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

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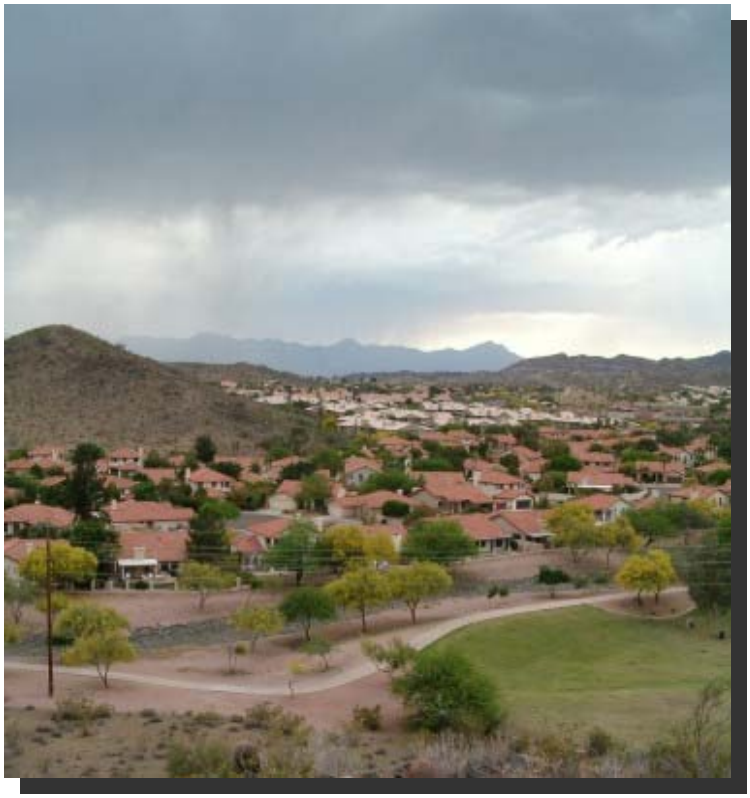

CAP LTER PHASE 2
2008 ANNUAL REPORT

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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 283 journal articles, books, and book chapters since the project's inception in 1997 through August 2007. Since the last annual report, CAP scientists have published 36 articles, books or book chapters, in addition to 18 currently in press and 26 in review. Over 300 individuals have been involved with the project since 2004, including 81 faculty members, 9 senior project managers, 12 post-doctoral scholars, and 49 technicians, support staff, and K-12 education personnel. Eighty-three graduate students have been involved in the project, including 35 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 100 undergraduate students have been involved in CAP LTER since 2004, 80 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). These 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); and a study of the effects of urbanization on trophic dynamics (NSF-Ecology, Faeth and Sabo 2005).

Recent leveraged grants continue to expand opportunities for CAP science. CAP scientist Sharon Harlan is the principal investigator, with several co-investigators who also are CAP scientists, on a $1.4 million grant from the NSF's Dynamics of Coupled Natural and Human Systems (CNH) program to investigate urban vulnerability to climate change, particularly focusing on the urban heat island. This project will identify community and demographic markers of high-risk environments that decision-makers can use to develop spatially informed early warning systems and heat-illness prevention programs.

CAP LTER's Information Manager, Corinna Gries, recently received $500,000 from the NSF's Biological Data Infrastructure program to improve the algorithm for species identification in Southwest Environmental Information Network (SEINet) website. SEINet is a set of resources on biodiversity used by scientists, land managers, independent contractors, and naturalists in the southwestern US. This new utility will enhance users' ability to make accurate identifications, an important advance for the biodiversity community.

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. Briggs, 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 94 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 21 active fellows, 4 associates, and 13 graduated fellows (emeriti) in our Integrative Graduate Education and Research Training (IGERT) program in urban ecology. Finally, close to 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:

- **Urban landscape patterns**
- **PASS**
- **Agrarian landscapes in transition**
- **Walkability, park access, and environmental justice**

During this program year, we have funded new LULCC initiatives, the preliminary results from which will be included in next year's report. One new project focuses on **Institutional drivers of growth in Phoenix** and examines urban growth policies since World War II. This effort will use multiple sources of data, including archival information on zoning ordinances and decisions about municipal water extensions, to tease out drivers of land use change.

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. A planning meeting at the regional LTER symposium in Albuquerque in July allowed the project partners to begin refining their research methodologies and assembling their research teams, including initiating a search for a project-wide post-doctoral associated to be hired at CAP LTER. This research and similar studies being conducted by CAP LTER scientists and collaborators builds upon the idea that advancing understanding of urban ecosystems will benefit from a comparative approach across biophysical and societal gradients (Grimm et al. 2008a,b; Redman and Foster 2008; Lepczyk et al. in press).

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 research projects addressing these questions in 2007-2008 were:

- **Urban heat island**
- **PASS**
- **Effects of urbanization on landscape pattern and ecosystem processes in the Phoenix metropolitan area**
- **Plant flowering phenology**
- **NDV ecosystem services**

CAP has also begun a new project in collaboration with a leveraged NSF grant, **Measuring urban surface energy fluxes**, under the CLIM-ECOS and FLUXES IPAs. By measuring surface momentum, latent and sensible heat fluxes, and components of the radiation balance at two new flux towers located in a residential neighborhood and in outlying desert slated for future development, this project will advance understanding of atmospheric dynamics in the Phoenix metropolitan area. It also will contribute to ongoing investigations in mesoscale meteorology and work on outdoor water use, and establish an important baseline for future NEON studies. A recently awarded 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. Active projects during 2007-2008 included:

- **Modeling fluxes of salt and water through the urban infrastructure**
- **PASS**

Work on aquatic biogeochemical processes and water quality, undertaken in the FLUXES IPA, is closely associated with the work under this area. A newly funded initiative begun in summer 2008 and continuing through the academic year will examine **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 recently 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.

Efforts in the WATER IPA are well integrated with the Decision Center for a Desert City (DCDC), which focuses on water-management issues in the Phoenix area. CAP scientists have been actively working with DCDC on initiatives related to a systems dynamic model known as **WaterSim**. Other ongoing work includes the **Phoenix ethnohydrology study,** which investigates local ecological knowledge about drinking water quality and how this matches with data on the chemical content of drinking water. Preliminary results from this multi-stage study will be forthcoming in the next annual report.

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 studies:

- **Nitrogen trace gas emissions in urban patches**
- **Lichen resurvey with heavy metal analysis**
- **Survey 200 soil analysis**
- **Small watershed biogeochemistry in an urban ecosystem**
- **CNDep: ecosystem processes along an urban atmospheric deposition gradient**

A major initiative of the FLUXES research group has been to establish long-term fertilization experiments in unmanaged desert at sites upwind, within, and downwind from the urban core, as part of CAP LTER collaboration with a leveraged NSF (Ecosystems) project, **CNDep: ecosystem processes along an urban atmospheric deposition gradient.** Results from the first three years of nutrient enrichment and measurement of shrub productivity, including a wet year with extensive annual plant production, are being analyzed and will be presented in the 2009 report. In the meantime, these sites have served as important points for examining the impact of atmospheric deposition on desert ecosystems absent direct human intervention. Studies of rates of atmospheric deposition, soil nutrient pools and microbial processes, and extracellular enzyme activity have been completed and will be discussed in the research findings section of this report.

This IPA includes multiple projects within the general category of **Small watershed and biogeochemistry in an urban ecosystem**, such as **Performance of storm water retention basins in nitrogen retention and removal** and **Biogeochemistry of an urban greenbelt**. A recent experiment from the former project focused on ^{15}N assessment of denitrification in storm-water retention basins, using a retention basin near a Scottsdale elementary school. A video of this experiment will be posted on the CAP LTER website; experimental results will be presented in the 2009 report.

New research, funded under a 2007 NSF Social Science Supplement, has begun to untangle the variability in urban ecological processes through examining **Socioecological drivers of residential landscape management and ecosystem responses**. This research is entering its third phase, and preliminary results may be available for the 2009 report. A preliminary study of soil properties under different landscape management regimes has been completed. While this work continues, CAP researchers have teamed up with investigators at other LTER sites on a cross-site initiative to share and compare research on residential landscapes through a workshop, funded by the LNO, in February 2009.

Other new work includes an investigation of the **Distribution of biomass- and fossil fuel-driven black carbon in CAP 200-point survey soils** that will address the pervasive idea that black carbon is extremely recalcitrant, using thermo-chemical techniques as well as ^{13}C-NMR and ESI-Mass Spectrometry molecular-level analyses.

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?

Studies during 2007-2008 that addressed these questions include:

- **Ground arthropod diversity at NDV**
- **Foraging decisions, bird community structure, and an urban-rural gradient**
- **The relationship between species richness and area**
- **NDV social survey**
- **Biodiversity and neighborhood social variation**

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. Findings from all of these studies relevant to the aims of the BIODIV IPA will be reported in this IPA's research findings section.

Newly funded work under this IPA includes an experiment conducted as part of the **Trophic dynamics in an urban ecosystem** project, **Urbanization effects on primary productivity** that focuses on the roles that wind and shade play in urban plant growth. As well, an addition to CAP's avian research examines **Ecophysiological and behavioral adaptations of birds to rapid urbanization of a desert environment**. This research, which includes physiological investigations, has involved REU students for the last two summers. Other ongoing avian work, **Competition between an alien and native bird species in an urban habitat,** examines competitive exclusion as a major cause for the global loss of diversity in urban settings (Shochat et al. in review) through a field experiment to test the effect of an alien, human-commensal species, the house sparrow, on a native species, the lesser goldfinch. Findings on these new and ongoing projects will be included in the 2009 report.

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 2007-2008 include: **long-term monitoring**, **long-term experiments, storm water,** and **knowledge exchange**. 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 is in the first year (reported in research activities under WATER). Work on knowledge exchange occurred through periodic meetings between CAP staff and those from the Sustainability Partnership.

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). A Survey 200 working group began meeting formally again during 2007-2008. The group's objectives are to initiate comparisons between the 2000 and 2005 survey data and standardize statistical methods for analysis.

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 (see FLUXES). Other ongoing work, described in previous reports, examines heavy metals in Phoenix area soils.

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.

The NDV research team has begun work on a new, 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. Early findings of this research are reported under the Climate IPA.

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 sample selection of neighborhoods for PASS was accomplished in 2005 by the classification of all Survey 200 sites as either urban or non-urban. Forty neighborhoods were carefully selected from among the 94 urbanized sites to represent a balanced design of neighborhoods by location, income level, ethnic composition, and age. The Institute for Social Science Research (ISSR) at ASU mapped all dwellings within each neighborhood and selected a random sample of households to recruit for participation in the study.

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 survey, which takes 30 to 60 minutes to complete, was available to respondents as an online, telephone, or face-to-face interview in English and Spanish. ISSR staff administered the PASS and managed survey data.

PASS-related activities greatly expanded in 2007. Research activities include:

- Multiple analyses of the 2006 PASS public sample.
- Collection of two additional PASS supplementary datasets from scientists and planning and policy professionals.
- Collection of additional datasets that are spatially matched with PASS neighborhood location.
- Development of models to explain variation in human response to the environment.

