CLIMAS
Climate Assessment for the Southwest
A NOAA RISA TEAM

Collaboratively Assessing Critical Social-Ecological System Buffers to Help Build Regional Climate Resilience

PROGRESS REPORT:

June 1, 2020 — May 31, 2021

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Photo credit Dan Ferguson

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CLIMAS Climate Assessment for the Southwest A NOAA RISA TEAM

THE UNIVERSITY OF ARIZONA

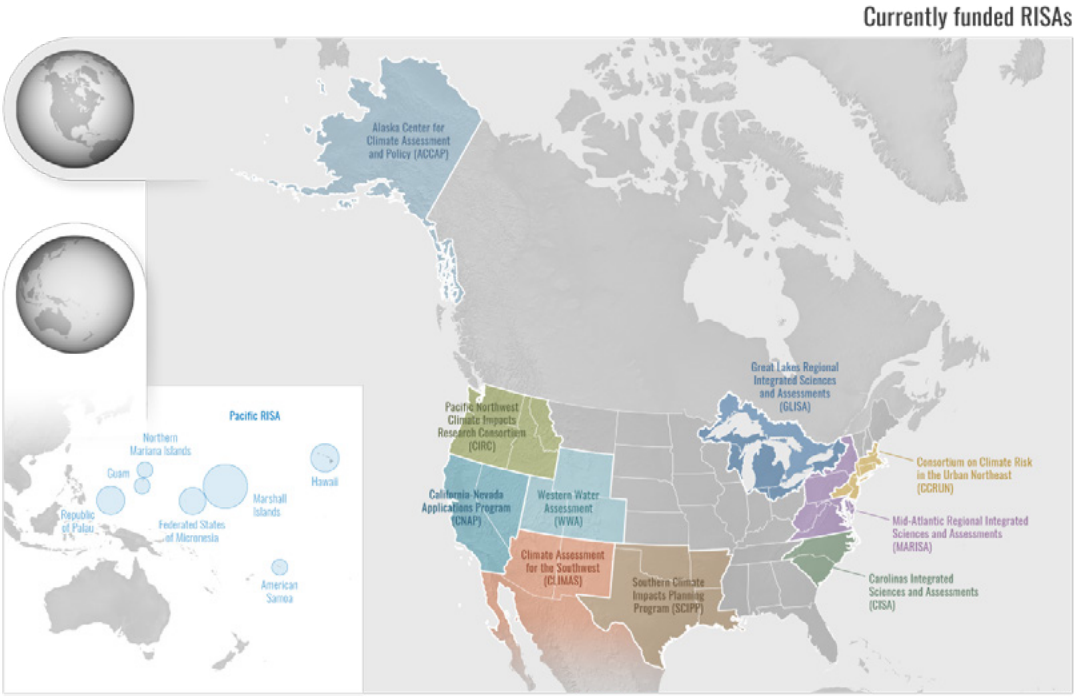
NM STATE UNIVERSITY

NIDIS

NOAA RISA Regional Integrated Sciences and Assessments

What is CLIMAS?

The Climate Assessment for the Southwest (CLIMAS) is a NOAA-funded program that connects researchers at the University of Arizona and New Mexico State University to partners from the private sector, academia, and local, state, federal, and tribal governments. Since 1998, CLIMAS researchers have brought the best available scientific knowledge to weather and climate-related challenges in the Southwest. CLIMAS is funded by the Regional Integrated Sciences and Assessments (RISA) program and the National Integrated Drought Information System (NIDIS), both of which are designed to improve the use of climate information in decision making.



2020 — 2021 CLIMAS Research Team

Principal Investigators:
Daniel Ferguson (Program Director, Lead PI), Heidi Brown, Michael Crimmins, George Frisvold, Connie Woodhouse

Co-Principal Investigators:
Stephanie Carroll, Bonnie Colby, David DuBois, Ladd Keith, Ben McMahan, Alison Meadow, Gigi Owen, Jeremy Weiss

Senior Personnel:
Erika Austhof, Christina Greene, Mitch McClaran, Craig Rasmussen, Marcel Schaap, Margaret Wilder

Research Affiliates:
Michael De Antonio, Stan Engle, Andrea Gerlak, Rey Granillo, Zack Guido, Sarah Leroy

Environment & Society Fellows:
2020 — Kunal Palawat, JoRee LaFrance, Rachel Rosenbaum, Emily Cooksey;
2021 — Lea Schram von Haupt*, Simone Williams*, Bailey Stephenson*

Student Researchers:
Talia Anderson, Antonio Arredondo, Leah Bishop, Patrick Bunn, Hsin-I Chang, Casey Cheung*, Jonathan Consford, Benni Delgado, Jennie Doss*, Ramon Driesen, Jaylen Fuentes, Zahra Ghodsizadeh, Hannah Hansen*, Mau Herrera, Dharma Hoy*, Emily Joiner, Surabhi Karambelkar*, Eden Kinkaid*, CJ Larsen*, Sean Maccabe*, Brian McGreal*, Trevor McKellar, Madeline Moeller*, Leslie Pilli, Genesis Rodriguez, Marie-Blanche Roudaut, Erika Schmidt*, Austin Walker*

** New additions to the CLIMAS team during the reporting period.*

CLIMAS by the Numbers

4724
CLIMAS-related Twitter Followers

103
Presentations Given to Stakeholder & Academic Audiences

12
Advisory Roles Served

31
Academic Articles Published

33
Reports Produced for Stakeholders

53
Climate Briefings Disseminated

1
Policy Brief Produced

10
Podcasts Recorded

55
Appearances in the Media

6
Workshops, Seminars, &

8
Online Tools Developed

10
New Proposals Funded

Photo credit Ben McMahan

Accomplishments

During the current reporting period, the fourth year of the current CLIMAS proposal, researchers produced and delivered tailored products that would be useful for our research partners and end users. These products were used to advance adaptive capacity, policy initiatives, and decision-making. Selected accomplishments are described below:

The Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future

C. Woodhouse, D. Ferguson, and T. Anderson filled an information gap for the City of Flagstaff and Flagstaff Water by evaluating the influence of climate on Lake Mary Water supplies. After providing the assessment, a water resources manager at Flagstaff water invited CLIMAS researchers to give a presentation to the Flagstaff Water Commission in August 2020. In November, the water department asked for spreadsheets with the climate data to do analysis on a longer lake level record that their technician had generated. This request suggests that increased learning occurred, in terms of a better understanding of the climatic controls on their only surface water supply, as well as increased data assets, in the form of shared hydroclimatic data.

Sectoral Impacts of Drought and Climate Change

G. Frisvold, with A. Bickel and D. Duval (both CLIMAS graduate alumni), produced a series of reports about the impacts of drought in Arizona. Research summaries were provided to Craig McLean, NOAA's Assistant Administrator for Oceanic and Atmospheric Research, for his briefing of the House Natural Resources Subcommittee on Waters, Oceans, and Wildlife on May 25, 2021. Report summaries included the following titles:

- The Effects of Reservoir Levels on Arizona National Recreation Area Visitation, Visitor Spending, and Local Economies
- The Effects of Drought on Arizona Forage Production
- Drought and Insured Crop Losses in Arizona
- Drought Effects on Arizona State Park Visits, Visitor Spending, and Local Economies
- Drought Effects on National Park Visits, Visitor Spending, and Local Economies

Photo credit Ben McMahan

Urban Heat and Health Interventions and Evidence Gaps

L. Keith and B. McMahan assisted the Pima Association of Governments (PAG) in updating the heat severity layer on an online Green infrastructure Prioritization Tool. The layer, launched in fall 2020, displays regional urban heat effect. PAG, local governments, and non-profits use this tool to make decisions about heat mitigation, to site green infrastructure, and develop urban forestry plans. This research has also led to improved understanding about city governance of extreme heat risk and the support city governments need to advance their efforts. H. Brown updated an online mapping tool to help people in Pima County find cooling stations. The map was made starting with the Tucson Pima Collaboration to End Homelessness Summer Sun Respite Sites, and included libraries, pools, and splash pads. Locations were updated with hours, restrictions and COVID requirements.

Photo by NOAA on Unsplash

Planning and Evaluating the Societal Impacts of Climate Change Research Projects

A. Meadow and G. Owen adapted and refined the CLIMAS program evaluation framework to develop a guidebook for evaluating the societal impact of climate change research. The guidebook was published in May 2021: Planning and Evaluating the Societal Impacts of Climate Change Research Projects: A guidebook for natural and physical scientists looking to make a difference. It has been circulated and downloaded by several physical and natural scientists and graduate students who have used the framework to design proposals with explicit societal impact.

Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations

The monsoon data aggregators developed earlier in this project, by M. Crimmins and B. McMahan, were recently added to the National Weather Service's Tracking the Monsoon webpage. These aggregators include the Southwest U.S. Summer Monsoon Season Precipitation Mapping tool and the Monsoon Season Station Climate Summaries. NWS Tucson serves the entire southern Arizona region. Currently the visualizer's best coverage is limited to the Tucson Metro area but include scaling this work into rural areas as well, in partnership with Arizona Department of Water Resources.

Building Regional Food System Resilience in Southern Arizona – Learning from COVID-19

A public report produced through this project documented the evolving impacts of the covid-19 pandemic in the local food system in Pima County, AZ. G. Owen, E. Kinkaid, and L. Bellante synthesized information from producers, distributors, advocacy and policy organizations, restaurants, and others to provide a holistic picture of the cascading impacts across the region. Documenting this information and other lessons learned provided support for those working to address systemic, logistical, economic, and climatic issues that preceded the pandemic. It provides policy support for current bills and initiatives that will help bolster local food economies. For example, several local food and agriculture bills are currently up for review in the AZ state legislature. One policy/advocacy group said, *"We've already shared your report findings in our conversations with legislators! To have this level of hyperlocal information is just priceless, we cannot thank you enough."*

> ***"We've already shared your report findings in our conversations with legislators! To have this level of hyperlocal information is just priceless, we cannot thank you enough."***

Photo by Disiana Caballero on Unsplash

Photo by Jeremy Weiss

Partnering with Southwest Indigenous Communities to Identify Data Challenges, Needs, and Opportunities

S. Carroll gave 30 presentations related to Indigenous data sovereignty. All talks were invited and addressed knowledge and practice gaps with respect to Indigenous rights and interests in science and research. S. Carroll also provided consultation to the United Nations Food and Agriculture Organization, Secretariat of the International Treaty on Plant Genetic Resources about post COVID-19 implications on collaborative governance of genomics research, innovation, and genetic diversity. For further discussion of impact from this project, please see the Evidence and Case Studies of Societal Impact section.

Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets

B. McMahan and A. Gerlak designed this project to in form Tucson Electric Power's (TEP) annual integrated resource planning process. CLIMAS research provided a tangible way for TEP to compare resource portfolios based on their relative contributions to warming. TEP was then able to better communicate the reasons behind their portfolio decisions to their stakeholder network and advisors, beyond the typical default metric of simple cost. TEP's Integrated Resource Plan, published in July 2020, reflects much more aggressive reductions targets in terms of timing and intensity than prior plans. For further discussion of impact from this project, please see the **"Evidence and Case Studies of Societal Impact"** section.

Community Climate Profiles

A. Meadow and J. Weiss mobilized climate change and adaptation information from the research realm into use in several communities over the course of this project. This mobilization occurred thanks to increased learning among our community partners because researchers provided the information in an accessible format. Stakeholders who came into the project with questions about the reality of climate change left with more clear evidence of its impacts. This observation is based on several conversations with community partners over the course of the project. The climate profiles were used in policies and plans. Written feedback from partners demonstrate how the profiles, and the process of working with CLIMAS, helped them feel more confident in their own understanding of the science. For further discussion of impact from this project, please see the **"Evidence and Case Studies of Societal Impact"** section.

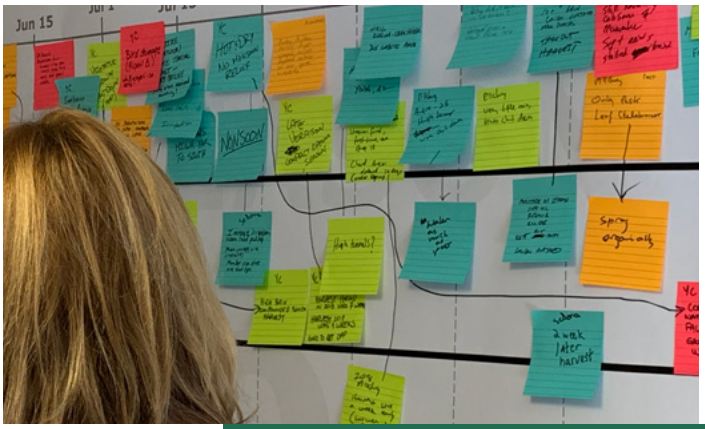


Photo by Jeremy Weiss

Selected Research Findings and Highlights

Photo by Melissa Merrick

Sectoral Impacts of Drought and Climate Change

The economic impacts of drought on state and national park visitation depends crucially on the length of the drought considered. For example, one-month drought measures have a positive effect on visits because people visit less in unusually wet months. Longer-term drought measures have an increasingly negative impact. Combining short- and long-term effects, drought is estimated as having net-negative impacts on national park visits in some years and net-positive impacts in others, with effects ranging between losses of $14.2 million in output (sales) to a $32.8 million increase.

Duval, D., A. Bickel, and G. Frisvold. 2021. *Drought Effects on Arizona State Park Visits, Visitor Spending, and Local Economies.* Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

Duval, D., A. Bickel, and G. Frisvold. 2021. *Drought Effects on Arizona State Park Visits, Visitor Spending, and Local Economies*. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

A similar relationship holds for agricultural crop losses, as measured by insurance indemnities. Because Southwest agriculture is almost entirely irrigated, short-term drought measures have little negative impact. Losses occur from failure of irrigation supply, which are tied to longer-term drought that affects reservoir levels and surface water deliveries. The effects of drought on agriculture in Arizona are non-linear and have threshold effects. Drought can have no impact on crop losses, up to the point where irrigation supplies are cut off. Once that happens, production on those acres is no longer economically viable. Studies of the effects of drought on agriculture usually focus on effects on crop yields. This research demonstrates that for Arizona (and likely other irrigation-dependent areas), yields are relatively insensitive to drought. Rather, *the effects of drought are not from lack of precipitation,* but through more pervasive drought that lowers irrigation water supplies. The negative impact from drought is on acres planted.

Bickel, A., D. Duval, and G. Frisvold. 2021. *Drought and Insured Crop Losses in Arizona.* Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

Comparing tree-ring based reconstructions of snowpack variability at different scales for the Navajo Nation

Developed in partnership with the Navajo Nation Water Management Branch, this study documents two snowpack reconstruction options to address Navajo concerns about the amount and variability of snowpack in the Chuska Mountains. The reconstruction calibrated on the Chuska snow record better matched the details of snowpack variability in the instrumental record, but generally failed to capture the magnitude of extremes. The Williams Ski Run reconstruction captured a broader range of regional snowpack variability, but it missed local low-snowpack intervals specific to the Chuska Mountains. Knowing these trade-offs allows Navajo water managers to determine what climate information contained within the reconstruction is most useful for their immediate decision-making.

Brice, B., G.H. Guiterman, C. Woodhouse, C. McClellan, P. Sheppard. 2021. Comparing tree-ring based reconstructions of snowpack variability at different scales for the Navajo Nation. *Climate Services* 22. DOI: 10.1016/j.cliser.2021.100213

Photo by Melissa Merrick

Adaptation to Climate Variability and Change: Markets, Policy, Technology, and Information

The USDA Conservation Reserve Enhancement Program (CREP) program potentially provides significant federal cost-sharing for state and local programs to voluntarily acquire water for environmental restoration. However, state CREP programs as implemented have fallen far short of initial water acquisition goals. In assessing reverse water auctions as a mechanism to reallocate water from agricultural to environmental purposes, this research found that water auctions are advantageous in some, but not all, instances. If little or no information exists about water transfer prices or quantities in the procurement area, or if the procuring authority has a limited budget, water auctions can be advantageous. If active water transactions with good price information already exist in the region, offering potential water suppliers a fixed, pre-determined price may work just as well as an auction, with fewer transactions costs.

Frisvold, G. and A. Marcheva. 2021. Reverse water auctions in theory and practice. Report.

Frisvold, G. and H. Chen. 2021. The Conservation Reserve Enhancement Program (CREP) as a vehicle for water conservation: An annotated bibliography.

