if management choices were quantified, it could influence the management of parks and refuges. This is because adaptation tends to be more implementable in these settings given the missions of the agencies that operate them.

See summary results for Management challenge 1: Heavy precipitation events and drought

1.8. Identify, design, and evaluate management interventions to maintain ecological integrity under future precipitation patterns.

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group agreed there are four major areas of uncertainty encapsulated by this topic: (1) what is meant by ecological integrity and how it is measured, (2) the drivers of the changes that are being managed for, (3) whether specific interventions would lead to desired outcomes, and (4) potential unintended consequences of interventions.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that methods for such research exist. However, such research requires (1) long-term collaboration between climate modelers, hydrologists, and ecologists, (2) consideration of both climate related flows and the role of human water use, and (3) addressing complex tradeoffs between different interventions.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group agreed that the potential to impact management depends on the setting and intervention. In some cases, managers are eager to incorporate this information, assuming this work is quantified in a meaningful way. Moreover, windows of opportunity for incorporating this information arise when previous interventions fail. However, when management interventions limit human behavior, a lack of political will and institutional barriers limit how much such information will impact on management. They group also noted the similarity between this topic and 1.10 (which they scored as "somewhat high potential" based on their pre-work) and the fact that this topic did not have lower potential than anything else on the list (all "somewhat high potential" and "high potential"), which furthered their agreement that this topic had "somewhat high potential".

See summary results for Management challenge 1: Heavy precipitation events and drought

1.9. Identify fish, wildlife, and ecosystems vulnerable to variability in precipitation and novel drought conditions.

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group agreed that this is relatively uncertain because systems haven't evolved or been exposed to novel drought conditions, so historical records and precedent are not useful for determining vulnerability. Moreover, defining a "novel drought" is itself uncertain, especially given the numerous forms of novel drought that have been described, and the impact of human water use on drought conditions. When combined, these two areas of uncertainty make it difficult to understand the relative vulnerability of fish, wildlife and ecosystems.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group agreed it was possible to make progress on this via experimentation. However, a lack of drought exposure, including of "novel" drought conditions, makes it harder to study at larger scales. Other challenges include difficulties in defining and quantifying types of drought.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** As in 1.2, participants stated that this information could help in the establishment of management goals and the focusing of attention on the most vulnerable systems and/or species, but that more concrete changes were contingent on topics that addressed management options (e.g. 1.10). Participants also stated that in order for this work to be useful, the research needs to not just identify species or systems that are vulnerable, but also rank them relative to each other.

See summary results for Management challenge 1: Heavy precipitation events and drought

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

Uncertainty	
Score: Somewhat uncertain **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that finding strategies to reduce drought impacts has remained mostly unaddressed in this region. In managed systems, operation of dams or demand management can play a role, but in natural systems or managed systems without storage, there may be few practical options available. There is potential to learn from efforts in Western states.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that this was feasible for some strategies (e.g. barrier removal, river flow / dam management, forest management and wetland habitat management) through experimentation and observation. However, longer time frames and spatial scales are harder to address.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that because droughts are less historically prevalent in the region, they may not be seen as priorities, potentially slowing uptake of such information. However, this will change as impacts are more widely recognized, at which point studies to evaluate alternative strategies could assist in management of species, ecosystems, and ecosystem function.

See summary results for Management challenge 1: Heavy precipitation events and drought

1.11. Assess the effects of human adaptation on water quality and quantity for fish, wildlife, and ecosystems.

Uncertainty	
Score: Somewhat uncertain **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that this topic has not received a lot of attention in the region. Moreover, it is very multifaceted, increasing uncertainty. For example, each component (e.g. human behavior, ecosystem impacts, climate models, hydrological models) has its own uncertainties, and the components feed back on each other (e.g. irrigation is changing the microclimate in some places).
Feasibility	
Score: Very feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that if researchers could be brought together across multiple disciplines (e.g. groundwater management, agriculture, water regulation, hydrology, etc.) then it was feasible to generate new and likely actionable knowledge. Such studies can include both observation (e.g. remote sensing of irrigation) and simulation modeling.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group agreed that there was some potential for management changes and that this information could be crucial for decision making. However, many of the mechanisms of change would be via policy, where there are often political and social barriers to implementation, no matter how sound the science.

See summary results for Management challenge 1: Heavy precipitation events and drought

2. Loss of winter

2.1. Assess the population-level effects of warming waters on cool and cold-water fish in streams and lakes.

Uncertainty	
Score: Somewhat certain **Method**: Discussion	**Justification:** The group discussed that this topic has been a big focus of research and is well understood relative to other areas. However, the group also agreed that the underlying mechanisms behind these patterns, as well as indirect effects of warming waters, were less understood and important for management.
Feasibility	
Score: Very feasible **Method**: Vote based on individual pre-work scores	**Justification:** Existing studies demonstrate the feasibility of addressing this priority. The research topic is well-defined, there are established methods, and monitoring data is available. Space-for-time studies, data synthesis, experiments, and improvements in mechanistic models could address existing gaps.
Potential Impact	
Score: Somewhat low potential **Method**: Discussion	**Justification:** The group agreed that knowledge on population effects was already relatively well integrated into institutionalized management practice; therefore, additional research might have diminishing returns. They thought there might be more room for changes in management based on improvements in mechanistic understanding and understanding of indirect effects, but these were not explicitly called out by the research priority.

See summary results for Management challenge 2: Loss of winter

2.2. Assess the vulnerability and adaptive capacity of boreal wildlife.

Uncertainty	
Score: Somewhat certain **Method**: Vote based on individual pre-work scores	**Justification:** While boreal wildlife will be relatively vulnerable to climate change, there is uncertainty regarding which part of their life history will be most affected, and which climate impacts will be most impactful. There is more uncertainty around adaptive capacity. Finally, while work exists on some high priority species, it is not systematic across boreal wildlife.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** Concerns about the feasibility of this science priority included the need for long-term studies as well as phenotypic and genotypic data. However, the group overall agreed that this had been demonstrated and was available for some species.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group agreed that the vulnerability component of this priority might have low potential for changing management, since boreal species in the upper Midwest are likely to *all* be highly vulnerable to climate change. However the group stated that two aspects of this priority could be useful for changing management: understanding the adaptive capacity of boreal species, and the relationship between this research priority and the identification of refugia.

