CAP3: Urban Sustainability in the Dynamic Environment of Central Arizona

2011 Annual Report to the National Science Foundation

Compiled by the CAP LTER Management Team

CAP LTER PHASE 3 - 2011
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CAP3: URBAN SUSTAINABILITY IN THE DYNAMIC ENVIRONMENT OF CENTRAL ARIZONA

I. Overview of Results and Transformative Research

Overview

Phase 3 of the Central Arizona–Phoenix (CAP) Long-Term Ecological Research project includes a new focus on urban sustainability while continuing a tradition of interdisciplinary research focused on metropolitan Phoenix and the surrounding desert. As one of two urban sites funded in the US LTER network, CAP is advancing knowledge and theory in urban ecology (Grimm and Redman 2004; Grimm et al. 2008a; Wu 2008a, b) and, with other scientists globally, expanding the horizons of research on socioecological systems (SES; Redman et al. 2004; Haberl et al. 2006; Costanza et al. 2007; J. Liu et al. 2007a, b; Grimm et al. 2008b).

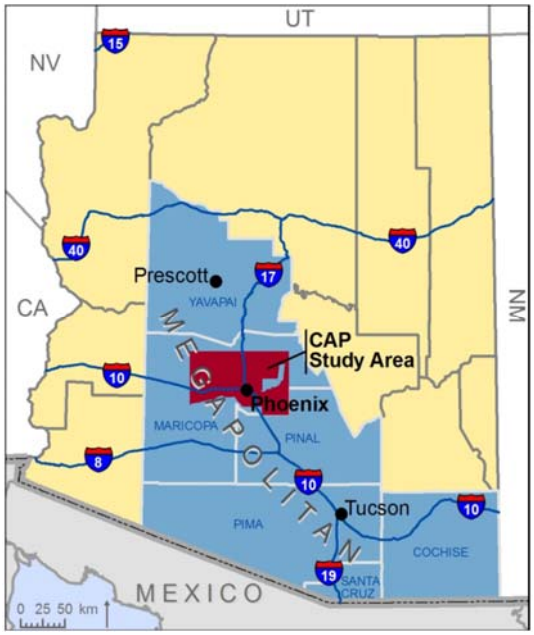

Figure 1. Map of Arizona, USA, showing extent of the Sun Corridor Megapolitan (blue shading) and the CAP study area within it (red shading). Gray lines are county boundaries.

The 6,400-km^2 CAP study area in central Arizona incorporates metropolitan Phoenix, surrounding Sonoran Desert scrub, and rapidly disappearing agricultural fields (Fig. 1). Rapid urbanization has been the dominant land change since the 1950s, accompanied by an order-of-magnitude increase in population. Coincident with rapid population growth, the rise of automobile transportation has led to air pollution and other problems that influence quality of life. Freshwater resources have been appropriated to support first agriculture and later urban development. Native desert vegetation has given way to mostly non-native species maintained by irrigation, affecting biodiversity at higher trophic levels. Most recently, the region has been hit by a severe economic crisis and by the growing politicization of immigration. This context has provided fertile ground for SES research on land-use and land cover change, climate-ecosystem interactions, water use, altered biogeochemical cycles, and biodiversity.

Key Results

- **CAP advances understanding of urban socioecological systems.** CAP participants have published 408 journal articles, books, and book chapters since the project's inception in 1997 (Fig. 2).

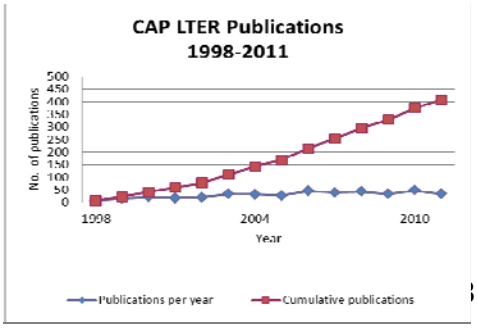

Figure 2. Annual and cumulative publications, 1998-2011.

- **CAP faculty engages in interdisciplinary collaboration.** CAP3 involves 57 faculty members from over 10 academic units at Arizona State University and eight universities across the United States, reflecting a large range of traditional disciplines in the academy.
- **Students participate in urban socioecological research.** 37 graduate students have served as CAP3 participants along with 14 undergraduate students, 8 of whom participated in the Research Experience for Undergraduates (REU) program.
- **Students advance scientific knowledge.** Since 2004, students have been authors on 109 publications (published, in press, and in review); for 70 of these publications, the student was the first author.
- **Funding secured for urban socioecological research.** Over $49 million in funding associated with CAP since 1997, 3.25 times our core funding from NSF, has created a rich interdisciplinary community at Arizona State University (ASU) focused on urbanization and sustainability in central Arizona and beyond.
- **CAP research impacts K-12 curriculum.** CAP LTER's program at the K-12 level, Ecology Explorers, trained 30 middle-school teachers from 8 school districts during 2011, potentially impacting thousands of middle-school students.
- **New community partnerships formed.** During 2010-2011, CAP initiated work on projects with new community partners, including the Nina Mason Pulliam Rio Salado Audubon Center, the City of Phoenix Water Department, the McDowell Sonoran Conservancy, and the Valley Permaculture Alliance, in addition to 17 existing partnerships.
- **Collaboration initiated across LTER sites.** CAP scientists have been actively collaborating with colleagues across the LTER Network to conduct cross-site research, mostly in the area of comparative urban socioecological research. Recently funded collaborative research includes the "Ecological homogenization of America" project involving CAP, PIE, FCE, BES, CDR and Los Angeles and the "Urban Sustainability RCN" program involving CAP, BES, CWT, FCE, PIE, and a number of ULTRA-Ex programs.

Transformative Research

1. **CAP LTER has developed new theory and knowledge at the intersection of ecology and social science research that has changed the way people – including scientists – perceive the natural environment in the city.**

For most of ecology's history as a discipline – and for the first 15 years of the LTER Network's existence – the focus of study was on pristine, wildland sites. Urban areas were seen as human-disturbed places less worthy of investigation. Urban ecology experienced a paradigm shift in the latter part of the 20th century, when it began to focus on the structure and function of cities as ecosystems. Research at the two LTER sites in the Phoenix and Baltimore metropolitan areas since 1997 has facilitated this growth in the study of urban ecosystems.

CAP LTER has been a leader in a burgeoning understanding of urban socio-ecological systems, and by extension, the broad integration of social and ecological studies. In the process, CAP has led a transformation in education and graduate training that truly integrates disparate disciplines with an emphasis on problem-solving in cities. This, of course, is a primary tenet of sustainability science. This transformation has extended to K-12 education through our award-winning Ecology Explorers program.

2. **CAP climate researchers and social scientists discovered that the extent to which neighborhoods are affected by extreme heat varies according to both physical and demographic characteristics.**

The Urban Heat Island Effect (UHI) is when a city is significantly warmer than the outlying rural area due to the preponderance of concrete and asphalt surfaces that store heat during the day and release it at night and to the concentration of heat-generating energy-intensive processes. While urban heat islands exist in most large cities, the Phoenix metropolitan area has presented a special case for the study of this phenomenon because of its rapid growth over the last 30 years and the already high summertime temperatures experienced in the valleys of the Sonoran Desert.

The emergence and intensification of Phoenix's UHI represents an important stressor on humans in the city. CAP researchers found that the UHI varies greatly in space, mirroring the physical heterogeneity of the urban landscape. Variations in amounts and distributions of soil, impervious surface, and vegetation in urban and suburban areas can either exacerbate or ameliorate the UHI. Superimposed on this are spatially variable demographic characteristics of the human population. As a result, extreme temperatures are distributed unevenly among neighborhoods, with minority, low-income, and elderly residents at greatest risk for exposure to high heat.

3. **Understanding how urban ecosystems function provides knowledge to urban planners who design urban systems for public benefit.**

Ecosystem services are the benefits that people derive from their life-supporting environment. These include the "goods" that nature provides to us (i.e. food, water, fiber, energy) as well as soil fertility, regulation of air and water quality, pest control, recreation, and aesthetics. Natural systems deliver these services, but humans have also designed or engineered ecosystems to deliver specific services. This ecosystem design is a particular characteristic of cities.

CAP research has found both intended and unintended ecosystem services associated with highly engineered aquatic systems in the urban environment (e.g., systems for water delivery, storm water removal, and wastewater processing). Parks along flood "greenways," such as Indian Bend Wash in Scottsdale, Arizona, are excellent examples. In addition to their obvious recreational value and capacity to absorb or ameliorate floods, these parks are also efficient at removing nutrients and contaminants from floodwater. Retention basins, established for flood management, double as recreational spaces and nutrient removal systems. Other engineered aquatic ecosystems, however, do not provide benefits beyond those for which they were originally designed (e.g. concrete stormwater spillways). Awareness of the potential benefits of ecosystem functions increases the potential for urban planners and policymakers to design systems that optimize the ecosystem services delivered to the public.

4. **Using long-term data sets, CAP research has extended tests of plant and animal diversity theory to urban environments where people's choices and actions are pervasive.**

Most ecological theories are based on ecological patterns and processes in non-urban and less human-dominated environments. As cities grow and the global population becomes more urban,

ecologists need to test their theories in urban settings and either modify them or develop new ones to reflect the ecology of cities.

CAP scientists have used the special characteristics of urban food webs (i.e. trophic dynamics) to test long-standing ecological theories about organismal interactions, biodiversity, and the assembly of communities. In particular, diversity patterns of birds and some arthropods in urban ecosystems suggest that exotic and invasive species associated with human settlements (e.g. pigeons and grackles) often outcompete native species that could otherwise inhabit cities. In Phoenix, the diversity of plants is actually higher in the city compared with the surrounding Sonoran desert ecosystems because people have introduced many species to create the desert "oasis city." Long-term data sets have allowed CAP researchers to investigate these changes over time as the Phoenix metropolitan area has grown.

5. LTER investigations across urban sites in the Phoenix, Baltimore, and Boston metropolitan areas have revealed that household decision-making and income influence species diversity in residential landscapes.

Residential landscapes are a critical ecological feature of the urban ecosystem because they are widespread and are made up of highly designed and managed combinations of plants (e.g., landscaping) and animals (e.g., pets). For example, as Phoenix has urbanized, native Sonoran desert ecosystems have been replaced by an "urban oasis" that includes both lush, watered environments and carefully managed desert-like landscapes. CAP's socio-ecological research evaluates the household decision-making, perceptions, and priorities that result in particular residential landscapes.

LTER research at the CAP, BES, and PIE sites reveals numerous complex interactions between social and ecological systems that occur at the scales of households and neighborhoods. Researchers have shown that: 1) household income is correlated with plant and bird diversity; 2) people tend to manage their front yards and back yards differently due to social considerations, and 3) preferences and attitudes for residential landscapes depend, in part, on history, gender, culture, and economics.

II. Research Activities

Central Research Question

In CAP3, we focus on the following research question:

> *How do the services provided by evolving urban ecosystems affect human outcomes and behavior, and how does human action (response) alter patterns of ecosystem structure and function and, ultimately, urban sustainability, in a dynamic environment?*

Conceptual Framework

Building on the framework proposed for the Integrative Science for Society and the Environment (ISSE) initiative (Collins et al. 2011), we developed a conceptual framework for CAP2/3 that reflected our need for a dynamic, potentially multi-scalar framework for describing the urban socioecological system in Central Arizona (Figure 3).

