CAP LTER IV 2023 ANNUAL REPORT TO THE NATIONAL SCIENCE FOUNDATION

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Report to the National Science Foundation

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REPORT TO THE NATIONAL SCIENCE FOUNDATION

GOALS OF CAP LTER IV

- To foster interdisciplinary social-ecological urban research aimed at understanding these complex systems using a holistic, ecology *of* cities perspective, while contributing to an ecology *for* cities to enhance urban sustainability through transdisciplinary partnerships with city practitioners.
- To use our long-term observations and datasets to articulate new questions that require a long-term perspective.
- To develop and use various models and scenarios to address our research questions.
- To apply our broad use of existing urban ecological theory, while contributing new theory from our knowledge-generating endeavor.
- To build and use transdisciplinary partnerships to foster resilience and enhance sustainability in urban ecosystems while contributing to the education and well-being of urban dwellers of all ages and experiences.

KEY RESEARCH ACTIVITIES

Long-term Observations and Experimentations

Ecosystem Response to Urban Atmospheric Deposition (DesFert experiment)

- 15 sites: Five west of urban area in desert parks, five east of urban area in desert parks, and five in urban core in desert remnant parks.
- Treatment plots fertilized with nitrogen (as ammonium nitrate) and/or phosphorus (as triple super phosphate)—winter and spring, all fifteen sites since 2006.
- Atmospheric deposition collection—collected and analyzed quarterly at six sites.

- PRS™ probes (Western Ag Innovations Inc., Saskatoon, Canada) deployed in rainy season and analyzed for NO_3^- and NH_4^+—winter and summer (monsoon) seasons at nine sites.
- *Larrea tridentate* (creosote) growth measured—spring and fall at nine sites.
- *Larrea tridentate* (creosote) leaves collected for CHN analysis—spring and fall at nine sites.
- Percent composition of annuals recorded for subplots; above ground material harvested from different subplots, and aboveground dry mass determined for harvested material—spring at nine sites.

Arthropods

- Twelve sites, including long-term desert sites (open desert and desert remnant) and residential sites (mesic and xeric yards) that coincide with birding locations.
- Eight additional sites at McDowell Sonoran Preserve, a citizen science partner.
- Ten pitfall traps per site.
- Traps are set quarterly and collected 72 hours after setting. McDowell Sonoran Preserve sites are not collected during the summer quarter.
- Arthropods stored in ethanol (one jar for each trap) and identified in the lab.

Bird Monitoring

- 70 points monitored in winter and spring at residential, desert, desert park, and riparian (Salt River) locations.
- 36 of these points located in Phoenix Area Social Survey (PASS) neighborhoods (three per neighborhood).
- Point count surveys by professional bird surveyors—all birds recorded that are seen and heard within a 15-minute window.
- Each point visited independently by three different surveyors during each season. Spring season truncated in 2020 due to the pandemic.

Bird Monitoring—Salt River Biodiversity Project

- 7 sites monitored quarterly. Spring 2020 surveys not completed due to the pandemic.
- Each site monitored at six points.
- Point count surveys by professional bird surveyor—all birds recorded that are seen and heard within a 15-minute window.

Herpetofauna Monitoring—Salt River Biodiversity Project

- 7 sites monitored three times a year—spring, summer, and fall. Spring 2020 surveys not completed due to the pandemic.
- Nine 10 m x 20 m plots per site.
- Two surveyors concurrently survey each plot for presence of herpetofauna.

Atmospheric Deposition

- Atmospheric deposition buckets collected from one urban location.
- Dry bucket collected monthly, wet bucket collected after precipitation events.

Stormwater

- Water collected from ISCO stormwater samplers at three locations along Indian Bend Wash (IBW): one long-term site at the southern outflow of IBW and at two sites further upstream in the IBW watershed.
- Discrete, time weighted sampling of runoff producing storms.
- Water analyzed for organic matter, total nitrogen, total phosphorus, dissolved organic carbon, total dissolved nitrogen, cations, and anions.
- Fluxes calculated by combining concentration and water flow data.

Regional Drinking Water Quality Analysis

- Water collected monthly at 5 locations in major influent reservoir systems.
- Water analyzed in lab for nutrients, major cations and anions, pH, temperature, specific conductance, DOC, taste and odor compounds, and particulate matter.

Eddy Covariance Tower

- One tower located in urban area. Tower houses sonic anemometer, infra-red gas analyzer, and temperature/humidity sensor to measure high-frequency (10 Hz) 3-D wind, CO_2 (flux), temperature (flux), and moisture (flux)
- 30-minute block averaged data is streamed daily. 10 Hz data is downloaded monthly.

