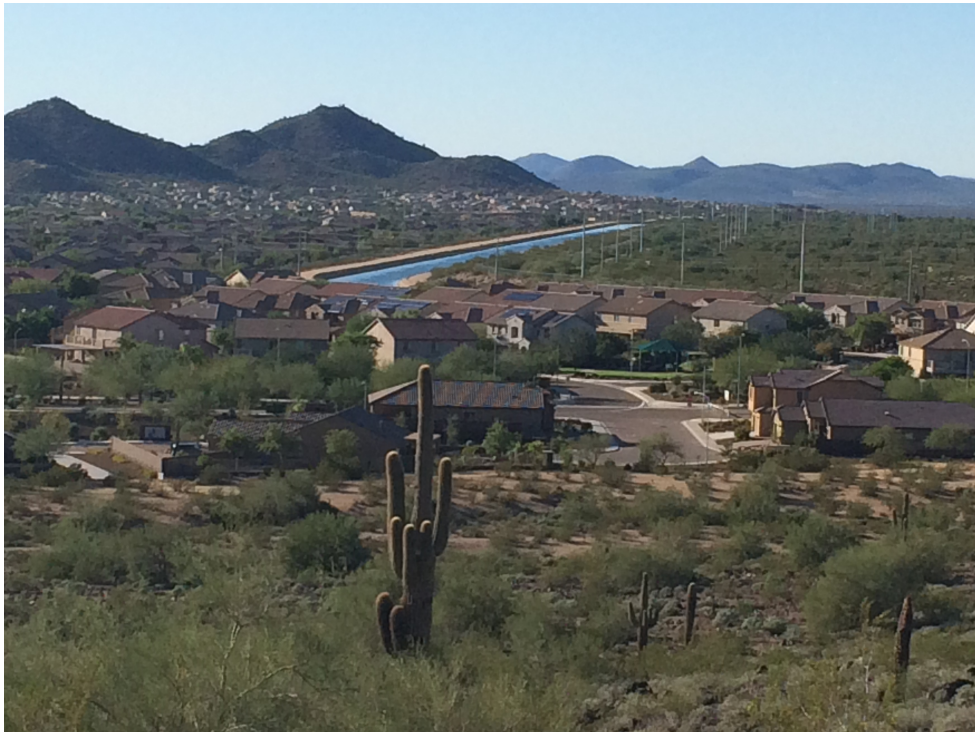
CAP LTER III 2015 ANNUAL REPORT



11/20/15

Report to the National Science Foundation

CAP LTER III
2015 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: Disinfection of swimming pools: A significant source of chloroform in Phoenix? (graduate student research)

- Collected swimming pool samples.
- Measured chloroform produced from chlorination of swimming pool water and model contaminants.
- Modeled chloroform flux from swimming pools in Phoenix.

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

- Part of long-term research on "accidental wetlands" from stormwater drains into the Salt River
- Collected ~100 samples for water chemistry data and spent ~50 field hours collecting hydrologic data.
- Performed a preliminary experiment to measure nitrate uptake rate and will be performing another experiment in September/October.

Project: CO_2 street-level emissions

- Built a street-level on-road fossil fuel CO_2 emissions data product for Maricopa County with analysis of the spatiotemporal variations in these on-road emissions

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
- Atmospheric Deposition Collection—quarterly
- Subplots fertilized with ammonium nitrate—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
- Percent composition of annuals recorded for subplot, aboveground material harvested, and aboveground dry mass determined—annually in spring

Long-term monitoring: Atmospheric deposition

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

Long-term monitoring: Eddy covariance tower

- One tower located in urban area
- Measures 3-D wind, CO_2 (flux), temperature (flux), moisture (flux)

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
- Constructed time-series models using river (i.e., Salt River and IBW) flows and rainfall in the lake to predict both metrics (i.e., DOM and O_2 sat)
- Examining impact of haboobs and dust storms on the chemistry of Tempe Town Lake (summer 2015)

Long-term monitoring: Water quality at Indian Bend Wash catchment outflow

- Part of long-term research on stormwater infrastructure in greater Phoenix area and long-term research on "accidental wetlands" along the Salt River.
- Water collected from Isco stormwater sampler at single location at the outflow of Indian Bend Wash
- Discrete, time-weighted sampling of each runoff-producing storm

Project: Soil biogeochemical consequences of the replacement of residential grasslands with water-efficient landscapes (graduate student research)

- Study builds upon long-term research on ecology of residential landscaping in the greater Phoenix area.
- Sampled yards of 47 houses in the City of Tempe, AZ to assess differences in nitrogen and soil properties between turf grass yards and alternative landscapes.
- Sent out a social survey (IRB approved) to collect data on the sample population and find study sites.
- Took soil cores in each yard and uses ion exchange resins to determine nutrient pools and fluxes and determine soil properties.
- Processed and analyzed samples and performed statistical analyses.

Project: Haboob (dust storm) characterization

- Collected and analyzed aerosol particles during the summer monsoons in 2014 and 2015
- Performed data analysis on concentration changes over time

Project: Measuring urban metabolism on Arizona State University's Tempe campus using scintillometry

- Set up, test and run a scintillometer measurement for atmospheric turbulence in a built environment
- Collect and share preliminary dataset

Climate, Ecosystems, and People

Project: Measuring individually experienced temperatures in Phoenix, AZ (undergraduate research)

- Conducted week-long personal temperature monitoring campaign across five Phoenix area neighborhoods using iButton technology.
- Involved several undergraduate research assistants in data gathering and analysis and in some aspects of research management.
- Analysis of data is ongoing.

Project: Urban homogenization (multi-site research funded through Macrosystems, leveraged from CAP, and using CAP data and resources)

- Conducted analyses of microclimates across selected neighborhoods in six study cities in comparison with native ecosystems situated in or adjacent to these cities.

Project: Mitigating urban heat island effects through strategic green space siting

- Quantified the day/night cooling effect of urban green space in the Phoenix region during pre-monsoon summer using remote sensing and land cover data.
- Created a model that maximizes the cooling effect of central Phoenix area by locating additional amount of green space.

Long-term monitoring: Eddy covariance tower

- One tower located in urban area
- Measures 3-D wind, CO_2 (flux), temperature (flux), moisture (flux)

Long-term monitoring: Microclimate towers

- Two 10-m towers, one located in desert remnant within urban area, other located in outlying desert

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.

Project: Urban vulnerability to climate change (CNH funded research leveraged off of CAP and using CAP land cover data as well as other public long-term datasets)

- Analyzed long-term, publically available climate datasets and long-term mortality data from the Arizona Department of Health Services
- Examined the relationship between heat, vegetation, morbidity, and mortality.
- Analyzed data from MASTER overflight of Phoenix, commissioned by CNH project and CAP LTER.

Long-term monitoring: Phoenix Area Social Survey

- Analyzed data on perceptions of heat and respondents' reporting of heat-related illness symptoms in their households as part of "Urban vulnerability to climate change" project.

