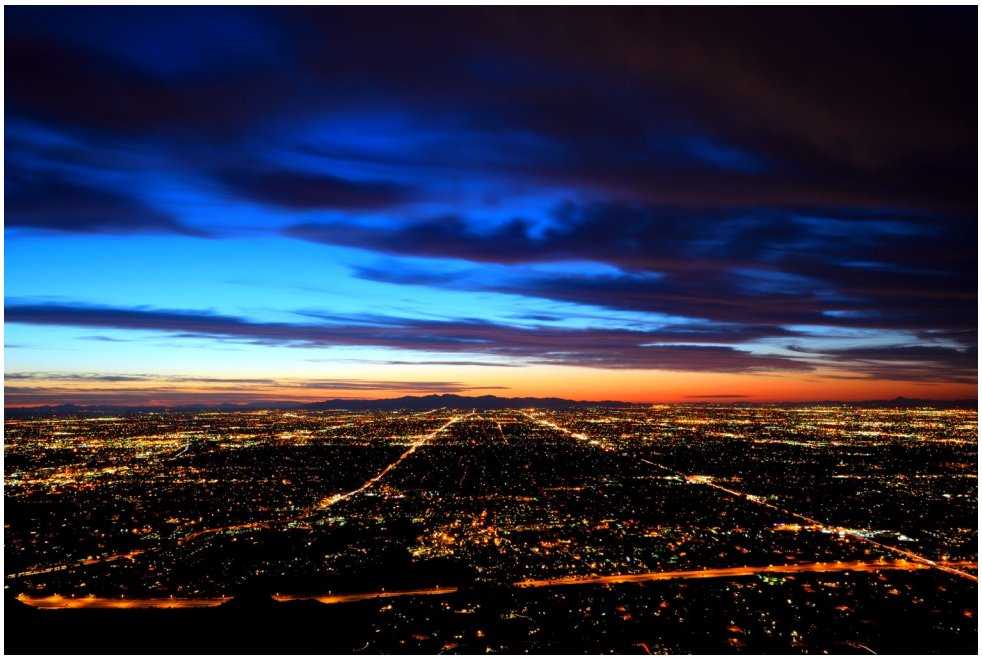
CAP LTER IV 2021 ANNUAL REPORT TO THE NATIONAL SCIENCE FOUNDATION



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Report to the National Science Foundation

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CAP LTER IV
2021 Annual Report to the National Science Foundation

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 DURING 2021

Long-term observations and experimentation: **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.

Long-term observations: **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.

Long-term observations: 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.

Long-term observations: Bird Monitoring—Salt River

- 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.

Long-term observations: Herpetofauna Monitoring—Salt River

- 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.

Long-term observations: Atmospheric Deposition

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

Long-term observations: 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.

- Water collected in stormwater bioswale systems on the Orange Mall of ASU's Tempe campus using five ISCO samplers; sampling includes flow rates within the various basins and from the overall system plus soil moisture measurements in the bioswales coupled with transpiration measurements from plants using an IRGA.
- 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.

Long-term observations: 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.

Long-term observations: 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.

Long-term observations: 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.

Long-term observations: 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.

Long-term observations: 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.

Long-term observations: Charismatic Fauna in and near 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 are now located at 35 sites along the Salt River.
- Recently deployed wildlife cameras are located in 20 urban parks that were chosen based on various neighborhood characteristics, including proximity to PASS neighborhoods.

Long-term observations: 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 (LISTED BY INTERDISCIPLINARY RESEARCH TEAM)

Adapting to City Life

Urban links to molt schedule, body condition, and carotenoid-based coloration in the house finch (*Haemorhous mexicanus*) (Sykes et al, 2021).

- Measured progression of feather replacement in urban and rural finches and compared this to variation in color intensity and body condition.
- Urban birds began molting earlier, peaked at a lower molt intensity and ended molt later than rural conspecifics. Both body condition and plumage hue in males explained variation in body molt intensity differently for urban and rural populations.

Anthropox - disappearance of poxvirus in house finches during the global coronavirus pandemic (McGraw et al., In Prep)

- Monitored poxvirus symptoms in finches before, during, and now near the end of the COVID-19 pandemic. Birds showed no signs of poxvirus during our sampling periods that overlapped with the COVID19 shutdown (summer 2020-winter 2021)

Climate and Heat

Project MaRTiny: Data analysis and validation of low-cost sensors measuring thermal conditions and space use (Kulkarni et al., In revision)

- Developed a low-cost IoT sensing device that measures atmospheric variables relevant to a person's experienced heat (air temperature, humidity, wind speed, globe temperature, UV) and counts pedestrians in the shade and sun.