Microclimate Towers

- Two 10-m towers, one located in desert remnant park within urban area, the other located in outlying desert park. Towers house sensors to measure temperature/relative humidity, horizontal wind speed and direction, incoming solar radiation, and precipitation. Data downloaded quarterly.

Earth Networks Weather Station and Greenhouse Gas Analyzer

- CAP LTER hosts this system on eighth-floor roof of ISTB4 building at Arizona State University.
- Weather station provides real-time weather observations for 27 parameters, including temperature, relative humidity (dew point calculated), barometric pressure, wind speed and direction, and precipitation.
- 360-degree weather camera provides weather-related photos to Earth Networks website and local news station.
- Picarro greenhouse gas analyzer provides real-time measurements of carbon dioxide and methane.

Tres Rios Constructed Wetlands

- Bi-monthly field visits.
- Measurements and samples are taken along two gradients representing the two hydraulic pathways of the treatment cell: whole-system, from inflow to outflow, and within the vegetated marsh proper, from the open water-marsh interface to the shoreline, along 10 permanent transects.
- Measure aboveground primary productivity (biomass) of marsh vegetation, foliar and soil nutrient content and water quality to produce whole system nutrient budgets, and transpiration and evaporation to produce whole system water budgets.

Tempe Town Lake Biogeochemistry

- Water samples collected every two weeks and after rain events and analyzed for temperature, conductivity, dissolved oxygen, pH, chlorophyll a, inorganic nutrient and DOC concentrations, and DOC fluorescence
- Eureka Manta+35 multiprobe datasonde deployed in Tempe Town Lake in June 2018. Sensors measure temperature, conductivity, turbidity, pH, dissolved oxygen, chlorophyll a, DOC concentration, and CDOM/*f*DOM at 30-minute intervals. Datasonde will eventually replace the need for water sample collection and analysis.

Charismatic Megafauna in Cities

- Wildlife cameras deployed at 50 sites in CAP study area in proximity to ESCA, DesFert, and Salt River sites. Data are downloaded monthly. This project was concluded in August 2020. With the pilot project completed, the cameras will now be relocated to 35 sites along the Salt River.

Drought-Net

- Two sites, each with seven rainout shelter plots and seven control plots.
- Desert annuals and soil samples collected for analysis each spring.
- Sites situated at DesFert sites, one west and one east.
- Project is in collaboration with researchers from Sevilleta LTER.

Significant Results

- **Human-Snake Interactions (Larson, Bateman, et al., In Review; Larson, Clark, et al. In Review)**
    - From March 2021-July 22, Bateman, Brown, and Larson conducted a survey of clients who paid for services including snake removals. In 2023, we developed and submitted two manuscript examining clients' reasons for snake removals, as well as how clients differ from PASS residents in their attitudes and norms about snakes.
    - Larson et al. (in review at Human Dimensions of Wildlife) identified three distinct motivations for snake removals: perceived threats associated with venomous snakes, generalized fear of snakes based largely on negative attitudes, and conservation intentions grounded in the view that snakes are ecologically valuable. Larson et al. (in review Biological Conservation) found that residents who paid to have snakes removed from their property have significantly more positive attitudes towards snakes and believe it is morally wrong to kill snakes. Further, while attitudes affected norms, experiences with snakes in nature and otherwise were the primary driver of attitudes.

- **COVID and Human Interactions with Nature (Mitchell, 2023. In submission)**
    - Starting in 2021, Professor Kelli Larson and Masters student Abby Mitchell began analyzing data from 2021 PASS understand how nature interactions changed during COVID, and how those and other nature interactions--along with local

environmental and social factors--affect different dimensions of human wellbeing.

  - This research (Mitchell 2023) demonstrates that distinct aspects of wellbeing have different drivers, and multiple local environmental and social features should be considered when designing healthy communities for urban sustainability. Specifically, while perceived social and environmental attributes of neighborhoods and proximity to desert preserves had a more significant impact on subjective wellbeing than nature recreation, age and park visitation largely influenced physical health and socio-demographic factors impacted mental health. Changes in nature recreation during the COVID-19 pandemic did not significantly impact any dimensions of wellbeing among the survey sample.

- **Multi-scalar drivers of residential vegetation changes in metropolitan Phoenix, Arizona (Zhu and Larson, In Review)**
  - Starting in 2021, Kelli Larson and PhD student Qinnan Zhu began analyzing data from the Wheeler et al. survey, in addition to 2012-2021 PASS data to better understand vegetation changes, associated drivers, and their implications for urban/landscape sustainability.
  - We found a sustainable trajectory of residential vegetation changes in Phoenix since mid-2010s, with a static change declining additions of grass and potential increases of in trees and desert plants across residential neighborhoods (Zu and Larson, in review). Aesthetics was an influential driver of both tree planting and native gardening. Additionally, tree planting was associated with low-maintenance needs, while desert plant additions reflected the appreciation of nature and wildlife.

