CAP LTER III 2016 ANNUAL REPORT

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Report to the National Science Foundation

CAP LTER III
2016 Annual Report

REPORT TO THE NATIONAL SCIENCE FOUNDATION

GOALS OF CAP LTER III:

- To advance theory in ecology to incorporate human and societal drivers and responses toward an understanding of the structure and function of the urban socioecological system.
- To continue to provide leadership and demonstrate excellence in urban socioecological research, education, and communication.
- To conduct research, engage stakeholders, and communicate the results of these activities toward building an understanding of how urban sustainability can be achieved.

OBJECTIVES:

- To show how the spatial structure of the urban socioecological system has changed and continues to change, and to understand the implications of these land-cover, human demographic, and urban configurational changes for socioecological system functioning.
- To elucidate interactions among urban and urban-hinterland climate, ecosystems, and social systems.
- To understand how the management of urban water systems in cities affects feedbacks and tradeoffs among water-related ecosystem services and how climate change and its uncertainty affect these tradeoffs.
- To investigate how and why biogeochemical cycles differ from those of undeveloped ecosystems and the consequences of those altered cycles and distribution patterns for human well-being.
- To examine how human activities, behaviors, and willingness to make tradeoffs change biodiversity and its components and how variations in biodiversity feed back to influence these same human perceptions, values, and actions.

KEY RESEARCH ACTIVITIES DURING 2015

Biogeochemical Patterns, Processes, and Human Outcomes

Project: Nitrogen cycling in urban wetlands: influence of vegetation and soil resources (graduate student research)

- Continued analysis of 100 samples for water chemistry
- Conducted a field incubation experiment at two sites in the Salt River Wetlands to compare the rate of nitrate attenuation between our laboratory microcosms and *in-situ* conditions.

Long-term monitoring and experimentation: Ecosystem response to urban atmospheric deposition (CNDep)

- 15 sites: 5 upwind of urban area, 5 downwind of urban area, 5 in urban core, each with 5 plots
- Atmospheric deposition collection (resin collectors)—quarterly
- Plots fertilized with ammonium nitrate and phosphate—winter and spring
- PRS™ probes (Western Ag Innovations Inc., Saskatoon, Canada) deployed and collected for analysis of NO_3^- -N and NH_4^+ -N—winter and spring
- *Larrea tridentata* (creosote) growth measured—spring and fall
- *Larrea tridentata* (creosote) leaves collected for metals analysis—spring and fall
- Per cent composition of annuals recorded for subplot, aboveground material harvested, and aboveground dry mass determined—annually in spring
- Analysis of how N deposition influences the soil microbial community (REU project)

Long-term monitoring: Atmospheric deposition

- Atmospheric deposition buckets collected from two locations (one urban, one desert); desert location discontinued after April 2016
- Dry bucket collected monthly, wet bucket collected after precipitation events

Long-term monitoring: Eddy covariance tower

- One tower located in urban area that includes the following instrumentation: 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 streamed daily; 10 Hz data downloaded monthly and archived.

Long-term monitoring: Tempe Town Lake biogeochemistry

- Water samples taken every two weeks and after rain events.
- Measure: Temperature, conductivity, dissolved oxygen, pH, DOC concentration, and DOC fluorescence
- Finalized ARIMA time-series model to assess effects of external (rain fall, water flow, antecedent conditions) and internal (oxygen saturation state, a proxy for primary

production) drivers on the concentration and composition of dissolved organic carbon in TTL
- Drafted manuscript describing model results and implications for oxygen saturation and organic carbon dynamics in the lake. Submission planned for Fall2016.
- Began sample collection to measure N_2/O_2/Ar saturation states in the lake to assess thermal vs. biological supersaturation of oxygen.

Long-term monitoring: Stormwater quality
- Water collected from Isco stormwater samplers at single location at the outflow of Indian Bend Wash and four locations along the Salt River where stormwater drains create "accidental wetlands"
- Discrete, time weighted sampling of each runoff producing storm
- Water analyzed for organic matter, total nitrogen, total phosphorus, dissolved organic carbon, total dissolved nitrogen, nitrate, ammonium, phosphate, and major cations and anions.

Long-term monitoring: Impact of haboob events (dust storms) on Tempe Town Lake geochemistry
- Development of a haboob classification based on meteorological and air quality measurements.
- Climatological and statistical analysis of Haboobs and dust storms for the Phoenix LTER area for the time period 2005-2014
- Modeling of deposition fluxes from haboobs and evaluation of their contribution to overall dry deposition of material to a location within the CAP LTER network.
- Evaluation of the impact of Haboob dust storms on Tempe town lake chemistry by comparing deposition dataset (developed here) to long term Tempe Town Lake chemistry dataset (Hartnett).

Project: Evaluating water, energy, and carbon fluxes across four distinct land cover types in a desert environment (graduate student research)
- Initiated research using data obtained from the mobile eddy covariance tower deployments and data from a stationary, extendable eddy covariance tower (see below) to obtain energy, water, and carbon fluxes, which are controlled by land surface characteristics, over four distinct land cover types.

Climate, Ecosystems, and People

Project: Impact of interior temperatures of shaded and unshaded vehicles on children's health – A case study in Phoenix, AZ (REU research)
- The summer 2016 REU project focused on children's health and heat in cars that were shaded and unshaded in a parking lot.
- Conducted background research on heat exposure in vehicles.

- Modeled thermal stress using the COMFA (COMfort FormulA) human energy budget model and predict actual thermal sensation (ATS) of 1–4 year old children who are left or forgotten in a car.

Project: Modeling the impact of urban trees on regional hydroclimate (graduate student research)

- Initiated work in spring to incorporate urban trees into regional scale, fully-coupled urban-atmospheric modeling in the Phoenix Active Management Area, using the WRF model.
- Using data from eddy covariance tower (see below) to test and evaluate the model

Long-term monitoring: Eddy covariance tower

- One tower located in urban area that includes the following instrumentation: 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 streamed daily; 10 Hz data downloaded monthly and archived.

Long-term monitoring: Microclimate towers

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

Long-term monitoring: North Desert Village microclimate

- Micro-met stations in four treatment areas
- Measuring irradiance (average and max; horizontal and lateral), wind speed, wind direction, ambient temperature (average, max and min), relative humidity and precipitation.

Long-term monitoring: Earth Networks Weather Station and Greenhouse Gas Analyzer

- System installed on eighth-floor roof of ISTB IV 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 shots to Earth Networks website and local news station
- Picarro greenhouse gas analyzer provides real-time measurements of carbon dioxide and methane

Human Decisions and Biodiversity

Project: Behavioral and physiological adjustments of birds to urbanization (graduate student research)

- Investigate the influence of elevated ambient temperature on the reproductive system.
- Research the physiological mechanisms that mediate rapid effects of stress on the immune system.

Project: The urban phyllosphere in Phoenix (graduate student research)

- Sampled leaves from *Dalbergia sissoo* and *Ulmus parvifolia* in parks and on roadsides from the City of Phoenix's urban forest. Bacterial colonizers of the leaves (i.e., phyllosphere) were extracted.
- 16S rRNA DNA metagenome sequencing and analysis performed to compare bacterial communities.
- Conducted a literature review to understand potential tree/human health implications of phyllosphere communities.

Project: Black widow spiders and the urban heat island: Temperature effects on an urban arthropod pest (REU research)

- REU project has been focused on splitting black widow spider clutches and rearing spiderlings from 30 widow families at urban heat conditions (33^{o}C) and desert conditions (27^{o}C).

Project: Effects of urbanization on a common, native bird species (*Haemorhous mexicanus*) (graduate student and REU research)

- Multiple research initiatives conducted by students and faculty in the McGraw and Deviche labs
- Conducted an experiment with 20 house finches in captivity, which were exposed to differing heat regimes as a means of measuring the effects of heat stress and the urban heat island on birds. Food consumption, body condition, as well as plasma hormones and metabolites were measured.
- For research on impacts of disease and urbanization on house finch coloration, completed analyses and began incorporating gut microbiome data
- Completed analyses on effects of light pollution on urban and rural house finches.
- Initiated research on the impact of bird feeders on the transmission of avian diseases, which included an experiment to understand the relationship between bird feeders and coccidia (parasite) loads.