Long-term monitoring: Urban heat, vegetation, and air and surface temperatures

- Statistical synthesis of long-term climatic and land use/land cover datasets

Human Decisions and Biodiversity

Project: How urbanization alters the top-down influence of herbivores on plant communities (undergraduate research project)

- Conducted small herbivore population census at four sites that are a subset of the CNDep long-term sites.
- This includes 2 consecutive nocturnal trappings of small rodents (mice, rats, squirrels) at each site
- Trappings were conducted at each site once in the fall of 2014 and once in the spring of 2015

Project: Impacts of altered precipitation on aboveground–belowground interactions in the Sonoran Desert (undergraduate research project)

- Artificially manipulated precipitation amount and frequency during the monsoon season over three different plant types.
- We simulated 5-mm pulse events plus a 50% increase in size either every 2 weeks or monthly (~50% reduced frequency).
- The four pulse treatments were applied to the basal area under three aboveground types: *Larrea tridentata*, *Ambrosia deltoidea*, and the interplant space.
- Soil samples were collected: 36 at the beginning and 36 at the end of the season.
- Invertebrates were extracted from the soil via heptane flotation.

Long-term monitoring: Wildflower survey (part of CNDep project – this year treated separately for reporting purposes)

- Recruited and trained seven citizen scientist botanists
- At each subplot volunteers used a datasheet to record the names of each annual wildflower found and what percentage of space the species occupied in that subplot. They recorded whether there was any perennial cover (usually *L. tridentata*) and the percentage of cover and stems occupied in the subplot. They recorded the amount of bare ground as a percentage, the date, name of the subplot, and names of the group members on every sheet.

Long-term monitoring: Examination of CAP LTER vegetation diversity and drivers (graduate student research)

- Analysis of the vegetation data from the Survey 200
- Urban vegetation spatial patterns following the Great Recession

- Drivers and dynamics of urban vegetation diversity before and after the housing boom-bust
- Interacting effects of household-level choices about foreclosure and residential landscaping

Project: Time course of stress-induced immunosuppression in a common urban bird (graduate student research)

- Brought adult, male House Sparrows into captivity at the end of the breeding season.
- We tested how different durations of stress (via restraint) affected three measures of immunity, and if these effects endured after the stressor was removed.

Project: Regulation of stress-induced immunosuppression in a common urban bird (graduate student research)

- Captive adult, male House Sparrows were treated with mitotane to temporarily eliminate endogenous corticosterone (CORT) production. We tested how the stress response for durations of 10 minutes and 2 hours affected innate immunity in both control and mitotane-treated birds.

Project: An analysis of life history strategies of *Parkinsonia* and *Prosopis* trees within the CAP LTER study area (graduate student research)

- Collected samples from healthy, mature, *Parkinsonia* and *Prosopis* trees using an incremental borer
- Measured green volume of samples via the water displacement method
- Oven dried samples to get dry mass
- Calculated specific gravity (oven dry mass/green volume)

Project: Black widow spiders and the urban heat island: Temperature effects on an urban arthropod pest (part of two long-term research foci: Urban climate and urban residential pests)

- All individuals in these experiments were F1 laboratory reared from urban-collected females.
- Temperatures represent desert (27°C) and urban (33°C) average July nighttime temperatures for black widow microhabitats (JCJ, unpubl. data).
- Ballooning dispersal was scored in response to the wind current produced by a standardized fan.
- Courtship and web building activity was scored every 5 minutes in standardized assays.
- Prey manipulations involved either 3 months of starvation or being fed one cricket every two days for two weeks.

Project: Urban homogenization (part of multi-site investigation through leveraged Macrosystems grant continuing work initiated in Phoenix)

- Analyzed vegetation surveys conducted across study cities, including Phoenix

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

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

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

- Analyzed data from interviews in four cultural sites (in U.S., New Zealand, Fiji, and Bolivia).
- Characterized perceived water scarcity risks and solutions for each setting
- Examined how perceptions differ across countries based on development and water scarcity.

Long-term monitoring: Tres Rios Constructed Wetlands

- Continued systems-level research in Tres Rios constructed treatment
- Collaborated with colleagues at the University of Strasbourg (France) on a second dye study to test our "biological tide" hypothesis in June-July 2015.
- Hosted two PhD students from the Environmental Engineering program at University of Strasbourg.

Long-term monitoring: Water quality at Indian Bend Wash catchment outflow

- Part of long-term research on stormwater infrastructure in greater Phoenix area and long-term research on "accidental wetlands" along the Salt River.
- Water collected from Isco stormwater sampler at single location at the outflow of Indian Bend Wash
- Discrete, time weighted sampling of each runoff producing storm

Long-term monitoring: Regional water quality analysis

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

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

- Completed soil core analysis: denitrification, soil organic matter, soil moisture, soil nitrate, soil texture.
- Prepared plant samples for CHN analysis.

Land Use, Land Cover, and Land Architecture

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

- Continued working with CAP scientists on use of 1 m resolution land cover dataset and initiate planning for next installment for this dataset.
- Prepare base NAIP land classification for WRF models & begin an assessment of open lands in PHX, 2010 and 2013.
- Used NAIP (CAP) data to work with R. Quay and the City of Phoenix Water Department to determine changes in yardscapes in order to determine estimates of water use. This work continues on an ad hoc basis.

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

- Began work on standardized land cover data for every 5 years from 1985 to present during summer 2015

Project: How has urbanization in riparian zones on two major streams affected ecosystem service provisions

- Created systematic assessment of land cover and use changes for Queen Creek and Indian Bend to determine urban impacts of vegetation.

Project: Discovering land-cover typology of residential parcels in metropolitan Phoenix

- Identified a robust topology that characterizing the majority of single family residential parcels in the CAP study area. The topology is defined using the land cover variables computed from the 1 meter LC map of CAP in year 2010.

Long-term monitoring of land cover and land use change: Tree canopy in Tempe (with the Walton Sustainability Solutions Service and City of Tempe)

- Phase 1 of this project included an assessment of Tempe's current percent tree canopy cover at various scales: city-wide, on publicly owned property, per Census tract, General Plan Character Area, and in flood irrigated areas.
- The analysis was performed in ArcGIS, using the CAP LTER 2010 1-m resolution NAIP land cover classification.

Project: City of Goodyear streetscape experimental project

- Initiated project with NSF-funded Decision City for a Desert City and the City of Goodyear.
- Project designed to test the effects of different streetscape designs on microclimate, water use, and fluxes as well as people's perceptions of these designs.
- Project was not realized due to city pulling out of initiative.

Project: Power Ranch mobile microclimate transects (Hab et al. 2015)

- This project developed a prototype visualization framework for mobile transects, using CAP's 1m land cover dataset as a component for the exploration of the spatial context and the multivariate relationships between the measured attributes in mobile transects.