The summary report of the survey was completed and is linked to the CAP LTER and DCDC web pages http://caplter.asu.edu/docs/contributions/2007_PASS2.pdf. CAP scientists working on the PASS made many presentations at academic conferences and workshops and gave a number of outreach talks. In addition, PASS director Harlan wrote a letter of support for sociologists at the University of Nevada Las Vegas, which helped them to obtain funding for a pilot survey on environment and society (Las Vegas Metropolitan Area Social Survey, LVMASS). This study will be designed with the intention of doing comparative analyses with PASS.

A subset of the PASS questionnaire items on perceptions of environmental conditions, causes of environmental problems, and support for policy actions was administered via Internet survey software to scientists affiliated with the Global Institute of Sustainability at ASU and to a broad spectrum of planning and policy professionals in the region. Response rates to the surveys were 70 percent for the scientists (n=110) and 50 percent (n=95) for the policy professionals. These data are being used to measure the degree of consensus about environmental problems and acceptable policy responses among the lay public, the scientific community, and government.

CAP LTER bird monitoring sites were moved to coincide with PASS neighborhoods. The first year of bird counts were completed during December 2006 and March 2007 using unlimited-radius point counts (as have been conducted since 2000 in CAP). Additional data on neighborhood temperatures, air quality, and housing sales were assembled in order to test the logic of survey questions used to estimate hypothetical tradeoffs that people would make in order to reduce temperature (heat island) or reduce air pollution in their neighborhoods. A dataset containing crime statistics, artifacts of social disorder, and a survey of vegetation was constructed for parks near PASS neighborhoods. The field work for all of these data gathering activities was primarily carried out by students.

Other CAP LTER/DCDC studies used PASS neighborhoods to conduct additional surveys. For example, an in-depth study of respondents´ knowledge of local water quality, the **Phoenix**

ethnohydrology study, is underway in four PASS neighborhoods (two with high levels of water quality concern and two with low levels of water quality concern) in South and Central Phoenix. Research questions in this study include: Is there a shared core of cultural knowledge around water quality? How closely does local ecological knowledge about water quality match water quality experts' understanding of these issues? The primary importance of this study lies in the ability to understand Phoenix residents' cognitive models of tap water quality, causes of water contamination, and appropriate mitigation actions.

Economic models to explain consumer choices regarding temperature and air quality in their neighborhoods are being developed. In another effort, regional weather modeling, land use classification, and GIS tools were used to inter-relate neighborhood-specific simulated temperature with socioeconomic characteristics of the population. These methods may lead to improving the spatial specificity of heat-watch warning systems by identifying the most vulnerable places and people in the region.

III. Highlights of Research Findings

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

Land-Use and Land-Cover Change (LULCC)

Since CAP's inception, this IPA has had a strong focus on exploring 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 Blaschke 2008) as well as a focus on examining historic land-use (Knowles-Yáñez et al. 1999; Keys et al. 2007) and landscape pattern (Buyantuyev et al. 2007; Shao and Wu 2008). New initiatives, described in the activities section of this report, are moving the LULCC IPA into a better understanding of the drivers of land-use change, while ongoing investigations continue to shed light on land-use and land-cover patterns.

Recent work on **urban landscape patterns** has examined changes in the CAP LTER study area from 1985 to 2005. This research has found that undisturbed desert decreased by about 25% during this time period (from 69% to 44% in 2005), reflecting very high rates of urban area expansion. Urban classes – pavements, industrial/commercial, and both residential land uses – increased between 3% and 7%. The highest growth rate was associated with the xeric residential class, which reflects a shift toward the prevalence of xeriscaped neighborhoods in new developments. Analysis of transition matrices revealed that urbanization during this period occurred mostly in the desert, unlike earlier stages of urbanization when urban land use increased primarily at the expense of agriculture. During the study period the overall area has become more fragmented and heterogeneous ecologically. Landscape diversity increased overall, because of the growing equality of proportional abundances of existing land cover classes. Researchers did not find any trends in patch boundary complexity and fractal properties of individual patches.

New analyses of the extensive **PASS** are illuminating the values, perceptions, and behaviors of greater Phoenix residents. Preliminary findings indicate that citizens generally believe that cheap land is a cause of sprawl in Phoenix and are supportive of increases in developer impact fees to reduce sprawl. Political self-identification, income, and tenure in the Valley explain some of the variation in citizen perception. As well, there is a strong negative reaction to population

growth in the region by the public and among GIOS scientists. The results show that 92% of the scientists and 67% of the general public surveyed believe that the desert ecosystem cannot support or cope with more growth. Other results deal with the distribution of urban amenities, like parks, and public perception of these spaces. Non-white neighborhoods have significantly fewer public parks, which are most abundant in suburban neighborhoods. The "ecology of fear" hypothesis, linking denser park vegetation to higher reported park crime, is not supported in the Phoenix region. Residents' fear of crime is highest in low-income urban core neighborhoods and reported crimes are also the highest, although vegetation density is variable. Residents' park satisfaction is the highest in suburban neighborhoods, despite the presence of reported crimes and dense vegetation in parks.

CAP scientists along with other researchers from five LTER sites across the country participated in the **Agrarian landscapes in transition** project, funded by NSF (Redman and Foster 2008). This research focused on the cycle of agrarian transformations and sought to understand a) how human activities influence the spatial and temporal structures of agrarian landscapes over time and across biogeographical regions; b) the ecological and environmental consequences of the resulting structural changes; and c) the human responses to both these structural and ecological changes, and how these responses drive further changes in agrarian landscapes. While researchers undertook investigations across different ecosystems, the study concludes that "process similarity far outweighs any differences in underlying mechanism in comparing the narratives" (Gragson 2008, 272). Gragson identified five themes stemming from the research that characterize the processes responsible for transformation and indicate lines of future inquiry. Among these are themes of examining agriculture as an adaptive, problem-solving process; heterogeneities of resource regimes; and the types and effectiveness of institutions that guide human-to-human and human-to-ecosystem interactions.

Other research associated with the **Agrarian landscapes** project focused on land conservation at three sites, western North Carolina, central Massachusetts, and central Arizona (CAP study area), to determine if protected lands encourage land conservation on adjacent parcels (McDonald et al. 2007). This study found that protected conservation areas tend to cluster near one another but that proximity to conservation lands did not correlate with a reduced land development rate of nearby land. This finding calls into question hypotheses that land conservation affects development decisions on adjacent and nearby parcels.

Landscape ecological perspectives and patch-dynamics theory have motivated CAP LTER since its inception, and CAP scientists continue to contribute to dialogues about the field of **landscape ecology (Fig. 1)**. Recent publications have reviewed the state of the field (Wu 2007), linkages between landscape ecology and urban sustainability (Wu 2008a), and the need for a landscape ecological perspective on urban forestry (Wu 2008b).

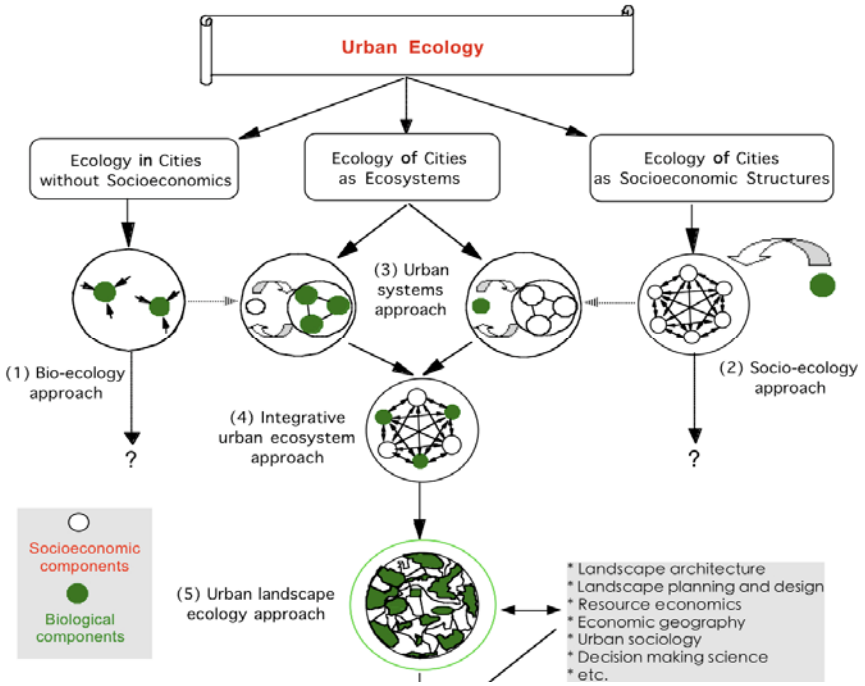


Fig. 1. Relationships among different approaches to urban ecology. Integrative urban ecosystem approaches and an urban landscape ecology approach characterize CAP LTER research. From Wu (2008a,b)

Work on environmental justice has begun to focus on the distribution of environmental amenities, such as parks and recreation spaces, in relation to minority and low-income households (Pastor et al. 2005). Research on **Walkability, park access and environmental justice** in Phoenix has examined access to two environmental amenities, parks and walkable neighborhoods (Cutts et al. in review). The authors relate this access to obesity, a new area of inquiry for environmental justice studies in Phoenix. Researchers hypothesized that Latinos in Phoenix would live in less walkable neighborhoods and have lower access to parks, providing some built-environment explanations for lower levels of leisure activity associated with increased risk of obesity. Using established methods for measuring neighborhood walkability, the team created a walkability index for each census block based on four measures: dwelling density, connectivity, land use attributes, and net retail area. The team also measured access to parks, using Dasymetric mapping techniques. Binary logistic regression and multivariate regression methods were used to analyze data. Contrary to their research hypothesis, Latinos in Phoenix and other sub-populations vulnerable to obesity were more likely to live near parks and live in walkable neighborhoods than were less-vulnerable groups. These groups live in built environments that should increase physical activity and lessen the risk of obesity. The researchers provide several explanations for this finding: the study did not take into consideration other neighborhood characteristics such as safety, aesthetics, noise or climate that could be important determinants of walking behavior; spatial patterns of obesity risk in Phoenix

might be more closely related to variations in food availability than the relationship between the built environment and physical activity; and Latinos and/or low income residents may face cultural or social constraints that prevent them from taking advantage of the built environment. The researchers call for new strategies to reduce obesity in at-risk neighborhoods that blend environmental justice studies with work that is rooted in analyses of cultural variation as an explanation for uneven rates of obesity.