- **Soil microbial activity in response to N fertilization, urbanization, and precipitation pattern (Williamson and Ball, 2023)**
  - A former undergraduate student analyzed results from her lab incubation on the interactions of multiple forms of human-induced environmental change (temperature, precipitation, N deposition, and urbanization) on soil microbial respiration and inorganic nutrient availability. She prepared the manuscript for peer-reviewed publication.
  - Results show that respiration and mineral nitrogen were significantly altered by changes in precipitation patterns and temperature. Biogeochemical responses to multiple co-occurring forms of global change differ than when considered individually.

- **Health implications of human-wildlife interactions (Rosales-Chavez et al., 2023; Larson et al., 2023; Haight et al., In Review)**
  - The lead authors developed an approach to examine physical, observational, attitudinal, and behavioral interactions with wildlife to advance understanding of

coexistence. Results demonstrate positive health and wellbeing outcomes in urban areas, which contrasts with the dominant focus on human-wildlife conflicts and negative outcomes in rural areas (Rosales-Chavez et al. 2023; Larson et al. 2023). / Work with Haight and others (in review) found that residents who were more comfortable living near wildlife commonly held pro-wildlife value orientations, reflecting the expectation that attitudes toward wildlife are primarily driven be an individual's value-based judgements. However, attitudes were further influenced by sociodemographic and environmental factors.

- Influence of Climate, Plant Communities, and Land-Use on Long-term Patterns of Soil Properties in the CAP LTER Ecosystem (Seelig et al. In Prep)
    - Land-use decisions most significantly influence soil attributes, and some impacted soil properties are strongly changing through time. This indicates that human decision making not only influences soil properties, but also their variability over time, particularly where irrigation and fertilization are part of the management. Human decisions regarding these practices play considerable roles in sub-local biogeochemical processes over time.

KEY OUTCOMES OR OTHER ACHIEVEMENTS

CAP LTER is a leader in urban social-ecological research:

- In 2023, we have published 17 peer-reviewed journal articles with 18 in review and 2 in press. In addition, we published two book articles and have two in press.

Faculty collaboration leads to additional grant funding for social-ecological research:

- We have leveraged $48 million in grant funding since the inception of CAP IV in December 2016 for a total of over $131 million since CAP's inception in 1997.
- Leveraged grants during this reporting period include:
    - Paul Coseo was a contributor on $5 million Greater Phoenix Urban Forestry Accelerator, a USDA-funded initiative (PI: Jennifer Clifton).
    - Kelli Larson was co-PI on "Social-Ecological Drivers and Consequences of Human-Carnivore Interactions within and among American Cities", a $1.6 million grant from the NSF.
    - Sara Meerow was awarded $360k from the NCAR Early Career Faculty Innovator Program, for her study entitled, "Models for planning multifunctional and equitable green infrastructure to mitigate rising stormwater and heat risks in cities."

Undergraduate and graduate students contribute to a knowledge of urban social-ecological systems:

- In 2023, students were authors on 10 publications and were first authors on six of these.
- One Ph.D. degree and two MS degrees were granted to CAP students in during this reporting period:
    - Jordan Cisco: "The Fate of Microplastics in Tres Rios, a Constructed Treatment Wetland."
    - Annika Enloe: "Snake Removals, Residential Yards, and Resident Attitudes Towards Snakes in the Phoenix Metropolitan Area, Arizona."
    - Jeff Haight: "Anthropogenic Environments Shape Wildlife Communities and Human-Wildlife Coexistence Across Urbanizing Landscapes."

CAP engages in knowledge exchange across institutional boundaries:

- CAP's future scenarios project has engaged expert stakeholders from county, state, and federal agencies, municipal departments, non-profits, academic institutions, the regional council of governments, and a tribal association in workshops visioning the future of greater Phoenix.

- CAP is an active partner in the Central Arizona Conservation Alliance (CAZCA), the Sustainable Cities Network, and the McDowell-Sonoran Conservancy's Field Institute. We share research findings, learn from our community partners, and collaborate on research, education, and outreach.

- CAP's Regional Water Quality project involves collaboration with the Salt River Project (a local utility responsible for water supply) and shares information with local water authorities and managers about quality of all major surface supplies for the metro area through a monthly newsletter and annual workshops.