Foundational and Crosscutting Projects

Characterizing Land Use, Land Cover, and Land Architecture

The CAP3 proposal outlines three scales of land classification that are foundational for CAP research: parcel, metropolitan, and megapolitan. The Environmental Remote Sensing and Geoinformatics Lab (ERSAG) has completed work on parcel-scale classification of the City of Phoenix, using Quickbird data (2.4 m resolution, multispectral data), as part of a joint project for CAP and the NSF-funded Decision Center for a Desert City. Using object-based image analysis, members of the ERSAG lab classified images into seven land-cover classes: buildings, impervious surfaces, soil, grass, pools, water, and trees and shrubs. These classes are consistent

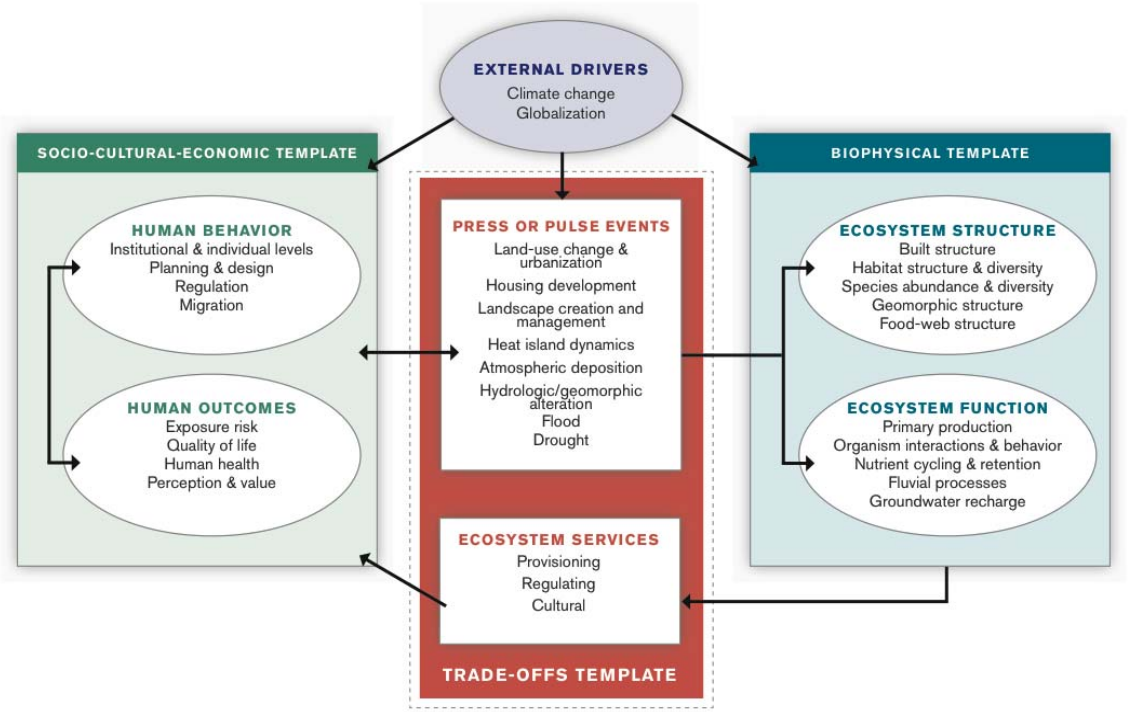

Figure 3. In CAP2, we adopted a slightly modified version of the Integrative Science for Society and the Environment (ISSE) conceptual model (Collins et al. 2011) as an expression of our conceptual framework for understanding urban socio-ecological systems.

with those used in CAP cross-site research initiatives, such as the residential landscapes work (see end of section), and with land classifications at the BES, FCE, and PIE sites. While the near infrared band in the Quickbird data makes it ideal for classification work, the cost of these data are prohibitive. Thus, the lab team is now using the free National Agriculture Imagery Program (NAIP) data to complete parcel-scale classification for the rest of the CAP study area. These 1 m. spatial resolution data have the advantage of greater resolution but lack the near infrared band. The ERSAG lab has begun classification of the NAIP images for Scottsdale, the location of CAP's stormwater research.

Research on land use and land cover has included studies of urban agriculture, both commercial operations on the rural-urban fringe and urban community gardens. One body of research is centered on the recent changes in the price of key agricultural commodities on the dynamics of peri-urban agriculture, particularly on irrigation use. The long-term goal of this research is to understand the feedbacks between urban and agricultural systems and how these adapt to changes in underlying economic and biophysical conditions. Community garden research (Bleasdale et al. 2011), led mostly by CAP students, has examined the social and organizational challenges of these efforts in the Phoenix metropolitan area, which, unlike areas such as New York, Seattle, and Los Angeles, does not have a long tradition of community gardening. Related research on urban food systems (Taylor and Aggarwal 2010) has explored local food value chains in the Phoenix metropolitan area.

CAP research has also investigated drivers of urban landscapes and the urban form. This includes work on urban codes and zoning (Talen in press), residential landscapes in greater Phoenix (Cook et al. in press), and land fragmentation in Phoenix (Shrestha et al. 2011). The latter two studies are part of larger cross-LTER site initiatives described at the end of this section.

North Desert Village Experimental Suburb

The NDV community landscape experiment at ASU's Polytechnic campus was designed to give a platform for CAP LTER researchers to study human–landscape interactions. In summer 2005, we established four residential landscape design/water delivery types in blocks of six households each (mini-neighborhoods) to recreate the four prevailing residential landscape types found across the study area during the last five years of research (Martin et al. 2003; Cook et al. 2004). These were:

- Mesic/flood irrigation: a mixture of exotic high water-use vegetation and shade trees with turf grass.
- Oasis: a mixture of drip-watered, high and low water-use plants on granite substrate, and sprinkler-irrigated turf grass.
- Xeric: individually watered, low water-use exotic and native plants on granite substrate.
- Native: native Sonoran Desert plants on granite substrate and no supplemental water.

We monitored an additional mini-neighborhood as a no-plant, no-water control.

During spring 2006, we installed micrometeorological stations in the central common area of each treatment. For five years, we have monitored soil temperature, soil heat flux, volumetric water content of soil at 30 cm depth, air temperature at 2 m height and soil-surface temperature (recorded by an infrared thermometer at 2 m height) regularly as well as landscape irrigation application volumes. Two publications (Martin et al. 2007; Martin 2008) and one thesis (Busse

2010) analyze aspects of this monitoring. We have conducted two social surveys of NDV residents, one before we installed landscape treatments and the other post-treatment (Casagrande et al. 2007; Larson et al. 2009; Yabiku et al. 2008). Ongoing research explores the sustainability of NDV treatment landscapes (Martin 2008).

Survey 200

The Survey 200 is an extensive field survey that provides a snapshot of broad-scale spatial variations in key ecological variables across the CAP region. Designed to be repeated every five years, it also is a central component of CAP's observations of ecosystem change over time. Launched in 2000, CAP technicians and managers completed the third iteration of the Survey in 2010. Measurements at each of the ~200 established 30x30m study plots include:

- Plants identified to the lowest taxonomic level, usually species
- Plant size measurements for biovolume calculations
- Mapping of built and vegetation structures
- Soil coring for physicochemical analyses
- Insect sweep-net sampling
- Mycorrhizal diversity (2000)
- Photo documentation
- Tree health (2010)

An added component of the 2010 Survey included measurements collected at the parcel level at locations where study plots fell in residential areas. Parcel-level measurements included a survey of the vegetation, and a detailed assessment of front- and back-yard characteristics. These additional measurements complement CAP's residential landscape research, which will move forward through a new, cross-site NSF grant, "Ecological homogenization of urban America." CAP technicians are processing the extensive number of soil samples collected during the recent survey and are working with the data manager to make survey data available to investigators.

CAP scientists have used Survey 200 data from both the 2000 and 2005 surveys in numerous studies (Bang and Faeth in press; Bang et al. in press; Dugan et al. 2007; Hope et al. 2003, 2005, 2006; Kaye et al. 2008; Oleson et al. 2006; Stuart et al. 2006; Majumdar et al. 2011, 2010, 2008; Walker et al. 2009; Zhu et al. 2006). Ongoing work using Survey 200 data includes research on black carbon in Phoenix soils (Hamilton and Hartnett. in prep.), work on the spatial distribution of varying levels of vegetation C and NPP (McHale and Majumdar. in prep.), and investigations quantifying the spatiotemporal dynamics and resilience of vegetation.

Phoenix Area Social Survey

The primary goal of PASS is to increase our knowledge of how human behavior shapes the dynamics of an urban socioecosystem, including the feedbacks of ecosystem processes to human health and well-being (Harlan et al. 2003; Harlan et al. 2007). The survey questions ask about human perceptions, values, and behaviors concerning climate, water, land use, air quality, biodiversity, and health. PASS is comparable to the Survey 200 as a major component of our long-term observational program. The survey design will enable us to track changes in attitudes

and behaviors over five-year intervals beginning with the pilot survey conducted in 2001-2002 and the first full administration in 2006.

A Steering Committee of 12 scientists, representing a range of social and biophysical disciplines, designed PASS 2011 to sample 45 neighborhoods and 20 respondents from each neighborhood for a total of 900 respondents. We retained the 2006 sample of 40 neighborhoods (defined as Census block groups and co-located with Survey 200 sites) and the 2006 sample of responding households in the 2011 sample in order to facilitate trend analysis. The original 2006 households that do not respond in 2011 will be replaced with new randomly selected households in the same neighborhoods. We received a LTER supplement for the purpose of increasing response rates among Spanish-speakers and people with low educational attainment in the 2011 survey, which enabled us to add four primarily minority neighborhoods to our sample. Three of these neighborhoods are co-located with Survey 200 sites and one is the site of community research for the NSF-funded "Urban Vulnerability to Climate Change" project. We added a fifth new neighborhood, which is a research site for another CAP-related NSF-funded grant, "Assessing Decadal Climate Change Impacts on Urban Populations in the Southwestern USA."

PASS 2011 is a 30-40 minute questionnaire that respondents may choose to complete online, over the telephone, or in person with an interviewer present. We have hired the Institute for Social Science Research (ISSR) at ASU to administer the survey, which began in May 2011 and will end in November 2011. We developed an elaborate marketing campaign directed to sampled households with the goal of achieving a 50 percent response rate in each sample neighborhood. PASS 2011retains some questions from the earlier two surveys, allowing for longitudinal analysis. We added new content on the impacts of the economic downturn in 2008, support for sustainable public and private household behaviors, urban agriculture, household food security and neighborhood food environments.

We received permission from NSF to conduct an experiment with the incentive payments offered to PASS participants, which will provide new data on how to increase survey response rates. ISSR staff randomly assigned PASS 2011 sample households to one of nine treatment groups that offered varying amounts of cash incentives ($10, $20, or $30) for completing the survey or varying amounts ($10, $20, or $30) donated to the local food bank or a personal choice about receiving the cash or having the money donated ($10, $20, or $30). We will analyze these data to determine optimum incentives to achieve high response rates.

PASS 2011, like the previous surveys in 2001-02 and 2006, will spatially link household responses with the most recently available population characteristics of census block groups and with ecological data at the parcel and block group scales. Ancillary spatial datasets, such as land cover, temperature, air quality, and water consumption have been joined to PASS in the past. We will join real estate data on foreclosures and home abandonment to the 2011 survey. The sampling strategy and the geographical linkages with other datasets make PASS an important vehicle for interdisciplinary collaborations among CAP LTER social and biophysical scientists.

Integrative Project Areas

Beginning in CAP2, we organized our research into Integrative Project Areas (IPAs) that integrate social and ecological elements of the urban system (Redman et al. 2004). In CAP3, we continue with this organization of our research, although the Land Use and Land Cover Change

(LULCC) IPA has now become a foundational activity (see above). New IPA titles and research questions reflect our lessons learned under CAP2 and the new research we intend to undertake.

Climate, Ecosystems, and People

The goal of this IPA is to understand interactions among the urban and urban-hinterland climate, ecosystems, and social systems, with a particular emphasis on understanding the ramifications of the UHI effect and extreme heat events in the Valley on human health and well-being. Research focuses on three main questions:

- *How does local climate influence ecosystem function and structure and consequently the provision or alteration of microclimate-related ecosystem services?*
- *What are the public perceptions of local climate and associated ecosystem services, and what tradeoffs would people make to enhance or avoid declines in the levels of these services?*
- *How does a spatially heterogeneous pattern of regional temperatures affect the distribution of ecosystem services and create health disparities among different social groups?*

In this report, we present findings from research on the urban heat island, related to the above research questions:

- Xeriscaping and urban heat
- Rural and urban heat fluctuations
- Perceptions of neighborhood and regional heat

New research activities include investigations using data from the energy budget flux tower constructed in a west Phoenix neighborhood, which also contributes data to the Biogeochemical IPA. In addition to the eddy covariance instruments currently on the tower, other meteorological and soil flux instruments will be deployed at the tower site, enabling researchers to collect a variety of data. The 2011 **PASS** (see above) includes a suite of questions related to perceptions of heat and health issues that will enable progress on the key research questions under this IPA. The **Power Ranch** project will initiate a broadly scoped, long-term experiment and modeling exercise that can directly measure and quantify the effects of arborified areas (turf and trees) and water application practices (quantity and timing) on air temperatures, resulting in the design of policies and management systems to optimize the use of water for urban arborification and heat island management in the Phoenix metropolitan area. In doing so, it will contribute to both the Climate and Water IPAs.

Water Dynamics in a Desert City

The goal of this IPA is to understand how the management of urban water systems affects feedbacks and tradeoffs among water-related ecosystem services and how climate change and its uncertainty affect these tradeoffs. Toward that end, research focuses on the following three questions:

- *How does urbanizations alter the hydrologic connectivity of aridland ecosystems and modify watershed boundaries and configurations, and what are the consequences for ecosystem services associated with stormwater?*
- *Can riparianization be accomplished in a sustainable manner – where water use and alteration of the natural hydrologic system are minimized while also retaining related ecosystem services – during urbanization?*
- *How can we combine the virtual water concept with tradeoffs models (economic and otherwise) to quantify feedbacks among water-related ecosystem services?*

This report relates recent results from three ongoing projects, including two long-term monitoring initiatives:

- Urban stormwater
- Global Ethnohydrology Study
- Phoenix Area Social Survey

During the past year, we have initiated work on two new projects. One, an **adaptive management plan for the Tres Rios ecosystem**, involves working with the City of Phoenix to develop a management plan for a wetland that was constructed to polish effluent from the city's largest wastewater treatment facility. We are analyzing wetland function over time and creating a model detailing its ecohydrologic dynamics to assist city operators in management. We have funded two REU students to work on this project. The other new initiative focuses on the creation of a **localized virtual water model,** which sheds light on the consumptive use of water that is required to produce a good or service. A CAP graduate student began work on this long-term project this summer.

