North Central CASC Strategic Science Plan

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Introduction to this Plan

This is a draft Strategic Science Plan. The North Central Climate Adaptation Science Center (NC CASC)[1] expects to use this as a living document to focus dialogue with partners and hopes the information contained in this document will help partners frame their input on how the center should invest its resources in the future. ***This document does not yet address in detail how the NC CASC will engage with or support tribes and tribal interests***.

This Plan provides basic information on our:

- mission,
- organization and governance,
- key partners,
- science approach and objectives,
- science priorities, strategic opportunities, and existing commitments,
- consortium expertise, and
- NC CASC-provided resources.

This Plan sets out key partners and principles about how NC CASC will conduct its work.

- Our mission is to assist natural and cultural resource managers in understanding and adapting to a changing climate.
- The NC CASC is a joint enterprise between the USGS and the University of Colorado Boulder and five additional academic and non-governmental partners.
- Our primary partners and intended beneficiaries are Department of the Interior bureaus, state fish and game agencies, and tribal nations and entities, but we work with the full range of public and private partners on the landscape. The Bureau of Indian Affairs supports a Tribal Resilience Liaison stationed with the NC CASC.
- Our science priorities are primarily determined through multiple, ongoing elicitation efforts with our key partners, and further informed by a Joint Stakeholder Committee, comprised of state, federal, and tribal representatives.

[1] With passage of the fiscal year 2018 budget on March 23, 2018, the name of the Climate Science Centers (CSCs) was changed to the Climate Adaptation Science Centers (CASCs). The name of the USGS National Climate Change & Wildlife Science Center (NCCWSC), which manages the eight regional centers, was changed to the National Climate Adaptation Science Center (NCASC).

This Plan lays out our scientific approach and priorities based upon identification of the key needs of our partners.

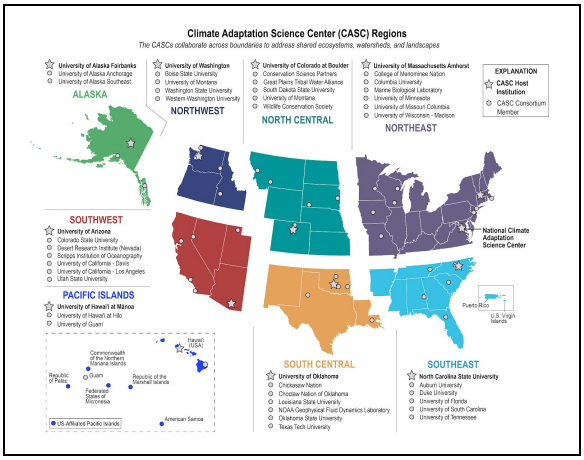
- Our focus is on creating *actionable science* – accessible and directly usable science that informs management and decision-making needs of one or more of key partners. This includes original research as well as science synthesis, assessment, and translation of science information to forms useful to managers and decision-makers.
- Our partners have identified four key ecosystems: freshwater, sagebrush steppe, grasslands, and high elevation areas and six primary, although interrelated, priority management issues: water availability and drought, habitat loss, connectivity, and habitat and ecological transformation, wildlife disease, invasives and encroachment, wildfire, and wildlife phenology. The majority of our work over the coming five years will relate to these topics, as they play out as management challenges for partners.

Comments and requests for briefings on the Strategic Science Plan should be addressed to Aparna Bamzai-Dodson, NC CASC USGS Deputy Director (abamzai@usgs.gov)

Mission, Operations, and Partnerships

Mission

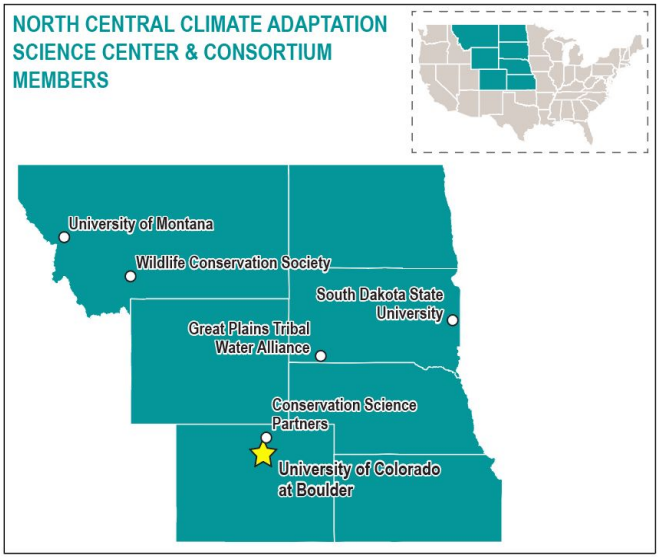
Work with natural and cultural resource managers to identify, gather, and apply the information they need to understand and adapt to a changing climate.[2]



The NC CASC[3] was established in 2012 as part of a national network of regional centers intended to support climate-informed decision making about fish and wildlife, their habitats, and the many benefits people derive from these systems. Changing environmental conditions have resulted in increasing demands for scientific support as managers seek to understand potential effects on their resources and identify adaptation strategies. We work closely with the National CASC and the seven other regional CASCs to address multi-region issues.

