University of Colorado-Boulder Hosted
North Central Climate Adaptation Science Center
Year 3 Annual Report

July 2021

Submitted by: Jennifer Balch (University Director)

North Central
Climate Adaptation
Science Center

1. TERM SHEET
The Term Sheet of key elements of the USGS-University of Colorado (CU) Boulder Cooperative Agreement for the hosting of the North Central Climate Adaptation Science Center (NC CASC) is located in **APPENDIX I**.

2. ADMINISTRATIVE
Award Recipient: Dr. Jennifer Balch
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Institution of the Award Recipient: University of Colorado-Boulder
Award Agreement Number: G18AC00325
Data of the Report: 30 July 2021
Period of time covered by the report: Oct. 1, 2020 to Sep. 30, 2021

2. PURPOSE AND OBJECTIVES
In Year 3, the NC CASC and its consortium partners continued to make significant progress towards its core goals: partnerships; science; capacity building; and communications/outreach. The efforts we describe in this report are the result of key partnerships with stakeholders, including the U.S. Fish and Wildlife Service (FWS), National Park Service (NPS) Climate Change Response Program, and Tribal Colleges and Tribal students.

Year 3 science highlights include climate science support for FWS, NPS, Tribes, state wildlife agencies and other partners, including the development of climate summary documents and historical and projected time series data for FWS Region 6 Species Status Assessments. Key consortium partner (CP) activities for Year 3 were the Wildlife Conservation Society (WCS) stakeholder workshops on adaptation and conservation planning with the Wyoming Game & Fish Department and formal evaluation of WCS-funded adaptation projects; University of Montana (UM) work on post-fire regeneration, stakeholder workshops, and continued collaboration with the Northwest CASC's *Deep Dive into Managing Post-Fire Vegetation in a Warming Climate*; Conservation Science Partners (CSP)'s leveraged work on transformational drought and visualizing ecological drought; and South Dakota State University (SDSU) outreach to land managers to understand climate information needs.

A highlight of our Year 3 capacity building activities was the *NC CASC Theory of Change* strategic planning process we engaged in with our USGS and consortium partners. Although this activity was not included in the original proposal, the effort greatly strengthened our internal capacity to meet the climate science needs of stakeholders in the North Central region (see **RESULTS: Capacity Building**).

In Year 3, the NC CASC continued to train the next generation of climate adaptation scientists and practitioners. We played a leadership role in the inaugural cohort of the CASC-network Climate Adaptation Postdoctoral (CAP) fellows program, focused on the *Future of Fire*. We are also coordinating with USGS partners to support a CU PI (Holly Barnard) with developing a North Central region project for the second cohort in the CAP fellows program focused on the *Future of Aquatic Flows*. This year the NC CASC supported four summer graduate research assistants, mentored undergraduate students in the University Corporation for Atmospheric Research - Significant Opportunities in Atmospheric Research and Science (SOARS), and the National Science Foundation funded Earth Data Science Corps (EDSC)

programs. Additionally, our Education Team hosted a remote half-day data-intensive Climate Data 101 in Python Workshop, and will be offering this workshop a second time in September 2021 (see **RESULTS: Capacity Building**).

We expanded our communications/outreach capacity in Year 3. In January 2021, we increased the frequency of the NC CASC Webinar Series to a monthly interval, and continued to share events and successes on our website and in our newsletter. Additional efforts in Year 3 arose in response to CASC-network discussions on program management, diversity and inclusion, and early career training programs. Throughout summer 2021, the NC CASC is actively participating in CASC-network Collaborative Visioning discussions related to future investments in climate adaptation science, information provision and support for adaptation and resilience efforts.

In Year 3, COVID-19 continued to cause significant administrative challenges for the NC CASC. COVID-19-related challenges, e.g., childcare constraints and remote schooling logistics, reduced the amount of time that members of our CU team and consortium were able to devote to NC CASC projects. We had one team member take advantage of the federal CARES Act. Additionally, COVID-related travel restrictions and public health guidelines on social-distancing limited our ability to meet some project deliverables (e.g., in-person meetings, stakeholder engagement, and science summits), as outlined in the award Term Sheet (**APPENDIX I**).

3. ORGANIZATION AND APPROACH

A summary table of funded University of Colorado (CU) personnel is located in **APPENDIX II**. This table also includes the roles, responsibilities and percentage of salary on the award for each individual.

Institutions receiving sub-awards: Conservation Science Partners (CSP): Co-PI Shelley Crausbay; South Dakota State University (SDSU) Extension: Co-PI Laura Edwards; University of Montana (UM): Co-PI Phil Higuera; and Wildlife Conservation Society (WCS): Co-PI Molly Cross. James Rattling Leaf (co-PI) is now conducting activities for the Great Plains Tribal Water Alliance (GPTWA) under the CU hosting agreement.

Contributions from unfunded personnel:

- Christy Miller Hesed (Postdoctoral fellow) is the project coordinator for the *Grasslands Synthesis Project* (see **RESULTS: Science**) that is funded by a USGS CASC directed funding research grant.
- Stefan Tangen (Tribal Resilience Liaison) engages regularly with NC CASC staff through a variety of meetings/activities, including but not limited to bi-monthly NC CASC All Hands Staff meeting, monthly Climate Science Support Platform meetings, monthly NC CASC Stakeholder Engagement meetings, monthly Consortium Partner calls, the Rosebud Sioux Tribe Climate Adaptation Planning efforts (see **RESULTS: Science**), and the NC CASC *Theory of Change* (see **RESULTS: Capacity Building**). This position is funded by the Bureau of Indian Affairs.
- TBD (Communication Specialist) will work with the NC CASC team to develop web content, write feature articles, and update the NC CASC Communication Plan. This 60% position will be supported by a USGS CASC funded research project, *Creating a North Central Regional Invasive Species and Climate Change (NC RISCC) Management Network* (PI R. Chelsea Nagy).

Issues hiring or retaining personnel: Max Joseph departed the NC CASC in March 2021, and as a result, Natasha Stavros and/or a graduate student may require some salary support to oversee the maintenance of the Climate Futures Toolbox (CFT) in the interim. Jenny Palomino departed the NC CASC in June of 2020 and Lauren Herwehe Kim took on the training responsibilities of the NC CASC, in coordination with Leah Wasser.

Summary of consortium governance and operations, and interactions. The role of each consortium partner (CP) is to produce actionable science on a dedicated management theme, serve as a connector between researchers and stakeholders in their region, and help guide the overall efforts of the NC CASC. Supported CP activities are co-determined by the CPs and the CU team (detailed in **RESULTS: Science**), and also include funds to support CP-hosted NC CASC meetings (e.g., annual CP meetings). Support from CU includes: support and consultation on the best-available climate science from the CU Climate Science Support Platform (CSSP); communications/outreach support (see **RESULTS: Communications/Outreach**); and access to additional training and skills-building opportunities. Monthly conference calls with Consortium Partner Co-PIs, monthly CSSP calls, and an annual CP meeting are key touch points for consortium interactions.

4. RESULTS

A selection of key results from Year 3 are summarized under our four core goals: partnerships; science; capacity building; and communications/outreach.

Partnerships: Our ongoing stakeholder tracking efforts illustrate that we continue to work with stakeholders from 99 different organizations or groups, including: 26 Tribal Nations or inter-Tribal organizations (1 new in Year 3); 10 Tribal Colleges; 11 Federal government agencies; 15 state government agencies; 17 academic or research institutions (4 new in Year 3); 18 nonprofit organizations (7 new in Year 3); and 2 regional boundary organizations. The Grasslands Project was responsible for 109 out of 167 stakeholder interactions logged in Year 3, and was a key mechanism for creating new connections and strengthening existing ties. James Rattling Leaf's outreach and engagement activities have been key to building/strengthening partnerships with Tribal organizations and colleges in the North Central region (see **OUTREACH**). Part of Heather Yocum's time (10% FTE) coordinating the *Grasslands Synthesis Project* (see *Grasslands Synthesis Project* in **RESULTS: Science**) is supported by the NC CASC Cooperative Agreement, including her effort to coordinate with and leverage the USDA Northern Plains Climate Hub's efforts to conduct a vulnerability assessment for U.S. Forest Service grasslands. To expand the number and depth of our partnerships, in Year 3 the NC CASC initiated a Stakeholder Engagement Working Group (includes Yocum, Rangwala, Wolken, Travis, Tangen and Miller Hesed). The working group is supporting Heather Yocum's efforts to improve stakeholder tracking and refine our Stakeholder Engagement Strategy.

Science: The monthly Climate Science Support Platform (CSSP) calls (co-led by Imtiaz Rangwala and Jane Wolken) continue to be the primary mechanism to promote in-depth science conversations within the NC CASC consortium on topics that inform and advance science activities in support of stakeholder needs in the North Central region. Topics covered in the Year 3 CSSP calls included the: FWS Species Status Assessment process; development of future ecological response scenarios (e.g., Resist-Accept-Direct (RAD) framework); creation of a North Central regional invasive species and climate change (NCRISCC) management network; wildfire risk; and ecological transformation.

In Year 3, the NC CASC continued to advance the understanding of the impacts of climate change and variability on fish, wildlife, plants, water, land, and people by providing relevant and usable science, data and analytic tools to support sound resource management and adaptation in the North Central region. To improve usability of the Climate Futures Toolbox (CFT), a R-Shiny utility was developed by Prasad Thota (see **RESULTS: Capacity Building**) under the direction of Imtiaz Rangwala. Additionally, the NC CASC developed several open workflows and datasets, and maintained other tools (see **APPENDIX III**).

Primary project climate support for FWS, NPS, and state wildlife agencies included developing climate summary documents and historical and projected time series data for FWS Region 6 Species Status Assessments for DeBeque Phacelia and Colorado Hookless Cactus, Cisco and Isely Milkvetch, and Brandegee's Buckwheat. Along with several partners, the NC CASC (Imtiaz Rangwala, Molly Cross, Laura Edwards, John Guinotte, Brian Miller, Stefan Tangen) led the development of the *Ecosystems and Biodiversity* section of the U.S. Climate Resilience Toolkit Northern Plains regional document (web page in development). The NC CASC (Rattling Leaf, Sr., Rangwala, Edwards) are also collaborating with Robin O'Malley (former USGS NC CASC Director) and Chad McNutt (formerly with NOAA/National Integrated Drought Information System (NIDIS); co-founder Livestock Wx) to support the Rosebud Sioux Tribe Climate Adaptation Planning efforts. The NC CASC is providing historic climate and potential futures data for Rosebud Tribal lands with liaison support from James Rattling Leaf, Sr. and Stefan Tangen. Additional project climate support activities with partners are included in **APPENDIX III**.

In Year 3, Max Joseph's NC CASC funded time supported work in partnership with the Playa Lakes Joint Venture and the Bird Conservancy of the Rockies. This effort resulted in a paper that describes an approach to integrate community science and systematic survey data for species distribution modeling (see Joseph et al. 2021 in **APPENDIX V**). Mentoring time by Joseph also supported undergraduate (Ally Fitts) work on watershed delineation using the StreamStats Python package that Earth Lab developed; this work is still in progress.

