Central Arizona–Phoenix
Long-Term Ecological Research: Phase 2

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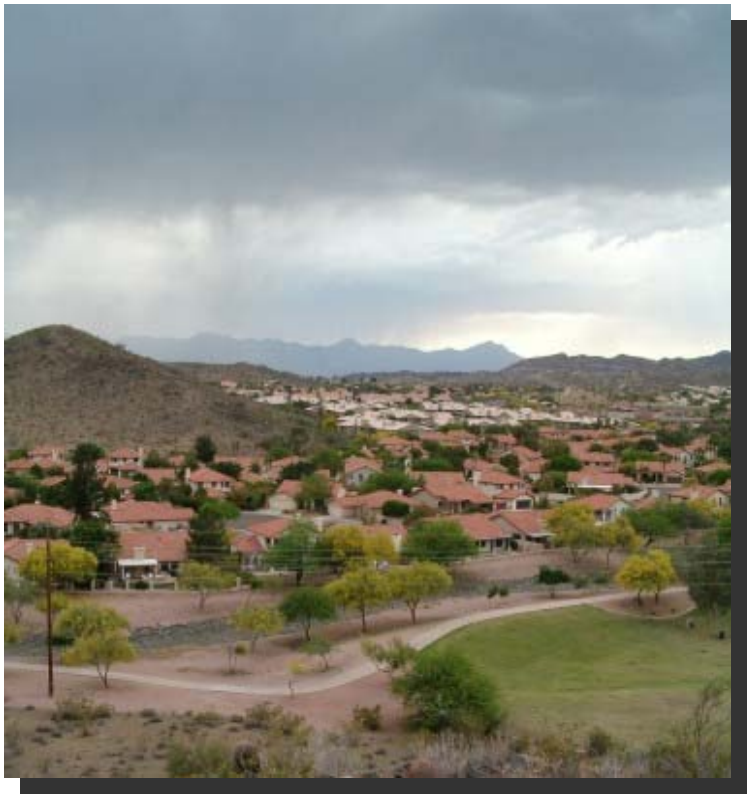

CAP LTER PHASE 2
2009 ANNUAL REPORT

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I. Overview of Results and Broader Impacts

Overview

CAP2 is the second phase of the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) project (NSF #DEB-0423704). As one of two urban sites funded in the US LTER network, CAP LTER is advancing knowledge and theory in urban ecology (Grimm and Redman 2004; Grimm et al. 2008a; Wu 2008a,b) through long-term monitoring, long-term experiments, and associated research projects. With other scientists globally, CAP LTER scientists are also expanding the horizons of socioecological research (Redman et al. 2004; Haberl et al. 2006; Costanza et al. 2007; Liu et al. 2007a,b; Grimm et al. 2008b).

The CAP LTER study area is located in the 6400-km^2 central Arizona and metropolitan Phoenix region, embedded in the Sonoran Desert, and situated in a broad, alluvial basin where two major desert tributaries of the Colorado, the Salt and Gila Rivers, converge. The basin, dotted with eroded volcanic outcrops and rimmed by mountains, once supported a vast expanse of lowland desert and riparian systems and now houses the fifth-largest city in the USA. Annual precipitation (~180 mm) falls in two distinct seasons, resulting in high biodiversity in desert areas. Undeveloped desert in the valley floor is dominated by widely spaced, low shrubs, primarily creosotebush, bur sage, salt bush, and brittlebush, while a rich and denser saguaro-palo verde forest covers the foothills. Urbanization has replaced native desert vegetation with mostly non-native species that are maintained by irrigation, with ramifications for higher trophic levels.

In this report, we highlight projects within each of five integrative project areas, which were chosen to encompass the traditional LTER core areas while embracing an interdisciplinary approach. We also report progress on over-arching monitoring and experimental programs that cross all of the project areas, and on development of data resources and information technology. We have made progress in ecosystem modeling applied to the desert region and in models of urban growth specific to Phoenix. In CAP1, we established an extensive long-term integrated field inventory (Survey 200), to be repeated every five years, and this year we continued to analyze data from the second survey, conducted in spring 2005. In CAP2, we began the long-term Phoenix Area Social Survey (PASS), conducted in 2006 and slated to be repeated every five years. Experimental work at North Desert Village (NDV), a residential area on the ASU Polytechnic campus, has proceeded and the initial research results have shed light on household landscape perceptions.

CAP LTER participants have published 296 journal articles, books, and book chapters from the project's inception in 1997 through August 2009. Since the last annual report, CAP scientists have published 21 articles, books or book chapters, in addition to 27 currently in press and 28 in review. Over 350 individuals have been involved with CAP2, including 101 faculty members, 9 senior project managers, 17 post-doctoral scholars, and 44 technicians, support staff, and K-12 education personnel. One hundred graduate students have been project participants, including 41 fellows in the Integrative Graduate Education and Research Traineeship (IGERT) in Urban Ecology, which is housed in the Global Institute of Sustainability (GIOS) at Arizona State University, the home of CAP LTER. A total of 101 undergraduate students have been involved in CAP LTER since 2004, 81 as student workers on various research and education initiatives,

19 as Research Experience for Undergraduates (REU) students, and one as a fellow of the Ecological Society of America's Strategies for Ecology Education, Development, and Sustainability (SEEDS) program.

Finally, CAP has leveraged funding for several large projects that complement its basic science emphasis, many funded by the National Science Foundation (NSF). The total leveraged funding from CAP since 1997 is $38.6 million dollars. Of that total, almost half has accrued during CAP2. CAP2 leveraged projects include: "Agrarian Landscapes in Transition," a multi-LTER project (NSF-BCE, Redman et al. 2002); "Decision Center for a Desert City" (NSF-SBE's Decision-Making Under Uncertainty program; Gober et al. 2003); a study of the effects of elevated nitrogen and organic carbon deposition in and around the urban ecosystem (NSF-Ecosystems, Grimm et al. 2005); a study of the effects of urbanization on trophic dynamics (NSF-Ecology, Faeth and Sabo 2005); and "Urban vulnerability to climate change: A system dynamics analysis (NSF-CNH, Harlan 2008).

Recent leveraged grants continue to expand opportunities for CAP science. CAP lead PI Nancy Grimm is the lead PI on two new grants, "LTREB: Multi-scale effects of climate variability and change on hydrologic regimes, ecosystem function, and community structure in a desert stream and its catchment" (NSF Long-term Research in Environmental Biology, 2009) and "Collaborative research: Impacts of urbanization on nitrogen biogeochemistry in xeric ecosystems" (NSF Ecosystems, collaboration with Lohse, University of Arizona, and Mikulski, Purdue University, 2009). CAP scientist Sharon Hall is the lead PI on a Mellon Foundation-funded project in South Africa, "Ecosystem science close to home: Impacts of the urban environment on nutrient cycling in Fynbos shrublands of the Cape Town metropolitan area," that builds on CAP's expertise in urban biogeochemistry.

Broader Impacts

CAP LTER's broader impacts include 1) providing leadership for national and international advancement of urban ecology, 2) education and outreach, and 3) decision making in Greater Phoenix. Individual scientists from CAP have been tapped extensively to contribute to international discussions of urbanization and sustainability; for example, Redman is a member of the international U.S. National Committee on the Scientific Committee on Problems of the Environment (SCOPE) and Grimm is a member of the U.S. Climate Change Science Program's Unified Synthesis Report, chairing the section on the impacts of climate change on society. Childers, Grimm, Boone, and Earl have been an active participant in NEON and LTER planning activities, and Wu, Boone, Gries, and Grimm have been instrumental in establishing a joint center for urban sustainability between Arizona State University and the Chinese Academy of Sciences. CAP LTER's program at the K-12 level, Ecology Explorers, has over 100 teacher-participants at 100 public schools (encompassing 25 school districts), 2 charter schools, and 1 private school. Several faculty members and graduate students participate in ASU's Community of Undergraduate Research Scholars program by mentoring undergraduate students in urban research. We have 20 active fellows, 4 associates, and 14 graduated fellows (emeriti) in our Integrative Graduate Education and Research Training (IGERT) program in urban ecology. Finally, over 20 community partners are engaged in CAP LTER, such as Salt River Project, Maricopa Association of Governments, the U.S. Geological Survey (USGS), and several local municipalities. Details on our education and outreach efforts appear in sections VI and VII of this report.

The role of CAP in decision making in Greater Phoenix has been enhanced by funded projects that promote community and governmental outreach. We have benefited from the establishment of projects that are more directly linked to local and regional government. For example, the Greater Phoenix 2100 (GP 2100) project and the Decision Center for a Desert City draw on CAP LTER data to help policy makers and others envision the long-term future of the greater Phoenix region. In addition, our information-management team continues to play a leadership role in developing new IT tools for handling ecological data. Finally, CAP LTER has contributed data to ASU's Decision Theater, which is an immersive environment that enables policy makers to visualize the consequences of policy decisions and environmental change.

II. Research Activities

Research Design and Approach

Our research is grounded in a conceptual framework that explicitly considers the interactions and feedbacks of the human system and ecological system, which together create an integrated socio-ecological system. In our ecological study, therefore, we monitor and interpret ecosystem change from a perspective that includes humans as part of nature (Cronon 1995; Kinzig et al. 2000, Kaye et al. 2006, Liu et al. 2007a,b, Grimm et al. 2008b, Wu 2008a,b). Research integrates the social sciences, encompasses longer time horizons, and is informed by flexible models and multi-scaled data (Wu and Li 2006). Finally, we recognize ecosystem services as the focal point of interaction between humans and ecosystems.

To fully integrate social and ecological components, we have organized our research under five integrative project areas (IPAs):

- Land-use and land-cover change (LULCC)
- Climate-ecosystem interactions (CLIM-ECOS)
- Water policy, use, and supply (WATER)
- Fluxes of materials and socio-ecosystem response (FLUXES)
- Human control of biodiversity (BIODIV)

Several projects are affiliated with multiple IPAs and are described below under the heading "Crosscutting Research": **Survey 200**, the **North Desert Village (NDV) Experiment**, and the neighborhood-scale **Phoenix Area Social Survey (PASS)**. In addition, we report on research activities conducted by formal and short-term working groups within CAP LTER.

Land-Use and Land-Cover Change (LULCC)

Land use and land cover define the context of the urban socioecosystem, and alterations in their patterns underlie most other ecosystem changes. We ask: *How have land use and land cover changed in the past, and how are they changing today? How do land-use and land-cover changes alter the ecological and social environment in the city, and how do human perceptions of these changes alter future decision-making?*

The LULCC IPA's developing understanding of the answers to these questions sets the stage for all other IPA research. In this report, we highlight findings from the following research:

- **Socioecological drivers of residential landscape management and ecosystem responses**
- **Institutional drivers of growth in Phoenix**
- **Sustainable landscapes**

During the 2009-2010 academic year, work will begin on **CAP's standard land classifications, land cover analysis, and land architecture**. This initiative will focus on creating a multi-scale, land-cover classification for the CAP study area, including fine-scale classification suitable for parcel-level research. Such classification is fundamental for a variety of ecological and social science projects under CAP as well as for cross-site research. A workshop in February 2009 brought CAP scientists and students together with other researchers from BES, FCE, and PIE to introduce a common method for land-cover classification, using the Definiens software.

Student and faculty interest in **urban agriculture** has led to several new research initiatives. These include research on cash-cropping in a Native American community, investigations into food security and gardening in a predominately Latino neighborhood, and broader research on the local food system in the Phoenix metropolitan area. A working group on urban agriculture was formed to integrate and coordinate research efforts across these initiatives.

Along with four other LTER sites (SEV, JRN, SGS, and KNZ), CAP scientists have initiated another project, **Socioecological gradients and land-use fragmentation**, in cities associated with these sites (the Phoenix, Albuquerque, Las Cruces, and Fort Collins metropolitan areas as well as Manhattan, Kansas). This research examines how water provisioning, population growth, and urbanization rates are linked to landscape fragmentation. CAP LTER hosted a workshop to begin this project in April. Work to date includes reclassification of land cover for the sites using NLCD, fragmentation analysis for all sites, and preparation of two manuscripts focusing on the Phoenix area. The research team will present at least two posters at the LTER ASM, one focusing on cross-site research, and will convene a workshop to present the results of the initial fragmentation analysis and move the research initiative forward.

Climate-Ecosystem Interactions (CLIM-ECOS)

Climate is an important driver of ecosystem processes like primary production, and of human outcomes such as health and quality of life; therefore, an understanding of climate dynamics is fundamental to much of our research. Studies of climate-ecosystem interactions (hereafter, CLIM-ECOS) are conducted at multiple scales from single organism to neighborhood to region. Research under this IPA centers on the following questions: *How does human-driven, local climate change compare with longer-term trends and/or cycles of climate in the region? How do regional drivers influence local climate as urbanization proceeds? What are people's perceptions of their local environment, including climate, and how does that affect their assessment of neighborhood or regional quality of life? What are the interactions among local management, local climate, net primary production and vegetation processes?*

Among the initiatives addressing these questions in 2008-2009 were:

- **PASS**
- **Climatology at urban LTER sites**

CAP is also continuing work in collaboration with a leveraged NSF grant, **Measuring urban surface energy fluxes**, under the CLIM-ECOS and FLUXES IPAs. In fall 2009, researchers will erect a tower in a west Phoenix neighborhood which will hold a suite of eddy covariance instruments. These instruments will measure wind, gas, and temperature at high frequencies and will enable researchers to derive sensible heat, water, and carbon dioxide fluxes in an urban environment. Data on sensible and latent heat fluxes will contribute to understanding of the causes of Phoenix's urban heat island effect. CO_2 data will be important in estimating the

footprint of Phoenix neighborhoods over different seasons and may provide insight into potential methods of reducing urban CO_2 emissions.

Work also continues on a recent NSF-CNH grant, **Urban vulnerability to climate change: A system dynamics analysis**, will continue work begun by CAP researchers under the **Neighborhood ecosystem study** (Jenerette et al. 2007; Harlan et al. 2006; Harlan et al. 2008), as well as under other urban heat island-related projects.

Water Policy, Use, and Supply (WATER)

Humans now appropriate 100% of the surface flow of the Salt River (Phoenix's river) and are increasingly exploiting groundwater resources and surface waters from more distant basins (e.g., the Colorado River). Controlled management and engineering shift the characteristic spatiotemporal variability of the hydrologic system. The WATER IPA examines the following: *What are the ecological and economic consequences and potential vulnerabilities of shifts in the hydrologic system? What institutional responses best address vulnerabilities arising from shifts in the hydrologic system?*

Within the WATER IPA, we examine landscape water management, water supply and delivery, riparian restoration, and resilience of the socioecosystem to water-related stress or catastrophe. Project results included in this report focus on collaborative work with the Decision Center for a Desert City:

- **Decisionmaker Responses to WaterSim**
- **Phoenix Ethnohydrology Project**

Work on aquatic biogeochemical processes and water quality, undertaken in the FLUXES IPA, is closely associated with the work under this area. New post-doctoral research will enhance CAP's work on urban ecohydrology and aquatic biogeochemistry. Other recent work on urban and peri-urban agriculture in conjunction with the LULCC IPA examines the tradeoffs inherent in farming as a water-use activity in the metropolitan Phoenix area.

A continuing initiative examines **Incorporating ecology into storm-water management solutions**. In this project, researchers investigate the complex relationships between urban development patterns and storm-water runoff. Storm water is a research topic identified by CAP LTER for further investigation and for partnership with local management entities; it involves scientists from both the WATER and FLUXES IPAs as well as practitioners in the public sector, specifically in the Flood Control District of Maricopa County, the City of Tempe, and the City of Scottsdale. CAP has initiated storm-water monitoring at one location in Indian Bend Wash, examining a suite of water-quality parameters including nutrients, pH, major anions/cations, and particulates.

CAP has continued its water-quality monitoring at locations of major influents into the Phoenix metropolitan area (the Salt and Verde rivers and the Central Arizona Project canal) as well as the major effluents (the Salt and Gila rivers). This monitoring focuses on a standard set of water-quality parameters. Other work includes groundwater-quality monitoring at one site along the Gila River in conjunction with the Flood Control District of Maricopa County.

Material Fluxes and Socio-Ecosystem Response (FLUXES)

Material fluxes and biogeochemical linkages have been studied for decades in relatively undisturbed ecosystems, but not in urban ecosystems where human-generated fluxes of nutrients and toxins are coupled with nonhuman biogeochemistry. Questions driving this IPA are: *How do*

urban element cycles differ qualitatively and quantitatively from those of nonhuman-dominated ecosystems?; What are the sociospatial distributions of anthropogenic toxins and other pollutants in the CAP ecosystem, and what hazards to organisms (plants, animals, humans) result from these distributions?; Do citizens and decision makers accurately perceive these hazards?