Survey 200 Long-Term Monitoring

- Enhanced data collection by a transition to digital data collection in the field
- Surveyed 175 plots or partial plots
  - Trees identified and counted, all trees measured and photographed; GPS location, tree shape and health recorded
  - Shrubs identified and counted, representatives measured and photographed, shrub shape and class recorded
  - Annual species recorded and photographed; percent cover estimated
  - Voucher specimens collected for unknown plants for later identification
  - Five soil cores and four surface soil samples collected
  - Three arthropods samples collected via sweep net from individual shrubs, trees, or ground cover
  - Qualitative description of plot, landscape, turf cover, and neighborhood recorded
  - Center point and synoptic photographs of plot taken
- Completed 29 parcel surveys on residential plots
  - Trees identified and counted, all trees measured and photographed; GPS location, tree shape and health recorded

- Shrubs identified and counted; photographed if uncommon
- Voucher specimens collected for unknown plants for later identification
- Qualitative description of parcel and neighborhood recorded
- Qualitative description of front and rear yard including landscape, turf assessment, and human indicators panel recorded
- Synoptic photographs of parcel taken

Phoenix Area Social Survey (PASS) Long-Term Monitoring

- Analyzed data from experiment conducted in conjunction with 2011 survey comparing public goods with private goods (cash) as response incentives for a household survey.
- Joined 2005 and 2011 PASS datasets through common variables
- Created codebook for 2005 and 2011 datasets
- Collaborated with colleagues in Berlin on comparative work between Berlin and Phoenix using similar survey instruments
- Prepared joined dataset for archiving
- Conducted longitudinal analysis across landscaping and biodiversity variables
- Initiated planning for 2016 survey

Sustainable Futures

- Analyzed documentation on state, regional, municipal, and community planning and development targets and priorities.
- Developed regional scenarios through participatory workshops with decision makers in November 2014 (Scenario components), March 2015 (Defining scenarios), and July 2015 (Detailing and visualizing scenarios).
- Engaged participants representing county, state and federal agencies, departments in five cities in the region, seven Arizona-based non-profits, the regional council of government, and a tribal association.

KEY RESEARCH FINDINGS IN 2015

Biogeochemical Patterns, Processes, and Human Outcomes

Project: Disinfection of swimming pools: A significant source of chloroform in Phoenix? (Rose 2014 – MS thesis)

- Chlorination of swimming pool water produced 0.025-0.190 mol $CHCl_3$/mol C and 0.005-0.060 mol $CHCl_3$/mol Cl_2 consumed. Chlorination of model contaminants produced 0.010-0.320 mol $CHCl_3$/mol C and 0.005-0.250 mol $CHCl_3$/mol Cl_2 consumed. Flux estimates yielded 4 Gg $CHCl_3$/year from swimming pools in Phoenix.
- This research demonstrates that swimming pools might have a significant impact on atmospheric chloroform; thus, swimming pools should be considered in urban planning in terms of their air quality impact.

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

- Nitrate is delivered to the wetland surface water via storm drains and is either taken up by plants or transformed via microbial processes. Data from experimental soil microcosms indicate that denitrification and DNRA are the microbial processes responsible for nitrate transformation and removal.

Project: CO_2 street-level emissions (Gurney & HESTIA project in progress)

- Majority of on-road CO_2 emissions in Maricopa County are from interstates I-10 and I-17. State Routes 51, 60 and State Highway Loops 101, 202 comprise the second largest emissions.
- Urban road segments inside Loop 101 and 202 generally have higher emissions compared to road segments in suburban/rural areas in western Maricopa County.
- The peak hours of CO_2 emission are during rush hours, from 8am to 9am and from 5pm to 6pm, primarily focused in Phoenix, Scottsdale, Mesa, and Chandler, which is consistent with the 2007 Maricopa Association of Governments report on freeway congestion.

Project: Soil biogeochemical consequences of the replacement of residential grasslands with water-efficient landscapes (Heavenrich 2015 – MS thesis)

- We found that soils in alternative yards (i.e., water-efficient landscapes) have both higher nitrate pools and higher nitrate availability than residential yards.
- We determined that this is likely caused by excess organic matter in the new landscapes after replacement from turf, and processes used to change the yard to an alternative yard that affect N cycling.
- We also found that water availability is the main driver of the magnitude of difference in soil N in alternative landscape yards of different ages (between 1-21 yrs. since land cover change).

Project: Analysis of metal content of wastewater (Westerhoff et al. 2015)

- Metals with significant monetary value end up in wastewater treatment plants and could be recoverable from sludge.

Project: Haboob (dust storm) characterization (Marcotte 2015 – Ph.D. dissertation; Herckes et al. in prep)

- Aerosol concentrations spike for only very short periods of time.
- Haboob impact on air quality is very limited in time.
- Not only mineral dust is elevated in haboobs but also many anthropogenic elements and organic compounds, suggesting strong re-entrainment of urban dust.

Long-term monitoring: Eddy covariance tower (Chow et al. 2014)

- Multi-method estimations of summer waste (anthropogenic) heat emissions compare favorably with observed daily energy balance residuals from eddy covariance tower.
- Waste heat via residential air conditioning is a significant factor influencing the surface energy balance (SEB) (Chow et al. 2014b).

Long-term monitoring: Tempe Town Lake biogeochemistry (Hartnett et al. in prep)

- Oxygen saturation is related to photosynthesis/respiration dynamics (i.e., DOM cycling and processing) in the lake.
- DOM concentrations spike following rain and especially high river discharge
- Oxygen is supersaturated during much of the year, which is in striking contrast to many non-urban lakes, which exhibit CO_2 supersaturation and O_2 undersaturation.

Long-term monitoring: Water quality at Indian Bend Wash catchment outflow (Hale et al. 2015)

- Used LT monitoring data in comparison with data on stormwater runoff from nine nested watersheds in the IBW catchment (Scottsdale, AZ) to examine how variations in stormwater infrastructure design affect fluxes of dissolved nitrogen (N), phosphorus (P), and organic carbon (DOC).
- There is spatial and temporal variation in stormwater infrastructure design in the catchment.
- Stormwater infrastructure design was significantly related to stormwater runoff and fluxes of N, P, and DOC, but did not affect their concentrations.
- Retention-basin density was the strongest infrastructure predictor of fluxes of water, nutrients, and DOC.

Long-term monitoring and experimentation: Ecosystem response to urban atmospheric deposition (CNDep) (Davis et al. 2015; Ball and Alvarez Guevara)

- REU project in conjunction with CNDep LT monitoring that focused on the role of top down factors, such as herbivory, and bottom up factors, such as resource availability (one focus of CNDep) on primary productivity. REU student conducted experiment with

control (accessible to animals) and exclusion areas across the CNDep gradient during two growing seasons. (Davis et al. 2015)
- Plant growth was primarily driven by precipitation, although herbivory reduced aboveground biomass by around 33%.
- While N availability is a limiting factor to primary production in the Sonoran desert, it had little effect on plant growth, consistent with other CNDep findings.
- REU project in conjunction with CNDep LT monitoring that focused on moss's role in biogeochemical cycling and how nutrient pulses affect their functional significance as an integrator of nutrient cycling in deserts (Ball and Alvarez Guevara 2015).
- Moss can take up excess soil N from deposition inside the city core, but moss abundance is lower inside the city, making them incapable of acting as a significant sink for anthropogenic N.

Climate, Ecosystems, and People

Project: Measuring individually experienced temperatures in Phoenix, AZ (Kuras, Hondula, Munoz et al. 2015 posters; undergraduate research)
- There is significant variation in individual and neighborhood level thermal exposure.
- These patterns contrast with expectations from traditional ecological proxy indicators for heat stress.

Project: Quantifying the tradeoff between landscape vegetation height, surface temperature, and water consumption in single-family residential houses for a desert city (Jia 2015 – Honors thesis project; REU).
- Trees of 1.5m-5m height and trees of 5m-10m height lowered daytime surface temperatures.
- Nighttime surface temperatures were increased by trees of 5m-10m height and decreased by grass.
- Houses that experienced higher daytime surface temperatures consumed less water than houses with lower daytime surface temperatures, but water consumption was not directly related to vegetation cover or height.
- Implications of this study support the practical application of tree canopy (vegetation of 5m-10m height) to mitigate extreme surface temperatures. The trade-offs between water and vegetation classes are not yet clear because vegetation classes cannot singularly predict household water consumption.

