CAP3: Urban Sustainability in the Dynamic Environment of Central Arizona

2012 Annual Report to the National Science Foundation

Compiled by the CAP LTER Management Team

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I. Overview of Program Results

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; Grimm et al. 2012).

The 6,400-km^2 CAP study area in central Arizona incorporates metropolitan Phoenix, surrounding Sonoran Desert scrub, and rapidly disappearing agricultural fields. 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 dynamics, altered biogeochemical cycles, and biodiversity.

Key 2012 Program Results

- **CAP advances understanding of urban socioecological systems.** CAP participants have published 422 journal articles, books, and book chapters since the project's inception in 1997.
- **CAP faculty members engage in interdisciplinary collaboration.** CAP3 involves 60 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.** 45 graduate students are counted among CAP3 participants, along with 12 undergraduate students who have participated in the Research Experience for Undergraduates (REU) program.
- **Students advance scientific knowledge.** Since 2004, students have been authors on 103 publications; for 66% of these publications, the student was the first author.
- **Funding secured for urban socioecological research.** Over $53 million in funding associated with CAP since 1997 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 48 middle-school teachers from 9 school districts during 2011-2012, potentially impacting thousands of middle-school students. This is in addition to the hundreds of teachers who attended CAP's teacher professional development activities in CAP1 and CAP2, many of who still are engaged with Ecology Explorers and use our online protocols and curriculum.
- **Community partnerships lead to use-inspired research.** During 2012, CAP initiated work on its first citizen-science project with the Salt River Project and the Valley Permaculture Alliance, began arthropod monitoring with the McDowell Sonoran Conservancy, and joined with a number

of Phoenix-area organizations to form the Conservation Alliance to conserve mountain park preserves.

- **Collaborations among LTER sites advance understanding of ecology and society across ecosystems.** 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. CAP scientists are currently involved in nine cross-site initiatives.
- **Data management enables wide usage of CAP datasets.** Recent enhancements to CAP's data management system as well as improvements to data and metadata have increased the usability of CAP's data sets, which were already frequently accessed.

II. Research Activities

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. Last year, our team in the Environmental Remote Sensing and Geoinformatics Lab (ERSAG) completed work on parcel-scale classification of the City of Phoenix, using Quickbird data (2.4 m resolution, multispectral data). This year we used 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. Considering the spectral resolution limitation of the aerial photography (three visible bands only), we established hierarchical classification networks to discriminate land-cover classes at different levels and generated a series of decision rules for different types of landscapes (i.e., urban, suburban, rural, desert-mountain, and agricultural areas). Within developed urban areas, we initially separated images into residential and non-residential parts, using cadastral parcel GIS data as masks. We based the image segmentation on each of the cadastral parcels at the upper level to reduce the misclassification between house and soil. We compared image objects with similar spectral information with their neighbor objects and their super-objects and sub-objects in terms of their spectral response, spatial relationship, geometry, and texture characteristics for their class identification. Land-cover mapping in the desert-mountain areas made use of the GIS data on water lines and road lines. Our object-based classification results achieved a higher overall accuracy than using pixel-based classification methods. In September, we received the fourth band of NAIP, which will allow us to generate a land-cover map with even higher accuracy.

Together with the NSF-funded "Urban Vulnerability to Climate Change" CNH project, we funded a MODIS/ASTER Simulator (MASTER) flight over sections of the Phoenix metropolitan area in summer 2011. MASTER data contain valuable spectral information within the fifty channels ranging from 0.4-14 µm. Data on surface temperature extracted from MASTER imagery are very useful for climate-related analyses, and the high-resolution spectral information from the visible channels can be used as ancillary data for high-resolution land-cover mapping. Our task this year was to work with colleagues at the NASA Johnson Space Center to preprocess the MASTER data in order to make it useful for analyses. This involved the conversion of radiance data to correct units; atmospheric correction in VSWIR channels and TIR channels; the normalization of temperature-emissivity; and the georeferencing of the MASTER dataset. These data are now archived with CAP datasets.

North Desert Village (NDV) Experimental Suburb

We designed the NDV community landscape experiment at ASU's Polytechnic campus as 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 CAP study area (Martin et al. 2003; Cook et al. 2004). During spring 2006, we installed micrometeorological stations in the central common area of each treatment.

For six years, we have monitored volume of landscape irrigation applied, 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. Two publications (Martin et al. 2007; Martin 2008), one thesis (Busse 2010), and one manuscript in preparation (Middel et al. in prep) 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; Casagrande et al. in prep.). Two recent student research projects using the NDV site have focused on 1) modeling soil moisture and plant stress and 2) lizard thermal regulation.

Last year, the university approached us about the cost of maintaining the landscaping at NDV. The university wanted us to assume a larger portion of the maintenance costs, which were likely to increase over time and place an untenable strain on our budget. In light of the university's request, we evaluated our commitment to the NDV Experiment. While productive initially, the platform has attracted a decreasing number of scientists in recent years due to scientists leaving ASU and other research projects competing for scientists' time and energy. We also know that ASU has plans to raze the NDV complex, which is composed of steadily decaying former military housing, for new development and university expansion. Since the economy has improved in the Phoenix area, it is possible these plans will be revived. After weighing these issues and discussing challenges and merits with scientists who were instrumental in establishing NDV, the CAP Executive Committee decided to end the project effective December 31, 2012, which gave all researchers one year to wrap up their NDV research. We will maintain our instrumentation in the four treatment areas and one non-treatment area for the time being until the university asks us to remove these or until the university removes our landscaping from the areas. As with all of our research, we will archive all NDV data and metadata for future analysis.

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. CAP technicians and managers completed the third iteration of the Survey in 2010 and have processed and vouchered all samples.

CAP scientists have used Survey 200 data in numerous studies (Bang and Faeth 2011; Bang et al. 2012; Dugan et al. 2007; Hope et al. 2003, 2005, 2006; Kaye et al. 2008; Lerman et al. in press; Oleson et al. 2006; Stuart et al. 2006; Majumdar et al. 2011, 2010, 2008; Walker et al. 2009; Zhu et al. 2006; Zhuo et al. 2012). Ongoing work using the full series of Survey 200 data includes research on black carbon in Phoenix soils (Hamilton and Hartnett in review.), work on the spatial distribution of varying levels of vegetation C and NPP (McHale and Majumdar in prep.), use of soil and vegetation data to fit parameters to a new hierarchical ecosystem model (Zhang et al. in press), and investigations quantifying the spatiotemporal dynamics and resilience of vegetation, funded through CAP's graduate grant program.

Phoenix Area Social Survey (PASS)

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, and its survey neighborhoods are located around Survey 200 points. We have conducted the survey three times: 2001-2002 (pilot), 2006, and 2011, and we now have longitudinal data in certain research domains. The publication record of PASS attests to its scientific productivity (Harlan et al. 2006, 2008, 2009; Kirby et al. 2006; Larsen and Harlan 2006; Larsen et al. 2004; Larson et al. 2009a and b, 2011a and b; Lerman and Warren 2011; Ruddell et al. 2010, 2011; Stefanov et al. 2004; Yabiku et al. 2009).

We ended the 2011 administration of the survey in late December 2011 with a total of 806 respondents and an overall response rate of 43.4%. We administrated the survey longer than anticipated in order to increase the overall response rate and more specifically to increase the response rate in lower-income, minority (primarily Spanish-speaking) neighborhoods. CAP received a social science supplement in 2010 that allowed us to put additional resources and effort into recruiting participants in these neighborhoods. We also used the supplement funds to add four primarily minority neighborhoods to our sample, three of which are co-located with Survey 200 sites and one which is the site of community research for the NSF-funded “Urban Vulnerability to Climate Change” project, a CAP-leveraged initiative.

We focused our work in the early part of 2012 on compiling the survey codebook (metadata), cleaning survey data, gathering US Census data for the census tracts in the survey, and producing additional GIS products for analysis. Once we completed the majority of these tasks, our team of interdisciplinary researchers began analyzing the data.

Among the many analyses underway is REU student Jacob Fishman’s hedonic modeling project, which uses PASS data and housing sale prices to understand the relationship between public goods and environmental attitudes (for preliminary results, see Undergraduate Training section of this report). We are also using PASS data in innovative ways to improve middle and high school students' understanding of basic data-analysis techniques. A graduate student worked this summer with CAP’s Ecology Explorers staff to create lesson plans for social studies classes based on PASS data and methods, which will be tested by teachers in the Phoenix area.

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 (Grimm and Redman 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 have begun 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 selected findings from our array of research on the urban heat island:

- Understanding the significance of Phoenix UHI research
- An urban climate vulnerability index

- Ecosystem services, vegetation, and vulnerability to urban heat (cutting across several IPAs)

We have continued our microclimate work in the **Power Ranch** neighborhood that examines the water and energy nexus. Our **PASS** research team is analyzing the suite of questions in the survey that pertain to perceptions of urban heat and health outcomes. Other researchers have begun analyzing data from our tall, **energy-budget flux tower** in a west Phoenix neighborhood. A CAP graduate student has initiated research on the **urban heat island and desert lizard thermoregulation**, which spans the Climate and Biodiversity 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 urbanization 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:

- Hydrogeomorphic alterations to desert water systems (also a Biogeochemical IPA project)
- Urban stormwater (also a Biogeochemical IPA project)
- Tres Rios Constructed Wetlands research (cutting across several IPAs)

We have continued our work on **regional water quality monitoring and evaluation**, which investigates pharmaceutical and personal care products (PPCPs) and persistent organic pollutants (POPs) in surface water and groundwater in the Phoenix area. We received international supplement funding under CAP2 to initiate comparative urban wetland research in the **Yongding River Green Ecological Corridor** in Beijing, and a CAP Ph.D. student returned to Beijing this summer to complete this research. As part of a collaboration with the Decision Center for a Desert City (DCDC; NSF-funded center for Decision Making Under Uncertainity), we have supported a new graduate-student project that examines the reaction of decision makers to uncertainty representations of climate change's impact on water availability in DCDC's **WaterSim** model.