Biogeochemical Patterns, Processes, and Human Outcomes

Research under this IPA will focus on understanding how and why urban biogeochemical cycles differ from those of undeveloped systems and the consequences of those altered cycles and distribution patterns for human well-being. Our research endeavors fall under three broad questions:

- *How do urban elemental cycles at multiple scales differ qualitatively and quantitatively from those of nonurban ecosystems?*
- *What are the fates of elevated material inputs, and how do they affect ecosystem processes and the delivery of ecosystem services in recipient systems?*
- *Are ecosystem services derived from biogeochemical processes distributed inequitably and how will this distribution change over the next 5-10 years?*

In this report, we summarize recent findings from three ongoing initiatives:

- Carbon and Nitrogen Deposition Project (CN Dep)
- An investigation into polycyclic aromatic hydrocarbons along transportation corridors
- Legacies on the landscape

Among the newly-initiated projects under this IPA are efforts to analyze urban sediment sources from Indian Bend Wash, which continues our investigations in this artificial lake chain. We also are examining the dynamics of biogeochemical cycling coupled with the interactions between soil microbial communities, the belowground food web, and land-use type.

Human Decisions and Biodiversity

The overarching questions of the IPA are: How do human activities, behaviors, and willingness to make tradeoffs change biodiversity and its components? In turn, how do variations in biodiversity feed back to influence these same human perceptions, values and actions? In CAP3, we will continue bird, arthropod, and plant monitoring via our long-term monitoring efforts but will also broaden our efforts to understand the underlying processes associated with species loss and change in urban settings. We also will continue to pursue understanding of the socioeconomic and policy drivers of habitat structure and of the impact that access to things wild biodiversity has on human well-being.

- *What mechanisms explain species loss or dominance and, ultimately, biodiversity in the urban environment?*
- *Can conservation and restoration of "natural" habitats within the urban environment restore "natural" animal communities?*
- *Through what pathways do humans modify urban food webs, and how do these changes cascade through food webs to influence the delivery of ecosystem services?*

This report details results from four projects that provide a cross-section of biota found in our study area:

- Bird distribution in residential yards
- Effects of urbanization on birds and mechanisms that drive bird behavior
- Population dynamics of an urban arthropod pest species across an urban-desert gradient
- Herpetofauna in riparian communities

Emerging research includes work on riparian communities along five reaches of the Salt River, conducted in cooperation with the Rio Salado Audubon Center's Urban Naturist program and ASU's Herbarium. We will have two undergraduate research assistants in the field beginning in 2012 as we initiate work on collecting data on plants and animals in these rehabilitated urban riparian zones.

Research Synthesis and Future Scenarios of Change

Synthesis of 12 Years of CAP LTER Research

We began work in spring 2011 on the CAP synthesis volume that will bring together nearly 15 years of socioecological research in the Phoenix area. We have identified four broad themes for the volume:

- Socioecological systems
- The urban heat island and anthropogenic change

- Designer ecosystems in the city
- Environmental justice

An October workshop further defined these themes into book chapters. We will hold a retreat in January 2012 after the CAP All Scientists Meeting to continue work on the book.

Sustainable Futures for Central Arizona

The cross-cutting CAP initiative on "Sustainable Futures for Central Arizona" (SF-CAP) aims to explore future scenarios for the Central Arizona-Phoenix area considering uncertainties in the regional socioecological system as well as exogenous driver uncertainty (e.g., climate change). As an initial activity within the SF-CAP stream, a pilot study was conducted to generate insights on how to design the content, process, and format of the main scenario study. We anticipate that this pilot study will allow us to apply a new research framework that combines social-ecological systems research with future-oriented sustainability science.

The SF-CAP pilot project was integrated into a larger research project entitled "The Future of Phoenix – Crafting Sustainable Development Strategies" which was composed of several activities including student research and an interdisciplinary graduate workshop as well as sustainability-oriented intervention research in small-scale communities in Phoenix. At the city level, the pilot project resulted in a sustainable future vision for Phoenix that reflected the preferences and values of a broad range of regional stakeholders, and a set of contrasting, less sustainable future scenarios that reflected the perceived uncertainties inherent in Phoenix' social-ecological system.

The SF-CAP pilot study applied a methodology that combines the crafting of a sustainable future vision (Carpenter and Folke, 2006) with the construction of a set of contrasting, less sustainable future scenarios (Wiek et al., 2006; Shaw et al., 2009). The SF-CAP pilot project was integrated into a systematic comparison among scenario studies conducted at LTER sites (Thompson et al., in review). The comparison was intended to highlight similarities and differences of future-oriented LTER research and to evaluate strengths and weaknesses of the applied scenario methodologies in order to guide and coordinate future scenario research with the LTER network.

Cross-LTER Site Research

While comparative urbanism has resurged in popularity (Nijman 2007), comparative studies of cities as socioecological systems are largely absent from the literature. We have collaborated with other LTER sites to advance comparative urban socioecological research through a set of initiatives, which are funded largely through LTER supplements and leveraged grants. These include:

- **Land fragmentation** (CAP, SEV, JRN, SGS, and KNZ): Examines land fragmentation patterns across the five urban areas associated with the LTER sites.
- **Urban residential landscapes** (CAP, PIE, FCE and BES): Focuses on understanding the form and drivers of urban residential landscapes as socioecological systems.

- **Cross-site zoning and land use** (CAP, BES, and FCE): Investigates the relationship between zoning and land use, focusing on environmental justice and land use change during the 20th century.
- **ULTRA Ex Land and water use decision-making and ecosystem services** (CAP, JRN, SEV): Focuses on perception, valuation, and management of ecosystem services in open spaces across three Southwestern cities.
- **Ecological homogenization of America** (CAP, PIE, FCE, BES, CDR and Los Angeles): Tests hypothesis of whether similar management practices across cities leads to homogenization in ecological structure and functions relevant to ecosystem carbon and nitrogen dynamics.
- **RCN-SEES for urban sustainability** (CAP, BES, FCE, PIE, and other cities): Integrates and synthesizes urban research while incubating solutions-oriented products.

Other cross-site initiatives involving CAP scientists are:

- **Scenarios of Change** (numerous LTER sites): Examines scenarios of land-use change.
- **Maps and Locals (MALS)** (numerous LTER sites): Investigates socioecological systems using a mixed methods comparative approach, including spatial analysis and ethnography.

III. Highlights of Research Findings

Climate, Ecosystems, and People

We have long studied the **urban heat island effect** (UHI) in the Phoenix metropolitan area, which exacerbates the already extreme summertime heat in the "Valley of the Sun" (Baker et al. 2002; Brazel et al. 2000; Buyantuyev 2010; Hedquist 2005; Hartz et al. 2006a and b; Myint et al. 2010; Sun et al. 2009). The role of vegetation in ameliorating the UHI has been a particular focus of recent CAP research. We have studied the patchy, cooler areas in cities, known as the park cool island (PCI), as a means of understanding how urban green spaces could be managed toward mitigating the UHI, and explored modeling the PCI at micro-spatial scales (Chow et al. 2011). We improved the vegetation parameterization scheme for a micro-scale urban climate model (ENVI-met) to include widely-used, desert-adapted vegetation. Using this modified model, we found that the PCI that forms over irrigated turf and xeric areas can be sufficient to mitigate the strong UHI in the Phoenix area. We also concluded that modified ENVI-met model has potential use as a planning tool for modeling micro-scale climates in our arid urban system (Chow et al. 2011).

Related research assesses **xeriscaping as a sustainable UHI mitigation approach** (Chow and Brazel in press). In a desert ecosystem with limited water resources, sustainable landscapes are an increasing concern to municipalities, which have instituted programs to move homeowners away from water-intensive grass lawns to xeriscapes that involve plantings of low water-use plants and trees in decomposed granite (Martin 2008; Larson et al. 2009). While the cooling effects of grass or mesic landscapes are well known, less is understood about xeric landscapes, which make up a large portion of land cover, particularly in the outlying suburban areas of the Phoenix metropolitan area. We examined two suburban neighborhoods in the metro area, one predominately mesic and the other xeric. Our research focuses on the effect of introducing xeric landscaping, consisting of low water-use shade trees, to varying proportions (10%, 25%, and 50%) of housing parcels in each neighborhood. Our results suggest that the introduction of low water-use shade trees into xeric neighborhoods with little existing shade trees is potentially effective in reducing UHI intensities. However, in the mesic neighborhood, large-scale residential xeriscaping results in greater thermal discomfort to residents (Chow and Brazel in press). Some of these findings are consistent with Gober et al. 2010, which indicated that efforts to increase vegetative cover should focus on areas with the least vegetation as this is where substantial gains can be made with minimal additional water. As well, other CAP research has established that lower-income neighborhoods have less vegetation and hence more exposure to heat than wealthier neighborhoods (Harlan et al. 2006, 2008; Jenerette et al. 2007). Thus, sustainable UHI mitigation is an environmental justice issue.

Part of our challenge in studying urban climate is in **disentangling urban effects from other climatic effects**, such as global climate change. Our study examines temperature thresholds between Phoenix and Gila Bend, a small, desert community (population 2,055) approximately 74 miles southwest of Phoenix (Ruddell et al. in review). Key findings indicate that the frequency and intensity of thresholds temperatures (i.e., frost days, misery days, and local characteristics of heat waves) in Phoenix has changed significantly from 1900-2008 while Gila Bend reports no to modest changes among the same measures during the same period of time. We attribute the

pronounced changes in temperatures in Phoenix to the effects of large-scale urbanization that has occurred since 1970. Correlations between global climate systems (ENSO and PDO) and threshold temperatures recorded at the Phoenix and Gila Bend weather stations also signal anthropogenic interference at the Phoenix station with modest changes at the Gila Bend station. The climate in Phoenix has reported warmer winters, hotter summers, and more intense heat wave conditions while threshold temperatures and heat wave characteristics in Gila Bend have largely remained stable. Potentially adverse impacts of warming conditions in Phoenix are significant and widespread; environmental, economic, and social systems may suffer as a result of pronounced changes in threshold temperatures.

As the UHI is defined by urban temperatures relative to rural temperatures, defining what is urban and what is rural is important and is particularly a challenge in fringe areas (McIntyre et al. 2000). We analyze how land use/land cover change affected near-surface cooling rates around selected long-term weather stations in Phoenix (Chow and Svoma in press). Our study applies a novel approach to quantify local-scale temperature changes (hourly station cooling rate) to directly measure land use/land cover change over a 15 year period and argues for this metric to be widely applied in other cities. Research results indicate that urbanization significantly reduced cooling rates over time and average cooling-rate magnitudes were usually larger in the summer months than in the winter.

While climatological research has established the intensity of the UHI in Phoenix, **residents' perceptions of heat** are critical since these not only relate to feelings of well-being but also may influence policy-making. Using results from the 2006 **PASS**, we examine perceptions of residents in 40 Phoenix neighborhoods to regional and neighborhood-scale temperatures and spatially compare these perceptions with scientifically-derived temperatures, which they simulated using the Weather Research and Forecast (WRF) model (Ruddell et al. in press). The results of these analyses indicate tremendous variability in mean daily temperature, particularly mean daily low temperatures, across metropolitan Phoenix, demonstrating significant differences in exposure to heat. There was wide agreement among PASS respondents that the region is getting warmer; 82.1% reported that it was getting a little hotter or a lot hotter, an accurate assessment of local climate change. There was more variation in perceptions of neighborhood temperatures with 24.1% of respondents perceiving their neighborhood to be warmer than other neighborhoods, 24.6% believing that there neighborhood was cooler, and 51% thinking that their neighborhood was the same temperature as other neighborhoods (Ruddell et al. in press). Correlation analyses revealed strong relationships between WRF-simulated neighborhood temperatures and perceived relative neighborhood temperatures; respondents accurately perceived their local environmental conditions. As well, residents living in the core of the UHI were more likely to perceive that the region as getting warmer than residents in the cooler urban fringe neighborhoods, again reflecting actual local conditions.