- The Edison-Eastlake neighborhood near downtown Phoenix has emerged as a focal point for Climate & Heat research and broader impacts, in coordination with the Urban Design IRT. In Edison-Eastlake, we deployed meteorological instrumentation for long-term, continuous monitoring at seven locations (including two with live internet feeds) and are conducting annual high-resolution microclimate assessments with a mobile biometeorological platform (MaRTy). We are using simulation modeling to understand the potential microclimate effects of a large-scale redevelopment project that is planned for the neighborhood in the coming years. Our meteorological measurements, transects, and the longer-term CAP archive of land cover, land use, and land surface temperature data sets will ultimately enable us to measure the realized impacts of this large-scale change to the urban landscape with respect to ecologically and socially relevant climatic variables and validate and improve state-of-the-art microclimate models.

TRAINING AND PROFESSIONAL DEVELOPMENT

- CAP's activities in the area of training and professional development are three-fold: 1) We actively promote and encourage training and professional development for faculty,

staff, and students; 2) we work with the Julie Ann Wrigley Global Institute of Sustainability and Innovation, the LTER Network Communication Office, and others to design and deliver training and professional development activities to the CAP community; and 3) we design and deliver training and professional development for various stakeholder groups, including teachers, citizen scientists, and practitioner partners. We detail some of these activities under Impacts on Human Resources.

- During summer 2023, CAP continued our Integrated Summer Research Experience for Undergraduates (REU). This year, we brought seven REU students together in bi-monthly seminars to share their research and engage in discussions about interdisciplinary research, career and graduate school planning, and science communication. We involved graduate students in these sessions, when possible, to promote near-peer mentoring, learning, and engagement.

- In 2023, the CAP Student welcomed a new leader, Luke Ramsey-Wiegmann, a PhD student in the School of Sustainability. He continued to build and develop the CAP LTER Student Group, picking up were Jeffrey Haight left off. They have also organized events with the goal of increasing networking opportunities for ASU students interested in CAP LTER-related work, including a monthly CAP coffee hour that coincides with the CAP JEDI committee's Equity Circle.

- ASU's Wetland Ecosystem Ecology Lab (WEEL) is highly integrated into CAP. The WEEL spearheads our research at the Tres Rios Constructed Treatment Wetlands and in other urban wetland systems. The City of Phoenix built these wetlands as an alternative to traditional wastewater treatment, and Tres Rios has become a living laboratory for high school, undergraduate, and graduate students who want to experience urban field and lab research for the first time. All field work at Tres Rios in the eight and a half years of the WEEL lab has been done by student volunteers.

- CAP encourages students, staff, and faculty to participate in research conferences and symposia as part of their professional development. Each year, CAP funds several students and faculty to present their research findings at the Ecological Society of America's conference, the American Geophysical Union's annual meeting, as well as other conferences and events. Other conferences and events where CAP researchers presented their findings in 2023 included the Urban Ecosystem Research Consortium and The Joint Annual Meeting of Wildlife and Fisheries Societies.

- CAP's annual All Scientist Meeting in January 2023 attracted over 100 participants, included 26 poster presenters, and we anticipate similar attendance and participation in January 2024.

DISSEMINATION

- In 2023, CAP students and scientists published a total of 17 peer-reviewed journal articles with 16 in review and three in press. Our journal publications span the biological, physical, engineering, health, and social sciences as well as landscape

architecture and urban planning and include journals such as: Urban Ecosystems, Sustainability, Landscape and Urban Planning, The Journal of Ornithology, Frontiers in Ecology and Evolution, and PLOS One.

- CAP joined the social media world in 2009 with its Twitter account @CAPLTER, which focuses on promoting urban social-ecological research and practice. We currently have 1849 followers, of whom the majority are scientists, scientific organizations and programs, or environmental and urban-focused non-profits.

- As noted earlier under Opportunities for Training and Professional Development, CAP actively supports students, staff, and faculty to attend professional meetings and research symposia to present CAP research. In addition to the 26 poster presentations at the January 2023 CAP All Scientists Meeting, CAP scientists and students have made 39 other presentations during this reporting period.

- As part of our NSF virtual site visit in May 2021, we created a series of virtual site visits that allowed our reviewers to experience learn about the work we do at different sites across the CAP area. Link: https://www.youtube.com/playlist?list=PLmV7x-JlhKmqbrOVCly_cGZpaa8HC34-h

- Every year, we hold our annual All Scientists Meeting and Poster Symposium (ASM) off campus at ASU's Skysong facility in Scottsdale, which is located north of the ASU Tempe campus. We will continue this tradition for our 26th ASM on January 12, 2024. Our ASM's agenda includes an "State of the Program" update from Dan Childers. He also gives out CAP Service Awards to individuals who have made great contributions to CAP LTER. Last year, we honored:

    - Professor Billie Turner for his long-time affiliation with CAP as well as his contributions to CAP's GIS/Remote Sensing work; and,
    - Professor Elizabeth Cook and Quincy Stewart for their leadership of the CAP Justice, Equity, Diversity, and Inclusion committee.