Long-term monitoring: Arthropods

- 31 sites distributed among mesic yards, xeric yards, commercial properties, agricultural land, desert remnants and open desert
- Ten pitfall traps per site
- Traps are set quarterly and collected 72 hours after setting
- Arthropods stored in ethanol (one jar for each trap) for identification in the lab.
- Worked with the McDowell-Sonoran Conservancy's Field Institute to engage citizen scientists to set pitfall traps across transects in the Conservancy and collect specimens that will be later identified by CAP's research technician.
- Examined change over time in arthropod communities, the associations between arthropods and yard landscaping through pre and post-recession, and people's perceptions of yard maintenance using the PASS 2, PASS 3, Survey 200 2005, and Survey 2000 2010 datasets.
- Developed a causal diagram for Structural Equation Modeling to define the linkages between social demographics, foreclosures, and landscaping on arthropod community parameters in

Phoenix. The purposes of the causal diagram were to: (1) predict how landscaping structure as a result of foreclosures are connected to arthropod community outcomes, and (2) determine how social and landscaping variables during recessions are connected to neighborhood perceptions.
- Performed a multivariate analysis to determine the patterns between the arthropod community in Phoenix and neighborhood characteristics during the recession. (graduate student research)

Long-term monitoring: Core bird monitoring
- 63 sites monitored in winter and spring
- All birds recorded that are seen and heard by a professional bird surveyor within a 15-minute window
- Each location visited independently by three different surveyors during each season
- Work on land-use, climate, food web dynamics and biodiversity patterns using core bird monitoring data. Conducted analyses of data: bird abundance; beta diversity partitioning; functional diversity metrics based on species-specific bird foraging, size, and reproductive traits; bird community structure trajectory changes in land use; bird community weighted mean trait values (REU and faculty project)

Long-term monitoring: PASS neighborhood bird monitoring
- 41 sites monitored in winter and spring
- Locations coincide with Phoenix Area Social Survey (PASS) neighborhoods
- All birds recorded that are seen and heard by a professional bird surveyor within a 15-minute window.
- Each location visited independently by three different surveyors during each season.
- Analyzed PASS bird surveys conducted in conjunction with 2011 PASS to understand relationship between bird species richness in neighborhoods and respondents' satisfaction with bird varieties in the neighborhood.

Long-term monitoring: Salt River biodiversity bird monitoring
- 7 sites monitored quarterly
- Each site monitored at six points
- All birds recorded that are seen and heard by a professional bird surveyor within a 15-minute window

Long-term monitoring: Salt River biodiversity herpetofauna monitoring
- 7 sites monitored three times a year—spring, summer, and fall
- Nine 10 m x 20 m plots per site
- Two surveyors concurrently survey each plot

Water Dynamics in a Desert City

Project: Global ethnohydrology
- Research conducted in five ecologically, culturally, and politically distinct world regions: tropical South America, North America (including Phoenix), Europe, Asia, and Oceania.

- Data collected each summer throughout the globe, with the assistance of global health and anthropology students from ASU. Undergraduate and graduate students collaborate in tool design and in data management and analysis.
- 2015-2016 work focuses on hygiene norms, stigma, and water Insecurity

Long-term monitoring: Tres Rios Constructed Wetlands

- Systems-level research in Tres Rios constructed treatment wetland
- Bi-monthly field visits (January, March…etc.), with several (5-8) trips taken to the site in each field month to collect samples and data.
- 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.
- Conduct monitoring on above- and below-ground primary productivity (biomass), foliar and soil nutrient content, water quality, transpiration, and evaporation.

Project: Residential soil water model evaluation to improve outdoor water use recommendations

- Tested and calibrated model with data from 12 residential yards in Phoenix.
- Continue to identify discrepancies between model output and observed soil moisture to improve ability of model to predict water use and needs.

Long-term monitoring: Stormwater quality

- Water collected from Isco stormwater samplers at single location at the outflow of Indian Bend Wash and four locations along the Salt River where stormwater drains create "accidental wetlands"
- Discrete, time weighted sampling of each runoff producing storm
- Water analyzed for organic matter, total nitrogen, total phosphorus, dissolved organic carbon, total dissolved nitrogen, nitrate, ammonium, phosphate, and major cations and anions.

Long-term monitoring: Regional water quality analysis (taste and odor)

- Water collected monthly at 5 locations at major influent and effluent lake systems and at intakes for drinking water treatment
- Water analyzed in lab for nutrients, major cations/anions, pH, temperature, specific conductance, DOC, taste and odor compounds, and particulate matter.

Project: Urban wetlands, ecosystem services, and homelessness in the Phoenix metropolitan area (graduate student research)

- Modify and pre-test existing water insecurity measurement tools for use with people in the Phoenix environment.
- Conduct semi-structured interviews (including the water insecurity tool) plus ethnographic observation with people living in Phoenix shelters and the Salt River environment.

Project: Denitrification in "accidental" urban wetlands: The relative importance of hydrologic regime and soil resources for shaping patterns of denitrification (graduate student research)

- Conducted spatial sampling of denitrification potentials among different plant patches.
- Conducted push-pull pre-tests to determine rates of denitrification and dissimilarly nitrate reduction to ammonia.

Land Use, Land Cover, and Land Architecture

Long-term monitoring: Parcel scale land-cover change using 1m NAIP classification

- Prepared base NAIP 2010 land classification for WRF (climate) model research in PHX. This involved land cover class transformations to be consistent in categories and spatial resolution with WRF project needs.
- In the process of developing NAIP 2007 data for the Baltimore area (Baltimore LTER data) to be consistent for WRF (climate) model research. Initial inventory undertaken for a central valley California city. This work and that above will permit climate change comparisons for use by the CAP.
- CAP NAIP data used to work with R. Quay and the City of Phoenix Water Department to determine changes in yardscapes and identify the landscape type (e.g., mesic, xeric, oasis, dormant turf, etc.) in order to determine estimates of water use. This work continues on an ad hoc basis.
- Generated parcel-level land-cover data for work with CAP researchers to determine the Impact of Homeowner Association (HOA) landscaping guidelines on residential water use (Wentz et al. 2016 below).
- Creating a machine-learning method for detection, a new data set on "open" land for the CAP area was generated, further reduced to "open" land physically suitable for cultivation. The data and meta-data to be available for CAP in the Fall of 2016 (1 yr publication embargo)
- Working with CAP scientists using NAIP and Landsat TM land cover/land use data for CAP workshop use dealing with adaptive, transformative, and strategic future land scenarios.

Long-term monitoring: Metropolitan region land cover change using Landsat 30 m data.

- Long-term mapping and monitoring: Metropolitan region land cover change using Landsat 30 m data. Standardized land-cover data were generated in five-year increments from 1985 to present. Project completed, meta-data created and made available to CAP in Fall 2016 (1 yr publication embargo).
- Continued working with CAP scientists on use of 1 m and 30m resolution land cover dataset and land system architecture to study the land composition and configuration impact on the land surface temperature at different scale, as well as their impact on the near ground air temperature. *(Li et al. 2016 and Li et. al under revision).*

Survey 200 Long-Term Monitoring

- Unidentified voucher specimens from 2015 survey identified and logged.
- Analysis of 2015 soil samples continued; completion in early 2017
- Identification of 2015 arthropod sweepnet specimens continued; completion in 2017.
- Continued work on soil core data from 2000, 2005, and 2010. Data were cleaned and linked to land use and climate data.
- Began work linking soil dataset to vegetation data.
- Examined change over time in arthropod communities, the associations between arthropods and yard landscaping through pre and post-recession, and people's perceptions of yard maintenance using the PASS 2, PASS 3, Survey 200 2005, and Survey 2000 2010 datasets. (graduate student research)

Phoenix Area Social Survey (PASS) Long-Term Monitoring

- Redesigned 2017 survey to focus in depth on 12 neighborhoods co-located with CAP biophysical monitoring sites and a sample of 1400 residents, approximately 117 per neighborhood. This will allow researchers to more easily engage in neighborhood-level socioecological analyses.
- Redesigned PASS survey instrument to reduce length and improve linkages with long-term biophysical monitoring.
- Engaged in planning for 2017 PASS in order to launch survey in January 2017.
- Aligned PASS bird monitoring sites with 12 neighborhoods.
- Improved metadata for 2001, 2005 and 2011 datasets, which were placed online.
- Refined 2005-2011 joined dataset to improve usability.
- Examined change over time in arthropod communities, the associations between arthropods and yard landscaping through pre and post-recession, and people's perceptions of yard maintenance using the PASS 2, PASS 3, Survey 200 2005, and Survey 2000 2010 datasets. (graduate student research)
- Developed theoretical framework and a series of models based on literature review to determine what social, landscape, and spatial determinants affected Phoenix resident's attitudes towards the desert from the PASS 2 and PASS 3 surveys.
- Preformed a regression analysis to determine what theories and variable groups had the largest impact on attitudes towards the desert.
- Used a cluster then subsequent spatial analysis to determine the positioning of neighborhoods and attitudes towards the desert in relationship to residential and neighborhood features. Determined city-wide spatial patterns and if positive and negative attitudes exhibit spatial correlation patterns.
- Analyzed PASS birds surveys conducted in conjunction with 2011 PASS to understand relationship between bird species richness in neighborhoods and respondents' satisfaction with bird varieties in the neighborhood.