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 selected ongoing initiatives:

- Soil black carbon dynamics
- Lead distribution in metropolitan Phoenix
- Phosphorus cycling

Analyses of data from the tall, energy flux tower in west Phoenix also fall under this IPA. Newly initiated research on **moss as integrators of soil and stream nutrients** in deserts spans two IPAs, the Biogeochemical and Biodiversity IPAs. We have continued our long-term monitoring and experimentation investigating **carbon and nitrogen deposition** and the **effects of urban atmosphere on Sonoran Desert ecosystems** as well as research on **microbial community structure and N cycling in arid ecosystem soils**. Many of our analyses of **environmental risk and justice** fall under this IPA too.

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 have continued long-term bird, arthropod, and plant monitoring and have broadened our efforts to understand the underlying processes associated with species loss and change in urban settings. We also continue to pursue understanding of the socioeconomic and policy drivers of habitat structure and of the impact that access to 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 selected findings from our long-term bird and arthropod research.

- Impact of HOAs on native bird species in the city
- Bird foraging behavior and landscape type
- Arthropod abundance, richness, and composition across land-use types
- Arthropod community composition across habitats

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 also are working with the Salt River Project, a local utility, and the Valley Permaculture Alliance, a Phoenix-based non-profit, to initiate a citizen science project focusing on **urban shade trees and fruit trees** (see Outreach section). Our work on **urban burrowing owls**, a charismatic native species, is ongoing with the collaboration of the Arizona Game and Fish Department. A REU project has commenced work on the **impact of exotic crayfish on the desert pupfish**, an endangered species (see Undergraduate Education section). We also began work on the interesting phenomenon of **fish communities in concrete-lined canals** used for water delivery in metropolitan Phoenix that seeks to understand the species in canals and the resources in this unusual habitat. Our work on **long-term changes in urban birds** has benefitted from a new research team member, Kevin McGraw, who brings his work on **urbanization and bird coloring.** This work joins other Biodiversity IPA projects, such as work on **black widow spiders**, which focus on potential evolutionary responses to urbanization.

Cross-LTER Site Research

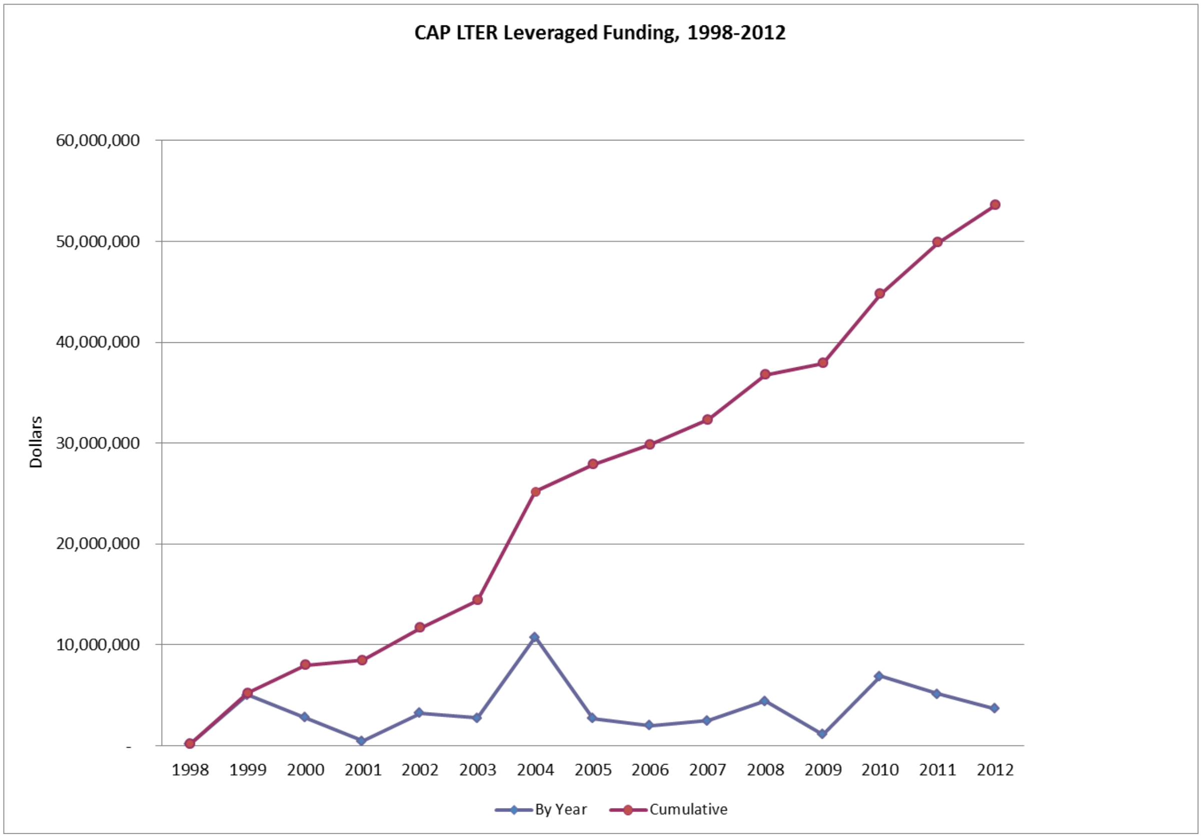
- **Social and ecological responses to climate change and land-use effects on water availability: contrasting resilience among major river basins of the US and Canada** (AND, CAP, CWT, HBR, LUQ, NWT, plus several non-LTER long-term hydrologic sites): Examines evidence for long-term change in climate and hydrology, using among other resources the ClimDB and HydroDB databases, impacts of human activities and land-use change on hydrology in major river basins (Jones et al. 2012). This project is ongoing.
- **Land fragmentation** (CAP, SEV, JRN, SGS, and KNZ): Examines land fragmentation patterns across the five urban areas associated with the LTER sites (Shrestha et al. 2012; York et al. 2011; S. Zhang et al. in press). Funded through social science supplement to CAP and other sites as well as CAP funds. Phoenix work is ongoing with expected completion in spring 2013.
- **Urban residential landscapes** (CAP, PIE, FCE and BES): Focuses on understanding the form and drivers of urban residential landscapes as socioecological systems (Brumand and Larson 2012; Cook et al. 2012; Harris et al. in press; Roy Chowdhury et al. 2011). Funded initially through a social science supplement to CAP and the other sites. Now has morphed into the "Ecological homogenization of America" project, supported by NSF Macrosystems Biology.
- **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. Funded through LNO working group grant to CAP and the School of Human Evolution and Social Change at ASU.
- **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. Funded through CAP-leveraged grant from NSF.
- **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. Funded through LTER sites leveraged grant from NSF.
- **RCN-SEES for urban sustainability** (CAP, BES, FCE, PIE, and other cities): Integrates and synthesizes urban research while incubating solutions-oriented products. Funded through LTER sites leveraged grant from NSF.
- **Scenarios of change** (numerous LTER sites): Examines scenarios of land-use change (Thompson et al. 2012).
- **Maps and Locals (MALS)** (numerous LTER sites): Investigates socioecological systems using a mixed methods comparative approach, including spatial analysis and ethnography. Funded through LNO working group grants.
- **Developing a framework for socio-ecological systems research** (numerous LTER sites, European LTER network): CAP has been an active participant in the development of the Integrated Science for Society and Environment framework for socioecological research (Collins et al. 2011), as well as participating in a book project arising from the European LTER network and other collaborators (Grimm et al. 2012).

Associated and Leveraged Awards, 2007-2012

Total associated and leveraged awards, 2007-2012: **$23,731,363**
Total associated and leverage awards for the duration of CAP (1998-2012): **$53,583,771**

Year	Title	Amount$	PIs	Funding Agency
2007	Learning through Engineering Design and Practice: Using our Human Capital for an Equitable Future	1,079,985	T. Ganesh	NSF
2007	DCDC Supplement	74,395	Patricia Gober	NSF
2007	CAP Supplement	90,000	Nancy Grimm	NSF
2007	Ecosystem Response to N and Organic C Deposition Supplement	12,000	Nancy Grimm	NSF
2007	Influence of Urbanization on Weather in Arid Phoenix Metro Area	624,000	Susanne Grossman-Clarke	NSF
2007	Strategic Investment in ARENA	60,440	Travis Huxman	Science Foundation of AZ
2007	Symbiota: A Virtual Flora Model for the Southwestern US	503,367	Corinna Gries	NSF
2007	Legacies on the Landscape: Prehistoric Human Land Use and Long-Term Change Supplement	48,814	Sharon Hall	NSF
2008	CAP Supplement	153,295	Nancy Grimm	NSF
2008	Ecosystem Response to N and Organic C Deposition Supplement	7,000	Nancy Grimm	NSF
2008	Sustainability Science for Sustainable Schools	2,999,964	Charles Redman	NSF
2008	Southwest Urban Collaborative Concept Paper	15,000	Christopher Boone	US Forest Service, Rocky Mountain Research Station
2008	Urban Vulnerability to Climate Change: A System Dynamics Analysis	1,264,982	Sharon Harlan	NSF
2008	Socioecological Dynamics of Residential Landscapes: A Multi-Site Collaboration	17,805	Kelli Larson	NSF
2009	Legacies on the Landscape: Prehistoric Human Land Use and Long-Term Change Supplement	7,000	Sharon Hall	NSF
2009	Ecosystem Science Close to Home	299,000	T. Bond	Andrew Mellon Foundation
2009	Arizona Water Institute MOU with Gries	30,000	Corinna Gries	Arizona Water Institute
2009	LTREB: Multi-Scale Effects of Climate Variability and Change	449,298	Nancy Grimm	NSF
2009	Impacts of Urbanization on Nitrogen Biogeochemistry in Xeric Ecosystems	259,769	Nancy Grimm	NSF
2009	CAP Supplement	64,000	Nancy Grimm	NSF
2009	The Modeling Institute	1,250,000	Elizabeth Capaldi	NSF
2009	Condition-dependent Signal Reception: Limitations and Functions of Carotenoids in Avian Color Vision	318,000	Kevin McGraw	NSF
2010	CAP Supplement	148,241	Nancy Grimm	NSF
2010	Land and Water Use Decision-Making and Ecosystem Services along a Southwestern Socio-Ecological Gradient	239,143	Christopher Boone	NSF
2010	Decision Center for a Desert City	6,500,000	Patricia Gober	NSF