- Our staff have offices in The Wrigley Center for Planetary Health and in the Goldwater Center on ASU's Tempe campus. Both include facilities for large and small meetings, most of which have large screens that allow us to connect with our collaborators remotely.

- During 2022-2023, CAP scientists were included in multiple local and national news items, including: The BBC, Grist, Christian Science Monitor, Chicago Tribune, NY Times, and Slate.

PLANS FOR 2024

- We look forward to launching CAP V, and in particular to expanding our urban air quality and environmental justice work and our work with underserved communities in

South and West Phoenix, and to beginning our work with local Indigenous communities for the first time.

- The next CAP LTER All Scientists Meeting and Poster Symposium, our 26th, will be held at ASU Skysong on January 12, 2024. The 27th meeting is tentatively scheduled for January 10, 2025.

- The CAP LTER Justice, Equity, Diversity, and Inclusion committee will continue to hold regular meetings, monthly Equity Circles, and work toward the goals outlined in the Impacts on in Human Resources section.

IMPACTS

Impact on Main Discipline

Early on in CAP, we along with our colleagues in the BES were initiators of a conceptual shift in urban ecology from examining ecology ***in*** the city to a more holistic approach of understanding the ecology ***of*** the city (Pickett et al. 1997; Grimm et al. 2000). CAP continues to contribute significantly to the theory and practice of urban ecology as evidenced by our publication record. The CAP program has published 681 journal articles, 13 books, and 117 book chapters since 1998. CAP research is copiously cited in numerous edited volumes on urban ecology that have been published over the past ten years (e.g., Douglas et al. 2011; Elmqvist et al. 2013; Gaston 2010; Lepczyk and Warren 2012; Marzluff et al. 2008; McDonnell et al. 2009; Niemela et al. 2012; Pickett and Cadenasso 2013), and many have CAP associated scientists as chapter authors. Recent textbooks on urban ecology also discuss CAP's work in the Phoenix region (Adler and Tanner 2013; Douglas and James 2015; Francis, Millington, and Chadwich 2016; Forman 2014; Parris 2016). CAP scientists have published recent papers that expand urban ecological theory into the realm of a transdisciplinary and translational ecology for cities (Childers et al. 2014, 2015; Pickett et al. 2016), into linking urban ecosystem services to urban resilience (e.g. Grimm et al. 2016; 2018), and on the concept of urban ecological infrastructure as a social-ecological bridge for translational urban ecology (Childers et al. 2019).

Impact on Other Disciplines

While CAP remains a fundamentally ecological research program, we are an inherently interdisciplinary endeavor, and thus have contributed to shaping urban ecology as a collaborative endeavor that includes perspectives, theories, and research from across the natural, physical, social, design, and engineering sciences to investigate the complexity of social-ecological processes in urban areas. During the 2022-2023 reporting period, we had over 50 faculty members, 8 graduate student researchers, and seven undergraduate researchers actively engaged in CAP research from 12 different academic units/disciplines at ASU and at six institutions beyond ASU: University of California-Berkeley, University of California-Davis, Yale University, University of Massachusetts at Amherst, Bowling Green University, Georgia State University, University of Georgia, University of Oklahoma, Barnard College, University of New Mexico, Pace University, and Northern Arizona University.

As such, CAP's contributions outside of urban social-ecological research are often at interfaces among disciplines. In fact, most of CAP's contributions to urban systems science are beyond the disciplines of ecology and urban ecology.

Impact on Development of Human Resources

- In 2020, Elizabeth Cook and Quincy Stewart co-founded the CAP LTER Justice, Equity, Diversity, and Inclusion (JEDI) committee. The JEDI Committee is guided by an initial set of responsibilities and goals. The goals and initiatives of the committee, as currently stated, have evolved from ongoing discussions with current CAP community members, the CAP Executive Committee, and the LTER Network Diversity Committee. Our DEI Committee's preliminary goals are to lead initiatives to:

    - Actively foster and support diversity within the CAP community and STEM more broadly;
    - Enhance representation and support underrepresented minorities in STEM career advancement through CAP initiatives;
    - Proactively review anti-racist policies and initiatives related to CAP research, programming, and hiring practices; and
    - Build awareness in the CAP community about the multiple facets of diversity encountered in the Greater Phoenix region every day.

- In order to actively work toward these goals, in Year 3 the CAP JEDI Committee will:

    - Continue to hold regular monthly community 'Equity Circle' discussions to broaden the conversation about the JEDI with CAP. This will include trainings, discussions of field safety plans, discussions of climate survey results, and other facilitated conversations.
    - Collaboratively develop a CAP JEDI Action Plan, including explicit short and long-term action items, mechanisms, and timeline to ensure the CAP community is actively working toward the JEDI goals with a clear process for evaluation and assessment. There will be opportunities for review and feedback by the community.