See summary results for [Management challenge 2](): Loss of winter

2.3. Assess the effects of decreased snow cover, rain-on-snow conditions, and ice storms on terrestrial wildlife and ecosystems.

Uncertainty	
Score: • Somewhat certain: biological impacts • Somewhat uncertain: climate projections **Method**: Discussion	**Justification:** The group distinguished between two aspects of this priority. Projections and definitions of such extreme events are somewhat uncertain, and were critical to addressing this question. On the other hand, the impact of these climatic changes on biological systems were more certain, and had been demonstrated in some model systems, while many other potential examples that had not been researched.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that the most feasible impact to study in this priority is snow cover, vs. discrete rain-on-snow and ice storms events. The group described the potential need to update snowfall, rain-on-snow, and ice storm projections in order to address this priority. They also described the challenge of fusing wildlife data and climatological models, which would both need to span large temporal and geographic scales in order to capture extremes and variation.
Potential Impact	
Score: Somewhat low potential **Method**: Discussion	**Justification:** The group identified some management actions that could help buffer the subnivium from extremes -- e.g. managing vegetation and recreation. However, overall they decided that management for such extreme events was difficult, and other research topics had a higher potential to impact management.

See summary results for Management challenge 2: Loss of winter

2.4 Determine the effects of variable winter conditions on fish, wildlife, and ecosystems.[7]

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group agreed that ecological impacts, additive impacts and lack of predictability all made winter variability uncertain and understudied. In addition, the breadth of the topic – all fish, wildlife, and ecosystem – made this inherently somewhat uncertain since there was so much that could potentially be covered by this, while each finding was likely to be context-specific.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** The group noted similarities with 2.3, since variability affects the likelihood of extreme events. As such, some challenges to feasibility are similar, including the potential need to update climate models as a precursor to this research. They also noted that this is challenging to study because it requires capturing time periods that include sufficient variability, and whether or not recent variability or its impacts could be extrapolated to future variability is not clear. However, they also stated that some long-term data sets for some species or ecosystems are available and could make this somewhat feasible to address.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** The group noted that the breadth of this topic means there are many potential ways that this information could influence management. They stated that more understanding about the extent and locations of variability would be useful to wildlife and forest managers designing adaptive management programs, including the protection and facilitation of refugia. They also stated that the relative lack of existing knowledge means that any information here would have a somewhat high potential for impact.

See summary results for Management challenge 2: Loss of winter

[7] The group stated that the phrasing and breadth of this priority made it difficult to assess. After discussion, the group took the term “variable” to mean “variability”, which they interpreted as referring to seasonality and interannual variability. We have provided their feedback about the term “variable” to the USGS.

2.5. Determine the indicators and effects of phenological mismatch and false springs on at-risk terrestrial species.

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group agreed that the effects of phenological mismatch were well studied for some species, and less studied for others, especially native trees. They also noted less research on false springs, downstream effects on demographics, and mediation by habitat. Finally, the group noted considerable uncertainty around the "indicator" part of this priority.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants described several challenges to addressing this: the need for long term data sets that capture variability, difficulties in testing mechanisms, and the need to determine when and where mismatch occurs before determining the effects and indicators. On the other hand, participants stated this is feasible, given intense data collection or existing data sets that exist for some species, or experiments with some terrestrial species.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** The group agreed that the ability to identify and predict good or bad years for important species could play into long-term planning, extinction risk models, and interventions for focal species. The group described several potential interventions that are not currently used for dealing with mismatches but could be developed: managing habitats to buffer species, changes to harvest limits, and fostering phenotypes that can handle the mismatch.

See summary results for Management challenge 2: Loss of winter

2.6. Assess the effects of lake ice loss on fish, wildlife, and ecosystems.

Uncertainty	
Score: Very uncertain **Method**: Discussion	**Justification:** The group agreed that the function of lake ice was uncertain even without the addition of climate change. There was particularly large uncertainty around the impact of lake ice loss at the community scale. Moreover, space-for-time substitutions across latitudes are inadequate for these systems.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** The group stated that this will be increasingly possible to study as lake ice loss and changes in timing of ice formation and duration become more common. Mesocosm experiments could also be used as well as models. However, the group noted challenges such as small-scale studies and the lack of coordinated research networks/synthesis efforts; larger-scale research is needed to understand the ecosystem scale.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group agreed that understanding the impacts of ice loss will help prepare for an ice-less future and the role of interacting stressors (e.g. nutrient run-off) across many species and ecosystem types. The group stated that adaptive management practices could incorporate this information into fish stocking practices, recreation planning, and water quality management (e.g. nutrient loading criteria).

See summary results for Management challenge 2: Loss of winter

2.7. Identify management strategies to facilitate small-scale (e.g., microclimate), short-term, or long-term refugia.

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group described several areas of uncertainty around *identifying* refugia, such as timescales, seasonality, and how to combine the concept of refugia across multiple species. They also agreed that the focus on *management* in this science priority is particularly uncertain.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group described the *identification* of refugia as a burgeoning field where work was feasible. They discussed that it is increasingly possible to locate stable microclimates using new tools and models. One challenge with this work is combining species-specific information across multiple species. Beyond identification, the group noted that it is even more challenging to study management strategies to *facilitate* refugia. However, they agreed that identifying locations is a critical and feasible first step in efforts to understand management options.
Potential Impact	
Score: High potential **Method**: Vote based on individual pre-work scores	**Justification:** The group agreed this topic, if addressed rigorously, transparently, and on long-term scales, would give actionable information that managers could use to promote the persistence of species and hunting/fishing/foraging opportunities. The group noted that such information could be integrated into adaptive management processes, and that there were several potential activities that could be impacted, including habitat management, protection, and restoration.