Water Dynamics in a Desert City

We are investigating how the concomitant roles of urbanization intensity, configuration, and type, and how the interaction of urbanization with climate variability modulates **urban stormwater** quantity and quality. Our research focuses on fluxes of macronutrients (nitrogen and phosphorus), organic matter, and sediments in stormwater in relation to urban heterogeneity and hydrology in the greater Phoenix metropolitan area. To meet project goals, we are sampling rain-

and storm-water in hierarchically-nested subcatchments spanning a gradient of stormwater infrastructure. To date, we have collected over 1,200 discrete, discharge-specific stormwater samples spanning multiple summer (monsoonal) and winter (frontal) storms at 11 locations across Scottsdale and Tempe. These data are facilitating an unprecedented assessment of dissolved and particulate runoff dynamics in an arid, urban metropolis. Preliminary analyses of runoff from a single storm in October 2010 suggest complex dynamics among catchment size, extent of urbanization (housing density), and stormwater infrastructure. Contrasting hydrology among the catchments appears to be the primary driver of nutrient dynamics, and nitrogen export was lowest in the catchment with the "hardest" stormwater infrastructure (primarily street flow and pipes). Nutrient export was indirectly correlated with spatial scale, suggesting that nutrients may become entrained within the channel network, and particle-bound transport was closely related to both nitrogen and phosphorus export. We observed a 'flushing' effect where dissolved inorganic nitrogen concentrations were highest at the initiation and peak of the hydrograph at all sites except in catchments dominated by natural-wash drainage and those with retention basins. In contrast, the flushing effect was evident for dissolved organic nitrogen at all sites. These results suggest that nitrogen export may be supply- or transport-limited depending on type of stormwater infrastructure.

Through the PASS and other social science initiatives, we have investigated human dimensions of the hydrologic systems in our desert cities. The **Global Ethnohydrology Study** began in Phoenix four years ago as a study of water quality and institutions in four PASS neighborhoods (Gartin et al. 2010). Since that time, we have added additional research sites in Bolivia, New Zealand, and Fiji, which provide contrasts in terms of natural water availability and institutional structures for assuring water availability and quality. Recent efforts have focused on analyzing data from across these sites to provide a better cross-cultural understanding of institutions and water. We examine the rules and norms regarding water access across the four research sites with the goal of capturing cross-cultural variability in the conceptualization of environmental justice as it relates to water access (Wutich et al. in review a). Using coded data from interviews, we found that institutions play an important role in people's understanding of justice in local water situations. Residents of the arid cities (Phoenix and the Bolivian site in Cochabamba) were much more likely to talk about norms of water use and less likely to discuss rules. On the other hand, those living in more humid and economically-developed cities focused on rules and distributive institutions. Another analysis examines conceptions of fairness around the right to water (Wutich et al. in review b.). We found consistent concern around water access, water quantity, the role of government, and equity/equality across the four locations. In contrast, water cost, water quality, water source, water rights, and infrastructure were relevant to people in only some of the cities. Again, hydrology and economic development levels explain much of this variation. We note that when water is plentiful and affordable, there is little or no discord around issues of fairness. But as scarcity and costs rise, discord around key notions of fairness increases. These global studies of water have implications for understanding water as a human right and for planners and policymakers.

We continue to analyze data on water from the 2006 **PASS** that focuses on drought and water consumption rates, perceptions of the anthropogenic and 'natural' causes for water scarcity, and support for voluntary and regulatory water management approaches. We have used a tripartite approach to better understand affective environmental concerns, cognitive risk perceptions, and

conative policy attitudes in relation to water governance in metropolitan Phoenix. Questions addressed by analyzing survey data include: How do perspectives on water risks and policies differ among men and women, and how do various cultural domains, including ecological worldviews, political orientations, and ethnic identity, affect multifaceted views about water consumption and regulatory policies, controlling for demographic factors? Overall, our clear conceptual approach to examining tripartite judgments helped to clarify how and why perspectives about water resources differ across different social groups. Regarding gender, we found that women were more concerned about water risks than men, but they did not perceive the causes of risks differently nor did they support particular types of policies, supporting the "safety concerns" thesis that posits women generally exhibit heightened worries and anxiety about their family's health (Larson et al. 2011).

Cultural domains were more significant than demographic factors in explaining people's perspectives on water risks and policies in metropolitan Phoenix with ethnicity and ecological worldviews most influencing affective, cognitive, and conative judgments (Larson et al. 2011). Yet conservative political beliefs increase opposition to raising the price of water, while ecological worldviews had no impact on this particular judgment. Liberal political orientations, meanwhile, intensify residents' concerns about consumption, which were best explained by the three cultural domains analyzed and not at all by demographic factors. Among ethnic groups, Spanish-speaking Latinos exhibited relatively strong pro-environmental views for all dimensions of judgment, whereas English-speaking Latinos appear acculturated to local Anglo perspectives. Long-term residents also appear acculturated to the status quo of well-watered landscapes and few regulations in the Phoenix oasis, given heightened opposition to water-use restrictions among them compared to newcomers. The overall findings of this study suggest that cultural beliefs, social experience, and other demographic attributes influence tripartite human-ecological perspectives in distinctive ways, thereby illustrating the validity of our cultural domains approach to understanding multifaceted judgments about water risks and policies (Larson et al. 2011). These findings lay important groundwork for CAP's sustainable futures research, as a key component of sustainable change in urban systems is behavior modification.

Biogeochemical Patterns, Processes, and Human Outcomes

The **Carbon and Nitrogen Deposition Project** (CN Dep) is one of our long-term monitoring initiatives, building on work conducted under a CAP-leveraged NSF grant. Under this initiative, we established 15 long-term sites in protected desert in across an urban-rural gradient of nitrogen deposition and annual rainfall, including sites upwind (west of city), within urban desert remnant parks (urban core sites), and downwind (east of city) of metro Phoenix. Each site contains five 20m x 20m plots: two control (not fertilized) sites and three plots that have received fertilizer every six months starting in Dec 2005. We continue to collect longitudinal data at each site – including herbaceous species composition and biomass, perennial shrub stem growth, perennial and annual tissue nutrient content, and soil properties. In Fall 2010, we built herbivore exclosures and 3 'control' exclosures (each 1m x 1m) at all downwind and core sites to explore the importance of herbivory by small mammals and birds on winter herbaceous biomass and community composition. We currently measure atmospheric nitrogen concentration and deposition via several methods, including bulk and throughfall ion exchange resin collectors and passive air samplers.

Our research has found that Sonoran Desert ecosystems within and outside the Phoenix metropolitan area were both resistant and sensitive to N enrichment, depending on the functional groups considered and the extent to which they were limited by factors other than N, including water, C, or P. Winter herbaceous vegetation production is controlled mainly by water availability followed by N and then P availability. In contrast, desert perennial shrubs (*L. tridentata, A. deltoidea*) were not responsive to nutrient additions (Hall et al. 2011). Preliminary findings from herbivory experiments (M Schmoker REU project) suggest that rates of herbivory do not differ significantly between urban and downwind locations. These results indicate that bottom-up factors (nutrient, water availability) are more important than top down factors in regulating herbaceous plant growth. We also found that urban carbon compounds are deposited regardless of upwind/downwind location, but most of the particles are not bioavailable to desert microorganisms (Kaye et al. in press).

We have been conducting other research on **polycyclic aromatic hydrocarbons** (PAHs) along transportation corridors in arid urban ecosystems as part of ongoing research on atmospheric deposition processes and environmental justice. PAH compounds are the by-products of incomplete combustion processes, such as vehicle engine emissions, industrial exhaust, wood burning, and food cooking. PAHs are widespread environmental pollutants and are identified in the US EPA Priority Pollutants list. Potential effects of PAH pollution include human immunotoxic responses and ecological changes through biological and physico-chemical interactions. We focus on PAH concentrations at 60 random sites along major highways in the Phoenix metropolitan area (Marusenko et al. 2011). While past research has established that PAH concentrations are higher in urbanized versus rural areas, this study examines the fate of PAH compounds in an arid ecosystem characterized by sprawling urban development. We found that PAH concentrations in soils along highways are low relative to those in temperate cities, and that concentrations are related more strongly to soil organic matter (SOM) than source inputs. In more temperate systems, pollutants readily adsorb to organic surfaces. SOM is low in Phoenix's dryland ecosystem, and this, in addition to the high temperatures and solar radiation in the region, decreases the sink of PAH compounds into soils and increases the environmental risk for human exposure via the atmosphere with environmental justice implications (Marusenko et al. 2011; Grineski et al. 2007).

Legacies on the Landscape is a multi-disciplinary project involving ecologists and archaeologists that examines the long-term ecological legacies of land use intensity in two different ecosystem types of the southwestern US, which supported agroecologically active and well-studied populations of humans until 1200-1400 AD (Briggs et al. 2006, 2007; Schaafsma and Briggs 2007). This study aims to 1) quantify century-millennial scale legacies of agricultural land use, and 2) determine runoff dynamics of terrace field systems as modulators of soil fertility. Altogether, this research will allow us to model prehistoric agricultural productivity, explore the potential water and nutrient benefits of runoff, and examine the long-term ecological importance of human landscape manipulation. Our study focuses on two sites of active prehistoric human populations: at Cave Creek in the Sonoran Desert of the northern Phoenix basin and at the Pueblo La Plata and Bull Tank fields, which are runoff agricultural terrace systems located on Perry Mesa in the semi-arid desert grasslands of the Agua Fria National Monument. At both sites, we collected soil and herbaceous plant biomass samples and analyzed these for a suite of physical and biogeochemical properties. Preliminary results show

that the surface soils are coarser textured on agricultural terraces compared to non-terrace locations due in part to surface runoff dynamics. Terraces contain less vegetated cover, which promotes generation of surface runoff and increases the amount of sediment transport compared to non-terrace surfaces. Soil texture drives alterations in nutrient cycling and carbon availability in soils.

Human Decisions and Biodiversity

Birds, mycorrhizal fungi, microbes, plants, herpetofauna and arthropods have been foci of biodiversity investigations, mostly using core monitoring datasets, such as **Survey 200** and our **long-term bird and arthropod monitoring**. Building on this are research endeavors that use experimental methods to examine specific biodiversity mechanisms as well as physiological studies of urban stressors. Emerging work in CAP will examine biodiversity responses to urban rehabilitation of riparian habitat along the Salt River.

We have a long tradition of investigating biodiversity in residential yards (Hope et al. 2006, 2003; Hostetler and Knowles-Yanez 2003; Martin et al. 2003). Recent research (Lerman and Warren 2011) has focused on identifying the patterns of **bird distribution in residential yards**, uncovering some of the mechanisms driving the loss of urban avian biodiversity, and highlighting potential management directions. In this investigation, we asked two main research questions: 1) Do native plants and vegetation structure support native birds in residential yards?; 2) How do humans indirectly associate with native diversity? We conducted bird surveys at the **PASS** long-term monitoring sites during 2006-2008, characterized the available habitat at the PASS sites at two scales, local and landscape, and linked the PASS sites to the US Census data. Our multivariate analysis indicated that native birds associated with neighborhoods with native plants and shrubs, neighborhoods closer to desert tracts, and higher income neighborhoods. Very few bird species were associated with low income and predominantly Hispanic neighborhoods, and none of these birds were native to the Sonoran desert. Additional analyses based on the PASS data demonstrated that residents noticed the varying levels of avian variety. Residents were more satisfied with the existing bird variety when their neighborhood had higher levels of native bird richness. Our study was one of the first to address the conservation potential of residential yards. Furthermore, our results suggest that habitat improvements for native wildlife have the ability to help reverse the loss of urban diversity, regardless of location along the urban rural gradient.

Urbanization in the desert has changed the environment for native birds by transforming the vegetation structure, increasing access to water, and altering predation levels. We seek to understand the **effects of urbanization on birds and the mechanisms that drive bird behavior**, particularly the role that hormones play in controlling behaviors. Recently published research focuses on the territorial behavior of native birds in the city versus their desert counterparts and the relationships between this behavior, circulating hormones, and ecosystem structure (Fokidis et al. 2011). We centered our investigations on males of two bird species found in the Sonoran Desert and the Phoenix metropolitan area, Abert's Towhee (*Melozone aberti*) and the Curve-billed Thrasher (*Toxostoma curvirostre*). We recorded the two species' responses to recorded bird calls that simulated an intrusion on territory. Our findings suggest that urban birds exhibit more aggressive territorial behavior than their desert cousins. Such aggression can take the form of approaching the site of the intruder, song, calls, and raising

wings. This behavior appears unrelated to blood levels of two hormones under investigation, plasma testosterone and corticosterone, which were thought to mediate territorial behaviors. Instead, we found that Abert's Towhees exhibited more aggressive territorial behavior in urban locations with a higher population density of towhees. Urban Curve-billed Thrashers, on the other hand, displayed more territorial behaviors in areas with a high proportion of desert vegetation such as cacti, mesquite, and cholla, which are important nest sites for this species. Both findings indicate that ecosystem structure plays a role in territorial behavior.

