University of Colorado Boulder Hosted
North Central Climate Adaptation Science Center
Year 5 Annual Report

July 2023

Submitted by: William R. Travis (University Director)

North Central
Climate Adaptation
Science Center

1. ADMINISTRATIVE

Award Recipient: Dr. William R. Travis
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Institution of the Award Recipient: University of Colorado Boulder (CU Boulder)
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Date of the Report: July 30, 2023
Period of time covered by the report: October 1, 2022 to September 30, 2023

2. PURPOSE AND OBJECTIVES

In Year 5, the NC CASC made significant progress towards achieving our vision that *natural and cultural resource managers use actionable and open data, tools, and innovative science and information to make climate-informed decisions that support resilient ecosystems.* To achieve this vision, our work is focused on *partnerships; science; capacity building*; and *communications* activities. At the foundation of our successes is a committed team of research scientists and staff, and strong institutional and administrative support from CU Boulder and the Cooperative Institute for Research in Environmental Sciences (CIRES).

Our Year 5 activities are the result of our cumulative successes throughout the five year cooperative agreement, as evidenced by our positive Year 5 external review (North Central CASC External Review Report, April 2023). These activities were informed by partnerships with regional stakeholders, Tribal Nations, and other organizations, including the Department of Interior (DOI) U.S. Fish and Wildlife Service (USFWS) and National Park Service (NPS) Climate Change Response Program, and U.S. Forest Service (USFS). These relationships enable us to respond to high priority natural and cultural resource management challenges and foster substantive, sustained engagement between scientists and managers.

Our science includes interdisciplinary research, synthesis, datasets and tool development, informed by collaborations with stakeholders, to provide usable science and applications for climate-informed resource management. Year 5 science highlights (see **RESULTS: Science**) include continued climate science support for USFWS species status assessments, development and refinement of tools hosted on the Climate Toolbox, wrap up of the *Future of Fire* and *Grasslands Synthesis Projects*, initiation of an *Ecological Scenarios Project*, and launch of a pilot Rapid Climate Assessment Program. Key consortium partner activities include: evaluation of wildlife crossings in supporting wildlife and ecosystem resilience in response to climate change (Caitlin Littlefield, Conservation Science Partners); launch of a project on Tribal climate adaptation water needs in South Dakota (Stefan Tangen, Great Plains Tribal Water Alliance); a survey to determine how managers prepare for and respond to environmental hazards (Jennifer Zavaleta Cheek, South Dakota State University); continued research focused on understanding the social and ecological resilience to changing wildfire activity (Phil Higuera, University of Montana); and a publication evaluating the effectiveness of co-production methods to support managers in using climate information in their planning activities (Molly Cross, Wildlife Conservation Society).

Capacity building activities help build a community of researchers and managers and fosters their leadership in science-based resource management. Year 5 capacity building activities (see **RESULTS:**

Capacity Building) included the involvement of six graduate research assistants and one undergraduate student in the launch of our pilot Rapid Climate Assessment Program in summer 2023, and the continuation of the host supported Tribal Climate Leaders Program (TCLP) and National CASC-funded Climate Adaptation Scientists of Tomorrow (CAST) pilot program at CU Boulder.

Communications are embedded in all aspects of the NC CASC's work and are integral to fostering our core values of equity, trust, communication and accessibility. This year we continued to grow our communications activities (see **RESULTS: Communications**) with the conversion of our bi-monthly newsletter to an embedded email MailChimp newsletter that effectively drives traffic to our website, the production of a Research Reel video for the NC CASC's YouTube channel, and the development of the Prairie Climate Companion series of handouts for grasslands managers.

3. ORGANIZATION AND APPROACH

The NC CASC team continually strives to efficiently utilize the resources (i.e., budget, human, space, equipment) made available by the cooperative agreement, CU Boulder, CIRES, and additional sources (e.g., USGS Pass-Through Projects), to ensure that the mix of administration, partnerships, science, capacity building, and communications achieves the best possible outcomes for managing climate-sensitive natural and cultural resources in the region. Key to achieving this goal is the ability to draw on the diverse expertise of the NC CASC team. Summary tables of funded CU Boulder personnel and contributions from individuals funded outside of the Host Agreement are located in **APPENDIX I**.

Institutions receiving sub-awards: Subawards to a consortium of science institutions in the region extends the expertise and informs the center's knowledge of regional challenges and opportunities. Consortium Partners include: Conservation Science Partners (CSP): co-PI Caitlin Littlefield; Great Plains Tribal Water Alliance (GPTWA): co-PI Stefan Tangen; South Dakota State University (SDSU): co-PI Jennifer Zavaleta Cheek; University of Montana (UM): co-PI Phil Higuera; and Wildlife Conservation Society (WCS): co-PI Molly Cross.

Consortium governance, operations, and interactions: The role of each Consortium Partner (CP) is to produce actionable science, serve as a connector between researchers and stakeholders in the region, and help guide the overall efforts of the NC CASC. Supported CP activities were co-determined by the CPs and the University Director and Deputy Director. Bi-weekly All Hands calls, monthly Climate Science Support Platform calls, participation in USGS milestone activities (i.e., Year 5 External Review, Annual Cooperators Meeting), and access to communications support are key touch points for CP interactions.

4. RESULTS

Year 5 activities are summarized below for our *partnerships*, *science*, *capacity building*, and *communications* activities.

Partnerships: Our ongoing stakeholder tracking efforts show that through the 5-year Host Agreement, we have worked with stakeholders from 107 different organizations, including: 25 Tribal Nations or inter-Tribal organizations; 12 Tribal Colleges or Native American education organizations; 13 Federal government agencies; 10 state government agencies; over 20 academic or research institutions; 12 nonprofit organizations; two regional boundary organizations; and close collaborations with two other regional CASCs. The *Grasslands Synthesis Project* was key to supporting the decision needs of grasslands managers, and strengthening cross-CASC partnerships (e.g., workshop co-organized with the Northwest and South Central CASCs; see **Science** below). Additionally, James Rattling Leaf's outreach activities helped the NC CASC build and strengthen partnerships with Tribal organizations, and connect Tribes

with relevant climate information and tools (e.g., Rosebud Sioux Tribe Climate Center; see **APPENDIX III**).

Science: In Year 5, the NC CASC continued to provide climate science support to partners in the region via 15 unique engagements/projects. Imtiaz Rangwala (Climate Science Lead) provided support for USFWS species status assessments that included Canada Lynx, Rio Grande Cutthroat Trout, and Sicklefin and Sturgeon Chub. Other important engagements included (a) working with USFWS Prairie Biologists in the prairie pothole region on incorporating climate change in the adaptive management program to manage the mixed/tallgrass prairie, (b) engaging with Utah state fish and wildlife scientists and partners on climate science and data for Utah State Wildlife Action Plans in collaboration with the SW CASC (prior work with USFWS R6 in Utah informed this; Utah remains a relevant region for NC CASC as it falls under the USFWS R6 boundary and is also part of the Upper Colorado River Basin), and (c) USFWS refuge managers in the Nebraska Sandhills region on future habitat assessments. Rangwala and Prasad Thota (Graduate Research Assistant) also developed climate data layers for a Montana Refugia mapping project.

Significant progress was also made in *climate tool development and outreach*. The Future Climate Scenarios tool was developed and its first version released. Improvements and functionalities were added to the Future Climate Scatter tool to enable the selection of future climate scenarios. Nine previously developed R-Shiny Apps were updated with new functionalities and observations were updated to 2022. Three more R-Shiny apps related to exploring large-scale drivers of precipitation across CONUS have been developed. The Drought Index Portal (DrIP) was completely revamped, although some issues remain to be further resolved, and the Landscape Evaporative Response Index (LERI) data received monthly updates. Lastly, Rangwala and Thota collaborated with Western Water Assessment to develop a webtool on precipitation predictability in the Intermountain West in collaboration with the University of Utah. More information on the newly developed applications is located in **APPENDIX III**.

In Year 5, the NC CASC engaged in several cross-agency *science synthesis* efforts. The center piloted a Rapid Climate Assessment Program (RCAP), which aims to create a synthesis of science information on particular topics that can be used as a baseline for further research and a foundation for future stakeholder engagement. In summer 2023, the RCAP supported six graduate research assistants and one undergraduate student to conduct synthesis research on ecological and social science topics. A summary of the 2023 RCAP projects is located in **APPENDIX II**. These projects will inform the stakeholder engagement and science priorities in Year 6, and will: (1) produce a high-level summary of findings; (2) identify key stakeholders for this work; and (3) produce a longer written report (or journal article) that synthesizes findings and identifies next steps for research and stakeholder engagement. Additionally, Imtiaz Rangwala engaged in a National Center for Ecological Analysis and Synthesis (NCEAS) Morpho working group comprised of grassland ecologists and policymakers at the Bird Conservancy of the Rockies, the USFWS, Environment and Climate Change Canada, and the JV8 Central Grasslands Conservation Initiative to synthesize research on grassland birds.