See summary results for Management challenge 2: Loss of winter

3. Altered hydrological regimes

3.1. Evaluate fluctuations of water levels in stream, lake, and wetland ecosystems.

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group agreed that the availability of data and sufficiency of models varies by system and scale. Overall, however, region-wide models are dated, and for lakes and wetlands, models are lacking. Moreover, data to document current and historic levels for streams are also limited.
Feasibility	
Score: Very feasible **Method**: Vote based on individual pre-work scores	**Justification:** The group stated that, in general, *in situ* and remotely sensed monitoring and modeling technology creates many options for addressing this topic. For streams, methods and data are more available. Evaluating this for lakes and wetlands will require more theoretical model development and data collection.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** The group agreed that water levels are of interest to a wide variety of managers and water quality agencies, and stated that many current tools are based on historical water levels, which may not remain relevant under changing climate. They described many ways that this knowledge could impact management. This information can help managers adjust control regimes for impoundments to buffer extreme fluctuations, which can be damaging for valued ecosystems and species. This information is also useful for designing stream restoration, road stream crossings, and dam removals. Participants noted that at larger scales, management changes are more challenging (e.g., tile-drained farmland), but at local scales there are more opportunities for management.

See summary results for Management challenge 3: Altered hydrological regimes

3.2. Determine the future geophysical conditions of inland lakes.

Uncertainty	
Score: Somewhat certain **Method**: Vote based on individual pre-work scores	**Justification:** The group described existing research on this topic on a limited number of systems in the region, but noted a need for more advanced models and improved data to improve projections, and more efforts to address systems that have not yet been assessed.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group discussed that the term "geophysical condition" could include many things (e.g. water temperature, chemistry, morphology) which would make this challenging to address, especially across many lakes. There are also data limitations (e.g. lake depth) in some places. Nevertheless, the group agreed it would be generally feasible to make progress on this using available models and some databases that have been developed.
Potential Impact	
Score: High potential **Method**: Discussion	**Justification:** The group agreed that information on changes to ice, stratification, and oxygen, which are major factors for recreational and threatened and endangered species, could impact lakeshed management. Specific mechanisms where it could be used include stocking decisions, setting management priorities, and water quality regulations.

See summary results for Management challenge 3: Altered hydrological regimes

3.3. Determine groundwater contributions to stream refugia and potential impacts of climate-induced ground water changes on ecosystems.[8]

Uncertainty	
Score: Somewhat uncertain **Method**: Vote based on individual pre-work scores	**Justification:** This knowledge is better understood at a large-scale, while more granular knowledge of where streams receive groundwater is limited, as is an understanding of projected climate impacts to groundwater.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group discussed that it is most feasible to address this at the scale of a stream reach that could serve as a refugia. In contrast, research to find where groundwater is entering the channel and creating very small-scale and/or temporal refugia is more challenging, although approaches used in other regions could be applied.
Potential Impact	
Score: High potential **Method**: Discussion	**Justification:** The group agreed that there were several ways this information could be used by managers: to inform the protection and management of groundwater-fed microrefugia, to prioritize dam and culvert removal, to pick release sites for reintroduction of coldwater fish, and to support Tribal views in permitting decisions.

See summary results for Management challenge 3: Altered hydrological regimes

[8] The group discussed different interpretations of the intended scale of this topic, which made scoring difficult.

3.4. Determine the future condition and ecological function of prairie pothole wetlands.

Uncertainty	
Score: Somewhat uncertain **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that there has been extensive data and monitoring in some areas but not others. Recent efforts include integrating future climate data into water level simulations, and translating impacts to migratory birds, macroinvertebrate communities and carbon cycling.
Feasibility	
Score: Very feasible **Method**: Discussion	**Justification:** The group described how available monitoring data could be used in models to address this question, and that efforts to demonstrate such methods were already underway. One potential challenge is that prairie potholes are inherently small, dynamic bodies of water, and it can be hard to generalize between them or to larger scales.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that managers would value this information; for example it is a priority for the Prairie Pothole Joint Venture and is relevant for the use of duck stamp funds. This information could be used to improve augmentation and/or management of water levels for migratory birds.

See summary results for Management challenge 3: Altered hydrological regimes

3.5. Assess changes to aquatic connectivity and the subsequent effects on wetland/aquatic ecosystems.[9]

Uncertainty	
Score: Somewhat certain: Impact of existing barriers on climate resilience Somewhat uncertain: Climate-driven changes to connectivity **Method**: Discussion	**Justification:** The group distinguished between two interpretations of this topic. They decided that knowledge about the impacts of lost connectivity on climate resilience is somewhat certain. It is clear that existing barriers decrease climate resilience, but have not been prioritized – i.e, it is not clear which barriers, if removed, would increase climate resilience the most. Knowledge of climate-driven changes to connectivity is less certain, given less work in the area and the additional uncertainty created by future climates and hydrologic conditions.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** The group stated that emerging data sets and modeling frameworks create many options for addressing this topic. They also described potential challenges to such research, including coordination across disciplines, the need for better understanding of future hydrology as a whole (i.e. topic 3.1), nuances to understanding at different spatial and temporal scales, and the need to ground truth or otherwise confirm the quality of inventory data.
Potential Impact	
Score: High potential **Method**: Discussion	**Justification:** The group agreed that this information would be of interest to managers, especially since there are already agency programs and funding that could incorporate this into improved prioritization and decision making.

See summary results for Management challenge 3: Altered hydrological regimes

[9] The group found this science priority difficult to assess; they were unsure whether it referred to (1) connectivity that has already been lost and resulting impacts on climate resilience, or (2) how climate change will cause losses to connectivity.

3.6. Predict the climate-driven establishment and spread of aquatic invasive species and the implications for ecosystems.

Uncertainty	
Score: Somewhat uncertain **Method**: Discission	**Justification:** The group stated that invasion ecology is generally fraught with uncertainty, especially given complications created by species interactions, and that adding the climate change dimension further complicated our understanding. They noted that most research has been focused on a few species, with many new or potential arrivals that haven't been studied yet.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants noted that feasibility will vary by species. Some species have been well studied, which has created a roadmap for conducting research for others and could be expanded to understand vulnerability to invasion over the region. However, participants noted that because of complex interactions, it is difficult to untangle mechanisms and therefore generate accurate predictions of establishment, spread, and impacts.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group agreed that there is a lot of funding and existing programs for invasive species management that could incorporate this information. However, the group also agreed that the current implementation and success of invasive species programs is limited by political will, and these challenges would persist in the face of climate change.