Climate-Ecosystem Interactions (CLIM-ECO)

CAP LTER scientists continue to be engaged in studies of the **Urban heat island**, which is a major driver of ecosystem change in the city and has a significant influence on human health and comfort. During 2007-2008, a REU student worked with CAP scientist Tony Brazel to evaluate the urban thermal climatic effects in southwestern American cities. They focused on the degree to which trends in summer minimum temperature for the latter half of the 20th and early part of the 21st century can be attributed to local urban development as opposed to global climate change. They selected a range of towns and cities in California, Nevada, and Arizona for which a "pairing" of sites from a town/city and a site outside that town/city was possible. Climate records for the period 1948 to 2007 were accessed, and statistical time trends determined for the urban vs. rural locations for towns/cities over a considerable range of population (i.e., from 3.5K to 3.2M). They found that the urban heat island effect increased with the natural log of the population, ranging from a total change in minimum monthly temperatures of ca. 1.5°F to over 12°F over the population range of 3.5K to 3.2M. These rates of change in the 1948-2007 period overwhelm any background global climate change, with the exception of the rural sites and smaller towns. The significance of this study is that for the first time the temperature trends of a range of towns and cities in the Sonoran and Mojave deserts have been identified to unravel the impact of urban warming from that of global warming in the contemporary global warming era – sometimes called the Anthropocene era. The study is consistent with the contention of Grimm et al. (2008b) that urban areas represent microcosms of future change. The impact depends on land cover and extent of population development over time.

Other work on the urban heat island has used results from the **PASS** coupled with the mesoscale Weather Research and Forecast (WRF) model**.** This work involved comparing simulations of temperature variability among Phoenix Area Social Survey neighborhoods with data on neighborhood socioeconomic status as well as the results from PASS questions related to heat and heat stress. Scientists examined the distribution of threshold temperatures upon people throughout 40 diverse PASS neighborhoods. WRF model simulations of temperature for a heat-wave period show that temperature is variably distributed over the neighborhoods. Residents' perceptions of temperature and self-reported experiences with heat-associated illnesses are related to neighborhood environmental conditions. The highest risk of exposure to extreme heat is among the elderly, minority, and low-income populations. Land use/land cover characteristics exhibit strong relationships with local temperatures.

The urban heat island affects not only human health and comfort but also biological processes. One graduate student project examines the effects of urbanization on **Plant flowering phenology in the Phoenix metropolitan area** (Neil and Wu 2006). Recent investigations using from ASU's herbarium records of 87 species of ephemerals and shrubs that bloom at different times of the year reveal that 19% of plant species examined either advanced or delayed their flowering. The flowering responses of 28% of the species examined showed significant differences between urban and non-urban areas: 24% advanced in urban areas and 5% delayed.

Thus, urbanization has a significant effect on the flowering phenology of a small, but substantial, proportion of plants, which will likely affect native biological diversity and ecosystem services due to potential changes in population and community dynamics (Neil in review). Other ongoing research in this area focuses on whether land cover type or water availability affect the flowering phenology of brittlebush (*Encelia farinosa*).

Research on the **Effects of urbanization on landscape pattern and ecosystem processes in the Phoenix metropolitan region** has used remote sensing techniques to examine vegetation leafing phenology. In this project, researchers analyzed response patterns of vegetation leafing phenology to climate factors along the gradient of urbanization in Phoenix (Fig. 2). They also estimated primary productivity and compared it along this gradient. They found that phenology of human-dominated land covers is unsynchronized with natural vegetation. Multimodality (more than one growth period a year) of growth in agricultural and urban land cover classes is common. While untransformed ecosystems follow growth cycles that can be predicted by climatic fluctuations, human-dominated ecosystems are clearly decoupled from climate. Correlation maps reveal extremely heterogeneous patterns within urban and agricultural land covers (Fig. 2): the majority of managed urban plant communities and agricultural crops are negatively correlated with rainfall and positively with temperature, whereas desert NDVI is positively correlated with precipitation, especially when rainfall >4 month is considered. Urban and agricultural land covers are insensitive to changes in rainfall accumulation. Effects of temporal lags in NDVI-temperature correlations are less significant, showing only a slight improvement in correlation at the first lag. The combined urban and agricultural areas contributed more to the regional ANPP than the natural desert did in normal or dry years, whereas this pattern was actually reversed in wet years.

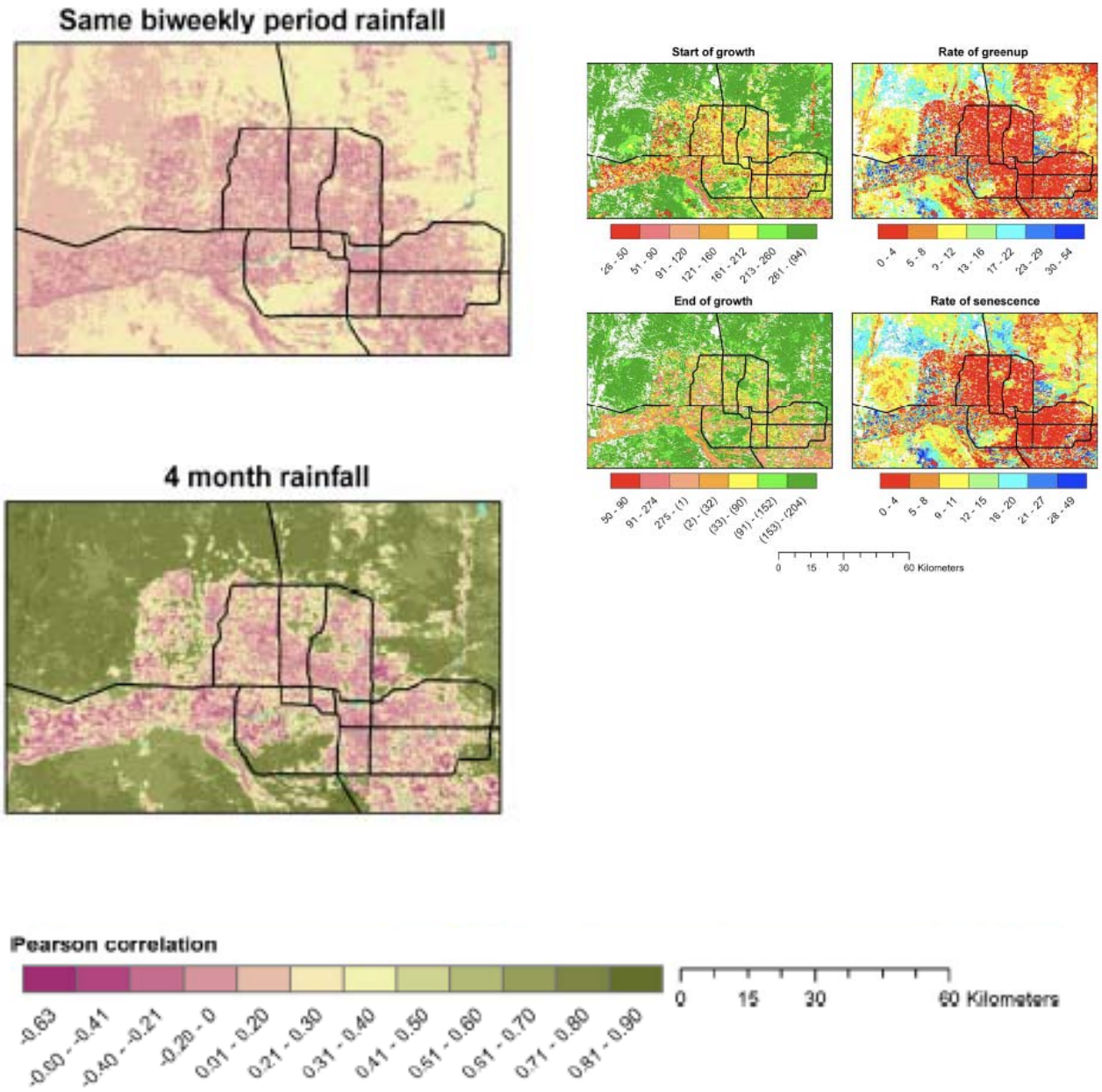


Figure 2. Spatial distribution of growth-season phenology in the CAP region (top right), and correlations between biweekly (top left) and 4-month (bottom left) rainfall and ANPP for the urban area (negative correlation) and desert areas (positive correlation) in CAP.

Ongoing research at **NDV** examines the characterization of microclimates created by landscape styles. Researchers took measurements at 5.0-m increments along five transects in each of four study sites between 900-1000, 1600-1700 and 2100-2200 hr on clear calm days in mid-June and late August. These measurements included air temperature at 5.0 m, 2.0 m, 1.0 m, 0.5 m and 0.25 m, as well as relative humidity at 2.0 m and surface temperature. Air temperatures were measured with shielded copper thermocouples, except at 2.0 m where air temperature and relative humidity were measured by a shielded HMP45C-L probe. Surface temperatures were measured with an Apogee IRR-PN infrared thermometer. Findings to date suggest that surface temperatures within the native and xeric treatments were consistently warmer than in the oasis and mesic treatments. During the afternoon and evening hours the microclimates in the four treatments between 0.25 m to 2.0 m were different with the mesic treatment being cooler. At 5.0 m above the landscape surface, air temperatures within all four treatments were similar. An intriguing result is the similarity of mesic and oasis treatments, which differ in water use by a factor of ~eight. This suggests that a microclimate benefit can be achieved with only slight increases in water use. Further research on ecosystem services is exploring this possibility.

An analysis of ecosystem services at **NDV** considers the effects of landscapes on 1) temperature moderation and energy use, 2) water conservation 3) aesthetics and satisfaction with a landscape, and 4) carbon sequestration. Preliminary results suggest that water-intensive landscapes are optimal for three of the four services considered. Based upon four infrared surface-temperature measurements collected from each side of every house within each NDV treatment area at 9 am, 4 pm, and then again at 9 pm (accounting for expected differences related to house-surface orientation), the mesic landscape conferred a statistically significant advantage for conserving cooling energy in summer. In the **NDV social survey**, residents in mesic landscapes rate quality of life higher than those living in other landscape types. Although the carbon sequestration data are still being analyzed, it appears that either the mesic or oasis landscapes will be most effective in providing the ecosystem services under consideration. The only ecosystem service that deviates from the overall trend favoring mesic landscapes is water conservation, which is best served by the xeric and desert landscape. Most interestingly, the research team's analysis very closely supports the cognitive optimization of NDV interviewees (indicated in the content analysis of interview transcriptions) as they make compromises among ecosystem services to arrive at a preference for oasis or mesic landscapes.

Water Policy, Use, and Supply (WATER)

Research under the Water IPA has focused on investigations related to the modification of streams and rivers in the CAP area (Roach et al. 2008), policymaker responses to drought and water shortages (Hirt et al. 2008; Larson et al. in review b), household perceptions, values, and behaviors regarding water (Harlan et al. in press; Larson et al. in review a), modeling water and salt fluxes, and a new emphasis on storm-water material export. Aquatic biogeochemistry research reported under the Fluxes IPA overlaps with this IPA.