Project: Urban homogenization (multi-site research funded through Macrosystems and leveraged from CAP) (Hall et al. in press)
- Urban residential microclimates across six cities situated in different ecosystems are more similar to one another than are the microclimates in native ecosystems in or adjacent to the cities.

- This suggests a convergence in residential landscape microclimates due possibly to similar land cover (turf, for example) and structural features.

Long term monitoring: North Desert Village microclimate

- Two recent studies used micromet data.
- See findings on lizards and urban heat under Climate IPA (Ackley et al. 2105a &b)
- See findings on irrigation and vegetation under Water IPA (Volo et al. 2015)

Project: Urban vulnerability to climate change (CNH funded research leveraged off of CAP and using CAP MASTER data, land cover data, and social survey data)

- There is a significant association of high environmental temperatures with cardiovascular mortality, heat-related mortality, and mortality resulting from conditions that are consequences of heat and dehydration (Petitti et al. in press).
- Health impacts related to heat begin before all-cause mortality threshold temperatures are met (Petitti et al. in press).
- Public health officials need an array of trigger temperatures for health warnings rather than just one all-cause mortality trigger temperature in order to address the variability across medical conditions in temperature thresholds for heat-related effects (Petitti et al. in press).
- Residents perceptions of heat in their neighborhoods correlated with empirical data on heat (Jenerette et al. in press)
- The effect of parcel daytime surface temperature on heat illness was greater for people with reduced access to home air conditioning than those who had sufficient access (Jenerette et al. in press).
- The mean parcel daytime land surface temperature was significantly higher for respondents who reported a heat related illness in their household than for those reporting no heat related illnesses (Jenerette et al. in press).
- Planting vegetation to reduce land surface temperatures is likely to be more effective in areas with the highest temperatures than areas with lower temperatures (Jenerette et al. in press).

Long-term monitoring: Eddy covariance tower

- Data from urban eddy covariance tower in Phoenix confirmed utility of multi-method approach for estimating summer waste heat emission from anthropogenic activities (Chow et al. 2014a).
- Waste heat via residential air conditioning is a significant factor influencing the surface energy balance (SEB) (Chow et al. 2014b).

Long-term monitoring: Urban heat, vegetation, and air and surface temperatures

- A unit increase in surface temperature of built up areas can increase the air temperature slightly higher than that in vegetated areas (Song et al. in review).
- Lower surface temperature over built-up surfaces in the late afternoon could be attributed to higher albedo and radiative shading effects of a built terrain (Song et al. in review).

- Most changes of the suburban urban heat island (SUHI) have taken place on outskirts of the city with no significant changes observed in existing developed urban areas. The areas being continuously cooled during the daytime are all located on the city outskirts and the total area is approximately 47 km^2. The largest drop of land surface temperature is approximately 4 °C from 2000 to 2014. Most areas with increasing daytime land surface temperature are found in the southeastern (e.g., southeast Chandler) and western (e.g., west Phoenix) parts of the metropolitan Phoenix that encompass a total area of 176 km^2, which is almost three times larger than the areas being cooled (Wang et al. in review).
- Land surface temperature has increased significantly from 2000 to 2014 during the daytime, ranging from 2 °C to 7.35 °C, with the highest increase found in the western part of Phoenix (Wang et al. in review).

Human Decisions and Biodiversity

Project: How urbanization alters the top-down influence of herbivores on plant communities (Bergin and Ball 2015 poster; undergraduate research)

- Overall abundances are the same inside and outside the city, which helps explain the similarities in herbivory levels found in previous work
- Diversity outside the city is greater at the genus level (not at the species level) than inside the city.
- Community composition differs between sites: Certain species are only found in parks outside of the city, and others only inside. The species found inside the city tend to be those with smaller individuals.

Project: Impacts of altered precipitation on aboveground-belowground interactions in the Sonoran Desert (Undergraduate research)

- Sample analysis is ongoing, and we predict there will be a change in composition and abundance of soil fauna as a result of the differing precipitation patterns.

Long-term monitoring: Examination of CAP LTER vegetation diversity and drivers (Ripplinger 2015 – PhD dissertation)

- See findings below under Survey200

Project: Time course and regulation of stress-induced immunosuppression in a common urban bird (Gao and Deviche 2015 poster; graduate student research)

- Stress via restraint seemed to suppress innate immune function within 10 minutes of experiencing the stressor, and the effects seemed to endure 1 hour after restraint was removed. Stress did not seem to influence adaptive immunity.
- When endogenous CORT was eliminated, mitotane birds demonstrated enhanced innate immunity within 10 minutes of restraint.

- This enhancement was also seen in birds restrained for 2 hours, which suggests that CORT may act through 2 different receptors during stress-induced immunosuppression.

Project: An analysis of life history strategies of *Parkinsonia* and *Prosopis* trees within the CAP LTER study area (Gryniewicz and Martin 2015 poster; graduate student research)

- Preliminary results indicate specific gravity differs significantly between irrigated *Parkinsonia* and *Prosopis* and non-irrigated *Parkinsonia* and *Prosopis*. Research is investigations the implications of this.

Project: Black widow spiders and the urban heat island: Temperature effects on an urban arthropod pest (Johnson et al. in prep)

- Urban heat island temperatures suppress female web building, but have little effect on courtship and spiderling dispersal.
- The lack of effect on courtship and dispersal suggests these behaviors are too costly to suppress.
- Abiotic forces (e.g., the urban heat island) interact with biotic variables such as urban prey abundance and relaxed selection to shape the behavior of urban black widows

Project: Effect of urban heat island on lizards in urban residential areas (Ackley et al. 2015a and b; Ackley 2015 – PhD dissertation)

- Lizard diversity is highest in affluent areas.
- Lizard abundance is greatest near large patches of open desert.
- Areas with a higher percentage of building cover had less lizard diversity and abundance.
- While lizards are thought of as a heat tolerant species, they are affected by thermal stress in the city, which has been exacerbated by the urban heat island effect.
- The presence of substantial vegetation, such as irrigated grass and shade trees, has a positive effect on lizard activity.

Project: Urban homogenization (Larson et al. 2015)

- Results underscored that cultural services were of utmost importance in determining landscape preferences?, particularly anthropocentric values including aesthetics, low-maintenance, and personal enjoyment.
- Using factor analyses, distinctive dimensions of residents' values were found to partially align with the Millennium Ecosystem Assessment's categories (provisioning, regulating, supporting, and cultural).
- Finally, residents' ecosystem service priorities exhibited significant homogenization across regions. In particular, the traditional lawn aesthetic (neat, green, weed-free yards) was similarly important across residents of diverse U.S. cities. Only a few exceptions were found across different environmental and social contexts; for example, cooling effects were more

important in the warm South, where residents also valued aesthetics more than those in the North, where low-maintenance yards were a greater priority.

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

- Result of unconstrained ordination (non-metric multidimensional scaling (NMDS)) showing temporal shifts in riparian bird community structure for 12 long-term riparian monitoring sites divided into 4 riparian habitat types.
- Bird community assemblage is shifting toward a composition found at sites with less water and more impervious surfaces, such as the ephemeral engineered sites. Therefore, with time, the riparian bird community in Phoenix is composed of more urban invaders and less specialist species.