The NC CASC is able to reach a diversity of partners and land managers throughout the North Central region through the science activities of our Consortium Partners. CP work continued to be disrupted by COVID-19-related issues, including limited capacity, travel restrictions, and an inability to convene in-person events. In addition to those activities described above (**PURPOSE AND OBJECTIVES**), highlights of our Consortium Partners in Year 3 are summarized below (additional details listed in **APPENDIX IV**):

- Conservation Science Partners (CSP): Shelley Crausbay worked with DOI stakeholders (FWS, NPS, BLM) and USFS and NOAA to craft a research agenda for science to support application of the Resist-Accept-Direct framework and effectively support natural resource management in a non-stationary world. Leveraged work by Crausbay includes research on transformational drought and visualizing ecological drought. Additionally, Crausbay's FY20 USGS CASC funded research project, *Exploring the Past to Plan for the Future: Integrating Indigenous Knowledge and Paleo Perspectives to Inform Climate Change Adaptation* with the Ute Mountain Ute Tribe will help inform the NC CASC's co-production model and best practices for combining western science and Traditional Ecological Knowledges.
- Great Plains Tribal Water Alliance (GPTWA): Throughout Year 3, James Rattling Leaf, Sr. has actively connected with Tribes in the North Central region. See list of presentations and webinars in **APPENDIX V**.
- University of Montana (UM): Phil Higuera and Kim Davis hosted a fire manager workshop (February 3-4, 2021), *Managing Post-fire Vegetation Under Climate Change*. Thirty-three participants from 6 state and federal agencies attended this workshop.
- South Dakota State University (SDSU): Laura Edwards and Sean Kelly performed outreach to land managers to understand climate information needs via small focus groups and one-on-one meetings.
- Wildlife Conservation Society (WCS): Molly Cross hosted stakeholder workshops on adaptation and conservation planning with the Wyoming Game & Fish Department. On July 12-13, 2021 she hosted a virtual meeting, *Measuring Climate Adaptation Outcomes* to share and solicit feedback on results from a recent evaluation of adaptation projects supported by the WCS Climate Adaptation Fund.

The *Future of Fire Project* is funded partially by the NC CASC Host Agreement and the National CASC Climate Adaptation Postdoctoral (CAP) Fellows Program. The project is implemented by Postdoctoral fellow Jilmarie Stephens, with supervision by PI Jennifer Balch, and co-mentors Jane Wolken and Imtiaz Rangwala. The NC CASC-led project aims to determine the future size and number of fires, total burn area, and rates of change among years and across space in the contiguous United States. The goal is to explain changes in these fire variables in relation to climate change and changing housing density, which drives human ignitions and fire suppression efforts (Balch et al. 2017). To predict the future (2020 to 2060) size and number of fires, the fire-climate relationships derived in a spatiotemporal Bayesian statistical model by Joseph et al. (2019) are being applied to climate data output from several global climate models (GCM) under two future climate scenarios. The Multivariate Adaptive Constructed Analogs (MACA) dataset consisting of 20 Coupled Model Intercomparison Project (CMIP5) GCMs will be used to provide daily output of requisite variables for future modeling experiments under RCP4.5 and RCP8.5 scenarios (Abatzoglou & Brown, 2012). This research will inform the National CASC CAP Fellows Program regional-to-national syntheses of climate change impacts on fire regimes, fire management, and fire response effort. Additionally, since Stephens was the first CAP Fellow to join the program, she and Wolken collaborated with the National CASC Fire Leadership Team to inform the agenda for the National Climate-Fire Synthesis Workshop (January 13-15, 2021), and Guidance Document to CAP Fellows (March 2021) for the National CASC *Future of Fire Project*.

The *Grasslands Synthesis Project* is funded by a USGS CASC directed funding research grant, and leverages university CASC supported time for Heather Yocum, Bill Travis and Imtiaz Rangwala. The goal of the *Grasslands Synthesis Project* is to establish a baseline of information to inform NC CASC efforts to provide relevant climate science to grassland resource managers. The project is led by PI Heather Yocum and implemented by Postdoctoral fellow Christine Miller Hesed. Despite the challenges of the pandemic, this project has successfully engaged 38 stakeholders (including representatives from BLM, FWS, NPS, Forest Service, Tribal Nations, state natural resource departments, and NGOs) who are volunteering their time to serve alongside NC CASC researchers on two working groups and an advisory committee. The *Management Priorities Working Group* collected, reviewed, and synthesized grassland management plans and documents from Federal, State, and Tribal agencies and NGOs in the North Central region. They identified the key science questions that, if answered, could help grassland managers be successful in meeting their goals and addressing their challenges in a changing climate. These questions are now being addressed by the *Climate & Ecology Working Group*, who are synthesizing existing science to answer questions and identify areas where more research is needed. The Advisory Committee is consulted periodically by both Working Groups to provide additional input to ensure major management issues or scientific considerations are not overlooked.

Capacity Building: A primary goal of the NC CASC is to build a community of researchers and managers, and foster their leadership in science-based resource management. Year 3 capacity building activities in support of this goal are described in more detail below.

To improve our ability to meet the climate adaptation science needs of resource and cultural managers in the North Central region, the NC CASC utilized the expertise of CIRES Education & Outreach to help facilitate the NC CASC (included participation by CU, USGS, CPs, and Tribal Resilience Liaison) through a *Theory of Change* strategic planning process. A *Theory of Change* is a collaboratively-produced, aspirational plan for an organization to effect long-term, transformative change. Through a series of four workshops (January-April 2021) the NC CASC co-developed a shared vision of what change it wants to effect in the world and a roadmap for how we plan to get there in the next 5- to 10-years. A working group (Aparna Bamzai Dodson: USGS Deputy Director; Alisa Wade: USGS Research Coordinator; Jane

Wolken: CU Program Manager; and Stefan Tangen: Tribal Resilience Liaison) is currently developing a summary document that outlines the *Theory of Change* process, results and next steps (Facilitation was supported through the hosting agreement).

In Year 3, we helped train the next generation of earth and environmental scientists and research managers through a data-intensive remote half-day workshop Climate Data 101 in Python Workshop on October 30, 2020. The event was aimed at federal and state agency employees, members of tribal organizations, university researchers, graduate students, and others who use climate data to understand global environmental change in their work. Participants learned how to use Python to open, subset, and visualize MACAv2 climate data downloaded from the Climate Futures Toolbox in the NetCDF hierarchical data format. There was overwhelming interest in this workshop. We received 114 RSVPs from participants from 23 states and were able to reach 45 people in 15 states. Given this interest, to achieve the broadest reach possible (1) we published all training materials online including lessons and assignments, and (2) the event was taught using the cloud-based programming platform JupyterHub, removing the need for software installation or a powerful machine.

The Tribal Climate Leaders Program (TCLP) provides five fully-funded, 2-year fellowships to Native American graduate students affiliated with one of the 32 federally-recognized tribes in the North Central region. The NC CASC welcomed the first PhD student, Shelby Ross (see additional details below) to the Geography Department in Fall 2019, and four masters degree students matriculated in Fall 2020 to the Environmental Studies Program and Department of Civil, Environmental and Architectural Engineering. This year was particularly challenging for the TCLP fellows due to COVID-19-related restrictions and online learning, which limited the benefits from the additional social, professional, and scholarly support from a variety of on-campus and community resources that the TCLP attempts to foster. One TCLP fellow has withdrawn from the program. Six CU programs provide funding for the TCLP, and we continue to seek funding to expand this program to support additional fellows, including applying for the National CASC CAP Fellows Program to Advance Diversity, Equity, and Inclusion in Climate Science Request for Proposal Ideas. These efforts include participating in conversations with the National CASC and other regional CASCs, and working with other CU researchers to include support for Native American graduate students in grant proposals, with the TCLP providing in-kind programmatic support. Heather Yocum is the current TCLP Program Coordinator.

In Year 3, the NC CASC supported four summer graduate research assistants (May-August 2021) at CU Boulder:

- Sarah Jaffe is a PhD student in the Environmental Studies program. She has managed ecological and human-wildlife conflict research projects across the globe, and is currently studying changing human and natural systems, remote sensing, GIS, and how to make Python code reusable for wildlife and land management. During summer 2021, she is working on the *Grasslands Synthesis Project* on spatial analytics and supporting the creation and dissemination of initial results.
- Phurwa Gurung is a PhD student in Geography. His research explores the political ecology of conservation and caterpillar fungus to examine climate change, indigeneity and state building in the Nepal Himalaya. During summer 2021, Phurwa is working on a literature review on the use of traditional ecological knowledges to understand climate change in the North Central region. This summary will provide insight into how to generate effective climate solutions using both indigenous and western science perspectives and best practices for engaging with Tribes.
- Shelby Ross is a PhD student in Geography and also a participant of our Tribal Climate Leaders Program. Her research is focused on understanding the impacts of climate change on health for the Pine Ridge Indian Reservation in South Dakota through qualitative methods of semi-structured

interviews and survey data. During summer 2021, Shelby is working as a graduate research assistant on the *Grasslands Synthesis Project*. Her summer project includes writing a literature review and summary of Tribal Nations grassland and climate change related goals and challenges.

- Prasad Thota is a new Masters student in Civil Engineering. During summer 2021, he is working to support research and data/tool development for the NC CASC Climate Science Support Platform. His activities include the development of an R-Shiny utility for the Climate Futures Toolbox (CFT) and workflows in R to project different downscaled climate metrics, and research into relating drought and heat related climate extremes to ecological response (e.g., wildfire impact, vegetation productivity).

The NC CASC also mentored five undergraduate students in the UCAR SOARS and nine undergraduate students in the Earth Data Science Corps (EDSC) programs. The students worked on projects that support the NC CASC Strategic Science Agenda and offer potential future opportunities to build out additional efforts related to our science and capacity building core goals. Bill Travis and Imtiaz Rangwala led an NC CASC technical project for six EDSC undergraduate students in summer 2020 (not reported in Year 2), guiding students in creating a Python workflow to understand the impact of climate change on the white-tailed ptarmigan in Rocky Mountain National Park. In summer 2021, they are mentoring five EDSC students on a project using big data and Python to relate ecosystem responses to climate drivers in the Northern Great Plains Grasslands ecosystem. The NC CASC also worked synergistically with CU's Earth Lab to train professional students. In spring and summer 2020, Imtiaz Rangwala and Gabriel Senay led an NC CASC technical project for a student in the Earth Data Analytics - Foundations Professional Graduate Certificate program (not reported in Year 2). The project created a reproducible Python workflow for turning raw soil moisture data into a usable and standardized format for study. Additionally, Rangwala provided statistics mentorship to another professional certificate student researching agricultural production in Australia in summer 2021.