While middle and upper-class residents may modify their yards to increase bird and plant diversity, they do not manipulate landscapes to increase arthropod diversity and abundance. In fact, homeowners and pest control companies in the Valley work diligently to decrease the abundance of key urban pest species. Our investigations of the **population dynamics of urban arthropod pest species across an urban-desert gradient** have focused on the Western black widow spider, *Latrodectus hesperus*, which thrives in urban habitats. We collect spiders in urban and desert locations and house them in enclosures at the ASU West campus and in the Johnson lab. This enables us to closely observe behavior, measure physiological characteristics, and conduct experiments with the spiders. To date this research has generated a number of findings (Johnson et al. 2010, in press a & b, in review a & b; Kitchen et al. in review; Trubl et al. 2011, in review):

- There is a strong effect of family origin on cannibalism, development speed, aggression, sex ratio and adult male body size.
- There are significant variations within urban sites in spider body mass, web volume and population density
- There are striking levels of genetic polymorphism within urban sites
- Black widow aggregations (i.e. infestations) in urban habitat exhibit minimal temporal variation in terms of population density, average female mass and web volume across the peak of their breeding season (June-August).
- Population density and average female mass show significant spatial variation among the ten black widow aggregations sampled.
- Population density, average female mass and web volume did not correlate with each other.

Other recent research has examined **herpetofauna in riparian communities**. In this research, we ask: how do the riparian microhabitat and the herpetofauna community vary between an urban rehabilitated, urban disturbed, and wildland reaches of the Salt River, Arizona? Our research objectives were: 1). To compare herpetofauna abundance, species richness, and diversity indices; 2). To compare riparian microhabitat characteristics, and 3). To investigate relationships between microhabitat characteristics and herpetofauna abundance, diversity indices, and species richness, among three reaches which differ in terms of urbanization and rehabilitation effort (urban rehabilitated, urban disturbed, and wildland). For each of the three research sites along the Salt River, we established eight transects (n=24) crossing the riparian communities and included three segments (10-m wide by 20-m long) within each transect to keep sampling effort consistent between transects. We performed visual surveys along the transects at about 2 m in height above ground, searched debris piles and downed logs, and moved vegetation to flush hidden reptile or amphibian individuals. Other activities included

quantification of microhabitat characteristics along each segment, recording of litter and debris depth, and measurement of stem density of selected riparian tree species.

We found that herpetofauna species richness was the greatest along the wildland reach and the lowest along the urban disturbed reach. The wildland reach had the greatest diversity indices, and diversity indices of the two urban reaches were similar. Abundance of herpetofauna was approximately six times lower along the urban disturbed reach compared to the two other reaches, which had similar abundances. A Principal Component Analysis reduced microhabitat variables to five factors, and significant differences among reaches were detected. Vegetation structure complexity, vegetation species richness, as well as densities of *Prosopis* (mesquite), *Salix* (willow), *Populus* (cottonwood), and animal burrows had a positive correlation with at least one of the three herpetofauna community parameter quantified (i.e., herpetofauna abundance, species richness, and diversity indices) and had a positive correlation with at least one herpetofauna species. Overall, rehabilitation activities positively influenced herpetofauna abundance and species richness, whereas urbanization negatively influenced herpetofauna diversity indices. Based on these results, we recommend that microhabitat features be considered when rehabilitating degraded riparian systems in order to attract and retain herpetofauna (Banville 2011; Banville and Bateman in review).

Characterizing Land Use, Land Cover, and Land Architecture

Western cities, such as Phoenix, are widely considered to be highly fragmented and polycentric. Through the cross-site **land fragmentation** study, we examined the nature of fragmentation in the Phoenix metropolitan area, using multitemporal land cover data, gradient analysis, landscape metrics, and socioeconomic data (Shrestha et al. in press). We used the National Land Cover Database (NLCD) as the major source of land cover data. Although studies in the temperate eastern US have found inaccuracies in the NLCD in characterizing exurban land cover, we found the NLCD to be a reliable data source for measuring land use in the Phoenix area. Our research also found that land cover fragmentation rates are highest in areas dominated by low-density land cover. Rates of change from 1992 to 2001 were highest in a transect stretching from 30-40 km from the city center. Despite common perceptions about fragmentation in metro Phoenix, urban growth has been more contiguous than “leap frog” in nature. This is due to water availability, American Indian reservation lands, topography, and other institutional barriers, all of which create a sharper edge to the urban development (Shrestha et al. in press).

The **residential landscapes** initiative addresses the overarching question: What are the causes, consequences, and feedbacks involved with residents’ land management practices? By linking social and ecological drivers and outcomes conceptually and empirically, this interdisciplinary project has involved assessing how varying values influence landscaping decisions and how ecological structure—specifically groundcover—affects management inputs in specific socio-spatial (neighborhood) contexts. Coupled analyses of a social survey and observational field data have been conducted to address these questions, while efforts are also underway to add a qualitative, interview-based component to enrich this Phoenix study as well as to compare landscaping practices and outcomes with other LTER sites (e.g., BES, FCE, and PIE). In Phoenix, for example, our study (Larson et al. 2010) examined agency-based factors (i.e., assorted values ranging from general life values and broad ecological worldviews to specific landscaping priorities) and structural factors (i.e., existing groundcover) as drivers of

landscaping decisions across four distinctive neighborhoods. The results indicate that only specific values alter particular decisions in somewhat counterintuitive ways, that is, with biocentric worldviews (emphasizing the rights and protection of nature) leading to watering of grassy landscapes as residents socially construct 'nature' in their yards. Moreover, prioritizing environmentally practical yards (that are low impact and low maintenance) leads to drought-tolerant, rock-covered (xeric) choices in arid Phoenix. In particular, wealth influences the irrigation technology used across neighborhoods, but regardless of income, historic areas have more traditional grassy landscapes relative to newer areas. Groundcover, in turn, appears to structure inputs, with intensified pesticide and herbicide use in xeric yards compared to mesic lawns. The latter finding challenges the assumption that desert-like xeric yards are the eco-friendly choice, in addition to highlighting key tradeoffs between yard choices—that is, that xeric yards may conserve water while causing pollution relative to lawns, which may use more water but appear to reduce the use of pesticides in yard management (Larson et al. 2010).

Other recent efforts under this project have focused on establishing a conceptual framework for **cross-site residential landscapes work** (Cook et al. in press; Roy Chowdhury et al. 2011). Through our synthesis of 256 social and ecological studies on residential land management, we found that complex human drivers, including attitudinal, structural, and institutional factors at multiple scales, influence management practices, which in turn determine biophysical characteristics of residential landscapes. Focusing on the multi-scalar drivers of various land management decisions and linked patterns in ecosystem structure, function, and services, the holistic framework emerging from our synthesis will be useful in guiding interdisciplinary research with its robust theoretical and conceptual integration of system components and interactions. Regarding research needs, gaps exist in interdisciplinary understanding of residential landscapes in four key areas: 1). the link between social drivers and ecological outcomes of management decisions, 2). the ecosystem services provided by these landscapes to residents, 3). the interactions of social drivers and ecological characteristics across scales, and 4). generalizations of patterns and processes across cities (Cook et al. in press). This in part explains our place-based focus in comparing how neighborhood and regional contexts affect landscaping practices within Phoenix and across other cities.

We have supported a body of research on **urban agriculture**, which reflects faculty and student concerns with sustainable food systems in metropolitan Phoenix and environs. Our ongoing research on **community gardening** examines a non-profit initiative in a low-income minority community in Phoenix (Bleasdale et al. 2011). While the non-profit started several pocket community gardens, many of these have become abandoned due to various causes. Our research investigates how the community perceives gardening as a means of shedding light on why gardens are not being vigorously maintained. Interviews with residents in the community revealed that while there was considerable interest in gardening, many did not know about the community gardening program. Other results showed that the non-profit's goals for gardening, enhancing opportunities for income earning and socializing, did not reflect the residents' perceived benefits of gardening, suggesting that this disjuncture may contribute to the lack of success with community gardens in this locale (Bleasdale et al. 2011).

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V: Research Training and Development

Undergraduate and Graduate Training

Undergraduate and graduate student research, education, and mentoring are fundamental to CAP's mission. CAP provides an excellent platform for student research, which has been instrumental in forwarding our socioecological investigations. Key indicators of this success include:

- 16 theses and dissertations completed in 2010-2011.
- 17 papers published with students as first authors from 2010-11; 65 papers in total (including in review and in press) with students as co-authors.
- Student authorship of papers in a wide range of top-ranked journals, including *Frontiers in Ecology and Environment*, *BioScience*, and *Social Science Quarterly*.
- 11 graduate research projects directly funded through CAP graduate grants during CAP3.
- 8 undergraduate research projects funded during the current program year, through the Research Experience for Undergraduates program on topics ranging from work on wastewater treatment wetlands to invasive crayfish.
- Growth in the number of students active in CAP LTER and CAP-related research: 37 graduate students and 14 undergraduate students active in 2010-2011.
- Reinvigoration of the CAP Students Group, which is ramping up plans for 2011-2012 events.

To foster greater student involvement in CAP, the lead PI Dan Childers is offering a new one credit course, "Long-term research in urban systems," in fall 2011 for graduate students and upper-level undergraduates, which includes a special focus on research conducted in the Phoenix metropolitan area. This interdisciplinary seminar includes students from a diversity of disciplines and fields, including urban ecology, biogeochemistry, hydrology, geomorphology, economics, geography, social dynamics, urban planning, and engineering. Weekly classes entail: 1) open forums for students to discuss their research ideas, present recent data and findings, and discuss collaborative projects; 2) readings of relevant literature on urban systems, and; 3) research presentations by ASU faculty and research associates who are working on urban systems.

Post-Doctoral Research Fellow Mentoring

CAP hosted four post-doctoral fellows (Milan Shrestha, Laura Turnbull, Chi Zhang, and Darren Ruddell) during this program year, three of whom completed their tenure in spring 2011. All worked with their respective faculty mentors to design mentoring plans in line with their career aspirations and needs for professional development. Some of the opportunities accessed by these post-doctoral research fellows include:

- The Mentoring to Advance Post-Docs and Students Program through the School of Life Sciences http://sols.asu.edu/rti/rti_mentoring.php . This series of seminars introduces post-doctoral researchers to issues of ethics, mentoring, science communication, and teaching.
- Seminars on teaching offered through the Center for Learning and Teaching Excellence at ASU.

- Mandatory training on research ethics offered through the Office of Research Integrity and Assurance.
- Support to attend national scientific meetings to present research findings.
- Office space in the Global Institute of Sustainability.
- Opportunities to meet with visiting scholars and to participate in national meetings hosted at ASU during 2011-2012, including the Sustainable P Conference, the Urban Global Environmental Change Conference, and the Resilience Alliance Conference.
- Mentoring support for moving to the next career stage.
- Support for publishing research findings and grant proposal preparation.

Theses and Dissertations

In Progress

Ackley, W. Jeffrey. Off the sand and onto the asphalt: Does the urban heat island impact desert lizards? (Ph.D. Biology, J. Wu).

Bleasdale, Tommy. Gardens of justice: A social movement built around food (Ph.D., Environmental Social Sciences, S. Harlan).

Chapman, Eric. Structural and functional complexity of soil microbial communities across a chronosequence of developing boreal wetlands (Ph.D., Environmental Life Sciences, D. Childers).

Cook, Elizabeth M. Net effects of co-occurring atmospheric pollutants on arid ecosystems (Ph.D., Plant Biology, S Hall).

Davies, Scott. Investigating the influence of food on reproductive physiology: urbanization as a natural experiment (Ph.D., Biology, P. Deviche).

Fan, Chao. Urban heat island and urban geometry: Linking temporal variations in surface urban heat island to urban pattern from a satellite perspective (Ph.D., Geography, S. Myint).

Hale, Rebecca. Urban ecohydryological landscapes: Design, disturbance, and institutional response (Ph.D., Biology, N. B. Grimm).

Hamilton, George Alex. Black carbon isotopic composition, concentration, and distribution in an urban/desert ecosystem (Ph.D., Chemistry and Biochemistry, H. Hartnett).

Hartz, Donna A. Human vulnerability and adaptation to heat. (Ph.D., Geography and Urban Planning, A. Brazel).

Ibes, Dorothy C. The value of nature in the city: The evolution of American urban design. (Ph.D., E. Talen).

Iwaniec, David. Envisioning future desirable states: Participatory modeling or urban systems (Ph.D., Sustainability, A. Wiek).

Kim, Won Kyung. Understanding open spaces in arid cities (Ph.D., Geography, E. A. Wentz and S. W. Myint).

Marusenko, Yevgeniy. Linking ecological dynamics in a changing environment with microbial population interactions of ammonia oxidizers and their soil function (Ph.D., Environmental Life Sciences, S. Hall and F.Garcia-Pichel).

Miles, Lindsay S. A population genetic approach to investigate effects of urbanization and habitat fragmentation on the Western black widow spider, Latrodectus hesperus (M.S., Biology, J.C. Johnson).

Ripplinger, Julie. Testing resilience theory in cities: Spatiotemporal dynamics and resilience of urban plant communities (Ph.D., Biology, J. Franklin).

Robinson, Scott M. Quantifying sediment dynamics in response to variation in climate and land use (PhD, Geology, A.M. Heimsath).