FLUXES is one of the most active IPAs in CAP LTER, and accordingly, it includes many projects. In this report, we highlight the following, ongoing studies:

- **Composition and distribution of black carbon in Phoenix area soil**
- **Characterization of dissolved organic carbon in Tempe Town Lake**
- **Environmental fate of combustion-derived organic compounds in arid, urban soils**

Work continues on the urban storm water initiative, as noted above, and the **CNDep** project, which has been folded into CAP's long-term experimentation efforts. Two new post-doctoral researchers promise to enhance CAP's research efforts under the FLUXES IPA in the areas of ecohydrology, aquatic biogeochemistry, and modeling the impacts of urbanization on biogeochemical cycles.

Human Control of Biodiversity (BIODIV)

Ecological approaches to studying human control of biodiversity (hereafter, BIODIV) have typically focused upon habitat loss and disturbance brought about by humans at high-population densities. We move beyond these approaches to ask: *How do human activities, behaviors, and values change biodiversity and its components—population abundance, species distribution and richness, community and trophic structure? In turn, how do variations in biodiversity feed back to influence these same human values, perceptions, and actions?*

Among the studies during 2008-2009 that addressed these questions were:

- **Ecophysical and behavioral adaptations of birds to rapid urbanization of a desert environment**
- **Biodiversity and neighborhood social variation**
- **NDV social survey**

The BIODIV team actively participated in **Survey 200** and the **NDV Experiment**, both also described under "Crosscutting Research." Long-term monitoring of bird and arthropod populations has been a core element of CAP research and has continued through this report period. A study of avian populations and neighborhood social variation has been folded into the **PASS** study, and researchers have continued collecting data in the PASS neighborhoods.

Crosscutting Research

Ongoing research activities include those that cut across and contribute to several IPAs, such as the **Survey 200**, extensive sampling conducted every five years; the **NDV Experiment**; and the neighborhood-scale **PASS.** Appendix B lists the full suite of CAP's long-term monitoring endeavors. Although sampling and analysis activities from these crosscutting projects often are carried out as a unit, the findings from these research endeavors are integrated into IPA research and are reported as such.

We also have several long-term and short-term working groups, not all of which fall cleanly within the IPA structure. Working groups active during 2008-2009 include: **long-term monitoring**, **long-term experiments,** and **storm water management**. Since Survey 200 is CAP's major long-term monitoring project, the long-term monitoring working group's work is largely subsumed under Survey 200 and will be reported there. Likewise, much of the activity in

long-term experiments is conducted under the NDV Experiment and will be reported in that section. The storm water working group involves both the WATER and FLUXES IPAs and has no significant results to report yet.

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 monitoring of ecosystem change over time. The survey has been carried out in 2000 and 2005, and included the following core measurements:

- Plants identified to species (2005) or genus (2000)
- Plant size measurements for biovolume calculations
- Mapping of built and vegetation structures
- Soil coring for physicochemical analyses
- Insect sweep-net sampling
- Mycorrhizal diversity.

Survey 200 data from both the 2000 and 2005 surveys have been used in numerous studies by CAP scientists (Hope et al. 2003, 2005, 2006; Oleson et al. 2006; Stuart et al. 2006; Zhu et al. 2006; Dugan et al. 2007; Kaye et al. 2008; Majumdar et al. 2008, in press, in review; Walker et al. in press).

Among the recent work with the Survey 200 data is an analysis of the five main carbon pools (trees, shrubs, cacti/succulents, herbaceous vegetation, and soil) for each of the 200 point survey locations, using Kaye et al.'s (2008) methods (hierarchical Bayesian scaling) to understand the spatial dynamics of carbon storage pools across the Phoenix metropolitan area. Researchers initially are using the 2005 data set but intend to eventually evaluate the 2000 data and analyze change over time, and to use these data to contribute to a carbon budget for the CAP ecosystem. Other ongoing work, described in previous reports, examines heavy metals in Phoenix area soils. A manuscript in review compares the sweep-net data from the 2000 and 2005 surveys (Bang and Faeth in review). This report details some initial findings of investigations of black carbon in Survey 200 soils (see FLUXES).

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

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

Six additional households are monitored as no-plant, no-water controls. Major research questions include: *How do landscape design and irrigation methods affect NPP and under-canopy microclimate, soil nutrient pools and fluxes, insect abundance and diversity, bird*

activity?, and how does landscape design affect direct human-landscape interactions in terms of both perceptions and behaviors?

During summer 2005, the landscape and irrigation systems for each of the treatment areas were completed. During spring 2006, micrometeorological stations were installed in the central common area of each treatment. Data continually monitored include soil temperature, soil heat flux, and 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) are also monitored regularly. Landscape irrigation application volumes are recorded monthly.

Data from the pre-treatment social survey have been analyzed, and findings from this round of research have been published (Yabiku et al. 2008; Casagrande et al. 2007). The follow-up social survey began in spring 2006 and continued through summer and fall 2006. Data from this survey are being analyzed and compared with the pre-treatment survey. Initial findings examining ecological knowledge, environmental behavior, and landscape preferences are reported under the Biodiversity IPA.

The NDV research team continues work on an integrated project focusing on ecosystem services of landscape treatments at NDV. Using data from a variety of sources, including infrared surface temperature measurements, the researchers will analyze which of the four NDV landscapes optimizes the trade offs between the following ecosystem services:

- temperature moderation and energy use
- water use
- aesthetics and quality of life
- carbon sequestration

This research will contribute to an academic and public dialogue about the values of various landscape types in the Phoenix area. While water conservation advocates have pressed for the conversion of mesic to xeric landscapes, this research will illuminate the energy-water tradeoffs in such a conversion.

Phoenix Area Social Survey (PASS): In 2001, eight social scientists and one biophysical scientist, all affiliated with the CAP LTER, conducted a pilot social survey of 302 residents in eight neighborhoods in Phoenix (Kirby et al. 2006; Larsen and Harlan 2006). The goal of the study was to increase understanding of how human behavior shapes the dynamics of an urban socioecosystem. PASS parallels the Survey 200 as a major component of our long-term monitoring program. Following the pilot study, CAP received two supplemental NSF grants in 2004 to enlarge the sample and continue the social survey. The NSF-funded Decision Center for a Desert City (DCDC) made an additional financial contribution to the study. Subsequent surveys, conducted every four to five years, will be part of CAP's core budget.

An expanded team of 20 CAP LTER and DCDC social and biophysical scientists, academic professionals, and graduate students designed the second wave of the PASS in 2005. PASS survey questions engage human perceptions, values, and behaviors concerning the environmental domains emphasized in the IPAs and the focal interests of DCDC:

- Water supply and conservation
- Land use, preservation and growth management
- Air quality and transportation
- Climate change and the urban heat island.

In addition, the survey continues to question residents about community sentiment and perceptions of their neighborhood social, built, and biophysical environments. The intellectual

goals of PASS are to help us address the following questions: *How do human communities form, adapt, and function in a rapidly urbanizing region? How do human knowledge, values, and preferences affect behaviors that transform the preexisting ecosystem into an urban landscape? How do spatial variations in ecosystem characteristics relate to social class inequalities and cultural differences across the urbanizing area? How do changes in social, economic, and environmental systems affect the quality of life and vulnerability to environmental hazards for diverse human populations?*

The PASS was conducted in spring 2006, with respondents comprising residents from 800 randomly selected households in 40 neighborhoods that are co-located with Survey 200 field sites. The summary report of the survey can be found at http://caplter.asu.edu/docs/contributions/2007_PASS2.pdf.

Since that time, researchers have analyzed PASS data and drafted numerous publications. These include works that explore urban growth (York et al. in review), scale and perceptions of climate change (Ruddell et al. in review), vulnerability and urban heat (Ruddell et al. in press), gender and water policy (Larson et al. in review), and cultural domains and water (Larson et al. in prep.). Additional studies conducted in concert with the PASS include the **Phoenix Ethnohydrology Study** (Crona et al. in prep., reported under the Water IPA), a comparison of responses on water resource sustainability among the lay public, ASU scientists, and Phoenix-area policymakers (Larson et al. in press c.), and the **biodiversity and social variation** study reported under the Biodiversity IPA.

III. Highlights of Research Findings

The following CAP2 findings are presented within their interdisciplinary, integrative project areas.

Land-Use and Land-Cover Change (LULCC)

Work under this IPA has ranged from explorations of land-use and land-cover classification through remote sensing techniques (Stefanov and Christensen 2001; Stefanov et al. 2001; Buyantuyev et al. 2007; Walker and Briggs 2007; Walker and Blasche 2008) to an examination of historic land-use (Knowles-Yañez et al. 1999; Keys et al. 2007) and landscape patterns (Buyantuyev and Wu 2007; Shao and Wu 2008). While these will be enduring themes in CAP research, recent initiatives reported below focus on formulating a better understanding of the drivers of land-use and land-cover change as well as elucidating the emerging concept of landscape sustainability.

Intensively-managed urban landscapes are an important, yet understudied, feature of urban ecosystems. Little is known, however, about how homeowner decisions about residential landscape management impact biogeochemical cycling or what the drivers of these landscape management decisions are. A multidisciplinary team of faculty, graduate and undergraduate researchers have begun investigating residential landscapes in four neighborhoods in Phoenix, Arizona through the **Socioecological drivers of residential landscape management and ecosystem responses** project. Their research delves into two pressing questions: What are the factors that drive residential landscape management decisions and how do landscape management practices affect ecological processes, specifically biogeochemistry? The research team administered a survey to 120 households eliciting information on residential landscape management practices including watering, pesticide and herbicide use, fertilization, and routine

maintenance. To examine institutional structures, the research team has examined the Covenants, Codes and Restrictions (CCRs) in Homeowner Associations (HOAs) that govern landscaping across the Phoenix area and conducted interviews with developers about their landscaping decisions and how these have changed over time. The researchers have coupled these analyses with measurements of ecological variables in the front yards of all 120 homes. These variables include plant community composition, distribution, and biovolume.

Their preliminary findings indicate that residential landscaping management is driven by a myriad of decisions at the household, neighborhood, and regional scales (Figure 1). Overall, core environmental values and environmental orientation did not have a measureable effect on the preferences for yard types or actual yard types in the neighborhoods under study. However, residents who either maintained desert-like yards or preferred xeric yards prioritized easy yard maintenance and the environment in their decisions. Other findings underline the importance of landscaping legacies for understanding current landscape patterns and practices. Housing developers respond to the market, landscaping trends, and economic constraints when producing residential landscapes. The effects of these decisions may last long into the future and become institutionalized in HOA CCRs. Future investigations under this project will examine a new, integrated approach to understanding multi-scalar drivers of residents' yard management and ecological structure while focusing on the influence of values, beliefs, norms, and social-structural factors on residential land cover types, management practices (such as chemical and water applications), and yard quality. Additional work includes comparative analyses with other LTER sites, including the Baltimore Ecosystem Study (BES), Plum Island Ecosystems (PIE), and Florida Coastal Everglades (FCE) sites.

The **Institutional drivers of growth in Phoenix** project is a multi-year initiative to understand how the complex mix of institutions, federal, state, and local, influence the pattern of growth in Phoenix. This year, the research team focused on state trust land, specifically changing state trust land policy in Arizona and the western states in general. In the American West, vast stocks of federally and state managed land and a relatively long history of self-governance and direct democracy unite to form heated public debates about use, management, and values. The research team is investigating the nexus of two threads of American politics, direct democracy and public land policies, through a qualitative study of ballot propositions on state trust land over the last century. They have developed a database of state trust land propositions with 42 propositions from fourteen states, of these over 90% are from the West. Using word count as ideological placements, they have identified 29 topics in the propositions. Text and principle component analysis reduced these to four dimensions of debate: 1) resource use procedures, 2) use of the fund, 3) management, and 4) investment. Additionally, they identified one issue that is receding in importance, resource extraction, while conservation and development concerns are emerging as new priorities. Future work under this research initiative will occur in concert with the **Socioecological gradients and land-use fragmentation** project.

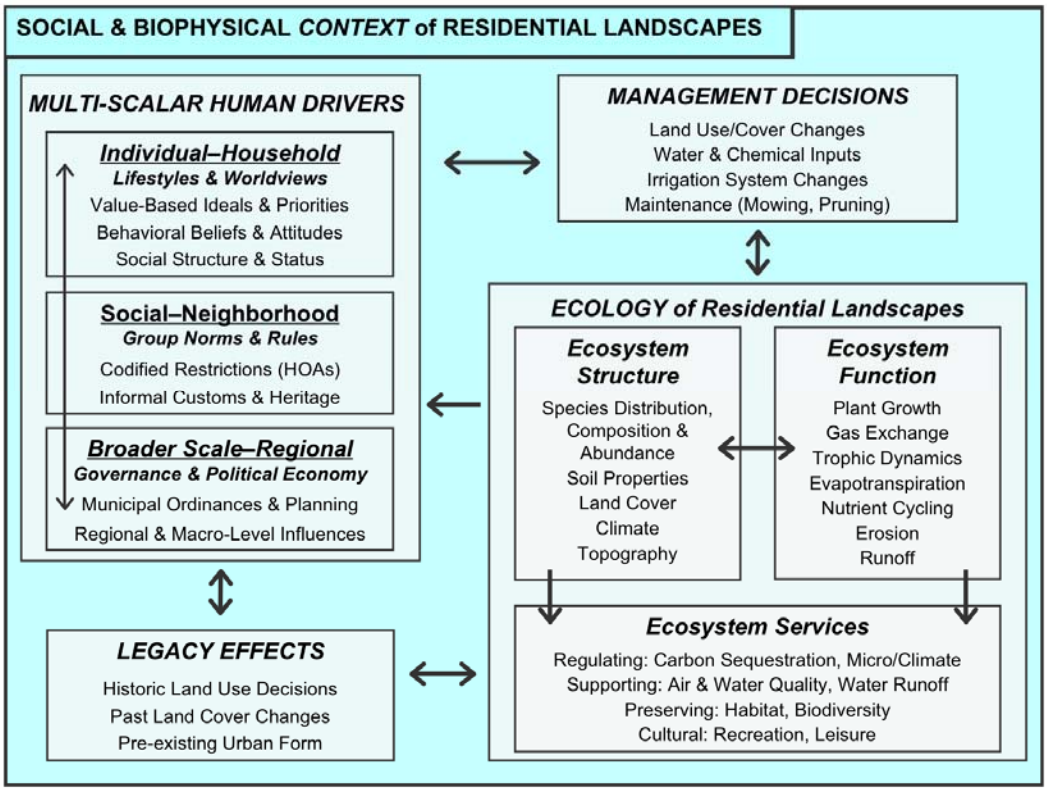


Figure 1: Conceptual framework representing the feedbacks and interactions between social and ecological components and processes of urban and suburban residential landscapes.

Sustainable landscapes is an emerging research theme within CAP LTER. While previous CAP research (Musacchio and Wu 2004) has explored collaborative landscape-scale ecological research, recent work by CAP scientists has forwarded conceptual and practical aspects of landscape sustainability. Chen and Wu (in press) argue that landscape ecology offers necessary theories and methods toward sustainability but that an approach integrating landscape ecology with landscape architecture would leverage the strengths of both disciplines toward a consideration of sustainable landscapes. They expound on principles and models of Chinese landscape architecture to illustrate how themes of sustainability, "the unity of man with nature," are woven through this tradition of landscape architecture and the great potential these present for sustainable landscape architecture. Martin (2008) focuses on the landscape experience in the Phoenix metropolitan area and the lessons that it provides for landscape sustainability. Drawing on past CAP research (Martin and Stabler 2002; Martin et al. 2003; Stabler and Martin 2004), he relates how landscaping practices, such as pruning and irrigation, have an impact on water-use efficiency, green waste generation, and soil salinity. Vegetation plays a role in ameliorating the urban heat island, although access to this ecosystem service varies by socioeconomic status (Harlan et al. 2008; Jenerette et al. 2007). Martin suggests that landscape sustainability in Phoenix can best be understood through concepts of ecosystem services and resilience.