2011	A Controlled Water Application Experiment to Quantify the Effects of Water Application and Arborification at the Neighborhood Scale in a Phoenix Area Community	77,000	Ben Ruddell	Salt River Project
2011	Assessing Decadal Climate Change Impacts on Urban Populations in the Southwestern USA.	750,000	Ben Ruddell	NSF
2011	CAP Supplement	47,985	Dan Childers	NSF
2011	Ecological Homogenization of Urban America	2,910,664	Peter Groffman	NSF
2011	Hydrology Versus Ecology: The Effectiveness of Constructed Wetlands for Wastewater Treatment in a Semi-Arid Climate	30,000	Laura Turnbull	Arizona Water Resources
2011	Moss Nutrient Plasticity in a Polar Desert: Insights from a Hot Desert Comparison	5,000	Becky Ball	New College of Interdisciplinary Arts and Sciences
2011	RCN-SEES for Urban Sustainability: Research Coordination and Synthesis for a Transformative Future	750,000	Dan Childers	NSF
2011	Students Authoring Intelligent Tutoring Systems for Constructing Models of Ill-Defined Dynamic Systems	550,000	Kurt VanLehn	NSF
2012	Wavelet Analysis of High Spatial Resolution Imagery for Urban Mapping Using Infinite Scale Decomposition Techniques	125,000	Soe Myint	NSF
2012	Evaluation of Drought Risks and its Impact on Agricultural Land and Water Use to Support Adaptive Decision-making	285,000	Soe Myint	NOAA
2012	The role of plant litter decomposition in determining the fate and outcomes of nitrogen inputs in arid ecosystems	5,000	Becky Ball	New College of Interdisciplinary Arts and Sciences, ASU
2012	Regional water quality monitoring and research	16,500	Paul Westerhoff	NSF/IUCRC, Water and Environmental Technologies Center
2012	Water Sustainability under Near-term Climate Change: A Cross-Regional Analysis Incorporating Socio-Ecological Feedbacks and Adaptations	1,500,000	Sankar Arumugam	NSF
2012	Feedbacks between Human Community Dynamics and Sociological Vulnerability in a Biodiversity Hotspot	1,449,521	Scott Yabiku	NSF
2012	Conservation Alliance	300,000	Kim McCue	Pulliam Trust



Information Management Activities

We have archived 331 datasets since CAP's inception in 1997. Fastlane only lists our long-term monitoring datasets. All CAP datasets can be found at http://caplter.asu.edu/data/ . We will be revising and reshaping the data search function on the CAP website in 2013.

This year, we completely refreshed the CAP LTER metadata contribution to the network Metacat catalog. It now reflects the same inventory (330+) datasets available on the CAP LTER data portal. We also brought all metadata up to the EML 2.1 standard and addressed a number of metadata quality issues identified in the IM review this spring.

A good proportion of the CAP LTER data catalog is spatial data. Earlier this year, we noted that there were a number of quality issues with these data, including non-standard projections, missing projection files, and missing metadata. We used IM supplement funds to conduct a complete spatial data audit. Where possible, we had a GIS student update the projections to a standard projection, and we revised and improved the metadata. We then repackaged all the datasets to include the metadata files.

We made further enhancements to our network ClimDB contribution by automating much of the harvesting process. This has taken our harvest ability from a once yearly upload to a weekly harvest of 30+ meteorological stations.

We used IM supplement funds to purchase a new development server. This server now provides a dedicated development environment for CAP LTER data management activities. The first project to take advantage of this is the redevelopment of the database used to track and coordinate CAP LTER projects, such as personnel data, project information, and publications. Once this new database is complete, it will enhance our ability to store relational data on our projects, which we then can display on the CAP website.

III. Major Findings by Research Area

Climate, Ecosystems and People

CAP's climate work has focused on the **urban heat island** (**UHI**) from both climatological and social vulnerability perspectives (Brazel et al. 2007; Chow et al. 2011; Harlan et al. 2006; Ruddell et al. 2010). The Phoenix UHI has been more extensively studied than that in many other major metropolitan areas. We found 55 published studies on the Phoenix UHI during a recent literature search in contrast to 28, 34, and 10 for New York City, Houston, and Los Angeles, respectively (Chow et al 2012). Partnerships between and among academic units and private sector agencies, a well-developed and extensive urban meteorological station network, and strong media coverage of UHI-related issues in Phoenix have all contributed to the development of UHI research in the Phoenix metropolitan area. In the late 1990s, CAP LTER provided an interdisciplinary framework for investigating the UHI and extending analysis beyond the climatological phenomenon to integrating analyses from the social, engineering, biological, and climatological sciences. The attention paid to the Phoenix UHI has encompassed the policy arena too as evidenced by municipal plans, such as the Downtown Phoenix Urban Form Project, a collaborative initiative among planner, scientists, and municipal officials to discuss altering the built environment in ways to ameliorate urban heat, and the Phoenix Tree and Shade Task Force, which developed a plan toward an average of 25% shade canopy coverage for Phoenix by 2030 (Chow et al. 2012). These initiatives indicate that our academic research has a practical application.

Our **climate vulnerability/environmental justice** work continues to explore new facets of vulnerability. Much CAP research has focused on understanding who in the population is at risk due to extreme heat and in defining an "urban heat riskscape," the spatial and temporal distribution of demographic, vegetation, and temperature characteristics across the city that combine to indicate different levels of heat exposure and capacity to deal with this situation (Harlan et al. 2006; Ruddell et al. 2010). We built on those investigations by constructing a vulnerability index made up of measures of physical heat exposure and adaptive capacity in order to better understand the spatial distribution of heat vulnerability over time. Our results revealed that the largest increases in heat vulnerability occurred in the western cities of the Phoenix metropolitan area where increased physical exposure coincided with the growth in the low-income, foreign-born population. We also saw vulnerability increases in the urban-fringe retirement communities that are being enveloped by an expanding UHI. These findings are interesting to us because they indicate vulnerability outside of the built-up city core, traditionally viewed as the main geographic site of high vulnerability. Our finding did show, however, high vulnerability in lower-income, Spanish-speaking neighborhoods relatively close to downtown Phoenix (Chow et al. 2012). Our analysis indicated that Hispanics are disproportionally vulnerable compared to other groups, and we note that this vulnerability extends beyond extreme heat to toxins and criteria air pollutants (Bolin et al. 2005, 2002; Grineski et al. 2007; Zhuo et al. 2012).

Other UHI work has sought to understand **patterns of cooling provided by urban vegetation, the water necessary to sustain this vegetation, and the relationship between vegetated surfaces and neighborhood income in the Phoenix area** (Jenerette et al. 2011). At the heart of this research is the understanding that trade-offs exist, particularly in arid environments, between the ecosystem services provided by vegetation and the water demands for maintaining this vegetation. We have identified this as an important urban sustainability issue. Focusing on surface temperature, we found that vegetation provided an almost 25°C cooling effect compared to bare soil. Yet, we estimated that it can take 2.7mm/day of water to maintain this cooling (Jenerette et al. 2011). Higher median-income neighborhoods had more vegetation and cooler temperatures than lower median-income neighborhoods, although this comes at the cost of greater quantities of water needed for irrigation. More water would be needed in lower-income neighborhoods to support a level of vegetation with similar cooling effects, which translates into a greater aggregate demand for water at the regional level. Our temporal analysis of the relationship between vegetation and income at the neighborhood level suggests that present-day inequalities do not necessarily have historic precedence; we found no relationship between income and vegetation in 1970, yet the trend toward growing inequality over time is evident in the data. We suggest a sustainability approach to ameliorating the urban heat riskscape and evaluating the economic, environmental, and social equity trade-offs in increasing urban vegetation (Jenerette et al. 2011).