Strawhacker, Colleen. Past perspectives on ancient irrigated agriculture in the Phoenix Basin, Arizona: AD 700 - 1950. (Ph.D., Anthropology, K. Spielmann)

Sweat, Ken. The use of lichens as biomonitors or heavy metal air pollution patterns in Arizona. (Ph.D., Plant Biology, T. H. Nash).

Taylor, Carissa. Local food in the Phoenix metropolitan area: Perceptions and heterogeneity of local food system stakeholders. (Ph.D., Sustainability, R. Aggarwal & H. Eakin)

Tomalty, Roger. Solar radiation modeling and spatial variability in CAP LTER and its impacts on surface processes (Ph.D., Geography, A. J. Brazel).

Trubl, J. Patricia. The diet of black widow spiders across an urban - desert gradient: urban behavioral ecology meets ecological stoichiometry (M.S., Biology, J.C. Johnson).

Wong, Christina. Managing for urban ecosystem services: The Green Yongding Ecological Corridor (Ph.D., Sustainability, Dr. Ann P Kinzig)

Wyant, Karl. Soil food webs of arid urban and riparian ecosystems (Ph.D., Biology, Sabo).

Zhang, Sainan. Socioecological drivers and consequences of land fragmentation under conditions of rapid urbanization (Ph.D., Sustainability, C.G.Boone)

Completed

2011

Baneville, Melanie J. 2011. Herpetofauna and riparian microhabitat of urban and wildland reaches along the Salt River, AZ. (M.S., Applied Biological Sciences, H. Bateman).

Chow, Winston. 2011. Microscale modeling of the canopy-layer urban heat island in Phoenix, Arizona: Validation and sustainable mitigation scenarios (Ph.D., Geography, A. Brazel).

Crouch, Carolyn. 2011. Community food resource assessment in central city south, Phoenix: A study of community capacity building. (M.A., School of Sustainability, S. Harlan).

Lerman, Susannah. 2011. Residential landscapes and bird community structure: Understanding the patterns and processes. (Ph.D., Graduate Program in Organismic and Evolutionary Biology, University of Massachusetts, P. Warren).

Metson, S. Genevieve. 2011. Phosphorus cycling in metropolitan Phoenix (M.S., Sustainability, D. Childers and R. Aggarwal).

Trujillo, Jolene. 2011. Seasonality and ecosystem response in two prehistoric agricultural regions of central Arizona (M.S., Biology, S. Hall).

2010

Bang, Christofer. 2010. The effects of urbanization on structure, diversity and trophic dynamics in arthropod communities (Ph.D., Biology, S. Faeth and J. Sabo).

Busse, Kendra. 2010. The effect of surface cover and vegetation on microclimates in Phoenix residential neighborhoods (M.S., Department of Applied and Biological Sciences, ASU-Polytechnic, C. A. Martin).

Cutts, Bethany B. 2010. Public knowledge of water resources as a product of multiple information providers. (Ph.D., Biology, A. Kinzig).

Fokidis, H. Bobby. 2010. Neuroendrocrine and nutrition-based mechanisms of adaptive plasticity underlying urbanization of native birds (Ph.D., Biology, P. Deviche).

Gade, Kris. 2010. Plant migration along freeways in and around an arid urban area: Phoenix, Arizona (Ph.D., Biology, A.P. Kinzig).

Hedquist, Brent. 2010. Micro-scale evaluation of the urban heat island in Phoenix, Arizona (Ph.D., Geography, A. Brazel).

Larson, Elisabeth. 2010. Water and nitrogen in designed ecosystems: Biogeochemical and economic consequences (Ph.D., Biology, N. B. Grimm).

Lund, Tracy. 2010. Major and trace element cycling in an arid-land stream (M.S., Geological Sciences, E. Shock).

Marusenko, Yevgeniy. 2010. Magnitude and distribution of polycyclic aromatic hydrocarbons in soils of urban transportation corridors in an arid ecosystem (M.S., Biology, S. Hall).

Zhuo, Xiaoding. 2010. Spatial distributions of toxic elements in urban desert soils: Sources, transport pathways, historical legacies, and environmental justice implications (Ph.D., Department of Chemistry and Biochemistry, E. Shock).

VI. K-12 EDUCATION AND COMMUNITY OUTREACH

Ecology Explorers, CAP LTER's K-12 education initiative, engages in a suite of activities with schools and programs targeted at the K-12 student population. During 2010-2011, these activities included:

- Teacher professional development
- Classroom presentations
- Out-of-school time program presentations
- Teaching resource development
- Community outreach (with CAP staff and researchers)

Teacher Professional Development

Teacher professional development has long been a centerpiece of the Ecology Explorers program. Popular summer workshops and internships have engaged over one hundred teachers and, in turn, thousands of their students in Ecology Explorers schoolyard sampling protocols for the vegetation survey, ground arthropod investigation, bird survey, and plant/insect interaction study.

This year, professional development workshops focused on new urban heat island (UHI) curriculum. We presented this material in a one-day workshop for 15 middle school teachers from across the Phoenix metropolitan area, sponsored by the ASU Office of Youth Preparation. We also collaborated with a CAP LTER-leveraged project funded by NSF, Urban Vulnerability to Climate Change (CNH, S.Harlan Lead PI), to offer a series of workshops using the new UHI curriculum, which incorporates natural science, social science, and engineering components. These workshops reached 30 middle school teachers in schools that serve low-income students.

Classroom Presentations

We continued to respond to requests for classroom presentations in schools across the metropolitan area and impacted an estimated 600 students with these presentations in 2010-2011. John Dole, our teacher consultant, worked with teachers in Gilbert Public Schools. The long-term goal of this work is to develop a network of district teachers implementing Ecology Explorers protocols and ultimately entering these data into a school district-wide database. Ecology Explorers coordinator, Gina Hupton, and graduate student, Melanie Banville, also made numerous classroom presentations, including those at Navajo Elementary School. Under a previous NSF LTER supplement, CAP purchased and installed a weather station at Navajo Elementary School and now continues to provide science education support to the school, which serves a low-income community in Scottsdale.

Out-of-School Time Program Presentations

During spring and fall 2011, undergraduate student interns from ASU's School of Sustainability joined the Ecology Explorers education team. After an extensive orientation to urban ecology and classroom pedagogy, these interns began work with 5th and 6th grade students at two after-school programs run by the City of Mesa Parks and Recreation Department, which targeted children from low-income backgrounds. The interns met with two different

groups of students weekly for three sessions each (approximately 30 students total) and presented lessons on distinguishing the natural and built environment and understanding the causes and consequences of the urban heat island.

The Spring 2011 interns became embedded in projects at Navajo Elementary School. They initiated a before-school science club in which they guided eight 2nd-4th grade students through four sessions of activities related to local bird identification, observation, bird behavior and ecology. Students played games, learned to use binoculars, built bird feeders and surveyed bird abundance in different microhabitats in their schoolyard. They also made visits to classrooms at the school to lead students in investigations of the ecology of palo verde trees and bruchid beetles as this relates to urban water use.

Teaching Resource Development

Ecology Explorers staff continued to develop new classroom curriculum for teachers aligned with the Arizona State Education Standards, including science, math, writing, social science and technology standards. We developed two new teaching modules during 2010-2011: Sustainable Environment and Urban Heat Island. Both of these modules will shortly become available on the Ecology Explorers website at
http://ecologyexplorers.asu.edu/overview/lesson-plans/

The website also contains other resources for teachers and students, including slide sets of materials that teachers can use for classroom learning. One new feature of the website is a presentation on herpetofauna and urban riparian habitats, featuring CAP scientist Heather Bateman http://ecologyexplorers.asu.edu/about-us/meet-scientists/ . Future plans include developing a similar presentation on urban black widow spiders.

Community Outreach

CAP LTER reached out to the wider community in several ways during the past year. Ecology Explorers staff participated in several events, including the Navajo Elementary School Family Science night, the Valley Forward Earthfest Education Night, and the Feathered Friends Festival. At these events, staff engaged hundreds of children and adults in activities related to urban ecology. Future community outreach plans include participation in the Arizona SciTech Festival occurring in February 2012.

CAP staff and researchers continued to work with community partners to co-produce scientific knowledge. Recent initiatives include a partnership between CAP and the ***Nina Mason Pulliam Rio Salado Audubon Center's*** Urban Naturalist initiative to inventory plants and animals at five sites along the Salt River. As well, CAP has submitted a proposal to the ***McDowell Sonoran Conservancy*** to monitor arthropods in the Conservancy area, using citizen scientists to collect and initially sort the arthropods and CAP expertise to design the monitoring scheme, train the citizen scientists, and identify the arthropods. We have joined the ***Desert Botanical Garden*** and other conservation-minded entities in metropolitan Phoenix in a proposal to form a conservation alliance focused on the park preserves in the metro area. CAP has also explored a relationship with the ***Valley Permaculture Alliance*** to involve community members in measuring the growth of shade trees in the metropolitan area. CAP staff has initiated discussions with the ***Sustainable Cities Network*** to link their stormwater group with CAP's ongoing stormwater research, particularly in the area of best practices for stormwater retention

basins. Finally, we have had conversations with individuals involved in ***Valley Forward's*** Canalscapes initiative to see how CAP's urban ecological research can inform this transformation of space in the Phoenix area.

CAP researchers have sought to engage the wider community in our scientific research. Post-doctoral researcher Darren Ruddell worked with staff at the ***Tempe History Museum*** on an urban heat island exhibit. He also shared his current research for visitors during the museum's Wild Wednesdays event. Site Manager Stevan Earl and colleagues contributed an article to *MountainLines*, the membership magazine for the ***McDowell Sonoran Conservancy***, on temperature variability and land conservation within metropolitan Phoenix. A local ABC news affiliate interviewed CAP scientists Tony Brazel and Darren Ruddell about on the impact of climate change on Arizona's cities, deserts, and forests http://www.abc15.com/dpp/news/state/as-climate-warms-az-deserts,-forests,-cities-face-uncertain-futures . CAP scientist Jonathan Fink participated in a ***National Research Council*** workshop on urban sustainability, the results of which have been disseminated in a book *Pathways to urban sustainability: Research and development*, which features CAP LTER.

VII: INFORMATION MANAGEMENT

Information management is a core function within CAP LTER, and a capacity that we continue to build. CAP's information management staff and infrastructure are shared with the Global Institute of Sustainability (GIOS), which affords our research program a number of advantages in terms of funding for human resources and hardware. This year, the information management staff grew from one 80% time person, CAP Information Manager Philip Tarrant, to 2.8 full-time positions, greatly increasing our capability in programming and database management and lessening our reliance on part-time student workers to provide essential information management services. We continue to work closely with the GIOS Communications Team, particularly in the area of database management as our website content is largely driven by a large database.

Over the last year, we have improved our database documentation and our metadata contributions to the LTER Network metadata repository. We extensively redeveloped the Survey 200 database and application to accommodate the significant additional data requirements of the latest round of this important long-term study. We continue to add information to an information management wiki to ensure that as much technical knowledge as possible is retained in the event of personnel changes. Finally, we are working with our laboratory and field technicians to provide automated uploads of some of the laboratory data produced by sample analysis. This automation will significantly reduce the data entry effort required.

VIII. CONTRIBUTIONS

Contributions within Discipline

- For most of ecology's history as a discipline and for the first 15 years of the LTER Network's existence, the focus of study was on pristine, wildland sites. Since 1997, CAP LTER has played an important role in advancing and refining the study of **urban ecosystems** and in developing the discipline of **urban ecology** (Grimm et al. 2008, 2000; Grimm and Redman 2004; Warren et al. in review).
- CAP has been at the forefront of a movement to conduct **socioecological investigations** that use social science and ecological methods to understand cities as well as to create socioecological theories to describe how urban areas function (Redman et al. 2004; Haberl et al. 2006; Costanza et al. 2007; Liu et al. 2007a, b; Grimm et al. 2008b).
- Our study of the **effects of urbanization on birds and the mechanisms that drive bird behavior** represents one of the few mechanistic studies of animal communities in urban ecology and begins to uncover the processes behind the well-documented patterns of high densities but low diversity in urban ecosystems. In addition, our study focuses exclusively within residential yards and gardens. Ultimately, our study demonstrates how landscape design and vegetation structure shapes urban bird diversity, thus providing potential management tools for future development plans that encourage a higher degree of urban biodiversity.
- Research on the Western **black widow spider**, *Latrodectus hesperus,* addresses a number of cutting edge questions in the field of behavioral ecology and provides intriguing data on this urban pest species. This research makes use of ecological stoichiometry (ES) as a tool to examine the nutrient composition of arthropods within urban habitat, which allows us to ask interesting research questions that tie the fields of behavioral ecology and urban ecology together.
- Many studies have reported disparities in the timing of avian reproduction between urban and outlying wildlands, however few studies have attempted to elucidate the mechanisms by which urbanization modulates the timing of reproduction. As such, our study of the **effects of urbanization on birds and the mechanisms that drive bird behavior** is of interest to urban ecologists and physiological ecologists.