Building on previous work with the City of Scottsdale, researchers have worked on **Modeling fluxes of salt and water through the urban infrastructure** for the City of Goodyear. Goodyear, a city in the western part of the greater Phoenix area, has less access to surface water than Scottsdale, which necessitates the use of more low quality (high salt content) groundwater. The research team used results from the municipal-level modeling to construct a regional water and salt flux model, using some inputs for groundwater and surface water

(including water transported into the region) from the DCDC WaterSim model. They ran simulations from 2007 to 2030. The expected result of water and salt mass balances for Maricopa County in 2030 are shown in Figures 3and 4. The model also allows users to examine water leaving the system as evaporation. For example, from 2008 to 2030 evaporation from irrigated agriculture significantly declines from 44% to 8% as the area of land under agriculture is converted to residential uses. Outdoor uses (i.e., landscaping) constitute the major source of evaporated water (about 37%) in 2030. In addition, the model simulates possible wastewater reuse. Since the area under agriculture is expected to be substantially reduced over time, reclaimed wastewater is assumed to be shared equally for irrigation of public lands and aquifer recharge. Further work on the model will continue into fall 2008 to integrate it with the WaterSim model and make it more useful for informing policy decisions regarding water use and water quality.

Other research under this IPA has focused on understanding influences on residential water use in Phoenix, using data on 205 single family households from the first **PASS,** property characteristics from the county assessor's database, and metered water usage (Harlan et al. in press). The selected households were distributed across eight neighborhoods, which were purposefully chosen to represent variations in median income, ethnic composition, age of housing stock, types of landscaping, and location. The research measured the water usage preferences of households at different income levels through an examination of household water consumption and how differences in this consumption could be attributed to characteristics of the home environs, orientation toward the community, and environmental attitudes. The research team found that there was a wide range of average monthly water consumption among the households: from 748 gallons to a high of 153,000 gallons. Similarly, annual income varied considerably from a low of $6,000 to a high of $500,000. Data were analyzed by regression, and indicated that household income was an important determinant of residential consumption, which is partially mediated by house size. Interestingly enough, "neither beliefs about water scarcity as a community problem nor neighborhood efficacy and trust had statistically significant effects on household water consumption after controlling for other variables" (Harlan et al. in press). The researchers conclude that this may be due to the fact that sentiments about community and environment do not significantly alter socially and culturally constructed lifestyles, including the possession of water-guzzling goods. They note that water conservation programs must consider and address the social organization of consumption.

Unit: Millions Acre-Foot per Year

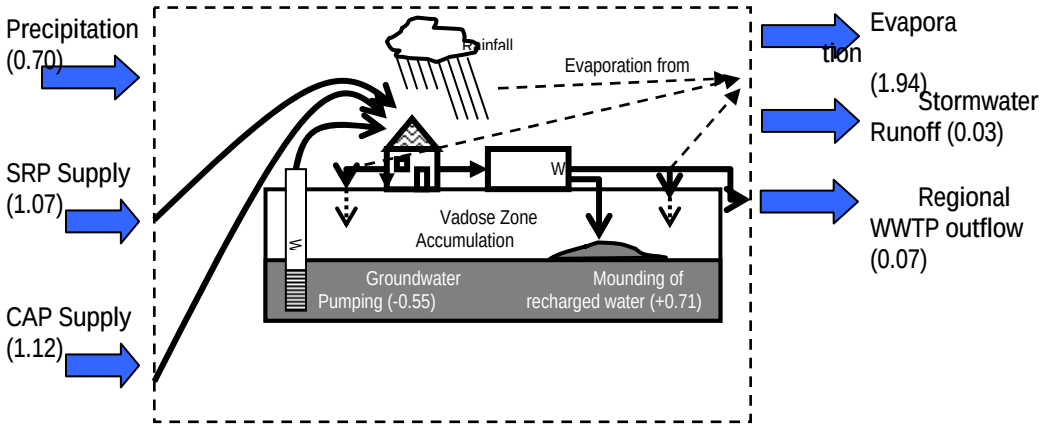


Figure 3. Water Mass Balance for Maricopa County, 2030

Unit: Millions Tons per Year

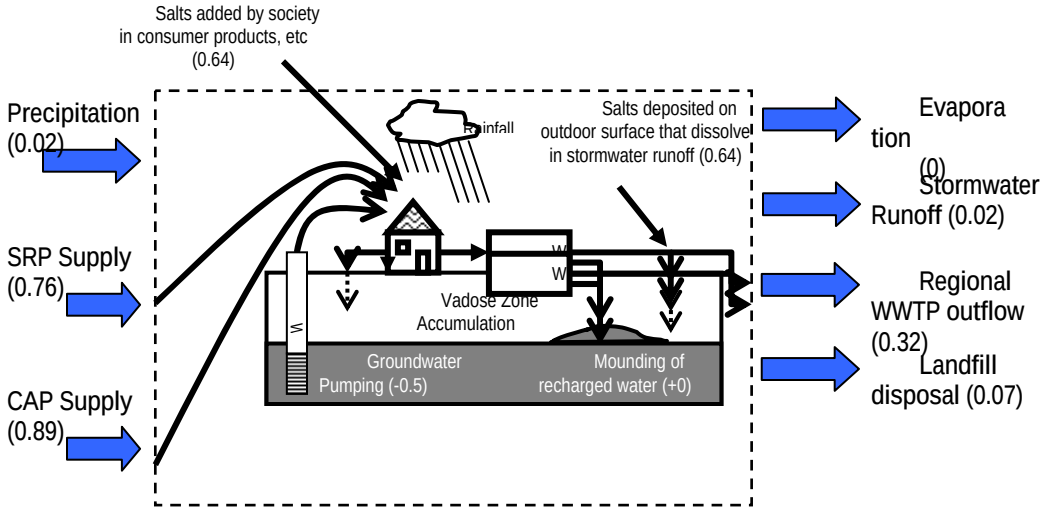
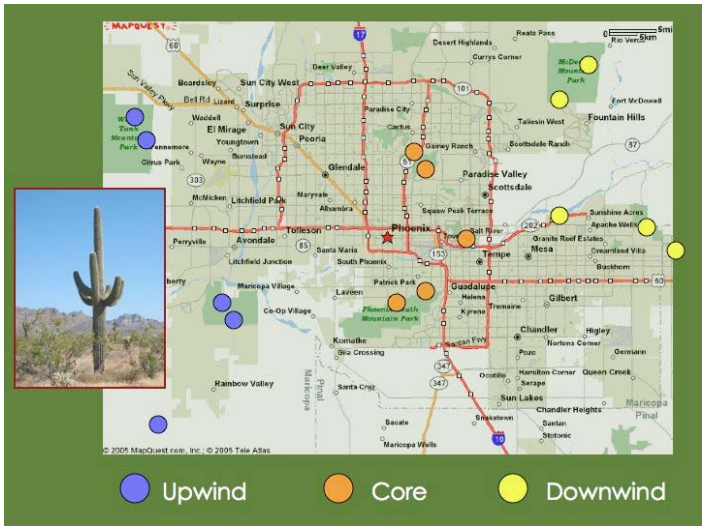


Figure 4. Salt Mass Balance for Maricopa County, 2030

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 work is linking biogeochemical work with environmental justice concerns, measuring urban surface energy fluxes, and investigating biogeochemistry and storm-water management.

The **CNDep: ecosystem processes along an urban atmospheric deposition gradient** project has established infrastructure (field sites, Fig. 5) at which questions concerning the effects of the urban environment, absent human management (such as fertilization or irrigation), can be addressed. Three years of monitoring of shrub productivity and atmospheric deposition



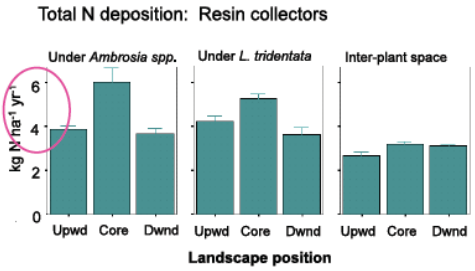


Figure 5. CNDep monitoring and fertilization sites across the Phoenix metropolitan area (left), and N deposition measured from passive collectors beneath and between plants at each position along the purported deposition gradient (above).

have found no responses to what was thought to be a strong deposition gradient, based upon modeling studies (Fenn et al. 2003). In fact, CAP research has shown that nitrogen deposition measured by passive collectors and standard wet-dry buckets is fairly low (Fig. 5, Lohse et al. 2008); however, state-of-the-art measurements of particle and gas concentrations coupled with eddy correlation estimates suggests higher deposition rates. No responses to N or P fertilization were observed over three years, except following the very wet winter of 2007-2008 (to be reported in 2009).

Several projects have examined the effects of the hypothesized urban-rural gradient in nutrient availability. Results generally confirm that, although there are some gradients in environmental conditions, any effect of enhanced nutrients on soils, microbial processes, or nutrient fluxes is swamped by the local effects of resource islands (McCrackin et al. 2008; Hall et al. in review; Lewis et al. in review) in unmanaged deserts. Further work has contrasted these unmanaged deserts with managed xeric and mesic yards, and shown that the effects of management far outweigh even those effects of resource islands (e.g., Davies 2008; Hall et al. in review).

Recently published research on **Nitrogen trace gas emissions in urban patches** explores the impact of urban land uses on soil N cycling and emissions of N_2O and NO from soils (Hall et al. 2008). Lawns are high in organic matter and irrigated and fertilized much like agricultural crops (Milesi et al. 2005). Because of this, the research team expected lawns to support high N-oxide fluxes compared to native landscapes. Furthermore, although the biogeochemistry of xeriscaped yards has not been well studied, they hypothesized that these managed ecosystems would be the largest soil sources of NO_x due to a combination of warm temperatures, coarse soil textures, periodic irrigation, and large N pools – all factors that are known to promote nitrification and emissions of NO_x to the atmosphere. The researchers collected data on emissions of N_2O and NO from three landscape types, urban desert, lawns, and xeric landscapes, during the spring (March 2001) and summer (May/June 2006) before and after artificial wetting. Their results confirm the hypothesis that lawns are the largest source of N_2O of the three landscape types studied. However, lawns are not significantly different than urban desert with regard to NO emissions when dry. Experimental irrigation resulted in pulses of NO in dry, desert soils as well as in xeriscape soils, which significantly exceeded emissions from lawns. Contrary to the researchers' expectations, managed xeric landscapes functioned similarly to desert with respect to NO_x pulses after watering, although a closer examination of the research results indicate some subtle similarities with lawns. The researchers conclude that land conversion from desert to lawn will significantly increase soil N_2O emissions and speed N cycling. Emissions of NO_x from Phoenix soils, as pulse events after rainfall, may contribute significantly to O_3 production during the summer months.

The goal of the **Lichen resurvey with heavy metal analysis** project is to document the patterns of air pollution by metals in Maricopa County using lichens, and to compare this with previous studies using similar techniques to ascertain long-term trends in air pollution for central Arizona. Preliminary findings suggest that for metals from all sources, lichens in urban areas are subject to significantly more deposition than lichens in more rural areas. Anthropogenically enhanced metals (mercury, copper, tin, cadmium, lead antimony and zinc) as well as rare earth and mafic rock metals (neodymium, praseodymium, yttrium, dysprosium and gadolinium for rare earth metals; nickel, scandium and cobalt for mafic rock metals) present in the lichens were found to be significantly higher in urban areas than in rural ones. Further examination of the data should elucidate major and minor sources of metal air pollution in the metropolitan Phoenix area and comparisons to previous work will allow an examination of long-term trends in air quality.