Communications/Outreach: Communications and outreach are embedded in all aspects of the NC CASC's activities, and integrate our co-produced science, partnerships, and capacity building efforts. In support of the capacity building and communications and outreach goals of the NC CASC, Katherine Halama was hired as a part time, regular employee when her temp-aide appointment expired in March 2021 and continues to work with Dawn Umpleby on the activities described below. The total combined funded percentage of effort for the two team members is 90% FTE. The NC CASC is currently advertising for a communications specialist (60% FTE) with a focus on writing and content creation.

We utilize the following strategies to broadly communicate our activities within the NC CASC network: NC CASC Website/Newsletter/Social Media: In Year 3, the NC CASC continued to develop its website by adding several new pages: Climate Science Support Platform (CSSP); Case Studies & Summaries; Webinars; Communications Tools; and Employment Opportunities; and upgrading others. The NC CASC website also hosts a For Tribal Partners page that contains content organized by the Tribal Resilience Liaison (Stefan Tangen), including links to the NC CASC Tribal Engagement Strategy (2019-2024), archived issues of the Tribal Climate Adaptation Newsletter (distributed to 250 subscribers), and videos of the Tribal Climate Webinars (attended by 30-50 participants, including 10 Tribal Nations). We continue to issue a NC CASC Newsletter, currently on a bi-monthly basis and distributed via the website, Facebook (281 followers), Twitter (791 followers), and a Mailchimp email distribution list (689 contacts).

The NC CASC YouTube channel has 99 subscribers. It contains 27 videos to date (from 2018 to present), including 11 Tribal Climate Webinars and 10 NC CASC monthly webinars (see below); the number of total views for all webinars for the period October 2018 to July 12, 2021 is 1,929.

In October 2020, the communications team worked with CIRES IT to set up the NC CASC help ticket system (Spiceworks) with the goal of centralizing the submission of communications content. The implementation of this system has increased efficiency and productivity. For the period October 1, 2020 to July 12, 2021, the team has processed 309 individual help ticket requests, with the majority of tickets requiring multi-part responses. NC CASC news is also distributed through CIRES and CU communications channels.

NC CASC Webinar Series: In Year 3, the frequency of the NC CASC Webinar Series increased from bi-monthly to monthly. 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. Topics for 2021 included revised thinking on adaptation, realizing drought, wildfire and climate change scenarios, changing fire regimes, and Grass-Cast, a grassland productivity forecast to inform rangeland decisions developed by the USDA Northern Plains Climate Hub. Since November 2020, we have had 673 registered participants (495 individuals, 98 who attended more than one webinar; attendance is ~60-75% of registered participants). Registrants came from 19 federal agencies, 12 states, 13 Tribal nations, 47 academic institutions, 24 non-profit organizations, 5 CASCS, and 6 private organizations.

5. OUTREACH

NC CASC researchers produced 24 peer-reviewed publications (includes one *In Press*, and one *In Revision*), technical reports and op-eds in Year 3. Additionally, the NC CASC engaged in several outreach activities, including 18 Tribal focussed presentations/webinars, 10 major stakeholder engagement activities, and 16 media requests (see **APPENDIX V**).

6. NEXT STEPS

The mission of the NC CASC is to generate the science to help resource managers in the North Central region adapt to a changing world. Our Strategic Science Plan (2019-2024), USGS-University of Colorado Boulder Cooperative Agreement (see **APPENDIX I: Term Sheet**), and shared vision (see *Theory of Change* in **RESULTS: Capacity Building**) of our core goals (partnerships, science, capacity building, and communications/outreach) will help guide our Year 4 activities.

Partnerships: Key partnership building activities will include targeted stakeholder engagement. In Year 4, we will continue to build partnerships with researchers and managers around fire, ecological transformation, grasslands management, invasive species, and climate futures. We will continue to strengthen partnerships within the CASC-network through our engagement in cross-CASC meetings (e.g., Network Collaboration Call, Program Manager Call, Communications Call, and Decolonize our Work Group). Further, since COVID-19 inhibited us from hosting the in-person Climate Solutions Summit originally proposed for Year 3, we will explore ways to host a meeting, or several smaller remote engagements, with the purpose of bringing together students, scientists, educators, and stakeholders engaged in NC CASC efforts. We will connect with our colleagues and build off of the successes of our regional CASC partners who have run successful remote meetings in this year, e.g., Northwest Climate Conference.

Science: The NC CASC will continue to actively engage in cross-CASC science activities, including the National CASC CAP Fellows Program for the *Future of Fire* and *Future of Aquatic Flows* postdoctoral cohorts, and the CASC-network Collaborative Visioning discussions and related products. To refine our understanding of climate adaptation science, we plan to conduct a systematic assessment of how climate scenarios have been incorporated into species status assessments, wildlife management plans, and landscape scenarios. Additional key science efforts in Year 4 include: continued climate science

support via several FWS species status assessments, climate information/services to the Rosebud Sioux Tribe, and the development of datasets and workflows (including Shiny App utilities); and outreach products for the *Grasslands Synthesis Project* (e.g., a USGS technical report for each working group, and a peer-reviewed journal article). Consortium Partner activities in Year 4 include CSP research informed by the RAD framework; continued work by UM to develop science and outreach tools to aid in post-fire revegetation; and continued outreach by SDSU to local stakeholders to understand climate science needs. See **APPENDIX IV** for additional details on planned workshops and meetings hosted by our Consortium Partners.

Capacity Building: The NC CASC recognizes the importance of building capacity and increasing diversity, equity, and inclusion in science. We will continue to look for ways (both in- and outside the CASC-network) to expand the Tribal Climate Leaders Program (TCLP) beyond the inaugural cohort. Due to the high interest in the Climate Data 101 in Python Workshop, the NC CASC education team plans to offer this training a second time in September 2021. In Year 4, we also plan to host at least one additional training focused on creating open and reproducible workflows, and working with heterogeneous data formats in support of climate data analysis.

Communications/Outreach: We will continue to expand on our communications/outreach efforts with the website (e.g., interactive webpages for featured projects such as the *Future of Fire* and *Grasslands Synthesis Project*), newsletters, and monthly webinar series. As we transition from Year 3 to Year 4, we will be expanding our NC CASC team to include a part-time Communication Specialist (see also Contributions from unfunded personnel) that will assist the NC CASC with developing web stories and targeted project summary documents (e.g., 2-page topical outreach materials), and refining our communications plan. The Communication Specialist will also increase our capacity to engage in communication activities within the broader CASC-network (e.g., monthly CASC Communications Call).

7. BUDGET

Table 1 below and the accompanying budget justification provide a summary of annual award expenditures in comparison to the proposed budget for Year 3.

Table 1. Comparison of Year 3 original budget, revised budget and amount changed in revised budget to anticipated ending balance (September 30, 2021).

Cost Category	Current Budget Year 3	Actual Expenditures (as of 6/30/2021)	Anticipated Expenditures (7/1 – 9/30/2021)	Anticipated Ending Balance (9/30/2021)
Salaries and wages	402,275	243,075	86,579	72,621
Fringe benefits / labor overhead	141,844	88,070	31,160	22,614
Equipment				
Supplies	1,591	1,661		
Services or consultants	1,910			1,910
Travel	23,638			23,638
Publication costs				
Other direct costs	**175,630**	**1,807**	**1,024**	**172,799**
Total Direct Costs (items 1 through 8)	746,888	334,613	118,763	293,512
Indirect cost/General and administrative (G&A) cost	323,905	180,759	64,132	79,014
Amount proposed (items 9 + 10)	1,070,793	515,372	182,895	372,526
CU Cost Share	71,248	59,180	2,179	9,889
Total Federal and non-Federal Amounts	**1,142,041**	**574,552**	**185,074**	**382,415**

Budget spending: At the time of submission of this annual report, we anticipate that 33.5% of our Year 3 budget will remain unspent. The anticipated remaining Year 3 budget of $382,415 is primarily attributed to unspent salaries and wages, and fringe benefits/labor overhead costs related to position vacancies, and COVID-19 reductions in percentage of effort by personnel (see Table 1 above). We plan to spend approximately $100,000 in Salary, Fringe and F&A for Dawn Umpleby, James Rattling Leaf, and Jilmarie Stephens with these unspent funds, if we receive a No Cost Extension to Budget Year 3.

We currently have $162,500 remaining to spend for the Year 3 Subawards (included under Other Direct Costs), and are working with our consortium partners to determine what unspent funds they will have remaining at the end of Budget Year 3. This information will be included in our request for a Budget Year 3 No-Cost Extension and Concurrent Spending of Year 3 and Year 4 funding.

Due to the COVID-19 pandemic, it was not possible to spend the Budget Year 3 funds set aside for Travel ($23,638) and Participant Support ($20,651). If we receive an extension to Budget Year 3, and we undertake these planned activities we could expense the full-loaded cost for Travel to reach $31,800 for Travel (with F&A added) and $20,651 for Participant Support.

The proposed planned expenditures outlined above would spend down approximately $382,000 of the total amount we expect to have unspent by September 30, 2021.

CU Cost Share: CU Boulder has spent $51,980 towards its in-kind commitment for Year 3 ($71,248), which primarily consists of support for the Tribal Climate Leaders Program students. We will continue spending on in-kind support for the project during future project years.

8. LITERATURE CITED

- Balch, J.K., Bradley, B.A., Abatzoglou, J.T., Nagy, R.C., Fusco, E., and Mahood, A. 2017. Human-started fires expand the fire niche across the U.S. (1992-2012). *Proceedings of the National Academies of Science*, 114(11):2946-2951.
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APPENDIX I--Term Sheet

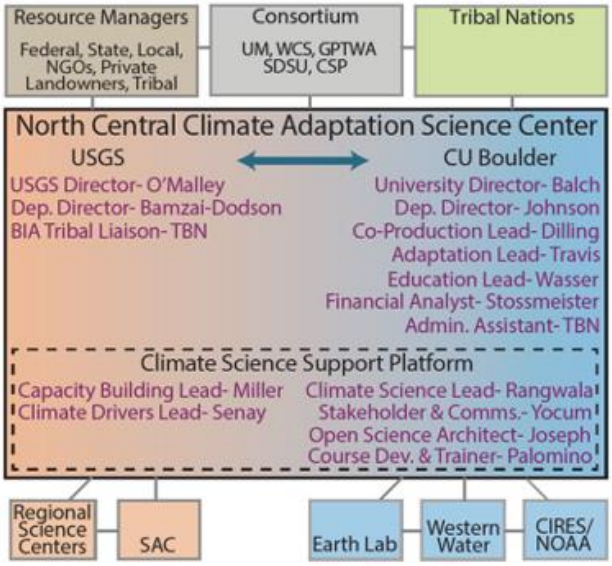
KEY ELEMENTS OF THE
USGS-UNIVERSITY OF COLORADO, BOULDER (ET AL.)
COOPERATIVE AGREEMENT FOR THE HOSTING OF
THE NORTH CENTRAL CLIMATE ADAPTATION SCIENCE CENTER

This information is excerpted from the University of Colorado proposal dated 04/09/2018. The intention of this cooperative agreement document is to guide activities of the North Central Climate Adaptation Science Center. These activities may change as a function of co-developed priorities and strategic directions identified and developed by the USGS Director and team, University Director and team, and with input from the stakeholder communities.