Sustainable Futures

- Analyzed governance documents pertaining to drought, flood, and heat adaptation strategies.
- Developed regional scenarios through participatory workshops with decision makers and experts representing five municipalities, eight non-governmental organizations, two federal agencies, and numerous academic disciplines as well as participants from county and regional governance organizations.
- Engaged REU student (Ramirez) in data visualization for scenarios during summer and fall 2016.
- Held two regional scenarios workshops during the current reporting period:
- Scenario Validation I and Co-Designing Multi-Criteria Assessments (December 2015). Workshop involved participants in: reviewing the scenarios based on design-based vignettes, land-use/land-cover maps, and model outputs and identifying indicators to use in sustainability and resilience multi-criteria assessments of the scenarios.
- Scenario Validation II and Co-Producing Dissemination Products (April 2016). Workshop involved participants in reviewing the main trends, outcomes, and uncertainties of the scenarios and working with data visualization experts to develop the final visualizations of the scenarios that will be used for broader engagement and decision making by community partners.
- Engaged in planning for final scenarios workshop to be held in late fall 2016/early 2017, which will engage a broader audience of stakeholders and decision makers in analyzing and discussing the scenarios.
- (graduate student research) Held a workshop with 26 community stakeholders to explore scenarios for decreasing light pollution in metropolitan Phoenix.

KEY RESEARCH FINDINGS IN 2015

Biogeochemical Patterns, Processes, and Human Outcomes

Project: Nitrogen cycling in urban wetlands: influence of vegetation and soil resources (Handler – Ph.D. dissertation in progress)

- Wetland sediment incubated with nitrate-enriched water demonstrated a high nitrate consumption capacity, which was enhanced in sediment from vegetated patches. Lack of vegetation in the microcosms combined with little changes in the ammonium concentration over the incubation period suggest that denitrification, rather than dissimilatory nitrate reduction to ammonium or plant uptake, was the dominant use of nitrate.

Project: Soil biogeochemical consequences of the replacement of residential grasslands with water-efficient landscapes (Heavenrich and Hall 2016)

- An unintended consequence of the transition from turfgrass to more water efficient landscaping (xeric or desert) is the accumulation of NO_3^--N that may ultimately become lost over time due to the application of water (irrigation or hand watering) or rainfall, which has implications for runoff water quality.

Long-term monitoring: Impact of haboob events (dust storms) on Tempe Town Lake geochemistry (Eager et al. in review; Eager 2016 Ph.D. dissertation)

- Over a 10-year period the mean annual haboob frequency is 9.6 dust storm events in Tempe, AZ.
- Haboob visibility, wind speed, PM10 differ from other dust, background conditions.
- Haboobs contribute 74% of Total suspended particle (TSP) annual dry deposition but only 5% of PM10 flux.
- Haboobs deposit an estimated mean annual 950 kg ha^{-1}.
- Haboobs have only minor impacts on Tempe Town Lake water chemistry, especially when compared to natural processes as well as natural and engineered flow control events.

Long-term monitoring: Tempe Town Lake biogeochemistry (Hartnett et al. in prep; Palta et al. in prep; Bone 2016 – honors thesis)

- Carbon concentration and composition vary seasonally and respond to both meteorological events and anthropogenic activity.
- Oxygen supersaturation is generally high and is a reasonable proxy for primary production; DOC concentration is primarily function of oxygen saturation state.
- Protein-like (microbially derived) material is highest during long dry periods when algal production is high; humic-like (terrestrially derived) material is highest when rain and runoff carry terrestrial material to the lake.
- Large events are difficult to account for in the ARIMA model because it looks at patterns in residuals of the seasonally detrended data.

Climate, Ecosystems, and People

Project: Land architecture and the urban heat island (Li et al. 2016; results also reported under Land Use, Land Cover IPA)

- Both composition and configuration (land system architecture) of land cover in the CAP area affect land surface temperature.
- Contrary to other studies, configuration trumped composition in its effect.
- This finding may result from the use of the normalized momentum of inertia (NMI) as the metric of composition.
- Land architecture with the addition of other variables explains a significant amount of parcel-level land surface temperature.

Project: Measuring individually experienced temperatures in Phoenix, AZ

-Findings from Vanos et al. 2016

- While scientific understanding of surface temperatures in cities has relied upon remotely sensed data, these measurements are inadequate for assessing heat risks to individuals from surfaces exposed to direct sunlight, such as playground equipment.
- Touch-scale (1-cm resolution) data are the most accurate means of understanding user experiences and risks associated with highly heated playground equipment.
- The study recommends that touch-scale data be incorporated into urban landscape design decisions and that well-placed shade structures and trees be used to shade playgrounds.

-Preliminary findings from summer 2016 REU research

- A car parked in the shade versus in the sun resulted in reduced overall frequency (50%) of a child reaching a critical 'extreme danger' heat threshold, as modeled by the COMFA energy budget (or heat balance model) based on limits set by OSHA guidelines.
- The greatest determinant of increased dangerous energy budget levels in the modeled child resulted from enhanced absorption of short and longwave radiation, which are a function of incoming solar radiation entering through the window and heightened surface and air temperatures within the car that are inescapable.
- Cooling cycles implemented (via air conditioning) within the sun significantly reduced the experienced energy budget.

Project: Extreme heat and human health (Petitti et al. 2016)

- While extreme heat warnings are triggered by reaching a heat threshold associated with an increased risk of mortality across all causes, the temperatures statistically associated with heat-related health events (morbidity and mortality consequences of heat and dehydration) were consistently lower than those associated with all-cause mortality.
- Public agencies issuing heat warnings and providing heat interventions (i.e., cooling stations) should move beyond focusing on one temperature trigger point to recognizing that there are in fact multiple temperature trigger points associated with health events.

Human Decisions and Biodiversity

Long-term monitoring: Arthropods (Andrade – PhD dissertation in progress)

- Arthropod abundance and diversity decreased between 2005 and 2010, including all foraging guilds (herbivores, carnivores, omnivores, detritivores, fungivores, and parasites).
- Arthropod abundance and richness are negatively related to grassy, homogeneous lawns, and positively related to plant species richness. Dominance of a few specific arthropod species was positively related to grass.
- Arthropod abundance and herbivore abundance are positively related to weedy plant species in residential landscapes.
- Foreclosures were associated with more mesic neighborhoods and neighborhoods with higher amounts of grassiness. Foreclosures were positively associated with weediness and negatively associated with plant species richness.
- Residents in neighborhoods with more foreclosures and grassy yards had more negative views of neighborhood landscaping.
- Vegetation richness, weediness, and social variables (residents with bachelor's degree, income) were correlated with the variation in the arthropod community over the two time periods 2005-2010.
- Weediness, grassiness, and foreclosures were correlated with the variation in the arthropod community in 2010.

Project: The urban phyllosphere in Phoenix (MacNeille 2016 – MS thesis)

- Parks and roadsides harbor unique subsets of phyllosphere bacteria; beneficial bacteria (to plant health and growth as well as atmospheric pollution remediation potential) found on park trees are absent from roadside trees. Road trees harbor a small subset of bacteria that are associated with polluted areas.
- Each park tree species harbors a unique subset of phyllospheric bacteria that are not found in roadside trees.

Project: Effects of urbanization on a common, native bird species (*Haemorhous mexicanus* – house finch) (Hutton – Ph.D. in progress, and REU research)

- Preliminary results from research on light pollution and urban finches suggest that light pollution inhibits corticosteroid production in rural, but not urban birds. Urban finches are more resilient to the effects of light pollution on disease progression relative to rural finches and appear to sleep much better when exposed to light at night than their rural counterparts (Hutton et al. in prep.)
- Work on allometric patterns in house finches found that allometric scaling patterns and the size of morphological characters vary depending on the habitat and sex of house finches (Hutton and McGraw in press).
- Summer REU experiments on *Coccidia* infections and bird feeders found a relationship between *Coccidia* levels and body mass loss among birds, but no relationship between the number of feeders a house finch visits and the level of *Coccidia* infection (Allred REU project).

- An overview of literature on the impacts of urbanization on oxidative balance and animal signals (e.g., songs, coloration, and odorants) revealed that while there is evidence that urbanization has a strong negative effect on signal quality and oxidative balance across animal taxa (including birds), there are few studies that focus on signals and oxidative balance in tandem and fewer that include elements addressing fitness, underlining the need for research that addresses these relationships (Hutton and McGraw 2016).