Organization and Operations

The NC CASC is a joint enterprise involving the USGS and the University of Colorado (CU) Boulder as primary partners, and five additional academic and non-governmental partners.[4] The NC CASC is jointly managed by a USGS Director and a University Director, and includes both Federal and university-supported staff. This relationship is re-competed every five years. CU Boulder was selected to serve as the NC CASC host until 2023, along with the named consortium members.



[2] This statement is provisional, and we invite comment on a succinct statement that characterizes the NC CASC's goals and objectives.

[3] North Central Climate Adaptation Science Center: https://nccasc.colorado.edu/

[4] Conservation Science Partners (CSP), Great Plains Tribal Water Alliance (GPTWA), South Dakota State University (SDSU), University of Montana (UMT), and Wildlife Conservation Society (WCS).

Input on priorities and the usefulness of the NC CASC's science is provided by a Joint Stakeholder Committee[5] comprised of state, federal, and tribal government representatives. This committee is managed by both the NC CASC and the USDA Northern Plains Climate Hub.[6]

The NC CASC supports and facilitates science to meet high priority regional needs by scientists from multiple institutions across the region: NC CASC staff are complemented by CU and consortium partner institutions, and other USGS labs and research units, and in collaboration with federal, state, tribal, nongovernmental, and private management partners. Students and post-doctoral researchers are directly engaged in NC CASC science, providing exposure to real-world application of their science.

Partners We Serve

The NC CASC's region includes the states of North and South Dakota, Nebraska, Kansas, Colorado, Wyoming, and Montana. This diverse landscape includes a variety of ecosystems and wildlife affected by climate change, ranging from the alpine ecosystems of the Rocky Mountains to the grasslands of the Great Plains.

The NC CASC provides climate science and adaptation information to support climate-informed natural and cultural resource management planning and decision making primarily by bureaus of the Department of the Interior, state fish and game agencies, and tribal nations. While these entities form our core users and beneficiaries, we use an "all lands and waters" approach that focuses on fish, wildlife, their habitats, and the benefits people receive from them, rather than on specific ownerships. The NC CASC also recognizes that other entities (e.g. US Forest Service and Department of Defense) are often necessary partners in specific landscapes. Our partners include managers, irrespective of their agency affiliation, with responsibilities across a wide spectrum: fish and wildlife, parks and protected areas, multiple use management, water supply agencies, water quality managers, invasive species control programs, among others. Our partners may also include agencies with other missions, such as transportation, whose plans and activities have impacts on natural or cultural resources.

Information developed by the NC CASC can also be useful to private landowners, municipalities, and other local entities. The NC CASC collaborates with individuals and organizations specializing in outreach and extension to these partners to ensure access and integrate this information with other relevant guidance. Key among these science partners are the USDA Northern Plains Climate Hub[7] and the Western Water Assessment,[8] a NOAA-funded program.

[5] Joint Stakeholder Committee: https://nccasc.colorado.edu/partners/stakeholder-advisory-committee
[6] The JSC met for the first time in over two years, on an October 12, 2018, teleconference. A face to face meeting occurred on June 25, 2019, and this Strategic Science Plan and related documents were reviewed at that time.
[7] USDA Northern Plains Climate Hub: https://www.climatehubs.oce.usda.gov/hubs/northern-plains
[8] Western Water Assessment: http://wwa.colorado.edu/

We strive to incorporate people and communities in our work, so that they can be fully considered in resource decision making.

The NC CASC collaborates and seeks input from other academic and public science partners in the region, conservation organizations, and other not-for-profit groups such as grazing associations. While these partners may not have direct land and resource management responsibilities, they do have important contributions to make to framing and identifying solutions. This includes both input on priorities and collaborative implementation of co-developed science activities.

Tribal Engagement: A Priority Partnership

Tribal nations are key partners in the generation of science and expertise at the NC CASC. Tribes are sovereign governments, with substantial legal and traditional resource management roles. Tribes are also challenged by intense competing priorities, resource limitations, and legal constraints. Lastly, the Department of the Interior has a major role in relations between the United States and tribal nations, and our work will support that fiduciary role. The NC CASC seeks to foster a continuing dialogue with tribal nations and inter-tribal organizations in the region to identify resource challenges that might benefit from climate-related science, capacity building, convening, and similar activities.

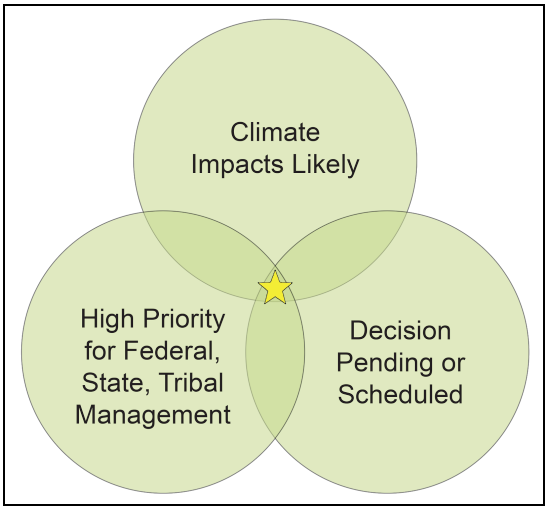
The NC CASC is the host for a Tribal Resilience Liaison, funded by the Bureau of Indian Affairs Tribal Resilience Program[9] and employed by the Great Plains Tribal Water Alliance.[10] The Tribal Resilience Liaison has a lead role at the NC CASC for communicating with tribes, identifying challenges and needs, and ensuring strong working relationships with tribes. This individual works on fostering dialogue with tribal partners, and with them, identifies appropriate roles, products, and services that could be of benefit to tribal communities. A key product from the liaison process will be a tribal engagement strategy to be adopted as part of this overall Strategic Science Plan.