See summary results for Management challenge 3: Altered hydrological regimes

3.7. Assess and predict changes in future abundance and distribution of high-value fish species and at-risk aquatic organisms

Uncertainty	
Score: Somewhat uncertain **Method**: Vote based on individual pre-work scores	**Justification:** Participants described existing research on changes in fish distributions, but much less for other organisms. They also noted a need for older models to be updated with better data, and improvements to models of abundance.
Feasibility	
Score: Very feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated this is very feasible to address due to a wealth of historical and contemporary data in the region. Participants noted that understanding changes in distribution is more feasible than changes in abundance, but that the latter is possible with an understanding of flow and thermal preferences and how these features will change in the future.
Potential Impact	
Score: High potential **Method**: Discussion	**Justification:** The group stated this information is at the crux of many managers' interest in climate change. This knowledge could impact management via many pathways: prioritizing systems and actions, informing habitat conservation projects, changing expectations of anglers, driving stocking decisions, and aiding permitting decisions.

See summary results for Management challenge 3: Altered hydrological regimes

3.8. Evaluate the efficacy of in-lake, landscape, and watershed management to protect the quality and function of wetland, stream, and lake ecosystems.

Uncertainty	
Score: Very uncertain **Method**: Discussion	**Justification:** Participants stated that existing research on the ecosystem-scale impacts of management has been focused on barrier removal but not other management actions. Moreover, the incorporation of climate change has generally been lacking. Finally, there has been a lack of work synthesizing across spatial scales.
Feasibility	
Score: Somewhat unfeasible **Method**: Discussion	**Justification:** The group agreed that the feasibility of addressing this varied by ecosystem type, and that it required challenging coordination across multiple scales and disciplines. Moreover, at least in some systems, what might be mapable at a landscape scale is not necessarily relevant to the scale of management. Overall, they described this as feasible to chip away at, but difficult to make substantial progress with a single project.
Potential Impact	
Score: High potential **Method**: Vote based on individual pre-work scores	**Justification:** The group agreed that research here could improve management and resulting quality and function of freshwater systems. Participants stated that this information could make site selection for habitat conservation more strategic (vs. opportunistic) and improve methods/project types. They also stated that many stakeholders are interested in this kind of work, and that this research is fundamental to integrated watershed management.

See summary results for Management challenge 3: Altered hydrological regimes

3.9. Assess the effects of climate change on recreational angling and subsistence fisheries.

Uncertainty	
Score: Somewhat uncertain **Method**: Vote based on individual pre-work scores	**Justification:** While there are some insights about this topic from work on specific species, there is uncertainty around impacts to fish abundance, especially for cool- and warm-water (vs. coldwater) fisheries, and creel data is poor and sparse.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group agreed that methods are available to address this topic, but that it would require substantial resources to gather data at the necessary scale. Data is particularly limited for subsistence angling, especially for Tribes in certain regions and non-Tribal subsistence fisheries.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that this information could impact management by providing evidence that "accept" or "direct" strategies might be more successful than "resist" strategies. Such strategies could help mitigate the economic and cultural impact of climate change on fisheries. For example, if trout will no longer be viable, this information could push investment away from cool- and cold-water fish rearing facilities. For Tribes, culturally driven research could help promote the acceptance of new subsistence species.

See summary results for Management challenge 3: Altered hydrological regimes

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

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** While there has been research on manoomin ecology and some studies of climate-mediated impacts to manoomin, less is known about current management and restoration effectiveness under current non-climate stressors, let alone the additional stress of climate change.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group agreed that this topic is somewhat feasible to address because of its relative specificity, compared to other topics such as 3.8. They noted that the lack of mechanistic understanding of manoomin abundance and distribution would make understanding management strategies challenging; on the other hand, they thought it might be possible to make progress on this without a full mechanistic understanding, pending appropriate, Tribal-led collaborations.
Potential Impact	
Score: High potential **Method**: Vote based on individual pre-work scores	**Justification:** Participants described how tribal communities will continue to prioritize protecting and restoring manoomin. Information gained by addressing could be incorporated into holistic management to maintain and establish manoomin plots.

See summary results for Management challenge 3: Altered hydrological regimes

3.11. Assess the effects of climate change on current and novel aquatic pests and pathogens, including transmission, ecosystem impacts, and management options.

Uncertainty	
Score: Very uncertain **Method**: Discussion	**Justification:** The group scored this as very uncertain by comparing this to topic 3.6, due to several factors. Because many pests and pathogens arrive via invasive species, this adds another level of uncertainty compared to 3.6. Moreover, unlike 3.6, this topic also included management options, which are very uncertain. Finally, we have decent knowledge of the current distributions of invasive species in 3.6, but less understanding of the current distribution of pathogens.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that feasibility would vary by pest or pathogen; most feasible would be further work on those that are already well studied. Efforts to research individual species could be extended to an overall approach for understanding vulnerability. However, management options need to be tailored to the specific pest/pathogen.
Potential Impact	
Score: Somewhat low potential **Method**: Discussion	**Justification:** The group agreed that responses to pests and pathogens tend to be reactive and it is less clear how this information could be used proactively. In addition, compared to invasive species (topic 3.6), there is much less funding for these programs.

See summary results for Management challenge 3: Altered hydrological regimes

4. Novel terrestrial landscapes

4.1. Determine changes in the composition, structure, disturbance, ecological function, and distribution of forests.

Uncertainty	
Score: Somewhat certain **Method:** Discussion	**Justification:** The group described this priority as "somewhat uncertain". On the one hand, forests are relatively well understood compared to other ecosystems, and older predictive models have accurately predicted real changes over time. However, there is higher uncertainty regarding future ecological functions.
Feasibility	
Score: Very feasible **Method:** Discussion	**Justification:** The group discussed how improved data from monitoring networks and remote sensing made this topic, and especially ecosystem functions, increasingly feasible to address at larger spatial and temporal scales. In contrast, work on species composition is likely to be site-specific and harder to generalize. Despite this challenge, the group decided it is very feasible to make progress on this topic.
Potential Impact	
Score: High potential **Method**: Vote based on individual pre-work scores	**Justification:** The group described several factors that gave this topic a high potential to impact management. These included management practices (e.g. burning, planting, selective logging) that could incorporate this information, federal and local interest in developing strategies to increase carbon storage and decrease losses due to catastrophic disturbance, and precedent in some places for managing forests for transition to future climate (e.g. South Indiana).