Long-term monitoring: Core bird monitoring (Allen et al. in prep)

- Preliminary results from work in progress on land use, climate, food-web dynamics, and biodiversity patterns, based on comparison of land-use types by season and over time.
- Interactions between land use (agriculture, desert, or urban) and time of survey affected bird abundance, richness, and evenness; i.e., differences in means between agricultural, urban, and desert sites were not consistent over time. Some significant land use x time of survey effects were found: a) for abundance, urban and agriculture effects (relative to desert) were larger in winter than in summer, and were larger when there was a drought in the prior year; b) for species richness, effects of agriculture were largest in winter, and were larger when there was a drought in the prior year; c) for species richness, urban effects have increased over time and also were stronger in winter.
- Bird community structure shows continuouschange in all land uses; but these changes are largest in desert and weakest in urban land uses. Change in desert sites is non-directional (not favoring any taxa in particular), but changes in agricultural and urban land uses are directional. Analyses of changes in community-weighted trait values suggest that this movement is towards migrating waterfowl (i.e., bird communities in agriculture/urban land uses are become more dominated by migrating water fowl over time).

Project: Behavioral and physiological adjustments of birds to urbanization (Davies et al. 2016a &b)

- Stress exerts rapid inhibitory effects on specific components of the immune system. These effects appear to partly result from direct actions of stress hormones, in particular, corticosterone.
- No support was found for the hypothesis that greater food abundance in urban areas drives earlier vernal gonad growth in urban Abert's towhees. Instead, the research suggests that the consistency and predictability of food availability in urban areas, which is decoupled from precipitation variability due to irrigation, may drive this earlier gonad growth.

Project: Black widow spiders and the urban heat island: Temperature effects on an urban arthropod pest (REU research)

- Spiders raised under the hot, urban conditions (33^{o}C) appear to have their development slowed to a halt. Development speed to the 3rd molt is significantly slowed under hot conditions compared to development speed of spiders reared under the desert-simulated heat (27^{o}C).
- Mortality among spiders in hot urban conditions was 20% compared to 5% for those under the desert conditions.
- Spiderling mass at day 105 was significantly lower for those raised in hot conditions.

- Most male spiderlings reared in hot conditions fail to complete the adult molt. Those in the experiment that did molt died within a few days.
- Associated research is investigating ecdysone (hormone responsible for growth and molting) in spiders and has found that these levels are high in spiders reared in hot conditions, leading to further questions about what is preventing males from completing the adult molt.

Long-term monitoring: Core bird monitoring analysis of riparian sites (Banville et al. in press)

- Bird abundance and diversity in Phoenix riparian areas have decreased over the past decade.
- Proportion of urban invader species has increased in the riparian bird community. Engineered sites support more broadly distributed generalists.
- Specialists are associated with dense, tall vegetation and less impervious surface, i.e., characteristics of 'natural' (non-engineered) sites.
- Riparian areas with perennial flows attract greatest abundance and species of birds.
- Long-term data analysis reveals that bird communities are changing more in natural settings than at engineered sites, which may reflect the impacts of urban expansion near these areas.

Water Dynamics in a Desert City

Project: Urban wetlands, ecosystem services, and homelessness in the Phoenix metropolitan area (Palta et al. 2016)

- "Accidental" wetlands created from stormwater drainage outfalls provide ecosystem services and disservices to persons experiencing homelessness.
- Provisioning services include water for bathing, clothes washing, toothbrushing, and drinking. *E.coli* counts from study sites indicate the danger in using water for drinking and toothbrushing at any time and water for bathing during the summer monsoon season, although the water at some sites may be safe for bathing and wading during the pre-monsoon period.
- The cooling provided by both the water in the wetlands and associated vegetation emerged as an important regulating service for homeless persons inhabiting or visiting the wetlands. The wetlands also provide privacy, and some interview respondents mentioned an appreciation of natural beauty.
- At the same time, occupancy of the wetlands is an illegal activity, and persons atthese sites risk harassment from various authorities and possibly arrest. The study underlines the need to consider social vulnerability when assessing ecosystem services and disservices.

Project: Denitrification in "accidental" urban wetlands: The relative importance of hydrologic regime and soil resources for shaping patterns of denitrification (Suchy Ph.D. 2016)

- Plant patch edges have higher potential denitrification than patch centers.
- The research demonstrates that "accidental" wetlands have high potential to attenuate reactive nitrogen.

Long-term monitoring: Regional water quality analysis (taste and odor)

- Length of thermal stratification in reservoir waters is increasing, leading to increases in carbon releases during turnover.
- Drought conditions will increase salinity in drinking water sources.

Project: Homeowner Association landscaping and water use

- See findings below under Land Use, Land Cover, and Land Architecture.

Land Use, Land Cover, and Land Architecture

Long-term monitoring: Parcel scale land-cover change using 1-m NAIP classification

–Findings from Wentz et al. 2016

- HOAs parcels have less vegetation and use less peak-season water than non-HOA parcels.
- This relationship holds despite HOA rules covering only "minimal" vegetation requirements.
- Back yard vegetation of HOA parcels mimics front yard vegetation, although the HOA rules apply only to front yards.
- Peak-season water could be lowered at least 24% if HOA-[ercemtenforced rules dealt with the maximum vegetation allowed.

–Findings from Li et al. 2016

- Both composition and configuration (land system architecture) of land cover in the CAP area affect land surface temperature.
- Contrary to other studies, configuration trumped composition in its effect.
- This finding may result from the use of the normalized momentum of inertia (NMI) as the metric of composition.
- Land architecture with the addition of other variables explains a significant amount of parcel-level land surface temperature.

-Findings from Li et al. in review

- Using linear mixed models, 1-m resolution land-cover data, and FRAGSTAT configuration metrics for residential parcels in the CAP, this study indicates that land cover composition has the largest daytime and nighttime impact on land surface temperature.
- The compactness and concentration of land covers, however, also affects land surface temperature with varying associations for daytime and nighttime results.
- Land system architecture provides more robust associations with land surface temperature than any other category of variables (i.e., cadastral, economic, social).

Survey 200 Long-Term Monitoring

-Soil analysis across 2000, 2005, and 2010 datasets

- Many soil properties are influenced by land use: Compared to urban and agricultural soils, desert soils are sandier and denser, with lower inputs of nutrients, carbon, and water and a lower pH.

- Several soil properties have changed over time across urban, agricultural, and desert sites: texture, NH_4^+ -N, total %N, PO_4 -P, pH, organic matter, and bulk density. Change was greatest for the urban and agricultural sites.
- Future work will link changes to drivers.

-Findings from Jenerette et al. in press.

- Research on urban tree biodiversity across multiple cities found that urban tree community richness, origins, and aesthetics (showy flowers or fruits) were correlated with minimum winter temperature.
- These findings confirmed the hypothesis that low winter temperatures restrict urban tree biodiversity while warmer winter temperatures and irrigation allow homeowners and landscapers to choose from a wide, global range of tree species, selecting species for specific ecosystem services (such as flowers or fruit), and thus increasing urban tree biodiversity.
- The findings provide an explanation for why some urban ecologists have found urbanization to decrease plant diversity while others have shown urbanization to increase it.

-See other findings for vegetation under Long-term arthropod monitoring (Andrade dissertation in progress)

Phoenix Area Social Survey Long-Term Monitoring

(Andrade - PhD dissertation in progress)

- There is a positive relationship between bird species richness and PASS survey respondent satisfaction with bird varieties in their neighborhoods, but this relationship is weaker for the 2011 PASS survey than for the 2006 PASS survey, as reported in Lerman and Warren 2011. We continue to investigate the reasons for this weaker relationship and will use the 2017 PASS and associated bird surveys to further flesh out this picture.
- Based on our literature review, we developed three sets of theoretical models of people's environmental attitudes and preferences: (1) Socialization- landscape preferences and exposure, Phoenix residency, (2) Vulnerability- Hispanic ethnicity, education, heat exposure, ecological worldviews, and (3) Distance- distance and access to desert parks
- The vulnerability model performed best for both residential and neighborhood scales. For individuals, socialization came into play when considering the interaction of vulnerability factors. Heat variables slightly outperformed ecological worldview at the neighborhood scale, but ecological worldview was more important for an individual respondent.
- Vulnerability holds as the most important theory underpinning attitudes towards the desert in Phoenix; adding a vulnerability aspect to socialization models improves the importance of socialization (moving socialization above distance theory models). At the individual level, socialization is more important than ecological worldviews; this rank is reversed at the neighborhood level.