Ecologists have long grappled with issues of scale and representation of ecological patterns and processes (Wu et al. 2006), although effective scaling of data from small-plot measurements to the region remains a persistent challenge. A team of CAP scientists proposed a hierarchical Bayesian framework to scale plot data on oC, iC, N, and P from **Survey 200** soil samples to the 6400 km^2 CAP LTER region (Kaye et al. 2008; Majumdar et al. 2008). Model development (discussed in depth in Majumdar et al. 2008) began with identifying 13 geomorphic, ecological, and socioeconomic independent variables that were likely drivers of soil properties. Researchers screened these using Bayesian information criteria in a simple multiple regression model, and seven emerged as significant: never in agriculture, ever in agriculture, elevation, slope, percentage impervious area, percentage lawn cover, and land-use category. These, with the eight dependent variables (iC, oC, N, and P at two soil depths), were used in the final model. Rather than interpolate between the 204 sample points to the region, the model used 5000 randomly selected additional points from the study area, and with data on the four independent variables (slope, elevation, ever in agriculture, and current land-use) at those points, predicted percentage

impervious area, percentage lawn cover, and all dependent variables. Model results indicate that 1140 Gg of oC have accumulated in urbanized soils of the region, while 130 Gg of N have accumulated. These estimates for oC and N compare reasonably well with prior etimates (Jenerette et al. 2006; Zhu et al. 2006). Comparing the Bayesian approach to a traditional approach, the researchers found that predictions for iC differed among the approaches because the Bayesian approach predicted iC as a function of elevation while the traditional approach used only land use. The researchers concede that, although computationally complex, the Bayesian model offers several advances over traditional ecological approaches. Among these advances are the ability to use diverse types of data to predict soil properties, the use of spatial autocorrelation, and the ability to model coupled biogeochemical processes. This exercise is the first work to apply hierarchical Bayesian modeling techniques and kriging strategies to study multivariate soil nutrient and C concentrations.

Watershed biogeochemistry studies have focused on nutrient exports from urban watersheds. Researchers have asked, *what locations in a watershed or ecosystem/patch types in an urban landscape are associated with high rates of nutrient storage or export?* Findings from an extensive analysis of storm-water chemical data from the USGS suggest that both catchment characteristics and storm characteristics interact to determine nutrient loads to downstream ecosystems (Lewis and Grimm 2007). This dataset is being further analyzed for other nutrient loads, as well as to establish sampling sites for additional storm-water studies. The streams and riparian zones that are the main sites of nutrient retention in desert landscapes are in many cases replaced in urban landscapes by designed ecosystems. This research team has studied retention basins, canals, and stream, lake and floodplains in an urban greenway to determine whether these systems are effective in nutrient removal. Results from the LINX experiments conducted in Phoenix (Mulholland et al. 2008, Hall et al. in press, Mulholland et al. in press, and papers in preparation) indicate that these systems are at the low end of the national database in terms of denitrification but overall are fairly retentive of nitrogen. Surprisingly, these results are attributed to low nitrate concentration in the streams. In another study, researchers measured denitrification in stream, lake, and floodplain patches of Indian Bend Wash, a once-ephemeral desert stream that has been 87% urbanized over the past 70 years (Roach et al. 2008). The floodplain habitat was the most efficient at removing nitrate, even accounting for management that added fertilizer to these grassy parks (Fig. 6). This result is consistent with findings of Zhu et al. (2004) and ongoing work in retention basins that suggest that grassy lawns are hot spots of denitrification.

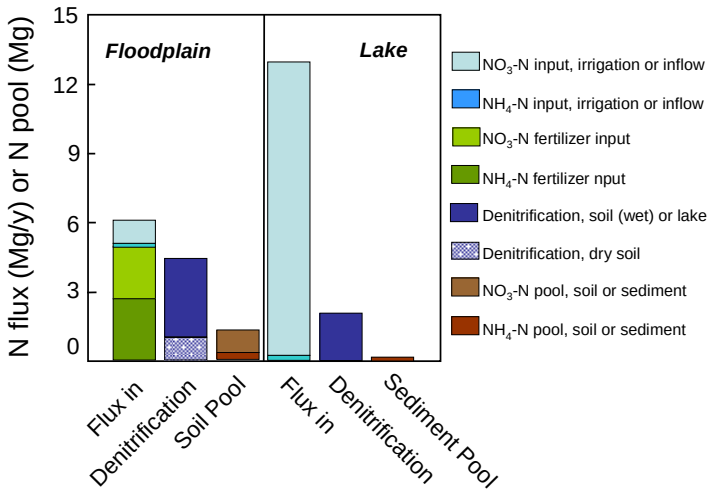


Figure 6. N fluxes and pools in an urban greenway, with lake and floodplain patches. Floodplains are much more effective at removing inputs of nitrate via denitrification than are lakes, especially given lower inputs from fertilizer and irrigation.

Biogeochemical studies of nitrogen in the CAP ecosystem were an early emphasis, based on the construction of a mass balance for nitrogen for the entire ecosystem (Baker et al. 2001). Work is underway on a comparable mass balance for carbon, which will incorporate net ecosystem exchange of carbon based on net primary productivity measurements, carbon storage estimates for built structure as well as vegetation, and industrial respiration (fossil-fuel burning). Findings to date are that the industrial respiration far outweighs any potential carbon sequestration by vegetation, even though carbon is accumulating the area's vegetation and soils.

Human Control of Biodiversity (BIODIV)

Studies in the CAP LTER region using brittlebush (*Encelia farinosa*) have indicated that desert remnants behave more like urban mesic yards than the outlying desert (Faeth et. al. 2005). These also found that urban habitats exhibit a reduction in species diversity and altered species composition. McIntyre et. al. (2001) investigated the effects of urban land use on ground arthropod communities in the CAP LTER region based on long term pitfall traps in replicated land use types. These studies examined regional scale effects of residential, industrial, agricultural and desert remnant areas on arthropod communities. Whereas species richness did not differ, community composition varied among land use types. More specifically, they found that predators, herbivores and detritivores were most abundant in agricultural sites and omnivores were abundant in all sites, indicating that trophic dynamics vary by land use type. Similarly, Cook and Faeth (2006) investigated ground arthropod communities in agricultural fields, commercial sites, residential neighborhoods (xeric and mesic), desert remnants, and natural desert areas. They found that the two most heavily irrigated and productive land use types (agricultural and mesic sites) supported the greatest abundance and number of arthropod taxa. Notably, desert remnants and outlying deserts differed in community composition. However, Shochat et al. (2004) found that the more productive habitats (mesic sites and agricultural sites) had a lower number of taxa but greater spider abundance when compared to desert sites. Consequently, urbanization results in changing the food web structure and dynamics in urban areas.

Although diversity is reduced for most animal groups, plants are a different story. Through importation and the influence of the nursery trade, CAP researchers have found that the total number of plant species is vastly increased by urbanization, with an almost entirely new set of species characterizing urban areas (Walker et al. in press; Fig. 7). In addition, homeowner choice

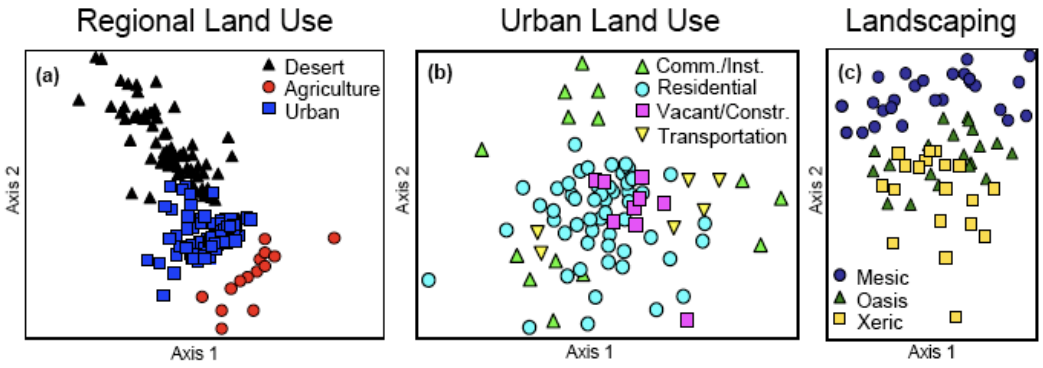


Figure 7. Non-metric multidimensional scaling at three scales in the CAP ecosystem, showing distinct plant communities at the regional scale, substantial overlap at the local land-use scale, and distinct communities characterizing different residential yards that vary by landscape aesthetic. From Walker et al. in press.

plays an important role in determining plant species composition of yards.

Understanding biodiversity changes and trophic dyamics is critical to management of habitats, species diversity, and invasive species in rapidly expanding urban areas. Investigations examining **Ground arthropod diversity at North Desert Village** have compared ground arthropod data from before and after the establishment of the four landscape types at NDV. The research team predicted that landscape treatment would significantly alter the trophic structure and community composition of ground-dwelling arthropods at NDV. Specifically, they predicted that the mesic habitats should have higher abundances but lower diversity than more xeric habitats or mesic > oasis > desert for abundances but the opposite for species richness. Rarefaction analyses showed that all of the treatments differed in species richness before and after the installation of the treatments with the exception of the control, and the differences found in the mesic and oasis treatments were significant. Species richness in the xeric and native treatments also significantly differed after the installation of the landscape regimes. While the native and non-native xeric treatments were more similar to one another than any other treatment, the mesic treatment was most different than any other and the oasis treatment, as expected, fell in between these two distinct types of landscape management. Greater arthropod abundances were found in the oasis treatment compared to the native and xeric treatments and an even greater abundance in the mesic treatment. This supports the hypothesis that trophic dynamics are mediated by bottom-up resources and as productivity increases, species abundance also increases. The opposite pattern was found for species richness. Species richness was greater in the less productive treatments. Notable differences were also found between the two least productive treatments where the main distinction between the two treatments is plant diversity. A significant difference was found between arthropod species richness in the xeric and native treatments. Furthermore, differences were also found in the distribution of the trophic guilds in these treatments. These analyses tell us that while species abundance in non-native vegetated xeriscapes mimics that found in xeriscapes with native vegetation, these landscaping treatments may differ fundamentally in community structure.

CAP research extends understanding of biodiversity in desert remnants through an examination of the **Nestedness of remnant desert plant communities in the Phoenix metropolitan area** and an analysis of what mechanisms may be responsible for a nested pattern (Stiles and Scheiner 2008). The researchers recorded plant diversity data via a transect method in 22 undeveloped desert remnant islands that had been possibly disturbed in the past but never developed. Researchers focused on the woody community composed of cacti, shrubs, and trees. Most of the patches were in mountainous parks that have been preserved for recreation and conservation. Using the Nestedness Temperature Calculator and other suitable methods, the researchers analyzed the nestedness of each data set. They also investigated whether declines in species abundance across sites were evident at the habitat level. They found that nestedness was ubiquitous in this system and was present at two scales, the entire island and individual habitat types. However, analyses did not indicate a primary mechanism for the nested pattern. At the island level, analyses did suggest that elevation has an important influence on nestedness. The researchers conclude that species respond individually to patterns and processes in nature and that nestedness likely results from multiple, not single, contributors.