[9] BIA Tribal Resilience Program: https://www.bia.gov/bia/ots/tribal-resilience-program
[10] Great Plains Tribal Water Alliance: http://www.tribalwateralliance.org/

Science Approach, Objectives, Challenges, and Priorities

Science Approach and Objectives

The primary objective of the NC CASC is to produce science[11] that is directly usable in making resource management plans and decisions; in other words, we create ***actionable science.***[12]



The NC CASC seeks to proactively and intentionally engage with our stakeholders – primarily natural and cultural resources managers in the North Central region – to identify and satisfy information needs related to high priority decisions or management actions that may be impacted by climate variability and change and which can benefit from adaptation planning to enhance resilience to those impacts.[13]

The NC CASC seeks to work on issues and with partners where:

- the issue is of ***high priority to federal, state, or tribal managers***, with the potential for significant economic, social, or ecological consequences;
- there is an ***identified endpoint*** – a decision, plan, or other concrete use or user that is ready and willing to apply the science; and
- ***climate related information is needed*** for an informed decision or action.

Our primary science objectives include both original research and solutions development, but also synthesis, assessment, and "translation" of existing scientific information to forms useful to managers as they make concrete plans. Scientific best practices clearly acknowledge that

[11] As a science agency, USGS and NC CASC provide information towards but do not make, recommend, or endorse specific decisions, policies or actions.

[12] Actionable science is described as "provid[ing] data, analyses, projections, or tools that can support decisions regarding the management of the risks and impacts of climate change" by the Advisory Committee on Climate Change and Natural Resource Science in Report to the Secretary of the Interior, 2015, Retrieved from: https://www.sciencebase.gov/catalog/item/5c1d05d3e4b0708288c9bc2a

[13] Stakeholder engagement covers a continuum of possible interactions with stakeholders, spanning from communication of results to "co-production" of science, whereby stakeholders are an integral part of the science team. For more information see:

USGS-produced short video regarding stakeholder engagement for actionable science: https://youtu.be/5_OW0kAJIzk

Beier, P., et al. (2017). A How-to Guide for Coproduction of Actionable Science. Conservation Letters 10(3): 288-296. http://dx.doi.org/10.1111/conl.12300

Meadow, A. M., et al. (2015). Moving toward the Deliberate Coproduction of Climate Science Knowledge. Weather, Climate, and Society 7(2): 179-191. https://doi.org/10.1175/WCAS-D-14-00050.1

effective use of science for management involves a broader suite of activities than might have been the case in the past. In addition to the core scientific activities (e.g. research, synthesis), it is clear that there are critical activities, goals, and objectives that round out the CASC strategic approach. These include:

- ***Skill building for practitioners and the next generation of scientists and managers:*** ensuring that management practitioners have the skills needed to use NC CASC-generated science; building a "pipeline" – the next generation of scientists and managers, trained in climate science and management applications.
- ***Building partnerships*** to identify common, high priority climate needs and ensure the delivery of relevant adaptation science and tools where and when needed
- ***Communicating our science*** so that it is accessible and useable.

Climate Challenges of the North Central U.S.

Resource managers and local communities are faced with a variety of climatic impacts associated with warming temperatures and changing precipitation patterns that result in changes to physical and biological processes, such as hydrologic cycles, primary production, disease transmission, and migration patterns. Although people and ecosystems across the region have adapted to past climate challenges, the magnitude and rate of expected changes and impacts will exceed those of previous experience.

Precipitation across the region has changed, with decreases in the West and Southwest and increases in most of the Northern and Southern Plains, with accompanying effects on surface and groundwater hydrology. These changes affect streamflows and water availability both in the region – such as in the Missouri River, one of the region's primary freshwater arteries – and in downstream regions – such as the Rio Grande River Basin. Temperatures have increased throughout the region, with an average increase in mean annual temperature of about 1.5°F since 1895, with most of that change occurring since 1970. Temperatures are expected to continue to rise, with projected increases of an additional ~2.5°F by 2050.

Changes in temperatures and precipitation have led to more intense disturbance events, such as increased flooding or incidence of large forest fires, or possible increased intensity of drought in some areas. The timing of vegetation green up or flowering has also shifted in conjunction with changes in temperature and precipitation. These and related trends have and will continue to impact the landscape and ecosystems, with varying effects on people, fish and wildlife, crops, and other important human and ecological values.[14]

[14] See 2014 National Climate Assessment for more information; the sections on the Great Plains (Montana, Wyoming, North Dakota, South Dakota, Nebraska, Kansas) and the Southwest (Colorado) cover states in the NC CASC region https://nca2014.globalchange.gov/

Science Focus 2012-2017: Building on Our Past

The NC CASC's 2012-2017 science agenda[15] highlighted the importance of integration across three principal domains; physical climate (*what will the future bring)*, ecological impacts (*how will those changes affect valued resources)*, and adaptation (*how will people address these changes)*. In addition, it identified precipitation and hydrologic extremes (including drought) as the core focal areas for both management support and scientific inquiry.