See summary results for Management challenge 4: Novel terrestrial landscapes

4.2. Determine the effects of mesophication on grassland ecosystems.[10]

Uncertainty	
Score: Somewhat certain **Method**: Vote based on individual pre-work scores	**Justification:** The group stated that there is a general knowledge of mesophication impacts on grasslands, but the specific details, context-dependence of different grassland ecosystems, and landscape-level models deserve more attention.
Feasibility	
Score: Very feasible **Method:** Discussion	**Justification:** The group agreed that it is very possible to make progress on this topic given that grasslands lend themselves to relatively short-term experiments, there is good data on land cover and land use, and knowledge of grassland-forest transitions are relatively well known.
Potential Impact	
Score: High potential **Method:** Discussion	**Justification:** The group discussed how remaining grasslands in the region often exist because of conservation, so there is already motivation to manage them. Moreover, many management practices could be prioritized and improved with this sort of information.

See summary results for Management challenge 4: Novel terrestrial landscapes

[10] Participants wondered about the relevance of grassland mesophication under climate change in the region, given predictions of drought. They were more concerned about predictions for climate-induced grassland encroachment into forests due to drying ("savannification"; the opposite of this priority). Participants also noted that they were much more aware of the term "mesophication" being applied to forest ecosystems. We have provided this feedback to the USGS.

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

Uncertainty	
Score: Somewhat uncertain **Method**: Vote based on individual pre-work scores	**Justification:** Participants stated that knowledge on this topic varies by region, ecosystem and stage of invasion, and that it is not clear if knowledge of current invasives is useful for predicting novel invasives that we're not aware of yet. Participants described the aspects of this topic with the most uncertainty as predicting which species will arrive in a new locale and context-specific details. On the other hand, general factors that favor invasives, patterns of spread, and impacts are typically better understood.
Feasibility	
Score: Somewhat feasible **Method:** Vote based on individual pre-work scores.	**Justification:** Participants described this as possible to address using existing literature and data to model potential scenarios. They noted that the feasibility of addressing this varied by species and system, and the process of interest: predicting which species will establish is challenging, while predicting their impacts is more feasible.
Potential Impact	
Score: Somewhat high potential **Method:** Discussion	**Justification:** The group described a high interest in invasive species management, and the fact that this information could improve early detection and responses of new invasive species, or the eradication of predicted spreaders. However, information on invasive species who are already spreading is less useful since there were fewer effective management responses.

See summary results for Management challenge 4: Novel terrestrial landscapes

4.4. Advance climate knowledge for under-studied terrestrial species.

Uncertainty	
Score: Very uncertain **Method:** Vote based on individual pre-work scores	**Justification**: Participants described this topic as "very uncertain" based on first principles: if the species are understudied, then we are very uncertain about their potential responses to climate change.
Feasibility	
Score: Somewhat feasible **Method:** Discussion	**Justification:** The group discussed how on the one hand, a single-species approach is often very feasible. What makes it less feasible is that such a one-at-a-time approach can be slow, especially across the many understudied species, making it difficult to create a comprehensive and efficient research agenda. In addition, some understudied species may be understudied because they are difficult to study.
Potential Impact	
Score: Somewhat low potential **Method:** Vote based on individual pre-work scores	**Justification:** The group stated that the extent to which this could impact management would vary by species. However, species that are understudied wouldn't necessarily be management priorities. Finally, the group also stated that in general, single species research doesn't inform management decisions, which are usually at the community level.

See summary results for Management challenge 4: Novel terrestrial landscapes

4.5. Assess climate-driven changes in the abundance and distribution of priority wildlife species.[11]

Uncertainty	
Score: Somewhat uncertain **Method:** Vote based on individual pre-work scores	**Justification:** The group stated that there is a lot of room for more knowledge on this topic, including the role of species and trophic interactions, and teasing apart the impacts of climate and land use change. They noted that the state of knowledge is context-specific, with some cases that are better understood. The breadth of this topic and potential meaning of the word "priority" added uncertainty here – "priority" could refer to terrestrial and aquatic species, and game/harvested or listed species (there is generally more knowledge about the former than the latter).
Feasibility	
Score: Somewhat feasible **Method:** Vote based on individual pre-work scores	**Justification:** Participants stated that such work at the single species level is generally feasible, especially since population dynamics and drivers of mortality have been well studied for many priority species. However, challenges include the need for long-term monitoring in order to detect changes, prioritizing an efficient research agenda across so many species, and teasing apart climate impacts from other drivers of change.
Potential Impact	
Score: • High potential: harvested species • Somewhat low potential: species of conservation concern **Method:** Discussion	**Justification:** The group drew a distinction between two kinds of priority species: those that are harvested, and those that are of conservation concern. For those that are harvested, there are already systems to incorporate such data into management and setting quotas, and motivated stakeholders. In contrast, for species of conservation concern, the use of this information would depend on whether there is enough motivation or concern.

See summary results for Management challenge 4: Novel terrestrial landscapes

[11] The group found this difficult to assess without information about which types of species the topic referred to – especially the distinction between game/harvested species and species of conservation concern.

4.6. Identify optimal future habitat (e.g., refugia) for at-risk or priority species.

Uncertainty	
Score: Somewhat uncertain **Method:** Vote based on individual pre-work scores	**Justification:** The group described that while there has been some general consideration of this in peer-reviewed literature and in state vulnerability assessments, a comprehensive assessment for each at-risk, priority species is lacking. They agreed that there is a need for more research on this topic, including the identification of refugia, and the feasibility of establishing and maintaining them.
Feasibility	
Score: Somewhat feasible **Method:** Vote based on individual pre-work scores	**Justification:** The group described this as relatively feasible due to reasonably well-known methodologies and datasets. Some noted the challenge of identifying microrefugia due to limitations in some data products, as well as the challenge of doing this comprehensively across taxa.
Potential Impact	
Score: Somewhat high potential **Method:** Discussion	**Justification:** The group agreed there are several pathways that this information could be used: for prioritizing land purchases, management, and restoration, in impact assessments for land developments (e.g. via NEPA), and as a way of identifying potential sites for assisted migration. They also noted that related information has been incorporated by non-profits (e.g. TNC's Resilient and Connected Network), although these approaches have so far not been species-specific (as this priority is). Finally, the group stated that the usefulness of this information would depend on people being motivated to conserve the focal species.