Project: Burrowing owl habitat and urbanization (Beebe et al. 2014; REU project)

- Burrowing owls can live in urbanized environments, provided that less than 40% of the land cover in the area is developed, surface water is available, and soil types are appropriate for burrowing.

Water Dynamics in a Desert City

Project: Global ethnohydrology (Wutich et al. 2014)

- Residents in diverse contexts worried more about quality than about quantity, and individual practices (e.g., preventing pollution) were most commonly cited as remedies.
- Residents in water scarce regions were relatively concerned about quantity, and they tended to emphasize collective policies and technologies.
- Residents of developed countries were more likely to suggest collective water policies as strategies, whereas those in developing areas stressed behavioral and technological strategies as solutions, primarily to pollution.

Project: Quantifying the tradeoff between landscape vegetation height, surface temperature, and water consumption in single-family residential houses for a desert city (Jia 2015 – REU and Honors thesis).

- Trees of 1.5m-5m height and trees of 5m-10m height lowered daytime surface temperatures.
- Nighttime surface temperatures were increased by trees of 5m-10m height and decreased by grass.
- Houses that experienced higher daytime surface temperatures consumed less water than houses with lower daytime surface temperatures, but water consumption was not directly related to vegetation cover or height.
- Implications of this study support the practical application of tree canopy (vegetation of 5m-10m height) to mitigate extreme surface temperatures. The trade-offs between water and

vegetation classes are not yet clear because vegetation classes cannot singularly predict household water consumption.

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

- Potential denitrification rates do not vary between seasons
- Ephemeral sites have lower potential denitrification rates after monsoon floods
- Plant patches affect denitrification only at intermittent and perennial sites.
- There is a significant interaction between season, site type, and plant patches at intermittent and perennial sites.

Long-term monitoring: Water quality at Indian Bend Wash catchment outflow

- See findings under Biogeochemical IPA (Hale et al. 2015)

Long-term monitoring: Regional water quality analysis

- Investigations using liposomes, synthetic vesicles that are representative of cellular vesicles found in untreated water, found that these may be responsible for 20-60% of the membrane fouling (degradation) during water and wastewater treatment ultrafiltration, but preozonation reduces this (Barry et al. 2014).
- Severe weather can have a significant impact on surface water quality, including turbidity, high DOC loads, and increases in total organic carbon (Barry et al. in press).

Land Use, Land Cover, and Land Architecture

Long-term monitoring: Tree canopy in Tempe (in collaboration with Walton Sustainability Solutions Service and City of Tempe; Middel et al. 2014 presentation to City of Tempe)

- Results show that the overall Tempe tree canopy cover in 2010 was 13.4% of the total land area, including private property.
- In flood-irrigated areas, tree canopy cover was significantly higher than in non-flood-irrigated areas (21.5% vs. 12.4%).
- City-owned trees in rights-of-way and on publicly owned land accounted for only 2.4% of the total tree canopy cover.
- These findings will be used in phase 2 of this project to develop an Urban Forestry Management and Action Plan for the City of Tempe.

Project: Discovering land-cover typology of residential parcels in metropolitan Phoenix (uses CAP 1m resolution dataset)(Y. Zhang et al. in prep)

- In general, four types of residential land covers can be found using the cluster analysis. This yields a residential land-cover typology that differs from previous such analyses: 1)

New Fringe, the small size newly developed parcels located at the periphery of the metropolitan region, 2) Historic Core, the small size historical parcels located at the urban core, 3) Medium Lush, the medium size parcels that have high vegetation cover and the highest density of swimming pools, 4) Large Lush, the large size parcels that have the highest proportion of vegetation cover.

Project: Urban vulnerability to climate change (CNH funded project using CAP data)

- CAP's 1m resolution dataset used in this study as well as MASTER data. See findings under Climate IPA (Jenerette et al. in press)

Survey 200 Long-Term Monitoring

Long-term monitoring: Examination of CAP LTER vegetation diversity and drivers (Ripplinger 2015 – PhD dissertation)

- Introduced and native annual richness increased on residential sites during the housing boom, then decreased afterwards, against background increases in total species richness from pre- to post-recession
- Bottom-up drivers govern residential plant community composition (e.g., winter precipitation, soil type, assessed home value
- Economic disturbance (tightly linked to a decrease in management activities) accounts for the re-emergence of bottom-up controls on vegetation.

Phoenix Area Social Survey Long-Term Monitoring

- People in neighborhoods who report higher rates of heat related illnesses live in hotter neighborhoods (Jenerette et al. in press)
- In an experiment with survey respondents regarding varying values of cash incentives, cash donations to charity, or a choice between cash and donation, there were no differences in response rates among the three cash incentive amounts, and when respondents were given a choice between a cash incentive or a donation to a local charity, they chose the cash incentive with the likelihood of donating declining as the size of the monetary incentive increases (Smith et al. 2015).
- A key conclusion of this experiment is that the public good—a contribution to a food bank—was not as effective as either a cash incentive or a format that allows each respondent to decide to keep or donate the cash (Smith et al. 2015)

Sustainable Futures

- Identified synergies and trade-offs (both normative and systems) among social-ecological targets and priorities to identify scenario logics and to compare and contrast with newly co-developed scenarios (on-going research)
- Co-produced scenarios to explore plausible and desirable futures for the CAP LTER region in the face of climate change and extreme events, as well as further urbanization and social-ecological-technological changes.

KEY OUTCOMES OR OTHER ACHIEVEMENTS

- CAP is a leader in urban socioecological research:
  - CAP students and scientists have published 197 journal articles, 2 books, and 31 book chapters since 2011.
  - In 2014, CAP students and scientists published a total of 58 peer-reviewed journal articles, more than any other year on record. Thus far in 2015, we have published 46 peer-reviewed journal articles with 22 in review and 11 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.)
  - Two recently awarded $12 million NSF Sustainability Research Network grants have been leveraged off of CAP: "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 scientists Harlan and Georgescu as senior scientists. Both will build off of past, current and future work done by CAP.
- Graduate students contribute to knowledge on urban socioecological systems:
  - Since 2011, students have been authors on 123 publications and have been first authors on 89 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 2015.
- CAP engages in knowledge exchange and creation of new knowledge across institutional boundaries:
  - CAP's future scenarios project has engaged 60 expert stakeholders from county, state and federal agencies, municipal departments, non-profits, academic institutions, the regional council of government, and a tribal association in three workshops visioning the future of the greater Phoenix.
  - CAP sent 29 participants (students, staff, and faculty) to the LTER All Scientists meeting in August 2015 who presented 15 posters and organized five working groups.
  - CAP scientists have been active participants in workshops at NCEAS and SEYSNC. For example, CAP Director Nancy Grimm and CAP scientist Abby York are part of a SESYNC project focusing on green infrastructure and stormwater, which involves scientists from multiple institutions as well as planners and municipal stormwater experts.

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 design and deliver training and professional development activities for our CAP community; 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.

In August, we sent 29 faculty, students, and staff to the LTER All Scientists Meeting in Estes Park, using both funds allocated by the LTER Network Office and funds budgeted in the CAP NSF budget. Outcomes included a better understanding of LTER science and network activities by new staff persons, new cross-site collaborations initiated, and enhanced knowledge of scientific tools and techniques. Additionally, feedback on the science communication session conducted by the Alan Alda Center for Science Communication generated interest and enthusiasm for similar training at CAP/ASU.