The NC CASC's plan envisioned the Resource for Vulnerability Assessment, Adaptation and Mitigation Planning (ReVAMP) as a strategy in which the NC CASC would bring state of the art visualization and collaborative strategies to working with managers.[16] Building off this foundational work, we are now planning for the future.

New Directions: Ascertaining Partner Science Needs

Over the past two years, the NC CASC has undertaken (and is continuing) a series of activities intended to elicit information on the needs of partners in the region.

- A short survey sent out broadly in 2018 to NC CASC partners, stakeholders, and interested parties including federal, state, tribal, and local government, academia, and non-profit organizations. This was accompanied by a series of webinars.
- A funded project[17] to systematically identify climate-related information gaps that, if addressed, would support state fish and wildlife and federal resource management decisions within the North Central region. This included:
    - A series of semi-structured interviews with 23 state fish and game agency staff in senior leadership roles (e.g."fish chief, wildlife chief"); and
    - A survey and facilitated face-to-face meeting of key federal resource management agencies in the region that reviewed and amplified on the results of the state surveys.

Through this engagement process, both state and federal resource managers expressed a preference in focusing on the ecosystem level in order to accomplish their management goals, even when addressing the needs of individual species. Participants identified key management priorities in each ecosystem type, and it was clear that similar management issues arose across multiple ecosystems.

[15] NC CASC Science Agenda 2012-2017: https://pubs.usgs.gov/of/2012/1265/OF12-1265.pdf
[16] See 2011-2018 NC CASC Consortium Final Report: https://www.usgs.gov/land-resources/climate-adaptation-science-centers/north-central-casc
[17] Enabling Climate-Informed Planning and Decisions about Species of Conservation Concern in the North Central Region: Phase 1: https://www.sciencebase.gov/catalog/item/596f58ebe4b0d1f9f0645e82

Additionally, the NC CASC consortium partners are working to identify the science support needs of partner scientists and managers. Information from these processes will be incorporated into this plan in the future.

- The Tribal Resilience Liaison and the lead consortium investigator for the Great Plains Tribal Water Alliance are gathering information on tribal plans, expectations, and needs.
- CU Boulder is conducting a series of training needs assessment surveys targeted towards partner scientists and managers.
- CU Boulder and Consortium Partners will convene a series of workshops for managers and scientists to identify pressing needs regarding science around freshwater and riparian systems, vegetation and water, fire as a change agent, tribal needs and capacity, and managing rangelands, croplands, and wildlife in a changing climate.

Strategic Focus 2019-2024: Priorities and Opportunities

Science Priorities

Based on the priorities identified by our management partners and as resources permit, the NC CASC will focus science on four ecosystem and six cross-cutting management themes that represent physical or structural properties, ecological processes, or disturbances and transformations within the ecosystems and associated habitats. There are inexorable connections between the ecosystems and critical ecological connectedness between the cross-cutting themes, but we identify them independently for clarity.

Priority ecosystems (columns in the figure below):

- *Freshwater and riparian*
- *Grasslands*
- *Sagebrush steppe*
- *High elevation*

Priority management themes (rows in the figure below), some term definitions, and example motivating science questions:

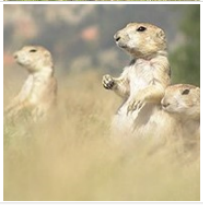
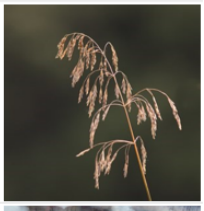
- *Water availability and drought*
  The NC CASC focuses on "ecological drought" defined as the ecosystem-wide response to drought, as opposed to agricultural, hydrological, or meteorological drought.[18]
  What are key climate drivers for ecological drought and what are the critical thresholds for species and ecosystems? How do we understand ecological drought, and what are the key metrics that work for individual species and entire assemblages? How do

[18] Crausbay, SD and AR Ramirez. 2017. Defining ecological drought for the twenty-first century. BAMS. *https://doi.org/10.1175/BAMS-D-16-0292.1.*

resource management actions, land and water use, and ecological and landscape characteristics interact with meteorological drought to drive ecological drought?

- *Habitat loss, connectivity, and transformation*
  Habitat loss represents the reduction in total area or the area of individual "patches" of habitat. Connectivity represents both structural and functional connectivity of habitat patches (the physical arrangement and proximity of patches and the ability for organisms or genes to move between patches) as well as the connectedness of the landscape that allows for natural processes (such as the degree to which a river is connected to its floodplains). Transformation entails the wholesale change of ecosystem composition, structure, and function that affects both habitats and the ecological services provided.
  How will a changing climate influence habitat quality? What changes might occur to important structural connectivity patterns and ultimately, to functional connectivity for species range shifts or genetic connectivity? How will climate-driven change precipitate vegetation transitions that are irreversible, or extremely challenging to reverse? What are guiding principles by species or systems regarding whether transformation should be resisted, accepted, or directed through management actions?
- *Wildlife disease*
  Where and for which species will climate most greatly increase disease prevalence and transmission? How will this affect both populations and intraspecific relationships? How do community-scale disease impacts relate to ecosystem-scale impacts? How do resource management actions assist or buffer disease exposure and infection rates? How does changing habitat structure or connectivity or shifting species ranges affect disease transmission?
- *Invasives and encroachment*
  What invasive species will we need to manage in the future and where? Are there key opportunities for management actions and what are the most successful adaptation options? What species and ecosystems are most threatened by invasives or encroachment? How does changing habitat structure or connectivity interact with the spread of invasives?
- *Wildfire*
  How will a changing climate alter fire probability and behavior? How will species and ecosystems respond to changing fire regimes? How will post-fire restoration efforts need to accommodate a changing climate? As a disturbance process, how will wildfires interact with climate and invasives to precipitate ecological transformation? What adaptation options are available for managing fire risk, intensity, and impact?