- First testing of the device shows good agreement with "gold standard" MaRTy measurements. An in-depth assessment was planned for the summer but delayed due to COVID. It is now planned for end of October 2021.

Air quality monitoring (Vanos et al., In prep)

- We have installed 22 air-quality sensors tracking PM 2.5, PM 10, and NOx in South and West Phoenix to document differences in air quality and explore potential links with environmental (in)justice. We are piloting a web platform to disseminate this data to the public and have conducted three focus groups with teachers, community organizers, and neighbors to test the web platform, which should be fully functional in January 2022.

Parks and Rivers

Wildlife Monitoring Projects (Lewis et al., In progress)

- **Salt River Wildlife Camera Project**: Set up and maintained 43 wildlife cameras across the Salt River. Also collaborating with PhD student, Kate Weiss, who collected coyote scats for diet analyses.
- **Phoenix Valley Wildlife Camera Project:** Maintained 50 wildlife cameras across gradient of urbanization. Advisor for PhD student Jeff Haight working on project. Data include wildlife occupancy across the valley both before and during the pandemic.

Residential Landscapes and Neighborhoods

Linking Community Ecology and Social Science (Andrade et al., 2021)

- We reviewed the literature connecting community ecology and social science theory to introduce a conceptual model explaining novel ecological communities. The published conceptual paper is reported here, and another empirical one is underway.
- Our conceptual model connects multi-scalar drivers of land management to the environmental composition and spatial configuration of the urban landscape mosaic, which in turn influences biodiversity patterns across scales. We integrated key concepts from metacommunity ecology (study of ecological communities in space) and interdisciplinary theory based on environmental social sciences to understand how human activities influence, and are influenced by, local to regional patterns of biodiversity.

Perceptions of Birds and Local Bird Communities (Andrade et al., 2021)

- We developed a set of survey questions for PASS 2017, which we have connected with the 36 bird monitoring points in the PASS neighborhoods. The manuscript is currently in review with a decision of minor revisions. We have subsequent work analyzing the scale in relation to place attachment and attitudes, as well as habitat stewardship in residential yards.
- Attitudes were spatially oriented and were largely influenced by the species traits of birds present in people's yards and neighborhoods. Positive attitudes were relatively steadfast and were concentrated in neighborhoods closer to urban parks and desert preserves. We also found that species with distinctive traits, such as color, song, and regional significance, were more likely to be perceived positively. Species traits that are

common in urban-dwelling birds, such as being large seed-eaters occurring in large abundances, were related to negative perceptions. People's perceptions were influenced by neighborhood attachment and attitudes towards the desert and in part explained people's land management decisions made to support bird biodiversity.

Human-Snake Interactions (Bateman et al., 2021)

- In collaboration with a local business that provides snake removal services, we examined records from over 2000 snake removals in Phoenix metropolitan area, Arizona, United States between 2018 and 2019. We examined removal locations in relation to neighborhood-level socioeconomic attributes from the American Community Survey and individual demographics from a social survey of 494 respondents.
- Removals occurred throughout the year except winter and peaked during summer rainy season. Snakes were frequently removed from neighborhoods with wealthier and more highly educated residents, greater proportion of Latinx residents, and recently constructed homes. Individual perceptions of snakes as problematic were not related to the number of snakes removed.

Urban Trees and Resident Satisfaction (Andrade et al., 2021)

- We analyzed Phoenix Area Social Survey data from 2017 and submitted the manuscript for review. The resulting manuscript has been published in the journal of Urban Forestry and Urban Greening.
- People with neighborhood landscaping associated with the desert are more satisfied with the trees and vegetation. However, this is influenced by structural constraints (income), attitudes (toward the desert and ecological world views), and preferences. Attitudes are more important for those who prefer mesic landscaping, whereas socioeconomic status is a driver for respondents who prefer xeric landscaping. Satisfaction is also related to management intensity.

Scenarios and Futures

Resilience, Equity, Sustainable Qualitative Assessment (Berbés-Blázquez et al., 2021).

- We are conducting a qualitative assessment of 11 scenario visions, five visions at the neighborhood scale (South Phoenix) and six at the CAP regional scale. The analysis assesses each vision against 40+ indicators of resilience, equity, and sustainability.
- Preliminary results suggest that participants at the village scale are most concerned with representation in decision making, while participants at the regional scale are most concerned with building urban ecological infrastructure and associated ecosystem services.

Engaging K-12 Students in Co-designing Urban Futures for the Rio Salado (Bisht et al., In progress) (Berbés-Blázquez et al., In prep)

- CAP-supported graduate students Vanya Bisht and Mandy Kuhn are collaborating with environmental justice teachers and middle school students of the Academia del Pueblo Elementary Charter School in South Phoenix, a school that serves predominantly Latix and low-income children, to co-design sustainable urban futures for the Rio Salado Habitat Restoration Area in downtown Phoenix.