Building Regional Food System Resilience in Southern Arizona – Learning from COVID-19

Local food systems played a crucial role during the recent pandemic crisis. In southern Arizona, local producers, distributors, and food and agricultural organizations quickly adjusted their operations to accommodate shifting conditions and meet local food needs. Flexibility, pre-established networks, sharing resources, and communication channels were vital to developing an effective local response to pandemic-related challenges. These local businesses were able to fill in immediate gaps and increased food need that occurred due to pandemic impacts on the conventional food system.

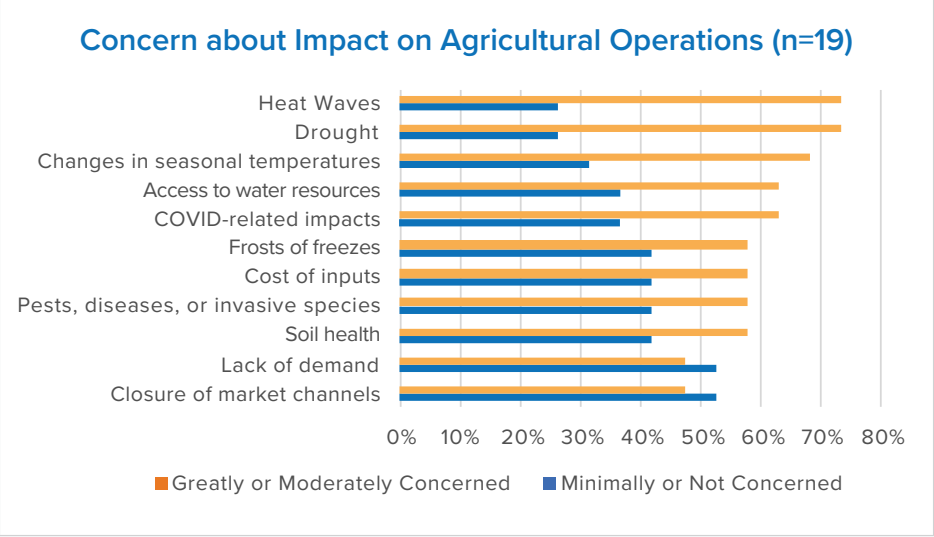
While COVID-19 caused many disruptions and hardships, other challenges present greater threats to the long-term stability and capacity of the local food system. For small-to-medium scale agricultural producers, heat waves, drought, changes in seasonal temperatures, and access to water resources were of greater concern than the pandemic. Other obstacles include lack of support for new or small-scale farming and ranching operations, inadequate local infrastructure such as processing facilities, cold storage, and transportation, and the need for skilled laborers and living wages for food system workers.

Findings from this study mirror trends in other climate adaptation work – long-term relationships, trusted partnerships, and local knowledge that is grounded in the unique social, cultural, and environmental context of the region, are the building blocks of social systems that are adaptable to various forms of risk.

State of the Tucson Food System Report: Assessing the impacts of the COVID-19 pandemic in southern Arizona 2020-2021

Full report [Link to Full Report]

Executive Summary [Link to Executive Summary]



Survey respondents reported their level of concern regarding the effects of various environmental stressors on their agricultural operation.

Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico

This research dives deeply into understanding the impact of temperature variability on wine grapevines. For example, during grapevine dormancy, the build-up of cold hardiness in the plant progresses through the stages of acclimation, maintenance, and deacclimation. Budbreak takes place when cold hardiness is lost.

Applying increased understanding of what occurs during deacclimation improves bud break models for grapevines in warm-climate growing regions.

Other project results suggest that duration of both heat and cold exposure influence the fruit composition of white grape varieties. The degree of heat or cold at several temperature thresholds is linked to these relationships. Neither duration nor degree of heat or cold seem to affect fruit composition of red varieties, perhaps indicating more inter-varietal differences.

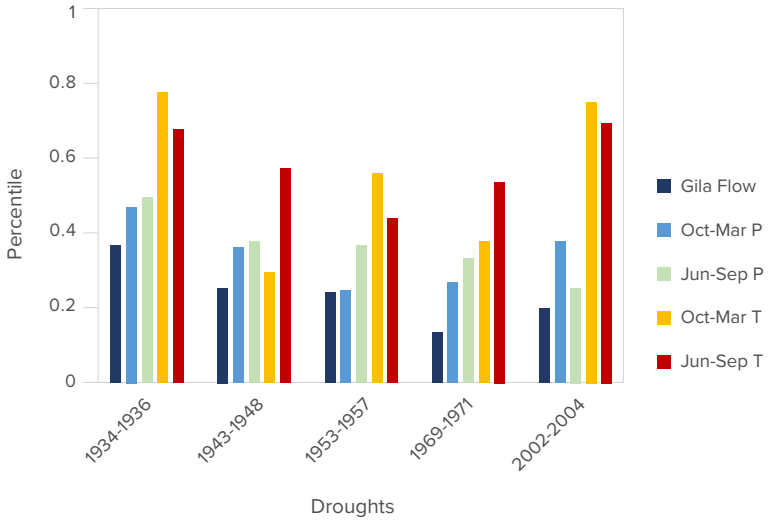
"What We're Reading" – Climate Viticulture Newsletter - 2021 April

Photo by Leslie Cross on Unsplash

The Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future

Analysis of the relationship between Gila River flow and climate: While cool season precipitation is the most important control on annual streamflow, the role of the monsoon in mediating the impacts of a dry cool season or a multi-year drought is notable, particularly in the upper Gila River basin. Currently, decreasing trends in annual streamflow are not evident, despite increasing trends in temperature. But there is evidence for the influence of warming temperatures on runoff in the fall and spring and on 21st century droughts.

Online Fact Sheets: The Influence of Climate on Lower Colorado Streamflow Variability. Short summaries of the main climatic controls on annual flow of the Upper Gila River, Salt River/Tonto Creek, and Verde River.



Multi-year droughts in the gage record for the Gila River, with water year streamflow, cool and monsoon precipitation and temperatures averaged for the years in each period of drought. Values are in percentile and color-code to correspond to the different variables.

Evaluating existing and developing new drought indices using modeled soil moisture time series

Soil moisture was modeled at 240 locations from southern New Mexico across Arizona and into southern California. T. McKellar assessed the relationship between daily modeled soil moisture (1979-2019) at depths up to one meter and standard monthly drought indices like the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI). One main finding is that standard drought indices do a reasonable job of tracking changes in soil moisture when adjusting the drought index timescale to match the relevant depth. For instance, shorter timescales (1 to 3 months) of SPI and SPEI track shallow (~10cm) soil moisture variability well, while longer timescales (9-12 months) track changes in deeper soil moisture (30 to 50 cm).

This is relatively consistent across the low desert areas of the southwest and can be further refined by considering the dominant texture of the soil. For example, sandy soil requires short timescales of drought indices to track changes. These results will help land managers and agricultural producers better utilize existing drought monitoring tools by helping them focus on key timescales to assess potential changes in shallow versus deeper soil moisture.

New Areas of Focus or Partnership

Four new CLIMAS projects began during this reporting period, including:

Community-Based Responses to Climate Water Challenges

CLIMAS Investigators: B. Colby, G. Frisvold, H. Hansen, E. Joiner, B. McGreal, and A. Walker

Research Partners: A. Lien, School of Natural Resources and the Environment, Univ. of Arizona; J. Overpeck, School for Environment and Sustainability, Univ. of Michigan; U.S. Bureau of Reclamation; U.S. Dept. of Agriculture; Arizona Department of Water Resources; Central Arizona Project; Salt River Project; Univ. of Nevada Reno; Univ. of Colorado; Sonoran Institute; The Nature Conservancy

End Users: U.S. Bureau of Reclamation; U.S. Dept. of Agriculture; Arizona Department of Water Resources; Central Arizona Project; Salt River Project

Additional Support: DOI Climate Adaptation Science Centers (CASC); DOI Landscape Conservation Cooperatives (LCC)

This project examines community perceptions and decisions about climate science, economics, and policies associated with resilience strategies that address increasing water scarcity in the Southwest. Strategies to be evaluated include: investments in built infrastructure (e.g., reservoirs and pipelines); incentive-based risk-sharing agreements; and watershed ecosystem services. The project emphasizes how ecosystem services can buffer water impacts of climate change, as well as the potential for climate mitigation as a strategy to enhance water supply security. Project outputs will include a replicable method for co-producing resilient water-related climate adaptation and mitigation strategies, including scientific and economic evaluation. Potential outcomes include improved water supply reliability and cooperation on adapting to shortages for a regional economy that exceeds $3 trillion annually.

Information Valuation Concerning Decisions Made in Response to Wildland Fires in the Southwest United States

CLIMAS Investigators: G. Frisvold, D. Ferguson, M. Crimmins, J. Doss

Research Partners: C. Maxwell, U.S. Forest Service; NOAA – National Weather Service; Bureau of Land Management; Arizona Department of Forestry and Fire Management; New Mexico Forestry Division; Bureau of Indian Affairs

End Users: U.S. Forest Service; NOAA – National Weather Service; Bureau of Land Management; Bureau of Indian Affairs; National Park Service; Arizona Department of Forestry and Fire Management; New Mexico Forestry Division

Research has established that the El Niño-Southern Oscillation (ENSO) pattern in the equatorial Pacific has relatively predictable seasonal influences on the weather and climate of the US Southwest, making climate information valuable for environmental and economic decision-making. Fire management agencies are an ideal target audience for climate information. Significant work has gone into creating wildfire-specific climate outlooks and information products. Research has identified networks of actors successful at disseminating this information. This study addresses two questions: how is climate information being used to inform wildland fire management decisions and what is the economic value of such information? Focus groups and an online survey of Southwest wildfire experts address the first question and form the basis of an economic analysis of the value of fire management information. This research seeks to reveal what opportunities exist to improve existing products and develop new ones.

Urban Heat and Health Interventions and Evidence Gaps

CLIMAS Investigators: L. Keith and E. Schmidt

Research Partners: NOAA Climate Program Office; City of Tucson, AZ; Pima County, AZ; City of Seattle, WA; King County, WA; City of Houston, TX; Harris County, TX; City of Baltimore, MD; Baltimore County, MD; City of Detroit, MI; Wayne County, MI

End Users: Urban planners, landscape architects, emergency managers, public health officials, sustainability/resilience staff, and climate service providers

This study will provide an in-depth investigation of the survey results on how communities plan and govern extreme heat risk. The case study methods include semi-structured interviews with decision-makers and content analysis of plans for heat management and mitigation strategies. It builds upon the work started with the CLIMAS Urban Heat Island Mapping project that assessed the use of UHI maps and decision-making in the Southwest, a literature review on planning for extreme heat, and the survey of U.S. planners on extreme heat. To document the current state of emergent extreme heat governance in the U.S., five case study communities were selected, including Tucson, AZ; Houston, TX; Baltimore, MD; Detroit, MI; and Seattle, WA. These communities represent five National Climate Assessment regions, and four of the communities have participated in the NIHHIS-CAPA Heat Mapping Campaign.

Photo by Frankie Lopez on Unsplash

Rethinking Social Vulnerability: Climate Risks and Impacts

CLIMAS Investigators: B. McMahan, R. Driesen, L. Pilli, M. Moeller, and C. Cheung

Research Partners: Bureau of Applied Research in Anthropology (BARA); Sonora Environmental Research Institute (SERI)

Additional Support: Bureau of Applied Research in Anthropology (BARA), University of Arizona; Sonora Environmental Research Institute (SERI); Agnese Nelms Haury Program, University of Arizona

This project seeks to better define social vulnerability to climate and the intersection of acute impacts and chronic conditions that further amplify these vulnerabilities. This project aims to develop climate services, build collaborative research partnerships, and engage regional stakeholder networks. Current activities focus on energy equity and thermal comfort in Tucson neighborhoods and developing improved characterizations of urban heat and air quality maps.

Collaborators from SERI and BARA focus on household experiences of thermal comfort, cooling infrastructure, and resulting behavior. CLIMAS researchers focus on assessing the role of neighborhood and regional patterns on thermal comfort, the role of long-term climate change) and investments in and inequitable distribution of buffering infrastructure. Expanding on previous work that views vulnerability as the accumulation of negative characteristics commonly associated with location (e.g., SOVI) or climate vulnerability, this research seeks to understand how vulnerability relates to lack of access to systems, more than the failure of those systems.

Two new CLIMAS-related efforts also developed during the reporting period:

Expanding ethical principles for transdisciplinary research

CLIMAS researchers A. Meadow, S. Carroll, D. Ferguson, C. Greene, and G. Owen conceptualized and wrote a paper with co-authors from the U.S. Forest Service, University of Idaho, Native Nations Institute, and U.S. Department of Agriculture, calling for the need to expand research ethics, beyond the Belmont principles, for conducting transdisciplinary research.

The paper titled, "Expanded ethical principles for research partnership and transdisciplinary natural resource management science" is in final review with the journal Environmental Management. A related presentation was delivered in November 2020 as part of a University of Washington actionable science webinar series hosted by the USGS Northwest Climate Adaptation Science Center, called Expanding Research Ethics in the Era of Transdisciplinary Research.

Managing the Colorado River System in Times of Water Shortage 25 Years Later

CLIMAS researchers G. Frisvold (editor) and C. Woodhouse (associate editor) are producing a special volume of the Journal of the American Water Resources Association, called "Severe Sustained Drought Revisited: Managing the Colorado River System in Times of Water Shortage 25 Years Later." In the 1970's, collaborative research supported by the Powell Consortium led to a set of studies published in 1995. The special volume reflects on the original studies and provides new insights on implications of multi-decadal drought in the Colorado River Basin.

Outreach and Engagement

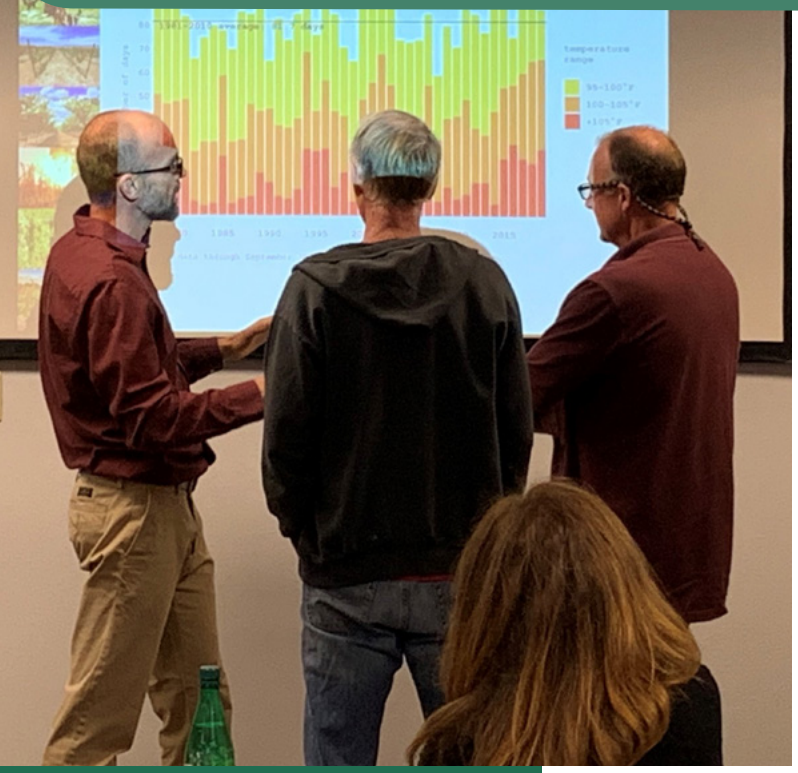


Photo by Jeremy Weiss

CLIMAS outreach and engagement occurred mostly virtually during this reporting period due to COVID-19 related restrictions. CLIMAS researchers gave presentations, hosted workshops, and used several online communication tools such as newsletters, data hubs, and interactive websites (see **"CLIMAS by the Numbers"**). One innovative approach to engagement culminated in a new online game called the **Southwest Monsoon Fantasy Forecasts**. The game was piloted in 2020 via the Southwest Climate Podcast, hosted by CLIMAS researchers M. Crimmins, Z. Guido, and B. McMahan. In the game, players estimate monthly rainfall totals for Tucson, Phoenix, Flagstaff, El Paso, and Albuquerque, and get points for how accurate and risky their forecasts are. The game is now live and bets are underway for July 2021.

Other forms of CLIMAS outreach and engagement are described below:

Newsletters:

The Southwest Climate Outlook (SWCO). SWCO summarizes climate and weather information from disparate sources in nonscientific language, providing more than 1,600 people with monthly climate-related information. Since SWCO's inception in 2002, stemming from the END InSight project, the publication has evolved into a tool for two-way communication with stakeholders and a platform for responding to needs throughout the region. Twelve issues were distributed between June 2020 through May 2021. Issues about the summer monsoon and heat (June, July, and August 2020) had the highest number of viewers. climas.arizona.edu/swco

Rainlog.org Monthly Climate Summary Email Newsletter. M. Crimmins authored and sent twelve newsletter issues between June 2020 – May 2021 to subscribers and those who log rain event totals.