- *Wildlife phenology*
  What phenological shifts will be most affected in the future? What are the primary environmental cues for species life histories and how will these be impacted by phenological shifts? What will be the rate of phenological shift and to what degree can behavioral changes be adaptive versus maladaptive?

Physical or structural property Ecological process Disturbance or transformation	Ecosystem			
Management Issue	Freshwater	Grasslands	Sagebrush Steppe	High Elevations
Water Availability & Drought Images: NOAA, Pixabay, USFW, Pixabay				
Habitat Loss & Connectivity & Transformation Images: NPS, No Attribution, USGS, NPS				
Wildlife Disease Images: No Attribution, NPS, NPS, NPS				
Invasives & Encroachment Images: USFWS, USFWS, USDA, NPS				
Wildfire Images: BLM, USFWS, NPS, NPS				
Wildlife Phenology Images: NOAA, USDA, BLM, F. Dulude de Broin				

The NC CASC will seek to respond to these science priorities through building and expanding partnerships. This will require reliance upon consortium and other partners to address key stakeholder needs. Tribal nations represent a priority partnership, and the NC CASC will expand access by tribal nations to climate science for adaptation and other planning. The NC CASC will also provide scientific support activities such as technical assistance and training for capacity building to help ensure that the science is not only useful, but accessible and used.

Science Opportunities

Below, we list continued science focus and strategic opportunities for NC CASC to expand our role in science and adaptation efforts either by priority ecosystem or management issue. We reiterate that these systems and management issues are interrelated, but we list pre-identified priority projects and other potential opportunities under their primary topic.

Priority Ecosystems

Freshwater and Riparian

- Launch an effort with state fish managers to address concerns about understudied fish populations in "plains-to-mountain transition rivers and streams."[19]
- Develop or expand a model to project future streamflow and temperature throughout the region for use in a wide range of management responsibilities, including recreational fishing, invasive species management and control, water diversion and use, forest planning and revisions, listing and habitat designation, and the like.

Grasslands

- Conduct a major synthesis of what is known about grasslands and climate change, identifying key gaps in existing research. This synthesis will aim to provide a climate-ecosystem context to assist managers in the Great Plains region as they confront a series of issues, including those posed by Species of Greatest Conservation Need or potential listings under the Endangered Species Act.
- Work to support the development of a "system view" of grasslands and expected changes to support management and conservation of the overall system and both dependent and associated species.
- In cooperation with both the Northeast and South Central CASCs and the CASC national office, identify climate change implications for migratory birds in the Central Flyway.[20]

[19] Enabling Climate-Informed Planning and Decisions about Species of Conservation Concern in the North Central Region: Phase 2: https://www.sciencebase.gov/catalog/item/5b33b928e4b040769c172ee0

[20] Strategies for Reducing the Vulnerability of Grassland Birds to Climate Change within the Central Flyway: https://cascprojects.org/#/project/4f83509de4b0e84f60868124/5d40ac88e4b01d82ce8d9db9

- Project future risk of encroachment and identify best land management practices for protecting grassland habitat, as expansion of woody vegetation into grasslands of the Northern Great Plains threatens native grassland conservation efforts.[21]
- Examine the interacting effects of climate and management (e.g., grazing and fire) on the distribution and expansion invasive/exotic grasses and the long-term impacts to forage and habitat.
- Work with management partners to identify locations, strategies, and practices that ensure that grassland restoration is "climate-smart" (e.g. seed selection, restoration site selection, timing, etc.).

Sagebrush Steppe

- Support the climate science needs of the agencies and partners involved in sagebrush and sage grouse conservation by remaining engaged with efforts such as the WAFWA-led Sagebrush Conservation Initiative and consulting with the Bureau of Land Management regarding their priorities in this effort.
- Continue research related to sagebrush conservation and management, with a focus on ensuring restoration success, refining and testing "resilience and resistance" categorization / prioritization schemes, and identification and evaluation of climate-relevant management practices.[22]
- Understand the nature of and mechanisms for ecological transformation events by examining the system-conversion of sagebrush to annual grasses and the subsequent management implications.
- Understand the effect of the composition and management of fuel breaks on their immediate effectiveness and long term persistence. Fuel breaks are a large investment with major landscape implications and ensuring long term success is vital.