- See other findings under Long-term arthropod monitoring (Andrade dissertation in progress)

Sustainable Futures

- Workshops with stakeholders, decision makers, and experts led to the development and refinement of six future scenarios for the greater Phoenix area:
    - Adaptive Flood scenario: Focuses on a multi-scalar network of floodplains, parks, and transportation systems.
    - Adaptive Drought scenario: Focuses on long-term water security, conservation, and water banking.
    - Adaptive Heat scenario: Focuses on addressing the issue of inequities in exposure to excessive heat through altering current patterns of green and grey infrastructure.
    - Transformative 3 hubs scenario: Re-envisions urban form and density as well as food and energy systems.
    - Transformative Emerald City scenario: Focuses on balancing targets for dealing with vulnerability to flood, drought, and excessive heat.
    - Transformative Almost Zero Waste scenario: Focuses on reducing water, material, and energy waste.
- An additional "strategic" scenario developed by content analysis of government planning documents and other forward-looking documents for the region provided a 'business as usual' case.
- Using modeled data, scenario leaders and participants identified conflicts and trade-offs associated with each scenario and discussed the conflicts between scenarios. More formal and final assessments of each scenario are forthcoming.

KEY OUTCOMES OR OTHER ACHIEVEMENTS

- CAP is a leader in urban socioecological research:
  - CAP students and scientists have published 230 journal articles, 2 books, and 36 book chapters since 2011.
  - In 2015, CAP students and scientists published a total of 53 peer-reviewed journal articles and one book chapter. Thus far in 2016, we have published 26 peer-reviewed journal articles with 23 in review and 9 in press.
- Faculty collaboration leads to additional grant funding for socioecological research:
  - We have leveraged over $38 million in grant funding since 2011 (inception of this grant cycle) for a total of over $83 million since CAP's inception in 1997. (nb: This report focuses on the activities and results from CAP's NSF funding, not the leveraged grants.)
  - Leveraged grants include two $12 million NSF Sustainability Research Network grants: "Urban resilience to extreme weather related events," based at ASU with CAP co-PI Redman as PI and "Urban water innovation network," based at Colorado State University with CAP scientist Georgescu as PI for the ASU sub-contract. Both involve multiple CAP scientists and will build from past, current, and future work done by CAP.
- Graduate students contribute to knowledge on urban socioecological systems:
  - Since 2011, students have been authors on 142 publications and have been first authors on 102 of these. Relative to the total CAP publications of the same period in time, students were authors on over half of all publications (53%).
  - Ph.D. degrees were granted to six CAP graduate students in 2016.
- 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, the Sustainable Cities Network, and the McDowell-Sonoran Conservancy's Field Institute where 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 (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.

TRAINING AND PROFESSIONAL DEVELOPMENT

CAP's activities in the area of training and professional development are three-fold: We actively promote and encourage training and professional development for faculty, staff, and students; we work with the Global Institute of Sustainability, the LTER Network Communication Office, and others to design and deliver training and professional development activities that our CAP community can access; and we design and deliver training and professional development for various external stakeholder groups, including teachers. We detail some of these activities under Impact on Human Resources.

We have encouraged staff to identify training and professional development opportunities that are relevant to their roles and responsibilities in the CAP program. CAP site manager, Sally Wittlinger, has participated in the Leadership in the New American University (LINAU) program at ASU, which is designed to help current and aspiring leaders to better understand and effectively integrate the goals of the New American University while also fulfilling the core expectations of management. CAP project manager, Marcia Nation, participated in ASU's Leadership Academy, another leadership program that emphasizes team building. CAP's information manager, Stevan Earl, has attended professional development workshops on data and information management. With the purchase of a new trace gas analyzer for the Goldwater Environmental Laboratories, CAP research technician Marisa Masles traveled to the instrument's manufacturing center to learn how to effectively use this new piece of equipment. Lisa Herrmann, CAP's education coordinator, attended the North American Association for Environmental Education's 2016 conference and participated in professional development activities while there. Other staff members have attended sessions held by ASU on a variety of topics from how to use specialized software packages to effective communication strategies.

During summer 2016, CAP partnered with the Urban Resilience to Extremes (UREx) Sustainability Research Network to create the Summer Research Experience for Undergraduates (REU) program. This brought 16 undergraduate research students (seven 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. We involved graduate students in these sessions when possible to promote peer-to-peer learning and engagement.

CAP post-doctoral researchers, David Iwaniec and Monica Palta, have been participating in CAP activities while being mentored by associated faculty members (Grimm, Hartnett) in accordance with the post-doctoral mentoring plan. Mentoring activities during this reporting period included: Serving as a panelist for CAP graduate grants, participating in several

seminars and workshops hosted by the Global Institute of Sustainability, supervising staff and graduate students involved in the future scenarios work (Iwaniec), and working with graduate and undergraduate students in the field and lab (Palta). Both have attended several conferences and professional development workshops and have had opportunities to job application materials and practice conference talks and job interview talks.

CAP is highly integrated into Childers's Wetland Ecosystem Ecology Lab (WEEL), which spearheads our research in the Tres Rios Constructed Wetlands. The City of Phoenix built these wetlands as an alternative to traditional wastewater treatment, and now, Tres Rios has become a living laboratory for high school, undergraduate, and graduate students who seek to understand how the constructed wetlands treat wastewater in an arid environment by investigating the function of wetland plants and soils as well as nutrient and water budgets. This year, WEEL has hosting a research scientist from the Chinese Academy of Sciences, Dr. Yufen Ren, who has been working with CAP to learn urban ecology field and lab techniques.

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 research presenters to attend the Ecological Society of America's conference and the American Geophysical Union's annual meeting, as well as other research meetings and events. This year, four CAP faculty members (one funded by the LTER NCO and the others by CAP) traveled to South Africa for the International LTER meeting. Other conferences that included presentations on CAP research include the INTECOL International Wetlands Conference in China and the International Society for Behavioral Ecology in Britain. CAP's annual symposium in January 2016 attracted over 120 participants, including 39 poster presenters.

CAP's Ecology Explorers program was involved in delivering three training workshops for teachers during 2016: A soil ecology workshop, a water workshop in conjunction with Arizona Project WET, and a sustainability workshop in conjunction with the Walton Teacher's Academy. More information on professional development and Ecology Explorers' initiatives can be found under Impact on Human Resources.

DISSEMINATION

CAP students and scientists have published 230 journal articles, 2 books, and 36 book chapters since 2011. In 2015, CAP students and scientists published a total of 53 peer-reviewed journal articles and one book chapter. Thus far in 2016, we have published 26 peer-reviewed journal articles with 23 in review and 9 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 *BioScience*, *Landscape Ecology*, *Environmental Research Letters*, *Urban Ecosystems, Society and Natural Resources, Journal of the American Water Works Association, Landscape and Urban Planning, Environmental Health Perspectives, Nature Climate Change*, and *Frontiers in Ecology and the Environment*.

We have been working with the GIOS Communications team and ASU media relations to get more stories about our research into local and national media through press releases, stories posted on the ASU website, and hyperlinks to these stories on social media. We also encourage faculty to work with their own units to promote their research. Recent examples include:

- CAP research technician Hannah Heavenrich discussed the unintended consequence of lawn conversion to xeriscape: high levels of nitrate. ASU Now, October 28, 2016.
- As part of a Halloween feature, CAP scientist Chad Johnson explained some recent findings from his lab's study of black widow spiders in the city, including the adaptation of this urban pest to heat in the city. ASU Now, October 28, 2016.
- CAP Director Nancy Grimm and CAP scientist Enrique Vivoni contributed their thoughts about the future of water in the West and water strategies. ASU Now, October 4 and October 5, 2016.
- Research on water use in residential communities by CAP scientists Libby Wentz, Billie Turner, and Xiaoxiao Li found that homes in areas belonging to Homeowners Associations (HOAs) used less water than those not in HOAs ASU Now, June 5, 2016.

CAP joined the social media world in 2010 with its Twitter account @CAPLTER, which focuses on promoting urban socioecological research and practice. We currently have posted a total of 1369 Tweets and have 911 followers, of whom the majority are scientists, scientific organizations and programs, and 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 39 poster presentations at the January 2016 CAP All Scientists Meeting, CAP scientists and students have made around 50 other presentations during this reporting period.

We launched our new website in spring 2016. It has a richer set of information on several of our long-term monitoring initiatives with a webpage devoted to each project including a detailed description of the project and its activities, links to protocols and data, and a list of publications. We also improved the layout and navigation of the site to accommodate smart phone users and expanded the Education section to include more detailed information on opportunities for students. Changes behind the scenes enhance the search engine optimization of the website.