Arizona Seasonal Climate Summary. Arizona Range and Livestock Newsletter. M. Crimmins authored quarterly climate summaries for this newsletter produced by University of Arizona Cooperative Extension.

The Southwest Climate Podcast. CLIMAS scientists discuss climate-related issues in monthly climate podcasts. The podcasts synthesize information from disparate sources that often do not have a Southwest bent, translating the national and global discussions into what it means for the Southwest. Ten episodes aired between June 2020 through May 2021. The top episodes aired in June, July, and August 2020. climas.arizona.edu/media/podcasts

University of Arizona Extreme Heat Network. L. Keith distributes a monthly newsletter to 200 subscribers from across the U.S. Other members of the network send requests to help promote their opportunities, such as grants or partnerships, related to heat. heat.arizona.edu/

Climate Viticulture Newsletter. J. Weiss produced 13 monthly and special issues of this newsletter for 90 subscribers, which provides a quick look at climate topics relevant to winegrape growing in Arizona and New Mexico. cals.arizona.edu/research/climategem/content/climate-viticulture-newsletter

Social Media:

New Mexico Climate Twitter. David DuBois continued his use of Twitter via the NM Climate Center account (@nmclimate). This account had 2887 followers as of June 2021, which increased by 702 people over the past 12 months. Activity on this Twitter account has generated many off-line conversations with local and national media. DuBois posts information, graphs, statistics, and photos of dust storms that impact southern New Mexico.

CLIMAS Twitter. The CLIMAS program's Twitter account (@CLIMAS_UA) has 914 followers as of June 2021. Posts that generated the highest amount of interest were related to the summer monsoon, the Southwest Climate Podcast, and winter precipitation.

CLIMAS PI M. Crimmins (@mike_crimmins) posts on climate conditions, drought impacts, tools/information and retweeting CLIMAS products like SWCO and podcast. He has 923 followers and posted about 100 tweets over past year.

Data Hubs and Online Tools:

Southwest U.S. Summer Monsoon Season Precipitation Mapping. A near real-time monsoon season precipitation mapping system was developed in May 2019. Several updates were added to maps and charts in 2020. This mapping product is often used for the SWCO and podcasts. They were recently added to the National Weather Service's Tracking the Monsoon webpage.

Southwest U.S. Station Climate Summaries: This hub houses station-based climate monitoring plots for 118 stations across Arizona and New Mexico. Interactive historical plots of temperature and precipitation were added this year for each station with updated website and near-real time updates to plots each morning.

Standardized Drought Index Visualization Tool: This interactive R-based Shiny app can be used to plot and explore drought indices calculated using NOAA NCEI climate division data. Plots are used in state level drought monitoring, by other climate monitoring efforts, and for general CLIMAS related outreach effort.

myRAINgeLog: This online data management and visualization tool is designed for ranchers and land managers who collect and interpret cumulative precipitation observations at remote sites. The account-based tool allows users to collect, manage and analyze multiple gauges and share observations through a public mapping feature. Custom reports can be generated for each gauge with accompanying charts of observations against historical climate conditions and summaries of field notes and photos entered by the user. The site is updated daily. The tool has continued in development as part of a broader rangeland precipitation monitoring program that started in 2017. New features were added in 2020, with additional training workshops conducted online in 2021. A new YouTube channel with how to videos was also added in 2021.

Arizona Station-based Drought Tracker: A new, real-time station-based drought tracking page was posted in spring of 2021 to assist with short-term drought monitoring in Arizona. This tool accesses precipitation data from over 1300 rain gauges from different networks including volunteer observers (e.g., Rainlog.org, CoCoRAHS, and home weather stations) to develop drought index values at time periods from the most recent 30 days to the past 365 days. The intention of this tool is to support fine scale adjustments of the U.S. Drought Monitor map across Arizona using as much observation data as possible.

Education and Outreach:

Weather and Climate Science Middle School Curriculum: Climate literacy is important at all ages but particularly in the elementary school curriculum. This project started by combining outreach efforts with middle school students and an agricultural extension class at New Mexico State University dealing with teaching science. The curriculum is available online and continues to be developed at the NMSU Extension and Research Youth Agricultural Science Center lead by P. Skelton.

Drought - Be a Citizen Scientist: Drought is one of the natural hazards impacting New Mexicans every year. This short article explains drought and was part of a publication from the NM Department of Agriculture (NMDA) addressing natural hazard mitigation. NMDA emails this publication and prints copies for events like the state fair, public meetings, and for schools.

Workshops and Seminar Series:

Advancing the Theory and Practice of Urban Heat Resilience: L. Keith led the organization of the virtual workshop with co-organizers D. Hondula and S. Meerow (Arizona State Univ.), V.K. Turner (Univ. of California Los Angeles), and H. Jones (NOAA). Aspen Global Change Institute assisted with logistics, virtual workshop technology, and facilitation. The workshop was held on October 19-20, 2020, and included participation from researchers at universities, leadership representatives from federal agencies (NOAA, USGS, EPA, CDC), non-profits, and stakeholders across the U.S. The workshop description, participants, agenda, and recordings are online.

NMSUCCESS NMSU Climate Change Education Seminar Series: D. DuBois assisted in four online, public presentations for this seminar series. The speakers invited to speak this year addressed impacts of climate change to water, endangered and threatened species, indigenous cultures, and soil health. Attendance ranged from 50-75 people at each event.

Photo credit Dan Ferguson

Photo credit Dan Ferguson

Ways stakeholders were served

CLIMAS researchers serve their partners and stakeholders in a variety of ways that are detailed in other sections of this report. Examples of services included: a) reports and data analyses tailored to specific information gaps and requests; b) supporting stakeholders' grant applications for their own funding; c) direct application to climate adaptation plans and actions; e) supporting stakeholders in talking to legislators and policy makers; and f) convening groups and providing space and infrastructure for communication and collaboration.

Working with Communities Underserved by Climate Research

Several CLIMAS projects and related efforts aim specifically to work in partnership with and provide information to communities that have been underserved by climate research, including:

- ***Partnering with Southwest Indigenous Communities to Identify Data Challenges, Needs, and Opportunities:*** This project seeks to improve Indigenous data sovereignty and governance.
- ***Community-Based Responses to Climate Water Challenges:*** As part of this work, researchers meet with tribal nations and organizations about water management, water rights, economies, and ecosystems.
- ***Urban Heat and Health Interventions and Evidence Gaps:*** Findings from this work aim to assist communities that experience high exposure to heat stress, which often include low-income and marginalized communities.
- ***Rethinking Social Vulnerability: Climate Risks and Impacts:*** This work focuses on low-income households in Tucson, AZ, which are predominantly Latinx. Researchers aim to assess climate impacts and thermal comfort through the lens of access and equity.
- ***Collaborative Research on Environmental Risks and Built Environment in the Borderlands of the Southwest:*** This project addresses environmental issues that affect residents along the U.S.-Mexico border, where inequality and rates of poverty are high.
- ***Building Regional Food System Resilience in Southern Arizona – Learning from COVID-19:*** This work engaged Indigenous representatives as research participants, who discussed how they have been ignored or left out of conversations about the local food system, and how this needs to change.
- In his role as the ***New Mexico State Climatologist***, CLIMAS PI D. DuBois works with members of tribal organizations. He collaborated with the Southwest Climate Hub and the Native American Producer Success Project (NAPS) to recruit for CoCoRaHS. He also provided drought outlooks for NAPS and collaborated with the Santa Ana Pueblo on their drought webinars.

COVID-19 Impacts on CLIMAS research

The COVID-19 pandemic hindered the pace of progress on most CLIMAS projects. Constraints on in-person meetings, travel, and fieldwork were commonly reported by investigators, as well as a general increase in anxiety and filling caretaking roles. Other constraints existed for project partners as their agencies and businesses shifted priorities to address the pandemic. Partners and research participants in rural areas sometimes did not have dependable access to internet, which slowed communication efforts. However, investigators made appropriate adjustments and progress was still made on all CLIMAS projects. Three CLIMAS projects shifted the scope of their projects to address pandemic impacts on food supply chains (Frisvold), local food system operations (Owen), and heat risk (Brown).

Next Steps for 2021 – 2022

The next reporting period represents the final year of the current CLIMAS grant. Our focus for the next year includes wrapping up current projects and synthesizing findings across projects to address the research questions and focus areas outlined in our current proposal. A second focus will be to develop our next RISA funding proposal. We have begun to brainstorm the priority research needs and focus areas identified by our research partners in the Southwest. We are in discussions with new potential program partners and funded investigators in New Mexico and in tribal organizations in the region.

Program Evaluation

CLIMAS Investigators: G. Owen and A. Meadow

The CLIMAS program evaluation model uses data collected from annual report templates and from periodic interviews with CLIMAS investigators. CLIMAS defines societal impacts as the ways that research, and the process of conducting research, influences the world beyond the academic realm. Societal impacts refer to the changes that research makes in the world, how, and for whom. We use the following five categories of impact:

- Instrumental applications – tangible changes to plans, decisions, practices, or policies
- Conceptual impacts – changes in people's knowledge about or awareness of an issue
- Capacity building impacts – enhancing the skills, expertise, or resources of an organization or group of people
- Connectivity impacts – new or strengthened relationships, partnerships, or networks that endure after a project ends
- Socio-environmental impacts – changes to social and/or ecological systems that result from actions taken because of research

Findings from an evaluation of CLIMAS projects during the 2012-2017 funding cycle were published in Research Evaluation. This article offers insight into how researchers envision their impact, the management and development of a mission-oriented research program, and the use of evaluation to understand how collaborative research contributes to societal and environmental change.

Owen, G. 2020. Evaluating socially engaged climate research: Scientists' visions of a climate resilient U.S. Southwest. *Research Evaluation*, rvaa028

This evaluation framework has been refined for use in the current CLIMAS funding cycle (2018-2022). G. Owen and A. Meadow are adapting and applying this framework to the Arizona Institutes for Resilience, the research institute where CLIMAS is housed at the University of Arizona. They were named as 2020 Fellows in Advancing Research Impacts in Society to develop a guidebook for evaluating the societal impact of climate change research using examples from CLIMAS and Southwest Climate Adaptation Science Center projects. The guidebook was published in May 2021.

Meadow, A.M. and G. Owen. 2021. *Planning and Evaluating the Societal Impacts of Climate Change Research Project: A guidebook for natural and physical scientists looking to make a difference.* Advancing Research Impacts in Society.

Photo credit Dan Ferguson

Evidence and Case Studies of Societal Impact

Partnering with Southwest Indigenous Communities to Identify Data Challenges, Needs, and Opportunities

This project seeks to improve Indigenous data sovereignty and governance. As Native nations seek to utilize the best available data and information to build climate resilience and healthy, sustainable communities, issues around data relevance, ownership, access, possession, and control arise. For example, a Native nation may collect their own data or have access to culturally sensitive traditional knowledge useful to inform climate-related decisions, but they may not wish to make that data widely available even though it may be helpful when seeking funding or engaging in regional climate adaptation planning.

A CLIMAS-sponsored summit held in 2019 led to several on-going initiatives that are led by Indigenous scholars to advance Indigenous data sovereignty efforts. Outputs from these efforts are housed online at the Collaboratory for Indigenous Data Governance, a website for research, policy, and practice. Some outputs include:

- Policy briefs calling for sovereignty of climate-related data in Arizona and the U.S.
- Journal articles that explore data sovereignty, impacts of the pandemic on data sovereignty, and how to operationalize principles for use in governing Indigenous data.
- Edited volumes that explore data sovereignty and policy; and
- Recorded presentations and panel discussions about data sovereignty and research priorities

This work has directly informed the CARE principles for Indigenous Data Governance (*Collective benefit, Authority to control data, Responsibility to engage respectfully, and Ethics*). The development and promotion of these principles have led to mindset shifts about ethical research and data collection, and data governance. It has provided the online infrastructure for Indigenous scholars to organize around operationalizing data sovereignty. This work contributes to building more equitable research relationships with tribal governments, organizations, and communities.

Photo by Jeremy Bezanger on Unsplash

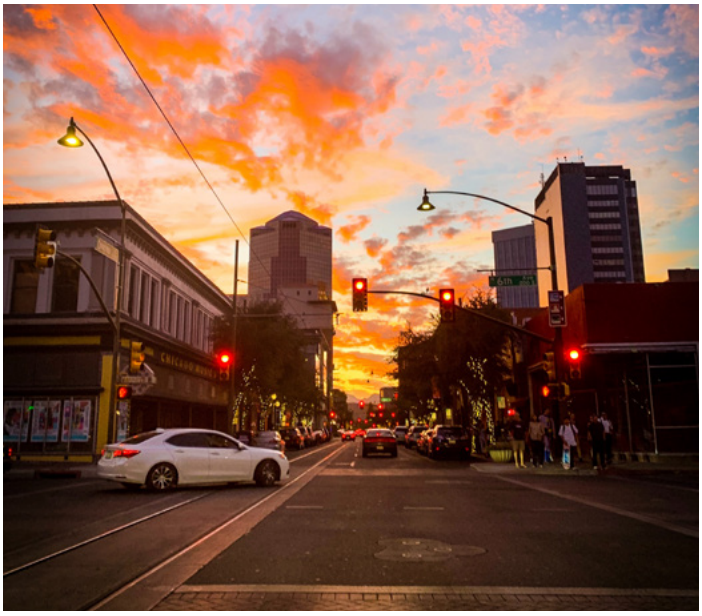


Photo by Frankie Lopez on Unsplash

Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets

CLIMAS's ongoing participation and final report played a substantive role in helping Tucson Electric Power evaluate and compare energy resource portfolios based on their relative contributions to warming. TEP was then able to better communicate the reasons behind their portfolio decisions to their stakeholder network and advisors, beyond the typical default metric of simple cost.

The data infrastructure developed to assess carbon budgets provided a replicable and transparent way to evaluate carbon budgets for any industry, organization, or company with emissions and warming targets. CLIMAS researchers adapted existing assessment methods but tailored the approach for their TEP partners. TEP is somewhat constrained given previous investments in carbon intensive generating resources, but this tool and data exploration provided some flexibility to explore how various portfolios would affect warming and emissions. Through this process, regional energy utilities learned that while complete elimination of carbon fuels might not be feasible in the intermediate term, a more rapid and complete elimination of carbon intensive generating resources, such as coal, would have a larger impact from the perspective of cumulative carbon emissions, even if these rapid reductions maintained some carbon resources, such as natural gas, as bridge fuels to 100% clean and renewable energy.

Some stakeholders in the advisory council were frustrated by this analysis, as it did not call for complete elimination of carbon fuels to meet carbon budget warming targets. Others saw that the cumulative carbon emissions resulting from a faster reduction while maintaining some carbon fuels was a productive step towards 100% clean energy. TEP's Integrated Resource Plan, published in July 2020, reflects much more aggressive reductions targets in terms of timing and intensity than prior plans.

Tucson Electric Power, their sister company UniSource Energy Services, and their parent company UNS Energy Corporation, provide power to approximately 700,000 residents of Arizona. These are all subsidiaries of Fortis, which owns utilities serving more than 3 million customers across Canada and in the United States and the Caribbean. The analysis and framework used in this project demonstrate the value of starting sooner than later to reduce emissions, as well as the impact of overall percent reductions.

This process will continue with a different Arizona energy utility company, who asked B. McMahan to sit on their advisory panel to develop their next integrated resource plan.

Community Climate Profiles

A. Meadow and J. Weiss mobilized climate change and adaptation information into use in several communities over the course of this project. This mobilization occurred thanks to increased learning among our community partners. Stakeholders who came into the project with questions about the reality of climate change left with more clear evidence of its impacts. Written feedback from partners demonstrate how the profiles, and the process of working with CLIMAS, helped them feel more confident in their own understanding of the science.

While communities found the climate projection data interesting, their biggest need was in understanding the most likely impacts for their area. Completing impacts and vulnerability assessments was not part of the original project plan, but researchers altered their plans to respond to community partner requests. Communities that were less progressive on climate change adaptation topic wanted clear and credible information. When presented with that information (with sources noted), they became comfortable engaging in climate change topics, asking questions, and sharing thoughts. The format of the Climate Profiles – straight-forward, well-referenced, and written for a general audience – appealed to a wide-range of readers.