- Students used photovoice, visualizations, and storytelling to document the presence of greenspace in their community and to reimagine sustainable future scenarios.

Water and Fluxes

Future fluvial and pluvial flood risk and the social, ecological, and technological characteristics of flood-prone areas in Phoenix, AZ (Grimm et al., In progress)

- Building upon previous studies that investigated the relationships between SETS domains, and utilizing modeling results from the First Street Foundation's Flood Lab on pluvial and fluvial flooding from 2020-2050, we ask the following two questions: (1) What are the characteristics of vulnerable parcels in Phoenix in terms of their SETS characteristics?; (2) how and where do city practitioners in Phoenix perceive flood-vulnerable areas, and how do these perceptions align with areas that the First Street Foundation's models have determined to be at high risk of flooding in the future? Further, we propose to compare and contrast our answers to these questions in Phoenix with three other US cities: Atlanta, GA, Baltimore, MD, and Portland, OR.

Tres Rios Constructed Treatment Wetland (Childers et al., In progress)

- Bi-monthly sampling of plant biomass and productivity, plant transpiration, whole system water budgets, and water quality. Annual sampling of soil characteristics and whole system nutrient budgets.
- We continue to document how well this wetland ecosystem is performing its "job" of removing nutrients from wastewater effluent before that effluent is discharged into the Salt River and into an adjacent and immediately downstream riparian restoration park that the City of Phoenix hopes to open soon. Notably, the ≈ 10 km of Salt River downstream of the Tres Rios outfall is the only reach in the valley where the Salt is actually a flowing and ecologically functioning river.

KEY OUTCOMES OR OTHER ACHIEVEMENTS

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

- As of November 2021, we have published 26 peer-reviewed journal articles with 10 in review and two in press. In addition, we have published one book and seven book chapters, with two chapters in press and two in review.

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

- We have leveraged $74 million in grant funding during CAP IV, for a total of over $129 million since CAP's inception in 1997.

- Leveraged grants during this reporting period include:
  - Paul Westerhoff is co-PI on an NSF-STC grant ($24 million) for the Science and Technologies for Phosphorus Sustainability (STEPS) Center.
  - Marta Berbes was awarded $50K from the Maricopa County-funded Healthy Urban Environments initiative for her researched entitled, "Making visible the invisible: An

art-based approach to engaging community in air quality monitoring in South Phoenix."
    - Mikhail Chester, Elizabeth Cook, Nancy Grimm, and David Iwaniec were awarded a $539K supplement to their SETS Convergence GCR.

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

- In 2021, students were authors on 15 publications and were first authors on 10 of these.
- Ph.D. degrees were granted to four CAP students in during this reporting period: Peter Crank, Pierce Hutton, Emily Webb, and Mahir Yazar.

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 has undertaken a number of ambitious but much needed initiatives focused on justice, equity, diversity, and inclusion (JEDI) during this reporting year. We actively recruited 13 new researchers to join the CAP Community in early 2021, from ASU and

beyond. These new scientists expanded our expertise (e.g. in urban air quality) or strengthened our existing expertise (e.g. in urban wildlife). Nine of these new members are Black, three are Indigenous, and one is Latino; eight of the 13 are women. Additionally, the CAP JEDI Committee continues to be very active, organizing relevant trainings and seminars and hosting the monthly CAP Equity Circle. They continue to refine the CAP JEDI Social Contract (our JEDI Statement) and the co-leads of our committee (Elizabeth Cook and Quincy Stewart) are very active at the Network level.

- 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 2021, CAP partnered with the Urban Resilience to Extremes Sustainability Research Network SRN (UREx) to continue our Integrated Summer Research Experience for Undergraduates (REU) program that began in 2016. This brought 12 REU students (five funded by CAP) together in bi-monthly seminars to share their research and engage in discussions about interdisciplinary research, career and graduate school planning, and science communication. Due to pandemic restrictions at Arizona State University, these seminars were held virtually. We involved graduate students in these sessions when possible to promote near-peer mentoring, learning, and engagement.

- CAP Student Representatives Marina Lauck and Jeffrey Haight continued to build and develop the CAP LTER Student Group. In Spring 2021, they began the CAP Seminar series, a monthly virtual event where a member of the CAP research community is invited to give a talk on their research. These events are open to the public, and available afterwards on YouTube. They have also organized events with the goal of increasing networking opportunities for ASU students interested in CAP LTER-related work. This group is already planning events for 2022, which will include the continuation of the CAP Seminar series.