We also launched a new Ecology Explorers website at the same time which features a new navigation system to make it easier for teachers and students to find material on the site. Our design of the Education tab on the CAP website makes the movement from one site to another seamless.

Starting with CAP3, we have held our annual All Scientists Meeting off campus at ASU's SkySong facility in Scottsdale, which has allowed us to attract more community partners to this all-day event. Our office location in Wrigley Hall is easily assessable to visitors traveling to campus either by car, light rail, bus, or bicycle. Wrigley Hall includes facilities for large and small meetings, most of which have large screens that allow us to connect with our collaborators remotely.

PLANS FOR 2016

CAP director Nancy Grimm will step down after 19 years of leadership, and long-time LTER researcher and former FCE director Dan Childers will assume the directorship of CAP.

Details of our CAPIV research plan are in our proposal and work has already begun on implementing new initiatives and any changes to ongoing work. We intend to engage participants in the January 2017 CAP All Scientists Meeting in activities to orient our CAP community to the new conceptual framework.

The CAPIV proposal details a number of changes to our long-term monitoring program, including those to more closely tie our monitoring sites together spatially, which will enable us to ecologically characterize neighborhoods and other sites of ecological interest, such as the Salt River and mountain parks. While our monitoring schemes will retain some urban-desert gradient features, we feel that we have answered many of the questions that we had on ecologies across such gradients. For example, we will eliminate our bird monitoring sites in agricultural and commercial areas while retaining the core residential and Salt River sites and adding sites to the PASS neighborhoods and mountain parks. We will continue to work with our scientists and staff to design and implement changes to our long-term monitoring sites.

We are adding an ISCO autosampler higher up in the Indian Bend Wash watershed to allow us to spatially expand our work on urban stormwater. We also intend to deploy a sensor on a buoy in Tempe Town Lake to collect data on DOC, pH, temperature, conductivity, and dissolved O2.

For our REU program in summer 2017, we will recruit one SEEDS SPUR fellow and up to two more REU students from groups underrepresented in STEM. After our successful pilot in summer 2016, we will be continuing to collaborate with the UREx SRN on a summer REU program with more seminars and activities planned. We have reached out to the School of Life Sciences at ASU, which has a similar program for summer undergraduate researchers (the SOLUR program) and will be planning some activities jointly.

We are in the process of adding more webpages to the long-term monitoring section of our website.

In spring 2017, we will conduct the third Phoenix Area Social Survey of neighborhoods in the greater Phoenix area and preliminary data will become available in late spring/early summer.

We are continuing a review of our online data and metadata and making necessary changes to enable users to download and use these data more effectively. We will be working closely with Ecology Explorers to create special datasets from our long-term data that can be easily used in classroom and outreach settings.

We will continue pursuing collaborative research opportunities with the Decision Center for a Desert City (DCDC) in the areas of governance, green infrastructure, the urban heat island, and landscape design for ecosystem services. The PI of DCDC, Dave White, and two of the co-PIs, Amber Wutich and Kelli Larson, are on the new CAP leadership team, which will enhance our collaboration.

In addition, we will continue our work with the Sustainability Research Network based at ASU, UREx SRN, which has outgoing CAP director Nancy Grimm as a co-director with CAP's former co-director Chuck Redman.

Our future scenarios work will continue, with a capstone workshop for phase 1 planned for January 2017.

We will be continuing our efforts to communicate science from our research in mountain parks in collaboration with our partners the McDowell Sonoran Conservancy's Field Institute and the Central Arizona Conservation Alliance (see below). We will be working with the Field Institute on how to expand our citizen science activities beyond arthropod monitoring on Conservancy land to other monitoring activities and to transfer this successful citizen science model to other mountain parks.

The Ecology Explorers program will hold a teacher workshop in summer 2017 on a CAP research topic to be determined. Ecology Explorers is leveraging its collaborations with other environmental education programs in the Global Institute of Sustainability and in other ASU units to expand its reach. In addition, it will continue to work with non-profits and programs across the Phoenix area, including the South Mountain Environmental Education Center, the McDowell-Sonoran Conservancy's Field Institute, the Central Arizona Conservation Alliance, and the Desert Discovery Center.

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 systems-oriented approach of understanding the ecology of the city (Grimm et al. 2000). CAP continues to have a large impact on the theory and practice of urban ecology as evidenced by our publication record. The CAP program has published 518 journal articles, 10 books, and 102 book chapters since 1998. 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) copiously cite CAP publications, 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 science is very frequently cited in publications dealing with urban ecology and highly cited in the broad socioecological field. A review of the Web of Science's "Highly Cited Papers" (papers that received enough citations to place them in the top 1% of the academic field based on a highly cited threshold for the field and publication year) found that seven CAP peer-reviewed articles published during this grant cycle were listed as "Highly Cited Papers" in the fields of Ecology and Environmental Studies (Fan et al. 2014; Groffman et al. 2014; Jenerette et al. 2016; Middel et al. 2014; Westerhoff et al. 2015; Wu 2014; and Wu 2013). A rapid review of CAP paper citations on the Web of Science found that at least 10 papers have been cited more than 100 times; Grimm et al. 2008 has been cited 1,070 times.

Our other major contributions to date are:

- A general insight from our research on infrastructure is that designed and built components dominate urban ecosystems, yet the functions and services they produce are not always as intended. For example, we found that urban areas can and do provide habitat for wildlife (Banville and Bateman 2012), that stormwater infrastructure design determines water and nutrient retention and transport (Hale et al. 2014, 2015) and can provide unintended services such as denitrification (Roach and Grimm 2011), that unplanned or "accidental" urban riparian wetlands are more faunally diverse than planned ones (Bateman et al. 2015; Palta et al. 2016), and that designed systems such as

treatment wetlands perform better in this arid city than expected (Sanchez et al. in press).

- Another key insight that crosses our research themes is that differences between urban and desert habitats are both structural and functional, and not always as predicted. Birds are not food-limited in the city yet experience much greater interspecific competition relative to desert habitats (Shochat et al. 2010; Lerman et al. 2012). The UHI accelerates phenology in both plants and animals (Buyantuyev and Wu 2012; Davies and Deviche 2014), and we have found other physiological differences related to urban environment stresses (Deviche et al. 2011; Giraudeau and McGraw 2014). Finally, community and ecosystem processes in urban desert parks are different from those of native desert, even though these two environments outwardly appear similar (Hall et al. 2009; Hall et al. 2011).
- Our integrated social-ecological research has shown that, in arid cities, climate, vegetation, social equality, and biodiversity are linked. We continue to document relationships between neighborhood income and biodiversity that are driven by vegetation differences (Faeth et al. 2011; Lerman and Warren 2011; Ackley et al. 2015). These same vegetation differences explain variation in heat exposure. More research on causes and impacts of the UHI has been done in Phoenix than any other city (Chow et al. 2012); our research on extreme heat is significant given the likelihood that heat-related mortality will increase under most climate-change scenarios (Hondula et al. 2015). Jenerette et al. 2016 – a recent excellent example of fully interdisciplinary research – analyzed remotely sensed temperature and land cover at parcel and neighborhood scales and included PASS data to show spatial disparities in human-health impacts and environmental perceptions. We also have uncovered relationships among urban vegetation, outdoor water use for irrigation, spatial variation in the UHI, personal incomes and property values, and disproportionate vulnerability to extreme heat (Ruddell et al. 2013; Harlan et al. 2014). These disparities may be mitigated with vegetation choices that modify microclimate (Chow et al. 2011; Chow and Brazel 2012; Declet-Barreto et al. 2013; Fan et al. 2015), but with the tradeoff of increased water use (Jenerette et al. 2011; Jia et al. 2015).

Impact on Other Disciplines

While CAP remains a fundamentally ecological research program, we also have contributed to shaping urban ecology as a collaborative discipline that includes perspectives, theories, and research from across the natural, physical, social, and engineering sciences to investigate the complexity of processes in urban areas (as illustrated by the contents of the edited urban

ecology volumes cited above). During the 2015-2016 reporting period, we had 34 faculty members, 4 post-doctoral researchers (two paid under CAP), 20 graduate student researchers, and 7 undergraduate researchers actively engaged in CAP research from 12 different academic units/disciplines.