The *Ecological Scenarios Project* (PI Imtiaz Rangwala, postdoctoral research fellow Kyra Clark-Wolf, and co-PIs: Wynne Moss, Brian Miller and Helen Sofaer) is funded by a USGS Pass-Through Project, *Crafting Ecological Scenarios for Decision Making,* and strongly leverages the NC CASC Host Agreement. The project aims to develop a generalizable approach for crafting ecological scenarios of future change that are useful in supporting climate adaptation planning, and will inform NC CASC scenario planning approaches going forward. This research is motivated by the significant information support needed for resource management decision-making given uncertainty in how ecological systems will respond to

future climate change, including the potential for ecological transformation. A science working group (~20 scientists) was formed and NC CASC convened a 2-day workshop in July 2023 (supported by host funds) to advance the work on developing a more robust framework for crafting future ecological trajectories under climate change. A case study to apply and refine the ecological scenarios approach is also in development for the Nebraska Sandhills region. This research will result in 1-2 peer reviewed publications, training materials for managers, and is supported by sustained collaboration and relationship-building with the USFWS and NPS. The research effort will be presented at the Ecological Society of America conference in August 2023.

The *Future of Fire Project* (led by postdoctoral research fellow, Jilmarie Stephens; PI: Jennifer Balch; and mentors: Jane Wolken and Imtiaz Rangwala) was funded by the NC CASC Host Agreement and the National CASC Climate Adaptation Postdoctoral (CAP) Fellows Program. The research modeled the future size and number of fires, total burn area, and rates of change among years and across space in the contiguous United States (CONUS). CONUS-wide the number of fires and burned area per year increase by 56% and 59% from 2020-2060 compared to baseline (1990-2019). A manuscript titled, "Fires of unusual size: Future of extreme and novel wildfire in a warming United States (2020-2060)" is being revised for publication, and the data will be made publicly available. This research was done in conjunction with the National CASC CAP Fellows Program which generated a regional-to-national synthesis on the future of fire titled, "The intentional fire use decision space: A synthesis across contextual components for improving U.S. land management." Both research efforts will be presented at the Ecological Society of America conference in August 2023.

The *Grasslands Synthesis Project* (PI Heather Yocum and Research Coordinator Christy Miller Hesed) was funded by a USGS CASC directed research grant, and leveraged Host supported time for Heather Yocum, Bill Travis, Jilmarie Stephens, and Imtiaz Rangwala. In Year 5, Miller Hesed and Yocum led the publication of two USGS Open File Reports, both of which will be cited in the forthcoming Fifth National Climate Assessment. Miller Hesed and Yocum also submitted a journal article to *Conservation Science and Practice* and led the publication of two USGS data releases to share additional findings. Other outreach products include a NC CASC webinar (May 2023), and the Prairie Climate Companion series of fact sheets for grasslands managers (4 issues are available online; 12 additional are in development). Miller Hesed also collaborated with the Northwest CASC, South Central CASC, and USFWS to develop a climate change and grasslands training series built on the findings of the *Grasslands Synthesis Project* to educate professionals in the use and application of climate data. The three-part training consisted of a self-led online course, three webinars, and a hands-on in-person workshop for USFWS professionals and their partners. Rangwala presented a webinar and provided training on the Climate Toolbox at the workshop, and has since identified several new research opportunities with USFWS partners. The *Grasslands Synthesis Project* was also highlighted in two posters at the CIRES Rendezvous in May 2023, and will be highlighted in upcoming CIRES outreach. See **APPENDIX III** for outreach products from this project.

The NC CASC is able to engage with and support a diversity of partners and land managers in the region through subawards to five Consortium Partners (CP). Year 5 CP highlights are summarized below (see **APPENDIX III** for outreach products/activities):

- Conservation Science Partners (CSP): Caitlin Littlefield and colleagues worked with agencies of transportation and wildlife to evaluate the role that wildlife crossings play in supporting wildlife and ecosystem resilience in the face of climate change. This effort yielded a literature review, a set of expert-informed recommendations, and an empirical case study with Southern Ute Tribe wildlife staff. The research team will convene a workshop in Durango, CO (August 2023) to operationalize the recommendations on wildlife crossings. In addition, Littlefield and collaborators from the

University of Montana, USFS, and NW CASC engaged with vegetation and fire managers from the NPS, USFS, and state agencies to understand the decision-space surrounding post-fire forest management. These engagements will inform a decision-support tool that uses climate analogs to calculate probabilities of future vegetation across the NC CASC and NW CASC regions. Building upon the NC CASC-supported work led by Shelley Crausbay (former CSP co-PI) and Wynne Moss (former CSP postdoctoral research fellow), Littlefield is designing a case study to ground Moss' conceptual framework of transformational ecological drought into a real-world example with climate adaptation management applications. Additional leveraged work includes supporting a National Park Service-wide climate vulnerability assessment, examining the implications of climate-adaptive silviculture on forest-dependent bird habitat, and mapping the degree to which protected areas (e.g., National Parks) will serve as stepping stones for species shifting their ranges in response to climate change.

- Great Plains Tribal Water Alliance (GPTWA): In Year 5, the GPTWA launched a new CP-funded project on Tribal climate adaptation water needs in South Dakota. In support of this effort, the GPTWA hired an intern to assist with the time intensive process of literature review and synthesis of tribal water needs in the Great Plains. Stefan Tangen is managing this work with the GPTWA staff and will be doing outreach to conduct interviews in September 2023.
- South Dakota State University (SDSU): In January 2023, Jennifer Zavaleta Cheek hired a graduate student, Vivian Hulugh to determine how managers prepare for and respond to environmental hazards. Following IRB approval, they conducted 35 interviews of conservation planners in South Dakota, including park managers at South Dakota Game, Fish and Parks; Conservation District officials, city park managers, and national park managers at Badlands and Wind Cave National Parks. The interviews were transcribed and coded for relevant themes. In Fall 2023, Hulugh will continue to conduct interviews and leverage new insights into a survey to send to all state employees involved in conservation planning processes in South Dakota.
- University of Montana (UM): In Year 5, UM CP activities continued to focus on understanding the social and ecological resilience to changing wildfire activity. Kim Davis (former UM Research Scientist) published a study in the *Proceedings of the National Academy of Sciences* with Jamie Peeler (UM postdoctoral research fellow) and Philip Higuera (UM co-PI) as co-authors; the research evaluated how climate and site conditions influenced post-fire tree regeneration at 10,000 locations after 334 wildfires in the western US. Notably, in Year 5, Davis transitioned to a permanent Research Ecologist position at the USFS Rocky Mountain Research Station's Missoula Fire Lab in November 2022. In Fall 2022, Jamie Peeler joined the NC CASC UM project, leveraging her NatureNet postdoctoral fellowship with The Nature Conservancy, which started in Higuera's lab in fall 2021. Peeler led a study that will be published in *Environmental Research Letters*, and highlights "opportunity hot spots" where prescribed fire and forest thinning could reduce the risk of wildfire-caused carbon loss in western U.S. forests. Higuera led a study published in *PNAS Nexus*, focused on understanding the patterns, causes, and impacts of wildfire-caused home and structure loss in the western U.S. This work included collaborators at CU Boulder, with partial support from the CP subaward. The paper highlights increasing home structure loss, the role of unplanned human-caused wildfires, and important variability among western states. The work received local and regional media coverage, including features in *High Country News, Scripps TV News, Montana Public Radio, The Missoulian,* and *Bozeman Daily Chronicle.* Higuera and coauthors also wrote an invited companion piece for a broad public audience in *The Conversation* (see **APPENDIX III**).
- Wildlife Conservation Society (WCS): In Fall 2022, Molly Cross and colleagues at WCS and the Wyoming Game and Fish Department (WGFD) published a paper on their collaboration to update the Wyoming Statewide Habitat Plan. The paper documents and evaluates the effectiveness of the co-production methods that were used to support the use of climate-related information by WGFD

managers. Additionally, Cross worked with a colleague at WCS to prepare a summary of results from a virtual workshop led by WCS in 2021 (report completed in Fall 2022). This workshop convened natural resource managers and scientists from the region to discuss challenges related to implementing and measuring the effectiveness of climate adaptation projects, and identify specific questions participants have about the effectiveness of process-based restoration and beaver-related adaptation techniques. By the end of Summer 2023, Cross will compile a summary of the various work completed on this portion of her CP activities.

Capacity Building: In Year 5, we continued to help train the next generation of earth and environmental scientists and research managers with expertise in climate adaptation. Prasad Thota (PhD student, Civil Engineering) worked under the direction of Imtiaz Rangwala to support research and tool development for the NC CASC Climate Science Support Platform (i.e., R-Shiny Apps) and one of the Rapid Climate Assessment Program projects (see **APPENDIX II**).