The range of groups/communities who participated in the Climate Profiles project indicates the growing concern about climate change impact in the Southwest. CLIMAS researchers worked with "standard" partners like the City of Flagstaff (a progressive city known for its work on conservation and climate change), but also worked with a golf-based retirement community outside of Tucson, and the City of Sedona, which is notably less progressive than Flagstaff. The Highlands' resident planning committee reached out to CLIMAS because they had questions and concerns about climate change and were interested in finding ways to make their community more sustainable. Golf retirement communities are not typically seen as leaders on climate change adaptation, but this group was really dedicated to getting climate change information out to their fellow residents. The partnership with Arizona Land and Water Trust also points to a new sector (non-profits) who are looking for guidance on how to incorporate climate change and adaptation into their work. While these are just a few examples, when taken together, the increased and more widespread interest in the topic is notable.

The climate profile produced for the City of Flagstaff was directly integrated into the city's Climate Adaptation and Action Plan, was adopted by City council in 2018, and won an Arizona Planning Association Award. The climate profile for the Pueblo of Laguna was integrated into their vulnerability assessment process, which is part of a larger effort by the Pueblo to develop a climate change adaptation plan. The profile of the Upper Santa Cruz Watershed is being used by Arizona Land and Water Trust to inform their plans to incorporate climate adaptation into their conservation easements, which are legal agreements between the land trust and landowners regarding future use and conservation of working lands in Arizona. Arizona Land and Water Trust protects over 2.7 million acres of land through its conservation easements. Partners with the Arizona Land and Water Trust sent the following feedback on their Climate Profile:

Photo credit Dan Ferguson

"Dear Alison, Thank you for all the work that you, Jeremy and Sarah put into this profile! We couldn't be more pleased with the final product. The Trust has, for some time, considered how we might integrate climate science and adaptation into our work – and this opportunity was just the jump-start we needed. As you know, this climate profile became central to a grant we received from the Land Trust Alliance's Land and Climate Program, and together these opportunities have motivated our participation in UA's University Climate Change Coalition (UC3) and our involvement with groups like the Southwest Climate Hub. We're eager to share the profile with our landowner partners and other stakeholders in the Upper Santa Cruz Watershed, and believe it will provide practical guideposts to encourage climate-adaptive land management across the region. The Trust is very grateful that CLIMAS was able to take on this project, and we hope we're able to work together again in the future."

Education and Training

Photo credit Melissa Merrick

Environment & Society Fellowship Program

The Environment & Society Fellowship was created in 2013 by CLIMAS, with support from the University of Arizona Office of Research, Innovation, and Impact. The fellowship, managed by Investigators G. Owen and B. McMahan, provides training and funding for graduate students to practice use-inspired research and science communication. Since its inception, the Fellowship program has funded 24 graduate students.

2020 Environment and Society Fellows:

The 2020 Fellowship cohort was heavily impacted by the COVID-19 pandemic. Most projects had to be readjusted as fieldwork and travel did not allow for in-person research and data collection. In their final reports, each Fellow reflected on pandemic impacts.

Emily Cooksey, a PhD student in Environmental Health Science, collaborated with Southern California Coastal Water Research Project to conduct research with oysters to reduce human health risk from exposure to pathogenic Vibrio. She hopes to influence current oyster harvesting policy in Southern California. V. parahaemolyticus: a small bacteria with a big name.

JoRee LaFrance, a PhD student in the Department of Environmental Sciences, researched surface water quality within the Little Bighorn River watershed. JoRee aims to support her tribe, the Apsáalooke/ Crow, in their efforts to set their own water quality standards based on cultural practices. Research on the Little Bighorn River - Reflections on the CLIMAS E&S Fellowship

Kunal Palawat, a MS student in Environmental Science, aimed to create a climate change and soil contamination-informed community cookbook. Their work with community partners was halted by the pandemic, however, they started to compile the recipes throughout the year. Community Cookbook - Reflections on the CLIMAS E&S Fellowship

Rachel Rosenbaum, a PhD student in Anthropology, collaborated with Recycle Lebanon in Beirut to facilitate the design and implementation of a data visualization platform. The platform, "Regenerate Lebanon," is an open-source online platform visualizing interconnected environmental and infrastructural issues around the country and connecting people to solutions. Caring in Crisis: Challenges and Lessons in Practicing Collaborative Research in 2020

2021 Environment and Society Fellows:

Lea Schram von Haupt
is a master's student in the School of Natural Resources and the Environment. Her focus is National Environmental Policy Act (NEPA) planning on federal lands. She will focus on fire restoration practices on the Coronado National Forest and how US Forest Service staff and stakeholder attitudes towards fire restoration and forest resilience influence forest planning.

Moriah Bailey Stephenson,
a PhD student in Anthropology, is collaborating with Local Environmental Action Demanded (LEAD), an environmental justice organization in Ottawa County, OK, to create a flooding response resource for county residents. She will compile interviews and create a resource for residents who are at heightened risk for flooding due to the passage of the National Defense Authorization Act for the year 2020.

Simone A. Williams,
a PhD student in the Arid Lands Resource Sciences program, is working with the Coconino Plateau Watershed Advisory Council and Coconino Plateau Watershed Partnership to characterize karst groundwater security issues, including quantity, quality, and access. She will produce a series of thematic resource maps, a searchable geodatabase and a story map of regional karst groundwater vulnerability in Arizona.

Photo credit Dan Ferguson

Photo credit Dan Ferguson

Transdisciplinary Environmental Science for Society Professional Development Program

The Transdisciplinary Environmental Science for Society (TESS) program trains researchers, practitioners, and educators to be well-equipped to address complex environmental challenges. The program is currently designed as a series of three 20-hour online professional development courses:
1) fundamentals of transdisciplinary research,
2) practicing collaborative research, and
3) communication strategies and skills.

Other related courses are under development including a graduate seminar and possibly an undergraduate course, both of which will focus on the challenges of global change and practical approaches to collaborative research that engages research and stakeholder communities. The goal of the TESS program is to provide training in the theory and practice of transdisciplinary research so that students have the knowledge and perspectives needed carry out successful collaborative research.

In Fall 2020, five students enrolled in the first course in the series, about the theory of transdisciplinary research. In spring and summer 2021, seven students enrolled in the second course, about transdisciplinary research in practice.

Appendix A: Publications 2020 – 2021

Anderson, T.G., C.A. Woodhouse, D.B. Ferguson. 2020. Upper Lake Mary Lake Level Response to Climate Variability: Report to Flagstaff Water Services.

Arizpe, A., D.A. Falk, C.A. Woodhouse, T.W. Swetnam. 2020. Widespread fire years in the US-Mexico sky islands are contingent on both winter and monsoon precipitation. International Journal of Wildland Fire 29: 1072-1087. DOI: 10.1071/WF19181

Bickel, A.K., D. Duval, G. Frisvold. 2020. Agriculture in Graham and Greenlee Counties. https://economics.arizona.edu/agriculture-graham-and-greenlee-counties

Bickel, A., D. Duval, G. Frisvold. 2021. Drought and Insured Crop Losses in Arizona. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

Bickel, A., D. Duval, G. Frisvold. 2021. The Effects of Drought on Arizona Forage Production. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

Brice, B., G.H. Guiterman, C. Woodhouse, C. McClellan, P. Sheppard. 2021. Comparing tree-ring based reconstructions of snowpack variability at different scales for the Navajo Nation. Climate Services 22. DOI: 10.1016/j.cliser.2021.100213

Brischke, A.S., M.A. Crimmins, J. Grace, A.L. Hall, M.P. Mcclaran. 2020. Financial Options for Livestock Producers During Natural Disasters. University of Arizona Cooperative Extension Bulletin. https://extension.arizona.edu/pubs/financial-options-livestock-producers-during-natural-disasters

Brischke, A.S., M.A. Crimmins, J. Grace, A.L. Hall, M.P. McClaran. 2020. Monitoring drought in Arizona. University of Arizona Cooperative Extension Bulletin. https://extension.arizona.edu/pubs/monitoring-drought-arizona

Brischke, A.S., M.A. Crimmins, J. Grace, A.L. Hall, M.P. McClaran. 2020. The U.S. Drought Monitor. University of Arizona Cooperative Extension Bulletin. https://extension.arizona.edu/pubs/us-drought-monitor

Brown, H.E., L. Sedda, C. Sumner, E. Stefanakos, I. Rubino, M. Roach. 2021. Understanding Mosquito Surveillance Data for Analytic Efforts: a case study. Journal of Medical Entomology tjab018. DOI: 10.1093/jme/tjab018

Carroll, S.R., R. Akee, D. Cormack, T. Kukutai, R. Lovett, M. Suina, R.K. Rowe. 2021. Indigenous Data During COVID-19: From Outside to Within. Frontiers in Sociology 6:617895. DOI: 10.3389/fsoc.2021.617895

Carroll, S.R., I. Garba, O.L. Figueroa-Rodríguez, J. Holbrook, R. Lovett, S. Materrechera, M. Parsons, K. Raseroka, D. Rodriguez-Lonebear, R.K. Rowe, R. Sara, J.D. Walker, J. Anderson, M. Hudson. 2020. The CARE Principles for Indigenous Data Governance. Data Science Journal 19: 43. DOI: 10.5334/dsj-2020-043

Carroll, S.R., E. Herczog, M. Hudson, K. Russell, S. Stall. 2021. Operationalizing the CARE and FAIR Principles for Indigenous Data Futures. Nature: Scientific Data 8: 108. DOI: 10.1038/s41597-021-00892-0

Carroll, S.R., M. Hudson, J. Holbrook, S. Materrechera, Ja. Anderson. 2020. Working with the CARE principles: operationalizing Indigenous Data Governance. Ada Lovelace Institute. https://www.adalovelaceinstitute.org/operationalising-indigenous-data-governance/

Carroll, S.R., D. Rodriguez-Lonebear, R. Akee, A. Lucchesi, J.R. Richards. 2020. Indigenous Data in the COVID-10 Pandemic: Straddling Erasure, Terrorism, and Sovereignty. Social Science Research Council, Items: Insights from the Social Sciences. https://items.ssrc.org/covid-19-and-the-social-sciences/disaster-studies/indigenous-data-in-the-covid-19-pandemic-straddling-erasure-terrorism-and-sovereignty/

Colby, B. 2020. Acquiring environmental flows: ecological economics of policy development in western U.S. Ecological Economics 173: 106655. DOI: 10.1016/j.ecolecon.2020.106655

Crimmins, M.A., B. McMahan, W.F. Holmgren, and G. Woodard. 2021. Tracking precipitation patterns across a western US metropolitan area using volunteer observers: RainLog.org. International Journal of Climatology 41: 4201–4214. DOI: 10.1002/joc.7067

Darapuneni, M.K., O.J. Idowu, B. Sarihan, D.W. DuBois, K. Grover, S. Sanogo, K. Djaman, L.M. Lauriault. 2021. Growth characteristics of summer cover crop grasses and their relation to soil aggregate stability and wind erosion control in arid Southwest. ASABE Applied Engineering in Agriculture 37(1): 11-23. DOI: 10.13031/aea.13972

Dormody, T.J., P.D. Skelton, G. Rodriguez, D.W. DuBois, D. VanLeeuwen. 2020. Lesson Worksheets: A Tool for Developing Youth Weather and Climate Science Comprehension. Journal of Extension, 58(2). https://tigerprints.clemson.edu/joe/vol58/iss2/16/

Dormody, T.J., P.D. Skelton, G. Rodriguez, D.W. DuBois. 2020. Science Comprehension Retention Among Youth Agriscience Students Instructed in Weather and Climate. Journal of Youth Development 15(6): 116-135. DOI: 10.5195/jyd.2020.902

DuBois, D.W. 2020. Drought - Be a Citizen Scientist. NMDA Natural Hazard Mitigation. Las Cruces, NM: New Mexico Department of Agriculture. https://www.nmda.nmsu.edu/wp-content/uploads/2020/03/NMSU_DeptAgri_3-29-FINAL.pdf

Duval, D., A. Bickel, and G. Frisvold. 2020. Arizona County Agricultural Economy Profiles. Tucson: University of Arizona Cooperative Extension. https://economics.arizona.edu/arizona-county-agricultural-economy-profiles

Duval, D., A. Bickel, and G. Frisvold. 2020. County Agricultural Economy Profiles for Southern Arizona. Making Action Possible in Southern Arizona (MAP Dashboard) White Paper #14. Economic and Business Research Center. Eller College of Management. University of Arizona, Tucson. https://mapazdashboard.arizona.edu/sites/default/files/images/county_agricultural_economy_profiles_final.pdf

Duval, D., A. Bickel, and G. Frisvold. 2021. Drought Effects on Arizona State Park Visits, Visitor Spending, and Local Economies. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

Duval, D., A. Bickel, and G. Frisvold. 2021. Drought Effects on National Park Visits, Visitor Spending, and Local Economies. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

Duval, D., G. Frisvold, and A. Bickel. 2020. The economic value of trails: A travel cost method study. Final Technical Report to the Arizona Parks Board. Tucson: University of Arizona Cooperative Extension. https://economics. arizona.edu/economic-value-trails-arizona-travel-cost-method-study

Duval, D., A. Bickel, and G. Frisvold. 2021. The Effects of Reservoir Levels on Arizona National Recreation Area Visitation, Visitor Spending, and Local Economies. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

Flores-Margez, J.P., J.A. Jimenez-Cervantes, J.A. Hernández-Escamilla, E. Olivas-Enríquez, M.K. Shukla, A. González-Delgado, D.W. DuBois. 2020. Fungal genus detected in soils of Chihuahuan Desert during dust storms along United States-Mexico border. Terra Latinoamericana 38(4): 725-734. https://www.terralatinoamericana.org.mx/index.php/terra/article/view/754

Frederick, S.E., C.A. Woodhouse. 2020. A multi-century perspective on the relative influence of seasonal precipitation on streamflow in the Missouri River headwaters. Water Resources Research. DOI: 10.1029/2019WR025756

Frisvold, G. and H. Chen. 2021. The Conservation Reserve Enhancement Program (CREP) as a vehicle for water conservation: An annotated bibliography.

Frisvold, G. and A. Marcheva. 2021. Reverse water auctions in theory and practice. Report.

Gardner-Vandy K., D. Scalice, et al. 2020. Relationships First and Always: A Guide to Collaborations with Indigenous Communities. An EDI Community Paper to the 2020 Planetary Science and Astrobiology Decadal Survey 2013-2032. Submitted as part of a collaborative effort organized by the Equity, Diversity, and Inclusion Working Group (EDIWG).

Garfin, G., D.A. Falk, C.D. O'Connor, K. Jacobs, R. Sagarin, A. Haverland, A. Haworth, A. Baglee, J.L. Weiss, J. Overpeck, A. Zuñiga-Teran. 2021. A new mission: Mainstreaming climate adaptation in the US Department of Defense. Climate Services 22: 100230. DOI: 10.1016/j.cliser.2021.100230

Greene, C. 2021. "Drought isn't just water, it is living": Narratives of drought vulnerability in California's San Joaquin Valley. Geoforum 121: 33-43. DOI: 10.1016/j.geoforum.2021.02.007

Hiraldo, D., S.R. Carroll, D.M. David-Chavez, M.B. Jäger, and M. Jorgensen. 2020. Native Nation Rebuilding for Tribal Research and Data Governance. NNI Policy Brief Series. Tucson: Native Nations Institute, University of Arizona.

Hiraldo, D., K. James, S.R. Carroll. 2021. Indigenous Sovereignty in a Pandemic: Tribal Codes in the United State as Preparedness. Frontiers in Sociology 6:617995. DOI: 10.3389/fsoc.2021.617995

Isaaks, R., and B. Colby. 2020. Empirical application of rubinstein bargaining model in western U.S. water transactions. Water Economics and Policy 6(1): 1950010. DOI: 10.1142/S2382624X19500103

Johnson, N., M.B. Jäger, L. Jennings, A. Juan, S.R. Carroll, D.B. Ferguson. 2020. Indigenous Foods Knowledges Network: Facilitating Exchange between Arctic and Southwest Indigenous Communities on Food and Knowledge Sovereignty. Witness the Arctic. https://www.arcus.org/witness-the-arctic/2020/3/highlight/2

Karambelkar, S. and A.K. Gerlak. 2020. Collaborative Governance and Stakeholder Participation in the Colorado River Basin: An Examination of Patterns of Inclusion and Exclusion. Natural Resources Journal 60. https://digitalrepository.unm.edu/nrj/vol60/iss1/3

Keith, L., N. Iroz-Elardo, I. Sami, E. Austhof. 2021. Extreme Heat at Outdoor Vaccination Sites: Banner South (Kino) Report. The University of Arizona.