EXPECTATIONS & DELIVERABLES

1. North Central Climate Adaptation Science Center (NC CASC) will host an annual one-and-a-half-day review meeting coordinated by the National Climate Adaptation Science Center (NCASC) to highlight the past year's accomplishments in science, regional dialogue, capacity building, and communications
    a. Review will also identify and discuss any administrative issues to be addressed
2. A standalone annual report, as required by the cooperative agreement, will be provided prior to the annual review and include the following elements:
    a. Specific examples of actionable science, including quotes, stories, and links to policy- and decision-making
    b. List of students, post-docs, and Fellows, their major accomplishments during their time associated with the NC CASC (e.g., publications, presentations), and how their work relates to NC CASC priorities and Science Agenda
3. All NC CASC projects will comply with NCASC data management policies [https://casc.usgs.gov/data-policies-and-guidance] and USGS Fundamental Science Practices, where appropriate.
4. CU Boulder will report on any federally-funded projects for which data management activities are deficient based on project agreements
5. Quarterly meetings will be held with the NC CASC Data Steward regarding progress on data management
6. All NC CASC products will comply with the CASC Communication Guidelines
7. Work to help implement recommendations as relevant from the five-year review report, noting that not all items are applicable to the CU Boulder-hosted NC CASC. Five-year review report recommendations can be found in Appendix I.
8. NC CASC will submit the following communication products to NCASC:
    a. During the first year of the cooperative agreement:
        i. At least six Land Resources Mission Area Highlights
        ii. At least three items for the Climate Adaptation Insights Newsletter
    b. On a quarterly basis, beginning the second year of the cooperative agreement onward, on average:
        i. At least six Land Resources Mission Area Highlights
        ii. At least three items for the Climate Adaptation Insights newsletter
        iii. At least one resource management- or climate policy-relevant success story from the CASC, to be used in promoting the CASC's work
9. NC CASC University /program/communications and/or program staff will attend the majority of monthly CASC Network Staff calls.
10. At the conclusion of the cooperative agreement, NC CASC will
    a. Produce a final report summarizing actionable science activities, scientific achievements, educational and training accomplishments, and communications highlights from the 5-year period of performance
    b. Host a multi-day 5-year review of the NC CASC that will be coordinated by NCASC.
    c. Deliver website/products to NCASC (in the event of a change in the NC CASC host at the end of the agreement period)

INSTITUTIONAL ARRANGEMENTS



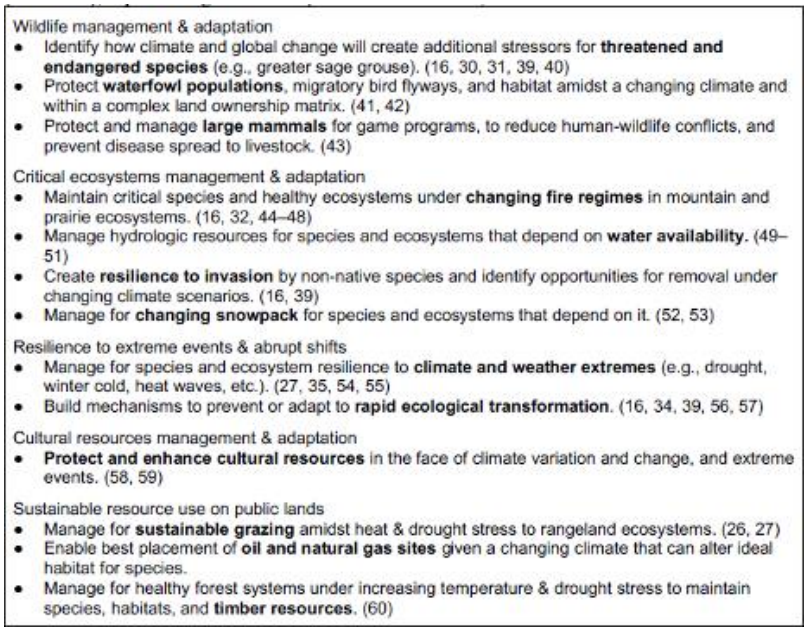
1. Proposal submitted by University of Colorado, Boulder (CU Boulder) with consortium partners University of Montana (UM), South Dakota State University (SDSU), Conservation Science Partners (CSP), Wildlife Conservation Society (WCS), and the Great Plains Tribal Water Alliance (GPTWA).
2. Professor Jennifer Balch will serve as the University Director/Principal Investigator of the NC CASC.
3. The co-production lead (Dilling) and the adaptation lead (Travis) will provide management and technical guidance to the university director (Balch).
4. Through the co-production process, CU Boulder will identify science goals and internal evaluation metrics in tandem and have regular check-ins related to the following roles, responsibilities, and resources. The university director (Balch) will get input from the consortium, seeking consensus on that year's priorities, balancing identified priorities and previous funding amounts.
5. The responsibility of each consortium partner is to: lead a workshop with resource managers in Years 1 or 2, identify and co-develop key science and training opportunities in coordination with USGS strategic science directions and needs in the region; mentor an early-career scientist in a CASC research project; contribute to decision making of the consortium; and participate in other workshops and summits when relevant.
6. Each year (years 2-5), the university director (Balch) will request one-page proposals to support 1-2 early-career scientists (graduate student, postdoc, early careerist, or other necessary salary support) to work directly with the consortium co-PIs on emergent science needs identified by the co-production workshop. If additional areas of expertise are needed, consortium co-PIs may also encourage other researchers at their institutions to submit proposals.
7. Additional funding opportunities through USGS will be disseminated by the co-PIs through their institutional networks.
8. The consortium partners are expected to host one of the annual consortium meetings and one of the climate science training workshops at their respective institutions. Dedicated resources are allocated for the consortium partners to fund these efforts.
9. Collective agenda-setting for the consortium activities will be accomplished through shared decision-making and sustained communication (monthly webinars, visits by host staff, and group meetings. A committee structure will provide input and set priorities on key management goals (e.g., rapid response capability, local-regional-national dialog, tribal engagement, and other priorities). Sustained communication among the CPs will involve monthly call-in meetings, alternately hosted by the university director (Balch) and USGS director

(O'Malley) to accommodate discussion of important issues, and a yearly in-person meeting that rotates to each consortium location, with the first being held in Boulder, CO.

10. Additional meetings, at the appropriate tier and cadence, will be held (e.g., weekly meetings of the CU and USGS leadership team, bi-monthly "all-hands" virtual meetings with everyone involved in the CASC, and frequent event-coordination meetings as appropriate).
11. Integral to the NC CASC model will be ongoing stakeholder touchpoints and appropriate course corrections.

SCIENCE

1. Key science opportunities for the CU Boulder NC CASC will include: i) Delivering the best climate science for resource managers derived through co-production; ii) Capitalizing on the wealth of big, diverse data to inform resource management decisions at an appropriate scale in the region; and iii) Leveraging work within and across CASCs through open science to synthesize information on climate sensitive wildlife, critical habitats, and cultural resources.



Wildlife management & adaptation

- Identify how climate and global change will create additional stressors for **threatened and endangered species** (e.g., greater sage grouse). (16, 30, 31, 39, 40)
- Protect **waterfowl populations**, migratory bird flyways, and habitat amidst a changing climate and within a complex land ownership matrix. (41, 42)
- Protect and manage **large mammals** for game programs, to reduce human-wildlife conflicts, and prevent disease spread to livestock. (43)

Critical ecosystems management & adaptation

- Maintain critical species and healthy ecosystems under **changing fire regimes** in mountain and prairie ecosystems. (16, 32, 44–48)
- Manage hydrologic resources for species and ecosystems that depend on **water availability**. (49–51)
- Create **resilience to invasion** by non-native species and identify opportunities for removal under changing climate scenarios. (16, 39)
- Manage for **changing snowpack** for species and ecosystems that depend on it. (52, 53)

Resilience to extreme events & abrupt shifts

- Manage for species and ecosystem resilience to **climate and weather extremes** (e.g., drought, winter cold, heat waves, etc.). (27, 35, 54, 55)
- Build mechanisms to prevent or adapt to **rapid ecological transformation**. (16, 34, 39, 56, 57)

Cultural resources management & adaptation

- **Protect and enhance cultural resources** in the face of climate variation and change, and extreme events. (58, 59)

Sustainable resource use on public lands

- Manage for **sustainable grazing** amidst heat & drought stress to rangeland ecosystems. (26, 27)
- Enable best placement of **oil and natural gas sites** given a changing climate that can alter ideal habitat for species.
- Manage for healthy forest systems under increasing temperature & drought stress to maintain species, habitats, and **timber resources**. (60)

REGIONAL DIALOGUE AND INFORMATION SHARING

1. CU Boulder will leverage existing collaborations and build new partnerships with DOI and USGS centers and programs that align with the NC CASC efforts, including with the USGS' Fort Collins Science Center, Geosciences and Environmental Change Science Center, Earth Resources Observation and Science Center, Natural Hazards Science Center, the seven Cooperative Research Units in the region, water science programs including the Center for Water, Earth Science and Technology that is located on the campus, the Southern Rockies Fire Science Network, the Landscape Conservation Cooperatives in the region, and/or other assets, as the partnerships become relevant and desired.
2. CU Boulder will follow a process that begins with understanding stakeholder needs in the context of their most pressing and climate-relevant challenges. CU Boulder will also deliberately build mechanisms to bring researchers and decision makers together over the grant period, as needs and coproduction opportunities become clear as interactions occur over some length of time. CU Boulder will build on the progress that has already been made in understanding what managers need, including efforts of the previous NC CASC host and consortium and will work directly with managers in the region in partnership with consortium members, the Stakeholder Advisory Committee (SAC), and their collective connections on the ground.
3. **Stakeholder-Scientist Co-production Meetings**: In Years 1 or 2, each consortium partner will host an opening ideas collider, a stakeholder-scientist meeting (15-20 participants, mostly local) on an identified management theme that aligns with relevant management needs for their subregional interests and science expertise. This initial meeting will identify key opportunities for science contributions and will result in design projects for

early careerists to work on. In Years 2, 3 or 4, each CP will also host a solutions collider, with clear communication of actionable science derived or developed for stakeholders' needs within a climate adaptation solutions framework. These meetings will be adapted based on consortium partner needs and networks, and continued iterative engagement would be expected in-between workshops.