High Elevations

- Evaluate how forage characteristics important to ungulates have changed over the past two decades and assess which remote-sensing metrics best represent on-the-ground phenological and forage quality changes and conditions. Given these findings, assess

[21] Projecting the Future Encroachment of Woody Vegetation into Grasslands of the Northern Great Plains by Simulation Climate Conditions and Possible Management Actions
https://www.sciencebase.gov/catalog/item/5012ab04e4b05140039e02f8

[22] Forecasting Future Changes in Sagebrush Distribution and Abundance:
https://www.sciencebase.gov/catalog/item/55195ee5e4b0323842782fd0
Big Sagebrush Response to Wildfire and Invasive Grasses in the 21st Century:
https://www.sciencebase.gov/catalog/item/5b31653fe4b040769c13ffe5
Improving the Success of Post-Fire Adaptive Management Strategies in Sagebrush Steppe:
https://www.sciencebase.gov/catalog/item/5b3160b9e4b040769c13ffca
Understanding Local Resistance and Resilience to Future Habitat Change in the Sagebrush Ecosystem:
https://www.sciencebase.gov/catalog/item/5d2366fbe4b0941bde64f26b

how potential land management and treatment alternatives could further affect forage characteristics.[23]

- Organize a "Science Collider", in partnership with CU Boulder's EarthLab, bringing together scientists and resource managers to discuss critical science and outputs related to projections of future snowpack and snowline, ultimately culminating in the development of a new model for the high elevation mountain habitats and connectivity, with direct management implications for wolverine, lynx, and other species of concern.
- Increase the availability of relevant science on issues related to wildlife migration, corridors, and interacting effects of climate and other change agents on montane / forest / alpine systems.

Priority Management Issues

Water Availability and Drought

- Support cross-CASC efforts to build science knowledge on the primary drivers and threshold responses of ecological drought and how climatic change may alter the frequency and distribution of ecological drought. Assist resource and water managers in understanding the relationship between meteorological and hydrological drought and the resulting ecological impacts.
- Continue the development and distribution of tools for predicting and monitoring ecological drought. Products to date include new tools for estimating how much water the atmosphere draws from the land surface and plants (Evaporative Demand Drought Index; EDDI)[24] and for evaluating land surface responses to drought (Landscape Evaporative Response Index; LERI).[25]
- Develop or expand a model to project future streamflow and temperature throughout the region (also listed under Freshwater and Riparian Ecosystems).

Habitat Loss, Connectivity, and Transformation

- Habitat loss
    - Explore climate-driven losses to important habitat. Examples include, but are not limited to, intermittency of surface water flows and reductions in the distribution and structure of aspen stands due to increases in temperature and changing precipitation timing and quantity, and reduced availability of wolverine denning sites due to changes in snowpack depth and connectivity.

[23] Predicting Future Forage Conditions for Elk and Mule Deer in Montana and Wyoming: https://www.sciencebase.gov/catalog/item/5b33bd97e4b040769c172f82
[24] Evaporative Demand Drought Index: https://www.esrl.noaa.gov/psd/eddi/
[25] Landscape Evaporative Response Index: https://www.esrl.noaa.gov/psd/leri/

    - Provide relevant science and data products in management-ready formats for inclusion in partner decision making and planning processes related to habitat conservation and acquisition.
- Habitat connectivity
    - Bring together scientists and resource managers to discuss critical science and outputs related to projections of future snowpack and snowline (listed above under High Elevation Ecosystems).
    - Examine climate change impacts to habitat connectivity and ungulate migration under Secretarial Order 3362.[26]
- Ecological transformation
    - Understand why and how and when ecosystems change and what management responses are effective in different situations.[27] Example of relevant transformations include, but are not limited to, fire and invasive-driven conversion of sagebrush to grass; expansion and contraction of pinyon and juniper; and decreasing recruitment of pinyon forests.
    - Expand the information available to managers regarding the likelihood of significant landscape transformation, as well as for identifying more-likely and less-likely areas of refugia and transformation.

Wildlife Disease

- Support an effort led by the USGS National Wildlife Health Center[28] to review and synthesize existing information on the impacts of climate change on fish and wildlife health and disease and identify unique areas of concern.

Invasives and Encroachment

- Understand how ecosystem composition and function will be altered by invasion and encroachment of species that are better adapted to future climate conditions. Examples include, but are not limited to, exotic grass encroachment in native grasslands, cheatgrass invasion in sagebrush steppe, and warm-water adapted mussel encroachment.
- Increase the relevant science available for resource managers to make robust decisions about whether and how to address the encroachment of exotic and non-native species.

[26] Secretarial Order 3362: https://www.doi.gov/sites/doi.gov/files/uploads/so_3362_migration.pdf
[27] Ecology and Management of Pinyon-Juniper Woodlands: State of the Science: https://www.sciencebase.gov/catalog/item/5a3ba858e4b0d05ee8b74108
Mapping the Risk of Ecological Transformation Across Pinyon Woodlands and the U.S. West: https://www.sciencebase.gov/catalog/item/5b3165dde4b040769c13fff0
[28] Synthesizing Climate Change Impacts on Wildlife Health and Identifying Adaptation Strategies: https://www.sciencebase.gov/catalog/item/5b4f654ce4b06a6dd184402a

Wildfire

- Understand how fire regimes are changing, leading to increased probability or more extreme fire behavior.
- Initiate an effort to project post-fire regeneration potential based on climate, location, fire severity and other factors.
- Examine the interacting effects of the distribution and expansion invasive/exotic grasses and fire (listed above under Grasslands Ecosystems).