The Tribal Climate Leaders Program (TCLP) is a pilot program coordinated by Heather Yocum that provides fully-funded, two-year fellowships to Native American graduate students affiliated with one of the 32 federally-recognized tribes in the North Central region. In Year 5, the TCLP provided support for three students, and professional development support for a fourth student. William Crawford (MA student, Environmental Studies) and Ida Clarke (MS student, Environmental Engineering) received financial support and graduated with their Master's degree in December 2022 and May 2023, respectively. Shelby Ross (PhD student, Geography) continues to receive mentoring support from the NC CASC as she continues her PhD program. Violet Eagle (professional research assistant, Evolutionary Biology) completed her research assistantship and has been accepted into a nationally-competitive graduate program.

The NC CASC is a host for one of the National CASC's Climate Adaptation Scientists of Tomorrow (CAST) pilot programs, which aims to increase justice, equity, diversity, and inclusion in climate adaptation fields. Heather Yocum is the Program Coordinator for the CU Boulder CAST program, which has supported three undergraduate research fellows in Summer 2022 and 2023, and five graduate students with small professional development grants. In Summer 2023, the CAST program hosted three undergraduate research fellows: Steelle Stevens (Integrative Biology: Fish and Wildlife major; Northeastern State University, Tahlequah, OK) is working with CU's Earth Lab on understanding compound disturbances in the mountains near Boulder, CO; Kandice Agudo (Biochemistry major at Regis University, Denver, CO) is working with Western Water Assessment to support a state vulnerability study in Colorado; and Jamie Ma (Environmental studies major, University of Southern California, Los Angeles, CA) is working with Matthew Burgess (CU Boulder, Department of Environmental Studies) to compare sustainability and related funding in business ventures.

Communications: Communications and outreach are embedded in all NC CASC activities, and integrate our *partnerships*, *science* and *capacity building* efforts. In Year 5, we increased our communication and outreach capacity with increased effort by Ulyana Horodyskyj Peña (Communications Lead), and event planning and communications support by Hailey Robe (Program Assistant), who joined the NC CASC in January 2023.

In June 2023, the *NC CASC Communication and Outreach Plan* was updated with more clearly defined communication goals, objectives and evaluation metrics for our communication tools (described below). Areas of growth include *Spotlight Stories* and *Science Byte*s for the website; Twitter campaigns to highlight NC CASC research and outreach efforts, using targeted hashtags to drive traffic (e.g.,

#climatetwitter, #TEK for Tribal posts and #grasslands to promote the *Grasslands Synthesis Project*); and the creation of video content for our YouTube Channel. Additionally, Peña participated in the American Geophysical Union's Voices for Science program, which trains scientists on best practices and strategies for communicating science to decision makers and public audiences. She is leveraging this opportunity to provide in-house communication training to NC CASC scientists and partners during the remainder of 2023 and into 2024.

We use the following tools to communicate our activities to our partners and stakeholders:

- NC CASC Website: With increased communication effort from Peña, we increased the number of *Spotlight Stories* and *Science Bytes* for our website and videos for our YouTube channel. The current *Spotlight Story* and *Science Byte* appear on the NC CASC landing page of our website. We continued to host a For Tribal Partners page that contains content organized by Stefan Tangen and Kynser Wahwahsuck (Tribal Resilience Liaisons), including archived issues of the Tribal Climate Adaptation Newsletter and videos of the Tribal Climate Webinars. We added a new page under "Resources" called Grasslands to highlight the work of the *Grasslands Synthesis Project*. From this page, users can access the USGS open file reports, as well as issues of the 'Prairie Climate Companion,' which is a series of 2-pagers focused on different grasslands management concerns, such as shifting temperature and precipitation, water availability, and wild and prescribed fire. A dozen or more 'Prairie Climate Companion' fact sheets are expected by the end of 2023 (see **APPENDIX III)**.
- NC CASC Newsletter: The newsletter is issued on a bi-monthly basis, and distributed via MailChimp. In the last year it was converted from a PDF format to an interactive MailChimp email newsletter, which helps drive traffic to our website and enables the tracking of metrics on what types of content our readers interact with.
- Social Media/Subscribers: Since 2022, our social media presence and subscriber list has grown. We have focused our efforts on Twitter (1,145 followers, up from 965) but have also observed some growth for Facebook (329 followers, up from 322 followers in 2022 and 281 in 2021). Our Mailchimp subscriber list has also increased (up to 1330 contacts, up from 1185 contacts).
- NC CASC YouTube Channel: Our YouTube channel has grown in subscribers (181 subscribers, up from 141 in 2022) and content (181 videos, up from 75 for 2018-2022), with combined views of over 18,000. New content in 2023 includes a research reel, highlighting research by several NC CASC scientists, and seven new NC CASC monthly webinar recordings.
- NC CASC Webinar Series: The NC CASC Webinar Series was held monthly from October 2022 through May 2023; webinars will resume in Fall 2023. The webinars highlight ongoing research from the NC CASC network, as well as feature topics of critical importance to natural resource managers and other stakeholders in the region. Since October 2022, the center hosted seven webinars with an average attendance of 71 participants per webinar.
- NC CASC Help Tickets: The NC CASC help ticket system (Spiceworks) is utilized by the communications team to process communication requests internally and collect content for the submission of *Weekly Highlights* to the National CASC. For the period October 1, 2022 to June 30, 2023, Robe and Peña processed 77 individual help ticket requests, with the majority of tickets requiring multiple responses.

5. OUTREACH

In Year 5, the NC CASC (CU team and Consortium Partners) produced 16 peer-reviewed publications and technical reports, and 14 pre-published works. The center engaged in several outreach activities, including 23 presentations/webinars, 31 major stakeholder engagements, and 5 media mentions/interviews. The team also developed 2 data releases, 5 new climate tools and applications, and 18 fact sheets/research briefs (see **APPENDIX III**).

6. NEXT STEPS

Our Year 6 activities were informed by the USGS NC CASC Regional Science Plan (2023-2028, *Draft in Revision - 2/16/2023*), Year 5 External Review Team Final Report (April 2023), and successes of our ongoing *partnerships, science, capacity building* and *communications* activities in Years 1-5.

Partnerships: In Year 6 we will continue to strengthen partnerships with regional partners/collaborators, in particular via outreach products from the *Grasslands Synthesis Project*, *Ecological Scenarios* project and its applications, cross-CASC activities, Tribal engagement activities, and refinement of our Rapid Climate Assessment Program, which aims to provide a baseline for future research and stakeholder engagement.

Science: The NC CASC is excited about the opportunity in Year 6 to extend and build on the major science efforts in Years 1-5: (i) advances in developing quantitative future climate scenarios for assessments of ecological impacts and adaptation strategies; (ii) research in ecological drought; (iii) ecological recovery and transformation from climate-induced disturbance; (iv) identifying key information needs and synthesizing climate and ecological sciences for the North Central grasslands; (v) assessing future fire risk in the NC CASC region and beyond; and (vi) developing and applying decision tools for managing natural and cultural resources under a changing climate. The Rapid Climate Assessment Program (RCAP) will be a key science effort in Year 6, as we refine the process of performing rapid science syntheses and assessments relevant to stakeholders. The topical foci of the RCAP projects will be informed by the Year 5 pilot program (Summer/Fall 2023), and the broader NC CASC team's understanding of the climate information needs of stakeholders in the region. We will also continue to support ongoing science efforts led by our Consortium Partners.

Capacity Building: The NC CASC is committed to building capacity and increasing diversity, equity, and inclusion in science. We will continue to work with the Center for Native American and Indigenous Studies at CU Boulder to explore options to support a second cohort of the Tribal Climate Leaders Program. Leveraging staff time from the NC CASC Host, we will continue to support the Climate Adaptation Scientists of Tomorrow (CAST) pilot program at CU Boulder. CAST activities in Year 6 include developing partnerships with Tribal Colleges and Universities in the North Central region, administering small professional development grants to support graduate students, collaborating with other regional CASC pilot programs to produce a journal article about the program, and applying to continue the program through supplemental funding requests to USGS.

Communications: In Year 5/6, we will offer in-house communication training to NC CASC scientists and partners, including training sessions on *How to create effective PowerPoint presentations*, *How to create effective scientific infographics*, *How to utilize social media for science*, and *How to shoot and edit a short science film*. We will also be developing outreach products for the pilot RCAP projects and continue to grow our social media audience. Short video pieces, like the *Who We Are* introductory film made for Climate Solutions Days (Year 4), highlighting our scientists and available data tools, are planned for our YouTube channel. Twitter campaigns using hashtags specifically for the NC CASC will allow us to better track metrics of engagement and provide an archival record of our projects and accompanying outreach products.

7. BUDGET

The annual award expenditures in comparison to the proposed budget for Year 5 and accompanying budget justification are located in **APPENDIX IV**.