Water Dynamics in a Desert City

The Phoenix metropolitan area is characterized by many hydrogeomorphic alterations to desert water systems, which began with Hohokam canal construction over a thousand years ago and continued when Americans moved into this area in the 1800s. Among the hydrogeomorphic changes common in the 20th and 21st centuries are **stormwater retention basins**, a management practice implemented in many neighborhoods and commercials areas, and **artificial lakes**, constructed mostly for recreation and neighborhood aesthetics to connote the "desert oasis" (Larson et al. 2009). Given the prevalence of these features in the urban landscape, we sought to determine the extent of hydrological modification to create lakes and retention basins and to explore the ecological implications of those modifications. We found that there are no accurate, existing maps of either artificial lakes or retention basins in the metropolitan area and employed agency data on lakes, remote sensing imagery, and data on drywells (a common feature of many retention basins) to produce maps for analysis. We determined that there are 900-1,400 artificial lakes in the Phoenix metropolitan area, covering an area ranging from 7.9 to 8.2 km^2, approximately 0.4% of the urbanized area (Larson and Grimm 2012). The sources of water for these lakes are about equally divided among groundwater, surface water, and treated effluent. It is notable that the source of water for about 30% of the lakes is unknown because these are so small that they did not fall under the permitting requirements of the Arizona Department of Water Resources. Using the dry-well data, we estimated that there may be as many as 10,000 stormwater retention basins in the Phoenix area (Larson and Grimm 2012). Ecologically, lakes provide habitat as well as year-round water for numerous species, thus mitigating the seasonal variation in available surface water in the desert. Lakes and stormwater basins could become sites of biogeochemical cycling, such as in the chain of lakes composing Indian Bend Wash (Roach et al. 2008). Economic analyses through hedonic modeling have examined the effect that Phoenix-area lakes (and the ecosystem services associated with them) have on housing prices (Abbott and Klaiber in review).

Over the past three years, CAP LTER investigators have been analyzing water and material transport associated with **stormwater runoff** within numerous urbanized catchments in Tempe, AZ and along the Indian Bend Wash in Scottsdale, AZ. Study catchments are characterized by the dominant land cover type in the Phoenix Metropolitan area (residential housing) but vary in size and stormwater infrastructure type, ranging from hydrologically disconnected systems (e.g., those characterized by numerous stormwater retention basins) to highly connected systems (e.g., those characterized predominantly by pipes or hardened channels that convey water directly to (dry) streams and rivers). Our results thus far suggest that stormwater infrastructure is functioning as designed, with highly disconnected types of stormwater infrastructure reducing the flow of water and dissolved nutrients from these systems. Stormwater infrastructure also exerts a critical influence over the transport of particulate materials from urban catchments, which, in turn, governs the export of nutrients in particulate form. In catchments with well-connected stormwater infrastructure, higher flow velocities increase the entrainment of particulate materials, thus increasing the export of particulate nutrients, which, in some instances, account for more nutrient export in particulate than dissolved forms. Dissolved and particulate nutrient export exhibit different behavior, and furthermore, all of the catchments monitored exhibit both supply-limited nutrient export behavior (i.e., storms flush all available materials) and transport-limited behavior (i.e., available materials exceed stormwater transport capacity), but under different antecedent conditions. This is the first comprehensive study of stormwater runoff quantity and quality in a highly urbanized, arid system. Ultimately, results of our study will provide critical information to state and municipal managers regarding the most effective design of stormwater infrastructure type for meeting urban water-quality goals.

At our research site in the **Tres Rios Constructed Wetlands**, we are interested in whether wetland uptake and transformation of bioactive solutes is sufficient to counteract the effects of evapoconcentration to improve wastewater quality. To answer this question, we have gathered data on wetland macrophyte biomass (both aboveground and belowground), plant species composition, plant transpiration rates, and water quality throughout the wetland every other month. Our preliminary results indicate that total biomass in the largest of three flow-through wetland cells was highest in July 2011, at 607,000 kg. Biomass declined 67% from July to September, which we attributed to 'thatching,' a phenomenon where large stands of *Typha latifolia* and *Typha domingensis* grew so tall that the plants literally fell over in large patches throughout the wetland. After this late summer thatching event, plant biomass remained lower through the winter. *Typha* spp. made up the largest proportion of biomass in all months and at its height accounting for 64% of the total. We also found that transpiration rates were highest during the hot summer months when the plants were responsible for a water-loss rate equivalent to 4–6 cm water depth per day. Water loss from the entire wetland due to evaporation and transpiration was about 50% lower in winter months. We saw some indication of nitrogen removal by the entire wetland cell during most of the year; most of this uptake was driven by nitrate removal. The pattern for phosphorus fluxes was irregular and showed no tendency towards net uptake or release. Water samples collected near the road and near the open water along our 10 vegetation transects showed much larger declines in nitrogen concentrations, including 73% removal of ammonium and 80% removal of nitrate+nitrite by the vegetated wetland itself. Nutrient budgets show that in summer, the wetland retains 90% of ammonium, 49% of nitrate, and 48% of nitrite. In winter months, retention of ammonium decreases by 50%, while retention of other forms of inorganic nitrogen decreases only marginally. Chloride concentrations increased an average of 15% along these same transects, suggesting that evapoconcentration of non-bioactive solutes is occurring within the vegetated portions of the wetland. Conductivity measurements showed a similar phenomenon. Derived budgets show no significant difference between input and output of chloride at the scale of the entire wetland cell, though, suggesting that evapoconcentration may not have a significant effect at the whole-system scale. Our preliminary interpretation of this contradiction is that much of the water flowing through the wetland cell does not come into contact with vegetated marsh. The high rates of water withdrawal via plant transpiration do suggest that considerable water must be moving laterally into the vegetated areas, though, through a process we are referring to as a "hydraulic pump." We will refine our whole-system water budget in order to estimate what volumes of water must be moving laterally via this process compared to total volumes of water entering and leaving the cell.

Biogeochemical Patterns, Processes, and Human Outcomes

Our **Survey 200** soil samples have yielded important data on biogeochemical cycling in urban, agricultural, and desert environments (Kaye et al. 2008; Majumdar et al. 2008, 2010; Oleson et al. 2006; Zhu et al. 2006). We have used these samples to investigate **soil black-carbon dynamics**. Part of this investigation examines the reactivity of organic and black carbon (OC and BC, respectively) in a desert/urban soil system, using photo-oxidation experiments. Our photo-oxidation experiments of OC and BC in soil revealed significant degradation of both materials over relatively short timescales of about 100 days, assuming 12 hours of light exposure per day. We found that degradation rates were slower during experiments using BC than in experiments using OC, which is consistent with the recalcitrant nature of BC. However, this does reveal a potential photochemical loss mechanism for BC in desert and urban soils that had been previously unknown. Fourier-transform infrared (FTIR) spectroscopy has revealed chemical functional-group changes during photo-oxidation. The presence of oxygenated functional groups in BC samples after photo-oxidation suggests not only that the material is photochemically altered/degrading but also that is being altered at the molecular level. The presence of oxygenated functional groups suggests that BC becomes more reactive upon photooxidation than previously considered.

We have also used **Survey 200** soil samples to understand the spatial distribution of heavy metals, including **lead**, a toxin that affects cognitive abilities in children (Zhuo 2010, Zhuo et al. 2012). We found elevated lead concentrations in the central core of the Phoenix metropolitan area as well as in southeastern parts of the region. While lead levels in our samples did not exceed the 400mg/kg level of safety standard proposed by the EPA, urban samples had lead concentrations as much as 10 times higher than the general desert background values. When we examined roadside soil samples, we did not find a relationship between the historical use of leaded gasoline and lead deposition. From these analyses, we concluded that lead in urban soils is most likely from lead-based paint used before 1978 rather than other sources. We conducted regression analyses to examine the demographic factors that might predict exposure to lead in the Phoenix area. We found that Hispanic neighborhoods with a large percentage of renters are likely to have relatively high soil lead concentrations. We also found that households without a car have more lead exposure than households with a car. Median family income and median household income turned out not to be good predictors of lead exposure. These results indicate an environmental justice issue in the Phoenix area where there is an inequitable distribution of risk associated with lead exposure. Those in the population with limited ability to mitigate lead exposure and the least social and political power are the most exposed to this toxin (Zhuo et al. 2012).

Building on CAP's work on nitrogen and carbon budgets (Baker et al. 2001; McHale et al. in prep) as well as an ongoing body of research on phosphorus cycling (Childers et al. 2011; Metson et al. in press), we (CAP graduate students) have focused on building a **phosphorus (P) budget** for the Phoenix metropolitan area. In constructing this budget, we examined the magnitudes and major fluxes and pools across the ecosystem boundary, the spatial arrangement of P movement and storage, as well as the linkages of P fluxes and pools to social, technological, and biophysical characteristics of the Phoenix area. We found that the Phoenix metropolitan area is a net P sink; P inputs exceed outputs. Food for human consumption is the largest P input followed by agricultural fertilizers. Together, these represent 24% of inputs to the system. In contrast, total P outputs are 0.7% of total inputs, more than an order of magnitude smaller. Our budget illustrates that many of the largest fluxes are internal to the ecosystem and represent recycling of P in the metro area, such as fluxes of human waste to wastewater treatment, agricultural feed crops fed to local cows, and the recycling of wastewater for irrigation (Metson et al. 2012). While water is an important vector for P transport in many systems, in our arid ecosystem, urban runoff represents a small flux of P from the built environment and soils to surface water, and may in fact be even lower than our estimates due to stormwater retention basins, which our research has shown are involved in nitrogen removal (Larson and Grimm 2012). People in the city, their pets, and their constructed environments (landscapes, buildings, and asphalt roads) constitute a large P pool in the system. As the Phoenix study area still contains large tracts of agricultural land, the agricultural P pool is significant too. While P budgets for cities are limited, our research suggests that features of our desert city system are evidence that support Kaye et al.'s (2006) assertion of a distinct urban biogeochemistry. Present-day P recycling in Phoenix is an unintended consequence of water management under conditions of scarcity in the metropolitan region. While agricultural and urban areas in more humid conditions grapple with P in water runoff, this is not a large concern under our arid conditions and stormwater management systems. Looking to the future, we perceive that the P budget for the Phoenix metropolitan area will change as population increases (increasing the P in human food in the system, among other things) and land under agriculture declines, reducing the recycling of wastewater and increasing food imports. We welcome collaboration with practitioners to better understand P cycling through the urban system and to develop plans for sustainable P recovery and reuse (Metson et al. 2012).