- The CAP Social Contract will include explicit short- and long-term action items, mechanisms, and timelines to ensure we actively work toward meeting our DEI goals. The DEI Social Contract will include a clear process for evaluation and assessment of success, and targets for success. These initiatives are the starting point for CAP's DEI work, and the goals and initiatives will continue to evolve and be refined. The DEI committee will establish an open engagement process with the larger CAP Community to ensure an inclusive planning and decision-making process.

- For our summer REU program, we traditionally recruit students from groups underrepresented in STEM. Our 2023 REU students included:

    - Brian Ballantyne: "Using CAP-LTER's arthropod dataset to examine urban evolution within a socio-ecological framework" (Mentor: Chad Johnson)

- Mariah Beltran: “Tres Rios for Two” (Mentors: Dan Childers and Julia Hernandez); “Examining the Opportunities, Constraints, and Contexts for Human-Wildlife Coexistence” (Mentor: Kelli Larson)

- Arshonne Cazares: “Diversifying Visions of the Future with Rural and Urban Indigenous Communities” (Mentors: Michelle Hale and Michele Clark)

- Zoe Gentry: “River Futures: Participatory visioning for an urban river” (Mentors: Nancy Grimm, Liliana Caughman, and Michelle Hale.)

- Carter Henry: “Examining the Opportunities, Constraints, and Contexts for Human-Wildlife Coexistence” (Mentor: Kelli Larson)

- David Nguyen: “Tres Rios for Two” (Mentors: Dan Childers and Julia Hernandez)

- Nadia Upah: “Birds in a Warming World: An Integrated Physiological Perspective” (Mentor: Pierre Deviche)

These seven students bring the total number of REU students supported under NSF funding since 1998 to 94. Many of these students have gone onto graduate school in traditional STEM fields and the in new field of sustainability, and others have entered STEM-related careers.

- CAP LTER held our Integrated Summer REU program for the seventh straight summer. This program brings together a critical mass of students— seven in total for 2023 — to share research across traditional academic boundaries. This year’s group also included students from other CAP researchers through separate NSF funding, which added further diversity to the group. The participating students connected in person or remotely via Zoom for five meetings covering topics such as interdisciplinary research, post-graduate career and education planning, and science communication. The final session involved each student giving a short presentation on their research and experiences. Feedback from students afterwards indicated that they appreciated these meetings and that the REU experience had left them with very positive impressions about post-graduation academic degrees and STEM careers. For many students, this was the first time that they had conducted research and the first time that they had engaged in research-related discussions across disciplinary boundaries. Further feedback from students and faculty will assist us in planning for our Integrated Summer 2024 REU program.

- In 2023, our CAP Grad Grants Program competitively granted $19,876 to support the research of four graduate students:

    - Timara Crichlow: “Modeling Community Perceptions of Tree Distribution in the Phoenix Region” (Mentor: Paul Coseo)

- Olivia Nguyen: "The effects of the COVID-19 pandemic on human behaviors and wildlife populations across the gradient of urbanization" (Mentors: Jesse Lewis, Dan Childers, and Esther Rubin)

- Peter Price: "Heat Reduction Benefits of a Residential Rooftop Green Space: Perceptions vs. Realities for a Vulnerable Population" (Mentors: Paul Coseo and Ariane Middel)

- Zachary Van Tol: "Mechanisms of Movement: Identifying the factors that decide the spaces people experiencing chronic homelessness occupy and the associated climate exposures" (Mentors: Ariane Middel and Jennifer Vanos)

- The impact of the graduate grants program goes beyond money for research. Previous recipients of graduate grants form a proposal review panel, run using the NSF panel model, to recommend the next round Grad Grant funding. This model is one of many ways that CAP trains the next generation of academic and agency scientists on how to write and review proposals effectively. The response to this process by our students has been overwhelmingly positive, and both the CAP Grad Grants Program and this review process have become models across the LTER Network.

Impact on Physical Resources that Form Infrastructure

The 6400 km² study area of CAP includes all of the Phoenix metropolitan area as well as surrounding desert. Because of the vast scale of our research endeavor, CAP's provisioning of field vehicles for research has always been essential for the collection of long-term data, for student research, and for more targeted experiments and investigations in our urban and peri-urban areas. CAP Site Manager Quincy Stewart ensures that the vehicles are maintained that researchers undergo the appropriate ASU training to use the vehicles, and that vehicles are used properly.

Shared instrumentation in the Metals, Environmental and Terrestrial Analytical Laboratory (METAL) allows CAP researchers access to equipment and training to conduct analyses. The METAL webpages provide a list of equipment.