- 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, for more than 10 years, 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 a number of 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 (e.g., American Association of Geographers). Other conferences and events where CAP researchers presented their findings in 2021 included the ASU Social Embeddedness Network Conference, the American Meteorological Society Meeting, the Annual Conference of the International Association for Landscape Ecology, and the INTECOL Wetlands Conference. CAP's annual All Scientist Meeting in May 2021 attracted over 100 participants, included 26 poster presenters, and we anticipate similar attendance and participation for our next ASM in January 2022, which will be fully in person.

DISSEMINATION

- In 2021, CAP students and scientists published a total of 26 peer-reviewed journal articles with 10 in review and two 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 Annals of the American Association of Geographers, Journal of Arid Environments, Environmental Science and Technology, Ecosystems, Economic Anthropology, Frontiers in Ecology and the Environment, and Sustainability.

- 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 1764 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 May 2021 CAP All Scientists Meeting, CAP scientists and students have made 34 other conference presentations during this reporting period. Needless to say the pandemic dramatically depressed participation in national and international conferences, even with the virtual option.

- In February of 2021, the CAP student group began hosting a monthly series of virtual seminars that showcase the work of CAP researchers from multiple scholarly fields. Its aim is to disseminate the work of our scientists and increase interest in and knowledge of CAP research across the community. We have had six seminars so far, four of which can be found on our YouTube channel. These include:

    - Enrique Vivoni: Water, Carbon, and Energy Fluxes in an Urban Park in Phoenix.
    - Timothy Ohlert: Ecology of southwest deserts: Past, present, and future
    - Jennifer Vanos: Heat, Air quality, and Human Health: Global Challenges and Local Solutions
    - David Proffitt: A framework for assessing GHG-related potential of community co-produced future development scenarios in metro Phoenix
    - Michelle Hale: "Building Community Indigenous-Style"
    - Charity Nyelele: "Modeling and mapping nature's contribution to humans"

- As part of our NSF virtual site review in October 2020, we created eight virtual field trip videos that allowed our reviewers to experience and 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. We will continue this tradition for our 24th ASM on January 14, 2022. Our office location in Wrigley Hall, on ASU's campus, includes facilities for large and small meetings, most of which have large screens that allow us to connect with our collaborators remotely. In early 2022, the CAP LTER office will move to the newly-built ISTB 7, a state-of-the-art facility located on the ASU Tempe campus.

- During 2020-2021, CAP scientists were included in multiple local and national news items, including:
    - The work of our Climate & Heat IRT was featured across multiple outlets, including: Vox, ABC, National Geographic, NPR, PBS, Phoenix New Times, and Euronews.
    - CAP Education Manager Monique Franco and CAP Scientist Marta Berbes were quoted in a story about their work at Academia del Pueblo, a charter school in South Phoenix.

PLANS FOR 2022

- We will wrap up the last year of CAP IV funding (2018-2022) and research, educational, and outreach activities and begin our transition to CAP V.

- The next CAP All Scientists Meeting and Poster Symposium will be held at ASU Skysong on January 14, 2022.

- The CAP Seminar series will continue into 2022.

- CAP will be hosting the 2022 LTER Science Council Meeting from May 16-18 at Arizona State University's Memorial Union, and will include a field trip to CAP research sites around CAP study area. The meeting theme, quite appropriately, will be "human-environment interactions and human-dominated ecosystems". CAP was originally set to host this meeting in May 2020, then in May 2020, but the pandemic put an end to those plans.

- The next LTER All Scientists Meeting will be held in September 2022 at Asilomar, CA, and will be attended by CAP LTER scientists and staff.

- The CAP JEDI Committee will continue to hold regular meetings and work toward the goals outlined in the Impacts on in Human Resources section. An important contribution of this committee will continue to be the monthly CAP Equity Circle events.

- CAP will continue to be represented on the Network Executive Board by Lead PI Dan Childers.

IMPACTS

Impact on Main Discipline

Early on in CAP, we along with our colleagues from the BES LTER Program 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), and then a further expansion into transdisciplinary and translational research through an ecology ***for*** cities (Childers et al. 2015; others). 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 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, now viewed as a field and not a discipline (sensu McPhearson et al. 2016) 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 this reporting period, CAP has grown to include more than 90 faculty members from 12 different academic units/disciplines at ASU and from nearly a dozen other institutions: University of California-Berkeley, University of California-Irvine, University of Michigan, University of Massachusetts-Amherst, Bowling Green State University, Georgia State University, University of Oklahoma, Barnard College, University of New Mexico, Pace University, and Northern Arizona University. CAP hosts two postdoctoral research associates, 16 graduate student researchers, and seven undergraduate researchers.

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.