Climate-Ecosystem Interactions (CLIM-ECO)

Work under the Climate IPA has fallen into six broad categories: urban heat island research (Baker et al. 2002; Hawkins et al. 2004; Hedquist 2005; Hartz et al. 2006a; Hartz et al. 2006b.; Myint et al. in review; Myint and Okin in review; Sun et al. in press), investigations of climate and environmental justice (Harlan et al. 2008; Ruddell et al. in press; Harlan et al. 2006; Jenerette et al. 2007; Ruddell et al. in review), work on climate-plant community interactions (Martin and Stabler 2004; Martin and Stutz 2004; Celestian and Martin 2004; Mueller and Day 2005; Celestian and Martin 2005; Stabler et al. 2005; Neil and Wu 2006; Buyantuyev and Wu 2009; Neil 2009; Neil et al. in review), comparative climate reviews (Brazel et al. 2000; Brazel and Heisler 2009; Brazel and Ellis 2003), climate and meteorological modeling (Grossman-Clarke et al. 2005; Grossman-Clarke et al. 2008), and integrated urbanization modeling with climate as a key variable (Shen et al. 2008). This year's report will present some overarching findings from climate research under the **PASS** as well as highlights from a recently-published paper on urban ecology and climate at the two urban LTER sites.

Building on earlier studies of heat in the Phoenix area and socioeconomic status (Harlan et al. 2008; Harlan et al. 2006; Jenerette et al. 2007), the **PASS** research team asserts that climate change is an environmental justice issue (Ruddell et al. in press; Ruddell et al. in review). The team found variable levels of exposure to extreme temperature among the 40 sites examined in the study (Figure 2). Residents at the greatest risk to environmental conditions tended to be minority, low-income, and elderly residents. The researchers also determined that public perceptions of environmental risks become increasingly distorted as spatial scale broadens. Their study indicates that public perceptions of environmental conditions are highly correlated at fine scales where people experience a given process (in this case temperature), but as the scale of analysis increases public perceptions progressively rely on social frames of reference which report weaker association to environmental conditions. One of the difficulties in pursuing policy to adapt to or mitigate the impacts of climate change is that global environmental problems (e.g., climate change) are largely perceived via social frames of reference rather than based on experience.

Both CAP and the BES have included climate-related studies as part of their research programs since their inception. A recent paper in the online journal *Geography Compass* underlines the importance of these investigations for forwarding urban ecological research (Brazel and Heisler 2009). Teleconnections to events such as the Pacific Decadal Oscillation (PDO) are drivers of climate at both CAP and BES, and the authors assert that links to these types of global and regional drivers are critical for ecological assessments at the sites. They note the importance of long-term ecological monitoring as a means of understanding the impact of press versus pulse climate events. Land-use and land-cover change influence microclimate and can lead to the formation of urban heat islands, which have ramifications for human and ecosystem health. Finally, the authors note the research value in installing air quality and meteorological flux towers in urban/suburban environments to gather data for linking the local climate system to ecological processes and for verifying atmospheric models.

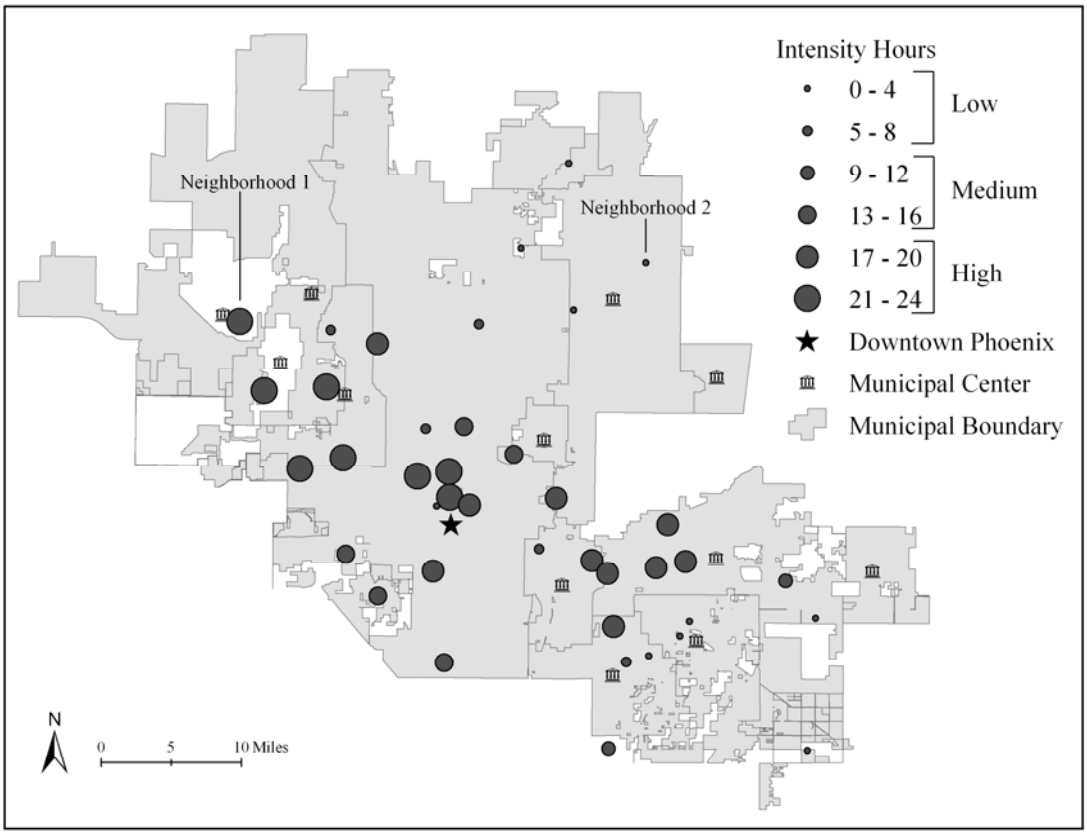


Figure 2: Hours of Exposure to Threshold Temperatures at or above the 97.5 percentile (113°F) from July 15-19, 2005 by PASS Neighborhood

Water Policy, Use, and Supply (WATER)

Research under this IPA has focused on several features of the water system in the CAP study area, including investigations related to the modification of streams and rivers (Roach et al. 2008), policymaker responses to drought and water shortages (Hirt et al. 2008; Larson et al. in press.b.), household perceptions, values, and behaviors regarding water (Harlan et al. in press; Larson et al. in press a.; Crona et al. in prep.), modeling water and salt fluxes (Westerhoff and Crittenden 2009), work comparing perspectives on water sustainability across expert and lay groups (Larson et al. in press c.), and a new emphasis on stormwater material export. Aquatic biogeochemistry research reported under the Fluxes IPA overlaps with this IPA. This report will focus on results from joint research with DCDC on **decision maker responses to the WaterSim** model and the **Phoenix Ethnohydrology Study**.

WaterSim, developed under the DCDC project, is an interactive model designed to facilitate decision-maker interactions around long-term water supply and demand in Maricopa County, Arizona. The model serves as a boundary object to inform water-related decision-making on issues of long-term sustainability in central Arizona. WaterSim is available online as well as shown in ASU's Decision Theater, a 260 degree, three-dimensional projection space designed to facilitate decision making and policy evaluation. The research reported below refers to work done using an earlier version of WaterSim with water decision-makers (policymakers, data

analysts, and consultants) in 12 focus groups. After viewing the WaterSim model, participants answered questions individually about the model and participated in a focus group session. Content analysis of individual response data demonstrated that stakeholders were overall critical of the credibility, saliency, and legitimacy of WaterSim, although some differences were noted between the groups (White et al. in press). For example, consultants tended to be more critical of the model's legitimacy because they felt that it was biased toward the status quo and not inclusive of all stakeholder perspectives, including Native American groups. These and other findings provide insight into design and study of boundary objects and were used to enhance further versions of the WaterSim model.

Debates rage among social scientists about the best methods for eliciting responses to sensitive topics. The WaterSim experience has helped shed some light on the efficacy of focus group methods compared to individual response formats, particularly for sensitive topics. The analysis compares focus group and self-administered questionnaire responses among 55 decision-makers for three types of sensitive topics: competence, risk, and gate-keeping (Wutich et al. in press). The results indicate that respondents: (1) gave similar responses in group and open-ended self-administered questionnaires when discussion topics were only moderately sensitive; (2) volunteered less information in focus groups than in open-ended self-administered questionnaires for very sensitive topics, when there did not appear to be a compelling reason for respondents to risk being stigmatized by other group members; and (3) volunteered more information in focus groups than in open-ended self-administered questionnaires for very sensitive topics when there appeared to be an opportunity to exchange important information or solve a pressing problem. The researchers concluded that multi-method research—including individual and group response formats—may be the best strategy for collecting data from decision-makers on sensitive policy-related issues.

The **Phoenix Ethnohydrology Study** is a follow-up study to the **PASS**. Based on respondents' assessment of water quality in their neighborhood in PASS, a multi-disciplinary team of researchers selected a sub-sample of four neighborhoods for additional in-depth study. Researchers selected four neighborhoods (two with high levels of water quality concern and two with low levels of water quality concern) in South and Central Phoenix to conduct an in-depth study of water quality local ecological knowledge (LEK) (Crona et al. in prep.). In the first research stage, they used a "successive free listing" technique to elicit information about respondents' cognitive models of tap water quality, causes of variation in water quality, and appropriate mitigation strategies for low-quality water for 30 respondents in each of the four neighborhoods (n=120). In the second stage, the team conducted 30 additional interviews with new respondents in each of the four neighborhoods (n=120) to assess whether or not people agree with "cultural statements" about water quality, causes, and mitigation. Using the "cultural consensus analysis" technique, researchers examined the following questions: (1) Is there a shared core of cultural knowledge around water quality?; (2) Does cultural consensus around water quality LEK vary across Phoenix neighborhoods with high and low concern?; (3) What kind of people have low or high levels of cultural competence around water quality LEK?; and (4) How closely does water quality LEK match water quality experts' understanding of these issues? The team found a shared but weak consensus among Phoenix neighborhoods associated with higher income and neighborhood concern about water quality. They also noted significant diversity in conceptualization around water quality issues, with residents in neighborhoods with high concern about water quality lacking shared conceptualization of the causes and solutions to poor water quality. There were also discrepancies between lay and scientific understanding.

Research protocols developed in the Phoenix study are now being used internationally in Bolivia, Ecuador, Fiji, New Zealand, Australia, and England (http://shesc.asu.edu/research/global_ethnohydrology).

Material Fluxes and Socioecosystem Response (FLUXES)

Work conducted under the Fluxes IPA has generally been focused in two areas, biogeochemistry and environmental justice. Biogeochemistry research has been conducted across land-use and land-cover types, including desert and desert remnants (McCrackin et al. 2008; Hall et al. 2008), agricultural areas (Lewis et al. 2006), residential landscapes (Hall et al. 2008) and natural and "designed" rivers, streams, lakes, and riparian areas (Lewis et al. 2007; Roach et al. 2008). This research has considered fluxes of N, C, P, and trace elements, such as Pb and As. Environmental justice work has focused on the uneven distribution of contaminants across the urban landscape, particularly in relation to minority and lower-income communities (Grineski et al. 2007; Bolin et al. 2005; Bolin et al. 2002). New, ongoing work is examining black carbon and organic compounds in soils, measuring urban surface energy fluxes, and investigating biogeochemistry and storm-water management.

Black carbon (BC), the partially combusted organic residue of fossil fuel and biomass burning, is ubiquitous in the environment and yet, its fate and reactivity are poorly understood. Global budgets suggest there is less BC present in the environment than can be accounted for by emissions. Two major open questions in BC biogeochemistry are: how much BC is tied up in soils and what is the reactivity of BC to microbial and photochemical attack? The ongoing project on the **composition and distribution of black carbon in Phoenix area soil** focuses on investigating the amount and distribution of BC in **Survey 200** soils as well as the isotopic and chemical composition of BC in these soils. Research results indicate that black carbon is present in soils with many different land-use types and is distributed across the greater-metropolitan Phoenix region (Figure 3). The black carbon (BC) in Phoenix-area soils ranged from 0.02 to 0.78% by weight; the bulk soil organic carbon (OC) content ranged from 0.08 to 3.97% by weight. The BC is a relatively small percentage of the bulk soil material; however, perhaps more importantly, in these low organic soils the BC represents from 2 to 64% (BC/OC) of the soil organic carbon at these sites. This is generally higher than the average BC/OC ratios reported for other soils (~ 8%; though admittedly, this value is not at all well constrained). The BC in the Survey 200 soils is not a function of the bulk soil OC; however, BC does appear to be related to land-use. Desert soils had an average BC content of 0.07 ± 0.07 wt% (n = 12) and urban soils had an average BC content of 0.29 ± 0.13 wt. % (n = 13). This difference is statistically significant at the >95% confidence level. Desert soils consistently had some of the lowest black carbon contents. The research team also found that $\delta^{13}C_{BC}$ was generally more positive (~ -16‰) than the bulk $\delta^{13}C_{OC}$ (~-25‰). The BC isotopic composition is altered relative to a fossil fuel or a biomass source, but whether this is due to a biological or chemical fractionation is still unknown. Explaining why Phoenix-area soils have high BC, and what controls BC composition and reactivity, will provide insights for microbial carbon processing in urban and arid-land soils and help improve the soil-BC estimates in global and regional BC budgets.

Tempe Town Lake is a constructed, urban aquatic system that provides primarily recreational and flood control services. Rainwater and stormwater flow into the lake during the summer monsoons and winter storms, carrying significant amounts of organic carbon into the lake. The **characterization of dissolved organic carbon in Tempe Town Lake** project focuses on monitoring long-term patterns in the amount and form of DOC in an urban aquatic system.

Comparison of DOC concentrations among years reveals that river flow events with different sources (Verde River vs. Salt River), dam management, and winter precipitation patterns impart different amounts of DOC. ESI-MS results suggest that this carbon has different compositions. Both the amount and composition of DOC in the lake varies over the course of the year. The distribution and number of peaks present in both low and high molecular weight ranges differs between winter river-flow periods (Feb) and summer monsoon periods (Aug). Seasonal changes in the overall distribution of peaks are clearly present, but it is difficult to describe the trends and patterns without quantitative numerical and statistical analyses. Changes in the number of compounds present from season to season are quite informative and provide evidence that the sources of organic matter to the lake change throughout the year. The research team is now poised to assess how the spectral patterns change seasonally, interannually and in response to specific events (i.e., high-river flow vs. evaporative periods or pre/post monsoon rain events). They are now examining relationships among abundant compounds, frequently occurring compounds, unique compounds. The overall pattern of results suggest that during winter river-flow seasons, terrestrial organic carbon from upstream watersheds is transported to Tempe Town Lake and that during summer monsoon periods, urban run-off caries a different pool of organic carbon into the lake. During dry periods, biogeochemical processes consume organic carbon and decrease DOC concentrations in the lake.

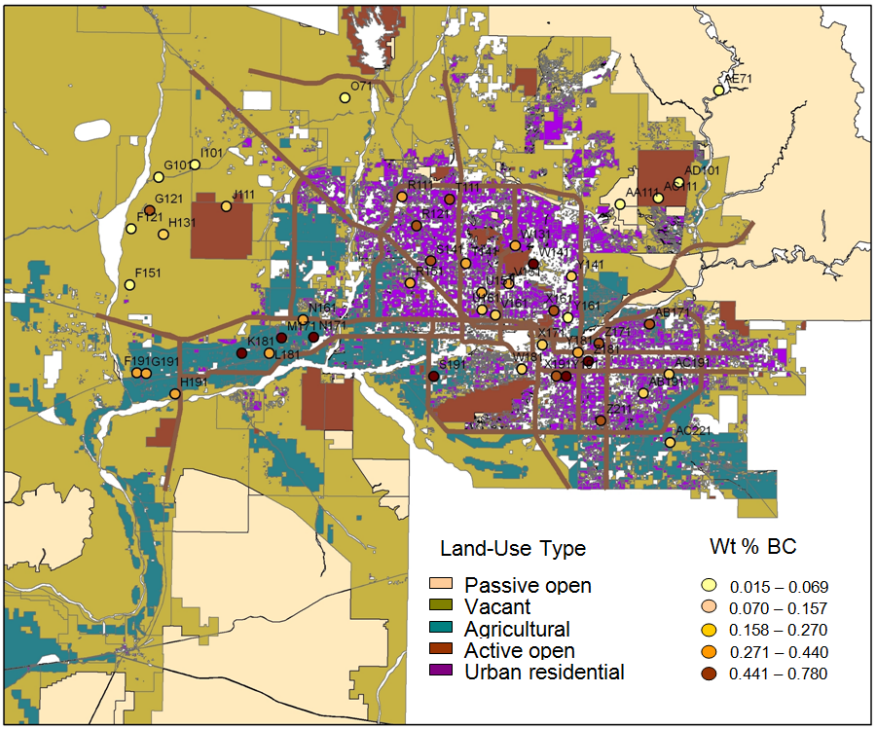


Figure 3. Map indicating locations (circles) of Survey 200 used in this study. Circles are color-coded with darker shading indicating higher BC contents. Color overlays are general land-use classifications identified by Maricopa Association of Governments.