APPENDIX I: Funded University of Colorado (CU) Personnel (Table A) and Contributions from Personnel Outside of the Host Agreement (Table B)

APPENDIX I Table A: *Budget Year 5 (10/1/2022 to 9/30/2023) funded University of Colorado Boulder (CU) personnel; NCASC=National CASC; TCLP=Tribal Climate Leaders Program; CAST=Climate Adaptation Scientists of Tomorrow; BY=Budget Year; NCE=No Cost Extension; and CS=Cost Share funds. Personnel changes: with the departure of Dawn Umpleby in August 2022, Hailey Robe joined the NC CASC as Program Assistant in January 2023.*

Person	Role	Responsibility	Total Months of Effort on Host Agreement BY4 NCE and BY5 funds (CS=Cost Share)
William Travis	University Director/ NC CASC CU Leadership Team	Responsible for overseeing all elements of the host cooperative agreement.	***Content Removed from this Version***
Jane Wolken	University Deputy Director/ NC CASC CU Leadership Team	Oversees day-to-day university operations of the NC CASC, coordinates with CIRES Finance to manage the host funding, CP subaward activities and Pass-Through Projects, engages in cross-CASC activities (e.g., network calls/meetings, working groups and CAP Fellows Program support), and supervises the communications team.	
Imtiaz Rangwala	Climate Science Lead/ NC CASC CU Leadership Team	Provides primary climate expertise to the NC CASC-directed projects, works with boundary organizations to facilitate effective integration of climate research into natural resource management and planning, conducts research on ecological drought and transformation, co-hosts the NC CASC Webinar Series, and mentors postdocs and graduate students.	
Heather Yocum	Social Science Lead/ NC CASC CU Leadership Team	Provides social science expertise to NC CASC projects, facilitates co-production and creation of useable science, leads the Rapid Climate Assessment Program (RCAP), co-hosts the NC CASC Webinar Series, leads NC CASC Justice Equity, Diversity, and Inclusion programs (TCLP and the NCASC CAST pilot program), serves as the PI for the *Grasslands Synthesis Project*, and supervises graduate students.	
Ulyana Horodyskyj Peña	Communications Lead	Translates the science, education and outreach activities of the NC CASC into engaging communication products for a diversity of audiences and outlets, updates the NC CASC communication and outreach plan, and supports the science communication activities of the CASC-network.	
Hailey Robe	Program Assistant	Assists the NC CASC team with daily operational activities, coordinates with the Communications Lead to keep the website and social media platforms up-to-date, compiles the *Weekly Highlights*, and supports event planning activities for the center.	

James Rattling Leaf, Sr.	Tribal Engagement Specialist	Performs outreach and engagement activities to build/strengthen partnerships with Tribal organizations and colleges in the North Central region. Served as a committee member for TCLP student William Crawford.	***Content Removed from this Version***
Kyra Clark-Wolf	Postdoctoral Fellow	Provides expertise on ecological impacts and transformation under climate change, and assists with collaborative research, science synthesis, and communication and outreach activities to support scenario planning, adaptation, conservation and resource management in the NC CASC region.	
Jilmarie Stephens	Postdoctoral Fellow	Conducts future of fire research in the North Central region that informs the NCASC CAP Fellow Program *Future of Fire* project.	
Ida Clarke	TCLP Student	MS Student in Environmental Engineering.	
William Crawford	TCLP Student	MS Student, Environmental Studies.	
Prasad Thota	Graduate Research Assistant	Develops climate datasets, workflows and tools, and conducts a literature review in support of the Rapid Climate Assessment Program (see **APPENDIX II**).	
Sarah Gonzales Coffin	Graduate Research Assistant	Conducts a review in support of the Rapid Climate Assessment Program (see **APPENDIX II**).	
Sarah Jaffe	Graduate Research Assistant	Conducts a review in support of the Rapid Climate Assessment Program (see **APPENDIX II**).	
Elizabeth Woolner	Graduate Research Assistant	Conducts a review in support of the Rapid Climate Assessment Program (see **APPENDIX II**).	
Alyson Ennis	Graduate Research Assistant	Conducts a review in support of the Rapid Climate Assessment Program (see **APPENDIX II**).	
Samuel Ahler	Graduate Research Assistant	Conducts a review in support of the Rapid Climate Assessment Program (see **APPENDIX II**).	
Ami Nacu-Schmidt	CIRES Graphic Designer	Conducts graphic design work for NC CASC outreach products.	

APPENDIX I Table B: *Contributions from personnel funded outside of the Host Agreement; CIRES=Cooperative Institute for Research in Environmental Sciences.*

Person	**Institution**	**Role**	**Responsibility**
Christy Miller Hesed	CU Boulder/ CIRES/ NC CASC	Regional Climate Adaptation Scientist	Project coordinator for the *Grasslands Synthesis Project* and PI of the USGS Pass-Through Project, *Understanding the intersection of climate vulnerability and resource management in rural communities: a study of social-ecological connections*. She engages regularly with the NC CASC team and is co-leading three of the Year 5 pilot Rapid Climate Assessment Program projects (see **APPENDIX II**).
Stefan Tangen	Great Plains Tribal Water Alliance (GPTWA)	Tribal Resilience Liaison/ co-PI of the GPTWA Consortium Partner subaward	Collaborates with the NC CASC through a variety of meetings and efforts, and serves as a co-PI for the consortium via the GPTWA .
Ulyana Horodyskyj Peña	CU Boulder/ CIRES/ NC CASC	Communications Lead	Works part-time with the NC CASC team. Support for this position is provided by a combination of funding from a USGS Pass-Through Project, *Creating a North Central Regional Invasive Species and Climate Change (NC RISCC) Management Network* (PI R. Chelsea Nagy), and the NC CASC Host Agreement (see **APPENDIX I Table A**).
Julia Goolsby	CU Boulder/ Institute of Behavioral Science/ CIRES/ NC CASC	Professional Research Assistant	Works on the USGS Pass-Through Project, *How institutional context and emotions shape manager decisions to resist, accept, or direct change in transforming ecosystems: A cross-CASC study in four national parks* (PI Heather Yocum), and works closely with key stakeholders in fire management (e.g., National Interagency Fire Center, NIFC).
Elizabeth Bannister	CU Boulder/ Earth Lab	Undergraduate student research assistant	Earth Lab made an in-kind contribution to the NC CASC host activities by supporting this undergraduate student to assist with compiling *Weekly Highlights* for submission to the National CASC. Bannister then joined a Rapid Climate Assessment Program project in Summer 2023 to build a roster of ecologically important extreme weather and climate events in the NC region (see **APPENDIX II**).

APPENDIX II: Rapid Climate Assessment Program Projects and Teams

1) **Synthesis of climate adaptation in Mountain ecosystems in the North Central region**
   CU Leads: Imtiaz Rangwala (Lead); Aly Ennis (GRA); Kyra Clark-Wolf (assisting)
   USGS Leads: Megan Oldfather (Co-lead)

Project description: This project consists of a regional synthesis of climate change impacts in the North Central mountain ecosystem. The team will synthesize current literature on the physical and biological (flora and fauna) impacts of climate change, associated potential climate adaptation strategies, and anticipated partner needs and challenges for the alpine ecosystem and contiguous treeline ecotone in this region. In this literature review, we will ask the important question – what are our knowledge gaps of alpine/treeline ecosystem responses to climate change that limit our ability to perform successful climate adaptation? Literature review and synthesis will include literature on climate and biological trends in the alpine/treeline regionally, and locally across the study region, as well as societal interests (e.g., water resources) and management actions (e.g., preservation) for this ecosystem in the context of changing climate. Expected outcomes from this project include: (1) establishing a baseline of available science information on these systems; (2) identifying gaps and remaining research needs for actionable mountain science in the region; and (3) a synthesis manuscript for publication (or substantial progress towards that goal).

2) **Synthesis of social science related to resource management and climate change in the Great Plains**
   CU Leads: Christy Miller Hesed (Lead); Heather Yocum (co-lead); Sarah Gonzales Coffin (GRA)
   Other Partners: Playa Lakes Joint Venture

Project Description: This project consists primarily of a review and synthesis of social science literature relevant to climate change and adaptation in the Great Plains region of the US. Building on findings from the *Grasslands Synthesis Project*, this project will synthesize information from published social science literature and databases to assess social aspects of resource management, attitudes toward conservation, views on climate change, social-ecological connections, and areas for adaptation across the Great Plains, with a particular focus on Kansas as a case study. Expected outputs for this RCAP project include: (1) written and visual representations of the synthesized data (e.g. maps, figures, charts, etc.); and (2) a synthesis manuscript for publication which also identifies remaining research needs (or significant progress towards a manuscript). Results of this RCA will synthesize existing information and identify remaining research gaps in understanding social processes that impact climate adaptation and conservation, which grassland and other natural resource managers in the region have identified as key information needed to support adaptation and conservation goals.