Keith, L., N. Iroz-Elardo, I. Sami, E. Austhof. 2021. Extreme Heat at Outdoor Vaccination Sites: Tucson Medical Center Report. The University of Arizona.

Keith, L., N. Iroz-Elardo, I. Sami, E. Austhof. 2021. Extreme Heat at Outdoor Vaccination Sites: UArizona POD Report. The University of Arizona.

Keith, L., S. Meerow, and T. Wagner. 2020. Planning for extreme heat: a review. Journal of Extreme Events 6(03n04): 2050003. DOI: 10.1142/S2345737620500037

Khatri-Chhetri P., S.M. Hendryx, K.A. Hartfield, M.A. Crimmins, W.J.D. van Leeuwen, V.R. Kane. 2021. Assessing Vegetation Response to Multi-Scalar Drought across the Mojave, Sonoran, Chihuahuan Deserts and Apache Highlands in the Southwest United States. Remote Sensing 13(6): 1103. DOI: 10.3390/rs13061103

Martin, J.T., G.T. Pederson, C.A. Woodhouse, and 16 co-authors. 2020. Increased drought severity tracks warming in the United States' largest river basin. Proceedings of the National Academies of Science (PNAS). DOI: 10.1073/pnas.1916208117

McCabe, G., D. Wolock, C.A. Woodhouse, G. Pederson, S. McAfee, S. Gray, A. Csank. 2020. Basin wide hydro-climatic drought in the Colorado River basin. Earth Interactions 24: 1–20. DOI: 10.1175/EI-D-20-0001.1

McMahan, B. A.K. Gerlak. 2020. Climate risk assessment and cascading impacts: Risks and opportunities for an electrical utility in the US Southwest. Climate Risk Management 29: 100240. DOI: 10.1016/j.crm.2020.100240

McMahan, B., R.L. Granillo, B. Delgado, M. Herrera, M.A. Crimmins. 2021. Curating and Visualizing Dense Networks of Monsoon Precipitation Data: Integrating Computer Science into Forward Looking Climate Services Development. Frontiers in Climate 3. DOI: 10.3389/fclim.2021.602573

McMahan, B., W. Holmgren, A. Gerlak. 2020. Climate and TEP Resource Portfolios – Emissions Reduction and Cumulative Carbon Budgets. An appendix to the Tucson Electric Power 2020 Integrated Resource Plan. https://www.tep.com/wp-content/uploads/TEP-2020-Integrated-Resource-Plan-Lo-Res.pdf

Meadow, A.M., G. Owen. 2021. Planning and Evaluating the Societal Impacts of Climate Change Research Projects: A guidebook for natural and physical scientists looking to make a difference. Advancing Research Impacts in Society, University of Michigan. https://www.rie.arizona.edu/sites/default/files/Meadow-Owen_Societal-Impacts_Guidebook.pdf

Meadow, A.M, J. Weiss, S. LeRoy. 2021. Climate Profile for the Upper Santa Cruz Watershed. https://climas.arizona.edu/research/community-climate-profiles

Owen, G. 2020. Evaluating socially engaged climate research: Scientists' visions of a climate resilient U.S. Southwest. Research Evaluation, rvaa028. DOI: 10.1093/reseval/rvaa028

Owen, G., E. Kinkaid, L. Bellante, S. Maccabe. 2021. State of the Tucson Food System Report: Assessing the impacts of the COVID-19 pandemic in southern Arizona 2020-2021. Center for Regional Food Studies, University of Arizona. https://crfs.arizona.edu/sites/crfs.arizona.edu/files/2020-21%20State%20of%20the%20Tucson%20Food%20System%20Report_3.pdf

Owen, G., E. Kinkaid, L. Bellante, S. Maccabe. 2021. Executive Summary: State of the Tucson Food System Report, Assessing the impacts of the COVID-19 pandemic in southern Arizona, 2020-2021. Center for Regional Food Studies, University of Arizona. https://crfs.arizona.edu/sites/crfs.arizona.edu/files/Executive%20Summary_2020-21%20State%20of%20the%20Tucson%20Food%20System%20Report.pdf

Pendergrass, A.G., G.A. Meehl, R. Pulwarty, M. Hobbins, A. Hoell, A. AghaKouchak, C. J.W. Bonfils, A.J.E. Gallant, M. Hoerling, D. Hoffmann, L. Kaatz, F. Lehner, D. Llewellyn, P. Mote, R. Neale, J.T. Overpeck, A. Sheffield, K. Stahl, M. Svoboda, M.C. Wheeler, A.W. Wood, C.A. Woodhouse. 2020. Flash droughts: High impact events that present a new challenge for subseasonal to seasonal prediction. Nature Climate Change 10: 191–199. DOI: 10.1038/s41558-020-0709-0

Robinson, J., E. Ortiz, C. Lowen, R. Winch, C. Rodriguez, S. Fowell, R. Ojeda, R. Gonzalez, S. Foulke, A. Lakdawala, G. Perelli, A. Della Croce, S. Maina, K. Chavez, E. Canfield, S. Buldoc, S. Kaplan, E. Schepp, M. Light, R. Stephenson, D. Tylutki, J. Hernandez, J. Blankenship, C. Crosson, J. Weiss, S. Brown, E. Morales, I. Ogata. 2020. Las Milpitas Autocase Project: A Triple-Bottom-Line Analysis Report of Las Milpitas de Cottonwood Community Farm. Pima County Office of Sustainability & Conservation: A Collaborative Project between the Community Foodbank of Southern Arizona, Pima County, Regional Flood Control District, and Autocase™ with Additional Support Provided by the University of Arizona. https://www.webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Administration/CHHmemosFor%20Web/2020/October/las%20milpitas%20de%20cottonwood%20community%20farm.pdf

Rodriguez-Lonebear, D., N.E. Barceló, R. Akee, S.R. Carroll. 2020. American Indian Reservations and COVID-19: Correlates of Early Infection Rates in the Pandemic. Journal of Public Health Management and Policy 26(4): 371-377. DOI: 10.1097/PHH.0000000000001206.

Stahle, D.W., E.R. Cook, D. J. Burnette, M.C.A. Torbenson, I.M. Howard, D. Griffin, J. Villanueva, B.I. Cook, P.A. Williams, E. Watson, D. Sauchyn, N. Pederson, C.A. Woodhouse, G.T. Pederson, D. Meko, B. Coulthard, C.J. Crawford. 2020. Dynamics, variability, and change in seasonal precipitation reconstructions for North America. Journal of Climate. DOI: 10.1175/JCLI-D-19-0270.1

Tintor, W.L., C.A. Woodhouse. 2021. The variable climate response of Rocky Mountain bristlecone pine (Pinus aristata Engelm). Dendrochronologia 68: 125846. DOI: 10.1016/j.dendro.2021.125846

Uhlman, K., C. Eastoe, Z. Guido, M.A. Crimmins, A. Purkey-Deller, S. Eden. 2020. Assessing the Vulnerability of an Aquifer to Climate Variability through Community Participation in Arivaca, Arizona. Journal of Contemporary Water Research & Education 170.

Weiss, J. 2020. Exploratory Analysis of Spinach and Temperature Data for Duncan Family Farms. University of Arizona Cooperative Extension.

Weiss, J. 2020. Initial Modeling of Sulfur Application Timing for Powdery Mildew at Buhl Memorial Vineyard, 2017-2020. University of Arizona Cooperative Extension.

Weiss J. 2020. Timing of Leaf Removal and Cluster Thinning in the Context of Seasonal Heat – An Analysis for Merkin Vineyards. University of Arizona Cooperative Extension.

Weiss, J., M.A. Crimmins, and G. Garfin. 2020. La Niña 2020-2021: An Overview of What It Might Mean for Arizona. University of Arizona Cooperative Extension Climate Fact Sheet. https://cals.arizona.edu/research/climategem/sites/cals.arizona.edu.research.climategem/files/la-nina-2020-2021-overview.pdf

Williams, A.P., K.J. Anchukaitis, C.A. Woodhouse, D.M. Meko, B.I. Cook, K. Bolles, E.R. Cook. 2020. Tree rings and observations suggest no stable cycles in Sierra Nevada cool season precipitation. Water Resources Research. DOI: 10.1029/2020WR028599

Woodhouse, C.A., E.K. Wise. 2020. The changing relationship between the upper and lower Missouri River basins during drought. International Journal of Climatology 1–18. DOI: 10.1002/joc.6502

Woodhouse, C.A., R.M. Smith, S.A. McAfee, G.T. Pederson, G.J. McCabe, W.P. Miller, A. Csank. 2021. Upper Colorado River Basin 20th century droughts under 21st century warming: Plausible scenarios for the future. Climate Services 21. DOI: 10.1016/j.cliser.2020.100206

Appendix B: Current CLIMAS Projects Index

(Organized alphabetically by project lead PI's last name)

Identifying gaps in stakeholder needs regarding the climate-health connection

CLIMAS Investigators: H. Brown, E. Austhof, and D. Ferguson

Research Partners: Arizona Department of Health Services – Pinal County and Maricopa County; Arizona State University

End Users: Arizona Department of Health Services – Pinal County and Maricopa County

Additional Support: Arizona Department of Health Services – BRACE: Climate and Health Adaptation Monitoring Program (CHAMP)

As part of the Climate-Ready States and Cities Initiative, the Centers for Disease Control (CDC) engaged 16 states and 2 large cities to implement a 5-step program Building Resilience Against Climate Effects (BRACE) in 2009. The program aimed to help communities prepare for the health effects of climate change. As BRACE ends, the CDC is now supporting the monitoring and evaluation of the efforts developed under BRACE: Climate and Health Adaptation Monitoring Program (CHAMP). To support these monitoring and evaluation efforts, we are working to map the Arizona network of climate/health advocates, to identify gaps that stakeholders need regarding the climate-health connection, and to develop strategies to better support these efforts.

A national survey was distributed from June 14, 2020 to July 15, 2020 (n=200) and from July 15 to August 14, 2020 (n=300). Results are currently being analyzed. Key Informant interviews were conducted among BRACE recipients to understand how health departments responded to the dual hazards of Heat Related Illness (HRI) and COVID-19 in January, 2021. Health jurisdictions who worked in both heat preparedness and on the COVID-19 response highlighted: adapting to changing roles and responsibilities, building and strengthening inter-organizational partnerships, and maintaining flexibility through cross-training as themes to maintain the public health capacity throughout the pandemic. With impending impacts of the changing climate and resultant extreme events with subsequent public health impacts, duplicative response needs are likely to arise again in the future.

Findings: During the summer of 2020 health departments across the country struggled to respond to COVID. The key informants identified the flexibility of funding agencies, co-workers, and partners as supportive of their response capacity.

Outputs

Data: In response to the current heat wave, researchers made a map for people to find cooling stations: https://arcg.is/iT0O90. This map was made starting with the Tucson Pima Collaboration to End Homelessness Summer Sun Respite Sites, and included libraries, pools, and splash pads. Locations were updated by reaching out to organizations who been listed in prior years to confirm hours, restrictions and COVID requirements.

Presentations:

Climate Change & Health. Guest lecture, Univ. of Arizona Medical School, March 2021. 50 Attendees.

Facing the Future of Vector Borne Diseases. Guest Lecture, One Health Seminar, Johns Hopkins Univ. Virtual, May 2021. 19 Attendees.

Media citations:

Cited in: Reznick A. and N. O'Gara. 2020. 'Feels like the end of the world': Tucson grapples with record heat during pandemic. Arizona Public Media.

Partnering with Southwest Indigenous Communities to Identify Data Challenges, Needs, and Opportunities

CLIMAS Investigators: S. Carroll, D. Ferguson, and S. Leroy

Research Partners: D. David-Chavez (Borikén Taíno), Colorado State University; A. Curley (Diné), University of North Carolina; S. Yazzie (Diné), Albuquerque Area Southwest Tribal Epidemiology Center; T. Lane (Diné), Inter Tribal Council of Arizona

Additional Support: National Integrated Drought Information System (NIDIS); Native Nations Institute, via the Morris K. Udall and Stewart L. Udall Foundation

As Native nations seek to utilize the best available data and information to build climate resilience and healthy, sustainable communities, issues around data relevance, ownership, access, possession, and control arise. For example, a Native nation may collect their own data or have access to culturally sensitive traditional knowledge useful to inform climate-related decisions, but they may not wish to make that data widely available even though it may be helpful when seeking funding or engaging in regional climate adaptation planning. A CLIMAS-sponsored indigenous data sovereignty summit held in 2019 led to several on-going initiatives and outputs, described below.

Outputs

Publications:

Carroll, S.R., I. Garba, O.L. Figueroa-Rodríguez, J. Holbrook, R. Lovett, S. Materrechera, M. Parsons, K. Raseroka, D. Rodriguez-Lonebear, R.K. Rowe, R. Sara, J.D. Walker, J. Anderson, M. Hudson. 2020. The CARE Principles for Indigenous Data Governance. Data Science Journal 19: 43. DOI: 10.5334/dsj-2020-043

Rodriguez-Lonebear, D., N.E. Barceló, R. Akee, S.R. Carroll. 2020. American Indian Reservations and COVID-19: Correlates of Early Infection Rates in the Pandemic. Journal of Public Health Management and Policy 26(4): 371-377. DOI: 10.1097/PHH.0000000000001206.

Hiraldo, D., K. James, S.R. Carroll. 2021. Indigenous Sovereignty in a Pandemic: Tribal Codes in the United State as Preparedness. Frontiers in Sociology 6:617995. DOI: 10.3389/fsoc.2021.617995

Carroll, S.R., R. Akee, D. Cormack, T. Kukutai, R. Lovett, M. Suina, R.K. Rowe. 2021. Indigenous Data During COVID-19: From Outside to Within. Frontiers in Sociology 6:617895. DOI: 10.3389/fsoc.2021.617895

Carroll, S.R., E. Herczog, M. Hudson, K. Russell, S. Stall. 2021. Operationalizing the CARE and FAIR Principles for Indigenous Data Futures. Nature: Scientific Data 8: 108. DOI: 10.1038/s41597-021-00892-0

Gardner-Vandy K., D. Scalice, et al. 2020. Relationships First and Always: A Guide to Collaborations with Indigenous Communities. An EDI Community Paper to the 2020 Planetary Science and Astrobiology Decadal Survey 2013-2032. Submitted as part of a collaborative effort organized by the Equity, Diversity, and Inclusion Working Group (EDIWG).

Carroll, S.R., D. Rodriguez-Lonebear, R. Akee, A. Lucchesi, J.R. Richards. 2020. Indigenous Data in the COVID-10 Pandemic: Straddling Erasure, Terrorism, and Sovereignty. Social Science Research Council, Items: Insights from the Social Sciences. https://items.ssrc.org/covid-19-and-the-social-sciences/disaster-studies/indigenous-data-in-the-covid-19-pandemic-straddling-erasure-terrorism-and-sovereignty/

Carroll, S.R., M. Hudson, J. Holbrook, S. Materrechera, Ja. Anderson. 2020. Working with the CARE principles: operationalizing Indigenous Data Governance. Ada Lovelace Institute. https://www.adalovelaceinstitute.org/operationalising-indigenous-data-governance/

Policy Brief:

Hiraldo, D., S.R. Carroll, D.M. David-Chavez, M.B. Jäger, M. Jorgensen. 2020. Native Nation Rebuilding for Tribal Research and Data Governance. NNI Policy Brief Series. Tucson: Native Nations Institute, University of Arizona.

Project Website: https://indigenousdatalab.org/swtribalclimateresiliencesummit/

Workshops:

Access to Indigenous Data: Integrating Community, Individual, and Analyst Interests Workshop. S. Carroll, co-Lead. Hosted by ORCID, the US Indigenous Data Sovereignty Network, and the Global Indigenous Data Alliance. June 9, 2020.

Developing Standards for Indigenous Peoples' Data Workshop Series. S. Carroll, Planning Member. Tikanga in Technology, ENRICH, the Collaboratory for Indigenous Data Governance and The Maintainers. February 10, April 7, & May 6, 2021.

Media citations:

Bichell, R.E. Pandemic complicates tribes' quest for data sovereignty. *KUNC*. July 13, 2020.

Goodluck, K. Indigenous data sovereignty shakes up research. *High Country News*. October 8, 2020.

Goodluck, K. In the COVID-19 era, tribal nations want research in service of their people. *Mother Jones*. October 11, 2020.

Presentations: 30 presentations related to this research were given this year. All were invited and addressed knowledge and practice gaps with respect to Indigenous rights and interests in science and research. Examples include:

The CARE Principles for Indigenous Data Governance. Indigenous Data Sovereignty: Tools for Transparency Virtual Workshop. Co-hosted by ORCID, DataCite, the US Indigenous Data Sovereignty Network, and the Global Indigenous Data Alliance. June 9, 2020.