See summary results for Management challenge 4: Novel terrestrial landscapes

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

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** While some Tribes within the region have worked on adaptation plans that assess the potential to lose focal species, the group was not aware of efforts to determine species that will be gained. Another source of uncertainty is that this topic is context-specific; for example, on smaller scale Tribal lands, projections are less certain.
Feasibility	
Score: Very feasible **Method:** Vote based on individual pre-work scores	**Justification:** The group described this as very feasible using available methods. For well-studied species, data and understanding may already be available, for others, preliminary work will be needed to understand species' environmental niches. Participants stated that for non-Tribal researchers, this work is contingent on collaboration and communication with Tribal leaders.
Potential Impact	
Score: Somewhat high potential **Method:** Vote based on individual pre-work scores	**Justification:** The group stated that this information could inform Tribal input on non-Tribal development proposals and impact assessments, as well as prioritization of climate adaptation interventions on Tribal lands. Participants described that using this information at a landscape scale would be a challenge, given the need to coordinate management across adjacent lands with different governance (e.g. Tribal, federal and state lands).

See summary results for Management challenge 4: Novel terrestrial landscapes

4.8. Evaluate the effects of climate-induced changes in agriculture on aquatic and terrestrial fish, wildlife and ecosystems.

Uncertainty	
Score: Somewhat certain **Method:** Group decided to vote based on individual pre-work scores and confidence scores. (As such, the justification at right summarizes individual pre-work, given a lack of discussion in the expert session)	**Justification:** Participants stated that most states have an idea of how agriculture will respond to climate change, and the effects of agriculture on natural resources are likely to increase in magnitude but unlikely to be novel. Because these effects have been studied throughout the region, we have a broad base of knowledge about the downstream effects of agriculture management. Participants stated that what is less certain is if/how changes in policies favorable to agriculture will be maladaptive for natural resources, and the magnitude of those effects.
Feasibility	
Score: Somewhat feasible **Method:** Vote based on individual pre-work scores	**Justification:** The group described several aspects of this topic that were feasible to address: questions dealing with the thermal environment, water quality, and hydrology; making use of of available tools (e.g. tile drainage systems) to connect agricultural practices to impacts; and analyzing policies and programs related to water use / discharge and the mechanisms to change them. One challenge is addressing questions of scale, for example understanding how much change in agriculture is needed to enhance resilience.
Potential Impact	
Score: Somewhat high potential **Method:** Discussion	**Justification:** The group agreed that site-level changes in harmful agricultural practices are difficult, since agricultural communities have other entrenched interests and motivations besides conservation. On the other hand, the group stated that there is a large amount of funding for climate-smart agriculture, and carbon storage and decreasing drought stress could motivate implementation of such practices. They also discussed the potential of this information to improve state-level policies (e.g. drainage and well permits) that would impact agriculture practices indirectly.

See summary results for Management challenge 4: Novel terrestrial landscapes

4.9. Evaluate the social and economic effects of climate change on hunting, gathering, fishing, and wildlife viewing opportunities, outdoor recreation, and Tribal livelihoods.

Uncertainty	
Score: Somewhat uncertain **Method:** Discussion	**Justification:** The economic impact of climate change on outdoor recreation is a newer and relatively rare topic of study, and there is limited qualitative work on some of the other topics listed. Much of what is known is local and/or context-specific. The group decided this is "somewhat uncertain" vs. "very uncertain" because Tribal climate adaptation plans have assessed impacts on Tribal livelihoods and subsistence use, and there is a fair amount of information on harvested and contested species (e.g. walleye) compared to others.
Feasibility	
Score: Somewhat feasible **Method:** Vote based on individual pre-work scores	**Justification:** The group stated that surveys of harvesters and other forms of social science research were feasible for studying social impacts. On the economic side, they noted the assumptions inherent to economic impact analysis, and the fact that such analyses become increasingly complicated with larger geographic scales and scopes. Participants stated that issues of Tribal use and livelihoods were feasible to address if there is good collaboration and communication between Tribal members and any non-Tribal researchers. They noted that Traditional Ecological Knowledge (TEK) and multi-generational resource use provides a rich foundation for this research, although melding this with economic analysis might be a challenge.
Potential Impact	
Score: High potential **Method:** Discussion	**Justification:** The group discussed a high level of motivation to use this information because of the clear economic stakes and impacts to people's livelihoods and identities. While individuals (e.g. harvesters) might vary in whether they will change behavior based on such information, there is a lot of potential for proactive policies, funding and agency responses.

See summary results for Management challenge 4: Novel terrestrial landscapes

4.10. Determine climate vulnerability in the non-breeding season for priority wildlife (e.g., migratory waterfowl, pollinators).

Uncertainty	
Score: Somewhat uncertain **Method:** Vote based on individual pre-work scores	**Justification:** Participants described a good knowledge base around this topic for some species, especially game species, but high uncertainty for others (e.g. non-game vertebrates, migratory birds that winter at tropical latitudes, invertebrates).
Feasibility	
Score: Somewhat feasible **Method:** Vote based on individual pre-work scores	**Justification:** Participants stated that feasibility here depended on the species. For game species, this is very feasible using existing data and knowledge. In contrast, participants noted that long-distance migrants (both vertebrate and invertebrate) and pollinators would be more challenging to study. For such species, environmental niches may be poorly known or difficult to observe at relevant life stages, and non-breeding grounds may be shifting due to climate change or other pressures.
Potential Impact	
Score: Somewhat high potential **Method:** Vote based on individual pre-work scores	**Justification:** Participants stated that management for harvested species could incorporate such information, given interested parties and management infrastructure. In contrast, this information would be less likely to impact management of non-game migratory species. Finally, participants stated that such information could be helpful for decisions related to environmental impact assessment.