Human Decisions and Biodiversity

We continue to conduct research that examines residential yards as ecosystems shaped by people's management decisions and preferences (Cook et al. 2012, Hope et al. 2006; Larson et al. 2009, 2010; Larsen and Harlan 2006; Yabiku et al. 2008). Homeowners Associations (HOAs) are a common feature of newer master-planned development in the Phoenix area. Individuals purchasing homes in a HOA must sign a legally binding document outlining the Covenants, Conditions, and Restrictions (CCRs) of the HOA, which typically deal with exterior features of the property, including landscaping, physical structures, and even paint colors. We have explored the role that HOAs and their CCRs play in determining landscape management regimes (Martin et al. 2003). Our recent research has sought to understand **relationships between HOAs and urban biodiversity** (Lerman et al. in press; Fokidis 2011). Using data from our long-term bird monitoring and Survey 200 data on plants and arthropods, we compared bird, arthropod, and plant diversity between HOA neighborhoods and non-HOA neighborhoods. We found that neighborhoods belonging to HOAs had significantly greater bird and plant diversity but that there was no difference in arthropod diversity between the two neighborhood types (Lerman et al. in press). We hypothesize that either the institutional structure of the HOAs or the landscape management regime imposed by the CCRs helps promote biodiversity.

In other research that examined **thorny plant regulations and native birds in HOAs**, we found that of the 43 HOAs surveyed, all had restrictions on thorny (non-cacti) plants in the front and/or back yards (Fokidis 2011). Nineteen of the HOAs also had restrictions on the size of certain cacti, such as barrel cacti, organ pipe cacti, and saguaros (Fokidis 2011). Given that many native bird species use thorny vegetation for nesting and habitat, HOAs with restrictions on this type of vegetation may limit the native bird populations in these areas. In previous research that was not specific to HOAs and their restrictions, we found that yards with native vegetation had greater diversity than those with exotic vegetation (Lerman et al. 2011). Follow-up research on native bird populations in HOAs with thorny-plant restrictions will bear out the effect that these have on native birds.

To understand the processes that change bird community composition, we have examined **foraging behavior** through experimentation, using the measure of giving up density (GUD: the density of resources remaining after foraging stops) (Shochat et al. 2004). Our recent research focused on whether landscape design affects foraging behavior and examined GUDs in xeric (drought tolerant and native vegetation) and mesic (grass and exotic species of vegetation) backyards. We found that birds in mesic yards spent more time eating from seed trays placed by the researchers than the same species in a xeric yard, indicating that the xeric yard had a greater abundance of alternative food sources. From this experiment, we concluded that yards with native-like landscaping support birds better than those with grass lawns and exotic plant species (Lerman et al. 2012). Xeric landscaping is already promoted by local governments in the metropolitan area as a means of conserving water. Linking such landscaping to additional ecosystem services, like preserving biodiversity and cultural aesthetics linked to birds, may provide other incentives for households to abandon mesic landscaping.

We have also conducted experiments to compare **arthropod abundance, richness, and composition** across urban, desert remnant, and outlying desert sites (Bang et al. 2012). In these experiments, we manipulated top-down (bird predation) and bottom-up (resource availability) forces on arthropod communities associated with a native plant, *Encelia farinosa*, commonly called brittlebush. Previous CAP research had established the moderating effect of urbanization on resource availability, particularly of water, in our desert cities through active landscape management (irrigation) (Faeth et al. 2005; Shochat et al. 2006). In our experiments, we manipulated water availability and monitored plant growth, the resource of importance to plant arthropods. We also used enclosures to manipulate bird predation, a top-down factor affecting plant arthropods. We found that plants grew larger in the urban areas, indicating strong bottom-up regulation. However, results from the exclosure experiments provided no evidence of top-down control. Instead of cages allowing arthropod communities to increase, we found the opposite occurred: the cages seemed in inhibit arthropod colonization, indicating some complex interactions between caging, plant growth, and herbivore abundance. Analyses of arthropods present on the brittlebush plants indicated that urban habitats were generally the lowest in terms of diversity, richness and evenness with desert remnants falling in between urban and desert habitats on these measures (Bang et al. 2012). Furthermore, our study confirms the results from other CAP research which asserted that preserving desert biodiversity around the city is not simply a function of preserving habitats but needs to consider the maintenance of community structure and natural fluctuations (Faeth et al. 2011). We look forward to better understanding arthropod communities in desert remnants through our collaboration with the Sonoran McDowell Preserve (see Outreach section).

We have monitored **arthropod communities** across xeric and mesic landscapes, desert remnants, and native desert habitats. Our results from analyzing these data suggest that arthropod community composition varies among the four habitats at all taxonomic levels (Bang and Faeth 2011). The arthropod composition of desert remnants was closer to that of deserts than of the other two habitats. Similarly, xeric showed more similarity with mesic landscapes in terms of composition. Mesic habitats have lower diversity than the native desert but higher arthropod abundance than all habitats due to irrigation, which enhances plant growth and smooths out seasonal variation in water availability. This allows certain taxa of arthropods to dominate and thus lower diversity. Ant diversity was highest in mesic habitats, which is where we also found non-native ant taxa, such as Argentine ants. We found that certain native taxa were mostly to entirely absent from urbanized areas, suggesting the loss of specialist species or groups from heavily urbanized areas (Bang and Faeth 2011).

Land Use, Land Cover, and Land Architecture

As part of a cross-LTER site initiative funded through a social science supplement and CAP grant funds, we have been examining **land fragmentation** in the Phoenix area (Shrestha et al. 2012; York et al. 2011). In addition to our research findings, we have also made methodological advances in analyzing fragmentation spatial patterns (S. Zhang et al. in press). Specifically, we have examined the effect of moving window (MW) size on observed fragmentation spatial patterns. MW analysis addresses the problems with approaches to characterizing fragmentation that average fragmentation metrics over an entire area, which can lead to incorrect interpretations of the causal dynamics of fragmentation since spatial variation is not taken into account. MW analysis uses a "window," a spatial extent that defines the analytical unit of analysis, to move across the landscape one cell (pixel) at a time, calculating the specified metrics within the window and assigning a value to the center cell of the window. Using the MW approach, we worked to develop an optimal MW size to characterize fragmentation in the Phoenix area, using Simpson's diversity index and based on the hypothesis that effective MW size captures the greatest diversity of land classes. We determined that a MW size of 690m x 690m was the optimal resolution for detecting maximum variance of land fragmentation in the Phoenix metropolitan whereas the MW size for examining individual cities varied (S. Zhang et al. in press). Our work demonstrated that optimal MW size can be calculated rather than chosen arbitrarily by researchers.

"**Legacies on the Landscape**" is a multi-disciplinary project funded through a CAP-leveraged grant and CAP funds involving ecologists and archaeologists who examine the long-term ecological legacies of land use intensity in two different ecosystem types in the southwestern US that supported agro-ecologically active and well-studied populations of humans until 1200-1400 AD (Briggs et al. 2006, 2007; Schaafsma and Briggs 2007). One student-driven portion of the project examines the relationship between prehistoric landscape manipulation and present-day plant growth. Surface rocks are known to significantly affect soil moisture and temperature and prehistoric dryland agriculturalists manipulated rocks for these purposes. Our undergraduate and graduate students assessed the frequency and strength of spatial associations between succulents and surface rocks in semi-arid grasslands within the prehistorically active landscapes of the Agua Fria National Monument in central Arizona. They explored the association of succulents with rocks by comparing actual distributions with an expected frequency across 6 randomly selected hilltop plots (625 m2 each). Using a goodness-of-fit test, they found a greater spatial association between rocks and succulents than expected by chance (G statistic =278, p = <0.01). This pattern strongly suggests that surface rocks influence succulent distribution in this semi-arid grassland, possibly by facilitating succulent establishment or success. Succulents grow preferentially within a 2 cm buffer zone around surface rocks (64% of all individuals surveyed), and relatively few succulents (18%) are found >5 cm from a surface rock. In grasslands with few trees, rocks may increase soil moisture without significantly reducing light availability. The students' surveys did not suggest that the strength of the rock-succulent association varies between succulent growth forms or species. Although the role of nurse plants in seedling success is well studied, their findings highlight the additional, possibly facilitative role played by abiotic landscape features. The strength of the spatial association between surface rocks and succulents suggests that rock manipulation by prehistoric agriculturalists may have lasting effects on the distribution of modern-day plant communities.