4. **Climate Solutions Summits**: In Years 3 and 5, CU Boulder will host an unconference style symposium with 50+ participants on solutions to five natural and cultural resource management themes, identified in advance with consortium partners. This semi-annual summit provides a mechanism to scale up engagement, with three specific goals:
    a. to provide a mechanism for connection and collaboration across the many different people connected with the NC CASC;
    b. to make climate data, code, workflows, and other information accessible to resource managers and scientists; and
    c. to identify adaptation solutions to common challenges across the different NC CASC efforts.
5. **Synthesis Working Groups:** Will cover the following topics and objectives.
    a. Drought, Wildfire, and Extreme Weather and
    b. Wildlife and Plants
    c. The objective of these focused working groups (10 individuals; targeting PIs funded across the CASC network) is to create a national network of researchers and stakeholders who have already co-produced work on themes of interest to the NC CASC, to leverage that work in an open science framework, and build toward useful applications for critical decisions in the NC region.
6. **The Climate Science Support Platform (CSSP)**, a "go-to" resource for climate science expertise and services, will allow for efficient and effective coordination and application of climate science.
    a. Through Earth Lab's strengths in deriving open, data-intensive solutions, the CSSP will develop 3-5 reproducible workflows annually around new or unmet needs identified through co-production that could be leveraged for multiple use cases, primarily serving the CPs and USGS-funded projects.
    b. CU Boulder team members (Climate Lead Rangwala, Deputy Director Johnson, Stakeholder & Communications Lead Yocum, and Open Science Architect Joseph) and USGS team members (Miller and Senay) will form the collective expertise of the CSSP.
    c. The CSSP will generate common solutions to common challenges identified through stakeholder engagement.
    d. The CSSP will be capable of deriving multiple future climate scenarios based on the latest climate science and a manager's area or species of interest.

EDUCATION, TRAINING AND CAPACITY BUILDING

1. NC CASC education efforts will target two audiences:
    a. current resource managers who need to learn scenario planning, vulnerability assessments, adaptation planning, and ecological impacts modeling
    b. students and early-career professionals who require data skills, synthesis approaches, and co-production practices to better understand climate impacts for resource management.
2. A needs assessment will be conducted in Year 1, in coordination with the stakeholder engagement workshops.
3. Graduate students, postdocs, and early-careerists will interact with end-users, enhancing their training by helping them understand and contribute to solutions for stakeholder problems.
4. CU Boulder will contribute to the National Conservation Training Center curriculum, if desired and appropriate with the developed materials, in geospatial technologies, statistics and modeling, decision analysis, and climate change. USGS CASC leadership team members will be invited to become adjunct faculty in an appropriate unit to engage with the education mission of the university, including serving on graduate advising committees. The adjunct process involves a statement of interest, colloquium, and faculty vote.
5. **Climate Science Training Workshops for Resource Management:** CU Boulder will design two separate sets of two-day workshops for students and stakeholders, both held annually, starting in Year 2. The first set of workshops will be taught at Earth Lab's VizStudio to 20 undergrad and grad students, providing skills in climate, land surface, and vegetation data, based on the successful program already taught by Wasser, Data Carpentry for Geospatial Data. These workshops will be open to students from universities and colleges across the region (selection based on an application process). Travel and participation of four undergraduate

students from tribal colleges will be supported annually. These workshops will be taught by both the CU Boulder NC CASC team and Carpentry instructors. The second set of workshops will be customized to NC stakeholder needs and taught on a rotating basis at each consortium location for 20 professionals and students. All developed teaching materials will be publicly available through Earth Lab's earthdatascience.org website. The Climate Solutions Summit and Synthesis Working Groups will also provide half-day climate workshops (based on developed materials for the two sets of workshops) to stakeholders, students, and scientists.

6. **Tribal Undergraduate & Graduate Student Climate Science Scholars Program:** CU Boulder will host four Tribal Undergraduate Climate Science Scholars each summer at CU Boulder for climate science trainings (see above), plus activities that introduce them to the CU campus and faculty. CU Boulder will sponsor five Tribal Graduate Climate Science Scholars, in a cohort-based, two-year Masters degree program (Years 3-5). CU Boulder will call on the consortium network (e.g., co-PI Rattling Leaf) and the CU Boulder faculty and researchers engaged with tribal communities to help recruit and mentor students.
7. **Education Impact Evaluation & Reporting:** Earth Lab has developed an open qtoolkit package to streamline survey data analysis and generate reports. CU Boulder will use and enhance this rubric to improve the education program and align with NC CASC goals. Reports will be shared with the USGS CASC Director and NCASC.

COMMUNICATIONS AND DATA MANAGEMENT

1. CU Boulder will develop a comprehensive and professional communications plan to support this effort, with the help of CU Boulder's Communications teams.
2. Key components of the CU Boulder Communications plan include responding to information needs of resource managers, disseminating usable, open, and reproducible science, and providing a mechanism for communication and idea exchange across stakeholders and scientists.
3. CU Boulder will host monthly webinars to reach out to partners in the region, utilizing Earth Lab's VizStudio to engage remote participants in virtual collaboration, track progress, provide updates, and iterate processes.
4. CU Boulder will host a new Drupal-based website for the NC CASC. Stakeholder & Communications lead (Yocum) will maintain website content with additional efforts supported by CIRES communications and IT staff.
5. CU Boulder will comply with USGS and DOI communication requirements, reporting upcoming activities on a weekly basis, and reviewing CASC communication with NCASC and USGS Communication staff.
6. CIRES IT will ensure that the website is universally accessible.
7. CIRES communications staff will help distribute information through their broad network of 100s of media outlets and strong connections with regional and national journalists.
8. CU Boulder will also ensure that all research activities will comply with USGS Public Access Plan and Data Management Policies and will apply best practices for open science.
9. Data created during these activities will be submitted to NCASC or the CASC Data Steward when projects are complete.

SPACE

1. The NC CASC will be housed in dedicated Earth Lab space in the Sustainability, Energy and Environment Complex (SEEC) on CU's east campus
2. Office space will be provided to all staff identified in this proposal, with workstations, dedicated IT support, internet connections, printers/copiers, whiteboards, teleconferencing, kitchen, and collaboration spaces. Any needed additional space can be configured in about two months.
3. Closed door offices will be provided for the USGS Director and Deputy Director.
4. The space is flexible and allows for expected growth over five years (e.g., IT connections already in place).
5. Office maintenance (e.g., changing light bulbs) is provided by SEEC and CU Facilities Management, as part of F&A.
6. CU Boulder would welcome a site-visit and discussion of telecommuting options for existing NC CASC USGS staff and the BIA Tribal Liaison, if needed.
7. Indirect costs for facilities and administrative expenses (F&A) are charged according to the University's federally negotiated rate. F&A costs cover a portion of the infrastructure needed, including

utilities such as light and heat, telecommunications, and the administrative functions necessary to comply with regulations and conduct business.

8. Indirect costs on subcontracts to consortium members and other "pass-through" funds will be charged the full indirect cost charge only on the first $25,000.

ADMINISTRATIVE

1. The NC CASC will benefit from the efficient administrative foundation already in place for Earth Lab via CIRES, including financial analysis, HR, event planning, IT support, and communications/outreach.
2. **CIRES administrative staff** are fully capable of handling complex cooperative agreements, subawards, and other transactions of the CASC in a timely and efficient manner. These services are supported by the F&A charge.
3. **Clerical/administrative support**, including room scheduling, incidental purchasing, etc. are provided by Earth Lab and CIRES to all participants in the NC CASC, including University and USGS staff.
4. A dedicated CIRES financial analyst will provide post-award grant management.

DIRECT & INDIRECT COSTS

1. **Office Supplies:** CU Boulder requests support in each year of the project to cover miscellaneous office supplies (e.g., connecting cables for workshops and remote participation in CASC meetings), that would exceed the amount of office supplies that would ordinarily be funded through indirect cost recovery.
2. **Laptop Computers:** CU Boulder requests funds for (3) laptop computers in Year 1 and (1) laptop computer in Year 2 to support the leadership team and postdocs associated with this project which will include substantial travel, and meetings outside of the office.
3. **Amazon Web Services:** CU Boulder requests funds during each year of the project for cloud compute capabilities dedicated to the CASC, specifically, Amazon Web Services S3 data storage and EC2 cloud compute infrastructure to assist the Climate Science Support Platform in providing information to the consortium partners.
4. **Website Design Contract Services:** CU Boulder will host a new Drupal-based website for the NC CASC. Will hire a web consultant to build initial platform and assure the type of functionality critical to a collaborative system in Year 1. The CU team will then update content to the website for the CASC over the five-year performance period. The provider of these services has not yet been identified.
5. **Travel funds**: CU Boulder requests travel funds to send 2 project personnel from the Climate Science Support Platform to travel to participate in stakeholder-scientist meetings at each of the Consortium Partner locations (Fort Collins, CO; Missoula, MT; Bozeman, MT; Rapid City, SD; Brookings, SD) twice during the project (either Years 1 and 3 or 2 and 4). Funds will cover lodging, per diem, airfare, and ground transportation, as appropriate to each location.
6. **Synthesis Working Groups**: CU Boulder requests funds for synthesis working groups in Years 2-5 to bring together 10 scientists (at least one individual from each CASC) to develop a "State of the Science" report and identify data, code, and/or workflows that could be made open and reproducible around a common theme (e.g., how fire regimes will respond to climate change). Funds will cover lodging, airfare, ground transportation, and per diem for 10 people/working group and four working group meetings (1/year in Years 2-5).
7. **Publications:** CU Boulder has requested funds for two publications per year in Years 2-5.
8. **Undergraduate Travel:** CU Boulder has requested funds for undergraduates to travel from anywhere in the seven-state North Central region (travel from South Dakota and Kansas is used as a model) to Boulder, CO to participate in a Climate Science Workshop Years 2-5.
9. **Climate Solutions Summit Travel:** CU Boulder requests funds for 30 people to travel to the Climate Solutions Summit in Years 3 & 5.
10. **Members of the Carpentries Travel:** CU Boulder requests funds for members of the Carpentries to attend and co-teach Climate Carpentry workshops in Years 4 & 5, to provide a mechanism to bridge between efforts. Funds requested include airfare, lodging, and per diem.

11. **Climate Science Workshops:** CU Boulder requests funds in Year 2 and (1) Climate Science Workshop per year in Years 3-5. Funds are requested to cover travel and lodging expenses of 2 instructors, plus modest amounts to cover catering for breaks.
12. **Climate Solutions Summits:** CU Boulder requests funds for (2) Climate Solutions Summits each year in Years 3 and 5. CU Boulder will host a symposium (50+ participants) around five natural and cultural resource management themes (identified in advance to meet the goals of the NC CASC). These will include consortium partners, the SAC, and other stakeholders working collectively over 3-4 days. Requested funds for the Climate Solutions Summits include catering and material costs.
13. **Support for Consortium Partner Activities:** CU Boulder requests funds in Yrs 1-5 for the consortium partners to participate in co-production meetings, an ideas collider and solutions collider, a Research Assistant, and travel for annual consortium partner meetings, with the exception of the year when that consortium partner hosts the meeting. The Research Associates will work with the consortium co-PIs on emergent science needs identified by the co-production workshops (referenced in Section 1.3 of the proposal, first paragraph, and in the budget justification under the subcontracts, which is now being folded into budget and responsibilities of CU Boulder directly), such as developing climate adaptation plans, determining future climate scenarios, or assessing species of concern, and informed by the Strategic Science Agenda. The original scope of work outlined in the proposal remains the same, including working with each of the Consortium Partners: University of Montana, South Dakota State University (SDSU), Wildlife Conservation Society (WCS), Conservation Science Partners (CSP), and Great Plains Tribal Water Alliance (GPTWA). This revision to our budget reflects a shift in how resources will be distributed to accomplish the proposed tasks, specifically supporting Consortium efforts. Research Associate 1: Research Associate 1 will be responsible for activities related to emergent science needs identified by the GPTWA (Year 1 efforts), CSP (Year 2 efforts), and University of Montana (Year 3 efforts). Funding will pay for 12 months of salary in Year 1 and Year 2 (100% time) and 12 months of salary (69.8% time) in Year 3. Research Associate 2: Research Associate 2 will be responsible for activities related to emergent science needs identified by SDSU (Year 2 efforts) and WCS (Year 3 efforts). Funding will pay for 12 months of salary in Year 2 (100% time) and 12 months of salary (69.8% time) in Year 3.
14. **Other Direct Costs:** Geography and Environmental Studies will also provide recruitment funds, designated as other operational costs, to recruit students from tribal backgrounds to the graduate program. Furniture and modest renovation costs will be covered in Year 1 associated with hosting the NC CASC in Earth Lab space.