Impact on Development of Human Resources

- In 2020, Elizabeth Cook (Barnard College) and Quincy Stewart (CAP Site Manager) co-founded the CAP 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 JEDI Committee's 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 the final year of CAP IV our JEDI Committee will:
    - conduct a 'community climate survey' to learn about and better understand the workplace experiences of the CAP Community.
    - continue to hold regular, monthly community 'Equity Circle' discussions to broaden the conversation about JEDI within CAP.
    - collaboratively finalize a CAP JEDI Action plan, which we will call the CAP JEDI Social Contract. It will include explicit short- and long-term action items, mechanisms, and timeline to ensure CAP continues to actively work towards meeting our JEDI goals, with clear process for evaluation and assessment of success. There will be opportunities for review and feedback from the CAP community, as this contract will be a living document.

- For our summer REU program, we traditionally recruit students from groups underrepresented in STEM. Our 2021 REU students included:

    - Hasti Asrari: "The effects of urbanization on the gut microbiome of an urban arthropod pest: An investigation into the gut of western black widow spiders across a gradient of urbanization." (Mentor: Chad Johnson)

    - Dayanara Avilez, Akilah Davitt, and Janelle Siefert: "Exploring Human-Nature Interactions in the Phoenix Area Social Survey (PASS) Neighborhoods." (Mentors: Jeff Brown and Kelli Larson)

    - Dean Drake: "Does food quality explain urban-rural variation in finch coloration and health?" (Mentor: Kevin McGraw)

  - Olivia Nguyen: "Comparing wildlife occupancy and AZGFD public reporting data across the gradient of urbanization during the Covid-19 pandemic." (Mentor: Jesse Lewis)

  - Brian Sehner: "Quantifying the spatial connectivity of surface urban heat island intensity and thermal refuges in the Phoenix metropolitan area." (Mentors: Amy Frazier & BL Turner II)

- These seven students bring the total number of REU students supported under NSF funding since 1998 to 83. 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 or the academy after completing graduate school.

- CAP LTER, in partnership Urban Resilience to Extreme Events Sustainability Research Network (UREx) held our Integrated Summer REU program for the fifth straight summer. This program brings together a critical mass of students—seven in total for 2021 (five women, two men), —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 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 2022 REU program.

- In 2021, our CAP Grad Grants Program competitively granted $41,000 to support the research of 16 graduate students:

  - Vanya Bisht & Amanda Kuhn: "Engaging K-12 Students in Co-designing Urban Futures for the Rio Salado." (Mentor: Marta Berbes)

  - Kanchana Chandrakanthan: "Spatial and temporal distribution of soil microplastics in warm arid environments." (Mentor: Pierre Herckes)

  - Alexandreana Cocroft: "Assessing the Influence of Income and Ethnicity on Wildlife in Residential Neighborhoods." (Mentor: Sharon Hall)

  - Annika Enloe: "Feeling rattled: Linking attitudes and habitat features to patterns of snake occurrence in urban landscapes." (Mentor: Heather Bateman)

- Elizabeth Fain, Michael Mann, Timothy Ohlert, Mariah Patton, & Purbendra Yogi: "Above and below ground connections under extreme drought in the Sonoran Desert." (Mentors: Scott Collins and Jennifer Rudgers)

- Aaron Mehner: "Summertime Heat Impacts of Solar PV Installation on Urban Park Shading Structures in Edison Eastlake Park, Phoenix, Arizona." (Mentors: David Sailor & Jennifer Vanos)

- Jason Sauer & Arun Pallathadka: "Future fluvial and pluvial flood risk and the social, ecological, and technological characteristics of flood-prone areas in Phoenix, AZ." (Mentors: Nancy Grimm & Heejun Chang)

- Matt Seelig: "Soil Responses to Land Use and Precipitation in the Phoenix Metropolitan." (Mentor: Becky Ball)

- Katherine Weiss: "Assessing the Ecological and Nutritional Drivers of Coyote (*Canis latrans*) Diets Along the Salt River Corridor." (Mentors: Jesse Lewis, Jan Schipper, and Beckett Sterner)

- Mary Wright: "A meta-analysis of social and environmental factors predicting household-level heat-related illness in Phoenix, Arizona." (Mentor: David Hondula)

- The impact of the CAP Grad Grants Program goes beyond funding for research. Previous recipients of Grad 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 km^2 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 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, "A Legacy of Discovery".