We continue to develop models that will enable us to examine urban ecosystem dynamics (Jenerette and Wu 2001; Wu et al. 2003, Wu and David 2002). Our most recent modeling work has produced the **Hierarchical Patch Mosaic-Urban Ecosystem Model (HPM-UEM)**, a multi-scaled model that explicitly treats the spatial pattern and hierarchical structure of urban landscape by incorporating both top-down controls and bottom-up mechanisms in the urban environment (C. Zhang et al. in press). In constructing this model, we recognized the importance of different scales of analysis to investigations in the biological, engineering, and social sciences as well as to urban systems practitioners (Wu et al. 2006). As such, we developed the HPM-UEM to include six nested hierarchical levels: individual plant – population – land cover (or local ecosystem) – land use – landscape – region. Using a wealth of data on natural ecosystems, land management, and biophysical processes, we designed the model to: (1) provide a "hierarchical scaling ladder" that could extrapolate the local ecosystem functions from the land-cover to the land-use, landscape, and regional levels, and facilitate linking ecosystem processes to the socioeconomic factors that control the urban land structure; (2) model the nested structure of human disturbances, assessing how multiple anthropogenic controls from different scales modify the environmental factors that constrain ecosystem functions; and (3) include two often overlooked ecosystem hierarchical levels – the population and individual plant levels – and model the related plant/population structure and processes. In evaluating the performance of the model, we applied it to the Phoenix metropolitan area, using land use and other datasets from CAP. We found that the HPM-UEM predicted the spatial pattern of C stocks and C fluxes with reasonable accuracy. It allowed us to gage the spatial patterns and multiple-scaled dynamics of the C cycle in the Phoenix metropolitan area. Our model can be expanded to incorporate socio-economic drivers at each ecosystem functional level, creating a whole urban system model that integrates human and ecological dimensions (C. Zhang et al. in press).

IV. Training and Development

K-12 Education Initiatives

We reach out to the K-12 community in a program called Ecology Explorers that includes teacher professional development, classroom presentations, out of school time programming, and teaching resource development. This is funded through a LTER Schoolyard supplement allocated with our main grant and with personnel funding in our grant.

Teacher Professional Development

Our popular summer workshops and internships have engaged over 100 teachers and thousands of their students in CAP's schoolyard sampling protocols for vegetation, ground arthropods, and plant/insect interactions since 1987. All of our schoolyard activities are aligned with the Arizona State Education Standards in science, math, writing, social science and technology.

In summer 2012, we held a week-long Urban and Field Ecology Workshop on the ASU West campus. Over 70 teachers applied for the workshop, and we selected 18 teachers (17 attended) from high schools in the western and central part of the Phoenix metropolitan area to attend. CAP scientists were actively engaged in the workshop, which featured research by CAP scientists Becky Ball and Chad Johnson. Dr. Ball presented her research on moss in cold and hot deserts while an undergraduate research assistant from Dr. Johnson's lab introduced teachers to a black widow behavior education module that the lab had developed. The field portion of the workshop took place at North Desert Mountain Preserve where we worked with the teachers to implement one of CAP's plant transect protocols. Teachers then were able to compare their results with the results of similar transects in the Preserve made by a CAP graduate student eight years ago.

Later in the summer in conjunction with the Decision Center for a Desert City, we presented an Advanced Water Educators Workshop to 35 teachers in the Phoenix area. CAP REU student Chris Sanchez presented ongoing research from the Tres Rios Constructed Wetlands, a CAP project that has engaged high school, undergraduate, and graduate students.

Classroom Presentations

Our staff, including Education Coordinator Gina Hupton and Teacher Consultant John Dole, worked with a variety of teachers in classrooms throughout the Phoenix. During the 2011-2012 academic year, we were joined by two undergraduate interns from the School of Sustainability and two undergraduate student workers who provided additional capacity to field requests for classroom visits and other programming. We trained the undergraduates in the fundamentals of urban ecology and in pedagogical techniques.

We continued our relationship with Navajo Elementary School, which is located in a lower-income neighborhood in Scottsdale. In the fall, students made two visits to each of the 3rd and 4th grade classrooms at Navajo, serving about 200 students. They guided the classes in investigations of plant adaptations to the desert and urban watersheds, exploring soil infiltration. In the spring, they made three 2nd grade classroom visits and led science classes in investigations of the ecology of palo verde trees and bruchid beetles as this relates to urban water use. They also worked with about 80 5th graders exploring heat related illnesses and how to avoid them.

Other visits involved vegetation surveys with five classes of middle school students at Connolly Middle School in Tempe and lessons in lizard thermoregulation for 10 classes at Bogle Jr. High in

Chandler. The undergraduate students also conducted six lessons on bruchid beetle ecology at the Montessori Academy in Paradise Valley.

We began a new partnership with ASU's Herberger Institute for Design and the Arts on a project with high school students called "At Home in the Desert: Youth Engagement and Place," funded by the National Endowment for the Arts and Arizona State University's Institute for Humanities Research. John Dole presented information on desert ecology to a high school dance class, who in turn interpreted this information via dance http://news.lternet.edu/Article2471.html . This fall, young hip hop artists accompanied our staff on an ecology hike up a local mountain to gather inspiration for their music and dances. This is part of CAP's larger initiative on engaging the arts and humanities in urban ecology.

Out-of-School Time Programming

Our undergraduate staff has enabled us to bring Ecology Explorers curriculum into before- and after-school programs. In the spring, we worked with approximately 30 students in grades K-8 in the Glendale Afterschool program at Sahuaro Ranch Elementary. We were fortunate that the program is held near a large city park, which enabled us to conduct field studies of birds. We also engaged the students in a lesson about the differences between built and natural structures.

Our undergraduate students worked with 5 and 6^{th} graders at two afterschool programs in collaboration with the Mesa Parks and Recreation Department which targets children from low-income backgrounds. They met with groups of 15 students each in fall 2011 and spring 2012. Their activities focused on urban watersheds, an audit of personal water use, soil infiltration, urban desert food webs, energy transfer in biotic systems, and predator prey relationships.

At the Navajo Elementary STEM focus school in Scottsdale, student interns held a before-school science club. During club time, they guided students through activities related to the built environment, surface temperatures, and microclimates and the impact of these abiotic factors on organisms.

Teaching Resource Development

We continue to develop teaching and learning resources, which we make available on our website, http://ecologyexplorers.asu.edu/. During this reporting period, we completed curriculum on the Urban Heat Island, which we tested during summer workshops in 2011 and through teacher implementation during the 2011-2012 academic year http://ecologyexplorers.asu.edu/overview/urban-heat-island/. This is complemented by a series of educational articles http://chainreactionkids.org/lounge-people-and-environment-lesson-plans written in *Chain Reaction* magazine for upper elementary, middle, and high school students and funded by a CAP-leveraged grant, Urban Vulnerability to Climate Change (NSF).

Research Assistantships for High School Students

We were awarded a 2011 supplement to support three minority high-school students to work with CAP scientists from spring-summer 2012. During the spring, the students worked with CAP scientist Kelli Larson, graduate student Erin Frisk, and undergraduate Raina Whittekiend on a research project concerning sustainability in their schools, households, and communities as a means toward understanding aspects of ecological footprints in the city. As part of their work, they initiated projects to encourage recycling behavior among their peers. The students gave presentations based on this work to a group of CAP faculty, staff, and students in May 2012.

During the summer, the high school students worked in the Wetland Ecosystem Ecology Lab with CAP scientist Dan Childers and his students as part of an innovative tiered mentoring system that involved REU students and graduate students. Their work focused on the Très Rios Constructed Wetlands, which the City of Phoenix constructed as an enhancement to traditional wastewater treatment.

The students engaged in a research project that included field and lab work to understand rates of plant decomposition within the wetlands. All of the students reported a change in understanding about science as a result of their summer experience and indicated an increased interest in science, which was significant, as none had shown an interest in science careers when entering the program (see news story on this experience https://asunews.asu.edu/20120911_urbanwetland). One of the students has continued to volunteer in the Childers lab during weekends.

Undergraduate Training

We involve undergraduates in our research primarily through the Research Experience for Undergraduates (REU) supplement that was folded into our main grant and also through funding we allocated for undergraduate research in our budget. During the current reporting period, which has spanned two academic years and one summer, we have funded 10 REU students (see table below). Selected research results and descriptions of research products follow. We are in the process of surveying former REU students and their faculty advisors to better understand the impact of REU support on the pursuit of post-graduate education and career paths.

We also employ a number of undergraduate students in various positions within CAP. We treat these student-worker positions as professional development opportunities and provide training on the job. For certain positions, we ask for some prior expertise or academic training but insure that the students are suitably challenged and supervised on the job. For example, our Ecology Explorers undergraduate workers are expected to have some background in the biological and/or social sciences while our staff trains them on how to interact with students and teachers in classroom and after-school program situations.

Student	Scientist Mentor	Funding Period	Research Project
Chris Sanchez	Dan Childers	Summers 2012 & 2011	Wastewater treatment wetlands at the Tres Rios Sewage Treatment Plant
Samuel Lane	Pierre Deviche	Summer 2012	Neuroendocrine bases of singing behavior in rural and urban Northern Mockingbirds
Danielle Shorts	Stevan Earl and Nancy Grimm	Summer 2012	Spatial variability of soil nutrients and denitrification potential along a stormwater flow path in an urban watershed
Jaleila Brumand	Kelli Larson and Sharon Hall	Academic year 2011-2012 Academic year 2012-2013	The effects of formal and informal institutions on residential land management in the Phoenix Metropolitan Area
Jacob Fishman	Kerry Smith	Summer 2012	Does sorting behavior in response to local public goods align households' Environmental attitudes? The New Environmental Paradigm and the market
Holly Vins	Amber Wutich and Alex Brewis Slade	Summer 2012	The science of water art
Olga Epshtei	Stevan Earl and Laura	Fall 2011	Effects of impervious

	Turnbull		pavements on reducing runoff in an arid urban catchment
Erica Warkus	Sharon Hall	Academic year 2011-2012	Spatial association between surface rocks and succulents in the Agua Fria National Monument
Meghan Still	Chad Johnson	Academic year 2011-2012	Predator-prey dynamics between urban, exotic crayfish and the threatened Sonoran desert pupfish: The role of chemical communication
Nicholas Weller	Dan Childers	Academic year 2011-2012	Wastewater treatment wetlands at the Tres Rios Sewage Treatment Plant

Meghan Still: I investigated the predator-prey relationship between the Northern crayfish (*Orconectes virilis*), an invasive, omnivorous predator that has been introduced across the Phoenix valley, and the native endangered desert pupfish (*Cyprinodon macularius*). I showed that invasive crayfish are capable of using chemical cues from this native, endangered prey item to heighten their foraging activity. I shared these findings during the CAP LTER poster symposium and am including them in a manuscript in preparation.