Research on the **environmental fate of combustion-derived organic compounds in arid, urban soils** examines the magnitude, distribution, and fate of non-point carbon pollution in urban areas. Using 63 soil samples from areas adjacent to Phoenix-area highways, this project seeks to characterize and quantify combustion-derived carbon compounds, explore the dynamic

fate of Polycyclic Aromatic Hydrocarbons (PAHs) in soils, and assess the importance of microbial community structure in PAH storage and dynamics. Preliminary research findings are that PAH concentrations in arid Phoenix soils range from 52 ug/kg dry soil to 8,296 ug/kg (mean 926 µg/kg), nearly an order of magnitude lower on average than expected based on data from other cities. This illustrates the extent of these pollutants, which are an EPA-priority group of hazardous compounds, in urban soils. Although the most likely sources for PAH content in roadway soils are vehicle emissions, PAH concentrations were not correlated with traffic density ($r^2 = 0.024$; $p = 0.26$) or highway age ($r^2 = 0.044$; $p = 0.13$) across all sites. However, they were significantly correlated to soil organic matter (Figure 2, $r^2 = 0.36$; $p < 0.001$). These results suggest that PAH concentrations in roadway soils of desert cities may be controlled by factors associated with carbon retention, such as soil organic matter, rather than source or rate of deposition.

Human Control of Biodiversity (BIODIV)

Biodiversity research under CAP is closely aligned with CAP's long-term monitoring: **Survey 200**, bird monitoring**,** and aspects of the **NDV** research platform. Birds, mycorrhizal fungi, microbes, plants, and arthropods have been foci of these investigations, mostly using core monitoring datasets. Building on this are research endeavors that use experimental methods to examine specific biodiversity mechanisms as well as physiological studies of urban stressors. Emerging work in CAP will examine herpetofauna responses to urban rehabilitation of riparian habitat.

A recent initiative, **Ecophysical and behavioral adaptations of birds to rapid urbanization of a desert environment**, has examined physiological responses of urban birds to stressors found in the urban environment (Fokidis et al. 2008, 2009). The main aim of the project is to test how differences in body condition (a direct measure of energetic stores obtained from food) may influence the ability of birds to cope with anthropogenic stressors associated with urban environments. Research from this CAP LTER-funded project focuses on elucidating: 1) whether predictability in food resources influences the acute stress response; 2). the physiological source of differences in the stress response between urban and desert birds; 3). whether urban and desert birds differ in the mechanisms by which they devote energy resources to dealing with stressors; and 4). other physiological processes, such as reproduction and immunity that can be impacted by increased seasonal predictability of food resources in urban birds. The research team, including a CAP graduate student, is addressing these questions using Curve-billed Thrashers, a common Sonoran Desert insectivorous species that is easy to locate and capture both in desert and urban environments, and is widely distributed in both types of environments. This research has thus far have generated several significant findings:

- Increased and less seasonally variable stress responses in male thrashers inhabiting the Phoenix metro area than adjacent rural areas (Fokidis et al. 2009).
- Male thrashers from Phoenix show earlier gonadal development (~ 1.5 to 2 weeks) in spring compared to outlying desert sites, based on two years of data (Deviche et al. in review).
- Differences in stress responses between urban and desert thrashers may stem from a combination of differences in perception of environmental factors or from mechanisms of regulation of stress by the brain and peripheral tissues (Fokidis and Deviche in review).

- Increased territorial behaviors in response to conspecific playback in urban thrashers compared to desert birds, possibly related to the patchy distribution of suitable nest site locations.
- During a stress response, desert thrashers convert circulating fat stores (i.e., triglycerides) to glucose to provide energy, whereas urban thrashers appear to rely less on endogenous energy reserves, suggesting increased intake as primary energy source.

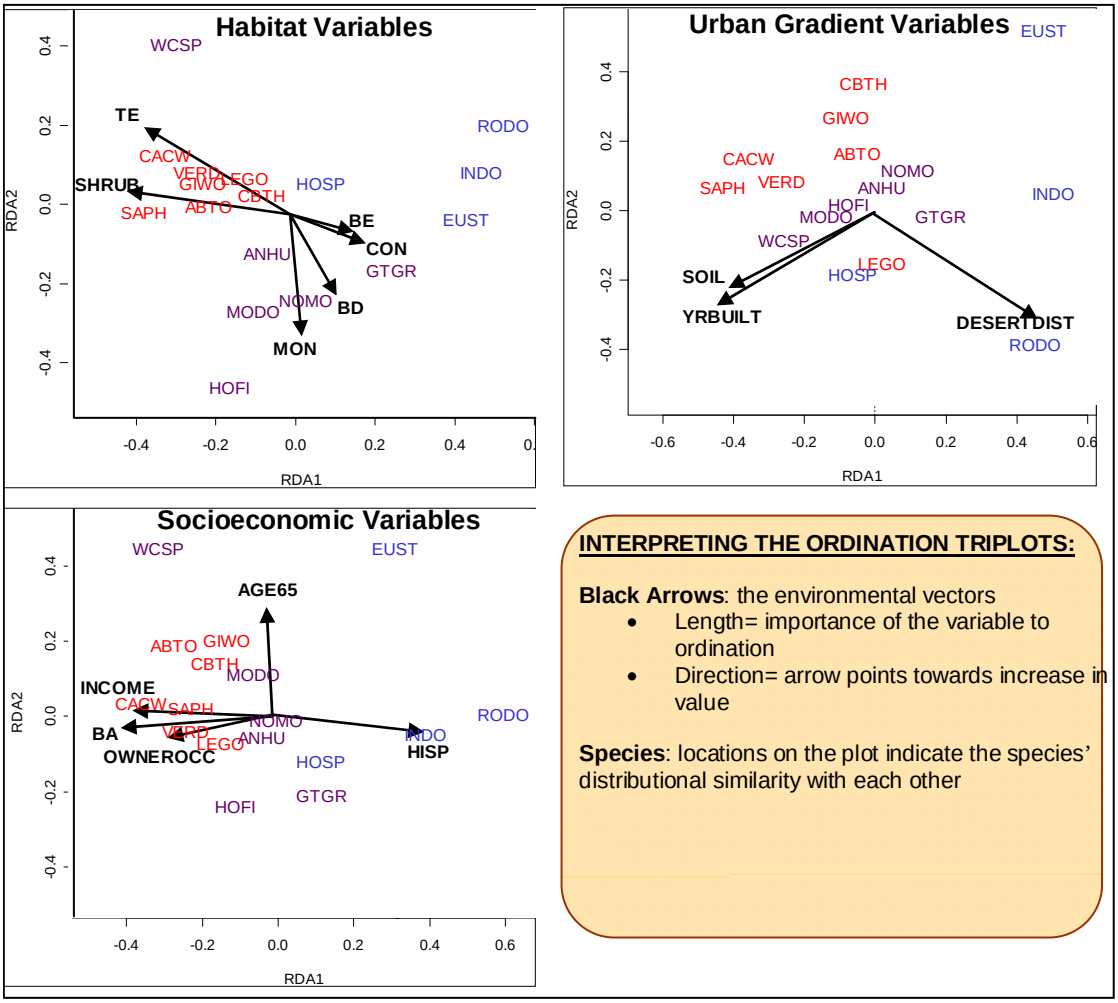
Other avian research, **Biodiversity and neighborhood social variation**, is being conducted in 39 of the **PASS** neighborhoods. To fully understand how birds respond to residential landscapes, the research team proposes a conceptual model that integrates socioeconomic factors that influence landscaping decisions and thus drive urban bird community patterns. Using the open radius point count method, the team monitored all birds using the sites. For further analyses, they only included birds within 40m from plot center, and birds recorded at 40% or more of the sites. The team quantified the habitat structure along a 100m x 40m transect, encompassing the point count. Their results suggest native bird species align closely with xeric landscaping (neighborhoods with greater densities of thin evergreen trees and shrubs), and areas closer to remnant desert patches. The census variables suggest a trend towards native birds aligning with higher income neighborhoods, college educated and owner occupied residents. The results also suggest racial and economic inequalities in regards to biodiversity where Hispanic and poor neighborhoods have fewer native birds (Figure 4).

Figure 4. Constrained Ordination (Redundancy Analysis) diagram of 17 bird species to explore bird community structure and associations with habitat, an urban gradient, and socioeconomic variables. Red species = native birds, purple species = opportunistic birds and blue species = alien birds. See Table 1 for species codes.

Habitat variables: TE = Thin Evergreen tree, SHRUB = shrub density, MON = monocots, BD = Broad Deciduous tree, BE = Broad Evergreen tree, CON = Conifer tree.

Urban gradient variables: SOIL = percent soil coverage within 1km radius (impervious surface measurement), YRBUILT = housing age, DESERTDIST = distance to large, desert tract

Socioeconomic Variables: INCOME = median household income, BA = Bachelor's Degree, OWNEROCC = home ownership, AGE 65 = older than 65, HISP = Hispanic.



NDV social science researchers have found that the causal relationships between environmental values, ecological knowledge, and landscape preferences remain controversial. Survey responses indicate that overall ecological knowledge could not predict environmental values. Respondents who thought the desert was beautiful were likely to have strong environmental values (regression ANOVA $p = 0.0006$). This suggests that subjects' environmental values are driven by aesthetics (in psychological terms: affective response, not cognition). When they considered only the ability to identify native desert plants and birds, knowledge of native desert biota was correlated with positive ratings of the desert landscapes

(L2, L8; regression ANOVA $p = 0.04$) and thinking the desert is beautiful (V5; regression ANOVA $p = 0.02$). Wave 2 data show an increase in aesthetic perception of desert among those who received desert landscapes, but no increase in knowledge, suggesting that aesthetic appreciation is independent of knowledge. The literature shows that affect takes precedence over cognition for broad based preferences. But **NDV** research suggests that cognition influences more subtle decisions and "expert" segments of the population. Knowledge about plants and birds does not influence landscape preference unless one is very knowledgeable about the desert biota. It appears that knowledge of desert biota is correlated with beauty, but is not directly correlated with environmental values – it must pass through aesthetics to affect values. Future research will carry this analysis through observed behavior, where ecological knowledge is likely have more influence.

Informatics

CAP continues a strong tradition of leadership in ecoinformatics. The CAP Information Manager, Corinna Gries, is currently finishing up the last year of her term as LTER Information Managers Committee (IMC) Co-chair and has begun her tenure as IM representative to the LTER Executive Board. Under Gries' leadership, the IM Executive Committee (IMExec) organized a regular monthly video conference open to all IMs for general information exchange and presentations from outside. This initiative has proven to significantly reduce the time spent at face-to-face meetings for updates from the various groups as well as keeping the IMC informed and engaged throughout the year.

At CAP, all ~500 metadata files received a major overhaul and update to the Ecological Metadata Language (EML) 2.1.0. Description of database access has been completely removed, and all data are available as comma-delimited text files for download. The time-out problem of accessing large databases has been resolved by making the data available in versioned annual increments according to best practices in METACAT. The renewed upload into METACAT and employment of the Data Access Server (DAS) developed by LNO will be accomplished this fall. Furthermore, improvements to the EML generation were implemented in standardizing certain aspects of the database structure for storing CAP datasets and recording of metadata. The metadata files generated for this year's datasets all contain complete sampling site and taxonomic information. This information has always been available within each dataset but had previously not been encoded in EML and will now enable advanced search applications.

Currently, a team of designers and programmers is working on redesigning the CAP website. This involves a translation of all existing functionality from Java/jsp into PHP and the addition of some content, especially in the area of outreach. The website will be launched later in fall 2009.

CAP was actively involved in organizing working groups funded by the LNO to develop a database and access application for a centralized project registry, a database for detailed descriptions of research projects at the different sites. These working groups developed an EML Project module and web-services to access the information. This code has now been employed at CAP and further expanded to access information in EML dataset and EML research protocol modules. This approach of using web-services has dramatically eased the developments for the new CAP website.

Work continued on several CAP-leveraged projects within the GIOS Data and Informatics Lab. While the Arizona Water Institute was disbanded this year due to state government cuts, the Informatics Lab received some funds to continue the development of the metadata editor. Work

on the Southwest Environmental Information Network (SEINet) continued with NSF funding. An ecoinformatics team lead by Gries expanded and developed the software originally driving the functionality of SEINet into a downloadable software package capable of providing search, mapping, checklist generation and keying functionality to any natural history collections database backend. Three independent biodiversity nodes are now employing the package: SEINet for higher plants of the Southwest which has added several new herbaria; the Consortium of North American Lichen Herbaria; CoTram for the Myrtacea of the world.

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V. Research Training and Development

CAP LTER's university setting enhances the ability to conduct, communicate, and synthesize our research activities. Faculty members have expanded their courses to consider urban ecology and, in some cases, have designed new courses to accommodate CAP LTER research interests. In addition, postdoctoral associates and graduate assistants gain exposure to interdisciplinary research, the importance of long-term datasets, metadata, and data archiving, as well as experience in database design and management, lab processing and analysis. The Goldwater Lab for Environmental Science accommodates CAP LTER's analytical needs and provides graduate-student training on instruments housed in its facility. Opportunities for summer support for graduate research and undergraduate research experiences are available. Theses and dissertations completed and in progress are listed below. Additional information is included in Contributions to Human Resource Development section below.

Theses and Dissertations

In Progress

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

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

Chow, Winston. Simulation of canopy-level UHI using a coupled urban canopy-mesoscale meteorological model: Evaluation using in-situ surface energy balance measurements (Ph.D., Geography, A. Brazel).

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

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

Hale, Rebecca. Landscape configuration controls on nutrient transport and retention in urban ecosystems (Ph.D., School of Life Sciences, N. B. Grimm).

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

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

Iwaniec, David. State change in urban systems (Ph.D., School of Sustainability, J. Wu).

Larson, Elisabeth. Water and nitrogen in designed ecosystems: Biogeochemical and economic consequences (Ph.D., School of Life Sciences, N. B. Grimm).

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

Marusenko, Yevgeniy. Microbial degradation of non-point carbon deposition in urban soil (M.S., School of Life Sciences, S. Hall).

Schaasfma, Hoski. Environmental legacies of ancient farming in the Sonoran Desert (Ph.D., J. Briggs).

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

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

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

Trujillo, Jolene. The historic agriculture and its effect on modern biogeochemical nutrient cycling (M.S., School of Life Sciences, S. Hall).

Zhuo, Xiaoding. Distribution, transport, and sources of trace elements in soils of an urban arid region (Ph.D., Department of Chemistry and Biochemistry, E. Shock).

Completed

2009

Choi, Chi Chi. 2009. Comprehensive water, salt and energy flux modeling for urban systems (M.S., Department of Civil, Environmental and Sustainable Engineering, P. Westerhoff).

Literral, Jennifer. 2009. Effects of urbanization on avian species diversity in the Phoenix, Arizona, usa metropolitan region: Patterns in vegetation remnants (M.S., School of Life Science, J. Wu).

Ontiveros Valencia, Aura V. 2009. Arbuscular mycorrhizal and dark septate endophytic fungi in urban desert preserves and surrounding Sonoran Desert. (M.S., Department of Applied Biological Sciences, J. Stutz).

Ruddell, Darren. 2009. Scale and scientific inquiry: an investigation of theoretical, methodological, and practical applications (Ph.D., School of Geographical Sciences, E. Wentz).

2008

Buyantuyev, Alex. 2008. Effects of urbanization on the landscape pattern and ecosystem function in the Phoenix metropolitan region: A multiple-scale study (Ph.D., School of Life Sciences, J. Wu).

Davies, Rachel. 2008. Human influence on nutrient cycling in Phoenix, AZ. (M.S., School of Life Sciences, S. Hall).

Neil, Kaesha. 2008. Effects of urbanization on flowering phenology in Phoenix, USA. (Ph.D., School of Life Sciences, J. Wu).

Walker, Jason. 2008. Socio-ecological effects of urban forest structure in Phoenix (Ph.D., School of Life Sciences, J. Briggs).

2007

Bigler, Wendy. 2007. Historical biocomplexity in irrigation agriculture. The Akimel O'Odham (Pima) and the Gila River, Arizona (Ph.D. ,Geography, R. Dorn).

Gonzales, Daniel. 2007. Dry deposition of speciated ambient fine particles measured using eddy correlation mass spectrometry (Ph.D., Department of Chemical Engineering, J. Allen).

McLean, Brandon. 2007. Geochemical consequences of management on water resources in central Arizona, USA. (M.S., School of Earth and Space Exploration, E. Shock).

Miller, James 2007. Local and regional climate change in the Mojave Desert, USA. (Ph.D., Geography, A. Brazel).