As such, CAP's contributions outside of urban socioecological research are often at the interface between disciplines. Examples include:

- The dataset on haboob (dust storm) occurrence and biogeochemistry contributes to meteorology, atmospheric sciences, and geological sciences.
- Research on the behavioral and physiological impacts on birds from urbanization contributes to work in ecology, physiology, animal behavior, immunology, and neuroendocrinology because the questions being investigated have rarely been asked in the context of urbanization.
- Work on the Great Recession and urban vegetation diversity contributes to bodies of literature in ecology, biogeography, and urban planning.
- Our stormwater research, including work on accidental wetlands, cuts across civil and water resources engineering, ecology, geography, and anthropology.

There are many other examples of how CAP research has forwarded knowledge in a particular discipline or research domain. CAP's support of research on the urban heat island in the Phoenix region is a major reason why there is more urban heat island research on Phoenix than any other metropolitan region in the world; an important contribution to climatology (Chow et al. 2012). The Global Ethnohydrology Project has advanced thinking in anthropology about human perceptions of water issues (Larson et al. 2016; Vins et al. 2014; Wutich et al. 2014). Our work on the impacts of the urban heat island and pollutants on minority neighborhoods has added to a rich dialogue about environmental justice and equity (Bolin et al. 2013; Declet-Barreto et al. 2013; Jenerette et al. 2016, 2011; York et al. 2014). Research and modeling by CAP students and scientists helped bring attention to the issue of phosphorus sustainability and has increased understanding of phosphorus inputs and outputs in the Phoenix metropolitan region (Iwaniec et al. 2016; Metson et al. 2015, 2012). Innovative approaches to envisioning futures piloted by CAP (e.g., Iwaniec et al. 2014) are being applied in the UREx SRN and will be employed in Baltimore by our BES colleagues.

Impact on Development of Human Resources

For our summer 2016 REU program, we targeted students from groups underrepresented in STEM. We worked with the Ecological Society of America's SEEDS SPUR fellowship program and recruited two students to join five other faculty-recruited students (also from underrepresented groups) in our summer REU program. These seven students bring the total

number of REU students supported under NSF funding to 33. Several of these students have gone onto graduate school in traditional STEM fields and the in new field of sustainability, and many others have entered STEM-related careers.

We piloted a set of seminars during summer 2016 to provide REU students with information and experiences beyond what they gain through working with a faculty member. We partnered with the UREx SRN to get a critical mass of students together to share research across traditional academic boundaries. Once the initiative had launched, we also included REU students in the Grimm lab and a visiting REU student associated with another NSF-funded SRN, the U-WIN. The 16 participating students (four of whom participated mainly via Vidyo) came together for four breakfast meetings covering topics such as interdisciplinary research, post-graduate career and education planning, and science communication. The final luncheon meeting involved each student giving a short presentation on learning from the summer's research experience. Feedback from students afterwards indicated that they had appreciated these meetings and that the REU experience had shaped their thinking about post-graduation academic work and careers. Selected student comments include:

- *I loved it! I have never appreciated the intricacies of research to this degree or valued the stops and starts.*
- *I enjoyed all the learning and seeing others' work as we all bonded as a group.*
- *I got experience doing hands-on scientific research, which is difficult to find during the school year.*
- *I learned that I enjoy the chemistry aspect to my project the most, and that I want to focus more on that in my future endeavors.*

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. The seminar conveners from CAP and UREx noted the fascination that students had with research very different from theirs: the stream ecology student asking questions of the UREx student researching urban protest movements in Mexico City; the landscape architecture student explaining his rendering of CAP scenarios to the pre-med student; and everyone's questions about the black widow spider in the plastic container that was an illustration for a presentation on black widow spider behavior. Other feedback from students and faculty will assist us in planning for summer 2017.

REU students are expected to give poster presentations on their work at CAP's annual All Scientists Meeting. Many students end up publishing their research with others in the lab where they were a REU student. Since 2011 our REU participants have been co-authors on 15 journal publications.

In 2016, our graduate grants program competitively granted $18,000 to support the research of five graduate students:

- Nicole Pierini: "Evaluating water, energy, and carbon fluxes across four distinct land cover types in a desert urban environment"
- Shelley Valle: "Effect of the Phoenix urban heat island on metabolic and reproductive physiology of a resident songbird"
- "Christine Demeyers: "The intersection of ecosystem services, homelessness, and water insecurity in Phoenix"
- Ruby Upreti: "Modeling the impact of urban trees on regional hydroclimate"
- Riley Burnette:"Social-spatial analyses of environmental attitudes in Phoenix, Arizona: 2006, 2011, and beyond"

Since 2011, we have awarded grants of up to $6000 to 47 students. The impact of the graduate grants program goes beyond money for research. Previous recipients of graduate grants form a panel, run like a NSF proposal review panel, to recommend the next year's graduate student applicants for funding. This model is how CAP trains the next generation of academic and agency scientists on writing effective proposals through hands-on experience with proposal review. The response to this process has been overwhelmingly positive.
Eight partner teams of teachers from the CAP LTER area were selected through a competitive application process to participate in an intense, week-long summer professional development workshop through the Ecology Explorers program. During this week, teachers learned about the LTER and CAP LTER research work and participated in the lessons and field studies of the Ecology Explorers curriculum. This focus of this workshop was soil ecology, and teachers worked directly with Dr. Becky Ball throughout much of the week. The teacher teams will report back later in the school year on classroom implementations of their summer learning experience.

Thirty-five teachers from the CAP LTER area participated in a joint professional development workshop on water in the environment that featured Ecology Explorers lessons for a portion of one day. The collaborative development and delivery of this workshop with Arizona Project WET and Decision Center for a Desert City is leading to ongoing projects with these organizations.

Additionally, the Ecology Explorers team work with the K-12 team from Walton Sustainability Initiatives to develop a 16-lesson unit for the Kyrene School District's summer program. Three Kyrene teachers were trained on the program and unit for facilitation of this program with students.

Four undergraduate student interns and one undergraduate student worker worked with the Ecology Explorers program in fall 2015 and spring 2016. These students learned basics of pedagogy for both classroom and non-formal education settings. They also contributed to the development of teaching materials and lesson plans. Students teamed together to implement learning experiences for schools, community events, and a unique afterschool program for families in transition.

Two graduate student workers assisted the summer 2016 teacher professional development workshop. These students produced presentations for the teachers on their research areas of expertise, and also facilitated aspects of the workshop related to these areas. It was evident through both observation and in post-workshop surveys that tremendous value was added for the participating teachers through engagement with these students.

Impact on Physical Resources that Form Infrastructure

As our field area is large, covering the Phoenix metropolitan area and surrounding desert, CAP's provision of field vehicles for research has been essential for the collection of long-term data and student investigations in the urban and peri-urban areas. We have purchased two new vehicles during this grant period, one with a 2015 equipment supplement and the other with funds from Arizona State University. Both enhance the ability of students, faculty, and staff to access field sites and replace aging vehicles in the CAP fleet. CAP's site manager is in charge of insuring that the vehicles are maintained, that researchers undergo the appropriate training to use the vehicles per ASU rules, and that vehicles are checked out and returned properly.

Shared instrumentation in the Goldwater Environmental Laboratory (GEL) allows CAP researchers access to equipment and training to conduct analyses. The GEL webpages provide a list of equipment http://rts.clas.asu.edu/gel . Some of CAP's part-time laboratory personnel are also employed by GEL, and CAP contributes to equipment purchases on a case-by-case basis. With a 2015 supplement, we contributed to the purchase of a trace gas analyzer (gas chromatograph) for the GEL lab, which addresses a need of several CAP scientists for this type of analytical instrument. The instrument was installed in October 2016. We sent a research technician to Gerstel, the company responsible for building the instrument according to our specification, to be trained on this instrument.

CAP maintains the below field infrastructure. During this reporting period (2015-2016), we focused on routine maintenance, instrument calibration, dealing with the vandalism inherent

in urban areas, and engaging faculty and students in using the long-term data from these monitoring efforts as well as in locating short-term investigations at these 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) that measures temperature, humidity, wind speed, precipitation, air pressure and dew point and includes a greenhouse gas analyzer. CAP also maintains a video camera attached to the same tower that the local Channel 3 weather team uses in broadcasts.
- At each of the CNDep 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 permanently marked quadrats for biomass and community composition of annual plants and marked creosotebush shrubs for stem elongation measurements.
- At the Desert Botanical Garden and Lost Dutchman State Park CNDep sites, micrometeorological stations measure temperature, humidity, wind speed, precipitation, air pressure, and dew point. For measurement of atmospheric deposition, CAP has installed resin-based bulk deposition and throughfall collectors at each CNDep site. 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.
- ISCO automated samplers at Indian Bend Wash and in four stormwater outfalls to the Salt River.