CAP maintains a diversity of field infrastructure. CAP Research Specialists perform routine maintenance, instrument calibration, and deal with the vandalism inherent in urban areas. Along with the CAP Site Manager, they assist faculty and students in locating short-term investigations at CAP sites.

- A retractable, 22.1m, four-section eddy flux tower, located in a suburban Phoenix neighborhood comprised of single-story housing. The eddy flux tower measures 3-D wind, CO_2, temperature, and moisture, and fluxes are calculated using standing eddy-correlation techniques. The following instrumentation is located on the tower: 3D sonic anemometer, infrared gas analyzer, temperature–relative humidity sensor, and net radiometer.
- An Earth Networks weather station on the roof of the ISTB4 building (ASU Tempe campus), which measures temperature, humidity, wind speed, precipitation, air pressure and dew point and includes a greenhouse gas analyzer. CAP also maintains a

weather camera attached to the same tower that the local Channel 3 weather team uses in broadcasts.
- At each of the DesFert sites, five permanently marked 20m x 20m plots, two unfertilized controls and three receiving fertilizer additions (N, P, or N+P) twice per year. Each plot also contains five marked creosote bush shrubs for stem elongation measurements and permanently marked subplots for biomass collection and surveys of community composition of annual plants.
- For measurement of atmospheric deposition, CAP maintains resin-based bulk deposition and throughfall collectors at six of the DesFert sites.
- At one urban DesFert desert remnant site and one outlying DesFert desert park site, micrometeorological stations measure temperature, relative humidity, wind speed and direction, precipitation, and solar radiation.
- Atmospheric deposition work also includes deposition collectors (wet/dry collector, resin-based bulk collector) on the roof of the Life Sciences A building at the ASU Tempe campus.
- At each of seven sites along the Salt River, CAP maintains nine permanent herpetofauna plots and six birding points.
- CAP maintains ISCO automated samplers at three stormwater sampling sites along Indian Bend Wash.
- A Eureka Manta+35 multiprobe datasonde is deployed in Tempe Town Lake with sensors to measure temperature, conductivity, turbidity, pH, optical dissolved oxygen, chlorophyll A, DOC concentration, and DOC fluorescence.
- Seven Drought-Net rainout shelters have been installed at each of two outlying DesFert sites (one west, one east) with seven permanently marked control plots also at each site.

Impact on Institutional Resources

- The initial CAP LTER grant from NSF in 1997 was the catalyst for the formation of what is now the Julie Ann Wrigley Global Institute of Sustainability and Innovation at ASU and the sustainability education and research efforts at ASU. CAP remains an important research platform for work on urban social-ecological systems at ASU and is included on the ASU Office of Knowledge Enterprise Development (OKED) timeline.

- One reason CAP has stimulated so much research on urban social-ecological systems is the openness of CAP's past and present leadership to new investigators and students who can contribute novel perspectives to our long-term work. Furthermore, our collaboration model has led to numerous research initiatives outside of CAP as evidenced by the impressive amount of research funding leveraged from CAP:

    - $7 million during this reporting period, bringing the total to $53 million in grant funding since December 2016 (inception of this grant cycle).
    - A total of $136 million since CAP's inception in 1997.

- The CAP information management system has been the exemplar of a data management system that now encompasses all sustainability research efforts at ASU.

Impact on Information Resources

Data Resources

- The CAP LTER added 15 new or revised datasets to its publicly available data holdings during the reporting year. The new additions bring the total number of project datasets archived with the Environmental Data Initiative (EDI) to 261 as of this writing. New or updates-to-existing datasets of note include: (1) expanding the temporal extent of time-series geospatial data, including Landsat-derived Land Use and Land Cover (LULC), and Soil Adjusted and Normalized Difference Vegetation Indices (SAVI and NDVI, respectively), and (2) high-frequency measurements of water quality and chlorophyll in the Tempe Town Lake (Tempe, Arizona, USA), a novel aquatic ecosystem optimal for studying dynamics among management decisions, environmental conditions, and limnological steady states. All CAP LTER dataset metadata are encoded in the XML-based Ecological Metadata Language (EML) schema, with data and metadata available through the CAP LTER data catalog on the project website, the EDI data portal, and DataONE.

Infrastructure

The CAP LTER Information Manager strives always to improve the presentation, utility, and management of CAP LTER information resources. Notable improvements for this reporting period include:

- Further expansion and refinement of tablet-based data-entry applications that improve the accuracy and efficiency of data acquisition by CAP LTER technicians.
- Continued improvement of a suite of R-based tools that aid the development of EML metadata used to describe research data. In particular, the expanded use of configuration (yaml) files that simultaneously increases the readability of inputs while reducing the amount of R coding required to generate data packages. Though developed by and for the CAP LTER, these tools are generalizable and publicly available.
- Refactored database and data-entry application to support the CAP LTER's long-running monitoring of arthropods in the study area. The new system improves the accuracy and efficiency of data processing and storage and integrates an updated taxonomy that aligns with community taxonomic resources, such as the Global Biodiversity Information Facility (GBIF) and Integrated Taxonomic Information System (ITIS).