IN-KIND AND RELATED SUPPORT

1. Earth Lab capability can be leveraged through the NC CASC to translate discoveries into usable knowledge and to derive data-intensive solutions for resource management problems.
2. Strong CU Boulder institutional support exists for hosting the NC CASC as evidenced by in-kind contributions from the largest college, Arts & Sciences, the largest institute, CIRES, Earth Lab, Geography, Environmental Studies, and the highest levels of university leadership, the Research & Innovation Office (RIO).
3. Graduate student participation in the Masters program is funded through contributed cost share funds from A&S, the Graduate School, and CIRES. The Masters program is available to graduate students through the Department of Geography, which will also provide recruitment funds.
4. Earth Lab will support a 50% time, 12-month, administrative assistant for Years 1 & 2, and furniture and modest renovation costs in Year 1 associated with hosting the NC CASC in Earth Lab space.
5. CU's Office for Outreach and Engagement will provide 10% time, 12-months in Years 1 & 2, of Community Outreach Program Manager Dr. Jenny Briggs (formerly Research Ecologist, USGS Geosciences and Environmental Change Science Center) to assist NC CASC in collaborative engagement with partners both on- and off-campus.
6. Fringe benefits are calculated on salary supported through cost-sharing, per the University's federally negotiated Rate Agreement with the Department of Health and Human Services (DHHS). The following fringe benefits are included in the fringe benefit rate(s): FICA, Workers' Compensation, Health/Life/Dental, Disability Insurance, Annuitant's Insurance, Unemployment Insurance, Retirement Plans, EcoPass Bus Pass, and Termination Pay.

7. CU Boulder will invest over a third of the budget in the consortium partners' subcontracts, travel, workshops, and training that is critical to consortium activities, and two synthesis postdocs that can leverage individual activities.

STAFF / SALARIES / CONTRACTS

1. **Graduate Research Assistants:** Five graduate students will be funded for Years 3-5 for 20 hrs/week for the spring and fall semester and during the summer at 20-40 hrs/week. The anticipated salary for graduate research students is estimated based in the current pre-composition rate. Funds will also be supported in Years 3-5 of the project for tuition remission for Graduate Research Assistants working on the NC CASC projects in the Tribal Graduate Climate Science Scholars Program.
2. **Community Outreach Program Manager**: CU's Office for Outreach and Engagement will provide 10% time, 12-months in Years 1 & 2, of Community Outreach Program Manager Dr. Jenny Briggs (formerly Research Ecologist, USGS Geosciences and Environmental Change Science Center) to assist NC CASC in collaborative engagement with partners both on- and off-campus.
3. **Administrative assistant:** Earth Lab will support a 50% time, 12-month, administrative assistant for Years 1 & 2.
4. **Dr. Jennifer Balch (University Director):** Balch will be responsible for coordinating all elements of this project, including overseeing the leadership team and consortium partners. Funding will pay for 1 month of summer salary (100% time) and 1 month of AY salary (90% time) in Years 1-5. One month of support and one course buyout is requested per year to support Balch in the role of University Director/Principal Investigator of the NC CASC.
5. **Dr. Brian Johnson (Deputy Director):** Johnson will oversee the operations of the CASC. He will manage the climate science support platform team, directly supervising Rangwala, Yocum, and Joseph. Funding will pay for 50% time for 12 months of his salary during Years 1-5.
6. **Dr. Lisa Dilling (Co-Production Lead):** Dilling will guide the co-production efforts of the CASC including working with Yocum, the consortium partners, and additional resource managers. Funding will pay for 0.25 months of summer salary (100% time) in Years 1-5.
7. **Dr. William Travis (Adaptation Lead)**: Travis will guide the development of adaptation strategies and their implementation through the co-production and consortium process. Funding will pay for 0.25 months of summer salary (100% time) in Years 1-5.
8. **Dr. Leah Wasser (Education Lead)**: Wasser (a certified Carpentry instructor who has taught workshops across the globe) will oversee the development of the lessons for climate data. Funding will pay for 1 month of salary (50% time) in Years 1-2 and 1 month of salary (25% time) in Yrs 3-5.
9. **Dr. Imtiaz Rangwala (Climate Science Lead)**: Rangwala will provide primary climate expertise to the NC CASC-directed projects and will work with boundary organizations to facilitate effective integration of climate research into natural resource management and planning. Funding will pay for 50% time for 12 months of his salary during Years 1-5.
10. **Dr. Heather Yocum (Stakeholder & Communication Lead)**: Yocum will facilitate research-cooperation processes, convening and structuring stakeholder engagement between scientists and information users, expanding the stakeholder base, and soliciting user feedback to refine information content and delivery platforms. She will also be responsible for developing content for communications strategy. Funding will pay for 50% time for 12 months of her salary during Years 1-5.
11. **Dr. Max Joseph (Open Science Architect)**: Joseph will develop open source, reproducible software, workflows and accompanying trainings to increase access and usability of various data sources. Funding will pay for 15% time (of 12 months) in Year 1, 25% time (of 12 months) in Year 2, and 45% time (of 12 months) in Years 3-5, representing a scaled effort that follows development of workflows and identification of needs through the Climate Science Support Platform team.
12. **Dr. Jenny Palomino (Education Trainer)**: Palomino will assist Wasser with the development of course materials for the Climate Science Workshops. Funding will pay for 25% time for 12 months of her salary during Years 1-5.

13. **Postdoctoral Researcher (TBN)**: The two postdocs will work to synthesize scientific information in partnership with the working groups and through the climate solutions summits. Funding will pay for 100% time (12 months) of salary during Years 2 & 3 (postdoc #1) and Years 4 & 5 (postdoc #2).
14. **Administrative Assistant/Project Manager (TBN)**: The Administrative Assistant will oversee project management for the CASC. They will plan events, help with reporting, and manage budget matters that arise within the CASC (e.g., sub-awards to the consortium partners). Funding will pay for 50% time for 12 months of their salary during Years 3-5. Support will be provided by the recipient as cost-share for the Administrative Assistant salary during Years 1 & 2.
15. **Salaries** for all named personnel are based on current University of Colorado Boulder (CU Boulder) academic and staff salary rates. The University of Colorado's current budget planning parameters include an annual inflation factor of 3% for salaries of investigators, post-doctoral researchers, graduate research assistants, and hourly students.
16. **Fringe benefits** are calculated on requested salary per the University's federally negotiated Rate Agreement with the Department of Health and Human Services (DHHS). The following fringe benefits are included in the fringe benefit rate(s): FICA, Workers' Compensation, Health/Life/Dental, Disability Insurance, Annuitant's Insurance, Unemployment Insurance, Retirement Plans, EcoPass Bus Pass, and Termination Pay.

Detailed information on staffing plans associated with the proposed budget is contained within the CU Boulder proposal.

APPENDIX II: Funded University of Colorado (CU) personnel

Funded University of Colorado (CU) personnel; GPTWA=Great Plains Tribal Water Alliance; NCASC=National CASC. YR3=Budget Year 3 funds; and YR2=Budget Year 2 funds carried forward to Year 3.

Person	Role	Responsibility	Actual Level of Effort (10/1/20-9/30/21)
Jennifer Balch	University Director	Responsible for coordinating all elements of the cooperative agreement, including the leadership and CU teams. Supervises Jilmarie Stephens.	YR3: 4.5 months, AY, 22.97% time; 0.74 months, summer, 100% time
Jane Wolken	Program Manager	Oversees day-to-day university operations of the NC CASC. Engages in cross-CASC activities, including the Fire Leadership Team, and Program Manager and Network Collaboration meetings. Co-mentors Jilmarie Stephens, and Phurwa Gurung.	YR3: 5 months, 100% time; 7 months, 75% time
Lisa Dilling	Adaptation Co-Lead	Guides the development of adaptation strategies and their implementation through the co-production and consortium process.	YR3: 0.26 months, summer, 100% time
William Travis	Adaptation Co-Lead		YR3: 0.50 months, summer, 100% time
Leah Wasser	Education Lead	Oversees the development of training plan and material for climate data.	YR3: 5 months, 20% time
Imtiaz Rangwala	Climate Science Lead	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. Rangwala also co-hosts the NC CASC Webinar Series, mentors Prasad Thota; and co-mentors Jilmarie Stephens.	YR3: 6.3 months total; YR2: 2.4 months total
Heather Yocum	Stakeholder & Communication Lead	Facilitates research-to-operations processes, convenes/structures stakeholder engagement between scientists and information users, expands the stakeholder base and solicits user feedback to refine information content and delivery platforms. Yocum developed the communications strategy, co-hosts the NC CASC Webinar Series, co-mentors Sarah Jaffe and Shelby Ross, and oversees the consortium partner activities. She is also the primary contact for the Tribal Climate Leaders Program, and PI for *Grasslands Synthesis Project*.	YR3: 12 months, 50% time; YR2: 12 months 10% time
Max Joseph	Open Science Architect	Develops open source, reproducible software, workflows and accompanying trainings to increase access and usability of various data sources.	YR3: 2.2 months total; YR2: 0.728 months total
Lauren Herwehe Kim	Education Trainer	Assists with the development of course materials for the Climate Science Workshops.	YR3: 2.75 months total