Wildlife Phenology

- Examine climate change impacts to forage greenup timing, quality, and quantity in relation to ungulate migration timing and locations.

Science Support Opportunities

NC CASC will build climate adaptation science effectiveness and capacity through technical assistance and training, among other efforts.

Technical assistance

NC CASC staff assist partners at all stages of climate-related science from consulting on ecological model choice and specification, identifying and accessing appropriate data, and providing scenario and adaptation planning expertise and facilitation. Specific examples include:

- Continue to support resource managers in applying the powerful combination of qualitative and exploratory approaches with well-vetted tools for understanding likely response changes under uncertainties in future climate, such as linking scenario planning with quantitative modeling (e.g. state and transition, agent-based, etc.). [29]
- Seek to refine and implement a structured and efficient framework for supporting the climate science needs of National Park Service Resource Stewardship Strategy and Fish and Wildlife Service Species Status Assessment development and transitioning to internally-led processes.
- Continue to respond to expressed needs for improved climate-data access and application for management decision-making by state fish and wildlife management agencies. One key opportunity will be to prepare to assist states in the revision and development of State Wildlife Action Plans (SWAPs). Most states in the NC CASC region

[29] Model-Based Scenario Planning to Inform Climate Change Adaptation in the Northern Great Plains: https://www.sciencebase.gov/catalog/item/55159d7fe4b03238427817eb
Informing Climate Change Adaptation Planning in National Parks: https://www.sciencebase.gov/catalog/item/5970adb8e4b0d1f9f065c2c6
Refining Guidance for Incorporating Climate Science and Scenario Planning into National Park Service Resource Stewardship Strategies: https://www.sciencebase.gov/catalog/item/5b6c8fcfe4b006a11f7bd139
Integrating Climate Considerations into Grazing Management Programs in National Parks: https://www.sciencebase.gov/catalog/item/5cf6fba8e4b0d63728b9b4cc

will be revising their SWAP in 2020-2021, and the NC CASC should be prepared to provide the science and support to ensure these plans – and the processes under which they are created – are climate-informed.

- Seek to reduce agencies' needs for unique novel research on individual species, instead building climate adaptation planning knowledge and capacity directly into their planning procedures.
- Provide technical assistance in big data and earth analytics. CU Boulder's EarthLab can provide ongoing expertise for projects seeking to employ big data analytics, such as combining multiple data sources ("data harmonization") or apply machine learning. EarthLab also is committed to reproducible science and can assist NC CASC project investigators in ensuring their data and products and open source and accessible.

Training

Training efforts will include:

- Implement the Tribal Climate Leaders Program at CU Boulder,[30] a cohort model for funding tribal graduate students to study topics related to climate adaptation science.
- Enhance access by tribal nations to climate science for adaptation and other planning by expanding training available for tribal members, including on-site hands-on training and building linkages with tribal colleges and universities.
- Conduct training to ensure partners have access to and skills in the latest tools for Big Data analytics.[31]
- Provide natural resource management specific, and decision-relevant, training regarding adaptation planning and decision making.

[30] Tribal Climate Leaders Program: https://nccasc.colorado.edu/sites/default/files/Tribal%20Climate%20Leaders%20Program%20flyer.pdf

[31] Data Carpentry for Geospatial Data: http://www.datacarpentry.org/lessons/#geospatial-curriculum

Addressing Foundational and Emergent Science Needs

In addition to climate adaptation science and science support, the full NC CASC consortium brings substantial expertise and skills in science arenas that provide foundational support for collaborative, climate-informed, natural and cultural resource adaptation planning and management. The NC CASC will bring these skills to bear via the Climate Science Support Platform (CSSP), a community of practice of consortium scientists and partners, with a primary goal of identifying the critical knowledge gaps that limit the delivery of climate adaptation science relevant to partners as identified in this Plan. The CSSP seeks to bridge those gaps through conducting transdisciplinary research, shared learning, and technical support.

There are key foundational science needs of the NC CASC that intersect climate science, adaptation science, ecological science, and social science. Our understanding within these fields is rapidly progressing, but critical to the NC CASC, and the stakeholders that we represent, are fundamental advances in:

Climate adaptation science entails analysis of social and natural responses to climate variability and change. Key advances will come from understanding adaptation elements of resource management decisions and whether they have been effective. The CSSP will work to identify frameworks for efficient and effective adaptation actions, including decision-making under uncertainty and adaptation pathways. Actionable adaptation science will include "provid[ing] data, analyses, projections, or tools that can support decisions regarding the management of the risks and impacts of climate change."[32] This arena also includes understanding how actionable and transdisciplinary science is best created to develop innovative adaptation solutions to complex socio-environmental issues.

Climate scenario development for species and ecosystems is a critical area to advance that lies at the intersection of climate and ecosystem science. There are key climate variables, or suites of variables, that drive individual species, entire assemblages, or ecosystem responses. Advances will be made in understanding what are the best metrics of ecological drought for species and ecosystems of interest. Further useful insights will come from identifying what proxy species or guilds can be used to understand threshold behavior where parameters are unknown for critical species.