Eclipsing Equity, Indigenous Peoples Sovereignty,

Data, and Research. National Academy of Medicine - Advancing Health Equity Science, Practice & Outcomes. Culture of Health Program Virtual Listening Workshop. December 8, 2020.

Advisory Role: Consultation on the Post COVID-19 implications on collaborative governance of genomics research, innovation and genetic diversity. UN FAO, Secretariat of the International Treaty on Plant Genetic Resources, in partnership with CIRAD and the Center for Science, Technology and Environmental Policy Studies, Arizona State University.

New Funding Acquired:

National Institute for Environmental Health Sciences. "Investigating linkages between arsenic exposure, diabetes, and COVID-19 infections and risks on the Navajo Nation." $154,199. September 2020 – August 2022. S. Carroll role: PI. Co-PI: J. Ingram.

National Science Foundation. "Collaborative Research: Impact of COVID-19 on Food Access in Indigenous Communities in the Arctic and Southwest: A Comparative Landscape Analysis." $65,092. July 2020 – June 2021. S. Carroll role: PI. Co-PIs: N. Johnson, D. Ferguson, M.B. Jager.

Community-Based Responses to Climate Water Challenges

CLIMAS Investigators: B. Colby, G. Frisvold, H. Hansen, E. Joiner, B. McGreal, and A. Walker

Research Partners: A. Lien, School of Natural Resources and the Environment, Univ. of Arizona; J. Overpeck, School for Environment and Sustainability, Univ. of Michigan; U.S. Bureau of Reclamation; U.S. Dept. of Agriculture; Arizona Department of Water Resources; Central Arizona Project; Salt River Project; Univ. of Nevada Reno; Univ. of Colorado; Sonoran Institute; The Nature Conservancy

End Users: U.S. Bureau of Reclamation; U.S. Dept. of Agriculture; Arizona Department of Water Resources; Central Arizona Project; Salt River Project

Additional Support: DOI Climate Adaptation Science Centers (CASC); DOI Landscape Conservation Cooperatives (LCC)

This project examines community perceptions and decisions about climate science, economics, and policies associated with resilience strategies that address increasing water scarcity in the Southwest. Strategies to be evaluated include: investments in built infrastructure (e.g., reservoirs and pipelines); incentive-based risk-sharing agreements; and watershed ecosystem services. The project emphasizes the role that ecosystem services can play in buffering water impacts of climate change, as well as the potential for climate mitigation as a strategy to enhance water supply security. Project outputs will include a replicable method for co-producing resilient water-related climate adaptation and mitigation strategies, including scientific and economic evaluation. Potential outcomes include improved water supply reliability and cooperation on adapting to shortages for a regional economy that exceeds $3 trillion annually.

Outputs

Publications:

Colby, B. 2020. Acquiring environmental flows: ecological economics of policy development in western U.S. Ecological Economics 173: 106655. DOI: 10.1016/j.ecolecon.2020.106655

Isaaks, R., and B. Colby. 2020. Empirical application of rubinstein bargaining model in western U.S. water transactions. Water Economics and Policy 6(1): 1950010. DOI: 10.1142/S2382624X19500103

Presentation:

Tribal Water Settlements. 2020. Economic Innovations for Addressing Water Conflicts Symposium Series, University of Arizona.

Advisory Roles:

Sonoran Institute Advisory Commission for Economic Analysis for the Colorado River Delta

Implementation Team for The Nature Conservancy Project: Water Transactions to Enhance Streamflow, Water Supply Reliability, and Rural Economic Viability in the Western United States

"Science for People and Nature" Collaborative Project on Water for Environmental Needs, National Center for Environmental Analysis and University of California, Santa Barbara

Board of Trustees, Arizona Nature Conservancy

U.S. Bureau of Reclamation, reviewer for external research grants funding program

USDA Livestock Forage Disaster Program and Ranching in the Southwest U.S

CLIMAS Investigators: M. Crimmins, M. McClaran, D. Ferguson, C. Greene

Research Partners: NOAA – National Weather Service; USDA – Natural Resources Conservation Service; Arizona Section of the Society for Range Management

End Users: Ranchers in Arizona and New Mexico; AZ and NM state drought monitoring committees; U.S. Drought Monitor authors; regional drought monitoring experts

The 2014 Farm Bill permanently authorized the USDA Livestock Forage Program (LFP), which provides compensation to livestock producers who suffer grazing losses caused by drought and wildfires. The LFP bases payment eligibility on drought status categories of the U.S. Drought Monitor (USDM). Yet, there is evidence that USDM status assignments do not accurately capture the timescales of climate variability driving forage production and drought impacts across Arizona and New Mexico. Therefore, the current system may understate the extent of losses and need for compensation of Southwest ranchers. This study evaluates how the current application of the USDM in the USDA-LFP addresses drought and wildfire risks faced by Arizona and New Mexico ranchers and will seek out drought monitoring best practices specifically for rangeland systems. This research connects to other ongoing projects (described below) that support the concept of drought early warning as conceived by NIDIS. Collectively, they will help identify best practices in employing more relevant, timely, and unique drought monitoring strategies needed for Arizona and New Mexico. Ongoing work includes:

- Engaging rural communities and ranchers in volunteer precipitation monitoring to improve the characterization of drought conditions in rural areas and to help inform the U.S. Drought Monitor (led by the USDA Southwest Climate Hub).
- Assessing the impact of drought on agricultural production and ranching in Arizona and developing an economic impact analysis of the Livestock Forage Program for Arizona (led by CLIMAS PI G. Frisvold, with A. Kerna Bickel and D. Duval).
- Understanding the impact of drought on the Rio Grande watershed in New Mexico (led by CLIMAS researcher C. Greene)

Evaluating existing and developing new drought indices using modeled soil moisture time series

CLIMAS Investigators: M. Crimmins, M. Schaap, C. Rasmussen, D. Ferguson, T. McKellar

Research Partners: The Nature Conservancy

End Users: Land managers at USDA – Natural Resources Conservation Service, Bureau of Land Management, and U.S. Forest Service; Arizona Governor's Drought Task Force; U.S. Drought Monitor

Additional Support: National Integrated Drought Information System (NIDIS)

This project is developing a drought monitoring 'playbook' for land managers in Arizona. Using long-term (>50 years) daily resolution soil water profile climatologies for several locations across the Southwest, we assess how seasonality, precipitation timing, and frequency relate to monthly scale, precipitation-based drought indices. This modeling approach is also used to assess the performance of temperature-based indices land further explore the role of increasing temperatures in driving drought stress across the region. The initial project study area focuses on Las Cienegas National Conservation Area (NCA), in partnership with The Nature Conservancy, to examine longer-term drought impacts in this multi-use, Bureau of Land Management NCA. We are working with TNC to develop modeled long-term soil moisture estimates to examine with long-term vegetation monitoring data. This will allow us to assess the impacts of precipitation variability and temperature changes on vegetation production and mortality and identify optimal drought monitoring metrics.

Findings: Soil moisture has been modeled at 240 locations from southern New Mexico across Arizona and into southern California. T. McKellar has been assessing the relationship between daily modeled soil moisture (1979-2019) at depths up to one meter and standard monthly drought indices like the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI). One main finding is that standard drought indices do a reasonable job of tracking changes in soil moisture when adjusting the drought index timescale to match the relevant depth. For instance, shorter timescales (1 to 3 months) of SPI and SPEI track shallow (~10cm) soil moisture variability well, while longer timescales (9-12 months) track changes in deeper soil moisture (30 to 50 cm). This is relatively consistent across

the low desert areas of the southwest and can be further refined by considering the dominant texture of the soil. For example, sandy soil requires short timescales of drought indices to track changes. These results will help land managers and agricultural producers better utilize existing drought monitoring tools by helping them focus on key timescales to assess potential changes in shallow versus deeper soil moisture.

Outputs

Presentation: *A Web Application for Improving Drought Monitoring on Rangelands.* 2020. AZ Space Grant Consortium.

Online Content: A prototype interactive web app has been developed that explores model data for the NCA study area at Las Cienegas. The final web app, a summary web page, model output, and code will be available online after project completion.

Impacts of climate extremes to interstate and local trucking industry across NM and AZ

CLIMAS Investigators: D. DuBois, A. Arredondo, Z. Ghodsizadeh, J. Fuentes, J. Consford, S. Engle, and M. DeAntonio

Research Partners: G. Lundeen, National Weather Service, Santa Teresa; K. Waters, National Weather Service, Phoenix; G. Michaud, Bureau of Land Management, Las Cruces; B. Edwards and N. Webb, Jornada Experimental Range (National Wind Erosion Network); D. Hadwiger, T. Botkin, and B. Hutchinson, NM Department of Transportation; T. Gill, University of Texas El Paso; R. Garcia, Mesilla Valley Transportation

End Users: NOAA-NWS Albuquerque, Santa Teresa, Phoenix, and El Paso Weather Forecast Offices; New Mexico Department of Transportation; Arizona Department of Transportation; Mesilla Valley Trucking; NM Trucking Association; Bureau of Land Management, Las Cruces Office

Additional Support: NOAA National Weather Service (NWS); NM Department of Transportation

Transportation along our nation's highways forms a basis for our economy, moves our food from place to place, and serves to connect our communities. Extreme weather impacts the transportation system in many ways. For this project, we focus on dust storms, particularly during drought. Our goal is to increase the resilience of drivers during these events. Our partners include the New Mexico Department of Transportation and trucking companies who are interested in improving the way they handle these dust storms through education and warning. We aim to characterize and document the climatic and visual conditions that exist during these storms through interviews with drivers and road managers, in addition to time-lapse camera imagery and dash cams. Providing resilience to extreme weather events is a critical step in improving our lives across the nation.

Outputs

Publications:

DuBois, D. 2021. Annual Progress Report 2020 for the Dust Mitigation Monitoring Project. Submitted to the Research Bureau New Mexico Department of Transportation, Albuquerque, NM.

This technical report summarizes the work completed during calendar year 2020 monitoring dust storms over the Lordsburg playa for the NM Department of Transportation mitigation project. The year began with water inundating the playa surface but due to the lack of precipitation starting in the spring, the playa began to dry out and be a source of dust. Peak wind gusts approaching 50 mph were observed in the summer causing several intense dust storms on the playa. Despite the activity in the summer, there were no traffic accidents on interstate 10 during the year. The sponsors are working to extend the research at this location based on the findings in the report. There has not been sufficient data collected to determine if the current control methods have reduced dust storm frequency, duration or intensity on the roadway.

Data: 15-minute PM2.5 concentration data at the study area west of Lordsburg is available:

PM2.5 at Road Forks undisturbed site and PM2.5 at Road Forks, disturbed site

Adaptation to Climate Variability and Change: Markets, Policy, Technology, and Information

CLIMAS Investigators: G. Frisvold

Research Partners: H. Chen and A. Marcheva, University of California, Berkeley

End Users: Arizona Land and Water Trust; The Nature Conservancy; The Audubon Society; Arizona Department of Agriculture

Additional Support: USDA – National Agricultural Statistics Service; USDA – Economic Research Service; USDA – Farm Services Agency

This project examines the potential for market mechanisms to facilitate voluntary reallocation of scarce water across different uses, specifically from agricultural to environmental purposes. It considers the scope for using reverse water auctions to obtain water for riparian restoration. This includes study of the economic theory behind reversed auctions as well as lessons from applications. It also examines the scope of the USDA Conservation Reserve Enhancement Program (CREP) to complement state and local programs for environmental water acquisitions.

Researchers at the University of California, Riverside have access to proprietary data on prices and quantities of water market trades. A hypothesis of the CLIMAS research is that USDA data on crop rental rates can be used to assess what likely water transfer prices will be. We plan to collaborate in the coming year, combining data to test this hypothesis.

Findings: The USDA Conservation Reserve Enhancement Program (CREP) program potentially provides significant federal cost-sharing for state and local programs to voluntarily acquire water for environmental restoration. Despite this potential, state CREP programs as implemented have fallen far short of initial water acquisition goals.

In assessing reverse water auctions as a mechanism to reallocate water from agricultural to environmental purposes, this research found that water auctions are advantageous in some, but not all, instances. If little or no information exists about water transfer prices or quantities in the procurement area, or if the procuring authority has a limited budget, water auctions can be advantageous. If active water transactions with good price information already exist in the region, offering potential water suppliers a fixed, pre-determined price may work equally as well as an auction, with fewer transactions costs.

Outputs

Publications:

Frisvold, G. and A. Marcheva. 2021. Reverse water auctions in theory and practice. Report.
This report explains the basics of reverse auctions, options for setting them up, and lessons from previous reverse auctions to procure water and other environmental services. The intended audience are environmental groups or state or local government agencies interested in setting up reverse water auctions.

Frisvold, G. and H. Chen. 2021. The Conservation Reserve Enhancement Program (CREP) as a vehicle for water conservation: An annotated bibliography.
This bibliography catalogues which states have designed CREPS with the goal of water conservation. It describes their basic structure, objectives, payment mechanisms and performance to date. The intended audience are environmental groups and state or local government agencies interested in developing a CREP for water conservation.

Sectoral Impacts of Drought and Climate Change

CLIMAS Investigators: G. Frisvold and M. Crimmins

Research Partners: A. Kerna Bickel and D. Duval, Agricultural and Resource Economics, University of Arizona; National Integrated Drought Information System (NIDIS); USDA – Natural Resources Conservation Service; USDA – Risk Management Agency; Graham and Greenlee County Governments; Arizona Department of Water Resources; Gila River Indian Community; University of Arizona Federally Recognized Tribes Extension Program; Maricopa County Food Coalition

End Users: Arizona State Parks Board; National Parks Conservation Association; Bureau of Reclamation; Central Arizona Project; Cotton Incorporated; Arizona Agri-Business and Water Council; Graham and Greenlee County Governments; Arizona Farm Bureau; Upper Gila Watershed Alliance

Additional Support: U.S. Geological Survey; Bureau of Reclamation; National Park Service; Arizona State Parks Board; National Integrated Drought Information System (NIDIS); NOAA Regional Climate Centers; USDA – Climate Hubs

This project examines the impacts of drought and climate change on climate sensitive sectors in the Southwest, focusing on agriculture, outdoor recreation, and tourism. Drafted a funded grant proposal on Economic Impacts on Drought on Agriculture, Recreational Tourism, and Rural Communities to a combination of NIDIS and the Arizona Department of Water Resources.

Findings: The economic impacts of drought on state and national park visitation depends crucially on the length

of the drought considered. For example, one-month drought measures have a positive effect on visits because people visit less in unusually wet months. Longer-term drought measures have an increasingly negative impact. Combining short- and long-term effects, drought is estimated as having net-negative impacts on national park visits in some years and net-positive impacts in others, with effects ranging between losses of $14.2 million in output (sales) to a $32.8 million increase.

A similar relationship holds for agricultural crop losses, as measured by insurance indemnities. Because Southwest agriculture is almost entirely irrigated, short-term drought measures have little negative impact. Losses occur from failure of irrigation supply, which are tied to longer-term drought that affects reservoir levels and surface water deliveries. The effects of drought on agriculture in Arizona are non-linear and have threshold effects. Drought can have no impact on crop losses, up to the point where irrigation supplies are cut off. Once that happens, production on those acres is no longer economically viable.

Studies of the effects of drought on agriculture usually focus on effects on crop yields. This research demonstrates that for Arizona (and likely other irrigation-dependent areas), yields are relatively insensitive to drought. Rather, the effects of drought are not from lack of precipitation, but through more pervasive drought that lowers irrigation water supplies. The negative impact from drought is on acres planted.

Outputs

Publications:

Duval, D., G. Frisvold, and A. Bickel. 2020. The economic value of trails: A travel cost method study. Final Technical Report to the Arizona Parks Board. Tucson: University of Arizona Cooperative Extension. https://economics. arizona.edu/economic-value-trails-arizona-travel-cost-method-study

The midpoint estimate of the economic value derived from non-motorized trail use in Arizona by in-state residents was $8.3 billion per year, with results suggesting trail users travel furthest to access areas that are more heavily forested, have cooler average maximum and minimum temperatures, and have steeper and more varied slopes. The intended audience included organizations and businesses specializing in outdoor recreation as well as policy makers who allocate resources for trail maintenance and expansion. Report has been posted or reported on the websites: Arizona State Parks and Trails, Prescott Living Magazine, Arizona Heritage Alliance, Arizona Trail News, Arizona Trail Backpacking, Tucson Hikers

Bickel, A.K., D. Duval, and G. Frisvold. 2020. Agriculture in Graham and Greenlee Counties. https://economics.arizona.edu/agriculture-graham-and-greenlee-counties

Considering a 20% reduction in irrigation water supplies in the two counties, and accounting for multiplier effects, the water cutback would reduce total output by $6.6 million annually. The study was cited in: A news article in the Eastern Arizona Courier and on Greenlee Cooperative Extension's Facebook page. This study was requested by the Arizona Farm Bureau, Farm Credit West, Gila Valley Irrigation District, Graham County government, and Greenlee County government. The intended audience were staff at these entities as well as businesses and public agencies in the two counties.