James Rattling Leaf, Sr.	GPTWA consultant/ Research Associate	Works with the GPTWA and other Tribal organizations in the NC CASC region to form Tribal engagement plans, identify key climate science training needs, raises awareness of adaptation and planning needs to resource managers in tribal communities, and encourages and recruits students into educational programs. Rattling Leaf also co-mentors Shelby Ross and Phurwa Gurung.	YR3: 6 months, 50% time; YR2: 2.76 months total
Dawn Umpleby	Executive Assistant	Provides project support in areas of website development, maintenance, content design, social media platforms, newsletter creation/distribution, logistics planning for events, reporting and budget planning and tracking, including sub-awards to consortium members. Provides support for the Tribal Climate Leaders Program, and Director.	YR3: 2 months, 51.5% time; YR2: 1 month, 75% time; 2 months, 25%; 9 months, 50% time
Katherine Halama	Temp aide - Oct 2020-Feb 2021 (hourly)/Communications Assistant - Mar 2021-current (hourly)	Assists Executive Assistant with website and social media content and maintenance, newsletter content and creation.	YR3: 5 months, 75% time; YR2: 3 months, 75% time; Oct 2020-Feb 2021: ~812.5 additional hours worked on YR2.
Jilmarie Stephens	Postdoctoral fellow	Conducts research on the future of fire in the North Central region under changing climate conditions. Results will inform the National CASC CAP Fellow Program *Future of Fire* project.	YR3: 11 months, 100% time
Sarah Jaffe	Graduate research assistant	Maps land cover, jurisdictional boundaries, and climate data for the *Grasslands Synthesis Project* communications products.	YR2: 3 months, 50% time, summer
Phurwa Gurung	Graduate research assistant	Reviews literature on the use of traditional ecological knowledges in the North Central region.	YR2: 3 months, 50% time, summer
Shelby Ross	Graduate research assistant	Tribal Climate Leaders Program; reviews literature on Tribal Nations grassland and climate change related goals and challenges.	YR3 Cost Share: 4.5 months, AY, 50% time; YR2: 3 months, 50% time, summer
Prasad Thota	Graduate research assistant	Develops climate datasets, workflows and tools, and conducts analysis and visualization of stakeholder tracking data.	YR2: 3 months, 50% time, summer
Will Crawford	Graduate research assistant	Tribal Climate Leaders Program	YR3 Cost Share: 4.5 months, AY, 50% time; 3 months, summer, 50% time

APPENDIX III: Open Workflows and Datasets, Tool Maintenance, and Project Climate Support for FWS, NPS, and State Wildlife Agencies

Open workflows and datasets:

- Heat stress index projections using MACA (workflow)--Imtiaz Rangwala
- Annual & Seasonal Water Deficit projections using MACA (Evaporative Demand minus Precipitation) (workflow)--Imtiaz Rangwala
- Forest Stress Drought Index gridded dataset for CONUS - historical; 1980-2018--Imtiaz Rangwala
- Standardised Precipitation Index (SPI) projections based on MACA--Imtiaz Rangwala
- R Shiny app for Climate Futures Toolbox (CFT)--Imtiaz Rangwala and Prasad Thota (Link: https://github.com/nc-casc/cft_Shiny_App)
- R Shiny app for Grasslands Productivity (GrassCast) and Climate (GRIDMET) (Link: https://nccasc.shinyapps.io/Grasslands_Productivity_Climate_App/)
- R Shiny app for quantifying events associated with Extreme Accumulation of Evaporative Demand (Link: https://nccasc.shinyapps.io/Evaporative_Demand_Extremes_App/)

Tool Maintenance:

- Continued operations of Landscape Evaporative Response Index (LERI) webtool with NOAA PSL--Imtiaz Rangwala
- Continued operations of Drought Index Portal (DrIP)--Imtiaz Rangwala
- Maintenance of Climate Futures Toolbox (CFT), Evaporative Demand Drought Index (EDDI), LERI R packages--Max Joseph

Project climate support for FWS, NPS and state wildlife agencies:

- FWS SSA on Pygmy Owl (reviewed climate analysis work)--Imtiaz Rangwala
- NC CASC funded project on future mule deer greenscape in WY (USGS+WY Game & Fish + NPS) (co-author on paper being developed)--Imtiaz Rangwala
- NC CASC funded project on breeding waterfowl pairs in US Prairie Pothole Region (USGS+FWS)
- Technical advisor for Regional Conservation Assessment (2020-21) led by The Nature Conservancy (TNC), Biohabitats and Metro Denver Alliance--Imtiaz Rangwala
- Paper on Wolverine Species Status Assessment (SSA) with FWS (submitted in Feb 2021)--Imtiaz Rangwala
- Contribute a paper to a joint special issue with the journals *Climate* and *Earth* on "Climate System Uncertainty and Biodiversity Conservation," titled "Uncertainty, Complexity and Constraints: How do we robustly assess ecological responses under a rapidly changing climate?" --Imtiaz Rangwala and Jane Wolken. Expected submission date: August 2021

APPENDIX IV--Timetable of Consortium Partner Activities

Summary of timetable of consortium partner activities; CU=University of Colorado; CSP=Consortium Science Partners; WCS=Wildlife Conservation Society; UM=University of Montana; SDSU=South Dakota State University; and GPTWA=Great Plains Tribal Water Alliance.

Consortium Partner	Year 2 (Oct 2019-Sept 2020)	Year 3 (Oct 2020-Sept 2021)	Year 4 (Oct 2021-Sept 2022)	Year 5 (Oct 2022-Sept 2023)
CU	• Host virtual CP meeting	● Annual CP meeting, with CSP host	● Annual CP meeting, with SDSU host	● Annual CP meeting, with GPTWA host
CSP		● Host annual CP meeting ● Synergistic Research: *Transformational Drought project (NCASC; Rangwala) *Visualizing Ecological drought project (NOAA-NIDIS; Cross)	● Planned work informed by RAD framework	
WCS	• Postponed due to CP funding	● Ongoing work with WY Game & Fish Department ● Evaluation of WCS adaptation projects + publication ● Virtual workshop on Measuring Climate Adaptation Outcomes (July 2021)	● 2-day workshop -- Adaptation Success (June 2022 target)	
MT	• Postponed due to CP funding	● Workshop with fire stakeholders (Feb 2021) ● Developing science and outreach tools to aid in post-fire vegetation management decisions	● Continue to develop science and outreach tools to aid in post-fire vegetation management decision ● Follow-up workshop (Jan-Feb; possibly moved to Sept)	
SDSU	• Postponed due to COVID-19	● Meetings with local stakeholders to ID climate info and research needs.	● Local meetings ● Host CP meeting	● Local meetings
GPTWA	• 2-day workshop postponed due to COVID		● 2-day workshop	● Host CP meeting

APPENDIX V--Outreach Products/Activities

Peer reviewed journals, non-peer reviewed technical reports and op-eds:
NC CASC researchers/consortium partners appear in **bold** text. ***** indicates a product was not funded by the NC CASC, but leverages NC CASC researchers/consortium partners expertise in support of NC CASC strategic science goals:

- **Balch, J.** 2021. Skip the fireworks this Independence Day, our firefighters need a break. *The Hill*, Published online: 4 July, 2021.
- *****Barsugli, J.J., Ray, A.J., Livneh, B., Dewes, C.F., Heldmyer, A., **Rangwala, I.**, Guinott, J.M., and Torbit, S. (2020). Projections of mountain snowpack loss for wolverine denning elevations in the Rocky Mountains. *Earth's Future*, 8(10): e2020EF001537, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020EF001537
- Buono, P., Rondeau, R., Bidwell, M., Monroe, S., Rank, G., Roberts, S., **Cross, M.**, and **Rangwala, I.** (2021). Prioritized Drought Resilience Strategies for the Mancos Watershed. Prepared for Mancos Watershed Group. https://tinyurl.com/8ek638kk
- *****Cattau, M.E., Wessman, C., Mahood, A., and **Balch, J.K.** (2020). Anthropogenic and lightning-started fires are becoming larger and more frequent over a longer season length in the U.S.A. *Global Ecology and Biogeography*, 29(4): 668-681, https://doi.org/10.1111/geb.13058 (*not reported in Year 2*).
- Clifford, K., **Travis, W.R.**, and Nordgren, L.T. (2020). A climate knowledges approach to climate services. *Climate Services*, 18:100155, 10.1016/j.cliser.2020.100155 (*not reported in Year 2*).
- **Crausbay, S.D.**, Sofaer, H., Cravens, A.E., Chafin, B.C., Clifford, K., Gross, J.E., Knapp, C., Lawrence, D.J., Magness, D.R., Miller-Rushing, A., Schuurman, G.W., and Stevens-Rumann, C. (*In Revision*). A science agenda to inform natural resource management decisions in an era of ecological transformation. *BioScience*.
- **Crausbay, S.**, Ramirez, A., Betancourt, J., Bradford, J.B., Cartwright, J., Dunham, J.B., Enquist, C., Frazier, A., Hall, K., Littell, J.S., Luce, C.H., Palmer, R., **Rangwala, I.**, Thompson, L., and Carter, S. (2020). Unfamiliar territory: emerging themes for ecological drought research and management. *One Earth,* 3(3), 337-353, https://doi.org/10.1016/j.oneear.2020.08.019
- *****Cravens, A.E., McEvoy, J. Zoanni, D., **Crausbay, S.**, Ramirez, A.R., and Cooper, A.E. (2021). Integrating Ecological Impacts: Perspectives on drought in the Upper Missouri Headwaters, Montana, United States. *Journal of Weather, Climate, and Society*, https://doi.org/10.1175/WCAS-D-19-0111.1
- **Cross, M.**, Dey, P., Tator, I., Bredehoft R., Mahoney, A., Smith, N., and Wasseen, J. (2020). Climate change and management of river, riparian, and wetlands habitats in Wyoming: Summary from Wyoming Game and Fish Department Climate Change Workshop-April 28-30, 2020. Wildlife Conservation Society & Wyoming Game and Fish Department.
- ***Davis, K.T., Higuera, P.E.**, Dobrowski, S.Z., Parks, S.A., Abatzoglou, J.T., Rother, M.T., and Veblen, T.T. (2020). Fire-catalyzed vegetation shifts in ponderosa pine and Douglas-fir forests of the western United States. *Environmental Research Letters*, 15, 1040b8, https://iopscience.iop.org/article/10.1088/1748-9326/abb9df
- *****Esit, M., Kumar, S. Pandey, A., Lawrence, D.M., **Rangwala, I.** and Yeager, S. (2021). Seasonal to multi-year soil moisture drought forecasting. *Climate and Atmospheric Sciences*, 4:16, https://www.nature.com/articles/s41612-021-00172-z
- *****Fargione, J., Haase, D.L., Burney, O.T., Kildisheva, O.A., Edge, G., Cook-Patton, S.C., Chapman, T., Rempel, A., Hurteau, M.D., **Davis, K.T.,** Dobrowski, S., Enebak, S., De La Torre, R., Bhuta, A.A.R., Cubbage, F., Kittler, B., Zhang, D., and Guldin, R.W. (2021). Challenges to the reforestation pipeline

in the United States. *Frontiers in Forest and Global Change*, 4: Article 629198, https://doi.org/10.3389/ffgc.2021.629198