Chris Sanchez: I collected and analyzed plant transpiration data from the Très Rios Constructed Wetland and calculated a water budget for the entire ecosystem. My budget found that a significant fraction of the total water entering the system leaves via evapotranspiration, and we are now working on a "hydraulic pumping" model using my water budget to calculate how vegetation transpiration moves water into the wetlands where nutrient loads are removed and processed. I have presented my research at ESA, the CAP poster symposium, and the LTER ASM and am working on a manuscript with my lab team.

Jacob Fishman: Models of sorting behavior in economics hypothesize that households move to communities based on the level of local public goods available in each community. I examined the sale price for over 13,000 homes in neighborhoods included in the Phoenix Areas Social Survey (PASS) to construct the hedonic estimates for the neighborhood price indexes and linked each index to the PASS survey respondents' environmental attitudes as represented by the New Environmental Paradigm (NEP). My analysis confirmed that neighborhoods with high price indexes, implying high levels of local public goods, also had high NEP indexes. I will present these results at the 2013 CAP poster symposium.

Erica Warkus: In the Agua Fria National Monument north of the Phoenix basin, I joined a team of archaeologists and ecologists who are exploring what types of prehistoric human activities may have left long-lasting ecological legacies. Prehistoric humans moved rocks on the surface of the soil to clear fields, cultivate agave, and construct pueblos and water-retention features. I hypothesized that the distribution of surface rocks is related to the distribution of succulent plant species across the landscape. Using a goodness-of-fit test, I found a greater spatial association between rocks and succulents than expected by chance. This pattern strongly suggests that the distribution of surface rocks influences succulent distribution in this semi-arid grassland, possibly by facilitating succulent establishment or success. I have presented my research at the CAP poster symposium and am working with the research team on a publication.

Jaleila Brumand: I qualitatively analyzed 12 ethnographic interviews about landscape-management practices in the Phoenix area while also contributing to cross-site LTER research on residential landscapes. I found that residents of the sampled Phoenix neighborhoods generally appreciated diverse yard types and these views were reinforced through dominant norms involving pervasive expectations for neatness as well as varied plant choices grounded in historic traditions and personal experiences. Legacy effects and paradoxes concerning water conservation and urban homogenization are two other factors that played a big role on residents' management practices. This research was the basis for my honors thesis, and I have published the results in *Triple Helix* and contributed to a cross-LTER-site publication.

Graduate Training

Graduate students are an integral part of our research program. During the 2011-2012 reporting period, 45 graduate students, representing seven different schools at ASU and multiple disciplines, participated in CAP.

We support student participation in many ways. First, we have a Graduate Grants program that awards small amounts of money (typically around $4000) through a competitive process to individuals and teams of graduate students pursuing graduate student-led research. This program involves former grant recipients in reviewing grant applications and is run much like a NSF panel, with final funding approval resting with the CAP Executive Committee. In spring 2012, we funded 10 proposals on topics ranging from urban plant communities to the urban heat island. Recipients use the money to fund field and laboratory research, purchase supplies, hire undergraduate assistants, and to pay themselves small stipends for summer subsistence. In the seven years since we began the Graduate Grant program, we have disbursed over $200,000 to graduate students in grants.

We also fund Summer Graduate Research Assistants, which provide employment and training opportunities for graduate students who work on faculty-led projects. We employed 10 graduate students in this manner during summer 2012 to work on projects such as developing K-12 science education curriculum, processing remote sensing images, and conducting research on black widow spider color.

On a case by case basis, we fund student travel to conferences and page charges associated with publications and allow all students access to our equipment and vehicles once ASU conditions for access have been met. Furthermore, we have an active student group that engages graduate and undergraduate students in activities, such as hikes and special seminars, several times a year.

One outcome of this graduate-student support is the peer-reviewed publications that graduate students have co-authored. During 2011-2012, student co-authored 39 articles. On 69% of these articles, a student was the first author. Since the project began recording data on student publications in 2004, students have co-authored a total of 103 articles with the number of student co-authored articles increasing steadily over time.

Student theses and dissertations are another product of student research. These are listed in Fastlane for students who have determined their dissertation/thesis titles. Research results from student work are included in the Major Findings section of this report.

Postdoctoral Training

CAP supported one postdoctoral research fellow, Laura Turnbull, during the reporting period. In her first years in residency, Dr. Turnbull participated in the Mentoring to Advance Post-Docs and Students Program, which is a series of seminars that introduce post-doctoral researchers to issues of ethics, mentoring, science communication, and teaching. She also completed ethics training at Arizona State University in accordance with the CAP Post-Doctoral Mentoring Plan. This past year, Dr. Turnbull presented her research at several national and international meetings and took a leadership role in the urban stormwater initiative. She continues to be actively engaged in CAP research from her current research post at Durham University in the UK.

V. Outreach Activites

Education Outreach

In addition to working with teachers and students, we also participate in outreach events over the year, typically involving hands-on activities for children and teens. We brought our traveling display and activities to six events this year: the Valley Forward Earthfest Education Night, the Arizona Science Center Resource Fair, the Feathered Friends Festival, Navajo Elementary School Family Science Night, National Animal Behavior Society's Outreach Education Fair, and ASU's Night of the Open Door. All together, we reached hundreds of students and families through these outreach venues.

Research Outreach

We continue to reach out to community partners to collaborate on joint research initiatives. Below are descriptions of three initiatives we began this year and one ongoing project.

McDowell Sonoran Conservancy: We are collaborating with the Conservancy's monitoring programs to study human impacts on the ecology of the McDowell Mountain Preserve, located east of Scottsdale. As part of this collaboration, we have trained Conservancy volunteers to sample the distribution of ground-dwelling arthropods on and off the Conservancy's trail system. This year, we have set pitfall trap lines along 10 transects and have sampled arthropods four times to coincide with CAP's long-term monitoring of arthropods in central Arizona. In November, we will hold our first training session for volunteers interested in helping sort and identify arthropods. Data from this initiative will be held by CAP and made available on its website.

Urban Tree Community Science: We are part of a unique collaboration between the Salt River Project (SRP: a local utility) and the Valley Permaculture Alliance (VPA: a Phoenix-based urban gardening educational non-profit) to involve citizens in studying the impacts of residential tree plantings. "Community Scientists" who opt into this program attend a training course on shade-tree planting and maintenance organized by the VPA and then plant shade trees, provided free by SRP, in their yards. They work with CAP scientists to monitor the growth and health of their trees and enter these data and other information every six months into an online data portal. We share these data with SRP and the VPA and summarize it for the community scientists. We are also working with the VPA on a separate, yet similar, project for tracking the outcomes of fruit trees that the VPA sells at cost each year. Our first cohort of shade-tree and fruit-tree community scientists will be entering their data in November. While we characterize this project as citizen science, we have chosen to publicly discuss it as a "community science" initiative since the term "citizen" has negative connotations in the Phoenix Latino community.

Conservation Alliance: We have joined with the Desert Botanical Garden (the lead institution), ASU's Ecosystem Conservation and Resilience Initiative, Audubon Arizona, the City of Phoenix Parks and Recreation Department, Maricopa County Parks and Recreation Department, and the Phoenix Mountains Preservation Council to form The Conservation Alliance, a collaboration to foster community engagement to study, restore, and promote the mountain park preserves of metropolitan Phoenix. This initiative was chosen as an awardee in the Five Communities Project competition sponsored by the Center for the Future of Arizona and recently received a $300,000 grant from the

Pulliam Trust. Work on the initiative will begin in 2013, and several CAP scientists and staff will be involved.

Tres Rios Wastewater Treatment Wetland: In 2011, we began work at this newly constructed wetland facility in the West Valley using a small grant from the USGS (L.Turnbull, PI). Our research focuses on understanding the water and nutrient budgets of this hard-working wetland. A main goal of our Tres Rios work is to partner with the City of Phoenix to manage this ecosystem in a way that maximizes its ability to provide both expected and serendipitous ecosystem services.

VI. 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. 2012, 2008, 2000; Grimm and Redman 2004; Warren et al. 2010).
- 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, 2012).
- 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 **black carbon** is developing a variety of analytical methods in the field of chemistry that have not yet been applied to complex soils. In addition, our findings on the composition of black carbon will improve our understanding of this recalcitrant organic material and contribute to knowledge of the global carbon cycle.
- 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.

Contributions to Other Disciplines

- 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.
- Few constructed wastewater treatment wetlands exist in hot, arid climates; our **Tres Rios Constructed Wetland** research thus has few analogues. Our approach of quantifying the water and nutrient budgets simultaneously allows us to examine the relative importance of climate-driven hydrology vs. biogeochemistry and ecological productivity in a system that was built with specific ecosystem service expectations. Our findings will contribute to the disciplines of urban ecology, wetland ecosystem ecology, wetland biogeochemistry, and urban ecohydrology.
- **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.