- 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:

    - $25.5 during this reporting period, bringing the total to $74 million in grant funding since December 2016 (inception of this grant cycle).
    - A total of $129 million in leveraged funding 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 added 11 new datasets to its publicly available data holdings during the reporting year. These new additions bring the total number of project datasets archived with the Environmental Data Initiative (EDI) to 234. New datasets of note include (1) a long-term (2010-current) record of reptiles and arthropods collected near an Arizona State University satellite campus in Mesa, Arizona that is part of a survey methods course taught by a CAP team leader (H. Bateman), and (2) a dataset of spatial resources that document Urban Ecological Infrastructure (UEI) features in the greater Phoenix metropolitan area and surrounding Sonoran Desert. In addition to the 11 new datasets added, 7 existing datasets featuring CAP long-term monitoring and experiment data were updated with new information and metadata. All CAP dataset metadata are encoded in the XML-based Ecological Metadata Language (EML) schema, with data and metadata available through the CAP data catalog on the project website, the EDI data portal, and DataONE.

Infrastructure

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

- A new virtual machine hosted by Arizona State University to support web-based applications that enable CAP research technicians to enter, upload, and view long-term monitoring data.
- Continued improvement of a suite of R-based tools that aid the development of EML metadata used to describe research data. Though developed by and for the CAP, these tools are generalizable and publicly available.

Network Participation

CAP is committed to making a strong contribution to informatics within the LTER Network and the ecological sciences generally. The CAP Information Manager (S. Earl) participates in all network information meetings and activities, serves as co-chair of the LTER Information Management Executive Committee (IM Exec), participates in and presents at numerous

scientific conferences, and contributes to scientific- and informatics-focused publications. In addition, though past its official end date, S. Earl remains actively involved in the continued workings of an LTER Synthesis Working Group addressing soil organic matter dynamics, and several spin-off projects that include (1) an effort to develop best practices for managing soil-centric data, and (2) an Earth Science Information Partnership (ESIP) working group focused connecting the soils research community and those whose research incorporates soils data to informatics tools for better research.

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 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 2021. 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.

PUBLICATIONS

Students in **Bold**

Journal Articles

Andrade, R., H. L. Bateman, K. L. Larson, C. Herzog and J. A. Brown. 2021. To the rescue -- evaluating the social-ecological patterns for bird intakes. *Urban Ecosystems* DOI: 10.1007/s11252-021-01135-1. (link)

Andrade, R., D. M. Hondula, K. L. Larson and S. B. Lerman. 2021. Landscaping preference influence neighborhood satisfaction and yard management decisions. *Urban Forestry and Urban Greening* 49(Apr):126983. DOI: 10.1016/j.ufug.2021.126983. (link)

Arnold, S., M. Weaver and K. J. McGraw. 2021. Ornamental plumage coloration interacts with habitat urbanization to predict problem-solving in the house finch (***Haemorhous mexicanus***). *Acta Ornithologica* 56(1):29-37. DOI: 10.3161/00016454AO2021.56.1.003. (link)

Basile, A. J., A. E. Mohr, P. Jasbi, H. Gu, P. J. Deviche and K. L. Sweazea. 2021. A four-week high fat diet does not alter plasma glucose or metabolic physiology in wild-caught mourning doves (***Zenaida macroura***). *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* 251(Jan):110820. DOI: 10.1016/j.cbpa.2020.110820. (link)

Basile, A. J., M. W. Renner, L. Kayata, P. J. Deviche and K. L. Sweazea. 2021. A four-week urban diet impairs vasodilation but not nutritional physiology in wild-caught mourning doves (***Zenaida macroura***).. *Physiological and Biochemical Zoology* 94(4):. DOI: 10.1086/714831. (link)

Bateman, H. L., J. A. Brown, K. L. Larson, **R. Andrade** and B. Hughes. 2021. Unwanted residential wildlife: Evaluating social-ecological patterns for snake removals. *Global Ecology and Conservation* 27(Jun):e01601. DOI: 10.1016/j.gecco.2021.e01601. (link)

Bilderback, A. H., A. J. Torres, M. N. Vega and B. A. Ball. 2021. The structural and nutrient chemistry during early-stage decomposition and desiccation of cacti in the Sonoran Desert. *Journal of Arid Environments* 195:104636. DOI: 10.1016/j.jaridenv.2021.104636. (link)

Bois, P., D. L. Childers, M. Walaszek and A. Wanko. 2021. Plant transpiration in constructed treatment wetland: Effects on water budget and management consequences. *Journal of Environmental Management* 295(Oct):113132. DOI: 10.1016/j.jenvman.2021.113132. (link)

Brown, J. A., K. L. Larson, S. B. Lerman, **A. Cocroft** and S. J. Hall. 2021. Resident perceptions of mosquito problems are more influenced by landscape factors than mosquito abundance. *Sustainability* 13(20):11533. DOI: 10.3390/su132011533. (link)