See summary results for Management challenge 4: Novel terrestrial landscapes

4.11. Assess the effects of climate change on current and novel terrestrial pests and pathogens, including transmission, ecosystem impacts, and management options.[12]

Uncertainty	
Score: • Somewhat certain: pests/pathogens that impact human health, and their management • Somewhat uncertain: pests/pathogens that impact non-human health, and their management **Method**: Discussion	**Justification:** Participants decided to distinguish between pests and pathogens that impact human health (e.g. Lyme disease, West Nile Virus), which have been better studied and have more developed management options, and those that impact non-human health (e.g. woolly adelgid), where knowledge is more uncertain and management options are more unknown.
Feasibility	
Score: Somewhat feasible **Method:** Vote based on individual pre-work scores	**Justification:** The group stated this would be more challenging for novel versus current pests and pathogens. They also noted that given historic investment on the topic, methods and tools are available to address this, pending appropriate collaboration with health and eco-epidemiology experts.
Potential Impact	
Score: Somewhat high potential **Method:** Vote based on individual pre-work scores	**Justification:** Participants stated that land managers are interested in incorporating such information, especially as it pertains to highly valued species (e.g. trees, deer). In contrast, there is less capacity and interest in changing management in response to pests and pathogens of less-valued species.

See summary results for Management challenge 4: Novel terrestrial landscapes

[12] The group agreed that this science priority was very broad and therefore difficult to characterize. The group assumed the term "novel" meant "new to the area" (and not genetically engineered). We have provided their feedback about this term to the USGS.

5. Barriers to and opportunities for adaptation

5.1. Assess the feasibility and effectiveness of current and potential ecological restoration goals under future conditions.

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group agreed that uncertainty is high around restoration goals, and that most managers have not articulated their goals in a measurable way, nor assessed whether those goals are achievable in the face of climate change. The group indicated that many people feel there is more certainty about this topic than there in fact is. However, they did not think this topic is as uncertain as 5.3, since this topic used known restoration tools, as opposed to the perceived novelty of assisted migration.
Feasibility	
Score: Somewhat feasible **Method**: Group decided to vote based on individual pre-work scores. (As such, the justification at right summarizes individual pre-work, given a lack of discussion in the expert session)	**Justification:** The group indicated that this is feasible to research in certain situations. To be feasible, such research would need to be limited to specific restoration goals, geographies, and climate scenarios, and species response to habitats would need to be known. Challenges to feasibility include uncertainty around projecting cumulative impacts and how those might require modifications of restoration goals, and the integration of climatic, economic, and social futures into a coherent framework for assessing how reachable goals are.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group discussed that managers are eager for this kind of information because of the potential for it to improve success and help avoid failures in costly restoration activities. The group agreed that research on this topic could directly resolve uncertainty in management decisions. Moreover, managers might be more willing to try new approaches if such research were conducted.

See summary results for Management Challenge 5: Barriers to and opportunities for adaptation

5.2. Advance climate-informed optimization of protected lands for fish, wildlife, ecosystems, and cultural resources.

Uncertainty	
Score: Somewhat certain **Method**: Vote based on individual pre-work scores	**Justification:** The group described many such prioritization efforts. However, most are based on current (vs. future) species or habitats, while some efforts incorporate climate change. Sometimes such efforts are species-specific, such that certainty varies by taxa. The group also described other efforts to incorporate climate change that are not species-specific (e.g. The Nature Conservancy's Resilient and Connected Landscapes Project).
Feasibility	
Score: Very feasible **Method**: Vote based on individual pre-work scores	**Justification:** The group described that existing efforts and tools could be readily improved upon. Available methods and tools include large spatial data, computing power, climate niche models, and statistical methods.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** The group described how this area of research and related tools are already influencing how land managers prioritize land for protection within nonprofits. However, they also stated that this impact is dependent on protection opportunities and willing landowners/stakeholders.

See summary results for Management Challenge 5: Barriers to and opportunities for adaptation

5.3. Conduct assessments to reduce the risks and measure the effectiveness of assisted migration activities.

Uncertainty	
Score: Very uncertain **Method**: Discussion	**Justification:** In the spectrum of potential adaptation actions, the group felt this is the area we know least about. The group noted the literature is small and that much more context-dependent work would need to be done to enhance certainty in this area, especially since the work that has been done (e.g. in forestry) shows that it is hard to generalize between contexts.
Feasibility	
Score: Somewhat feasible **Method**: Group decided to vote based on individual pre-work scores. (As such, the justification at right summarizes individual pre-work, given a lack of discussion in the expert session)	**Justification:** The group agreed that the most feasible aspects of this priority are studies focused on assessing benefits, especially if we know the species' response to habitat and know where those habitats exist for translocation. Controlled experiments are also highly feasible. Studies focused on reducing risks and on assisted gene flow are also more challenging. The group described overall challenges for this priority including long timeframes, and the potential need to replicate studies across geographies and taxa.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group discussed that because assisted migration is a very localized activity, this might have a somewhat low potential to change management *at scale*. However, they ultimately decided that this had somewhat high potential to change management because assisted migration is an idea that managers gravitate towards, and more knowledge about ramifications and safeguards could potentially lead to better choices about if and when it is pursued.

See summary results for Management Challenge 5: Barriers to and opportunities for adaptation

5.4. Provide climate-informed decision science in the selection, application, and siting of restoration tools (e.g., prescribed burning, water control, grazing, seed selection).

Uncertainty	
Score: Somewhat certain **Method**: Discussion	**Justification:** The group felt that work here was limited, localized and uncertain when thinking about an all-encompassing tool that would help managers incorporate climate into land management decisions. However, the group ended up deciding to use a broader reading of the science priority, and stated that there is, in fact, some certainty in this regard because some decision support tools already exist. Examples included the Soil and Water Assessment Tool (SWAT), various conservation prioritization tools, and work by NIACS.
Feasibility	
Score: Very feasible **Method**: Vote based on individual pre-work scores	**Justification:** The group agreed that this topic is feasible to address, pending the investment of time and resources, and can utilize research in topic 5.1, as well as climate modeling and the climate sensitivities of different management techniques. Restoration practices are well understood, and changes in restoration monitoring could aid in this research. If adaptive management is considered to be the research itself, then this is highly feasible but may look different than typical research. One challenge is the extent to which results are applicable across different geographies and ecosystems.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** The group stated that addressing this research could feed directly into management decisions, with immediate practical value. This is especially critical given the limited funds and opportunities to conduct restoration. As with other priorities, the group described that the potential here depends on the willingness of landowners and stakeholders.

See summary results for Management Challenge 5: Barriers to and opportunities for adaptation

5.5. Determine perceptions of and acceptance for climate adaptation for fish, wildlife, and ecosystems, including by private landowners and Indigenous communities.