- **PASS** 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. Phoenix has one of the most studied UHIs in the world.
- 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 west Phoenix 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.
- Since the inception of CAP LTER, close to 30 postdoctoral associates have taken leadership roles in research and outreach activities. 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, and we have awarded a total of 58 grants. 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 39 papers and book chapters have been co-authored by students and on 69% 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 30 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.
- We involved three high school students in CAP during spring and summer 2012 through the Research Assistantships for High School Students in CAP research. In addition, two CAP faculty members involved high school students from the Southwest Center for Education and the Natural Environment (*SCENE*) SCENE program in their laboratory work.

Contributions Beyond Science and Engineering

- 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.
- The **Salt River Biodiversity** project will contribute to the understanding of plants and small wildlife habitat use within urban restored and passive restored riparian areas. The project will provide recommendations on how to rehabilitate urban degraded riparian communities to promote an abundant and diverse flora and fauna assemblage. In degraded ecosystems, promoting an abundant and diverse biota contributes to the re-establishment of ecosystem functions.
- 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 will soon begin working more closely with the City of Phoenix on management plans and approaches for the **Tres Rios** wetland system. These plans are currently driven by engineers and engineering considerations. Thus, we will be contributing biogeochemical, ecological, and ecohydrological information to what might otherwise have been a relatively uniform engineering approach to management of this ecosystem.
- 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 and arthropods, 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.

APPENDIX A
2011-2012 CAP LTER PARTICIPANTS

	Duration of Involvement
Principal Investigator	
Daniel Childers, Sustainability	2008-2012
Nancy Grimm, Life Sciences	1997-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
Christofer Bang, Life Sciences	2005-present
George Basile, Sustainability	2010-present
Bob Bolin, Human Evolution and Social Change	1999-present
Anthony Brazel, Geographical Sciences and Urban Planning	1997-present
Alexandra Brewis, Human Evolution and Social Change	2012-present
Mikhail Chester, Sustainable Engineer. & Built Environ.; Sustainability	2012-present
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	2010-2011
Matei Georgescu, Mathematics and Statistical Sciences	2011-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	2010-2011
Ananda Majumdar, Mathematics and Statistical Sciences	2006-2011
Kevin McGraw, Life Sciences	2012-present

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	2010-2012
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
Julie Stromberg, Life Sciences	2011-present
Jean Stutz, Applied Sciences and Mathematics	1998-present
Emily Talen, Geographical Sciences and Urban Planning	2009-present
Laura Turnbull, Geography, Durham University	2009-present
Enrique Vivoni, Sustainable Engineering; Earth and Space Exploration	2010-present
Arnim Wiek, Sustainability	2009-present
Amber Wutich, Human Evolution and Social Change	2006-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	

Winston Chow, Engineering, Ruddell lab	2011-present
Monica Palta, Life Sciences, Grimm lab	2012-present
Darren Ruddell, Global Institute of Sustainability, Harlan lab	2009-2011
Milan Shrestha, Global Institute of Sustainability, York lab	2009-2011
Laura Turnbull, Global Institute of Sustainability, Childers lab	2009-2012
Chi Zhang, Global Institute of Sustainability, Wu lab	2009-2011
Research Technical Personnel	
Amanda Kate Lindekugel, Research technician, CAP LTER	2009-2012
Johnida Dockens, Research technician, CAP LTER	2012-present
Roy E. Erickson, Research specialist, CAP LTER	2000-present
Michael Holland, Research technician, CAP LTER	2008-present
Grace Kan, Research technician, CAP LTER	2011-2012
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
Marisa Masles, Research technician, CAP LTER	2012-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
Joseph Tuccillo, Research assistant, York lab	2011-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	
John Dole, Teacher consultant	2009-present

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 Siddall, Global Institute of Sustainability	2010-present
Linda Williams, Global Institute of Sustainability	1997-2010
Michelle Wolfe, Global Institute of Sustainability	2012-present
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
Michael Bernstein, Sustainability	2011-present
Tommy Bleasdale, Human Evolution and Social Change	2010-present
Lane Butler, Life Sciences	2011-present
Eric Chapman, Life Sciences	2011-present
Winston Chow, Geographical Sciences and Urban Planning	2007-2011
Wen Ching Chuang, Sustainability	2012-present
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
Stephanie Deitrick, Geographical Sciences and Urban Planning	2012-present
Xiaoli Dong, Life Sciences	2009-present
Chao Fan, Geographical Sciences and Urban Planning	2011-present
Janet Ferrell, Sustainable Engineering and the Built Environment	2012-present
Erin Frisk, Sustainability	2008-present
Christopher Galletti, Geographical Sciences and Urban Planning	2010-present
Theresa Gburek, Life Sciences	2012-present
Mac Gifford, Sustainable Engineering and the Built Environment	2010-present
Joe Hackman, Human Evolution and Social Change	2012-present
Rebecca Hale, Life Sciences	2007-present
George Alexander Hamilton, Chemistry and Biochemistry	2008-present
Dorothy Ibes, Geographical Sciences and Urban Planning	2010-present
David Iwaniec, Sustainability	2012-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
Jorge Ramos, Life Sciences	2012-present
Jacelyn Rice, Sustainable Engineering and the Built Environment	2012-present
Julie Ripplinger, Life Sciences	2010-present
Scott Robinson, Earth and Space Exploration	2011-present

Kihwan Seo, Geographical Sciences and Urban Planning	2012-present
Colleen Strawhacker, Human Evolution and Social Change/IGERT	2006-present
Amanda Suchy, Life Sciences	2012-present
Carissa Taylor, Sustainability	2009-present
Patricia Trubl, Life Sciences	2010-present
Kelly Turner, Geographical Sciences/IGERT	2007-present
Thomas Volo, Earth and Space Exploration	2011-present
Ben Warner, Sustainability	2010-present
Melinda Weaver, Life Sciences	2012-present
Christina Wong, Sustainability	2008-present
Karl Wyant, Life Sciences	2011-present
Sainan Zhang, Sustainability	2009-present
Undergraduate Student Workers	
Chad Allen (Arthropod Lab)	2012-present
Holly Barton (Ecology Explorers Intern)	2011
Courtney Baxter (Ecology Explorers)	2012
Jaleila Brumand (Larson/Hall Research)	2010-2011
Becky DePuydt (Salt River Research)	2012
Brianna Edgell (Arthropod Lab)	2010-present
Stephen Hilinski (Ecology Explorers Intern)	2011
Venkataraman Krishnamani (Informatics Lab)	2011
Hannah Laluzerne (Larson/Hall Research)	2010-2011
Madison Pike (Goldwater Lab and GIOS)	2012-present
Michelle Schmoker (Ecology Explorers)	2012
Brenton Scott (Salt River Research)	2012
Soheila Shahidi (Ecology Explorers intern)	2011
Jessica Webber (J-Earth lab)	2010-2011
David Wernsman (Ecology Explorers Intern)	2011

Dustin Wolkis (Salt River Research)	2012
Megan Wolverton (Goldwater Lab and GIOS)	2012
Research Experience for Undergraduates (REUs)	
Shaneen Beebe, Environmental Technology Mgmt., ASU Poly	2011
Jaleila Brumand, Sustainability and Economics	2011-2013
Olga Epshtein, Civil Engineering	2011-2012
Jacob Fishman, Finance and Economics	2012
Samuel Lane, Biology	2012
Chris Sanchez, Ecosystem Science and Policy & Biology, Miami U.	2011
Michelle Schmoker, Life Sciences/Biology	2010-2011
Danielle Shorts, Biology	2012
Meghan Still, Life Sciences, ASU West	2011-2012
Holly Vins, Global Health and Justice	2012-2013
Erica Warkus, Conservation Biology and Ecological Sustainability	2011-2012
Nicholas Weller, Sustainability	2010-2012
Research Assistantships for High School Students	
Ariah Evans, St. Mary's High School	2012
Aunese Evans, St. Mary's High School	2012
Daniel Morales, North High School	2012
Ecology Explorers Teachers	
Jennifer Anfinson, Deer Valley Unified School District	2011
Elise Bostic, Phoenix Unified High School District	2012
Richard Burkhart, Isaac School District	2011
Maylene Byers, Agua Fria High School District	2012
Emily Carrasco, Mesa Public Schools	2011
Chris Coupelin, Phoenix Unified High School District	2012

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
Leslie George, Agua Fria High School District	2012
Olga Gilchrist, Isaac School District	2011
Eric Hansen, Isaac School District	2011
Stephanie Homyak, Isaac School District	2011
Amber Hughes, Phoenix Unified High School District	2012
Jon Hutman, Kyrene School District	2011
Ashley Janaulis, Deer Valley Unified School District	2011
Alisa Jones, Peoria Unified School District	2012
Erin Joyner, Isaac School District	2011
Jenna Judd, Peoria Unified School District	2012
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
Jonathan Miller, Glendale Unified High School District	2012
Rebecca Nichols, Kyrene School District	2011
Julia Perry, Phoenix Unified High School District	2012
Thomas Polliard, Glendale Unified High School District	2012
Afroza Rahman, Phoenix Unified High School District	2012
Dee Bee Raymo, Peoria Unified School District	2012
Rebecca Rutledge, Phoenix Unified High School District	2012
Joy Scheitlin, Chandler Unified School District	2011

Michele Schiff, Peoria Unified School District	2012
Joni Sheesley, Peoria Unified School District	2012
Miles Smith, Kyrene School District	2011
Susan Sosa, Kyrene School District	2011
Laura Steffen, Kyrene School District	2011
Ann Thumm, Isaac School District	2011
Rebecca Tucker, Phoenix Unified High School District	2012
Julie Vastine, Agua Fria High School District	2012
Melanie Wetmore, Isaac School District	2011
Brooke White, Peoria Unified School District	2012
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