Duval, D., A. Bickel, and G. Frisvold. 2020. County Agricultural Economy Profiles for Southern Arizona. Making Action Possible in Southern Arizona (MAP Dashboard) White Paper #14. Economic and Business Research Center. Eller College of Management. University of Arizona, Tucson. https://mapazdashboard.arizona.edu/sites/default/files/images/county_agricultural_economy_profiles_final.pdf

Commissioned by the Economic and Business Research Center, Eller College of Management. This collection of county profiles presents agricultural production, water use, and regional economic data in a standardized, integrated, and easy-to-read format to provide context on the role of agriculture within state and county economies.

Duval, D., A. Bickel, and G. Frisvold. 2020. Arizona County Agricultural Economy Profiles. Tucson: University of Arizona Cooperative Extension. https://economics.arizona.edu/arizona-county-agricultural-economy-profiles

This collection of county profiles presents agricultural production, water use, and regional economic data in a standardized, integrated, and easy-to-read format to provide context on the role of agriculture within state and county economies. The intended audience is anyone interested in agricultural production, land use, and water use in Arizona counties. Study has been cited by the University of Arizona, Water Resources Research Center

Summaries of the following publications were provided to Craig McLean, the Assistant Administrator for Oceanic and Atmospheric Research (OAR) at NOAA for his briefing to the House Natural Resources Subcommittee on Waters, Oceans, and Wildlife on 25 May 2021:

Duval, D., A. Bickel, and G. Frisvold. 2021. The Effects of Reservoir Levels on Arizona National Recreation Area Visitation, Visitor Spending, and Local Economies. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

The study estimates that visitor spending in Arizona alone would decrease by $7.9 million if Lake Powell reservoir levels decline to 3,490 feet (minimum level for power generation) and by $15.7 million if reservoir levels decline to 3,370 ft (dead pool elevation), for Lake Mead, visitor spending would decrease by over $4 million with reservoir levels falling to dead pool levels (895 ft). Intended audiences are state and local government and business leaders in Northern Arizona as well as managers of Lakes Powell and Mead.

Bickel, A., D. Duval, and G. Frisvold. 2021. The Effects of Drought on Arizona Forage Production. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

Examining the impacts of additional weeks in different drought intensity levels on annual county-level forage yield in Arizona, the study found a 0.5% decrease in forage yields for each additional week in D1 (moderate) drought to a 0.9% decrease in forage yields for each additional week in D3 (extreme) drought, equivalent to a reduction in average yield by 3.6 pounds per acre and 6.2 pounds per acre, respectively.

Bickel, A., D. Duval, and G. Frisvold. 2021. Drought and Insured Crop Losses in Arizona. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO. Longer-term measures of drought (12- to 36-month SPI and SPEI) explain a greater share of variation in Arizona crop insurance indemnities than short-term measures of drought (3- to 6-month SPI and SPEI), suggesting that reservoir storage and management and allocation of irrigation water acts as a buffer against short-term drought.

Duval, D., A. Bickel, and G. Frisvold. 2021. Drought Effects on Arizona State Park Visits, Visitor Spending, and Local Economies. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

While short-term (1-month) drought is positively associated with visits, longer-term drought (measured by the 24-month SPI) exerts a negative influence on state park visits, suggesting that visitors respond negatively when drought conditions persist and affect streamflow, vegetation, reservoir levels, etc. and longer-term drought.

Duval, D., A. Bickel, and G. Frisvold. 2021. Drought Effects on National Park Visits, Visitor Spending, and Local Economies. Final Report to the National Integrated Drought Information System (NIDIS) program. Boulder, CO.

Combining short- and long-term effects, drought is estimated as having net-negative impacts on national park visits in some years and net-positive impacts in others, with effects ranging between losses of $14.2 million in output (sales) to a $32.8 million increase.

Media citations:

Research cited by: Kruzman, D. 2021. U.S. Southwest, Already Parched, Sees 'Virtual Water' Drain Abroad. UnDark and subsequently carried by Mother Jones and Grist.

Information Valuation Concerning Decisions Made in Response to Wildland Fires in the Southwest United States

CLIMAS Investigators: G. Frisvold, D. Ferguson, M. Crimmins, J. Doss

Research Partners: C. Maxwell, U.S. Forest Service; NOAA – National Weather Service; Bureau of Land Management; Arizona Department of Forestry and Fire Management; New Mexico Forestry Division; Bureau of Indian Affairs

End Users: U.S. Forest Service; NOAA – National Weather Service; Bureau of Land Management; Bureau of Indian Affairs; National Park Service; Arizona Department of Forestry and Fire Management; New Mexico Forestry Division

Research has established that the El Niño-Southern Oscillation (ENSO) pattern in the equatorial Pacific has relatively predictable seasonal influences on the weather and climate of the US Southwest, making climate information valuable for environmental and economic decision-making. Fire management agencies are an ideal target audience for climate information. Significant work has gone into creating wildfire-specific climate outlooks and information products. Research has identified

networks of actors successful at disseminating this information. This study addresses two questions: how is climate information being used to inform wildland fire management decisions and what is the economic value of such information? Focus groups and an online survey of Southwest wildfire experts address the first question and form the basis of an economic analysis of the value of fire management information. This research seeks to reveal what opportunities exist to improve existing products and develop new ones.

Findings: Our focus group sessions did not include specific questions about the challenges of climate change for wildfire management. Yet, fire managers regularly noted that looking to past climate and weather conditions are no longer adequate for predicting future fire risks because climate is changing.

An assessment of drought and climate vulnerability and resilience in the Rio Grande basin in New Mexico

CLIMAS Investigators: C. Greene, D. Ferguson, and B. McMahan

End Users: New Mexico Drought Monitoring Working Group

Additional Support: National Integrated Drought Information System (NIDIS)

The 2018 New Mexico Drought Plan calls for more in-depth assessments of New Mexico drought vulnerabilities and this project contributes to this need by identifying stakeholder concerns and drought research priorities along the Rio Grande Basin. This drought and climate vulnerability assessment engages with areas of concern identified by the New Mexico Drought Task Force, including water, economy, fire, recreation, health, agriculture, and the environment. With initial engagement with state officials, the NM Drought Task Force Team, and the NM Drought Monitoring Group, this project will expand CLIMAS's network of collaborators and stakeholders in New Mexico and identify emergent drought research priorities that feed into subsequent years of CLIMAS/NIDIS project work.

Urban Heat and Health Interventions and Evidence Gaps

CLIMAS Investigators: L. Keith and E. Schmidt

Research Partners: NOAA Climate Program Office; City of Tucson, AZ; Pima County, AZ; City of Seattle, WA; King County, WA; City of Houston, TX; Harris County, TX; City of Baltimore, MD; Baltimore County, MD; City of Detroit, MI; Wayne County, MI

End Users: Urban planners, landscape architects, emergency managers, public health officials, sustainability/resilience staff, and climate service providers

This study will provide an in-depth investigation of the survey results on how communities plan and govern extreme heat risk. The case study methods include semi-structured interviews with decision-makers and content analysis of plans for heat management and mitigation strategies. It builds upon the work started with the CLIMAS Urban Heat Island Mapping project that assessed the use of UHI maps and decision-making in the Southwest, a literature review on planning for extreme heat, and the survey of U.S. planners on extreme heat. To document the current state of emergent extreme heat governance in the U.S., five case study communities were selected, including Tucson, AZ; Houston, TX; Baltimore, MD; Detroit, MI; and Seattle, WA. These communities represent five National Climate Assessment regions, and four of the communities have participated in the NIHHIS-CAPA Heat Mapping Campaign.

Outputs

Presentations: Heat Risk Project Update to NOAA CPO Heat Risk Team on March 3, 2021. Informed NOAA CPO Heat Risk Team of community needs. Interest expressed in seeing original extreme heat planning survey and future work in this area.

Evaluating the Use of Urban Heat Island Maps for Extreme Heat Planning. American Collegiate Schools of Planning 2020 Annual Conference. Virtual. November 5-8, 2020.

Publication: Keith, L., S. Meerow, and T. Wagner. 2020. Planning for extreme heat: a review. Journal of Extreme Events 6(03n04): 2050003. DOI: 10.1142/S2345737620500037

Using a systematic literature review for extreme heat planning research, we found most studies focused on heat mapping and modeling, while few studies delved into extreme heat planning and governance processes.

New Funding Acquired: Urban heat and health interventions and evidence gaps. National Oceanic and Atmospheric Administration (NOAA), A Regional Integrated Sciences and Assessments Program (RISA), Climate Assessment in the Southwest (CLIMAS). 2020-2021. PI: L Keith ($40,000)

Collaborative Research on Environmental Risks and Built Environment in the Borderlands of the Southwest

CLIMAS Investigators: B. McMahan, L. Bishop, I. Palomo, R. Driesen, and L. Pilli

Research Partners: NOAA – National Weather Service Tucson; Environmental Protection Agency – Border Environment Cooperation Commission/Border 2020; AZ Department of Environmental Quality; Asociación por Revegetación en Ambos Nogales (ARAN); Sonora Environmental Research Institute; Borderlands Restoration

End Users: Environmental Protection Agency – Border Environment Cooperation Commission/Border 2020; Schools and teachers in partner network in Ambos Nogales; Centro de Capacitación para el Trabajo Industrial (CECATI); Instituto Tecnológico de Nogales; Universidad Tecnológica de Nogales

Additional Support: Agnese Nelms Haury Program, University of Arizona; Environmental Protection Agency – Border Environment Cooperation Commission/Border 2020

Outputs

Presentation: Adaptando métodos para el proyecto de mini-split solares durante COVID-19. Virtual Event hosted by Universidad Tecnológica de Nogales. Nov 5, 2020. Approx. 80 participants.

Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations

CLIMAS Investigators: B. McMahan, M. Crimmins, P. Bunn, G. McGowan, H. Chang, R. Driesen, R. Granillo, M. Herrera, B. Delgado, C.J. Larsen, and D. Hoy

Research Partners: J. Glueck, NWS Tucson; W. Holmgren, Institute for Energy Solutions, Univ. of Arizona

End Users: National Weather Service (Tucson office, phoenix office); NWS Regional Climate Services Director; County Flood Control Districts; Pima County OEM; Oro Valley Police Dept.; Municipal/Irrigation Outreach group; Pima County Natural Resources Division; National Phenology Network (NPN)

Additional Support: NOAA National Weather Service (NWS); Office of Research, Innovation, and Impact, Univ. of Arizona; Center for Agricultural and Life Sciences, Univ. of Arizona; Institute for Energy Solutions, Univ. of Arizona

Monsoon precipitation is difficult to forecast and analyze. Daily and seasonal precipitation are commonly used, but other sources of data, such as citizen science monitoring, could be integrated into a higher resolution and more accurate monsoon assessment framework. Tucson has dozens of observations collected by these networks, along with datasets based on radar and weather models. A central monsoon data repository would form a dense network of observations, facilitate innovative visualizations, and offer an unparalleled high-resolution view of regional precipitation patterns. This project is testing a process to combine southwestern data networks into an integrated monsoon assessment database and data visualization platform.

Outputs

Publications:

Crimmins, M.A., B. McMahan, W.F. Holmgren, and G. Woodard. 2021. Tracking precipitation patterns across a western US metropolitan area using volunteer observers: RainLog.org. International Journal of Climatology 41: 4201–4214. DOI: 10.1002/joc.7067
This paper assesses the contributions of citizen science precipitation monitoring for warm and cool season precipitation in the SW.

McMahan, B., R.L. Granillo, B. Delgado, M. Herrera, and M.A. Crimmins. 2021. Curating and Visualizing Dense Networks of Monsoon Precipitation Data: Integrating Computer Science into Forward Looking Climate Services Development. Frontiers in Climate 3. DOI: 10.3389/fclim.2021.602573
This paper describes the processes and protocols of combining computer science technology and climate services development, using monsoon variability as an example.

Data: Southwest U.S. Summer Monsoon Season Precipitation Mapping and Monsoon Season Station Climate Summaries. These monsoon data aggregators were developed earlier in this project remain intact

and in use. They were recently added to the National Weather Service's Tracking the Monsoon webpage. https://www.wrh.noaa.gov/twc/monsoon/monsoon_tracker.php

Tools: A daily monsoon visualizer is currently being developed based on input from National Weather Service Tucson, and other local stakeholders. All aggregated data from the visualizer will be available for download on the CLIMAS web tools page.

New Funding Acquired: Arizona Institutes for Resilience (AIR) Resilience Grants, January 2021, Co-PI T. Crimmins and E. Posthumus (National Phenology Network), M. Crimmins, R. Granillo, B. McMahan. $43,438

Rethinking Social Vulnerability: Climate Risks and Impacts

CLIMAS Investigators: B. McMahan, R. Driesen, L. Pilli, M. Moeller, and C. Cheung

Research Partners: Bureau of Applied Research in Anthropology (BARA); Sonora Environmental Research Institute (SERI)

Additional Support: Bureau of Applied Research in Anthropology (BARA), University of Arizona; Sonora Environmental Research Institute (SERI); Agnese Nelms Haury Program, University of Arizona

This project seeks to better define social vulnerability to climate and the intersection of acute impacts and chronic conditions that further amplify these vulnerabilities.

This project aims to develop climate services, build collaborative research partnerships, and engage regional stakeholder networks. Current activities focus on energy equity and thermal comfort in Tucson neighborhoods and developing improved characterizations of urban heat and air quality maps.

Collaborators from SERI and BARA focus on household experiences of thermal comfort, cooling infrastructure, and resulting behavior. CLIMAS researchers focus on assessing the role of neighborhood and regional patterns on thermal comfort, the role of long term climate change) and investments in and inequitable distribution of buffering infrastructure. Expanding on previous work that views vulnerability as the accumulation of negative characteristics commonly associated with location (e.g., SOVI) or climate vulnerability (e.g., climate gap), this research seeks to understand how vulnerability relates to lack of access to systems, more than the failure of those systems.

Outputs

Presentation: A Collaboration with the Sonora Environmental Research Institute (SERI) to Measure Perceived Household Comfort and Determine Feasibility of Implementing a Solar Mini-Split Installation Loan Program. Mar 2021, SfAA Virtual Conference Poster Session.

New Funding Acquired: U.S. Department of Housing and Urban Development Health Homes Initiative. A.M. Wolf (Lead PI), F. Sandoval (Co-PI), D. Austin (Co-PI), and B. McMahan (Co-PI). $624,250. The research aims to determine the effectiveness and longevity of healthy homes interventions and education for reducing unintentional injuries and fires resulting from housing-related hazards, and determining the barriers and incentives affecting future use of these cost-effective strategies.

Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets

CLIMAS Investigators: B. McMahan and A. Gerlak

Research Partners: Unisys/Tucson Electric Power; W. Holmgren, Institute for Energy Solutions, Univ. of Arizona

End Users: Tucson Electric Power; Western Energy Institute; Salt River Project; Arizona Public Service

Additional Support: Tucson Electric Power

Tucson Electric Power contracted CLIMAS researchers, based on the results a prior research partnership, to explore plausible scenarios for greenhouse gas and carbon reduction in their energy portfolio. These scenarios focus on internal data regarding the economics of portfolio decisions and external data (e.g., social, environmental, climate). CLIMAS researchers analyzed energy portfolios based on emissions reduction targets and cumulative carbon budgets. Results from this project informed the company's 2020 integrated resource plan.

Outputs

Publications:

McMahan, B., W. Holmgren, and A. Gerlak. 2020. Climate and TEP Resource Portfolios – Emissions Reduction and Cumulative Carbon Budgets. An appendix to the Tucson Electric Power 2020 Integrated Resource Plan. https://www.tep.com/wp-content/uploads/TEP-2020-Integrated-Resource-Plan-Lo-Res.pdf

This appendix summarizes the global warming implications for various resource portfolios developed by TEP as part of their 2020 integrated resource plan.