Chang, H., **A. Pallathadka, J. Sauer**, N. Grimm, R. Zimmerman, C. Cheng, D. M. Iwaniec, Y. Kim, R. Lloyd, P. T. McPhearson, B. Rosenzweig, T. Troxler, C. Welty, R. Brenner and P. Herreros-Cantis. 2021. Assessment of urban flood vulnerability using the social-ecological-technological systems framework in six US cities. *Sustainable Cities and Society* 68(May):102786. DOI: 10.1016/j.scs.2021.102786. (link)

Crystal-Ornelas, R., J. A. Brown, R. E. Valentin, C. Beardsley and J. L. Lockwood. 2021. Meta-analysis shows that overabundant deer (Cervidae) populations consistently decrease average population abundance and species richness of forest birds. *Ornithological Applications* 123:1-15. DOI: 10.1093/ornithapp/duab040. (link)

de Albuquerque, F. S., H. L. Bateman, **C. Boehme**, D. C. Allen and L. Cayuela. 2021. Variation in temperature, precipitation, and vegetation greenness drive changes in seasonal variation of avian diversity in an urban desert landscape. *Land* 10(5):480. DOI: 10.3390/land10050480. (link)

de Tranaltes, C. D., J. Dunn, J. M. Martin and J. C. Johnson. 2021. Siblicide in the city: The urban heat island accelerates sibling cannibalism in the black widow spider (***Latrodectus hesperus***). *Urban Ecosystems* DOI: 10.1007/s11252-021-01148-w. (link)

Hoover, F., S. A. Meerow, Z. J. Grabowski and P. T. McPhearson. 2021. Environmental justice implications of siting criteria in urban green infrastructure planning. *Journal of Environmental Policy & Planning* 23(5):665-682. DOI: 10.1080/1523908X.2021.1945916. (link)

Hutton, P., J. McKenna and K. J. McGraw. 2021. Urban links to molt schedule, body condition, and carotenoid-based coloration in the house finch ***Haemorhous mexicanus***. *Journal of Avian Biology* 52(5):. (link)

Iwaniec, D. M., M. N. Gooseff, K. N. Suding, D. S. Johnson, D. C. Reed, D. P. Peters, B. J. Adams, J. E. Barrett, B. T. Bestelmeyer, M. Castorani, E. M. Cook, M. J. Davidson, P. M. Groffman, N. P. Hanan, L. F. Huenneke, P. T. Johnson, D. M. McKnight, R. J. Miller, G. S. Okin, D. L. Preston, A. Rassweiler, C. Ray, O. E. Sala, R. L. Schooley, T. R. Seastedt, M. J. Spasojevic and E. R. Vivoni. 2021. Connectivity; insights from the U.S. Long Term Ecological Research Network. *Ecosphere* 12(5):e03432. DOI: 10.1002/ecs2.3432. (link)

Meerow, S. A., **A. Helmrich**, **R. Andrade** and K. L. Larson. 2021. How do heat and flood risk drive residential green infrastructure implementation in Phoenix, Arizona? *Urban Ecosystems* DOI: 10.1007/s11252-020-01088-x. (link)

Mills, R. and K. J. McGraw. 2021. Cool birds: Facultative use by an introduced species of mechanical air conditioning systems during extremely hot outdoor conditions. *Biology Letters* 17(3):20200813. DOI: 10.1098/rsbl.2020.0813. (link)

Munoz-Erickson, T. A. and A. Robles-Morua. 2021. Beyond bouncing back? Comparing and contesting urban resilience frames in US and Latin American contexts. *Landscape and Urban Planning* 214(Oct):104173. DOI: 10.1016/j.landurbplan.2021.104173. (link)

Patrick, C. J., K. E. McCluney, A. Ruhi, A. Gregory, J. Sabo and J. H. Thorp. 2021. Multi-scale biodiversity drives temporal variability in macrosystems. *Frontiers in Ecology and the Environment* 19(1):47-56. DOI: 10.1002/fee.2297. (link)

Sampson, M., M. Budruk and K. L. Larson. 2021. Exploring symbolic meaning in landscaping choices within a desert city. *Journal of Park and Recreation Administration* (Online First):. DOI: 10.18666/JPRA-2021-10643. (link)

Schaper, L., P. Hutton and K. J. McGraw. 2021. Bird-feeder cleaning lowers disease severity in rural but not urban birds. *Scientific Reports* 11:12835. DOI: 10.1038/s41598-021-92117-y. (link)

Wang, Z., E. R. Vivoni, T. Bohn and Z. Wang. 2021. A multiyear assessment of irrigation cooling capacity in agricultural and urban setting of central Arizona. *Journal of the American Water Resources Association* 57(5):771-788. DOI: 10.1111/1752-1688.12920. (link)