3) **Synthesis of climate change impacts on the Mixed/Tall-Grass Prairie ecosystems in the Northern Great Plains**
   CU Leads: Imtiaz Rangwala (Lead); Kyra Clark-Wolk (co-lead); Sam Ahler (GRA); Chelsea Nagy (NC RISCC)
   Other Partners: Cami Dixon (USFWS)

Project Description: This project consists of a synthesis of climate change impacts on the mixed/tall-grass prairie ecosystems in the Northern Great Plains. The project team includes experts in invasive species and wildfire at NC CASC and Earth Lab, and our partners at the US Fish and Wildlife Service (US FWS) to synthesize our best understanding of the physical and ecological impacts of climate change in the study region through literature review and consultation with subject-matter experts. This work is expected to inform US FWS Refuge managers to better understand and anticipate plausible impacts to these ecosystems, and develop/improve decision-making processes and adaptation strategies in accordance with that knowledge. Expected outputs include: (1) a review of literature to synthesize expected climate and hydrological trends in the study region, and projected impacts on ecological systems and processes that include ecological transformation, invasive species and wildfire; (2) continued engagement across teams and with key stakeholders to develop the best understanding of plausible impacts and useful adaptation strategies; (3) a synthesis report; and (4) related communication products.

4) **Supporting grassland managers to conserve grassland ecosystems and adapt to climate change in the North Central Region**
CU Leads: Heather Yocum (Lead); Christy Miller Hesed (co-lead); Elizabeth Woolner (GRA)
Other Partners: Playa Lakes Joint Venture

Project Description: This project consists of conducting outreach and interviews with federal, state, and Tribal natural resource managers in the Great Plains region of the US. This research builds upon findings from the *Grasslands Synthesis Project* to further refine information needs and research gaps to support grassland managers in the North Central Region. The team will conduct virtual/online interviews with federal and state grassland managers across the region. We will also be asking them about upcoming planning processes that the NC CASC could provide climate science support to identify opportunities for engagement and collaboration with these key partners. Expected outcomes of this project include: (1) identify relative priorities and science needs for key stakeholders at federal and state management agencies; (2) list of possible future opportunities and planning processes in which the NC CASC can collaborate and/or support grassland managers; and (3) a manuscript for publication that integrates this as a key step building on the *Grasslands Synthesis Project* findings (or substantial progress towards this goal).

5) **Grasslands GIS**
CU Leads: Heather Yocum (Lead); Christy Miller Hesed (co-lead); Sarah Jaffe (GRA)

Project Description: This project will finalize GIS analysis started during the *Grasslands Synthesis Project* in summer 2021 specifically by writing up research results and identifying additional GIS-related information needs. Outcomes of this project include: (1) a publication on spatially explicit information for conservation (or substantial progress towards this goal); and (2) information on key research gaps in GIS information needed to identify grassland quality and management across the Northern Great Plains region.

6) **Examination of large-scale drivers of water availability in the US Great Plains**
CU Leads: Imtiaz Rangwala (Lead); Prasad Thota (GRA)

Project Description: This project will provide a synthesis of the processes and mechanisms that determine water availability (in soils and streams) in the US Great Plains region, examining both short and long duration processes and cross-season relationships. It will specifically research large-scale climatic conditions and processes that control precipitation (both cold and warm season precipitation) in the region and how they vary spatially across the Great Plains. Additional information on future hydroclimate and hydrologic information is a key research priority in this region (e.g., Yocum and Ray 2019; NC CASC FY22 RFP priority), and this project builds upon other NC CASC-funded research (e.g., work by Rangwala and McKenna).

7) **Ecologically and/or infrastructurally impactful weather and climate extremes in the region**
CU Leads: Bill Travis (Lead); Elizabeth Bannister (Undergraduate Research Student)

Project Description: A quick canvassing of regional resource managers, other experts, and various sources will be performed to build an initial roster of extreme weather and climate events over recent decades that have had marked ecological, infrastructural or other land impacts (e.g., the 982-83 El Nino winter; 1983 big Colorado River runoff; 2002 Rockies drought and fires; 2012 northern Plains flash drought; 2022 Yellowstone NP floods). Special attention to the nature of impacts and responses, the compound character of events, and lingering ecological effects. The initial roster will be posted on the NC CASC website to invite additions and elaborations. This rapid assessment is aimed at formulating a deeper look into how extremes have, and might in the future, factor into adaptation plans, and species and RAD assessments.

APPENDIX III: Outreach Products and Activities

In Year 5, the NC CASC developed/engaged in a variety of outreach products/activities. Note that NC CASC researchers and consortium partners appear in **bold** text; * indicates a product was not funded by the NC CASC, but leverages the expertise of NC CASC personnel*:*

Published peer reviewed journal articles and technical reports:

- *Brenkert-Smith, H., Champ, P.A., McConnell, A,E., Gomez, J., Barth, C.M., Meldrum, J.R., Donovan, C.; Wagner, C., **Goolsby, J.B**. (2023). Living with wildfire in Park County, Colorado: 2021 data report. Res. Note RMRS-RN-97. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 93 p, https://doi.org/10.2737/RMRS-RN-97.
- **Ciocco, T., Tangen, S.,** and Smith, C. 2023. Actualizing Indigenous Knowledge in tribal wildlife management: basic preconditions. *Wildlife Society Bulletin*, e1467, https://wildlife.onlinelibrary.wiley.com/doi/10.1002/wsb.1467.
- ***Clark-Wolf, K.**, **Higuera, P.E.**, and **Davis, K.T.** 2022. Conifer seedling demography reveals mechanisms of initial forest resilience to wildfires in the northern Rocky Mountains. *Forest Ecology and Management*, 523:120487.
- *Clifford, K.R., **Goolsby, J.B.**, **Cravens, A.E.**, and Cooper, A.E. (2022). Rapidly assessing social characteristics of drought preparedness and decision making: A guide for practitioners. U.S. *Geological Survey Techniques and Methods,* 17-A1, 41 p., https://doi.org/10.3133/tm17A1.
- **Cross, M.S.**, Oakes, L.E., Kretser, H.E., Bredehoft, R., Dey, P., Mahoney, A., Smith, N., Tator, I., and Wasseen, J. (2022). Tackling the research-implementation gap in a warming world: Co-producing useable climate information for natural resource management. *Environmental Management,* 70:881-895, https://doi.org/10.1007/s00267-022-01718-4.
- **Davis, K.T., Peeler, J.**, and **Higuera, P.E.** (*2023*). The West's iconic forests are increasingly struggling to recover from wildfires – altering how fires burn could boost their chances. *The Conversation,* March 6, 2023.
- **Davis, K.T.** ,Robles, M.D., Kemp, K.B., **Higuera, P.E.**, Chapman, T., Metlen, K.L. , **Peeler, J.L.**, Rodman, K.C., Woolley, T., Addington, R.N. , Buma, B.J., Cansler, C.A., Case, M.J., Collins, B.M., Coop, J.D., Dobrowski, S.Z., Gill, N.S., Haffey, C., Harris, L.B., Harvey, B.J., Haugo, B.J., Hurteau, M.D., Kulakowski, D., **Littlefield, C.E.**, McCauley, L.A., Povak, N., Shive, K.L., Smith, E., Stevens, J.T., Stevens-Rumann, C.S., Taylor, A.H., Tepley, A.J., Young, D.J.N., Andrus, R.A., Battaglia, M.A., Berkey, J.K., Busby, S.U., Carlson, A.R., Chambers, M.E., Dodson, E.K., Donato, D.C., Downing, W.M., Fornwalt, P.J., Halofsky, J.S., Hoffman, A., Holz, A., Iniguez, J.M., Krawchuk, M.A., Kreider, M.R., Larson, A.J., Meigs, G.W., Roccaforte, J.P., Rother, M.T., Safford, H., Schaedel, M., Sibold, J.S., Singleton, M.P., Turner, M.G., Urza, A.K., **Clark-Wolf, K.D.**, Yocom, L., Fontaine, J.B., and Campbell, J.L. (2023). Reduced fire severity offers near-term buffer to climate-driven declines in conifer resilience across the western United States. *Proceedings of the National Academy of Sciences,* 120:e2208120120.
- ***Goolsby, J.B.**, Brenkert-Smith, H., Reid, D., Meldrum, J.R., Champ, P.A., Barth, C.M., Donovan, C., and Wagner, C. (2023). Living with wildfire in Emigration Canyon, Utah: 2022 data report, Res. Note RMRS-RN-98. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 143 p, https://doi.org/10.2737/RMRS-RN-98.
- Gude, J.A., DeCesare, N.J., Proffitt, K.M., Sells, S.N., Garrott, R.A., **Rangwala, I.**, Biel, M., Coltrane, J., Cunningham, J., Fletcher, T., Loveless, K., Mowry, R., O'Reilly, M., Rauscher, R., and Thompson, M. (2022). Demographic uncertainty and disease risk influence climate-informed management of an alpine species. *Journal of Wildlife Management*, e22300, https://doi.org/10.1002/jwmg.22300.