Impact on Institutional Resources

CAP LTER's grant from NSF in 1997 was the catalyst for the formation of the Julie Ann Wrigley Global Institute of Sustainability at ASU and the sustainability research efforts at ASU. It remains an important research platform for work on urban socioecological systems at ASU and is included on the ASU Office of Knowledge Enterprise Development (OKED) timeline, "A Legacy of Discovery" https://research.asu.edu/ .

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

CAP LTER's data management system is the core for a data management system encompassing sustainability research efforts at ASU.

The on-line Urban Ecology module for educators, developed through the Mary Lou Fulton Teacher's College, is accessible for classroom teachers and non-formal educators throughout the year. https://pll.asu.edu/p/class/orc-ecologyexplorers1

CAP's Ecology Explorers program provides teachers with professional development training and resources for engaging middle and high school students in learning about urban ecology. Several lesson plans are available on the CAP website. This spring, we collaborated with the Data Nuggets program to disseminate a lesson on the effect of urbanization and habitat restoration on reptiles, such as lizards, to teachers nationally via the Data Nuggets website.

CAP has contributed to the establishment of a citizen science arthropod monitoring program at the McDowell-Sonoran Preserve and is a key partner with the McDowell Sonoran Conservancy. This relationship continues to grow.

Since 1998, over $83 million in leveraged funding has had a significant impact on institutional resources to support research in the CAP community and beyond, although this report focuses on the results of CAP's direct funding from NSF.

Impact on Information Resources

The CAP LTER publishes data via multiple avenues to maximize the availability and discoverability of the project's research products. We maintain a local data catalog on the CAP LTER website (https://sustainability.asu.edu/caplter/), and data are also available through the LTER Network Information System (NIS; https://portal.lternet.edu/nis/browseServlet?searchValue=CAP) and DataONE data repository (http://www.dataone.org/find-data).

As of this writing, twelve datasets have been published or revised during 2016. Recent submissions of note include multi-year records of stormwater runoff chemistry across drainages in the cities of Scottsdale and Tempe, AZ; ecosystem-level measures of a constructed wetland in Phoenix, AZ; and the initial publication of data from the CAP LTER's extensive neighborhood landscaping experiment at the North Desert Village in Mesa, AZ. In addition to new data publications, data pertaining to the CAP LTER's Phoenix Area Social Survey (PASS) have been repackaged to enhance the clarity and utility of the information.

Publishing data in both the local data catalog and the LTER NIS, which provides quality checking as an integral feature of dataset submissions, helps to ensure the integrity of data published by the CAP LTER while simultaneously increasing discoverability.

The Julie Ann Wrigley Global Institute of Sustainability (GIOS) informatics team continues to make improvements to the presentation, utility, and management of CAP LTER information resources.

Notable for 2016 was the launch of a completely redesigned project website. The revised website features greatly improved navigation, updated imagery and content, and streamlined search capabilities among many other enhancements.

The team is developing workflows intended to improve submission rates, and metadata and data quality. A proposed enhancement is to increase the number and quality of data submissions by lowering the barrier to submission and improving communication with investigators through the use of collaborative tools such as the the Open Science Framework (https://osf.io/). Ultimately, these tools, which provide project wikis, version control, and archived dialogue among other features for the purpose of managing research data and associated information throughout the research cycle, may facilitate interaction with the CAP LTER information manager from project inception as opposed to only at the point of data submission.

Former information manager (P. Tarrant), current information manager (S. Earl), and the GIOS senior systems programmer (R. Raub) will teach a course on research data management at Arizona State University in the spring of 2017. This course is designed to provide graduate students, including students actively involved with the CAP LTER, with a greater awareness of the importance of data curation, and the skills and tools to more effectively manage their research data.

Proposed to coincide with the start of the start of a successful renewal proposal is the formation of an advisory committee consisting of CAP LTER principal investigators, graduate students, and project staff to guide the direction and implementation of information management at the CAP LTER. Input from the planned Information Management Advisory Committee (IMAC) is sought to provide (1) insight regarding information management tools and resources that project participants will find most useful and, thus, aid research production, and (2) perspectives from a diversity of backgrounds and areas of expertise to shape data products such that they are maximally discoverable, decipherable, and usable.

The CAP LTER is committed to active participation in informatics within the LTER network. Former information manager (P. Tarrant) helped spearhead the Network Information Management Office (NIMO) proposal that became an integral component of the recently awarded Environmental Data Initiative (EDI). P. Tarrant had served as co-chair of the LTER

Information Management Executive Committee through August 2016. Current information manager (S. Earl) participates in all network information meetings, and was elected to the LTER Information Management Executive Committee at the 2016 meeting of the Information Management Committee.

Impact on Society beyond Science and Technology

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 North American Association for Environmental Education, and the Central Arizona Conservation Alliance.

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. In the current reporting period, we engaged in 44 outreach activities, including the ASU Night of the Open Door, AZ SciTech Festival, and classroom visits, which reached approximately 1638 youth, 649 adults, and 185 teachers. We produced five new Ecology Explorers lessons and engaged in three highly effective multi-day teacher training sessions. Below are some reactions from teachers to our curriculum resources, classroom visits, and professional development opportunities:

- *Many students have spent their whole lives in Phoenix but have no idea how Phoenix has changed over the years. This activity was a great way to let them realistically see how our area has changed and to get them thinking about the pros and cons of these changes.*
- *Students are looking at their own backyard now as an ecosystem. They are seeing how the individual components work as a whole.*
- *I was motivated by what I learned during the workshop to have my class design and create a Sonoran desert preserve on campus. My AP class designed the 60' x 60' area and all of my classes worked on putting it together. We removed the rock and planted native plant species. We also created a pathway for students to walk around and see the plants. Lastly, we put up an informational sign describing the area and the Sonoran Desert.*

We partnered with the City of Phoenix and other organizations to work with Wilson School District students as the city invests in green infrastructure in this low-income majority Latino neighborhood. Signage for an "Urban Heat Island Learning Arroyo" explaining the urban heat island and the role of vegetation in ameliorating urban heat will be installed near one of the schools in early 2017. The signage uses visuals from CAP LTER. CAP scientist/AZ State Climatologist Nancy Selover and the Ecology Explorers program have been involved during

the last few years in engaging students in the Wilson School District in learning about heat and vegetation.

CAP engages with the Sustainable Cities Network, a vehicle for communities in the greater Phoenix region to share knowledge and coordinate efforts to understand and solve sustainability problems. We sit on the Green Infrastructure working group to learn what our issues our city partners are facing and to understand possible synergies with our CAP research.

Our Scenarios work, described under Activities and Findings, involves many expert stakeholders from across levels of government, the non-profit sector, and the research community. Far from being a purely academic exercise, the Scenarios workshops engage participants in defining future scenarios and understanding the consequences of these designs for water, heat, the urban form, waste, and food systems through modeling by CAP scientists and visualizations by design students. Development of these scenarios allows us to contrast diverse alternative future pathways and explore interacting strategies for urban sustainability and resilience. This project demonstrates how scenario construction can enhance research and decision-making capacity for long-range sustainability planning and ultimately, we hope this will spark a larger conversation in the greater Phoenix area about future pathways.

CAP's involvement with the McDowell-Sonoran Conservancy's Field Institute began with our contribution to their arthropod monitoring program. The Conservancy seeks to understand how the McDowell Mountains are being impacted by human activity. We have engaged an active group of volunteers in pitfall trapping arthropods along 10 transects in the McDowell Sonoran Preserve and have trained the volunteers to identify arthropods. During this reporting period, we initiated work with the Field Institute to communicate CAP's monitoring and research conducted in the mountain parks surrounding the Phoenix region to park staff. CAP scientists Sharon Hall and Stevan Earl are members of the Field Institute's Science Advisory Committee and both have been featured in the *Field Institute Insider*, the scientific magazine of the McDowell Sonoran Conservancy, which is distributed to Conservancy members.

CAP staff, students, and scientists are actively involved in the Central Arizona Conservation Alliance (CAZCA), an organization composed of partners from the non-profit, public, and education sectors focused on research and education toward the conservation of the mountain parks surrounding and within the Phoenix metropolitan area. CAP was one of CAZCA's founding partners in 2010, and we continue to work with the organization on citizen science, education, and research efforts. During 2015-2016, several CAP staff, faculty, and students

served in working groups that crafted a 25-year Regional Open Space Strategy for the greater Phoenix area.

The Desert Discovery Center is a partnership between the City of Scottsdale and ASU to build a world class research and education facility to improve public understanding of desert ecosystems worldwide and to generate ideas on how to live in a rapidly growing urban area situated within a desert ecosystem. Our work on this initiative to date has mainly involved contributions to planning sessions as well as discussions about the development of curriculum for K-12 schools.