Contributions to Other Disciplines

- Urban ecology is inherently interdisciplinary and may, in fact, be defined as a field rather than a discipline. In studying urban systems, scientists are inherently making cross-disciplinary contributions.
- CAP LTER is an **interdisciplinary endeavor** and involves scientists from a range of disciplines in examining a common set of research problems. While multidisciplinary projects have their challenges (Baker 2006), they can lead to important syntheses of data and information that would otherwise be impossible under a single disciplinary approach. As a result, contributions often extend beyond disciplinary boundaries.
- **Survey 200** findings provide a probability-based, spatially extensive snapshot of a suite of key ecological variables that is unique in covering the complex landscape of a rapidly urbanizing region and surrounding desert. These data provide a framework for

understanding the spatial picture across the CAP region and have been used extensively by a wide variety of project researchers (both faculty and students) in fields ranging from avian community ecology to soil biogeochemistry. To date, we have prepared 13 papers using these data.

- **PASS** 2006 has successfully launched transdisciplinary collaborations across a number of important environmental issues in a rapidly urbanizing region. There is not a single dominant disciplinary perspective in PASS, but it is contributing to sociology, geography, economics, ecology, anthropology, and meteorology in unique and important ways. The longitudinal design of the survey is in keeping with tradition in the field of sociology, which values research on long-term trends in social attitudes and behaviors. The most highly-regarded social surveys have continued over a period of 40 or 50 years. PASS researchers are pioneering new methods of survey design in order to allow spatial analyses of people's attitudes and behavior in relation to fine-scale environmental conditions in neighborhoods. PASS 2011 has been designed to allow us to analyze the effects of the economic downturn on the perceptions and attitudes of individuals and households in the greater Phoenix area.
- A primary contribution of **residential landscapes** research involves the development of a conceptually rich framework for integrated analyses and understanding of residential landscapes as social-ecological systems in cities. The analysis of how values, groundcover, and neighborhood context affect landscaping practices also contributions to human-environment research by assessing both agency-based and structural drivers of environmental decisions, especially since much research focuses on one or the other set of drivers. As we move toward cross-site research on the causes, consequences, and feedbacks involved with residents' land management, this work also advances multi-scalar, comparative analyses incorporating mixed research methods to enhance interdisciplinary knowledge of how landscaping practices and dynamics across distinctive contexts.
- CAP research on the **urban heat island** (UHI) has contributed to knowledge about the spatial variation in the UHI across metropolitan areas and the environmental justice implications of this distribution. Using remotely sensed data, CAP researchers have found that the distribution of urban heat islands in the Phoenix metropolitan area is spatially variable, mirroring the physical variability of soils, extents of pavement, housing density, and vegetation. Their research has shown that extreme temperatures are distributed unevenly among neighborhoods with the most affected neighborhoods characterized by already vulnerable minority, low-income, and elderly populations. Combined with data on urban heat events and human well-being from the **PASS**, this body of research has contributed greatly to an understanding of extreme heat and vulnerability in the city.
- The **legacies on the landscape** project contributes a unique, interdisciplinary experimental design in the spatially extensive and understudied arid and semi-arid ecosystems of the US Southwest where prehistoric human populations were some of the largest in North America.

Contributions to Resources for Research and Education

- CAP LTER's setting within a university enhances the ability to conduct, communicate, and synthesize research activities. Faculty members have expanded their courses to include a consideration of urban ecology and, in some cases, have designed new courses to accommodate CAP LTER interests.
- The Global Institute of Sustainability, the administrative home for the CAP LTER, houses the Informatics Lab and provides support, management staff, shared office space, and meeting facilities for CAP participants. This infrastructure supports services that enhance the dissemination of project results, foster new collaborations, enable access to project data resources, engage K-12 students in the science of the CAP LTER, and reach out to community members and organizations. Interdisciplinary working groups are organized that often result in the generation of new research opportunities and funding.
- The Southwest Environmental Information Network (SEINet) was created to serve as a gateway to distributed data resources of interest to the environmental research community in Arizona and beyond. Through a common web interface, we offer tools to locate, access, and work with a variety of data including biological collections, ecological research data, GIS data, taxonomic name information, bibliographies, and research protocols.
- New initiatives to create multi-scalar land cover and land use classification maps provide important resources for future CAP research. Efforts to standardize classification schemes among LTER sites provide scientists with necessary data for comparative research.
- The Goldwater Lab for Environmental Science has been expanded to accommodate the project's analytical needs and provide graduate-student training on instruments housed in this facility.
- The new eddy flux tower will allow CAP scientists to gather data on the effects of residential development on the surface energy balance, which has numerous applications for CAP research on urban climate.

Contributions to Human Resource Development

- CAP LTER provides a powerful framework for training undergraduate and graduate students, nourishing cross-disciplinary projects, and contributing to the new and growing field of urban ecology. A recent presentation by CAP scientist, Sharon Hall, to the NSF's National Science Board, underlined the importance of urban ecology as a means for involving urban youth in science education at the high school and undergraduate levels. Residential landscapes, for example, are a common, everyday socioecological system that can be a teaching platform for understanding 21st century challenges and their solutions.
- Since the inception of CAP LTER, close to 30 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports four post-doctoral associates, three full-time on CAP LTER and one shared with DCDC. The individuals interact, participate in planning meetings with the co-project directors and project managers, work with faculty members and team leaders, collaborate with graduate students, and organize and coordinate the annual poster symposium and summer

summit. They are integral to the research and field experience of CAP LTER and receive training in interdisciplinary collaboration, graduate-student supervision, data collection and analysis, and presentation techniques.

- In 2004 CAP established a competitive summer graduate student grant program under which a total of 48 grants have been awarded. Under CAP3, this competition is being run like a NSF grant review panel with past awardees serving as panelists. Ten graduate grants will be awarded per year during a once a year competition.
- Faculty members in geography and other social sciences, geological sciences, life sciences, and civil and environmental engineering have delivered additional training through graduate courses designed around CAP LTER activities.
- Students involved in CAP LTER are encouraged to present their research results at various local, national, and international meetings. Students have been presenters in approximately 42% of presentations given by CAP scientists at national and international meetings. They comprise around 45% of the presenters at CAP poster symposia.
- As active participants in CAP research, students are involved in publishing research results. During the current grant period, a total of 109 papers and book chapters have been co-authored by students (including works in press and review) and on 70 of these, the student was the first author. These papers have appeared in a wide range of journals, including *Ecology*, *BioScience*, *Social Science Quarterly*, the *International Journal of Remote Sensing*, *Frontiers in Ecology and the Environment*, and *Human Organization*.
- Since 2004, CAP LTER faculty members, postdoctoral associates, and senior graduate students have mentored 24 summer and academic year REU students. Many other REUs have become involved in CAP research through other, CAP-leveraged projects. Undergraduates from ASU who are working on CAP LTER projects during the academic year can be part of the Community of Undergraduate Scholars, a program sponsored by the Global Institute for Sustainability and the Barrett Honors College. Other undergraduate students have benefited by participating in data collection for the PASS, ground arthropod and bird studies, collection and curation activities, and courses that relate to the CAP LTER. Students have also incorporated project research into undergraduate honors and senior theses.

Contributions Beyond Science and Engineering

- Droughts and water shortages, combined with explosive growth of urban and suburban areas, have created a situation that is being viewed with increasing concern across the western United States. We believe that the publication and communication of our research results will enhance policy-makers' ability to address water-related environmental problems in the Southwest. CAP scientists active with DCDC have been working to communicate these results. In addition, CAP will continue to be active in initiatives forwarded by GIOS and the Sustainable Cities Network, such as those involving water managers in Arizona, which gives the project access to important stakeholder groups.
- The **PASS** is a vehicle for increasing knowledge of how residents shape and respond to the local environment, which is a necessary step in devising a more sustainable city. Communities, social lives, values, and behaviors must be understood in order to

comprehend the place of humans in the environment. This is vitally important in rapidly urbanizing regions, such as Phoenix. Arid cities face unique environmental challenges that accompany population growth, including extreme heat, limited water resources and shade, and harsh conditions for species survival. Many scientists and policy makers believe that these challenges can be overcome only creating strong, engaged communities that understand and appreciate their biophysical environments.

- Research on the **urban heat island**, including work on populations vulnerable to excessive heat, been shared with policymakers and practitioners through the City of Phoenix's Urban Heat Island Task Force and its Tree and Shade Task Force. These budding partnerships between practitioners and scientists will enhance efforts toward ameliorating the heat island as well as possibly influence new research directions within CAP LTER.
- We have established several new community partnerships in CAP3 for **use-inspired research** focusing on biodiversity and conservation. These partnerships with the McDowell Sonoran Conservancy, the Rio Salado Audubon Center, and the Desert Botanical Garden involve CAP scientists and students in gathering data on ecological community composition as a means of establishing baseline data for measuring ecological change in human-impacted parks, preserves, and restoration areas throughout the greater Phoenix area. Research, such as work on herpetofauna, also helps conservation planners understand critical habitat features necessary for maintaining biota.
- Understanding **how urban ecosystems function** provides knowledge to urban planners who design urban systems for public benefit. CAP research has found both intended and unintended ecosystem services associated with highly engineered aquatic systems in the urban environment (e.g., systems for water delivery, storm water removal, and wastewater processing). Parks along flood "greenways," such as Indian Bend Wash in Scottsdale, Arizona, are an excellent example. In addition to their obvious recreational value and capacity to absorb or convey floods, these parks are also efficient at removing nutrients and contaminants from floodwater. Retention basins, established for flood management, double as recreational spaces and nutrient removal systems. Other engineered aquatic ecosystems, however, do not provide benefits beyond those for which they were originally designed (e.g. concrete stormwater spillways). Awareness of the potential benefits of ecosystem functions increases the potential for urban planners and policymakers to design systems that optimize the ecosystem services delivered to the public.
- Complex dynamics among **urban stormwater** catchment characteristics, storm attributes, and runoff in urbanized settings of the Southwest are poorly understood. This investigation will contribute critical information requisite to developing science-based strategies for the effective management of stormwater runoff in arid-land urban environments.
- The **Sustainable Futures**-CAP pilot study was conducted in close collaboration with planners from the City's Planning Department and stakeholders across the city. More than 100 citizens, administrators, business representatives, non-profit organizations, and planners participated in the visioning workshop. As this effort moves forward, we

anticipate significant synergies with policymakers and planners when we facilitate scenario building around the futures for metropolitan Phoenix.

- Research on **community gardening** is being conducted via a partnership between academic researchers and a community development organization. Our community partners served as our guide to the research questions. We operationalized their questions and employed academic research methods to synthesize a holistic understanding of food justice and food security within a local food initiative. In the full spirit of use-inspired research, we have worked with the organization to analyze the research results and to understand their implications for community development efforts.

IX. PUBLICATIONS 2010-2011

JOURNAL ARTICLES

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APPENDIX A 2010-2011 CAP LTER PARTICIPANTS	
	Duration of Involvement
Principal Investigator	
Daniel Childers, Sustainability	2008-present
Executive Committee and Co-Principal Investigators	
Christopher Boone, Sustainability; Human Evolution and Social Change	2006-present
Nancy Grimm, Life Sciences	1997-present
Sharon Harlan, Human Evolution and Social Change	1999-present
Charles Redman, Sustainability; Human Evolution and Social Change	1997-present
Billie Turner, Geographical Sciences and Urban Planning; Sustainability	2009-present
Co-Principal Investigators	
Heather Bateman, Applied Sciences and Mathematics	2009-present
David Casagrande, Sociology and Anthropology, W. Ill. U.	2003-present
Sharon Hall, Life Sciences	2005-present
Kelli Larson, Sustainability; Geographical Sciences and Urban Planning	2005-present
Chris Martin, Applied Sciences and Mathematics	1997-present
Ray Quay, Global Institute of Sustainability	2010-present
Benjamin Ruddell, Engineering	2009-present
Kerry Smith, Economics	2006-present
Paige S. Warren, Natl. Res. Con., U of Mass-Amherst	2004-present
Paul Westerhoff, Sustainable Engineering and the Built Environment	2002-present
Jianguo Wu, Life Sciences; Sustainability	1997-present
Abigail York, Human Evolution and Social Change	2007-present
Senior Scientists	
Josh Abbott, Sustainability	2009-present
Rimjhim Aggarwal, Sustainability	2009-present
Luc Anselin, Geographical Sciences and Urban Planning	2010-present
Ramon Arrowsmith, Earth and Space Exploration	1997-present
Becky Ball, Mathematics and Natural Sciences	2010-present
George Basile, Sustainability	2010-present
Bob Bolin, Human Evolution and Social Change	1999-present
Anthony Brazel, Geographical Sciences and Urban Planning	1997-2011
Pierre Deviche, Life Sciences	2008-present