Other work has been recently published (Stiles and Scheiner 2007) that explores mathematical functions for describing the **Relationship between species richness and area**. Many researchers have assumed that this relationship is a power function. This research investigates alternative species-area functions, using data on Sonoran plant species richness in

desert remnants found in urbanized portions of the Phoenix area. The study indicates that while researchers have perpetually used power functions, other species-area functions provided the best fit for certain datasets. No one function best described all species. This work ends with a call to researchers to explore and compare the range of species-area functions in their research to obtain a best fit rather than relying on the ubiquitous power function.

Urbanization, as it transforms natural biotic systems into human-dominated landscapes, has become recognized as one of the greatest threats to bird diversity throughout the world. However, certain landscape designs may provide mini refuges within urban areas, enabling the persistence of a natural bird community. Researchers at CAP LTER have used mechanistic approaches to potentially uncover some of the causal relationships between urbanization and biodiversity (Shochat et al. 2006a,b). Research on **Foraging decisions, bird community structure, and an urban-rural gradient** has used giving-up density (GUD) as a measure at artificial food patches. The GUD quantifies a forager's perception of costs and risks associated with a patch, as well as the quality of the habitat. In this research design, investigators manipulated the missed opportunity cost (MOC) by enriching the habitat with additional food resources on day 2 of a two day experiment. They predicted that birds foraging in mesic yards will show no significant change in GUDs from day 1 to day 2 because of the higher resource levels in this habitat type. In other words, adding additional resources will not alter foraging behavior since the environment is already saturated with food resources. However, they predicted that in xeric yards the GUDs on day 2 would be higher because of the increased resources (i.e. foragers will spend more time foraging on the additional resource patch). Preliminary results from 13 residential landscapes in 2008 suggest that birds employ different foraging behavior between mesic and xeric yards (Repeated Measures ANOVA, $p=0.02$) and that increasing resources had a marginally significant effect on GUD (Repeated Measures ANOVA, $p=0.06$). This study provides key information on some of the mechanisms responsible for high densities in urban bird communities. In particular, birds foraging in xeric yards behave more similarly to desert birds, thus providing additional justification for this landscape design in future developments to increase urban biodiversity.

Preliminary results from analyzing the second wave of the **NDV social survey** indicate that preferences for different types of landscapes elicited using computer-generated images did not change with the installation of new (actual) landscapes. High water use landscapes remained most preferred, and low water use landscapes were least preferred. Residents' satisfaction with their landscaping did change in response to installation of experimental treatments. Residents were most satisfied with mesic landscapes and least satisfied with native desert landscapes. There was a statistically significant increase in the likelihood that those who lived in desert landscape treatment areas would agree with the statement "The natural desert landscape is beautiful." There was no statistically significant change in responses to this statement by those who do not live in the desert-landscaped area. This strongly suggests that it was the experimental treatment that caused the change in aesthetic appreciation among those living in the desert landscape. This supports the observation from Wave 1 that the nature-human dichotomy increases with exposure to desert landscapes. People with desert landscapes grow to appreciate the desert aesthetically over time, while their preference for having it in their own yard decreases. This finding is further supported by content analysis of people's reasoning during Wave 2 interviews. One interviewee from the desert treatment area clearly stated that she "loved the way it looks," but that it is not appropriate for children playing and doesn't cool the house

like trees and grass. These findings contradict a dominant policy assumption that people will grow to like desert landscapes over time.

Biodiversity and neighborhood social variation, an avian research project in **PASS** neighborhoods, is yielding interesting results. Researchers have found that bird community structure is significantly influenced by different residential landscape designs and vegetation structures. Specifically, native bird communities demonstrated strong associations with xeric landscaping (drought-tolerant trees and crushed gravel) while urban specialist birds exhibited a significant preference for mesic landscaping (water-dependent trees and turf). People in neighborhoods with high bird diversity are twice as likely as people in low diversity neighborhoods to be satisfied with the variety of birds. This suggests that people notice and value biodiversity in their immediate surroundings and that similar neighborhood characteristics are attractive to people and to birds.

Informatics

CAP continues a strong tradition of leadership in ecoinformatics. The CAP Information Manager is currently co-Chair of the LTER Information Management Committee (IMC). In collaboration with several other groups involved in information management, the LTER IMC organized a large 'Environmental Information Management Conference' in Albuquerque, NM this year. Over 100 participants came together from all over the US, Australia, and Europe for two days of presentation, panel discussions, keynotes, and posters. The conference proceedings are peer reviewed and a printed version is available here http://www.lulu.com/content/3822310. In collaboration with staff from the network office the IMC is developing a new web page http://intranet.lternet.edu/im/ in Drupal. This new format allows for a very dynamic web site, which currently is mostly used to collect important documents but the larger vision is to create an extensive resource collection for environmental information management practices.

As noted earlier in this report, SEINet received a NSF BDI grant to further develop the described specimen identification application and to work more closely with its stakeholders. It is envisioned that SEINet will be operating as a consortium endorsed and governed by all data providers. Transferring more ownership to all stakeholders will hopefully achieve a more sustainable mode of operation.

Ongoing projects include the Arizona Hydrologic Information System, which was funded for another year. Informatics staff are currently developing a Drupal portal where the separate developments from last year are pulled together to become a prototype application that will serve water related data.

Development on the web-based EML editor has progressed well. The current version has more features than originally envisioned with a schema walker allowing any XML schema, not only EML, to be used for generating a web-based editor. More information and the code can be found http://intranet.lternet.edu/im/project under SchemaWalker and MetadataEditor.

CAP has begun to process streaming sensor data. Two remote stations are currently collecting weather data and another one located in a schoolyard will go online shortly. CAP is in the process of updating the hardware on the currently operating stations and putting together the appropriate software packages to handle the incoming data. Automating data upload from analytical instruments is still a challenge requiring close collaboration between the CAP wet lab and the information manager.

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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).

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

Choi, Chichi. Comprehensive water and salt flux in an urban system (M.S., Fulton School of Engineering, P. Westerhoff).

Fokidis, J. 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).

Gustafson, Annie. Sustainable desert cities: A comparative analysis of water resource management in Phoenix and Tucson (Ph.D., History, P. Hirt).

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

Hedquist, Brent. Spatial and temporal dynamics of the urban heat island in Phoenix, Arizona (Ph.D., Geography, A. Brazel).

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).

Neil, Kaesha. Effects of urbanization on the spatiotemporal pattern of plant flowering phenology in the Phoenix metropolitan area. (Ph.D., School of Life Sciences, J. Wu).

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-Taft, Laura. Urbanization effects on biodiversity and food webs (Ph.D., School of Life Sciences, S. Faeth).

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).

Completed

2008

Davies, Rachel. The effects of urbanization on belowground ecosystem processes in the Sonoran Desert. (M.S., School of Life Sciences, S. Hall).

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 aims to:

- develop schoolyard ecology programs where students collect data similar to CAP LTER data, enter results into a database, share data with other schools, and develop hypotheses and experiments to explain their findings;
- improve science literacy by exposing students and teachers to real research conducted by University-level scientists;
- enhance teachers capabilities to design lessons and activities that use scientific inquiry and encourage interest in science;
- provide access to and promote the use of CAP LTER-generated materials and information;
- encourage collaboration between CAP LTER researchers and the K-12 community

From an initial collaboration with 12 schools in 1998, **Ecology Explorers** has grown to include over 100 teachers in 25 school districts, 4 charter schools, and 2 private schools. 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 Arizona State Education Standards, including science, math, writing, social science and technology standards. The website continues to be updated (http://caplter.asu.edu/explorers), and the teacher's manual was updated to reflect the new Arizona Science Standards. This summer program engages CAP LTER personnel, ASU personnel and community partners.

Ecology Explorers continues to provide teacher training in ecology to schools that have underserved, minority populations. On average, the schools where Ecology Explorer participants teach have 39% of their students enrolled in the free or reduced lunch program. About 42% of students in these schools are from under-represented minority groups (African-American, Native American and Hispanic). Hispanic students account for the vast majority (around 80%) of minority students on average.

A hallmark of the **Ecology Explorers** program is continued teacher support during the academic year. We work with teachers in their classrooms as well as hold day-long workshops based on teacher requests. We worked to expand our partnerships with local natural areas to

expand CAP LTER teacher training. We held a focus group for high school teachers at the Gilbert Riparian Institute to gauge their interest in conducting Ecology Explorer protocols at this site in addition to their schoolyard work. We are working with the Deer Valley Unified High School district to provide more in-service teacher training on ecology and urban ecology.

We developed and delivered a one-day workshop on urban ecology to a larger group of teachers (~25) in a partnership with a local environmental education association. This workshop entitled, "Neighbors and Nature," was very successful.

Additionally we were provided with an opportunity to deliver three one-day workshop on doing schoolyard ecology in El Salvador. Approximately 60 teachers from El Salvador participated in this workshop.

The **Ecology Explorers** program employs a range of methods for program evaluation (Banks, Elser and Saltz 2005). Pre- and post-program teacher surveys gauge teacher's expectations and response to the summer internship program, while follow-up surveys and interviews indicate how teachers have implemented their teaching plans during the school year. The high school teachers in the past summer's internship participated in pre- and post-surveys, tests and an analysis of their conceptual models. The results suggested that after participating in the two-week internship these teachers had developed more complex models of interactions within ecosystems. Results of this evaluation have been submitted for publication.

We provided after-school science activities based on Ecology Explorers programs to middle-school children associated with the non-profit Boys Hope Girls Hope mentoring organization. We also delivered a program on doing backyard ecology for home schooled children in association with the Arizona Science Center.

Finally, we are part of a newly funded NSF ITEST grant that has created after-school science/engineering clubs targeting middle school-aged girls and minorities. Our part of this program focused on developing lessons related to the Urban Heat Island. The children participating in the NSF ITEST funded program are being more formally evaluated via pre- and post- tests as well as analysis of reflection notebooks. This program is just ending its first year and data have not been analyzed.

We have developed programs in conjunction with ASU's Science Service Learning. One program, **Service at Salado** (http://caplter.asu.edu/explorers/riosalado), formed two after-school clubs that engaged 50 children in local environmental projects. **Service at Salado** works closely with staff of the City of Phoenix Rio Salado Habitat Restoration Project. During 2007-2008, this endeavor involved 22 ASU undergraduate students working as club facilitators and interns. Events in November and April allowed student participants to present their projects to each other, Rio Salado staff, and representatives from other public and non-profit organizations. Projects from each of the clubs can be found at the Service at Salado website at http://caplter.asu.edu/explorers/riosalado. One project, a coloring book of common wild plants found at Rio Salado, is a resource for the Rio Salado visitors center.

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 anticipates involving its graduate and undergraduate students in CAP research over time.