Network Participation

- The CAP LTER is committed to making a strong contribution to informatics within the LTER Network and the ecological sciences generally. The CAP LTER Information Manager (S. Earl) participates in all Network information management meetings and activities, participates in numerous informatics and scientific conferences, and contributes to publications spanning both the ecological and informatics sciences. S. Earl is a contributor to numerous working groups, including: (1) a joint effort by the LTER and EDI to improve tools and resources to characterize units of measure, (2) a LTREB and NCEAS synthesis working group exploring the impacts of wildfire on the biogeochemistry of flowing waters in the arid Southwest, and (3) developing ontologies

and other resources to improve the discoverability and interoperability of soil chemistry data.

Impact on Society beyond Science and Technology

- Our Ecology Explorers program (work described in several sections above) is our major vehicle for engaging with K-12 students, teachers, and the general public. The Ecology Explorers team has participated in statewide and national meetings and conferences for science and environmental educators. We are participating in the development of initiatives involving the Arizona Association for Environmental Education, the Arizona Science Teachers Association, the Arizona Environmental Literacy Community of Practice, and the Arizona Department of Education.

- In 2019 and 2020, CAP received supplemental NSF support for a summer RET program, and based on the success of that we received additional support in 2020 for a larger "RET on steroids" program that will continue through Summer 2023. In both cases we were able to support research experiences for two K-12 teachers, and both cohorts are from Roosevelt School District, which serves a lower income, predominantly Hispanic population (97% of the students are minority). Notably, Roosevelt School District includes one of our PASS neighborhoods (#U18), where 93% of residents are Mexican/Latino, where the median annual household income is less than $37,000 and where fewer than 4% of residents hold a bachelor's degree or above (Larson et al. 2017). The district is also part of the City's South Mountain Village, which is 63% Hispanic and 15% Black. Our four RET educators represent each of these demographic groups. The 2019 RET educators were paired with scientists and students from our Adapting to City Life IRT. Their collaborative summer research projects involved research on how birds adapt to the challenges of urban life (e.g., various stressors) or take advantage of resource subsidies that close habitation with humans may provide (e.g., bird feeders, water baths). Our new RET educators began their collaborative research with scientists from our Climate and Heat IRT, where they are focusing on extreme heat in school playgrounds, how the microclimate of playgrounds affects the health and wellbeing of children, and how UEI may be used to mitigate playground climate extremes while solving other health-related schoolyard challenges.

- The Rio Salado 2.0 Urban Ecological Working Group was formed by CAP Scientists to work with Melissa McCann, Associate Director of ASU's University City Exchange, on assessing the state of information about urban ecological infrastructure (UEI) related to the Rio Reimagined (Rio Salado 2.0) project, a partnership between municipalities and tribal groups along the Rio Salado river whose goal is to revitalize the river and it's watershed through environmental restoration coupled with sustainable economic and community development. This group plans to create a UEI framework for data collection and monitoring to support the planning and design activities for the Rio Reimagined project. This project brought together representatives of the Central Arizona Conservation Alliance, Arizona Game and Fish, and Flood Control District of Maricopa County to envision needed data for urban ecological planning and design along the Salt River.

- CAP LTER, Healthy Urban Environments and Robert Wood Johnson Foundation funded-project with Braden Kay (PI), Paul Coseo (Co-PI), Katja Brundiers (Co-I), Carlos

Casanova (Co-I), Jenni Vanos (Co-I) Ariane Middel (Co-I), David Hondula (Co-I), and others is a partnership with the City of Tempe to assess urban infrastructure's impact on thermal comfort and work toward creating cooler infrastructure in Tempe, AZ . Funded by a Healthy Urban Environments grant until December 2002 and a Robert Wood Johnson grant until April 2024. Initial conclusions of this study indicate that thermal extremes impact on society are exacerbated by lack of clarity about organizational responsibilities and coordination between local governmental departments or agencies. Data and solutions webtools can help but need to be paired and embedded within a community of practitioners.

- The Phoenix Zoo project is a designed experiment with the City of Phoenix and the Phoenix Zoo to create a more sustainable parking lot with potential for work on the Zoo campus in future phases. This is supported by a collaboration between CAP, HUE, and UREx SRN including CAP members Ray Quay, Ariane Middel, Kristian Kelley, Allyce Hargrove, Paul Coseo, and others. Social and meteorological data collection began in summer 2020.

PUBLICATIONS

Students in **Bold**

Journal Articles

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