- **Higuera, P.E.**, Cook, M.C., **Balch, J.K.**, and Stavros, E.N. 2023. Western wildfires destroyed 246% more homes and buildings over the past decade – fire scientists explain what's changing. *The Conversation,* February 1, 2023.
- Iglesias, V., **Travis, W.R.**, and Balch, J.K. (2022). Recent droughts in the United States are among the fastest-developing of the last century. *Weather and Climate Extremes*, https://doi.org/10.1016/j.wace.2022.100491.
- Janousek, W.M.,Douglas, M.R., Cannings, S., Clément, M.A., Delphia, C.M., Everett, J.G., Hatfield, R.G., Keinath, D.A., Koch, J.B.U., McCabe, L.M., Mola, J.M., Ogilvie, J.E., **Rangwala, I.**, Richardson, L.L., Rohde, A.T., Strange, J.P., Tronstad, L., and Graves, T.A. (2023). Recent and future declines in a historically widespread pollinator linked to climate, land cover, and pesticides. *Proceedings of the National Academy of Sciences,* 120(5), e2211223120, https://doi.org/10.1073/pnas.2211223120.
- **Miller Hesed, C.D., Yocum, H.M., Rangwala, I.,** Symstad, A.J., Martin, J.M., Ellison, K., Wood, D.J. A., Ahlering, M., Chase, K.J., **Crausbay, S**., Davidson, A.D., Elliott, J., Giocomo, J., Hoover, D.L., Klemm, T., Lightfoot, D., McKenna, O.P., **Miller, B.W., Mosher, D., Nagy, R.C.**, Nippert, J.B., Pittman, J., Porensky, L., **Stephens, J**., and Zale, A.V. (2023). Synthesis of climate and ecological science to support grassland management priorities in the North Central Region. *U.S. Geological Survey Open-File Report* 2023-1036, 21 p., https://doi.org/10.3133/ofr20231036.
- **Miller Hesed, C.D. and Yocum, H.M**. (2023). Grassland management priorities for the North Central Region. *U.S. Geological Survey Open-File Report* 2023-1037, 53 p., https://doi.org/10.3133/ofr20231037.
- *****Miner, K. Canavera, L., Gonet, J., Luis, K., Maddox, M., McCarney, P., Bridge, G., Schimel, D., and **Rattling Leaf, J.** 2023. The co-production of knowledge for climate science. *Nature Climate Change*, 13: 307-308.
- ***Yocum, H.M.**, and Knight, E.H. (2023). Colorado climate change vulnerability study: A SWOT analysis prepared for the Colorado Water Conservation Board. Denver, CO: Western Water Assessment.

Pre-published research:

- Hartway, C. and **Cross, M.** (*In Prep*). Summary report: Virtual workshop on measuring climate adaptation outcomes. Wildlife Conservation Society.
- Klemm, T., Peck, D.E., **Miller Hesed, C.D., Yocum, H.M., Wade Wilcox, A.A.**, Kelley, W.K., Halofsky, J., Elliott, J., Reeves, M.C., and **Jaffe, S.M.** *(In Prep).* Assessing the vulnerability of northern mixed-grass prairie vegetation and livestock to climate change. *Rangeland Ecology & Management.*
- ***Littlefield, C.E., Cross, M**., Suraci, J., Kintch, J., Callahan, R., Cramer, P., Dickson, B., Duncan, L.A., Fisher, J., Freeman, P., Seidler, R., Wearn, A., Andrews, K., Brocki, M., Dodd, N., Gagnon, J., Johnson, A., Krosby, M., Skroch, M., and Sutherland, R. (*In Review*). Evaluating and elevating the role of wildlife crossings in climate adaptation. *Frontiers of Ecology and the Environment.*
- **Miller, B.W**., Eaton, M., Symstad, A.J., Schuurman, G.W., **Rangwala, I.**, and **Travis, W.R.** (*In Press*). Scenario-based decision analysis: Integrated scenario planning and structured decision making for resource management under climate change. *Biological Conservation*.
- **Miller Hesed, C.D.** and **Yocum, H.M.** (*In Press*). Grassland management priorities for the North Central region. *U.S. Geological Survey Scientific Investigations Report,* 356 pp.
- **Miller Hesed, C.D.** and **Yocum, H.M.** (*In Press*). Synthesis of climate and ecological science to support grassland management priorities in the North Central region. *U.S. Geological Survey Scientific Investigations Report*, 322 pp.

- **Miller Hesed, C.D., Yocum, H.M., Cross, M., Bamzai-Dodson, A.**, Wheeler, B., Beckmann, J.P., Ahlering, M., Hall, K.R., Boyd-Valandra, E., **Mosher, D., Miller, B.W.,** and **Jaffe, S.** (*In Press*). Seventy questions of importance to the conservation of the North Central grasslands of the United States in a changing climate. *Conservation Science and Practice*.
- **Peeler, J.L.**, McCauley, L., Metlan, K.L., Woolley, T., **Davis, K.T.**, Robles, M.D., Haugo, R.D., Riley, K.L., **Higuera, P.E.**, Fargione, J.E., Addington, R.N., Bassett, S., Blankenship, K., Case, M.J., Chapman, T.B., Smith, E., Swat, R., and Welch, N. (*In Press*). Identifying opportunity hot spots for reducing the risk of wildfire-caused carbon loss in western conifer forests. *Environmental Research Letters.* (Accepted 7/14/2023).
- **Wade, A.A.,** Thurman, L., **Miller Hesed, C.D.**, Davidson, A., **Ciocco, A.**, and Thompson, L. (*In Prep).* Terrestrial wildlife, *In* Medicine Bow-Routt National Forests and Thunder Basin National Grassland Climate Change Vulnerability Assessment (Report)
- Payton et al. (*In Press*). Chapter 4: Water. *In* The Fifth National Climate Assessment Report. (**I. Rangwala** is a co-author)
- Knapp et al. (*In Press*). Chapter 25: Northern Great Plains. *In* The Fifth National Climate Assessment Report. (**A. Bamzai** and **S. Tangen** are co-authors)
- Whyte et al. (*In Press*). Chapter 16: Tribes and Indigenous Peoples. *In* The Fifth National Climate Assessment Report. (**J. Rattling Leaf, Sr.** served as a review editor)
- **Moss, W.**, **Crausbay, S.**, **Rangwala, I.**,...**Miller, B.**, et al.. (*In Press*). Transformational ecological drought: an emergent driver of ecosystem change in the 21st century. *Bioscience.*
- **Stephens, J.J**., Joseph, M.B., Iglesias, V., Tuff, T., Mahood, A., **Rangwala, I**., **Wolken, J.**, Balch, J.K. (*In Prep*). Fires of unusual size: Future of extreme and novel wildfire in a warming United States (2020-2060).

Data releases:

- **Miller Hesed, C.D., Yocum, H.M.,** Beckmann, J.P., **Bamzai-Dodson, A.**, Hall, K.R., **Cross, M.,** Ahlering, M., Boyd-Valandra, E., **Mosher, D.**, and Wheeler, B. (April 2023). Broadly shared information needs among grassland managers in the North Central Region, U.S. Geological Survey, doi: https://doi.org/10.5066/P9PCQHA2.
- **Yocum, H.M., Bannister, I.** and **Miller Hesed, C.D.** (April 2023). Species of greatest conservation need in the North Central Region, U.S. Geological Survey, doi: https://doi.org/10.5066/P97JFAXP.

New Climate Tools and Applications Released:

- Future Climate Scenarios (developed in collaboration with Katherine Hegewisch, University of California Merced): https://climatetoolbox.org/tool/Future-Climate-Scenarios
- Clustering CONUS Gridded Rainfall R-Shiny App (to understand large scale drivers of regional precipitation and precipitation extremes): https://nccasc.shinyapps.io/Clustering_CONUS_Gridded_Rainfall_App/
- Clustering CONUS Rainfall R-Shiny App (based on climate division data): https://nccasc.shinyapps.io/Clustering_Trends_Rainfall_CONUS/
- Integrated Vapor Transport R-Shiny App: https://nccasc.shinyapps.io/IVT_World_App/
- AQM R-Shiny App (for seasonal precipitation predictability in the Intermountain West): https://nccasc.shinyapps.io/AQM_App/

Project-related conference presentations, seminars, webinars, workshops, and public presentations:

- **Clark-Wolf, K., and Rangwala, I.** (July 18-19, 2023): Developing a framework to generate future ecological scenarios. This workshop hosted by the NC CASC at CU Boulder convened ecologists,

climate scientists and adaptation practitioners to generate creative thinking around the development of ecological scenarios for climate adaptation applications, and develop a shared vision of robust approaches for generating ecological scenarios across a range of management contexts.