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 Sustainability Partnership (SP), a quasi-consulting arm of the GIOS, engages policy makers, resource managers, and industry leaders in planning and responding to the challenges of urban growth, environmental protection, resource management, and social and economic development. SP is currently engaging developers and stakeholders on the eastern and western edges of the greater Phoenix area in a dialogue with ASU faculty with the aim of developing projects of mutual benefit. CAP LTER has been active in these initial discussions. GIOS plays a central, liaison role in ensuring effective knowledge exchange from academic researchers (i.e., CAP LTER) to decision makers and end users of the science.

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 **2008 Annual Poster Symposium** celebrated 10 years of ecological and socioecological research in CAP LTER. More than 15 scientists, staff, and individuals in the public and non-profit sectors were honored for participating in the project for 10 years. Martina Alberti, University of Washington, gave the keynote address. The central theme of the morning session was research partnership between individuals in the academy, public sector, and non-profit sector. CAP organized a roundtable discussion on the urban heat island, storm water management, and conservation and open space, involving participants from CAP, the Nature Conservancy, Sonoran Institute, Flood Control District of Maricopa County, Pima County Natural Resources, and the Arizona State Climate Office. IPAs meet during the symposium to discuss research strengths, emerging initiatives, and how to better involve public and non-profit partners in research.

Box 1: CAP LTER Meetings, 2007-2008

September 2007: Graduate student orientation; NSF site visit
October 2007: Jess Zimmerman, Luquillo LTER
November 2007: Graduate student summer grant presentations
January 2007: Annual poster symposium
February 2008: Discussions about new ASM format
March 2008: Climate-Ecosystem Interactions IPA presentations
April 2008: Water Policy, Use, and Supply IPA presentations
May 2008: Summer graduate student meeting
July 2008: First Regional LTER Symposium, Albuquerque, NM
August 2008: CAP retreat

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 sought to reorient its ASMs to enable greater collaboration between scientists of varying disciplines. Toward this end, a brainstorming session was held in February 2008 and a newly-adopted ASM format, focusing on integrative IPA research was tested during the March and April meetings. Fall 2008 meetings will involve the remaining three IPAs in giving presentations.

CAP held a retreat in August 2008 to discuss future research directions and the structure of project as a precursor to planning for its 2010 renewal proposal. Small groups considered the advantages and challenges of the current IPA structure and provided feedback on possible changes. Plenary sessions involved participants in identifying new research directions for the project and changes to the conceptual theme.

Collaborations and Partnerships

CAP LTER seeks to maintain and expand its collaborations and partnerships within academia and beyond. In fall of 2006, ASU and the Chinese Academy of Sciences formed the *Joint Center on Urban Sustainability* in Beijing. This initiative involves several CAP LTER scientists in fields ranging from landscape ecology to environmental justice. In June 2008, CAP scientists Jianguo Wu, Corinna Gries, and Christopher Boone traveled to China with colleagues from the BES to engage in further discussion on how to forward research linkages on urban ecology between US and Chinese scientists.

Building on relationships established at the 2008 Annual Poster Symposium, CAP managers Stevan Earl and Marcia Nation participated along with CAP scientist Susanne Grossman-Clarke and the GIOS Sustainability Partnership in the *Superstition Vistas Experts Workshop*, which focused on proposed development along the eastern edge of the metropolitan area. This workshop, led by the California-based consulting firm EDAW and the Sonoran Institute, was the first step in visioning sustainable development in this large tract of publicly owned, desert land. CAP will continue its involvement in the development process with an eye to establishing monitoring sites and possibly experiments in the area.

Lead PI Nancy Grimm has been involved in a US Climate Change Science Committee (CCSP) activity, commissioned by the President to NOAA, to develop an overall summary of the CCSP's research on the impacts of climate change on the United States. This synthesis will be published and available early in the next administration. The synthesis is relevant to CAP LTER planned research on understanding urbanization in the context of a changing world, where climate change will assume greater prominence as a press event.

CAP LTER was approached by Beth Vershure, Executive Director, Cahava Springs Conservancy, to work with this organization to integrate ecological monitoring into a housing development in the Cave Creek (north of Phoenix) area. CAP scientists are planning monitoring of stormwater runoff from the development, as well as ecosystem integrity of a small riparian area, which is downstream from this eco-development. Initial plans include involving citizen scientists in this monitoring.

CAP LTER's participation in NEON continues. NEON Inc. completed its site visit of the tower in the CAP study sites and the STREON site at Sycamore Creek. CAP scientist Dan Childers will represent CAP at a fall 2008 NEON meeting in Washington, D.C.

CAP LTER has begun an initiative with Navajo Elementary School, Scottsdale Unified School District, to install a weather station and storm water monitoring equipment at the school. CAP LTER Education staff will work with teachers at school to integrate data from these

instruments into curriculum. CAP graduate students will also be involved in classroom activities and data analysis.

For the first time since CAP's inception, project personnel participated in a **Regional LTER Symposium** with SEV, JRN, NWT, and SGS LTERs, held in Albuquerque in July. Approximately 20 CAP scientists, including graduate students, staff, and faculty, attended the highly successful event. Triennial regional symposia are planned from now on.

Several cross-site research projects have been initiated recently with funding from NSF supplements and the LNO. 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. These scientists will work with scientists at four LTER sites associated with these metropolitan areas and cities, which also received funding to support this research.

CAP scientists are co-PIs on four grants from the LTER Network Office. A team of researchers from across the US lead by a CAP LTER scientist (Kelli Larson) has been awarded a grant of $17,805 from the LTER Network Office to convene a workshop at ASU in 2009 to further understanding about the management of residential landscapes. CAP's Information Manager, Corinna Gries, is co-PI on a grant to establish a collaborative project database for LTER sites. Work on this project will be done over two workshops, involving approximately 16 sites. CAP co-Directors Grimm and Redman are co-PIs on a grant to establish a working group to examine alternative future scenarios for LTER regions and to evaluate the implications of these for key ecosystem services, habitat integrity, and connectivity. Another LNO-funded project that includes a CAP scientist as co-PI (Christopher Boone) focuses on convening participants from LTER sites to consider how to design studies of social and ecological systems (SES) that lead to comprehensive, transdisciplinary understanding of how these systems function.

Education Manager Monica Elser is a participant in the Teaching Ecological Complexity project which involves the Andrews, Shortgrasse Steppe, Jornada, Luquillo and CAP sites. Our education program has established several strong community partnerships. These include those with the Desert Botanical Garden, the Gilbert Riparian Preserve, the Creighton Elementary District, the Phoenix Elementary District, the Roosevelt School District, the Arizona Foundation for Resource Education, the Sonoran Institute, the Sonoran Desert Center and the Southwest Center for Education and the Natural Environment.

CAP scientists have recently partnered with counterparts from Jornada and Sevilleta as well as researchers with the U.S. Forest Service (Rocky Mountain Research Division) to write a white paper conceptualizing a Southwest urban collaborative formed around the metropolitan areas of Phoenix, Albuquerque, and Las Cruces. This white paper will establish the background for an eventual grant application to the USFS/NSF Urban Long Term Research Areas (ULTRA) initiative. 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 a 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 59 journal articles (28 published, 7 in press, 24 in review) and 22 book chapters and books (8 published, 11 in press, 3 in review). In addition, research results are routinely presented at meetings and conferences in a diverse array of fields.

CAP scientists have been involved in several high-visibility publications recently. Nancy Grimm was the lead author (with four CAP scientists among the seven co-authors) for an article in *Science*, "Global change and the ecology of cities." Grimm was the lead author on another high impact publication, Grimm et al. (2008a.) "The changing landscape: Ecosystem responses to urbanization and pollution across climatic and societal gradients," *Frontiers in Ecology and the Environment*, which was part of a special feature in that journal organized by JRN lead PI Debra Peters (e.g, Peters et al. 2008).Former CAP graduate student, John Roach and other CAP scientists recently published a paper in *BioScience* that examines how urbanization and associated changes in hydrology and geomorphology have affected a desert stream.

CAP scientist Chad Johnson was featured in a *Science News* article that focused on behavioral syndromes among spiders, including the urban black widows that Johnson studies. Nancy Grimm was the G.W. Minshall Lecturer at Idaho State University in 2007 and presented two guest lectures, "Urbanization of the desert: Patterns and processes of a socioecosystem" and "A long-term perspective on biogeochemistry of desert streams."

CAP researchers also disseminated research results to non-academic audiences. Kelli Larson gave a presentation on water issues, risk perceptions, and policy preferences to the Riparian Institute in Gilbert, Arizona. Sharon Harlan shared her research on household water consumption to a group during the First Thursdays venue at Winslow|Orcutt Architects in Phoenix. A fall 2007 article in the *Arizona Republic* included comments by CAP scientist Chris Martin on why newly-planted sycamore trees around the University of Phoenix stadium (host of the 2008 Super Bowl) died. Martin questioned the wisdom of using a riparian species as a parking lot tree. Participation in various workshops and working groups in metropolitan Phoenix and beyond allowed CAP scientists to share their research through informal presentations.

Box 2: Selected Other Outreach Activities

- Classroom presentations to elementary through high school students: 600 students
- ASU Geosciences Day: >100 community members
- Feathered Friends Festival: >100 community members
- Sally Ride Science Festival: > 100 community members
- Arizona Science Center Global Awareness Day: > 50 community members
- Valley Forward's Earthfest Educations Night: >75 educators
- Phoenix Outdoor Festival: >75 community members

The CAP LTER website continued as a vehicle for communicating research results and data to scientists and the general public. CAP staff has summarized key research findings for the website's Research Highlights section.

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*.
- 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.
- Research on **nestedness of remnant desert plant communities in the Phoenix metropolitan area** is the first investigation of its kind to examine nestedness of plants in an urban environment. This research is likely the first study to explore the relationship between species abundance and community nestedness.
- Work on **modeling fluxes of water and salt through the urban infrastructure** has created a dynamic model that provides a holistic view of urban water supply and water use. The model is being used to examine fluxes in the city of Goodyear, Arizona in an upcoming CAP LTER project and can be applied to different cities to address water and salt flux concerns.
- 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.

- The development of an **online EML editor** will make the task of editing metadata much easier for researchers. Informatics staff at the LNO are interested in how this can be applied network-wide.

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.
- For example, under the **drought and water conservation policy** project, research has fostered interdisciplinary collaborations between historians, geographers and key policy and stakeholder informants. A main product of this effort is a conservation program database including nominal data indicating whether or not ten municipalities have different conservation programs and summary information for broad categories of conservation programs (e.g., regulations, conservation/drought management plans, and economic- and information-based programs). This information will be available for future researchers at CAP and may also aid conservation education planning in the region.
- 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 **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. This fall, for instance, CAP scientists Sharon Hall and Kelli Larson are convening an IGERT workshop course on residential landscapes.
- A spring 2009 course, "From yardstick to gyroscope: Interdisciplinary methods for the long-term study of social-ecological systems," will involve students from four universities (ASU, University of Georgia, Florida International University, and University of Vermont) in learning about socioecological research in the LTER Network.
- 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.
- Data collected as part of the Geological Remote-Sensing Lab's (GRSL) research programs is archived and is available to CAP LTER researchers and graduate students. This archive includes data collected within the study area as well as many other sites through the western US. As such, it represents a rich data resource for faculty members and graduate students. Data products produced by the GRSL are available for use as class and presentation materials and have been used both for K-12 and college-level classes and presentations. The datasets from the historic land-use project can be used for further research as well as in GIS, geography, planning, or other instruction.