Wheeler, M. M., S. L. Collins, N. B. Grimm, E. M. Cook, C. Clark, R. A. Sponseller and S. J. Hall. 2021. Water and nitrogen shape winter annual plant diversity and community composition in near-urban Sonoran Desert preserves. *Ecological Monographs* DOI: 10.1002/ecm.1450. (link)

Yazar, M., A. M. York and G. Kyriakopoulos. 2021. Heat exposure and the climate change beliefs in a desert city: The case of Phoenix metropolitan area. *Urban Climate* 36(Mar): Art. 100769. DOI: 10.1016/j.uclim.2020.100769. (link)

York, A. M., C. Drummond Otten, S. B. BurnSilver, S. L. Neuberg and J. M. Anderies. 2021. Integrating institutional approaches and decision science to address climate change: A multi-level collective action. *Current Opinion in Sustainability* 62(Oct):19-26. DOI: 10.1016/j.cosust.2021.06.001. (link)

Book Chapters

Berbés-Blázquez, M., N. B. Grimm, E. M. Cook, D. M. Iwaniec, T. A. Munoz-Erickson, V. Hobbins and D. Wahl. 2021. Assessing future resilience, equity, and sustainability in scenario planning. Pp. 113-127 In: Hamstead, Z., D. M. Iwaniec, P. T. McPhearson, M. Berbés-Blázquez, E. M. Cook and T. A. Munoz-Erickson eds., *Resilient Urban Futures*. Springer. ISBN: 978-3-030-63130-7.

Cook, E. M., M. Berbés-Blázquez, L. Mannetti, N. B. Grimm, D. M. Iwaniec and T. A. Munoz-Erickson. 2021. Setting the stage for co-production. Pp. 99-111 In: Hamstead, Z., D. M. Iwaniec, P. T. McPhearson, M. Berbés-Blázquez, E. M. Cook and T. A. Munoz-Erickson eds., *Resilient Urban Futures*. Springer. ISBN: 978-3-030-63130-7.

Hamstead, Z. and **J. Sauer**. 2021. Mapping vulnerability to weather extreme: Heat and flood assessment approaches. Pp. 47-66 In: Hamstead, Z., D. M. Iwaniec, P. T. McPhearson, M. Berbés-Blázquez, E. M. Cook and T. A. Munoz-Erickson eds., *Resilient Urban Futures*. Springer. ISBN: 978-3-030-63130-7.

Iwaniec, D. M., M. Berbés-Blázquez, E. M. Cook, N. B. Grimm, L. Mannetti, P. T. McPhearson, T. A. Munoz-Erickson and E. M. Cook. 2021. Positive futures. Pp. 85-97 In: Hamstead, Z., D. M. Iwaniec, P. T. McPhearson, M. Berbés-Blázquez and T. A. Munoz-Erickson eds., *Resilient Urban Futures*. Springer. ISBN: 978-3-030-63130-7.

Kim, Y., L. Mannetti, D. M. Iwaniec, N. B. Grimm, M. Berbés-Blázquez, S. A. Markolf and E. M. Cook. 2021. Social, ecological, and technological strategies for climate adaptation. Pp. 29-45 In: Hamstead, Z., D. M. Iwaniec, P. T. McPhearson, M. Berbés-Blázquez and T. A. Munoz-Erickson eds., *Resilient Urban Futures*. Springer. ISBN: 978-3-030-63130-7.

McPhearson, P. T., D. M. Iwaniec, Z. Hamstead, M. Berbés-Blázquez, E. M. Cook, T. A. Munoz-Erickson, L. Mannetti and N. B. Grimm. 2021. A vision for resilient orban futures. Pp. 173-186 In: Hamstead, Z., D. M. Iwaniec, P. T. McPhearson, M. Berbés-Blázquez, E. M. Cook and T. A. Munoz-Erickson eds., *Resilient Urban Futures*. Springer. ISBN: 978-3-030-63130-7.

Munoz-Erickson, T. A., K. Selkirk, R. J. Hobbins, C. A. Miller, M. Feagan, D. M. Iwaniec, T. R. Miller and E. M. Cook. 2021. Anticipatory resilience bringing back the futures into urban planning and knowledge systems. Pp. 159-172 In: Hamstead, Z., D. M. Iwaniec, P. T. McPhearson, M. Berbés-Blázquez, E. M. Cook and T. A. Munoz-Erickson eds., *Resilient Urban Futures*. Springer. DOI: 10.1007/978-3-030-63131-4_11. ISBN: 978-3-030-63130-7.

Books

Hamstead, Z., D. M. Iwaniec, P. T. McPhearson, M. Berbés-Blázquez, E. M. Cook and T. A. Munoz-Erickson eds. 2021. *Resilient Urban Futures*. Springer. DOI: 10.1007/978-3-030-63131-4. ISBN: 978-3-030-63130-7.