In collaboration with the Julie Ann Wrigley Global Institute of Sustainability and Arizona State University's Media Relations staff, CAP organized a media training session for CAP scientists, staff, and post-docs in October 2015. This is the first of a series of science communication sessions planned for the coming years.

CAP's Ecology Explorers program held a workshop with teachers from the Scottsdale Unified School District in the McDowell Sonoran Preserve, which focused on desert ecology and the impact of urbanization on this ecosystem.

CAP post-doctoral researcher, David Iwaniec, is participating in CAP activities while being mentored by associated faculty members (Grimm) 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 (including media training), and supervising staff involved in the future scenarios work.

CAP and its host institution, the Julie Ann Wrigley Global Institute of Sustainability, promote a variety of professional development opportunities available to staff working on CAP. Examples include media training (see above), the LTER ASM, travel to conferences, and training workshops available at Arizona State University. For example, staff has attended workshops on time management, supervisor training, effective presentations, and stress management.

CAP Education manager, Monica Elser, and CAP Project manager, Marcia Nation, attended the Citizen Science Association's first Citizen Science Conference in San Jose in February 2015. They presented a poster on citizen science work in CAP and networked with other citizen scientists.

DISSEMINATION

CAP students and scientists have published 197 journal articles, 2 books, and 31 book chapters since 2011.We summarize research results and communicate these to the wider scientific community and the public via Research Highlights on the CAP website.

We have been working with the GIOS Communications team and NSF to get more stories about our research into local and national media through press releases and stories posted on the ASU website. Examples include:

- Zoning gets a bad rap, but as CAP scientist **Abby York** said in a recent interview for *ASU News*, it is "really the teeth of any kind of planning." In an article on sustainable cities, York noted the importance of zoning in planning for urban sustainability, drawing on her considerable research in Phoenix from 1930 forward that was supported by CAP.

- Sludge is thought of as a liability; however it could be a commodity. CAP scientist **Paul Westerhoff** is the lead author on a recent paper about recovering valuable metals from sludge. Along with CAP scientist **Pierre Herckes** and others, he estimates that there could be as much as $13 million of metals, including around $2.6 million in gold and silver, in the sludge produced in a city of a million people annually. This is based on research conducted in Phoenix partially-supported by CAP and covered by *Science News*.
- Arizona leads the nation in heat-related deaths, a dubious distinction not lost on CAP scientist Sharon Harlan. She was interviewed recently for a story on the health impacts of excessive heat on a local NPR affiliate station. Harlan's research has focused on which communities and neighborhoods are most vulnerable to heat and what can be done to change this vulnerability.
- When high school students give up their fall break to be in the classroom, you know something special is happening. CAP graduate student Jessica Guo brought together a group of Mesa high school girls, many from groups underrepresented in STEM, to learn to code in R, a computer language used for statistical analysis. Guo is passionate about coding and determined to bring more girls into STEM. Among the datasets used were LTER data from the EcoTrends site.
- Shade provided by trees has been long acknowledged as providing some relief from high daytime temperatures in the Valley of the Sun. An ASU News article on the roles of trees and lawn in ameliorating the urban heat island featured CAP scientists Ben Ruddell, Ariane Middel, and Nancy Selover. The team has worked to quantify the effects of different types of shade on urban microclimates, useful information for homeowners, urban designers, and planners.

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 1016 Tweets and have 601 followers, of whom the majority are scientists, scientific organizations and programs, and environmental and urban-focused non-profits.

We continue to use our website as our primary means of communicating broadly with the scientific community and others interested in socioecological research. We have been working on the CAP website to improve Search Engine Optimization (SEO) through employing keywords to more appropriately reflect our site's content. We will continue to monitor this and address SEO issues on the website while enhancing content and planning for a new website to be launched in early 2016.

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. We have two to three community meetings per semester, which focus on our research (usually 2-3 presentations from CAP PIs). Excellent office space, meeting facilities, and event support at GIOS have allowed us to facilitate interactions among scientists and students year round.

PLANS FOR 2016

Our research plan is articulated in our grant proposal and includes the long-term monitoring and experiment activities that we undertake every year, which are listed under Activities. New activities are listed below.

One major activity in the coming year will be to transition to a new organizational framework and a reworking of the CAP3 conceptual framework, both of which will be articulated in our upcoming renewal proposal to NSF.

We are adding four ICSO samplers to our long-term stormwater monitoring, which will expand our geographic monitoring of stormwater. We will conduct a full analysis of CNDep soil samples for cations and anions in winter 2015-2016 and summer 2016 as part of our five-year plan for this analysis. We will also be analyzing creosote (*Larrea tridentata*) leaves for metals.

We are revamping our website and moving to a new structure based on ASU web standards while maintaining our LTER identity. The new website will include: improved articulation of our long-term monitoring activities and data from these activities, enhanced information on CAP projects, an expansion of resources for undergraduate and graduate students, and better access to CAP's K-12 education resources. Longer term goals for the website include the creation of a relational structure among projects, data, and publications that would allow users to fully explore CAP projects and their products.

In spring 2016, we will conduct the third Phoenix Area Social Survey of neighborhoods in the greater Phoenix area. In concert with this survey, we are conducting bird and vegetation surveys of selected neighborhoods in winter 2015, spring 2016, winter 2016, and spring 2017.

In the coming year, we will continue to engage our scientists and students in analyzing time series data from our long-term datasets as many of these have grown to a point where longitudinal data analysis is now possible. For example, we now have four time points in our Survey200 long-term monitoring program and will have a third time point for the Phoenix Area Social Survey in 2016. These time series data in addition to other time series data will enable us to create rich analyses of the evolving socioecology of the greater Phoenix area.

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 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 anticipate large synergies with two Sustainability Research Networks recently funded: "Urban resilience to extreme weather related events," based at ASU with CAP co-PI Redman as PI and CAP scientists Grimm and Chester as co-PIs and "Urban water innovation network," based at Colorado State University with CAP scientists Harlan and Georgescu as senior scientists. Our future scenarios work will continue with workshops planned for December 2015 and spring 2016. A dissemination event for a wide stakeholder group is planned for fall 2016.

We will be continuing our efforts to communicate science from our research in mountain parks in collaboration with our partners the McDowell Sonoran Conservancy and the Central Arizona Conservation Alliance (see below). We are funding a graduate student to work with our partners and staff to develop communication templates so that research results can be shared with park managers across the large Phoenix area mountain park system (which are managed by municipal, regional, and federal entities) on an annual basis.

In spring 2016, we plan to hold a session for graduate students and early career scientists on using online media to promote science. This is in response to feedback that indicated such a session was desired.

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 485 journal articles, 10 books, and 97 book chapters since 1998. Scientists associated with CAP, either as current contributors or former post-doctoral researchers, are included in the majority of the 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).

CAP science is very frequently cited in publications dealing with urban ecology and highly cited in the broad socioecological field. A recent 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 six CAP publications were listed as "Highly Cited Papers" in the field of Environment/Ecology (Grimm et al. 2008; Mulholland et al. 2008; Shochat et al. 2008; Wu 2013; Groffman et al. 2014; Beaulieu et al. 2011) and six were similarly listed for the Social Sciences (Liu et al. 2007; Harlan et al. 2006; Middel et al. 2014; Fan and Myint 2014; Wu 2013; Wu 2014). 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 842 times.