Zhang, Peng. 2007. Urban water supply, salt flux, and water use. (M.S., Civil and Environmental Engineering, J. Crittenden and P. Westerhoff).

2006

Bills, Robert. 2006. Effects of urbanization on community structure and functioning of arbuscular mycorrhizal fungi. (M.S., School of Life Sciences, J. Stutz)

Block, Jessica. 2006. 3-D Visualization for water resources planning and for Salt River paleo-geomorphology in central Arizona (M.S., School of Earth and Space Exploration, J R. Arrowsmith).

Grineski, Sara. 2006. Social vulnerability, environmental inequality and childhood asthma in Phoenix, Arizona. (Ph.D., B. Bolin).

Parker, John. 2006. Organizational collaborations and scientific integration: The case of ecology and the social sciences (Ph.D., Ed Hackett).

Singer, Catherine. 2006. Effects of landscape surface mulches on desert landscape microclimates and responses of three Southwest desert plants to landscape surface mulches and drip irrigation. (M.S., School of Life Sciences, C. A. Martin).

Stiles, Arthur. 2006. Structure and distribution of Sonoran Desert plant communities in metropolitan Phoenix, Arizona. (Ph.D., Plant Biology, S. Scheiner).

White, Jacqueline. 2006. Resilience of the plant community and seedbank in an urbanized riparian corridor (Salt River Phoenix, Arizona) (M.S., School of Life Sciences, J. Stromberg).

2005

Collins, Timothy. 2005. The production of hazard vulnerability: The case of people, forests, and fire in Arizona's White Mountains. (Ph.D., Geography, K. McHugh).

Roach, W. John. 2005. How anthropogenic modifications influence the cycling of nitrogen in Indian Bend Wash (Ph.D., School of Life Sciences, N. B. Grimm).

VI. Education and Outreach

Education and outreach activities are woven throughout CAP LTER. We are committed to sharing what we learn with community organizations, governmental agencies, industry, and the general public.

K-12 Education

We reach out to the K-12 community in a program called Ecology Explorers that works with K-12 teachers and students in the metropolitan Phoenix area. Popular summer workshops and internships have engaged over one hundred teachers and thousands of their students in our schoolyard sampling protocols for the vegetation survey, ground arthropod investigation, bird survey, and plant/insect interaction study. The program is aligned with the AZ State Education Standards, including science, math, writing, social science and technology standards. Evaluations from these workshops indicate that teachers benefited from the workshops and used workshop materials in their classrooms (Dresner and Elser 2009; Banks et al. 2005).

This year, we initiated work with Navajo Elementary School on watershed monitoring activities, funded through an NSF supplement to CAP. We installed a Weather Bug http://weather.weatherbug.com/weather-education/ station at the school and plan a series of teacher training workshops on using the instrumentation in lessons on weather and the built environment. During spring 2009, we engaged Navajo Elementary students in all 2nd, 3rd, 4th, and 6th grade classrooms in urban ecology activities related to phenology and storm run-off. In the

coming year, we intend to replicate our work with Weather Bug at either a low-income school in central Phoenix or a Boys and Girls Club as part of work on the CAP-leveraged grant on heat and vulnerability in the city.

We have worked over the past year to expand our partnerships with institutions in local natural areas, which provide excellent opportunities for environmental education and outreach. During our summer 2009 week-long internship for high school teachers, we worked with staff from the Gilbert Riparian Institute to conduct Ecology Explorer protocols at the Gilbert Riparian Preserve. As part of our efforts to involve the regional park system in our outreach efforts, we visited Usury Mountain Park and discussed opportunities with the ranger staff. We have continued discussions with the new Chandler Environmental Education Center about conducting teacher workshops at their facility in the fall and expanding aspects of CAP's monitoring program to their site. A recent meeting with the McDowell Sonoran Preserve indicates that there is considerable potential at this site for establishing a citizen science project.

Other workshops over the last year included a sustainability workshop for middle school teachers, sponsored by the ASU Office of Youth Preparation, which used CAP LTER urban land use and heat island material. We provided afterschool science activities based on Ecology Explorers programs to middle-school children associated with the non-profit Boys Hope Girls Hope mentoring organization, and this work will continue into the next academic year. We also delivered a program on doing backyard ecology for home schooled children in association with the Arizona Science Center. During summer 2009, CAP participated in a program providing research experience for local high school teachers on the ASU campus. Funded by the Arizona Science Foundation, this program involved CAP scientists in training teachers in field and laboratory science. The teachers also were introduced to Ecology Explorers activities and protocols. Another summer activity involved a former Ecology Explorers undergraduate assistant using Ecology Explorers protocols to engage homeless children in activities during a summer camp program.

We have continued their involvement with ASU partners on a NSF ITEST grant. This year, we continued to refine and test the urban heat island module and included CAP LTER lessons related to aerial photographs of our changing neighborhoods in the curriculum. Formal evaluations of the children participants through pre- and post-tests and reflection notebooks will give insights into the effectiveness of this pedagogy.

Knowledge Exchange

The **Global Institute of Sustainability** (**GIOS**) is the home base of CAP LTER, as well as the Decision Center for a Desert City, the Urban Ecology IGERT, the Decision Theater, the Urban Environmental Monitoring of 100 Cities, and many other programs. GIOS' outreach efforts engage academic, business, and governmental groups in dialogues about pressing environmental issues affecting our rapidly growing desert metropolis. In October 2006, ASU launched the new School of Sustainability (an entity under GIOS) as the first academic school in the country to be focused upon sustainability science and studies. CAP LTER retains strong linkages to the School through its faculty and is involving its graduate and undergraduate students in CAP research.

GIOS produces a weekly e-newsletter digest, "Sustainability Digest," with events, announcements, and job postings that are of interest to the university and community. To inform residents at the **North Desert Village** experimental suburb about ongoing research, CAP LTER

management produces an occasional newsletter on this initiative and distributes letters to households living in the study areas.

In addition, there are initiatives under GIOS that strive to apply the work of university researchers to the business of the private and public sectors. For example, the Sustainable Materials and Renewable Technologies (SMART) program based at GIOS is working closely with private industry and state and local agencies to minimize the impacts of rapid urbanization, through existing and emerging technologies and sound policy recommendations. This project involves CAP LTER scientists and builds on urban heat island research conducted under CAP LTER. The Sustainable Cities Network (SCN) is an initiative launched in February 2009 to engage cities in the greater Phoenix area in discourses and common projects around sustainability. CAP anticipates working with the SCN in the future.

The highlight of each year is the CAP LTER **Annual Poster Symposium**, held in January. This day-long event, attended by researchers, students, K-12 teachers, community partners, and state and local agencies, features a keynote speaker and poster presentations by all supported projects (view posters at http://caplter.asu.edu/home/symposia.jsp). The **2009 Annual Poster Symposium** celebrated 11 years of ecological and socioecological research in CAP LTER. This year, the symposium focused on examining theoretical and conceptual themes under CAP LTER through a series of presentations during the morning and afternoon of the symposium.

Box 1: CAP LTER Meetings, 2008-2009

September 2008: Graduate student orientation; presentations by the LULCC IPA
October 2008: Presentations by the Biodiversity IPA
November 2008: Presentations by the Fluxes IPA
January 2009: Annual poster symposium; thematic group meetings
February 2009: Presentations on cross-regional comparisons of residential lawns and landscapes
March 2009: Mark Klett, "Phoenix Transect Project;" thematic group meetings
April 2009: Thematic group meetings
May 2009: Thematic group meetings

Monthly **All Scientists Meetings** (ASMs) attract between 40 and 100 participants, including community partners, and feature scientific presentations by visitors or discussions of project results (Box 1). Following recommendations from reviewers in the September 2007 NSF site review, CAP reoriented its ASMs to enable greater collaboration between scientists of varying disciplines. Toward this end, the fall 2008 and spring 2009 meetings involved IPA presentations. Other meetings during spring and summer 2009 focused on shaping the research agenda for each new, proposed thematic research group.

Collaborations and Partnerships

CAP LTER seeks to maintain and expand its collaborations and partnerships within academia and beyond. Lead PI Nancy Grimm was a co-author on a report released in June 2009, *Global Climate Change Impacts in the United States* www.globalchange.gov/usimpacts. The report, a product of the interagency U.S. Global Change Research Program, is a synthesis of years of scientific research on climate change in the U.S. A central message of the report is that climate change has already impacted ecosystems and that policy choices made now will determine the severity of future climate impacts.

Several cross-site research projects have been initiated recently with funding from NSF supplements and the LNO. In 2008, four CAP scientists received $67,250 from the National Science Foundation to lead a research project on water resource availability and land fragmentation, including sprawl development, in four metropolitan areas (Phoenix, Albuquerque,

Las Cruces, and Fort Collins) and one city, Manhattan, Kansas. An April 2009 workshop brought scientists from all five sites together to engage in information exchange and research planning for the coming year.

Residential landscape management is a research theme that cuts across several LTER sites. In February 2009, CAP scientists convened a three-part workshop with colleagues from other LTER sites. One part of the workshop focused on synthesizing residential landscape research at CAP, Baltimore Ecosystem Study (BES), Florida Coastal Everglades (FCE), and Plum Island Ecosystem (PIE) as well as manuscript and grant proposal writing. The researchers from these four sites were joined by researchers from nine other sites to explore related research across the LTER Network during a second portion of the workshop. The third portion of the workshop involved technical training of CAP scientists and graduate students in object-oriented lawn mapping by student staffers of Clark University's Human-Environment Regional Observatory (HERO) Map lab. Further work on residential landscapes among CAP, BES, PIE, and FCE scientists has just been funded through a NSF social science supplement to the four sites. This new work will examine variations in landscape structure and management across four metropolitan areas and involve implementing research protocols developed at CAP and BES at all four sites.

Scientists from CAP hosted Sam Foster, the new station director of the US Forest Service Rocky Mountain Research Station (RMRS). One objective of this visit was to discuss future research collaboration between CAP and RMRS. The other objective was to lay a framework for a collaborative NSF ULTRA-EX proposal involving CAP, RMRS, Jornada (JRN), and Sevilleta (SEV).

Related to work on the ULTRA EX proposal, CAP scientists partnered with counterparts from JRN and SEV as well as researchers with RMRS to write a white paper conceptualizing a Southwest urban collaborative formed around the metropolitan areas of Phoenix, Albuquerque, and Las Cruces. This white paper established the background for ULTRA EX, and efforts during 2009-2010 will focus on turning this into a publishable manuscript. We view this effort as the first step in a process of expanding our research to regional and eventually larger scales, placing our understanding of urbanization effects in rapidly urbanizing arid regions in the context of gradients in urban growth rate, environmental conditions, climate, and other bio-geo-socio-physical parameters.

In addition, CAP LTER participants partner with a wide range of institutions on associated projects. For example, our research teams have substantial collaborations, through workshops and publications, with scientists at the Baltimore Ecosystem Study site, Coweeta, Shortgrasse Steppe, Kellogg, Konza Prairie, Jornada, Sevilleta, University of Michigan, The Nature Conservancy, Stanford University, University of Nevada-Las Vegas, UNAM Hermosillo, University of Arizona, University of Melbourne's Center for Urban Ecology, numerous academic and research institutions through Grimm's involvement in the LINX project, and several institutions in China.

From CAP LTER's inception, we have focused upon meaningful community outreach by establishing a series of community partnerships. Numerous individuals and organizations have permitted short- and long-term monitoring on their sites. Local municipalities, such as the *City of Scottsdale*, the *City of Tempe*, and the *City of Phoenix*, have been actively supporting CAP research on water quality. In all cases, the municipalities have granted CAP access to research sites and have engaged in data sharing for research. Discussions are underway with the *City of Scottsdale* to initiate a storm-water quality project in Indian Bend Wash, and the *City of*

Phoenix's Rio Salado Habitat Restoration project staff has approached CAP with the desire to collaborate on studies of vegetation and animals in the restoration area. CAP and the *U.S. Geological Survey* (USGS) have installed a water sampler in Indian Bend Wash cooperatively. The *USGS National Water-Quality Assessment* (NAWQA) program is also participating in our long-term water-monitoring project, collaborating on studies of water quality and storm sampling.

At the state agency level, numerous agencies have collaborated with CAP researchers or lent assistance with research endeavors. The *Arizona Department of Water Resources* has engaged in a data sharing arrangement with CAP, and the *Arizona Department of Environmental Quality* has assisted with atmospheric deposition studies. Public land access is critical for CAP research and the *Arizona State Land Department* has generously permitted access to its land for various projects. State entities are also involved in learning experiences for our students through internships and providing data and assistance with research projects. For example, the *Arizona Department of Game and Fish* has participated in the Research Experience for Undergraduates (REU) program.

Maricopa Association of Governments (MAG), consisting of the 24 incorporated cites and towns, two Indian communities, and Maricopa County, has been an integral partner, supporting the project by supplying GIS information and data and collaborating on investigations into growth planning, land-use projections, and open-space implementation. We have also worked with the *Flood Control District of Maricopa County* in projects involving storm hydrology and storm-water chemistry and are collaborating on research in the Gila River basin.

The *Salt River Project*, a semipublic organization responsible for water management and supplying electrical energy to the region, has a long-term research and outreach relationship with CAP LTER. They have facilitated the work of the land-use team, contributed substantively to the nitrogen mass balance study, and even provided a helicopter to reach several remote Survey 200 sample locations. The *Desert Botanical Garden* has allowed CAP researchers access to its site for experiments on tropic dynamics and nitrogen deposition as well as allowing researchers to erect a flux tower.

Dissemination of Research Results

Since the last annual report, CAP2 participants have produced 57 journal articles (17 published, 13 in press, 27 in review) and 19 book chapters and books (4 published, 12 in press, 3 in review). In addition, research results are routinely presented at meetings and conferences in a diverse array of fields. Media attention on CAP LTER in the past year included a special feature on CAP in the *ASU Insight* and a segment on the local PBS affiliate that focused on CAP scientist Hilairy Hartnett's work on carbon cycling in Arizona rivers, lakes, and urban aquatic systems.

CAP scientists have been involved in notable publications recently. As mentioned above, Nancy Grimm was a co-author on the *Global Climate Change Impacts in the United States* report. Former CAP graduate student Jason Walker collaborated with several CAP scientists on a paper to be published in *Frontiers in Ecology and the Environment* that examined plant diversity using **Survey 200** data. Data from the **PASS** were used by Sharon Harlan and colleagues to analyze attitudes around household water consumption, the results of which will be published in *Society and Natural Resources*.

CAP graduate students along with their colleagues in the School of Life Sciences convened the Dynamic Deserts conference in the spring. The interdisciplinary conference focused on resource uncertainty in arid ecosystems and brought together 60 students and scientists from academia and the public sector to consider this theme through presentations, working groups, and poster sessions over a three-day period. One unique feature of the conference was a special workshop on photography as an art form and means of scientific representation for communicating varying and conflicting views of arid environments. This initiative involved students in ASU photography professor Mark Klett's class and is linked to a pending, CAP-leveraged grant proposal to NSF's Informal Science Education program.

The CAP LTER website continued as a vehicle for communicating research results and data to scientists and the general public, and a new website design, which will be launched in fall 2009, will continue this work. CAP staff has summarized key research findings for the website's Research Highlights section and have been exploring new media, such as video and podcasts, for communicating CAP research.

Box 2: Selected Other Outreach Activities

- Tempe Historical Museum: >500 community members
- Arizona Science Center Global Awareness Day: >500 community members
- ASU Polytechnic Education Fair: .100 educators
- Valley Forward's Earthfest Educators Night: >100 educators
- Feathered Friends Festival: > 600 community members
- WeatherFest: >500 community members

Other Outreach

CAP LTER participates in other outreach activities during the year (Box 2). Many of these involved K-12 students and educators, although some were geared to the general public. Through these activities, CAP has reached over 1000 people. CAP will continue to find venues for reaching the public, particularly underserved populations, in the Phoenix metropolitan area.

VII. CONTRIBUTIONS

Contributions within Discipline

Overarching CAP LTER investigations are contributing baseline data and analysis upon which to build future work and projections for central Arizona. Specific areas where contributions have been made this past year include:

- Recent research on the **Urban heat island** has extended the spatial and temporal understanding of this phenomenon. The comparative study of towns and cities in the Sonoran and Mohave deserts is the first study of its kind to unravel the impact of urban warming from global warming. Researchers on this study, including a REU student, are preparing a manuscript on this work for submission to either *Urban Ecosystems* or *PNAS*.
- Behavioral research on black widow spiders addresses a number of cutting edge questions in the field of behavioral ecology and provides intriguing data on this urban pest species.
- The **Institutional drivers of growth in Phoenix** project uses a unique union of text and factor analysis to understand the policy dimensions of direct democracy. This analysis illustrates the shifting priorities of the public with regard to land management, which is useful for applied scientists interested in public lands policy in the US.