- 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 two post-doctoral associates, all full-time on CAP LTER. 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 25 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 57 papers have been co-authored by students (including works in press and review) and on 31 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.
- 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. A new CAP/BES cross-site initiative and the PASS project both use working group formats to plan their study designs.
- 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 Sustainability Partnership, such as those involving water managers in Arizona, which gives the project access to important stakeholder groups.

- The **PASS** is a vehicle for increasing knowledge of how residents shape and respond to the local environment, which is a necessary step in devising a more sustainable city. Communities, social lives, values, and behaviors must be understood in order to comprehend the place of humans in the environment. This is vitally important in rapidly urbanizing regions, such as Phoenix. Arid cities face unique environmental challenges that accompany population growth, including extreme heat, limited water resources and shade, and harsh conditions for species survival. Many scientists and policy makers believe that these challenges can be overcome only creating strong, engaged communities that understand and appreciate their biophysical environments.
- Research on the **urban heat island**, including work on populations vulnerable to excessive heat, been shared with policymakers and practitioners through the City of Phoenix 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

Hall, R.O., Jr., J.L. Tank, D.J. Sobota, P.J. Mulholland, J.M. O'Brien, W.K. Dodds, J.R. Webster, H.M. Valett, G.C. Poole, B.J. Peterson, J.L. Meyer, W.H. McDowell, S.L. Johnson, S.K. Hamilton, N.B. Grimm, V. Gregory, C.N. Dahm, L.W. Cooper, L. R. Ashkenas, S.M. Thomas, R.W. Sheibley, J.D. Potter, B.R. Niederlehner, L. Johnson, A.M. Helton, C. Crenshaw, A.J. Burgin, M.J. Bernot, J.J. Beaulieu, and C. Arango. In press. Nitrate removal in stream ecosystems measured by ^{15}N addition experiments: total uptake. *Limnology and Oceanography.*

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Janssen, M., and J. Anderies. In press. Robustness of social-ecological systems in spatial and temporal variability. *Society and Natural Resources.*

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*.

Martin, C. A. In press. Landscape sustainability in a Sonoran Desert city. *Cities and the Environment*.

Mulholland, P.J., R.O. Hall, Jr., D.J. Sobota, W.K. Dodds, S.E.G. Findlay, N.B. Grimm, S.K. Hamilton, W.H. McDowell, J.M. O'Brien, J.L. Tank, L. R. Ashkenas, L.W. Cooper, C.N. Dahm, S.V. Gregory, S.L. Johnson, J.L. Meyer, B.J. Peterson, G.C. Poole, H.M. Valett, J.R. Webster, C. Arango, J.J. Beaulieu, M.J. Bernot, A.J. Burgin, C. Crenshaw, A.M. Helton, L. Johnson, B.R. Niederlehner, J.D. Potter, R.W. Sheibley, and S.M. Thomas. In press. Nitrate removal in stream ecosystems measured by ^{15}N addition experiments: denitrification. *Limnology and Oceanography.*

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APPENDIX A
CAP LTER PARTICIPANTS

	Duration of Involvement
Principal Investigators	
Nancy Grimm, Life Sciences	1997-present
Charles Redman, Sustainability	1997-present
Co-Principal Investigators	
Jonathan Allen, Engineering	2004-2008
John M. Anderies, Human Evolution and Social Change	2004-present
Ramon Arrowsmith, Earth and Space Exploration	1997-present
Bob Bolin, Human Evolution and Social Change	1999-present
Anthony Brazel, Geographical Sciences	1997-present
John Briggs, Life Sciences	1999-2008
Monica Elser, Global Institute of Sustainability	1998-present
Stanley Faeth, Life Sciences	1997-2008
Corinna Gries, Global Institute of Sustainability	2000-present
Sharon Hall, Life Sciences	2005-present
Sharon Harlan, Human Evolution and Social Change	1999-present
Diane Hope, Global Institute of Sustainability	1997-2006
Jason Kaye, Life Sciences	2002-2005
Ann Kinzig, Life Sciences	1999-present
Lauren Kuby, Global Institute of Sustainability	1998-present
Kelli Larson, Geographical Sciences	2005-present
Chris Martin, Applied Biological Science	1997-present
Peter McCartney, Global Institute of Sustainability	1997-2006
Jordan Peccia, Engineering	1997-2005
Brenda Shears, Global Institute of Sustainability	1997-present
Jean Stutz, Applied Biological Science	1998-present
Elizabeth Wentz, Geographical Sciences	2004-present
Paul Westerhoff, Engineering	2004-present
Jianguo Wu, Life Sciences	1997-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
Christopher Boone, Human Evolution and Social Change	2006-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
Pierre Deviche, Life Sciences	2007-present
James J. Elser, Life Sciences	1997-present
Ananias A. Escalante, Life Sciences	2005-present
Stanley Faeth, Life Sciences	1997-present
Joseph Feller, Law	2004-present
H.J.S. Fernando, Engineering	1997-present
Jonathan Fink, Global Institute of Sustainability	2004-present
Stuart Fisher, Life Sciences	1997-present
Patricia Gober, Geography	1997-present
Susanne Grossman-Clarke, Global Institute of Sustainability	2004-present
Subhrajit Guhathakurta, 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
Hilairy Hartnett, Earth and Space Exploration	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	2004-present
Leslie Landrum, Life Sciences	1998-present
Tim Lant, Decision Theater	2008-present
Kathleen Lohse, Natural Resources, U of Arizona	2005-present
Anandamaye Majumdar, Mathematics and Statistics	2004-present
Nancy E. McIntyre, Bio. Sciences, Texas Tech	1997-present
Geoffrey Morse, Integrated Natl. Science	2006-present
Laura R. Musacchio, Landscape Arch., U of Minn.	1999-present
Soe Myint, Geographical Sciences	2006-present
Thomas H. Nash III, Life Sciences	1997-present
Margaret C. Nelson, Human Evolution and Social Change	1998-present
David L. Pearson, Life Sciences	1997-present
K. David Pijawka, Planning	1997-present
Mark Schmeeckle, Geographical Sciences	2008-present
Everett L. Shock, Earth and Space Exploration	2001-present
Kerry Smith, Business/Econ.	2006-present
Milton Sommerfeld, Life Sciences	1997-present
Ryan Sponseller, Biological Sciences, U of Alabama	2006-present
Juliet C. Stromberg, Life Sciences	1997-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
Amber Wutich, Human Evolution and Social Change	2006-present
Scott T. Yabiku, Social and Family Dynamics	2005-present
Abigail York, Human Evolution and Social Change	2008-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
Eyal Shochat, Global Institute of Sustainability	2006-present
Chona Sister, Global Institute of Sustainability	2007-present
Ryan Sponseller, School of Life Sciences	2006-2007
Amber Wutich, Global Institute of Sustainability	2006-2007

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
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
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-present
Cindy Zisner, Global Institute of Sustainability	1997-present

Public Outrearch/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-present
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

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
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
Kendra Busse, Life Sciences	2006-present
Alexander Buyantuyev, Life Sciences	2002-present
Yolanda Chavez-Cappellini, Languages and Literatures	2006
Chichi Choi, Engineering	2007-present
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-present
Juan H. Declet, Geographical Sciences	2006
Christopher Eisinger, Earth and Space Exploration/IGERT	2003-2005
Michelle Elliott, Human Evolution and Social Change/IGERT	2001-present
Vanessa Escobar, Earth and Space Exploration	2006-2006
Elizabeth Farley-Metzger, Human Evolution and Social Change	2004-2007

Haralambos Fokidis, Life Sciences	2007-present
Sheila Fram, Institute for Social Science Research	2006
Kristin Gade, Life Sciences/IGERT	2004-present
Daniel Gerrity, Engineering/IGERT	2004-2006
Daniel Gonzales, Engineering	2005-2007
Sara Grineski, Human Evolution and Social Change/IGERT	2001-2006
Anne Gustafson, History/IGERT	2005-present
Rebecca Hale, Life Sciences	2007-present
George Alexander Hamilton, Chemistry and Biochemistry	2008-present
Tamara Harms, Life Sciences	2004-present
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
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-present
Scott Norby-Cedillo, Sustainability/IGERT	2007-present
Aura Ontiveros, Applied Biological Sciences	2007-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-present
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
Laura Taylor-Taft, Life Sciences	2006-present
Nathan Toke, Engineering/IGERT	2006-present
Roger Tomalty, Geographical Sciences	2004-present
Jolene Trujillo, Life Sciences	2007-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
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-present
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
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-present
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, Mathematics and Economics	2008-2009
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

Chris Allred, Deer Valley School District	2008
Stephanie Arnold, Veritas Preparatory Academy	2005
Amy Bell, Arcadia High School	2005
Debra Bornstein, Desert Sage Elementary School	2005
Kristy Braaksma, Desert Ridge Junior High	2005

John Brands, Desert Ridge Junior High	2005
Matthew Burke, Trevor G Browne High School	2007
Shiloh Carroll, Highland High School	2006
Kara-Anne Carpenter, Chandler Prepratory Academy	2006
Mark Chatigny, Deer Valley School District	2008
Thomas K. Daniels, Kyrene Akimel A-Al Middle School	2005
Cher Fesenmaier, Desert Mountain High School	2005
Kathryn Frederick, Queen Creek High School	2007
Amanda Grunden, Deer Valley School District	2008
Sharon Harrison, Vista Verde Middle School	2006
Kathleen Hartnett, Alta E Butler School	2005
James Jaeger, Deer Valley School District	2008
Andrea Jewett, Deer Valley School District	2008
John Jung, Mesa High School	2007
Kimber Kay, Ingleside Middle School	2006
Denise Komorous, Deer Valley School District	2008
Scott Krumpos, Deer Valley School District	2008
Melissa Mara, Sandra Day O'Conner High School	2006-2008
Stephanie Maynard, Queen Creek High School	2007
Christin McLellan, Willow Canyon High School	2007
Stephanie Morgan, Perry High School	2007
Jonathan Poe, Deer Valley School District	2008
Linda Riggs, Augusta Ranch Elementary	2006
Jessica Rushford, Deer Valley School District	2008
Michele Schiff, Ironwood High School	2005
Leslie Schramm, Deer Valley School District	2008
Clarice Snyder, Camelback High School	2005
Jeffrey Snyder, Washington High School	2005
Lynn Stinson-Keys, Tempe Preparatory Academy	2005
Kiva Stone, Frank Borman Middle School	2005
Jeffrey Taylor, Mesquite Jr High School	2005
Aaron Ullman, Red Mountain High School	2007
Cheryl Vitale, Mesquite Jr High School	2006
Kim Wallis-Lindvig, Boulder Creek High School	2006

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
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