Climate-driven habitat contraction or transformation is critical to understand as managers increasingly focus on habitats that hold many species of interest. Disturbances such as drought, flooding, wildfire, and invasive species can cause rapid, or irreversible transformations, making landscape management challenging. These disturbances may be climatically-driven or

[32] Advisory Committee on Climate Change and Natural Resource Science in 2015 Report to the Secretary of the Interior: https://www.sciencebase.gov/catalog/item/5c1d0816e4b0708288c9d0d9

influenced, leading to a need to better understand how a changing climate will alter the probability and severity of disturbances, individually and combined. Predicting ecosystem thresholds, or potential for "tipping points," is a key area of research. Further, understanding the interactions across multiple types of disturbances and potential for extreme events is critical as these events can result in surprising habitat change.

Further, capitalizing on advances in understanding the **pathways to co-produced science** could make for more efficient and productive scientist and stakeholder teams. Additional advances in **environmental data science** and **novel analytical approaches** (e.g., machine learning) could also greatly benefit resource managers, if new techniques, tools, and data products are developed in conversation with end users. For example, there are key opportunities to leverage novel data combinations across scales, from ground-, drone-, airborne-, or satellite-based observations, to yield new insights into how species and ecosystems respond to a changing climate from the leaf-level to entire biomes.

Selection and Funding of Projects and Activities

The NC CASC will seek to both strategically and iteratively concentrate investment in the areas identified above, such that a core of work is funded in a topical area (e.g. four ongoing sage-related projects), followed by a period in which smaller projects focus on effective transfer to managers, evaluation of new needs, etc. The JSC will be involved to ensure that the NC CASC addresses a diversity of management priorities as it moves through annual funding cycles.

In general, the NC CASC uses three methods to identify and implement projects:

1. *Request for Proposals (RFP) Announcement*
   RFPs generally call for initial Statements of Interest with the NC CASC requesting full proposals from responding investigators such that roughly 1-in-3 full proposal submissions are funded. RFPs are coordinated to the maximum extent possible with the National and other regional CASCs.
2. *Direct Funded Projects*
   The NC CASC may also collaboratively develop projects with Consortium or USGS scientists in order to directly respond to identified stakeholder needs.
3. *NC CASC Host and Consortium Activities*
   CU Boulder and the NC CASC consortium partners are currently developing activities and approaches for using resources provided under the USGS hosting award to support the needs identified by stakeholders. Further, consortium partners will conduct foundational science to build knowledge on best practices for effective and efficient climate adaptation management actions.

The NC CASC uses the following guiding principles when funding projects:

- Generally, projects are selected following an RFP. RFPs are usually released bi-annually, as commitments to prior awarded projects reduce the pool of funding in some years to such a degree that an RFP-based approach is inefficient. In such cases, the NC CASC will directly fund projects, in keeping with this Plan.
- The NC CASC consortium and the JSC help to refine general climate adaptation science priorities initially identified by natural resource management partners, as reflected in this Plan. However, the specific target science topics outlined in a given RFP are developed solely by the USGS employees of the NC CASC, and selection of awards is conducted solely by Department of Interior employees.
- Each funded project must have a Principal Investigator from one of the NC CASC consortium partners or a USGS center or program. Proposals may include co-investigators from other federal agencies, universities/research centers, private corporations, NGOs, etc. However, other partners – such as federal, state, or tribal agencies or non-profits concerned with climate-informed natural and cultural resource

management – are encouraged to establish working partnerships with one of the recognized eligible groups to seek participation in a funded project.

- As a matter of policy, the NC CASC will defer from supporting new atmospheric projections (dynamical or statistical) and large scale hydrologic projections; rather we will rely upon providers with greater technical resources and clearer mandate to produce such products.
- Primary funding evaluation criteria include:
    - Climate-informed management significance
    - Engagement of stakeholders and science beneficiaries for actionable science
    - Scientific merit and quality of the project
    - Study team qualifications
- The NC CASC seeks to fund projects that:
    - Support diverse, early-career scientists
    - Proactively and specifically consider the appropriate stakeholder-engagement strategy for the project goals and objectives
    - Consider a framework for evaluation of their stakeholder engagement strategy

Additional, more detailed, information about how the NC CASC approaches funding and evaluation of science and science support projects can be found in the full-length RFP guidance.

Understanding Success

The National CASC conducted external reviews of the first five years of operation for each regional CASC consisting of an expert Science Review Team, focus groups of science users and producers, and a survey of partners and stakeholders in the region. Each review concluded with a final report on institutional development, partnerships, science, and communications.[33]

In addition to this external review process, the NC CASC is committed to developing our own framework for long-term evaluation in order to learn from our previous engagement and more thoroughly understand successful production of actionable science. We approach evaluation of our activities as a way to teach us how to better provide actionable science in support of stakeholder decision-making and planning and not as a project grading process. The NC CASC will strive to document (and implement) best practices for effective engagement of stakeholders and co-production of knowledge by researchers and managers.

We have chosen to develop a survey instrument that we will distribute to stakeholders involved in our funded activities. The questions in this instrument broadly cover stakeholder engagement in the research process, use of information, and perceptions of relationship building. In 2019, we will conduct a pilot test of this instrument on completed projects from the first five years of operation, with the goal of developing a repeatable process that can be used by the center to conduct ongoing evaluation of future activities.

[33] C[A]SC external review reports: https://www.usgs.gov/land-resources/climate-adaptation-science-centers/about/program-evaluation