- The **Ethnohydrology** research contributes to a long history of research on ethno-ecological or local ecological knowledge. The novel contribution of this project is to expand this area of research to studies of (1) urban ecological knowledge and (2) water quality and sources. The latter, in particular, was identified as an important area of future research by members of the "Water, Water Everywhere" panel at the 2008 Meeting of the Society for Applied Anthropology. By linking perceptual data to information about the actual chemical content of drinking water in the Phoenix area (in Year 2 research), researchers will make ethno-ecological findings relevant to the research interests of hydrologists and civil engineers.
- Xeriscapes are landscape types becoming popular in the western United States as concerns over landscaping water usage grow. Little biogeochemical research has been conducted in xeriscaped yards. Research on **Nitrogen trace gas emissions in an urban patch** is increasing knowledge about the biogeochemical implications of this popular landscape type.
- The **lichen resurvey with heavy metal analysis** is contributing to a better understanding of the uses of lichens as biomonitors of air pollution. This research project has also furthered the application of mass spectrophotometry to questions of environmental contamination and air pollution patterns.
- CAP scientists have created one of the first datasets examining **black carbon** (or soot) in urban soils or in arid-land soils. Initial results suggest that the organic fraction of urban soils may have a substantially greater contributions from black carbon than soils from mesic or pristine environments. Isotopic composition results are particularly intriguing as the black carbon in Phoenix-area soils appears to be isotopically heavy compared to bulk organic carbon. This is in contrast to the small amount of published literature that suggests $\delta^{13}C_{BC}$ is more like C3 photosynthetic material.
- Research on **urban bird dynamics** uses a mechanistic approach to understanding avian communities within urban settings. Such an approach is rare in community ecology, and CAP scientists are at the forefront of debates on how to achieve a better balance between observational and mechanistic research in urban ecology (Shochat et al. 2006b)
- The **PASS** contributes to the fields of urban sociology, environmental sociology, urban ecology, and planning and design. PASS provides unique human data on environmental values, behaviors, and preferences that have consequences for the natural and built environments. The spatial identifiers of PASS sample households and neighborhoods are linked to other geo-referenced data sets that can be used to investigate the distribution of environmental amenities and disamenities among social groups.
- **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). To date, 12 papers have been prepared using these data, and researchers are conducting initial analyses.

Contributions to Other Disciplines

- CAP LTER is a multidisciplinary 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.

- Collaborations between statisticians and biological scientists have led to fruitful collaborations that use new techniques to analyze CAP data. A recent example of this was the analysis of **Survey 200** data, using hierarchical Bayesian modeling techniques. This endeavor was the first work of its kind to use such techniques and kriging strategies to study multivariate soil nutrient and carbon concentrations.
- **PASS** 2006 has successfully launched transdisciplinary collaborations across a number of important environmental issues in a rapidly urbanizing region. There is not a single dominant disciplinary perspective in PASS, but it is contributing to sociology, geography, economics, ecology, anthropology, and meteorology in unique and important ways. The longitudinal design of the survey is in keeping with tradition in the field of sociology, which values research on long-term trends in social attitudes and behaviors. The most highly-regarded social surveys have continued over a period of 40 or 50 years. PASS researchers are pioneering new methods of survey design in order to allow spatial analyses of people's attitudes and behavior in relation to fine scale environmental conditions in neighborhoods. Applications of advanced spatial statistics and GIS tools are planned for combinations of social and biophysical data. Social scientists are working with ecologists and other biophysical scientists in the relatively new field of urban ecology, which is leading to new insights about human-environmental interactions. Methods of linking economic models of consumer choice to models of biophysical processes are being developed.
- Findings from the **NDV Experiment** have applications in fields such as architecture and landscape planning. Researchers are working toward an improved understanding of the effect of different landscaping types on power and water usage - both from the biophysical effects of the landscapes themselves, and on the behavior of residents within different experimental landscapes. For example, will people living in xeric (low water use, desert-like) treatments become more aware of water conservation issues and lower their in-home water use? Subsequent data analysis will focus on how social variables we are studying affect behavior, which ultimately affects biophysical landscape processes.
- Work on residential lawns contributes to integrated social-ecological approaches through development of multidisciplinary conceptual framework and mixed methods involving coupled social-field surveys (most of past research is social or ecological in orientation) . Whereas many past studies have focused on experimental plots (e.g., in lawn/turfgrass research) as well as broader regional-scale land use/cover change analyses, this research is an integrated field-based study of residential landscapes at the parcel scale. Furthermore, the study of residential lawns includes multidimensional analyses of different types of values (general life values, ecological orientations, and landscape-specific priorities) in relation to multiple human ecological behaviors in residential landscapes (land cover/structure and associated management practices), whereas many studies have narrowly examined singular or relatively few values and behaviors.
- Work on **modeling land use change and ecosystem responses** and landscape ecology in general has made noticeable contributions to these fields in the US and around the world. For example, the landscape gradient approach to urban pattern analysis has been applied

in several studies in China and Europe. Work on urban modeling and land use analysis contributed significantly to the special issue of the journal, *Urban Ecosystems* (Musacchio and Wu 2004) and a book on scaling and uncertainty analysis in ecology (Wu et al. 2006). The Hierarchical Patch Dynamics framework has been used for urban ecology and landscape analysis in several other countries (including, China, Canada, Australia, and Europe).

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 multi-disciplinary courses taught in the IGERT in Urban Ecology program are good examples of integrative science in action. In fall 2008, for instance, CAP scientists Sharon Hall and Kelli Larson convened an IGERT workshop course on residential landscapes, which was centered on an ongoing CAP research initiative.
- A spring 2009 course, "From yardstick to gyroscope: Interdisciplinary methods for the long-term study of social-ecological systems," involved students from four universities (ASU, University of Georgia, Florida International University, and University of Vermont) in learning about socioecological research in the LTER Network.
- CAP research provides a learning laboratory for undergraduate and graduate students at ASU. For example, CAP scientist Hilairy Hartnett's research on dissolved organic carbon in Tempe Town Lake, is a unique "backyard" research project for her laboratory and classroom students. CAP scientist John Sabo has used project resources to teach undergraduate students in his ecology course about controls of food chain lengths in urban desert environments through experimentation with brittlebush (*Encelia farinose*) at CAP's experimental space in the Desert Botanical Gardens.
- 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.
- Collaborations such as **Ecology Explorers** and **Service at Salado** share project results with underserved community schools to enrich programming and encourage future educational pursuits in the sciences.

Contributions to Human Resource Development

The CAP LTER provides a powerful framework for training graduate students, nourishing cross disciplinary projects, and contributing to the new and growing field of urban ecology. Our project is also committed to engaging pre-college and undergraduate students, and K-12 teachers, community organizations, governmental agencies, industry, and the general public in our multilayered investigation.

- Since the inception of CAP LTER, close to 30 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports four post-doctoral associates, three full-time on CAP LTER and one shared with DCDC. The individuals interact, participate in planning meetings with the co-project directors and project managers, work with faculty members and team leaders, collaborate with graduate students, and organize and coordinate the annual poster symposium and summer summit. They are integral to the research and field experience of CAP LTER and receive training in interdisciplinary collaboration, graduate-student supervision, data collection and analysis, and presentation techniques.
- Five graduate students a semester and during the summer months are involved in CAP LTER, each immersed in the research at hand and working together as a cohort for the project at large. They are drawn from a wide range of university programs, departments, and schools, representing disciplines such as anthropology, biology, curriculum and instruction, engineering, economics, geography, geological sciences, planning and landscape architecture, plant biology, and sociology. Graduate students serve as research associates and are trained in field-investigation techniques, data analysis, scientific writing, oral presentation, interdisciplinary interaction, GIS, and remote sensing.
- In 2004 CAP established a competitive summer graduate student grant program under which a total of 32 grants have been awarded. The awardees present their research finding at a CAP All Scientists Meeting in the fall and often present additional results at the annual poster symposium.
- Faculty members in geography, 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 since 2004. 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 66 papers have been co-authored by students (including works in press and review) and on 46 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 19 summer and academic year REU students, funded under NSF Supplements or directly from CAP funds, who gained research training via summer projects integral to CAP LTER. Many other REUs 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 new 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. Project research has also been incorporated into undergraduate honors and senior theses.
- Outside of the CAP-funded REU experience, CAP scientists are involving undergraduates in their research. One excellent example of this is Chad Johnson, who has involved numerous undergraduates into his research on black widow spider behavior. Presently, his students are first authors on five academic papers in review and in preparation.
- Monthly All Scientists Meetings (ASMs) provide opportunities for cross-disciplinary interaction and information exchange through science- and results-based presentations. Attendance ranges from 40 to 80 people per meeting and includes faculty members, postdoctoral associates, graduate students, and community partners. Smaller groups of CAP researchers assemble for various projects. Remote Sensing Working Group meetings have been held to foster collaborations among CAP LTER scientists doing research involving remote sensing via discussion of ongoing and planned work, proposal generation, image acquisition, and workshops. Other working groups, such as atmospheric deposition, human feedbacks, soils, and modeling, meet as needed.
- The Schoolyard LTER supplement has created special opportunities for K-12 teachers to work alongside LTER researchers in summer internships on several monitoring projects. CAP graduate students and postdoctoral associates have mentored high-school students through a laboratory internship program coordinated by the Southwest Center for Education and the Natural Environment, a collaborative program with the Global Institute of Sustainability. CAP participants serve as judges each year in the Central Arizona Science and Engineering Fair and the American Indian Science and Engineering Fair.

Contributions Beyond Science and Engineering

By taking a long-term view of complex issues that defy simple explanation, not simply the circumstances we find ourselves in today, CAP LTER and its community partners are striving to comprehend the social, economic, and biological forces that drive the processes shaping our region. CAP LTER activities and research potentially provide information for planning urban growth, especially in sensitive ecosystems. Many results from CAP LTER projects have public policy implications, and working through other projects within GIOS, such as the Decision Center for a Desert City (DCDC), and our partners, we are able to convey these results to decision makers.

- Droughts and water shortages, combined with explosive growth of urban and suburban areas, have created a situation that is being viewed with increasing concern across the western United States. We believe that the publication and communication of our research results will enhance policy-makers' ability to address water-related environmental problems in the Southwest. CAP scientists active with DCDC have been working to communicate these results. In addition, CAP will continue to be active in initiatives forwarded by GIOS and the Sustainable Cities Network, such as those involving water managers in Arizona, which gives the project access to important stakeholder groups.
- Divergence in mental models between the public and decision makers can be problematic and lead to controversy over risk management priorities. Such divergences can also represent areas where dialogue between experts and lay groups could be fruitful. Research on **ethnohydrology** points to areas where public education and outreach can play a role in educating those concerned about their water quality to: i) reduce unnecessary concern for quality and safety surrounding tap water, and ii) cultivate consensus about how communities can communicate with authorities regarding improvements to local municipal water. To facilitate such dialogue, CAP scientist and water resources engineer, Paul Westerhoff, has begun to discuss and share research findings with Phoenix water planners on an informal basis.
- The **PASS** is a vehicle for increasing knowledge of how residents shape and respond to the local environment, which is a necessary step in devising a more sustainable city. Communities, social lives, values, and behaviors must be understood in order to comprehend the place of humans in the environment. This is vitally important in rapidly urbanizing regions, such as Phoenix. Arid cities face unique environmental challenges that accompany population growth, including extreme heat, limited water resources and shade, and harsh conditions for species survival. Many scientists and policy makers believe that these challenges can be overcome only creating strong, engaged communities that understand and appreciate their biophysical environments.
- Research on the **urban heat island**, including work on populations vulnerable to excessive heat, been shared with policymakers and practitioners through the City of Phoenix Urban Heat Island Task Force. This budding partnership between practitioners and scientists will enhance efforts toward ameliorating the heat island as well as possibly influence new research directions within CAP LTER.
- Avian research under CAP LTER has fostered important links between academic research and the wider community when "citizen scientists" become involved in research. For example, research on **foraging decisions and bird community structure** involved individuals from 21 families in research, including 11 students, whose work was integrated into the curriculum at a Phoenix high school. Other work on urban raptors engaged community members and utility company employees in reporting raptor sightings.
- The social science component of **WaterSim**, a joint research venture with DCDC, engages policymakers directly in a dialogue about possible water resource futures in the Phoenix metropolitan area.
- **NDV** research seeks to discover whether people's landscape preferences can be changed, or if they evolve over time. Do people prefer mesic to more water-saving designs simply

because they are unfamiliar with xeric and native designs? Understanding the mechanisms behind landscape preferences is important for urban planning as municipalities seek to promote water-saving landscapes. As well, new research on ecosystem services will explore tradeoffs principally between water and energy in landscapes. Researchers anticipate that this will allow them to determine if any landscape is optimal for water and energy conservation.

- Research on **nitrogen deposition** will provide policymakers with information on how to reduce nitrogen loads in urban runoff and surface waters, thus reducing public expenditures on stream restoration.
- CAP scientists' work on residential landscaping has the potential to reach many nontraditional audiences through "backyard ecology" outreach efforts. Recent media attention on the **North Desert Village** experiment indicates that media outlets are eager to report on such findings.
- **Survey 200** data provide regional planners and public policy makers a unique information source for how explosive urban and suburban growth is changing the ecological resources of the CAP region. As data analysis and modeling efforts continue to be refined, they will provide the facility to predict how future urban growth will affect the ecological infrastructure in the region.
- Research on **environmental risk and justice** is shifting from a focus on analyzing the distribution of disamenities and amenities in relation to population groups to a combined analysis of these patterns and the processes that create them as well as equity in public decision making. There has been an increased emphasis on vulnerability analysis in environmental justice work in order to mitigate future environmental inequities. This provides considerable scope for engaging policymakers in research.

VIII. PUBLICATIONS 2007-2008

Journal Articles

In Press

Chen, X., and J. Wu. In press. Sustainable landscape architecture: Implications of the Chinese philosophy of "unity of man with nature" and beyond. *Landscape Ecology* 24, DOI 10.1007/s10980-009-9350-z (online first 2009).

Cutts, B., K. Darby, C. Boone and A. Brewis. In press. City structure, obesity, and environmental justice: An integrated analysis of physical and social barriers to walkable streets and park access. *Social Science and Medicine.*

Harlan, S. L., S. Yabiku, L. Larsen, and A. Brazel. In press. Household water consumption in an arid city: Affluence, affordance, and attitudes. *Society and Natural Resources.*

Larson, K, D. Casagrande, S. Harlan, and S. Yabiku. In press. Residents' yard choices and rationales in a desert city: Social priorities, ecological impacts, and decision tradeoffs. *Environmental Management.* Accepted pending minor revisions.

Larson, K. L., A. Gustafson,, and P. Hirt. In press. Insatiable thirst and a finite supply: Assessing municipal water conservation policy in greater Phoenix, Arizona, 1980-2007. *Journal of Policy History.*

Larson, K. L., D. White, P. Gober, S. Harlan and A. Wutich. In press. Divergent perspectives on water resource sustainability in a public-policy-science context. *Environmental Science and Policy*.

Majumdar, A., C. Gries, and J. Walker. In press. A non-stationary spatial generalized linear mixed model approach for studying plant diversity. *International Journal of Statistics and Systems*.

Marussich, W. A., and S. H. Faeth. In press. Effects of urbanization on trophic dynamics of arthropod communities on a common desert host plant. *Urban Ecosystems*. DOI 10.1007/s11252-009-0086-y. Online first, 2009.

Singer, C. K., and C. A. Martin. In press. Effect of landscape mulches and drip irrigation on transplant establishment and growth of three North American desert native plants. *Journal of Environmental Horticulture* (2009).

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White, D., A. Wutich, T. Lant, K. Larson, P. Gober, and C. Senneville. In press. Credibility, saliency, and legitimacy of boundary objects for environmental policy and decision making: Stakeholders' reaction to DCDC WaterSim. *Science and Public Policy*.

White, J. and Stromberg, J. In press. Resilience, restoration and riparian ecosystems: Case study of a dryland urban river. *Restoration Ecology*.

Wu, J., G. D. Jenerette, A. Buyantuyev, and C. L. Redman. In press. Quantifying spatiotemporal patterns of urbanization: The case of the two fastest growing metropolitan regions in the United States. *Ecological Modelling* (accepted 2009)

Wutich, A., T. Lant, D. White, K. L. Larson, and M. Gartin. In press. Comparing focus group and individual responses on sensitive topics: A study of water decision makers in a desert city. *Field Methods*.