- **Clark-Wolf, K., Rangwala, I., Moss, W., Miller, B.**, and Sofaer, H. (August 6-11, 2023): RAD storylines: developing ecological scenarios for resource management planning. Contributed Abstract ID 1478286. Ecological Society of America Annual Meeting, Portland, OR.
- **Goolsby, J.B.**, **Cravens, A.E**., Clifford, K.R., Carr, W., and Antonova, G. (June 14, 2023): Responses to ecological transformation in the Kenai National Wildlife Refuge, AK, and East Jemez Landscape, NM: Different agencies, different decisions? Oral presentation in organized session. International Association of Society and Natural Resources Conference, Portland, ME.
- **Higuera, P.E.** (April 13, 2023): Making sense of changing wildfire activity in the West, Montana Edition. Invited presentation to "Leadership Missoula 38," a community organization made up of local business leaders invested in the Missoula community.
- **Higuera, P.E.** (November 1, 2022): Changing human causes and impacts of Western wildfires in the 21st century. *Fall Seminar Series, WA Franke College of Forestry and Conservation, University of Montana*.
- **Horodyskyj Peña, U., Robe, H., Wolken, J., Travis, W., Rangwala, I., Miller Hesed, C.D.,** and **Yocum, H.** (May 16, 2023): The NC CASC: Generating the science to help resource managers adapt to a changing world. Presented by Ulyana Horodyskyj Peña at the *CIRES Rendezvous 2023*, Boulder, CO.
- **Littlefield, C.** (June 5, 2023): What we know about climate change and wildlife crossings: A literature review and case study. Presentation at the International Conference on Ecology and Transportation, Burlington, VT.
- **Miller Hesed, C.D.** and **Yocum, H.M.** (May 11, 2023): *Grasslands Synthesis Project:* Findings and next steps, North Central Climate Adaptation Science Center Webinar Series [60 minutes; ~125 registrants].
- ***Moss, W.** (February 9, 2023): The increasing role of drought in ecological transformation, North Central Climate Adaptation Science Center Webinar Series. (W. Moss was formerly with CSP, and is now an NC CASC affiliate working with the USGS Northern Rocky Mountain Science Center). The work presented was part of a larger ongoing NC CASC/CASC-network effort to inform research on ecological transformation.
- **Peeler, J.L.**, McCauley, L., Metlan, K.L., Woolley, T., **Davis, K.T.**, Robles, M.D., Haugo, R.D., Riley, K.L., **Higuera, P.E.**, Fargione, J.E., Addington, R.N., Bassett, S., Blankenship, K., Case, M.J., Chapman, T.B., Smith, E., Swat, R., and Welch, N. (April 27, 2023): Identifying opportunity hot spots for reducing the risk of wildfire-caused carbon loss in western conifer forests. Spring Seminar Series, USFS Missoula Fire Sciences Laboratory.
- **Rangwala, I.** (October 19, 2022): Projected changes in climate and water availability in the Northern Great Plains. Oceti Sakowin (Lakota) Climate Crisis Summit, Rapid City, SD.
- **Rangwala, I.** (January 24, 2023): Incorporating future climate and uncertainty into impact assessment. Grassland-Climate Workshop. U.S. Fish & Wildlife Service – Regional Office, Lakewood, CO.
- **Rangwala, I.** (April 14, 2023): Climate change and water in the West: Pre-symposium Webinar. 2023 CPNR Water Symposium. Thermopolis, WY.
- **Rangwala, I.** (April 17, 2023): Incorporating climate change into impact assessment. Utah Wildlife and Parks. Conversation of Utah SWAP.
- **Rangwala, I.** (May 24, 2023): Incorporating climate change into impact assessment, USGS Northern Prairie Wildlife Research Center, Jamestown, ND.

- ***Rattling Leaf, J., Sr.** (February 6-9, 2023): Presented at the twelfth annual Coastal GeoTools Conference. This event provides a learning experience for planners, engineers, natural resource managers, geospatial analysts, and scientists from all sectors.
- **Rattling Leaf, J., Sr.** (February 9, 2023): Presented a keynote address on Tribes and Climate at the North Dakota Chapter of the Wildlife Society Annual Meeting in Mandan, North Dakota (February 7-10, 2023).
- ***Rattling Leaf, J., Sr.** (May 23-25, 2023): Helped plan and implement the ESIIL Innovation Summit, University of Colorado Boulder, Boulder, CO.
- ***Rattling Leaf, J., Sr.** (June 22, 2023): What is TEK and why does it matter?, Crow Canyon Archaeological Center.
- ***Rattling Leaf, J., Sr.** (June 29-30, 2023): Ethical Space: Indigenous Engagement for Environmental Science Professionals, Compass Virtual Workshop.
- ***Rattling Leaf, J., Sr.** (July 25-27, 2023): Indigenous Engagement Institute Workshop, Cawston, BC, Canada.
- **Travis, W.R.** (September 8, 2022): The challenge of planning for extremes in natural and cultural resources, North Central Climate Adaptation Science Center Webinar Series [60 minutes)].
- **Yocum, H.M., Miller Hesed, C.M.,** and **Rangwala, I.** (May 16, 2023): Climate impacts, stakeholder needs, and adaptation in Northern Great Plains Grassland ecosystems. Presented by Heather Yocum at the *CIRES Rendezvous 2023*, Boulder, CO.

Major engagements with regional decision-makers, stakeholders, and resource managers

- **Clark-Wolf, K.** (April 2023): Led a virtual ecological scenarios case study scoping meeting with Nebraska Sandhills national wildlife refuge staff
- **Clark-Wolf, K.** and **Rangwala, I.** (July 18-19 2023): Organized and led an in-person Ecological Transformation Workshop Team Science Meeting to develop a conceptual framework for crafting ecological scenarios to support RAD decision-making [16 participants: 3 CU, 5 USGS, 5 USFWS, 1 NPS, 2 other academic], CU Boulder campus, Boulder, CO.
- ***Cross, M.** (October 2022): Gave a presentation on making conservation "climate-smart" at the 2022 National Adaptation Forum.
- ***Cross, M.** (October 2022 - present): Participated in a National CASC and National Wildlife Federation led working group on advancing innovation in climate adaptation.
- **Cross, M.** (November 2022): Gave a presentation to kick off a discussion on rapid climate change assessments for an NC CASC Climate Science Support Platform meeting.
- **Cross, M.** (March 2023): Gave a presentation and led a discussion with a national, cross-CASC Evaluation Working Group on measuring effectiveness of climate adaptation projects.
- **Cross, M.** (April 2023): Led a discussion with NC-CASC all-hands meeting participants on measuring effectiveness of climate adaptation projects.
- ***Cross, M.** (April 2023): Gave a lecture on Climate Change Adaptation and Conservation for a class on Climate Change at Montana State University.
- ***Cross, M.** (April 2021-present): Participated in an informal climate adaptation working group of Federal agency managers and NGOs in the Greater Yellowstone Ecosystem.
- Elliot-Smith, E., Finn, S., Kuster, E., **Miller Hesed, C.D.**, and Carlson, J. (January 24-25, 2023): Organized and led a Grasslands-Climate Workshop. USFWS Region 6 Headquarters, Lakewood, CO. Approximately 40 USFWS staff and partners working on grassland conservation met in person in Lakewood, CO for the *Grasslands-Climate Workshop.* This workshop was collaboratively organized by the North Central CASC, Northwest CASC, South Central CASC, and the USFWS to equip USFWS with tools and practice in incorporating considerations of climate change into management

decisions. The workshop used a broad Learn-Do-Reflect approach and included information delivery, hands-on tool training, peer-to-peer networking, and a scenario-based exercise. Imtiaz Rangwala of the North Central CASC presented on the use of the Climate Toolbox. The workshop focused on Central North American Grasslands (Tallgrass, Northern Mixed Grass, Central Mixed Grass and Shortgrass Ecoregions and the Sagebrush-Grassland Ecotone) with some relevance to southern and montane grassland systems. This in-person workshop followed four recorded web-based training modules that can be viewed here.