McMahan, B. A.K. Gerlak. 2020. Climate risk assessment and cascading impacts: Risks and opportunities for an electrical utility in the US Southwest. Climate Risk Management 29: 100240. DOI: 10.1016/j.crm.2020.100240

This paper presents a case study example of climate services development, co-produced between a regional electrical utility and researchers at the University of Arizona, that integrates and adapts a climate risk management framework to better connect university climate expertise with utility needs for climate risk management and planning.

Data: A github data repository was developed and made publicly available here: https://github.com/CLIMAS-UA/tepcarbon/

Media citations:

McVeigh, Q. 2020. TEP's 2035 energy plan and the role of UA's Institute of the Environment

Davis, T. 2020. New TEP plan ends coal use by 2032, ratchets up renewables use

Community Climate Profiles

CLIMAS Investigators: A. Meadow, J. Weiss, L. Keith, and S. Leroy

Research Partners: Pueblo of Laguna; Arizona Land and Water Trust; City of Sedona, AZ; Adaptation International

End Users: City of Sedona, AZ; Pueblo of Laguna, NM; Arizona Land and Water Trust; City of Flagstaff, AZ; Tohono O'odham Nation – Office of Emergency Management; The Highlands at Dove Mountain

Additional Support: Adaptation International

Climate change adaptation planning requires decision-makers to envision the future of their communities, and make well-grounded assumptions about economic, demographic, and cultural trends that are likely to affect that vision. However, may communities lack the technical resources to compile and analyze climate data and research findings, thus making the information essentially inaccessible to them. This project addresses the lack of access to appropriate climate change information by producing climate profiles for communities to support their adaptation planning efforts. These profiles include information such as historical/instrumental temperature and precipitation data from 1895 to present at a scale appropriate to the decisions made within the community of interest, explanations of key climate phenomenon that impact climate and weather in the region, current climate trends, projections of climate change for two RCPs (4.5 and 8.5), at a regional scale, and a summary of general regional climate impacts.

We completed a profile of the Upper Santa Cruz Watershed for use by Arizona Land and Water Trust on a small project that explores how to integrate climate change considerations into their long-term conservation easements. ALWT is in the process of applying for new funding to expand their work and allow them to fully mainstream climate adaptation planning within their conservation easement processes.

Outputs

Publications:

Meadow, A.M, J. Weiss, and S. LeRoy. 2021. Climate Profile for the Upper Santa Cruz Watershed. https://climas.arizona.edu/research/community-climate-profiles

This climate profile of the Upper Santa Cruz Watershed in Southern Arizona summarizes expected climatic changes (warming and drying) as well as likely ecosystem and agricultural impacts due to warming and drying. It was developed for staff of the Arizona Land and Water Trust, the Trust's board of directors, and the Trust's stakeholders. ALWT requested the profile because they needed to understand anticipated climate changes and likely impacts to the lands they manage in the Upper Santa Cruz Watershed. They sign long-term conservation easements with landholders in the region and are exploring how they can incorporate climate change information into those agreements to better-protect the lands and resources even as the climate changes.

Presentations:

Arizona Land and Water Trust "Happy Hour" meeting, March 5, 2021, online. Approximately 25 attendees, comprised of landholders who work with the Arizona Land and Water Trust and the Trust's Board of Directors.

Deep Roots Make Strong Trees: Climate Adaptation Rooted in Community History. April 12, 2021, online. Oil Water and Climate – Environmental Histories of Texas. Institute for Historical Studies, University of Texas at Austin. Approximately 35 attendees, including students and faculty of the University of Texas Department of History. https://notevenpast.org/ihs-panel-oil-water-

and-climate-environmental-histories-of-texas/

Building Regional Food System Resilience in Southern Arizona – Learning from COVID-19

CLIMAS Investigators: G. Owen and E. Kinkaid

Research Partners: L. Bellante, Center for Regional Food Studies, Univ. of Arizona; S. Maccabe, Center for Planning and Landscape Architecture, Univ. of Arizona

End Users: Pinnacle Prevention; Local First AZ; Community Food Bank of Southern Arizona; Southern Arizona Young Farmers and Ranchers Coalition; Pima County Food Alliance

Additional Support: Arizona Institutes for Resilience, Univ. of Arizona; Paul D. Coverdell Fellows Program, Peace Corps

From 2020 through spring 2021, this project aimed to document the impacts of the COVID-19 pandemic in the local food system in Pima County, Arizona. The evolving crisis highlighted several long-standing issues in the local food system, including inequities in food access, food policy, food production and distribution, and food sovereignty. The crisis also revealed strengths in the local food system and opportunities to address these issues while building capacity and resilience. Our 2021 report synthesizes people's experiences and lessons learned over the past year, in support of building a strong and equitable food system in southern Arizona that is resilient to future environmental, climate, economic, and health risks.

The next phase of research seeks to build on these findings through data collection, interviews, network building, and focus group discussions. Current project goals include: a) conducting in-depth analyses on cascading economic, climatic, and societal risks in the local food system over time, b) bolstering local partnerships between food businesses, organizations, and researchers, and c) developing a coordinated strategic plan for building local food system resilience and equity in the southern Arizona region.

Findings: Local food systems played a crucial role during the recent pandemic crisis. Flexibility, pre-established networks, sharing resources, and communication channels were vital to developing an effective local response to pandemic-related challenges. Local businesses were able to fill in immediate gaps and increased food need that occurred due to pandemic impacts on the conventional food system. Findings from this study mirror trends in other climate adaptation work – long-term relationships, trusted partnerships, and local knowledge that is grounded in the unique social, cultural, and environmental context of the region, are the building blocks of social systems that are adaptable to various forms of risk. While COVID-19 caused many disruptions and hardships, other challenges present greater threats to the long-term stability and capacity of the local food system. For small-to-medium scale agricultural producers, heat waves, drought, changes in seasonal temperatures, and access to water resources were of greater concern than the pandemic. Other obstacles include lack of support for new or small-scale farming and ranching operations, inadequate local infrastructure such as processing facilities, cold storage, and transportation, and the need for skilled laborers and living wages for food system workers.

Outputs

Publications:

Owen, G., E. Kinkaid, L. Bellante, S. Maccabe. 2021. State of the Tucson Food System Report: Assessing the impacts of the COVID-19 pandemic in southern Arizona 2020-2021. Center for Regional Food Studies, University of Arizona. https://crfs.arizona.edu/sites/crfs.arizona.edu/files/2020-21%20State%20of%20the%20Tucson%20Food%20System%20Report_3.pdf

This report documents how the impacts of the COVID-19 pandemic played out in the local food system in Pima County, Arizona. The evolving crisis highlighted several long-standing issues in the local food system but also revealed strengths and opportunities for growth. Intended audiences include people who work in local regional food system planning, policy-setting, and food distribution operations.

Owen, G., E. Kinkaid, L. Bellante, S. Maccabe. 2021. Executive Summary: State of the Tucson Food System Report, Assessing the impacts of the COVID-19 pandemic in southern Arizona, 2020-2021. University of Arizona. https://crfs.arizona.edu/sites/crfs.arizona.edu/files/Executive%20Summary_2020-21%20State%20of%20the%20Tucson%20Food%20System%20Report.pdf

The executive summary provides a quick snapshot of findings. This document is aimed toward policy and advocacy organizations.

Presentations:

Launch of the State of the Tucson Food System Report. 2021. Center for Regional Food Studies. Virtual. Approximately 75 attendees.

The state of the Tucson food system in the time of COVID-19. 2021. Annual Meeting of the Association of American Geographers. Virtual. Approximately 20 attendees, mostly academics who were conducting similar research studies.

2020 Building Regional Food System Resilience in Southern Arizona – Learning from COVID-19. Tucson Meet Yourself, University of Arizona Museum of Art, & Center for Regional Food Studies Panel. Virtual. (invited) Approximately 50 attendees.

Media citations:

Caballero, L. 2021. UArizona research shows perseverance in Tucson food industry. KGUN 9 News.

Rascon, I. 2021. Estudio: pandemia impactó en el sistema alimenticio de hispanos en Arizona. Telemundo.

McNeil, M. 2021. State of the food system: The pandemic impacts restaurants, food security. KOLD News 13.

New Funding Acquired:

RISA Special Funding Opportunity: Business Disruption and Resilience in the Context of Complex Climate Events. Building Resilience in Southern Arizona's Local Food System. PI, G. Owen; Co-PI L. Bellante, Center for Regional Food Studies. NOAA Climate Program Office. Grant #NA20OAR4310253C. 2021-2022 ($85,000)

Arizona Institutes for Resilience (AIR) Resilience Grants. Building Resilience in Southern Arizona's Local Food System. PI, G. Owen; Co-PI L. Bellante, Center for Regional Food Studies. 2021. ($11,625)

Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico

CLIMAS Investigators: J. Weiss, G. Frisvold, A. Meadow, and M.B. Roudaut

Research Partners: University of Arizona Cooperative Extension; New Mexico State University Cooperative Extension; Yavapai College Viticulture and Enology Program; Arizona Vignerons Alliance

End Users: University of Arizona Cooperative Extension; New Mexico State Cooperative Extension; Yavapai College Viticulture and Enology Program; fruit and nut tree growers; winegrape growers

Additional Support: NOAA National Weather Service (NWS); NOAA Regional Climate Centers (RCC); USDA Climate Hubs; NOAA National Centers for Environmental information; PRISM Climate Group; TopoWx; Arizona Meteorological Network; U.S. Geological Survey

Orchards and vineyards are particularly sensitive to temperature. Information is lacking about how recent and future warming in the Southwest affects climatic conditions important to orchards and vineyards. This project works closely with Cooperative Extension in Arizona and New Mexico and individual growers to survey a set of orchards and vineyards currently under production to gather information about their siting and cultivars. Assessments will be made of the required temperature conditions for current cultivars, whether these have historically been met, and if they are likely to be met in the coming decades. Crop insurance indemnity records will be used to perform a financial assessment of how site and cultivar selection are functioning in the current regional climate. The suitability of present-day cultivars will be evaluated in the context of anticipated increases in regional temperature. Orchards and vineyards are increasingly important to rural economies of the Southwest, but growers of these high-value perennial fruit and nut crops have limited climate information to support critical decisions about selecting sites and cultivars.

Findings: During grapevine dormancy, the build-up of cold hardiness in the plant progresses through the stages of acclimation, maintenance, and deacclimation. Budbreak takes place when cold hardiness is lost. Applying increased understanding of what occurs during deacclimation improves bud break models for grapevines in warm-climate growing regions.

Other project results suggest that duration of both heat and cold exposure influence the fruit composition of white grape varieties. The degree of heat or cold at several temperature thresholds is linked to these relationships. Neither duration nor degree of heat or cold seem to affect fruit composition of red varieties, perhaps indicating more inter-varietal differences.

Outputs

Presentations:

How Growers Help Identify When and Why Heat Matters in Vineyards. CNRS-iGLOBES and University of Arizona tipping points working group. Oral online presentation, May 2021.

How Growers Help Identify When and Why Excessive Heat Matters in Vineyards. Climate Prediction Applications Science Workshop – Drought, Vegetation, and Heat

session. Virtual, April 2021. 30 attendees.
State of the Climate for Arizona Pecan. Arizona Pecan Growers Association 2020 Annual Conference, Tucson AZ. Invited, recorded.

Media citations:

Talking Wine, Weather, and Science: Parts I and II. Come Rain or Shine Podcast. USDA Southwest Climate Hub and DOI Southwest Climate Adaptation Science Center. Part I. Part II.

Online Information:

Produced 13 monthly and special issues of Climate Viticulture Newsletter, which provides a quick look at some timely climate topics relevant to winegrape growing in Arizona and New

New collaboration with the Arizona Vignerons Alliance. Applied for an Arizona Department of Agriculture grant using some of their fruit quality data in analysis of climate effects on state viticulture. Pending review: Principal Investigator, "Effects of Arizona Climate on Wine Grape Composition", Arizona Department of Agriculture Specialty Crop Block Grant Program.

The Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future

CLIMAS Investigators: C. Woodhouse, D. Ferguson, A. Gerlak, T. Anderson, and S. Karambelkar
Research Partners: Brad Udall, Colorado State University
End Users: R. Doba, Ron Doba Management Services LLC; M. Mahmoud, Central Arizona Project; K. Mott Lacroix, U.S. Forest Service; B. Svoma, Salt River Project; E. Young, E. Schenk, and B. Hill, Flagstaff Water Services

The overarching goal of this study is to evaluate the seasonal climatic components that control surface water supplies in the lower Colorado basin, with a specific focus on the Gila River and the influence of temperature on annual streamflow in recent decades. The project investigates questions and produces scientific results that are meaningful and useful for decision makers in the LCRB. To achieve that goal, the project team identified interested resource management partners in the LCRB who were willing to help shape a research agenda that addressed climatic controls on surface water supplies in the lower basin in a way that is relevant to resource management. We began a dialogue in late summer 2018 with a small group (10-12) of potential research partners to identify research questions, followed up with a webinar in spring 2019, and have continued to work with a subset of these partners on topics of interest (e.g., Flagstaff Water, SRP, and CAP).

Findings: Analysis of the relationship between Gila River Flow and Climate: While cool season precipitation is the most important control on annual streamflow, the role of the monsoon in mediating the impacts of a dry cool season or a multi-year drought is notable, particularly in the upper Gila River basin.

Currently, decreasing trends in annual streamflow are not evident, despite increasing trends in temperature. But there is evidence for the influence of warming temperatures on runoff in the fall and spring and on 21st century droughts.

Outputs

Publications:

Karambelkar, S. and A.K. Gerlak. 2020. Collaborative Governance and Stakeholder Participation in the Colorado River Basin: An Examination of Patterns of Inclusion and Exclusion. Natural Resources Journal 60. https://digitalrepository.unm.edu/nrj/vol60/iss1/3 This paper examines the institutional design of stakeholder participation in five formal collaborative venues and finds that while the evolution of institutional arrangements has resulted in the broadening of stakeholder composition over time, there continues to remain unevenness in participation within and across venues.

Anderson, T.G., C.A. Woodhouse, and D.B. Ferguson. 2020. Upper Lake Mary Lake Level Response to Climate Variability: Report to Flagstaff Water Services. This report addresses the question: how do Upper Lake Mary water levels respond to climatic conditions in the Rio de Flag and Walnut Creek watersheds? Flagstaff water was interested in understanding how climate has influenced Lake Mary levels, to anticipate how warming temperatures and drought may impact this water supply. Flagstaff Water Commission requested an additional presentation.

Presentation: Upper Lake Mary: Lake Level Response to Climate Variability. Aug. 2020. Virtual presentation, for the Flagstaff Water Commission monthly meeting.

Online Fact Sheets: The Influence of Climate on Lower Colorado Streamflow Variability. Short summaries of the main climatic controls on annual flow of the Upper Gila River, Salt River/Tonto Creek, and Verde River.

Transdisciplinary Environmental Science for Society (TESS) Professional Development Program

CLIMAS Investigators: C. Woodhouse, D. Ferguson, and G. Owen
Research Partners: G. Garfin and M. Ramirez-Andreotta, School of Natural Resources and the Environment, Univ. of Arizona
End Users: Those interested in training in transdisciplinary research
Additional Support: Univ. of Arizona Office of Digital Learning; Univ. of Arizona Continuing and Professional Education

The Transdisciplinary Environmental Science for Society (TESS) program trains researchers, practitioners, and educators to be well-equipped to address complex environmental challenges. The focus is on theoretical insights and practical skills to improve research collaborations between many kinds of experts. The program is currently designed as a series of three 20-hour online professional development courses: 1) fundamentals of transdisciplinary research, 2) practicing collaborative research, and 3) communication strategies and skills. Other related courses are under development including a graduate seminar and possibly an undergraduate course, both of which will focus on the challenges of global change and practical approaches to collaborative research that engages research and stakeholder communities.

Traditional graduate training—even programs that emphasize interdisciplinarity—tends to overvalue disciplinary knowledge and undervalue other ways of knowing (e.g., from different disciplines, but also from non-academic epistemologies) and integrative ways of viewing a complex problem. Typical graduate programs also commonly neglect the critical need for grounding students in the ideas and concepts that illuminate both barriers and opportunities for interactions and partnerships between science and practice and how to truly become boundary-spanning individuals. The goal of the TESS program is to provide training in the theory and practice of transdisciplinary research so that students have the knowledge and perspectives needed carry out successful collaborative research.

Outputs

Online Course: Transdisciplinary Environmental Science for Society (TESS) online professional development program. TESS is built for both working professionals and graduate students who want a solid grounding in approaches to bring scientific insights to real world challenges. In Fall 2020, five students enrolled in the first course in the series, about the theory of transdisciplinary research. In spring and summer 2021, seven students enrolled in the second course, about the practice of transdisciplinary research. Feedback was positive.

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