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** Initially some participants discussed that perceptions and acceptance could be gauged by proxies, without direct research, even though this information has almost never been purposefully collected. However, after discussion the group agreed that purposeful collection is necessary given that perceptions of adaptation can be complex, and public surveys that show attitudes don't necessarily align with political parties or other proxies.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group agreed that the methods to do this work are known and feasible, and would include a mixed approach of both survey research and qualitative interviews or focus groups. They described that the difficulty here is that this is very context-specific for each community, so the scale is a challenge. However, if focused on a particular group (e.g. a particular Indigenous community) this would be more feasible because the context is then limited, making it possible to get representative information.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group agreed that in theory, this information could help communication about adaptation and improve uptake. However, the group also decided that in order to be useful, this research would have to be very local; otherwise, the role of formal social science research in influencing management can be modest.

See summary results for Management Challenge 5: Barriers to and opportunities for adaptation

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

Uncertainty	
Score: Somewhat certain **Method**: Discussion	**Justification:** Participants discussed specific examples of maladaptive policies and practices they have encountered in their own work and the work of others. They agreed that the problems have been "identified" in an *ad hoc* way, from national bills to specific neighborhood covenants. But they noted that resources have not been dedicated to do this in a comprehensive way (which they think our CASC should address). They also emphasized that what is more needed than "identification" is raising attention about and amending these issues once identified.
Feasibility	
Score: Somewhat feasible **Method**: Discussion	**Justification:** The group agreed that the methods to address this topic are well known: reading and identifying components of written documents. The challenge to addressing this is the vastness of laws and practices that are potentially maladaptive. Therefore, the group stated that research would need to be limited to specific strategy or practice to be feasible. The group also noted that this is more feasible than some of the other science priorities because it could be completed in a relatively shorter time frame.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** On the one hand, the group stated this is a necessary first step. On the other, they stated that *identifying* the laws, policies and regulations alone cannot change management; they also need to be modified in order to impact management. Participants described how this second step depends on the willingness of legislatures and communities to make changes, a process that is often not driven by science. Feasibility here likely depends on the scale and type of law, policy or regulation. In contrast to laws, policies and regulations, the group stated that managers might be able to more readily change practices themselves.

See summary results for Management Challenge 5: Barriers to and opportunities for adaptation

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).

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group agreed that while some co-benefits research is more certain (e.g. wildlife habitat, carbon sequestration, heat island mitigation), other, perhaps more critical co-benefits (e.g. social benefits, especially the well-being of at-risk communities) are still somewhat uncertain, context-dependent, and unintegrated.
Feasibility	
Score: Somewhat feasible **Method**: Vote based on individual pre-work scores	**Justification:** The group described that this is feasible if a set of practices and co-benefits are identified and prioritized for the region. They also stated that established research can be built upon with existing frameworks and tools.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** The group described that existing research on this topic has already resulted in changes to local practices, and interest in incorporating this information is expected to increase. They stated that this research could make land managers more effective in advocating for adaptive practices, which could increase or improve interventions. One challenge they noted is the political feasibility of implementing changes based on this information. For example, co-benefits of riparian buffers for human communities are known, but we continue to build in floodplains. However, early collaboration with the right policymakers could potentially lead to action.

See summary results for Management Challenge 5: Barriers to and opportunities for adaptation

5.8. Inform the design of monitoring programs and early warning systems to detect and respond to climate change.

Uncertainty	
Score: • Somewhat certain: Monitoring • Somewhat uncertain: Early warning systems **Method**: Discussion	**Justification:** The group noted a distinction between the knowledge needed to design a monitoring system versus an early warning system. Regarding monitoring, the group felt that the state of knowledge is somewhat certain, because we are well versed in how to monitor. However, the group agreed that designing early warning systems would necessitate an understanding of tipping points and thresholds, which we know little about. For example, it is unknown how to design an early warning system that would inform when to change management from managing to support a forest to managing to support a savannah.
Feasibility	
Score: • Very feasible: Monitoring • Somewhat unfeasible: Early warning systems **Method**: Discussion	**Justification:** The group again drew a distinction between a monitoring system and an early warning system. Informing the design of an early warning system seemed somewhat unfeasible in the short-term given the limited state of knowledge on tipping points and thresholds. In contrast, informing the design of a monitoring system is very feasible. The group noted the varying definitions of feasibility complicated these rankings – from the availability of methods and foundational knowledge, to the resources required to address a research topic.
Potential Impact	
Score: Somewhat high potential **Method**: Vote based on individual pre-work scores	**Justification:** The group noted that efforts to inform monitoring that also make it cost-effective, easily adopted, and replicable have the potential to change management, although this potential varies by site / ecosystem. For the early warning part of this priority, they described the potential for this to change management, although it is more challenging. For example, if managers knew a tree die-off was underway, it might change their decisions from maintaining a forest to supporting a transition to grasslands – but this would depend on managers finding the identified thresholds credible.

See summary results for Management Challenge 5: Barriers to and opportunities for adaptation

5.9. Identify barriers to and opportunities for the integration of climate adaptation in existing natural resource policies, programs, and practices.

Uncertainty	
Score: Somewhat uncertain **Method**: Discussion	**Justification:** The group noted the similarities between this priority and 5.6. They noted an existing literature on barriers to adaptive land management in agency policies. However, participants also noted higher uncertainty regarding the involvement of local communities in adaptation plans, which is crucial to plan success. Therefore, they scored this as somewhat uncertain because while some barriers are known, there are many spatial scales and topics that are less known in this very broad topic.
Feasibility	
Score: • Very feasible: availability of methods • Somewhat unfeasible: resources required **Method**: Discussion	**Justification:** The group distinguished between two aspects of feasibility: the resources it would take to address this (funding, time), vs. the availability of appropriate methods. Regarding the former, they noted that addressing this would require significant funding and a truly interdisciplinary team, and ranked this "somewhat unfeasible". In contrast, in terms of technical feasibility, there are well known methods that would make this very feasible.
Potential Impact	
Score: Somewhat high potential **Method**: Discussion	**Justification:** The group discussed that ideally, addressing this research topic *should* change management, but in practice, it alone is often not enough to change management. The group agreed that this information could help lay the groundwork to expand the manager's toolbox and funding opportunities.

See summary results for Management Challenge 5: Barriers to and opportunities for adaptation