Stanley Faeth, Biology, U. North Carolina, Greensboro	1997-present
Eli Fenichel, Life Sciences	2010-present
Lara Ferry, Mathematics and Natural Sciences	2010-present
Janet Franklin, Geographical Sciences and Urban Planning; Life Sciences	2009-present
Matthew Fraser, Sustainability	2010-present
Patricia Gober, Geographical Sciences and Urban Planning; Sustain.	1997-present
Susanne Grossman-Clarke, Global Institute of Sustainability	2004-present
Hilairy Hartnett, Earth and Space Exploration; Chemistry & Biochem.	2007-present
Darrel Jenerette, Plant Biology, U. Calif-Riverside	2010-present
J. Chadwich Johnson, Mathematics and Natural Sciences	2006-present
Darren Julian, AZ Game and Fish	2006-present
Jason Kaye, Crop and Soil Sciences, Penn State University	2002-present
Tim Lant, Decision Theater	2010-present
Ananda Majumdar, Mathematics and Statistical Sciences	2006-2011
Melissa McHale, Biology, North Carolina State	2007-present
Laura R. Musacchio, Landscape Arch., U of Minn.	1999-present
Soe Myint, Geographical Sciences and Urban Planning	2008-present
Carol Raish, US Forest Service	2010-present
Helen Rowe, Life Sciences	2010-present
John Sabo, Life Sciences	2009-present
Osvaldo Sala, Life Sciences; Sustainability	2010-present
Eyal Shochat, Independent researcher	2002-present
Everett Shock, Earth and Space Exploration; Chemistry & Biochem.	2004-present
Katherine Spielmann, Sustainability; Human Evolution & Social Change	2009-present
Jean Stutz, Applied Sciences and Mathematics	1998-present
Emily Talen, Geographical Sciences and Urban Planning	2009-present
Arnim Weik, Sustainability	2009-present
Amber Wutich, Human Evolution and Social Change	2006-present
Enrique Vivoni, Sustainable Engineering; Earth and Space Exploration	2010-present
Thomas Ziemba, Maricopa Community Colleges	2010-2011
Senior Personnel: Managers	
Stevan Earl, Site Manager	2006-present
Monica Elser, Education Manager	1998-present
Marcia Nation, Project Manager	2006-present
Philip Tarrant, Information Manager	2010-present
Sherry Yazzie, Finance Manager	2011-present
Linda Williams, Finance Manager	1997-2010

Post-Doctoral Research Fellows	
Darren Ruddell, Global Institute of Sustainability	2009-2011
Milan Shrestha, Global Institute of Sustainability	2009-2011
Laura Turnbull, Global Institute of Sustainability	2009-present
Chi Zhang, Global Institute of Sustainability	2009-2011
Research Technical Personnel	
Amanda Kate Elrod, Research technician, CAP LTER	2009-present
Roy E. Erickson, Research specialist, CAP LTER	2000-present
Michael Holland, Research technician, CAP LTER	2008-present
Cathy D. Kochert, CAP LTER lab manager	1999-present
Karen Lafrance, Research lab aide, CAP LTER	2006-present
Xiao Xiao Li, GIS and remote sensing technician, CAP LTER	2011-present
Heather Matthies, Research technician, CAP LTER	2010-present
Quincy Stewart, Research technician, CAP LTER	2005-present
Maggie S. Tseng, Research technician, CAP LTER	1997-present
Informatics Lab	
David Julian, Global Institute of Sustainability	2011-present
Ryan Raub, Global Institute of Sustainability	2011-present
Philip Tarrant, Global Institute of Sustainability	2010-present
Public Outreach/Education Personnel	
Monica Elser, Global Institute of Sustainability	1998-present
Gina Hupton, Global Institute of Sustainability	2009-present
Research Support Personnel	
Bryan Barker, Global Institute of Sustainability	2009-present
Travis Buckner, Global Institute of Sustainability	2010-present
Sara Eeds, Global Institute of Sustainability	2008-2010
J. Nikol Grant, Global Institute of Sustainability	2001-present
Amanda Jung, Global Institute of Sustainability	2010-present
Mindy Kinnard, Global Institute of Sustainability	2011-present
Elizabeth Marquez, Global Institute of Sustainability	2005-2011
Diana Rodak, Global Institute of Sustainability	2009-present
Susan Siddell, Global Institute of Sustainability	2010-present
Linda Williams, Global Institute of Sustainability	1997-2010
Sherry Yazzie, Global Institute of Sustainability	2011-present
Cindy Zisner, Global Institute of Sustainability	1997-present

Graduate Research Associates	
Jeffrey Ackley, Life Sciences/IGERT	2009-present
Melanie Banville, Applied Sciences and Mathematics	2009-2011
Tommy Bleasdale, Human Evolution and Social Change	2010-present
Eric Chapman, Life Sciences	2011-present
Winston Chow, Geographical Sciences and Urban Planning	2007-2011
John Connors, Geographical Sciences and Urban Planning	2011-present
Elizabeth Cook, Life Sciences	2008-present
Carolyn Crouch, Human Evolution and Social Change	2010-present
Scott Davies, Life Sciences	2009-present
Juan Declet, Human Evolution and Social Change	2011-present
Xiaoli Dong, Life Sciences	2009-present
Chao Fan, Geographical Sciences and Urban Planning	2011-present
Erin Frisk, Sustainability	2008-present
Christopher Gallati, Geographical Sciences and Urban Planning	2010-present
Mac Gifford, Sustainable Engineering & the Built Environment	2010-present
Rebecca Hale, Life Sciences	2007-present
George Alexander Hamilton, Chemistry and Biochemistry	2008-present
Dorothy Ibes, Geographical Sciences and Urban Planning	2010-present
Ben Jewell, Human Evolution and Social Change/IGERT	2009-present
Shai Kaplan, Geographical Sciences and Urban Planning	2009-present
Won Kyung Kim, Geographical Sciences and Urban Planning	2010-present
Susannah Lerman, Natural Resources Conservation, U Mass	2006-2011
Yevgeniy Marusenko, Life Sciences	2009-present
Genevieve Metson, Sustainability	2010-2011
Lindsay Miles, Life Sciences	2010-present
Yun Ouyang, Sustainability	2009-present
Katelyn Parady, Human Evolution and Social Change	2011-present
Julie Ripplinger, Life Sciences	2010-present
Scott Robinson, Earth and Space Exploration	2011-present
Colleen Strawhacker, Human Evolution and Social Change/IGERT	2006-present
Carissa Taylor, Sustainability	2009-present
Patricia Trubl, Life Sciences	2010-present
Kelly Turner, Geographical Sciences/IGERT	2007-present
Ben Warner, Sustainability	2010-present
Christina Wong, Sustainability	2008-present
Karl Wyant, Life Sciences	2011-present
Sainan Zhang, Sustainability	2009-present

Undergraduate Student Workers	
Jaleila Brumand (Larson/Hall Research)	2010-2011
Brianna Edgell (Arthropod Lab)	2010-present
Stephen Hilinski (Ecology Explorers Intern)	2011
Venkataraman Krishnamani (Informatics Lab)	2011
Hannah Laluzerne (Larson/Hall Research)	2010-2011
Jessica Webber (J-Earth lab)	2010-2011
David Wernsman (Ecology Explorers Intern)	2011
Research Experience for Undergraduates (REUs)	
Shaneen Beebe, Environmental Technology Mgmt., ASU Poly	2011
Jaleila Brumand, Sustainability and Economics	2011
Olga Epshtei, Civil Engineering	2011-2012
Chris Sanchez, Ecosystem Science and Policy & Biology, Miami U.	2011
Michelle Schmoker, Life Sciences/Biology	2010-2011
Meghan Still, Life Sciences, ASU West	2011-2012
Erica Warkus, Conservation Biology and Ecological Sustainability	2011-2012
Nicholas Weller, Sustainability	2010-2012
Ecology Explorers Teachers	
Jennifer Anfinson, Deer Valley Unified School District	2011
Richard Burkhart, Isaac School District	2011
Emily Carrasco, Mesa Public Schools	2011
Janet Deppe, Isaac School District	2011
Sarah Eary, Isaac School District	2011
Ginny Enright, Chandler Unified School District	2011
Dan Fortney, Chandler Unified School District	2011
Jennifer Galbreath, Deer Valley Unified School District	2011
Pamela Gavina, Isaac School District	2011
Olga Gilchrist, Isaac School District	2011
Eric Hansen, Isaac School District	2011
Stephanie Homyak, Isaac School District	2011
Jon Hutman, Kyrene School District	2011
Ashley Janaulis, Deer Valley Unified School District	2011
Erin Joyner, Isaac School District	2011
Jeannine Kuropatkin, Mesa Public Schools	2011
Angela Lee, Isaac School District	2011

Mark Lemieux, Kyrene School District	2011
Allison McIntosh, Mesa Public Schools	2011
Melissa Melville, Kyrene School District	2011
Rebecca Nichols, Kyrene School District	2011
Joy Scheitlin, Chandler Unified School District	2011
Miles Smith, Kyrene School District	2011
Susan Sosa, Kyrene School District	2011
Laura Steffen, Kyrene School District	2011
Ann Thumm, Isaac School District	2011
Melanie Wetmore, Isaac School District	2011
Holly Williams, Isaac School District	2011
Nancy Zimmerman, Kyrene School District	2011
Juan Zozaya, Isaac School District	2011
Community Partners	
City of Mesa	
City of Phoenix	
City of Scottsdale	
Deer Valley Unified School District	
Desert Botanical Garden	
Gilbert Public Schools	
Glendale Unified School District	
Kyrene School District	
Maricopa Association of Governments	
Maricopa Community Colleges	
McDowell Sonoran Conservancy	
Mesa Public Schools	
Nina Mason Pulliam Rio Salado Audubon Center	
Paradise Valley Unified School District	
Salt River Project	
Rocky Mountain Research Station, US Forest Service	
Scottsdale Unified School District	
Southwest Center for Education and the Natural Environment	
Valley Permaculture Alliance	
Organizations Giving Permission for Sampling on Their Sites	

Arizona Dept. of Transportation	2011-present
Arizona State Parks	2011-present
City of Phoenix	2011-present
City of Scottsdale	2011-present
City of Tempe	2011-present
Desert Botanical Garden	2011-present
Flood Control District of Maricopa County	2011-present
Maricopa Co. Parks and Recreation Dept.	2011-present
Scottsdale Silverado Golf Club	2011-present
US Forest Service	2011-present

APPENDIX B
CAP LTER LONG-TERM MONITORING

Monitoring Program	Number of Sampling Locations	Sampling Frequency	Variables Measured
Arthropods	31 sites	Quarterly	• Ground-dwelling arthropods
Birds	56 sites (Core) 40 neighborhoods (PASS)	Core: semiannually (Jan, Mar) PASS: semiannually (Dec, Feb) the year of and year following the PASS survey	• Point-count bird census
Survey 200	~200 sites	Five years (spring)	• Photo documentation • Vegetation composition, and cover/biovolume • Soil: physical, chemical and biological • Habitat/built structure • Human activity • Tree Health • Vegetation-dwelling arthropods • Residential yard characteristics
North Desert Village	4 treatment areas	Continuous	• Air temperature • Ground surface temperature • Soil temperature • Soil heat flux • Soil water content
North Desert Village	4 treatment areas	Monthly	• Landscape water use • Electricity use • Dwelling surface temperature
North Desert Village	5 treatment areas	Quarterly (arthropods), semiannually (birds)	• Ground-dwelling arthropods • Point-count bird census
Atmospheric deposition	15 locations (upwind, core, and downwind of greater Phoenix) 2 locations: urban core and downwind of greater Phoenix	Quarterly Quarterly and following precipitation-producing storms	• Bulk nitrogen deposition • Major cations and anions in wet & dry deposition

APPENDIX B
CAP LTER LONG-TERM MONITORING

Monitoring Program	Number of Sampling Locations	Sampling Frequency	Variables Measured
Desert flora productivity	15 locations (upwind, core, and downwind of greater Phoenix)	Semiannually (spring and fall), except annuals in the spring only	• Productivity (stem length growth) of Creosote (*Larrea tridentata*) • Productivity (biomass harvesting) of annual plants
Desert soil chemistry	15 locations (upwind, core, and downwind of greater Phoenix)	Semiannually (spring and fall)	• Nutrients, and major cations and anions
Stormwater monitoring	11 nested locations located primarily within the Indian Bend Wash catchment	Discrete, time-weighted sampling of each runoff-producing storm	• Nutrients • Major cations/anions • pH • Temperature • Specific conductance • Particulates • Runoff volume (hydrograph)
Land-use and land-cover	CAP LTER site	Five years	• Land use change • Land cover change
Microclimate	AZMet stations	Data mined as needed	• Growth and intensity of urban heat island • Decline in frosts and freezes
Microclimate	2 locations corresponding to atmospheric deposition study sites	Continuous	• Standard suite of meteorological variables
Phoenix Area Social Survey (PASS)	40 neighborhoods	Five years	Survey themes include: • Water supply and conservation • Land use, preservation and growth management • Air quality and transportation • Climate change and the urban heat island