Our other major contributions to date are:

- Climate, vegetation, and social equality: A highly integrated and interdisciplinary set of studies from CAP LTER and other leveraged projects has exposed the complicated interactions among the distribution of vegetation, with its requirement for high rates of outdoor water use, the spatial variation of the urban heat island (UHI), the incomes and housing values of residents, and the disproportionate vulnerability of poor and minority segments of the population to extreme heat. Studies have also focused on how these disparities could be ameliorated with vegetation choices that can modify microclimate, but with tradeoffs associated with water use.
- Perceptions about the local environment are related to residential landscape decisions, parcel to neighborhood ecological properties, and economic value: Our longitudinal

survey (PASS) reveals that people's attitudes and perceptions about the environment do influence their behavior, sometimes in surprising ways. Our economic modeling has shown that in many cases homeowners are willing to pay for proximity to amenities, such as artificial lakes and parks.

- Not just structural, but functional differences between urban and desert habitats: While many studies have documented reduced, or sometimes enhanced, biodiversity in the city, CAP researchers have focused on the mechanisms that explain observed patterns. For example, birds are not food-limited and may experience much greater interspecific competition in the city. The urban heat island effect (UHI) may accelerate phenology in both plants and animals. And community and ecosystem processes in urban desert parks are different from those of the surrounding desert, even though their outward appearance is similar.
- Urban ecosystems are dominated by designed and built components, yet the functions and services they yield are not always as intended: We have found that urban areas can and do provide habitat for wildlife, that stormwater infrastructure design determines water and nutrient retention and transport, that unplanned urban riparian habitats are more diverse than planned ones, and that designed ecosystems such as treatment wetlands perform better in our arid city than we expected. These are just some of the findings that have lead CAP researchers to emphasize the key interactions among infrastructure, ecosystems, and society.

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). CAP publications from 2007-2011 appeared in journals covering 48 disciplinary areas, defined by the Thomson Reuters Web of Knowledge. Of these disciplinary areas, 53% were in the natural sciences, 23% in social sciences, 15% in physical sciences, 4% in engineering sciences, and 5% in other disciplines. We will be undertaking a similar analysis shortly and anticipate that the results will show that while a large number of CAP publications are in the natural sciences and in ecology journals specifically, our collaborations across disciplines have resulted in our research touching many fields of study.

Our success in leveraging over $83 million in grants since 1997 is because of the multidisciplinarity that has been a part of CAP since its inception. Some of these grants have been for projects centered in the ecological and biological sciences, but the majority has supported multidisciplinary efforts. While we have not collected systematic data on the impact

of CAP on urban-based research and socioecological research in general, anecdotal evidence plus our leveraged funding record points to a fairly significant influence. Comments on Twitter from a former post-doc, "I learned about social science @CAPLTER," remarks in the hallway from an ecology professor, "… if it wasn't for CAP, I wouldn't have started collaborating with a geographer," an email from faculty team representing three disciplines celebrating a significant new grants, "… we all started collaborating through CAP," and a remark from a social science faculty member, "I tell all my grad students to get involved in CAP," all indicate that CAP has been influential in stimulating cross-disciplinary collaboration.

Impact on Development of Human Resources

During the 2014-2015 academic year and summer 2015, we supported four REU students pursuing a variety of projects from analyzing residential landscaping data from our long-term social survey to a long-term analysis of biodiversity patterns, land-use, and climate anomalies on urban community structure. Since 2011, we have funded 32 students to work with our scientists as either summer or academic year REU participants. Since 2011 our REU participants have been co-authors on 10 journal publications:

In 2015, our graduate grants program competitively granted $18,000 to support research of five graduate students. Since 2011, we have awarded grants of up to $6000 to 42 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.

In our Ecology Explorers outreach program, we send undergraduate interns and graduate student workers into classrooms, after school programs, and to public events to lead lessons on urban ecology. Each new intern or student worker begins her/his work with an overview of basic ecology principals and becoming familiar with the Ecology Explorers curriculum. Throughout the semester the students practice, discuss, and refine their pedagogical skills. Gina Hupton and Monica Elser mentored the students in learning about classroom and public event presentation skills in the fall and spring. New employee, Lisa Herrmann assisted in the spring semester. During the summer of 2015, graduate students Jorge Ramos and Nicholas Weller assisted with the Ecology Explorers Urban and Field Ecology Teacher Workshop.

Graduate student, Jessica Guo, created a new lesson using data from CAP LTER study site, Indian Bend Wash—this lesson was presented at the Urban and Field Ecology Workshop.

We have continued to work with teachers as they implement Ecology Explorers in their classroom. This summer, 17 teachers participated in the Urban and Field Ecology Workshop. Our team also assisted with leading a variety of urban ecology lessons at the inaugural Walton Sustainability Teacher's Academy. Twenty-eight teachers participated in the first academy session in June and 25 teachers will participate in the July workshop. Additionally Jessica Guo's lesson and the UHI Heat Illness unit were shared with 25 teachers at the annual Advanced Water Educator Workshop sponsored by the Decision Center for a Desert City.

The on-line Urban Ecology module for Teachers was made available to those teachers who were unable to attend the Urban and Field Ecology Workshop (40 applicants, only 17 admitted). We will also be using the module to train our incoming undergraduate interns.

We offered a one-day teacher workshop with the McDowell Sonoran Conservancy in Fall 2014. We worked closely with the Conservancy personnel to design and run the workshop that introduced local teachers to the citizen science projects being run by Conservancy volunteers including a CAP LTER arthropod pitfall trapping protocol. Eighteen middle and high school teachers from the Scottsdale Unified School District attended the workshop.

We have been involved in developing the new Walton National Sustainability Teacher's Academy and shared a variety of Ecology Explorer curriculum with the teachers. The first week-long academy in June had 28 middle school teachers from across the country and the second week-long academy in July had 25 middle school teachers, the majority from Arizona. Additionally, Monica Palta and Nich Weller spoke about CAP LTER research projects to the teachers.

Lisa Herrmann presented Ecology Explorers activities to the Arizona Center for STEM Teachers (ACST) summer institute. The institute hosted 40 1st-5th grade teachers equipping and training them on how to incorporate science, technology, engineering, and mathematics into their classrooms. Additionally, Lisa participated in two meetings of various stakeholder organizations across Arizona convened by the Arizona Association for Environmental Education to participate in efforts toward the development of a statewide Environmental Literacy Plan.

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.

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 gas analyzer for the GEL lab, which addresses a need of several CAP scientists for this type of analytical instrument.

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

During this grant cycle, CAP has been instrumental in establishing the Central Arizona Conservation Alliance http://mymountainparks.org/ with the Desert Botanical Garden and other public and non-profit partners in the Phoenix area. CAP has contributed to the establishment of a monitoring program at the McDowell-Sonoran Preserve and is a key partner with the McDowell Sonoran Conservancy.

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 funding from NSF.