- **Littlefield, C.** and collaborators (March 15 and 21, 2023): Met remotely with representatives from the United States Department of Transportation and Federal Highway Administration to advance the climate-informed wildlife crossings recommendations.
- **Littlefield** and collaborators, including wildlife biologist staff from the Southern Ute Tribe, are planning a 2-day workshop in Durango, CO (mid-August, 2023): Anticipated attendees include planners and managers from state (CO and NM) agencies of transportation and wildlife as well as the Federal Highway Administration. The primary objective of the workshop is to explore how to carry out on-the-ground implementation of the "high-level" recommendations for climate-informed wildlife crossings generated by a group of experts Littlefield and collaborators convened in November 2022.
- **Littlefield** and collaborators from the University of Montana (e.g., **Phil Higuera**) and USFS (e.g., **Kim Davis**, former co-PI at University of Montana) engaged with nine groups of stakeholders from the NPS, USFS, state agencies, and other land management groups (e.g., TNC) to understand the decision-space surrounding post-fire forest management. This project is funded primarily by the NW CASC, but NC CASC Consortium Partner funds enabled the inclusion of fire and vegetation managers from both Yellowstone and Rocky Mountain National Parks.
- **Peeler, J.L.** (Spring 2023): Participated in a workshop to set conservation science priorities for *The Nature Conservancy*'s (TNC) new initiative on western dry forests and fire. Participants included 25 forest scientists representing TNC's state chapters, TNC's North America chapter, USDA and DOI's LANDFIRE team, the US Forest Service, and TNC's Global Conservation Impact team.
- **Rangwala I.** (October 2022): Science advisor to Aspen Global Change Institute: Participated in a joint science and advisory board meeting in Aspen in October 2022. Reviewed proposals for AGCI/NSF sponsored workshops
- **Rangwala I.** (March 2023): Reviewed a US Forest Service report on climate change scenarios for the Medicine Bow-Routt National Forests and Thunder Basin National Grassland, and had follow-up discussion with Linda Joyce (at USFS) on improving approaches and tools used in the service's current efforts.
- **Rangwala I.** (April 2023): Participated in the all authors meeting in Washington, D.C. as a co-author of the Fifth National Climate Assessment (NCA5) Water chapter.
- **Rangwala I**. (May 2023): Site visit to the Prairie Pothole Region in May 2023. In-person meeting with USGS and USFWS partners including participating in a May Pond Four Mile survey. Conducted a scenario planning workshop at USGS Northern Prairie Wildlife Research Center.
- **Rangwala I.** (June 2023): Reviewed sections of the 2023 Climate Change in Colorado report (Bolinger et al. 2023)
- **Rangwala I.** (June 2023): Reviewed a manuscript on changing snow dynamics in the southern Rocky Mountains for *Ecosphere*
- **Rattling Leaf, J., Sr.** (October 2022): Facilitated Tribal consultation related to Traditional Knowledge and climate adaptation at Wind Cave National Park.
- **Rattling Leaf, J., Sr.** (December 6, 2022): Presenter at the "Federal Global Change Research for the Next Decade: A Discussion of USGCRP's New 10-Year Strategic Plan," hosted by the White House Office of Science Technology Policy and the U.S. Global Change Research Program.

- **Rattling Leaf, J., Sr.** (Winter 2022-Spring 2023): Supported Rosebud Sioux Tribe Climate Center with planning tools, processes, reviews and technical assistance.
- ***Rattling Leaf, J., Sr.** (May 2023): Supported ESIIL Tribal Engagement Strategy, ultimately producing a one-page document; participated in and presented at the Tribal Data Sovereignty and Tribal Data Governance workshops, which includes ESIIL activities, programs, and outreach.
- **Rattling Leaf, J., Sr.** (June 2023): Served in an advisory role to the Institute for Tribal Environmental Professionals Climate Report to Tribes.
- **Rattling Leaf, J., Sr.** (2023): Served on the Department of Interior Traditional Knowledge Handbook and Training Initiative.
- **Tangen, S.** (May 2023): Led several sessions at the Tri Ute Climate Resilience Workshop Series with Ute Mountain Ute, Ute Tribe of Utah, and Southern Ute, which wrapped up with the fourth and final workshop in Montrose, CO. Tangen helped plan the workshop and facilitate the agenda alongside Margie Connolly from Ute Mountain Ute.
- **Wolken, J.M., Yocum, H.** and **Bamzai Dodson, A.** (November 7-8, 2022): Organized and facilitated a virtual 3 Center Retreat with the NC CASC, Western Water Assessment (WWA) and the USDA Northern Plains Climate HUB. With input from Benét Duncan and Katie Clifford at WWA, this 3 Center Retreat focused on the theme of *How do we do equitable adaptation work when we prioritize engaging and partnering with underserved frontline communities?* In addition to a presentation on *The Injustice Continuum: Environmental Justice from Redlining to 14008* by guest speaker (Sachin Shah, USGS Hydrologist, Manager of the Social & Economic Drivers Program in the USGS Water Mission Area and Science Advisor for the Department of Interior Office of Environmental Policy Environmental Justice Team), the meeting included a discussion of what are the ethical and process guardrails for our centers when working with frontline communities?
- ***Yocum, H.M.** (January - May 2023): Interviewed State of Colorado agency personnel to improve state vulnerability assessment revision.
- ***Yocum, H.M.** (May 2023): Organized and convened a panel, "Stronger Together: Climate Vulnerabilities and Disproportionately Impacted Communities, at the Colorado Drought Summit.
- **Yocum, H.M.** (June, 2023): Reviewed the 2023 Climate Change in Colorado report (Bolinger et al. 2023)

Fact sheets and research briefs:

- **Littlefield, C.** and collaborators from state transportation and wildlife agencies, connectivity and conservation non-profits, and universities across the country collectively developed and released a joint statement to decision-makers and a suite of recommendations for elevating climate adaptation considerations into wildlife crossing prioritizations and development.
- ***Wolf, K.D., Davis, K.T.**, and **Higuera, P.E.** 2022. Wildfire effects on microclimate conditions and tree regeneration in mixed conifer forests. Northern Rockies Fire Science Network Research Brief 15, 3 p.
- ***Grasslands Synthesis Project*–Prairie Climate Companion series**:
  - **Miller Hesed, C.D., Yocum, H., Rangwala, I.,** and **Peña, U.** (May 2023). Prairie Climate Companion: Shifting Temperature and Precipitation. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2pp.
  - **Miller Hesed, C.D., Yocum, H**., Chase, K., McKenna, O., **Rangwala, I.,** and **Peña, U.** (May 2023). Prairie Climate Companion: Water Availability. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2pp.

- **Miller Hesed, C.D., Yocum, H., Stephens, J., Rangwala, I.,** and **Peña, U.** (May 2023). Prairie Climate Companion: Wild & Prescribed Fire. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2pp.
- **Miller Hesed, C. D., Yocum, H.**, Symstad, A., Porensky, L., **Rangwala, I., & Peña, U.** (June 2023). Prairie Climate Companion: Native Plant Composition & Diversity. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2pp.
- **Miller Hesed, C.D., Yocum, H.,** Symstad, A., Nagy, R.C., **Rangwala, I.,** and **Peña, U**. (*Planned Release Summer 2023*). Prairie Climate Companion: Invasive Species. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2pp.
- **Miller Hesed, C.D., Yocum, H**., Symstad, A., Wood, D. A., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Plant Productivity. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.
- **Miller Hesed, C.D., Yocum, H.**, Symstad, A., **Miller, B.W., Crausbay, S., Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Transformation. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.
- **Miller Hesed, C.D., Yocum, H.,** Ellison, K., Davidson, A., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Mammals. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.
- **Miller Hesed, C.D., Yocum, H.**, Ellison, K., Ahlering, M., Giocomo, J., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Birds. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.
- **Miller Hesed, C.D., Yocum, H.,** Ellison, K., Zale, A., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Fishes. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.
- **Miller Hesed, C.D., Yocum, H.**, Ellison, K., Lightfoot, D., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Arthropods. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.
- **Miller Hesed, C.D., Yocum, H**., Ellison, K., Ahlering, M., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Wildlife Conservation. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.
- **Miller Hesed, C.D., Yocum, H.,** Martin, J., Klemm, T., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Forages. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.
- **Miller Hesed, C.D., Yocum, H.,** Martin, J., Klemm, T., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Grazers. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.

- **Miller Hesed, C.D., Yocum, H.,** Martin, J., Klemm, T., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Social-Ecological Grazing Systems. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.
- **Miller Hesed, C.D., Yocum, H.,** Elliott, J., **Rangwala, I.,** and **Peña, U.** (*Planned Release Summer 2023*). Prairie Climate Companion: Land Use Change. North Central Climate Adaptation Science Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO. 2 pp.

Media mentions and interviews:

- **Davis , K.T.** et al. (2023): Publication mentioned by 52 news outlets (as of 14 July, 2023). Significant coverage from local to international outlets, including *The Guardian*, *Inside Climate News*, *The Hill*, *The Missoulian*.
- **Higuera, P.E.** et al. (2023): Publication mentioned by 41 news outlets (as of 14 July, 2023). Significant coverage from local to national outlets included *High Country News*, *Scripps TV News*, *Montana Public Radio*, *The Missoulian*, *Bozeman Daily Chronicle*, *Daily Montanan*.
- ***Littlefield, C.** (February 15, 2023)--Public News Service, Experts: Plan for effect of climate change on wildlife crossings
- ***Wolf, K.D.** (October 2022)--University of Montana News Brief, picked up by Science Daily
- ***Wolf, K.D.** (October 2022)--ABC FOX Montana interview

APPENDIX IV: Budget Year 5 Comparison and Justification

Budget Removed from this Version