In Review

Aguilar, R., J. Pan, C. Gries, I. San Gil, and G. Palanisamy. In review. A flexible online metadata editing and management system. *Ecological Informatics.*

Bang, C., and S. H. Faeth. In review. Variation in diversity, trophic structure and abundance in response to urbanization: a decade of arthropod monitoring. *Conservation Biology.*

Davies, R., and S. J. Hall. In review. Direct and indirect effects of urbanization on soil and plant nutrients in desert ecosystems of the Phoenix metropolitan area, AZ. *Urban Ecosystems.*

Fokidis, H. B., and P. Deviche. In review. Sources of variation in the hypothalamo-pituitary-adrenal axis activity of city and desert Curve-billed Thrashers *Toxostoma curvirostre*. *Journal of Experimental Biology*.

Gober, P., C. Redman, T. Lant, and A. Wutich. In review. WaterSim: Integrated modeling, decision support and boundary science. *Population and Environment.*

Johnson J. C., P. Trubl, and V. Blackmore. In review. Male mate choice in black widows: Chemical and physical cues allow males to avoid sexual cannibalism by poor-condition females. *Proceedings of the Royal Society*.

Kaye, J. P., S. E. Eckert, D. A. Gonzales, J. O. Allen, S. J. Hall, R. A. Sponseller, and N. B. Grimm. In review. Can atmospheric carbon deposition stimulate microbial respiration in desert soils? *Journal of Geophysical Research, Biogeosciences*.

Kitchen, K., M. C. B. Andrade, and J. C. Johnson. In review. Age differences, family origin and maternal investment explain juvenile cannibalism in the black widow spider better than kin selection. *Animal Behaviour.*

Larson, K.L**.,** D. Ibes, and D. White. Gendered perspectives on water scarcity and resource governance: a tripartite conceptual approach. *Environment and Behavior*.

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In Review

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APPENDIX A 2008-2009 CAP LTER PARTICIPANTS	
	Duration of Involvement
Principal Investigator	
Nancy Grimm, Life Sciences	1997-present
Co-Director	
Charles Redman, Sustainability	1997-present
Co-Principal Investigators	
Rimjhim Aggarwal, Sustainability	2009-present
John Anderies, Sustainability; Human Evolution and Social Change	2004-present
Ramon Arrowsmith, Earth and Space Exploration	1997-present
George Basile, Sustainability	2009-present
Bob Bolin, Human Evolution and Social Change	1999-present
Christopher Boone, Sustainability; Human Evolution and Social Change	2009-present
Anthony Brazel, Geographical Sciences and Urban Planning	1997-present
John Briggs, Life Sciences	1999-2008
Daniel Childers, Sustainability	2009-present
Pierre Deviche, Life Sciences	2009-present
Stevan Earl, Sustainability	2009-present
Monica Elser, Sustainability	1998-present
Stanley Faeth, Life Sciences	1997-2008
Matthew Fraser, Sustainability	2009-present
Corinna Gries, Sustainability	2000-present
Susanne Grossman-Clarke, Sustainability	2004-present
Sharon Hall, Life Sciences	2005-present
Sharon Harlan, Human Evolution and Social Change	1999-present
Hilairy Hartnett, Earth and Space Exploration; Chemistry & Biochem.	2009-present
Diane Hope, Sustainability	1997-2006
J. Chadwich Johnson, Mathematics and Natural Sciences	2009-present
Jason Kaye, Life Sciences	2002-2005
Ann Kinzig, Life Sciences	1999-present
Lauren Kuby, Sustainability	1998-2009
Kelli Larson, Sustainability; Geographical Sciences and Urban Planning	2005-present
Ananda Majumdar, Mathematics and Statistical Sciences	2009-present
Chris Martin, Applied Sciences and Mathematics	1997-present

Peter McCartney, Sustainability	1997-2006
Soe Myint, Geographical Sciences and Urban Planning	2009-present
Thomas Nash, Life Sciences	1997-present
Marcia Nation, Sustainability	2009-present
Jordan Peccia, Engineering	1997-2005
John Sabo, Life Sciences	2009-present
Brenda Shears, Sustainability	1997-2009
Everett Shock, Earth and Space Exploration; Chemistry & Biochem.	2009-present
Kerry Smith, Business	2009-present
Jean Stutz, Applied Sciences and Mathematics	1998-present
Billie Turner, Geographical Sciences and Urban Planning	2009-present
Arnim Weik, Sustainability	2009-present
Elizabeth Wentz, Geographical Sciences and Urban Planning	2004-2009
Paul Westerhoff, Engineering	2004-present
Amber Wutich, Human Evolution and Social Change	2009-present
Jianguo Wu, Life Sciences	1997-present
Scott Yabiku, School of Social and Family Dynamics	2009-present
Abigail York, Human Evolution and Social Change	2009-present
Senior Personnel: Managers	
Stevan Earl, Site Manager	2006-present
Monica Elser, Education Manager	1998-present
Corinna Gries, Information Manager	2000-present
Diane Hope, Field Project Manager	1997-2006
Lauren Kuby, Communications Manager	1997-present
Peter McCartney, Information Manager	1997-2006
Marcia Nation, Project Manager	2006-present
Brenda Shears, Assistant Dir., GIOS	1997-present
Linda Williams, Finance Manager	1997-present
Senior Personnel: Scientists	
Braden R. Allenby, Engineering	2004-present
Ariel D. Anbar, Earth and Space Exploration	2004-present
James R. Anderson, Engineering	2001-present
Lawrence A. Baker, Water Resources Center, U of Minn.	1997-present
Heather Bateman, Applied Sciences and Mathematics	2009-present
Alexandra Brewis, Human Evolution and Social Change	2007-present
Megha Budruk, Community Resources	2006-present
David Casagrande, Sociology and Anthropology, W. Ill. U.	2003-present
Phillip Christensen, Mars Space Flight Facility	1997-present

Elizabeth A. Corley, Public Affairs	2004-present
James Collins, Life Sciences	2004-2005
William Cook, Biological Sciences, St. Cloud State U.	2004-present
John C. Crittenden, Engineering	2004-present
James J. Elser, Life Sciences	1997-present
Ananias A. Escalante, Life Sciences	2005-present
Stanley Faeth, Biology, U. of North Carolina, Greensboro	1997-present
Joseph Feller, Law	2004-present
H.J.S. Fernando, Engineering	1997-present
Jonathan Fink, Sustainability	2004-present
Stuart Fisher, Life Sciences	1997-present
Janet Franklin, Geographical Sciences and Urban Planning; Life Sciences	2009-present
Patricia Gober, Geographical Sciences and Urban Planning	1997-present
Subhrajit Guhathakurta, Geographical Sciences and Urban Planning	2004-present
Edward J. Hackett, Human Evolution and Social Change	1997-2006
Nora M. Haenn, Human Evolution and Social Change	2004-present
Randel Hanson, Justice & Social Inquiry	2004-present
Pamela Hunter, Institute for Social Science Research	2005-2006
Jana Hutchins, Institute for Social Science Research	1997-present
Marcus A. Janssen, Human Evolution and Social Change	2005-present
James Johnson, Integrated Natl. Sciences	2006-present
Paul C. Johnson, Engineering	1997-present
Eric Keys, Geographical Sciences	2004-2006
Andrew Kirby, Social/Behavioral Science	1997-present
Jeffrey M. Klopatek, Life Sciences	1997-present
Jennie J. Kronenfeld, Social and Family Dynamics	2004-present
Michael Kuby, Geographical Sciences and Urban Planning	2004-present
Leslie Landrum, Life Sciences	1998-present
Tim Lant, Decision Theater	2008-present
Kathleen Lohse, Natural Resources, U of Arizona	2005-present
Nancy E. McIntyre, Bio. Sciences, Texas Tech	1997-present
Melissa McHale, Biology, North Carolina State	2008-present
Geoffrey Morse, Integrated Natl. Science	2006-present
Laura R. Musacchio, Landscape Arch., U of Minn.	1999-present
Margaret C. Nelson, Human Evolution and Social Change	1998-present
David L. Pearson, Life Sciences	1997-present
K. David Pijawka, Geographical Sciences and Urban Planning	1997-present
Mark Schmeeckle, Geographical Sciences and Urban Planning	2008-present
Milton Sommerfeld, Life Sciences	1997-present
Katherine Spielmann, Sustainability; Human Evolution & Social Change	2009-present

Ryan Sponseller, Biological Sciences, U of Alabama	2006-present
Juliet C. Stromberg, Life Sciences	1997-present
Emily Talen, Geographical Sciences and Urban Planning	2009-present
Sander van der Leeuw, Human Evolution and Social Change	2004-present
Paige S. Warren, Natl. Res. Con., U of Mass-Amherst	2004-present
David White, Community Resources	2005-present
Joseph A. Zehnder, Geographical Sciences	2004-2007
Post-Doctoral Research Fellows	
David Casagrande, Global Institute of Sustainability	2004-2005
William Cook, Global Institute of Sustainability	2004-2005
David Lewis, Global Institute of Sustainability	2004-2005
Jose Lobo, Global Institute of Sustainability	2005-2007
Kathleen Lohse, Global Institute of Sustainability	2005-2006
Louis Machabee, Global Institute of Sustainability	2002-2005
Melissa McHale, Global Institute of Sustainability	2007-present
Maik Netzband, Global Institute of Sustainability	2004-2005
Darren Ruddell, Global Institute of Sustainability	2009-present
Eyal Shochat, Global Institute of Sustainability	2006-present
Milan Shrestha, Global Institute of Sustainability	2009-present
Chona Sister, Global Institute of Sustainability	2007-present
Ryan Sponseller, School of Life Sciences	2006-2007
Laura Turnbull, Global Institute of Sustainability	2009-present
Amber Wutich, Global Institute of Sustainability	2006-2007
Lin Ye, Global Institute of Sustainability	2009-present
Chi Zhang, Global Institute of Sustainability	2009-present
Research Technical Personnel	
M. Amy DiIorio, Research technician, CAP LTER	2001-2005
Laura E. Dugan, Research technician, CAP LTER	2005-2006
Roy E. Erickson, Research specialist, CAP LTER	2000-present
Martin J. Feldner, Research technician, CAP LTER	2005
Steven W. Higgins, Research lab aide, CAP LTER	2004
Michael Holland, Research technician, CAP LTER	2008-present
Jill E. Jones, Research lab aide, CAP LTER	2004-2005
Roy M. Jones, Research lab aide, CAP LTER	2004-2005
Hooi Hong Khor, Institute for Social Science Research	2006
Cathy D. Kochert, CAP LTER lab manager	1999-present
Karen Lafrance, Research lab aide, CAP LTER	2006-present
Erin Manton, Research technician, CAP LTER	2008-present

Emily Morris, Research technician, CAP LTER	2008-present
Shalini Prasad, Graphic designer, Global Institute of Sustainability	2005
Phil Puleo, Institute for Social Science Research	2006
Suzanne D. Rester, Research lab aide, CAP LTER	2005-2006
Laura Riley, Research lab aide, CAP LTER	2006-2008
Janaina Scannel, Institute for Social Science Research	2006
James Smith, Research lab aide, CAP LTER	2008
Quincy Stewart, Research technician, CAP LTER	2005-present
Valerie Steen, Research technician, CAP LTER	2005-2006
Diana Stuart, Research technician, CAP LTER	2000-2005
Maggie S. Tseng, Research technician, CAP LTER	1997-present
Katrina Wells, Institute for Social Science Research	2006
Sean A. Whitcomb, Research technician, CAP LTER	2005
Kymberly C. Wilson, Research technician, CAP LTER	2006-2007
Informatics Lab	
Raul Aquilar, Global Institute of Sustainability	2006-present
Ed Gilbert, Global Institute of Sustainability	2002-present
Corinna Gries, Global Institute of Sustainability	2000-present
Peter McCartney, Global Institute of Sustainability	1997-2006
Wayne Porter, Global Institute of Sustainability	2000-2009
Cindy Zisner, Global Institute of Sustainability	1997-present
Public Outreach/Education Personnel	
Monica Elser, Global Institute of Sustainability	1998-present
Lauren Kuby, Global Institute of Sustainability	1998-present
Kathryn Kyle, Global Institute of Sustainability	1997-present
Maggie McGraw, Global Institute of Sustainability	2007-present
Tina Salata, Global Institute of Sustainability	2006-2008
Charlene Saltz, Global Institute of Sustainability	2000-2006
Research Support Personnel	
Sara Eeds, Global Institute of Sustainability	2008-present
Tamlin Engle, Global Institute of Sustainability	2005-2009
J. Nikol Grant, Global Institute of Sustainability	2001-present
Karen Gronberg, Global Institute of Sustainability	2005-present
Elizabeth Marquez, Global Institute of Sustainability	2005-present
Helen Palmaira, Global Institute of Sustainability	2006-2008
James Quinn, Global Institute of Sustainability	2007-2008
Barry Redmond, Global Institute of Sustainability	2008-present

Shirley Stapleton, Global Institute of Sustainability	1997-2005
Kathleen Stinchfield, Global Institute of Sustainability	1997-2007
Megan Wilkins, Global Institute of Sustainability	2007-2008
Linda Williams, Global Institute of Sustainability	1997-present
Cindy Zisner, Global Institute of Sustainability	1997-present
Graduate Research Associates	
Jeffrey Ackley, Life Sciences/IGERT	2009-present
Carol Atkinson-Palumbo, Geographical Sciences/IGERT	2004-2007
Stacy Avent, Human Evolution and Social Change	2007-2008
Marea Baggetta, Life Sciences/IGERT	2004-2005
Christofer Bang, Life Sciences	2006-present
Melanie Banville, Applied Sciences and Mathematics	2009-present
Troy Benn, Engineering/IGERT	2006-present
Wendy Bigler, Geographical Sciences	2004-2007
Robert Bills, Life Sciences	2004-2006
Jessica Block, Earth and Space Exploration	2005-2006
Ed Burgess, Sustainability/IGERT	2009-present
Kendra Busse, Life Sciences	2006-present
Alexander Buyantuyev, Life Sciences	2002-2008
Yolanda Chavez-Cappellini, Languages and Literatures	2006
Chichi Choi, Engineering	2007-2009
James Clancy, Geographical Sciences/IGERT	2004-present
Robin Cleland, Human Evolution and Social Change/IGERT	2008-present
Winston Chow, Geographical Sciences	2007-present
Tim Collins, Geographical Sciences/IGERT	2000-2006
Shannon Conley, Public Policy	2008-present
Elizabeth Cook, Life Sciences/IGERT	2007-present
Bethany Cutts, Life Sciences	2006-present
Kate Darby, Human Evolution and Social Change/IGERT	2006-present
Rachel Davies, Life Sciences	2006-2008
Scott Davies, Life Sciences	2009-present
Juan H. Declet, Geographical Sciences	2006
Xiaoli Dong, Sustainability	2009-present
Christopher Eisinger, Earth and Space Exploration/IGERT	2003-2005
Michelle Elliott, Human Evolution and Social Change/IGERT	2001-2004
Vanessa Escobar, Earth and Space Exploration	2006
Elizabeth Farley-Metzger, Human Evolution and Social Change	2004-2007
Haralambos Fokidis, Life Sciences	2007-present
Jessica Fox, Sustainability	2009-present

Sheila Fram, Institute for Social Science Research	2006
Erin Frisk, Sustainability	2008-present
Kristin Gade, Life Sciences/IGERT	2004-present
Daniel Gerrity, Engineering/IGERT	2004-2006
Ted Gilliland, Sustainability/IGERT	2009-present
Daniel Gonzales, Engineering	2005-2007
Praveen Gorthy, Computer Science	2009-present
Sara Grineski, Human Evolution and Social Change/IGERT	2001-2006
Arijit Guhu, Sustainability/IGERT	2009-present
Anne Gustafson, History/IGERT	2005-2008
Rebecca Hale, Life Sciences	2007-present
George Alexander Hamilton, Chemistry and Biochemistry	2008-present
Tamara Harms, Life Sciences	2004-2007
Donna Hartz, Geographical Sciences/IGERT	2005-present
Brent Hedquist, Geographical Sciences/IGERT	2005-present
Allison C. Huang, Student worker	2004-2006
Scott Ingram, Human Evolution and Social Change/IGERT	2003-present
Darrel Jenerette, Life Sciences	2000-2004
Ben Jewell, Human Evolution and Social Change/IGERT	2009-present
Shai Kaplan, Geographical Sciences and Urban Planning	2009-present
Alethea Kimmel-Guy, Geographical Sciences	2006-2008
Elisabeth Larson, Life Sciences/IGERT	2004-present
Susannah Lerman, Natural Resources Conservation, U Mass	2006-present
Jen Litteral, Life Sciences	2007-present
Matthew Lord, Geographical Sciences/IGERT	2001-2006
Tracy Lund, Earth and Space Exploration	2007-present
Yevgeniy Marusenko, Life Sciences	2007-present
Wendy Marussich, Life Sciences	2000-2004
Brandon McLean, Earth and Space Exploration	2005-2007
Cathryn Meegan, Human Evolution and Social Change/IGERT	2003-present
James Miller, Geographical Sciences/IGERT	2003-2007
Thad Miller, Sustainability/IGERT	2006-present
Chad Monfreda, Life Sciences/IGERT	2008-present
Tisha Munoz, Sustainability/IGERT	2006-present
David Murillo, Mathematics and Statistics/IGERT	2007-present
Kaesha Neil, Life Sciences	2006-2008
Scott Norby-Cedillo, Sustainability/IGERT	2007-present
Aura Ontiveros, Applied Biological Sciences	2007-present
Yun Ouyang, Life Sciences	2008-present
Katelyn Paraday, Human Evolution and Social Change/IGERT	2009-present