Our Ecology Explorers program has contributed to new resources for teachers, included an on-line urban ecology course for teachers: https://pll.asu.edu/p/class/orc-ecologyexplorers1

Impact on Information Resources

The CAP LTER publishes data via multiple avenues to maximize the availability and discoverability of our research products. We maintain a local data catalog on the CAP LTER website (http://caplter.asu.edu/data/data-catalog/), 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, seven new datasets have been published in 2015 in addition to new data being added to our long-term monitoring datasets. Recent submissions of note include a long-term (> 15 y) record of water quality in the drinking water supply system of the greater Phoenix metropolitan area that is a collaborative effort among several University departments and regional municipalities; neighborhood-scale temperature data stemming from a collaboration with NASA; and land-use/land-cover (LULC) classifications of the entire CAP LTER study area derived from multiple sources reflecting different scales of analysis, including Landsat and the National Agricultural Imagery Program (NAIP) imagery.

All publicly accessible data have now been migrated into the LTER NIS, and new submissions are routed to that resource as well as the local data catalog. The NIS is based upon an architecture that accommodates both data and metadata (PASTA), and provides quality checking as an integral feature of dataset submission. This feature helps to insure the quality of our data publications.

The Julie Ann Wrigley Global Institute of Sustainability informatics team continues to make improvements in the management of our live and published data. The team is developing workflows intended to improve submission rates, and metadata and data quality. A proposed workflow focuses on working with graduate students and project investigators early in their programs and projects to provide guidance regarding sound data management. Nascent collaborative tools, such as the Open Science Framework (https://osf.io/), 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. These tools and workflows provide a single source of the information needed for metadata preparation, help to ensure project continuity, and facilitate interaction with the CAP LTER information manager throughout the life of the project.

Proposed to coincide with the start of the start of CAP IV 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 team is committed to active participation in the LTER network. Both the current (S. Earl) and former (P. Tarrant) information managers are contributing to the Network Information Management Office (NIMO) initiative, and Tarrant remains the co-chair of the LTER Information Management Committee.

Impact on Society beyond Science and Technology

Through out-of-school time programs and events, we have reached over 1700 students and community members with our presentations and displays on urban ecology during our 2014-2015 grant year. This year we put more effort into direct contact with students through working with a variety of teachers and classrooms throughout the Valley. Ecology Explorers staff, our teacher consultant, and our student interns designed and delivered these lessons.

We have continued our collaboration with Homeward Bound, a transitional housing community, providing after school urban ecology and sustainability science programs for pre-K through 5th grade. A recent Tweet acknowledged our work: *The children are loving learning about birds and creating bird feeders to hang around campus! Thanks @caplter*

We partnered with the City of Phoenix to work with Wilson School District students as the cities invests in green infrastructure in this low socio-economic status neighborhood. In spring 2015, undergraduate and graduate students, as well as staff member Lisa Herrmann and scientist Nancy Selover, presented 4 sessions related to understanding the urban heat island to 2 classrooms of 6th grade students. We will continue to provide programing related to urban biodiversity for 7th grade students in Fall 2015.

This year we have continued to put effort into direct contact with students by working with a variety of teachers and classrooms throughout the Valley. Classroom presenters included Gina Hupton and John Dole (teacher consultant). We supported a continuing UHI program with 15 kids from the summer UHI engineering camp at Kyrene del Pueblo. These students learned about designing a sustainable neighborhood and presented their work at ASU's Night of the Open Door.

In summer 2015, we continued to work with colleagues at ASU to offer summer camp opportunities for students. Lisa Herrmann and grad student, Nich Weller, taught the urban ecology portions of the ASU Deer Valley Petroglyph Preserve's summer camp. We also co-offered two one-week camp on the Urban Heat Island in conjunction with ASU's School of Engineering. Additionally we shared our UHI material with a teacher from the Kyrene School district who also presented this during a summer camp within the district.

In CAP3 our central research question evolved to encompass an explicit consideration of sustainability in the urban system. Accordingly, many of our research and outreach activities have included a sustainability focus, although our long-term data collection remains focused on answering some basic questions about characterizing the urban environment. We have sought to create and enhance partnerships to create and share scientific knowledge toward urban sustainability:

- Central Arizona Conservation Alliance (CAZCA): CAP is a partner with the Desert Botanical Garden and several public and non-profit agencies focused on the conservation of the mountain parks that surround and are in the Phoenix metropolitan area. Work new to 2015 is to summarize existing research on local mountain parks in a format that is easily understood by our partner organizations and can be used to inform improved policies and practices. During spring 2015, we worked with CAZCA in selected mountain parks on the citizen science Wildflower Survey associated with our CNDep project. CAZCA trained citizen botanists who worked with CAP staff on this effort. We will continue this work in 2016. We featured this work when we participated in the CAZCA exhibit during the Desert Botanical Garden's open day in April 2015. Arizona Forward and the Salt River Project recognized the considerable work already done by CAZCA by naming the organization as a finalist for the 2015 "**Governor's Award for Arizona's Future**" as part of the 35th Annual Environmental Excellence Awards.
- McDowell Sonoran Conservancy (MSC): CAP's involvement with this non-profit began with our contribution to their 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. New work initiated in 2015 in conjunction with CAZCA (see above) focused on collaborating with MSC's Field Institute on communicating science conducted in the McDowell Sonoran Preserve. CAP had a significant presence at the first McDowell Sonoran Preserve Research Symposium in October 2015. CAP scientist Sharon Hall was a keynote speaker and CAP information manager (former site manager) Stevan Earl presented the results of several years of arthropod monitoring in the Preserve. A number of CAP students and faculty presented posters during the symposium.
- Urban Tree Community Science: To date, we have had over 400 people respond to our survey on urban shade trees. Long-term data collected through the Urban Tree

Community Science initiative will enable CAP scientists, Valley Permaculture Alliance staff and volunteers, and Salt River Project staff to better understand the effectiveness of tree planting programs in the Valley, tree health and mortality, how households care for trees, and the ecosystem services associated with trees. We have shared some initial survey findings with participants and our partner organizations and with the public through our webpage, https://caplter.asu.edu/outreach/shadetree/ . One new initiative is having citizen scientists share photos of their trees, which we then post on the website.

- Arizona Department of Transportation: CAP partnered with the Arizona Department of Transportation on the "Extreme weather vulnerability assessment" project, funded by the Federal Highway Administration under the Federal Highway Administration Climate Change Resilience Pilot program. The study assessed the vulnerability of transportation infrastructure along the Nogales-Flagstaff corridor to extreme weather. CAP provided support for the scientific stakeholders meeting, and CAP scientists Nancy Grimm and Nancy Selover participated in the meeting.
- P-Futures: CAP post-doc David Iwaniec is a co-investigator and co-leader of this cross-city initiative, which examines how food systems can cope and transform in the face of the emerging phosphorus challenge http://www.p-futurescities.net/the-p-futures-project/
- Efforts with the Walton Sustainability Solutions Initiative and the Sustainable Cities Network: CAP is a partner at the table with two initiatives in the Julie Ann Wrigley Global Institute of Sustainability, the Walton Sustainability Solutions Initiative (WSSI) and the Sustainable Cities Network (SCN). With the WSSI, a consulting initiative focused on putting together academic expertise with the needs of municipalities, businesses, and nonprofits, we have met with WSSI staff and potential clients to scope out ventures and point to CAP human and technical resources. WSSI's work with the City of Tempe on mapping the urban forest has made use of CAP's 1m land cover data (Middel et al. 2014 report to City of Tempe). With the Sustainable Cities initiative, CAP attends the green infrastructure meetings to better understand the needs of cities in this area and to meet with potential collaborators.