- ***Higuera, P.E.**, Shuman, B.N. and Wolf, K.D. (2021). Rocky Mountain subalpine forests now burning more than any time in recent millenia. *Proceedings of the National Academy of Sciences of the United States of America*, 118(25):e2103135118, https://doi-org.colorado.idm.oclc.org/10.1073/pnas.2103135118
- Hobbins, M.T., Glaudemans, M., Huntington, J.L., McEvoy, D.J., **Rangwala I.**, Ray, A.J., Tan, X., and **Yocum, H.M.** (2020). Operationalizing an Evaporative Demand Drought Index (EDDI) service for drought monitoring and early warning. Final project report to NOAA Joint Technology Transfer Initiative Program, NOAA Physical Sciences Division, Boulder, CO, March 19, https://tinyurl.com/wpxn3xb
- *Hoell, A., Parker, B.-A., Downey, M., Umphlett, N., Jencso, K., Akyuz, F. A., Peck, D., Hadwen, T., Fuchs, B., Kluck, D., **Edwards, L.**, Perlwitz, J., Eischeid, J., Deheza, V., Pulwarty, R., and Bevington, K. (2020). Lessons learned from the 2017 flash drought across the U.S. Northern Great Plains and Canadian Prairies. *Bulletin of the American Meteorological Society*, 1–46, https://doi.org/10.1175/BAMS-D-19-0272.1
- ***Joseph, M.B.**, Pavlacky, Jr., D.C., and Bartuszevige, A.M. (2021). Data fusion for abundance estimation: community science augments systematically collected removal-in-time distance sampling data. bioRxiv preprint doi: https://www.biorxiv.org/content/10.1101/2021.05.02.442379v1
- *Lukas, J., Payton, E., Deems, J., **Rangwala, I.**, and Duncan, B. (2020). Observations—Hydrology. Ch. 5 in Colorado River Basin Climate and Hydrology: State of the Science, edited by J. Lukas and E. Payton, 154-219. Western Water Assessment, University of Colorado Boulder. doi:10.25810/3hcv-w477, https://wwa.colorado.edu/publications/reports/CRBreport/ColoRiver_StateOfScience_WWA_2020_Chapter_5.pdf
- *Mietkiewicz, N., **Balch, J. K.**, Schoennagel, T., Leyk, S., St. Denis, L.A., and Bradley, B.A. (2020). In the Line of Fire: Consequences of human-ignited wildfires to homes in the U.S. (1992–2015). *Fire*, *3*(3), 50, https://doi.org/10.3390/fire3030050.
- *Oakes, L.E., **Cross, M.S.**, and Zavaleta, E. (2021). Rapid assessment to facilitate climate-informed conservation and nature-based solutions. *Conservation Science and Practice*, e472, https://doi.org/10.1111/csp2.472.
- **Rangwala I.** (2020). Monitoring and predicting drought on our grasslands. Grasslands News. USDA's National Grasslands Council's Spring 2020 Newsletter, pg. 6-8, https://tinyurl.com/sbb7bag
- *Schulz, T.T., Wilmer, H., **Yocum, H.**, Winford, E., Peck, D., Monlezun, A.C., Schmalz, H., Klemm, T., Epstein, K. Jansen, V., Kelley, W., Bruegger, R., Stephen, F., Gazing Wolf, J., Grace, J., Mann, R., and Derner, J. (2020). Campfire conversations at the 2020 Annual Meeting: Insights & lessons learned from "Cuss-and-Discuss" rather than "Chalk-and-Talk." *Rangelands*, https://doi.org/10.1016/j.rala.2021.04.003.
- Schuurman, G.W., Cole, D.N., Cravens, A.E., **Crausbay, S.D.**, Hawkins Hoffman, C., Lawrence, D.J., Magness, D., Morton, J., Nelson, E., and O'Malley, R. (*In Press*). Navigating ecological transformation: Resist-Accept-Direct (RAD) as a path to a new resource management paradigm. *BioScience*.
- *St-Laurent, G.P., Oakes, L.E., **Cross, M.**, and Hagerman, S. (2021). R-R-T (resistance-resilience-transformation) typology reveals differential conservation approaches across ecosystems and time. *Communications Biology*, 4, 39, https://doi.org/10.1038/s42003-020-01556-2.
- ***Yocum, H.M**., Sassorossi, D. and Ray, A.J. (*Accepted with minor revisions*). Assessing the use of climate change information in state wildlife action plans. *Conservation Science and Practice*.

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

- 2020 Academic Data Science Alliance Annual Meeting (15 October, 2020) -- Presentation by James Rattling Leaf, Sr.: From Data Sovereignty to Data Science: Implications for American Indian Self-Determination
- Environmental Law Institute (21 October, 2020) -- Presentation by James Rattling Leaf: Swept Away: Safeguarding Tribal Cultural Heritage from the Impacts of Climate Change
- Group on Earth Observations (GEO) Week 2020 (6 November, 2020) -- Presentation by James Rattling Leaf, Sr.: Every Tribal Nation Has a Data Story: Challenges and Opportunities Moving Forward
- ESA Watercooler Chat (13 November 2020) -- Presentation by James Rattling Leaf: Exploration of Modern Indigenous Knowledge and the Power of Indigenous and Western Science
- Cooperative Institute for Research in Environmental Sciences (18 November, 2020) -- Presentation by James Rattling Leaf, Sr.: Building Relational and Effective Partnerships with Indigenous Communities
- Tribal GIS 2020 (19 November, 2020) -- Presentation by James Rattling Leaf: Every Tribe Has a Climate Story: Climate Assessment Planning on Tribal Lands in the Great Plains
- Lancet Countdown: Tracking Progress on Health and Climate Change (3 December, 2020) -- Presentation by James Rattling Leaf,, Sr.
- GEO Indigenous Summit (7-12 December, 2020) -- James Rattling Leaf, Sr.: Welcome Session, Moderator for COVID-19 Panel and Education/Intergenerational Knowledge Transfer Panel, Closing Ceremony and Remarks
- American Meteorological Society (14 January 2021) -- Panel Discussion by James Rattling Leaf, Sr.: Sixth Symposium on US-International Partnerships- Engaging International Users in the Development of Environmental Satellite Data and Applications
- Inter-American Academy of Geosciences and Applications (9-11 February, 2021) -- Webinar by James Rattling Leaf, Sr.: Engaging with Indigenous Peoples
- Posner Center (25 February, 2021) -- Presentation by James Rattling Leaf, Sr.: Climate Justice and Indigenous Rights
- Warm Regards (22 February, 2021) -- Podcast with James Rattling Leaf, Sr.: Indigenous Climate Knowledges and Data Sovereignty
- Bay Area Environmental Research Institute (3 March, 2021) -- Podcast with James Rattling Leaf, Sr.: Connecting Tribal Lands with NASA Remote Sensing Tools
- Aspen Center for Environmental Studies (4 March, 2021) -- Presentation by Phil Higuera: Colorado's Record-Setting 2020 Fire Season in the Context of the Past 6000 Years
- Navajo Medicine Man Association from Navajo Tribal Nation (14 March, 2021) -- Presentation by James Rattling Leaf, Sr.: Climate Change
- Society for Conservation GIS (1 April, 2021) -- Presentation by James Rattling Leaf, Sr.: Building Effective Partnerships with Indigenous Communities
- South Dakota 'Drought Hour' Webinar (19 April, 2021) -- Presentation by Laura Edwards: Climate Update
- Boulder Labs Diversity Council (21 April, 2021) -- Presentation by James Rattling Leaf, Sr.: Engaging with Native American Communities: Mitakuye Oyasin
- InterTribal Buffalo Council (4 June, 2021) -- James Rattling Leaf, Sr.: 2021 Annual Membership Meeting Panel: Planning for Drought and Resilience to Climate Change
- American Water Resources Association 2021 Virtual Summer Conference (21 July, 2021) -- Panelist James Rattling Leaf, Sr.: Collaborative Approaches to the Use of Earth Observations in Indigenous Communities

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

- National Academies of Sciences Engineering Medicine: Wildland Fires: Towards Improved Understanding and Forecasting of Air Quality Impacts - A Workshop (23 September, 2020) -- Presentation by Jennifer Balch, *Our Changing Fire Regimes*.
- NC-CASC-funded project resulted in a climate-informed Statewide Habitat Plan in Wyoming that was released by the Wyoming Game and Fish Department in November 2020: https://wgfd.wyo.gov/getmedia/8ba62756-6d1c-4257-8644-82383dfa605a/SHP2020_Final.
- Letter of Invitation to participate in the *Grasslands Synthesis Project* (December, 2020) -- Heather Yocum and Christy Miller Hesed: a formal letter was sent to Tribal Chairs at each of the 30 Tribal Nations in the North Central region with grasslands. This letter described the goals of the Project and invited a member of the Tribal Nation to help us identify grassland management priorities by serving on our Advisory Committee.
- CASC National Climate-Fire Synthesis Workshop (13-15 January, 2021) -- Presentation and participation by Jennifer Balch, Jane Wolken and Jilmarie Stephens.
- High Plains Regional Climate Center Climate and Fire Workshop with Nebraska Forest Service (28-29 January, 2021) -- Presentation and participation by Jilmarie Stephens and Jane Wolken
- Managing Post-fire Vegetation Under Climate Change (February 3-4, 2021) -- Workshop hosted by Consortium Partner University of Montana (Phil Higuera and Kimberley Davis); Participation by Jilmarie Stephens and Jane Wolken.
- Congressman Neguse's First Annual Wildfire Summit (18 February, 2021) -- Panelist presentation by Jennifer Balch, *The Science of Wildfires*.
- Crown Managers Partnership Fire in the Crown of the Continent Fire Forum (22-26 March, 2021) -- Participation by Jilmarie Stephens.
- Hearing of the House Natural Resources Subcommittee on Parks, Forests, and Public Lands (23 March, 2021) -- Molly Cross (Wildlife Conservation Society) testified at a hearing of the House Natural Resources Subcommittee on Parks, Forests, and Public Lands, on the role of federal programs in supporting natural climate solutions in the U.S.
- Measuring Climate Adaptation Outcomes (12-13 July, 2021) -- Virtual meeting hosted by Molly Cross (Wildlife Conservation Society). The purpose of the meeting was to initiate discussion among researchers and practitioners in the NC CASC region about how we define and measure outcomes for climate adaptation practices, with a particular focus on process-based and beaver-related restoration techniques designed to help wildlife and ecosystems adapt to a changing climate.

Fact sheets and blogs:

- Climate Toolbox Case Study: Species Assessments, The Climate Toolbox (ClimateToolbox.org) features Imtiaz Rangwala's climate data work on Species Status Assessments with the U.S. FWS.
- NC CASC (Jennifer Balch and Jane Wolken) partners with Earth Lab and CIRES to compile a list of resources on current fires and air quality: How Bad is the Smoke? Current Fires and Air Quality Resources: Top 10 ways to get up-to-date information on fires and air quality. Published online: 25 August, 2020 (*not reported in Year 2*).

Media mentions:

- Throughout the 2020 wildfire season (*not reported in Year 2*) NC CASC University Director Jennifer Balch fielded 15 media requests for her expertise in wildfire science. A list of these media engagements is located on our website.
- Imtiaz Rangwala quoted in The Guardian: Record-Shattering Heat Wave Bakes Western US, Raising Drought and Fire Concerns. Published online: 18 June, 2021.