John Parker, Human Evolution and Social Change/IGERT	2001-2006
W. John Roach, Life Sciences/IGERT	1999-2006
Darren M. Ruddell, Geographical Sciences	2006-2009
Avraj Sandhu, Computer Science	2006
Nilavan Sarveswaran, Engineering	2006
Hoski Schaafsma, Life Sciences/IGERT	2003-present
Shade Shutters, Life Sciences/IGERT	2003-present
Catherine Singer, Life Sciences	2005-2007
Arthur Stiles, Life Sciences	2002-2006
Colleen Strawhacker, Human Evolution and Social Change/IGERT	2006-present
Steve Swanson, Human Evolution and Social Change/IGERT	2001-present
Ken Sweat, Life Sciences	2006-present
Philip Tarrant, Geographical Sciences	2005-2006
Carissa Taylor, Sustainability	2009-present
Laura Taylor-Taft, Life Sciences	2006-2009
Nathan Toke, Engineering/IGERT	2006-present
Roger Tomalty, Geographical Sciences	2004-present
Jolene Trujillo, Life Sciences	2007-present
Eli Tural, Geographical Sciences and Urban Planning	2009-present
Kelly Turner, Geographical Sciences/IGERT	2007-present
Deva Visamsetty, Computer Science and Engineering	2007-2008
Jason Walker, Life Sciences/IGERT	2005-2008
Christina Wong, Life Sciences	2008-present
Jacqueline White, Life Sciences	2004-2006
Peng Zhang, Engineering	2006-2007
Sainan Zhang, Sustainability	2009-present
Xiaoding Zhuo, Chemistry and Biochemistry	2005-present
Undergraduate Student Workers	
Melinda Alexander, Institute for Social Science Research	2006
Cristian Aquino-Sterling, Institute for Social Science Research	2006
Rosario Armenta, Institute for Social Science Research	2006
Humberto Badillo, Global Institute of Sustainability	2007
Mandana M. Behbahani, Life Sciences lab	2006
Kallista Bernal, Institute for Social Science Research	2006
Karyn Boenker, Global Institute of Sustainability	2008
David Borough, Institute for Social Science Research	2006
Julianna Bozler, Service at Salado	2007-2008
Molly Brennan, Institute for Social Science Research	2006
Hillary Butler, Service at Salado	2006

Matthew Cavazos, Institute for Social Science Research	2006
Christina Cole, Institute for Social Science Research	2006
Marc Contijoch, Institute for Social Science Research	2006
Jordan Costello, Service at Salado	2007
Kimberly Cronin, Institute for Social Science Research	2006
Arturo Diaz Hernandez, Institute for Social Science Research	2006
Karla Dille, Institute for Social Science Research	2006
Bradley Durham, Institute for Social Science Research	2006
Courtney Edel, Life Sciences lab	2007-2008
Wilford Eiteman-Pang, Service at Salado	2007
Alexandra Flournoy, Service at Salado	2007
Cassandra Fronzo, Institute for Social Science Research	2006
Justin E. Goering, Global Institute of Sustainability	2004-2005
Jonathan Gonzalez, Institute for Social Science Research	2006
Jocelyn Hackett, Institute for Social Science Research	2006
Travis Hitchner, Life Sciences lab	2008-present
Amy M. Hodge, Global Institute of Sustainability	2004-2005
Daniel Hoyt, Service at Salado	2007
Dillan Isaac, Institute for Social Science Research	2006
Christopher Jarzabek, Service at Salado	2007
Ruth Jensen, Institute for Social Science Research	2006
Marsha Johnson, Service at Salado	2007
Kevin King, Institute for Social Science Research	2006
Crissy Knight, Service at Salado	2007
Mark Leeper, Institute for Social Science Research	2006
Mildred Levine, Institute for Social Science Research	2006
Danielle Lindsey, Institute for Social Science Research	2006
Kathryn Mayer, Global Institute of Sustainability	2008
Nazune Menka, Service at Salado	2006
Erin M. Mills, Global Institute of Sustainability	2002-2007
Lindsey Miller, Institute for Social Science Research	2006
Clifford Millett, Service at Salado	2006
Kathleen M. Mills, Global Institute of Sustainability	2004-2005
Hanna Milosevic, Service at Salado	2007
Rebecca Minghelli, Service at Salado	2007
Jennifer Monninger, Institute for Social Science Research	2006
Sandra L. Muldrew, Global Institute of Sustainability	2004-2005
Keith Mulvin, Service at Salado	2007
Casey Oakes, Service at Salado	2006
Sean O'Reilly, Service at Salado	2007

Viswesh Parameswanan, Global Institute of Sustainability	2006
Jason Parker, Service at Salado	2007
Chiranjeevi Pavurala, Global Institute of Sustainability	2006-2007
Erika Paulus, Service at Salado	2007
Danielle L. Prybylek, Global Institute of Sustainability	2004-2006
James Quinn, Institute for Social Science Research	2006
Roxanne C. Rios, Global Institute of Sustainability	2004-2005
Jennifer C. Roberts, Global Institute of Sustainability	2004-2006
Juan Rodriguez Martin, Institute for Social Science Research	2006
Heather K. Rothband, Global Institute of Sustainability	2006
Sean Russell, Institute for Social Science Research	2006
Matthew Salem, Global Institute of Sustainability	2008
Janaina Scannell, Institute for Social Science Research	2006
Sharon Schleigh, Service at Salado	2006
Rosie Servis, Global Institute of Sustainability	2005-2008
Nafis Shamsid-Deen, Service at Salado	2007
Krystin Sheekey, Institute for Social Science Research	2006
Alex Silva, Service at Salado	2007
Sone P. Sithonnorath, Life Sciences lab	2005
Myra Snodgrass, Service at Salado	2007
Rebecca Sommer, Service at Salado	2007
Cynthia Soria, Service at Salado	2006
Emily Starr, Service at Salado	2007
Grayson Steinberg, Institute for Social Science Research	2006
Carena Van Riper, Service at Salado	2007
Francisco Vargas, Institute for Social Science Research	2006
Julianne Vittal, Global Institute of Sustainability	2008
Benjamin Wachter, Service at Salado	2007
Randy Wagman, Institute for Social Science Research	2006
Stephanie Williams, Institute for Social Science Research	2006
Research Experience for Undergraduates (REUs)	
Erin Adley, Life Sciences	2004
Bony Ahmed, Life Sciences,	2006-2007
Garth Baughman, Economics	2008
Nicole Broughton, Biology, Chicago State University	2008
Tejkaran Dhillon, Biology and Society	2008
Michelle Ashley Gohr, Life Sciences	2007-2008
Megan Kelly, Chemistry	2006-2007
Genevieve Luikart, Environmental Studies, New College of FL	2007

Kathryn McCormick, Life Sciences	2007
Hannah Mensing, Geography	2007-2008
Andrew Miller, St. Olaf College	2007
Vivian Miller, Life Sciences	2007
Patrick Ortiz, Life Sciences	2007
Matthew Salem, Geography	2008-2009
Shondra L. Seils, Ecology and Evolutionary Biology, U of AZ	2006
Erica Schwartzmann, Life Sciences	2006-2007
Kristina Waterbury, Life Sciences	2004
Hilary Waterman, Engineering	2008
Christina Wong, SEEDS student, Occidental College	2006
Thomas M. Zambo, Life Sciences	2006
Ecology Explorers Teachers	
Jodi Alder, Mesquite High School	2009
Josh Applebach, Mesquite High School	2009
Stephanie Arnold, Veritas Preparatory Academy	2005
Amy Bell, Arcadia High School	2005
Marissa Boomgaard, Westwood High School	2009
Debra Bornstein, Desert Sage Elementary School	2005
Kristy Braaksma, Desert Ridge Junior High	2005
John Brands, Desert Ridge Junior High	2005
Kris Brimhall, Mesquite High School	2009
Matthew Burke, Trevor G Browne High School	2007
Rochelle Burson, Mesquite High School	2009
Shiloh Carroll, Highland High School	2006
Kara-Anne Carpenter, Chandler Prepratory Academy	2006
Barbara Cortez, Mesquite High School	2009
Thomas K. Daniels, Kyrene Akimel A-Al Middle School	2005
Kim Davis, Highland High School	2009
Amy Dean, Kyrene del Milenio	2008
John Dole, Mesquite High School	2009
Daryl Dubas, Mesquite High School	2009
Fe Dumapias, North High School	2009
Mary Ellis, Mesquite High School	2009
Cher Fesenmaier, Desert Mountain High School	2005
Annette Fields, Gilbert High School	2009
Kathryn Frederick, Queen Creek High School	2007
Eileen Geronimo, Mesquite High School	2009
Kendall Gilliland, Mountain Pointe High School	2009

Taylor Hale, Highland High School	2009
Sharon Harrison, Vista Verde Middle School	2006
Kathleen Hartnett, Alta E Butler School	2005
Anne Hudson, Mesquite High School	2009
John Jung, Mesa High School	2007
Kimber Kay, Ingleside Middle School	2006
Karly Kocks, Kyrene de la Mirada	2008
Lisa Lasch, Highland High School	2009
Roger LeBlanc, Mountain Pointe High School	2009
Melissa Mara, Sandra Day O'Conner High School	2006-2007
Stephanie Maynard, Queen Creek High School	2007
Christin McLellan, Willow Canyon High School	2007
Laura Moore, Kyrene de la Mariposa	2008
Stephanie Morgan, Perry High School	2007
Caryn Morrison, Mesquite High School	2009
Linda Riggs, Augusta Ranch Elementary	2006
Dorothy Ruot, Desert Ridge High School	2009
La Rinda Saylor, Kyrene del Cielo	2008
Sheila Scanlan, Highland High School	2009
Michele Schiff, Ironwood High School	2005
Karen Smeltzer, Kyrene del Cielo	2008
Clarice Snyder, Camelback High School	2005
Jeffrey Snyder, Washington High School	2005
Sharon Solberg Ayers, Kyrene de la Mariposa	2008
Lynn Stinson-Keys, Tempe Preparatory Academy	2005
Kiva Stone, Frank Borman Middle School	2005
Jeffrey Taylor, Mesquite Jr High School	2005
Karen Thompson, Kyrene del Sureno	2008
Aaron Ullman, Red Mountain High School	2007
Melina Vibber, Kyrene del Cielo	2008
Cheryl Vitale, Mesquite Jr High School	2006
Kim Wallis-Lindvig, Boulder Creek High School	2006
Melissa Wendell, Mountain Pointe High School	2009
Jamie Wilson-Fioramonti, Highland High School	2009
Cheryl Zastrow, Kyrene Monte Vista	2008
Community Partners	
Arizona Audubon	
Arizona Dept. of Water Resources	
Arizona Dept. of Environmental Quality	

Arizona Dept. of Game and Fish	
Arizona Foundation for Resource Education	
Arizona Public Service	
Arizona Science Center	
Arizona State Land Dept.	
Boys Hope Girls Hope	
City of Phoenix	
City of Scottsdale	
City of Tempe	
Creighton School District	
Deer Valley High School District	
Desert Botanical Garden	
Flood Control District of Maricopa County	
Fountain Hills High School District	
Gila River Community Schools	
Gilbert Public Schools	
Gilbert Riparian Preserve	
Glendale School District	
Kyrene School District	
Maricopa Association of Governments	
Maricopa Community Colleges	
Maricopa Parks and Recreation Department	
Mesa Public Schools	
Peoria Unified School District	
Phoenix College	
Phoenix Elementary School District	
Phoenix Union High School District	
Roosevelt School District	
Salt River Project	
Sonoran Desert Center	
Tempe Elementary School District	
Tempe Preparatory Academy	
Tempe Union High School District	
The Phoenix Zoo	
Tonto National Forest	
US Dept. of Agriculture	
US Forest Service	

US Geological Survey	
Veritas Preparatory Academy	
Organizations Giving Permission for Sampling on	
Their Sites	
Arizona Dept. of Environmental Quality	
Arizona Public Service	
Arizona Dept. of Transportation	
Arizona State Land Dept.	
Arizona State Parks	
City of Phoenix	
City of Chandler	
City of Scottsdale	
City of Tempe	
Dawn Lake Homeowners Association	
Desert Botanical Garden	
Dobson Ranch Homeowners Association	
Duncan Family Farms	
Flood Control District of Maricopa County	
Honeywell	
Intel	
Insight Enterprises	
Las Brisas Homeowners Association	
Maricopa Co. Dept. of Environmental Services	
Maricopa Co. Parks and Recreation Dept.	
Morrison Brothers Farms	
Ocotillo Homeowners Association	
Ross Management Inc.	
Salt River Project	
Sonoma Farms, Inc.	
Tempe Union High School District	
Tonto National Forest	
Town of Fountain Hills	
US Forest Service	
US Geological Survey	
Val Vista Lakes Community Association	
Valley Lutheran Hospital	

APPENDIX B:
LONG-TERM MONITORING AT CAP LTER

Monitoring Program	Number of Sampling Locations	Sampling Frequency	Variables Measured
Arthropods	31 sites	Quarterly	• Ground-dwelling arthropods
Birds	56 core sites	Semiannually (Jan, Mar)	• Point-count bird census
Birds	40 PASS neighborhoods	Semiannually (Dec, Feb) in each of two years following the PASS survey (see below)	• Point-count bird census
Tree survey	50 sites	Annually (winter)	• Tree biovolume • Tree condition
Survey 200	204 sites	Five years (spring)	• Photo documentation • Vegetation composition • Vegetation cover • Soil: physical, chemical and biological • Habitat/built structure • Human activity
North Desert Village	4 treatment areas	Continuous	• Air temperature • Ground surface temperature • Soil temperature • Soil heat flux • Soil water content
North Desert Village	4 treatment areas	Monthly	• Landscape water use • Electricity use • Dwelling surface temperature
North Desert Village	4 treatment areas	Annually, with exception of bird and arthropod monitoring (as above)	• Birds • Arthropods • Primary productivity
Atmospheric deposition	15 locations (upwind, core, and downwind of greater Phoenix)	Quarterly	• Wet & dry nitrogen deposition
Desert flora productivity	15 locations (upwind, core, and downwind of greater Phoenix)	Semiannually (spring and fall)	• Productivity (stem length growth) of Creosote (*Larrea tridentata*)

Monitoring Program	Number of Sampling Locations	Sampling Frequency	Variables Measured
			• Productivity (biomass harvesting) of annual plants
Desert soil chemistry	15 locations (upwind, core, and downwind of greater Phoenix)	Semiannually (spring and fall)	• Nutrients, and major cations and anions
Water-quality monitoring	5 locations at major influent (Salt and Verde Rivers, CAP canal) and effluent (Salt and Gila Rivers) systems	Bimonthly	• Nutrients • Major cations/anions • pH • Temperature • Specific conductance • Particulates
Groundwater-quality monitoring	Single experimental plot along Gila River	Bimonthly	• Water quality
Stormwater monitoring	Single location at outflow of Indian Bend Wash	Flow-weighted sampling of each runoff-producing storm	• Water quality
Land-use and land-cover	CAP LTER site	Every five years	• Land use change • Land cover change
Microclimate	AZMet stations	Data mined as needed	• Growth and intensity of urban heat island • Decline in frosts and freezes
Microclimate	2 locations corresponding to atmospheric deposition study sites	Continuous	• Standard suite of meteorological variables
Phoenix Area Social Survey (PASS)	40 neighborhoods	Five years	Household perception, behavior, and knowledge in the areas of : • Water supply and conservation • Land use, preservation and growth management • Air quality and transportation • Climate change and the urban heat island