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

Nancy B. Grimm, Principal Investigator
Nancy B. Grimm and Charles L. Redman, Co-Directors

CAP LTER PHASE 2
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COMPILED BY
NANCY GRIMM
CORINNA GRIES
LAUREN KUBY
MARCIA NATION
KATHLEEN STINCHFIELD
LINDA WILLIAMS
CINDY ZISNER

DRAWN FROM REPORTS SUBMITTED BY
PROJECT PARTICPANTS

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I. OVERVIEW OF RESULTS AND BROADER IMPACTS

Overview

CAP2, the second phase of the Central Arizona-Phoenix LTER (NSF #DEB-0423704), builds upon a seven-year foundation of a comprehensive investigation of rapidly growing metropolitan Phoenix, Arizona. This year marks the second formal year of the CAP LTER renewal, although some research conducted during 2005-2006 was supported through CAP1 supplemental funds under a no-cost extension. A separate report for CAP1 (NSF #DEB-9714833) will be submitted for the work conducted describing activities and findings for the Phoenix Area Social Survey; however, these have been repeated in this report in order to provide a full picture of this year's accomplishments.

Phoenix has proven to be an exciting and stimulating environment for an urban LTER site. The Phoenix metropolis is situated in a broad, alluvial basin at the convergence of the Salt and Gila rivers. The basin, dotted with eroded volcanic outcrops and rimmed by mountains, once supported a vast expanse of lowland desert and riparian systems, but now houses the fifth-largest city in the USA. Phoenix metro occupies much of Maricopa County, consistently one of the fastest-growing counties in the nation (47% since 1990). Water is clearly the single-most important factor controlling diversity, organismal populations, primary productivity, trophic dynamics, and ultimately, human settlement patterns in this desert city, giving credence to a new project area for CAP2 focusing on water use, supply, and policy.

For this report, we highlight projects within each of the 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. Experimental work at North Desert Village, 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 266 journal articles, books, and book chapters since the project's inception in 1997 through 2006. This year (2005-2006), CAP scientists have produced 71 publications that have been published, are currently in press or are in review. Over one hundred individuals have worked on the project since 2004, including 59 faculty members, 11 professional staff persons, 9 post-doctoral scholars, 28 graduate students, 13 undergraduate students, and 30 technicians or support staff persons. During 2005-2006, CAP scientists gave 28 presentations and posters at regional, national and international conferences, and 57 at LTER-related conferences. Finally, CAP has leveraged funding for several large projects that complement its basic science emphasis. Active during 2005-2006 were: "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).

Broader Impacts

CAP LTER's broader impacts are in three main areas: raising national awareness and profile of urban ecology, education and outreach, and 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). Briggs has been an active participant in NEON and LTER planning activities, and Grimm has been involved in efforts to establish a joint center of 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 31 school districts), 4 charter schools, and 2 private schools. 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 13 active fellows, 6 associates, and 5 graduated fellows (emeriti) in our Integrative Graduate Education and Research Training (IGERT) program in urban ecology. Finally, over 20 community partners are engaged in CAP LTER, such as Salt River Project, Maricopa Association of Governments, the U.S. Geological Survey (USGS), and the Gila River and Salt River-Pima Indian communities. 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. While preserving our scientific objectivity, 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.

II. Research Activities

Research Design and Approach

Although our program is fundamentally ecological (*sensu* Likens 1992), we include humans among the organisms interacting and participating in fluxes of energy and materials and contend that an ecological study must monitor and interpret change from a perspective that includes humans as part of nature (Cronon 1995; Kinzig et al. 2000, Kaye et al. 2006). Research thus must integrate the social sciences, encompass longer time horizons, and be informed by flexible models and multi-scaled data (Wu and Li 2006).

To fully integrate these 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 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-forest classification system for Leipzig, Germany
- High-resolution land-cover classification
- Historic land use, Phase II
- Modeling land-use change and ecosystem response

Climate-Ecosystem Interactions (CLIM-ECOS)

Climate is an important driver of processes in most ecosystems, therefore an understanding of microclimate is fundamental to much of our research. Studies of climate-ecosystem interactions (hereafter, CLIM-ECOS) are conducted at multiple scales from single organism 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 2005-2006 were:

- Land use effects on urban tree primary productivity
- Growth effects on *Encelia farinosa* (brittlebush) due to a suppression of arbuscular mycorrhizal fungi at an urban and a desert site
- Impact of the urban heat island on frosts and freezes
- Modeling daytime and nighttime near-surface air temperatures

As well, work has continued on analyzing the data from the **Neighborhood Ecosystem Project**, an outgrowth of the PASS project, which is funded through a NSF Biocomplexity and the Environment planning grant. This project is an interdisciplinary study of the impact of urbanization on human-ecological-climate interactions in Phoenix.

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 2005-2006 included:

- Landscape preferences in the arid Southwest
- Salt River paleogeomorphology

Work on aquatic biogeochemical processes and water quality, undertaken in the FLUXES IPA, is closely associated with the work under this area. Work in the WATER IPA is also well integrated with the Decision Center for a Desert City (DCDC), which focuses on water-management issues in the Phoenix area.

Material Fluxes and SocioEcosystem 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 the most active IPA in CAP LTER, and accordingly, it includes many projects. In this report, we highlight the following studies: Aquatic core monitoring

- Environmental risk and justice
- Atmospheric deposition
- Decoupled biogeochemical cycles: ecological response to C and N deposition from the urban atmosphere
- Aquatic core monitoring
- Water chemistry in local rivers after the spring 2005 rain events
- Patterns of trace-element distribution in an urban desert system

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 2005-2006 that addressed these questions include:

- Microbial biodiversity
- Pollen concentration in surface soil and extant perennial vegetation
- Comparisons between arbuscular mycorrhizal fungal community in the Phoenix metropolitan area and the surrounding desert
- Ecological and social interactions in urban parks

The BIODEV 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 also been a key to 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 determined locations for bird counts in the PASS neighborhoods in spring 2006. Findings from all of these studies relevant to the aims of the BIODEV IPA will be reported in this IPA's research findings section.

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**. Although these activities are carried out in a distinct manner, 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 2005-2006 include: **models and conceptual development**, **long-term experiments**, and **ecosystem services**. Here we summarize activities of those working groups, with findings reported under appropriate IPAs.

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
- Plant size measurements
- Soil coring for physicochemical analyses
- Insect sweep-net sampling
- Mycorrhizal diversity.

All plant-voucher specimens have been identified to species and filed in the ASU Vascular Plant Herbarium. Pictures of cacti have been identified as far as possible and also filed in the herbarium. Data are entered and quality controlled in the database, slides of the sites are labeled and filed. Processing and analysis of the soil-core samples collected during the survey is nearly completed. In addition to the nutrient and organic-matter analyses conducted in 2000, all soil samples from the survey in 2005 have been analyzed for trace elements using ICP-MS, with a focus on heavy and trace metals. The first analyses of plant diversity have been conducted and have been presented at various meetings this summer.

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). 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 are discussed later in this report. The follow-up social survey began in spring 2006 and continues through summer and fall 2006.

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 in press). 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, we 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 our 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.

Respondents (in 800 randomly selected households in 40 neighborhoods that are co-located with Survey 200 field sites) began completing the PASS in spring 2006. 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. Activities are currently underway to link US Census population data and CAP LTER biophysical data sets to the 40 PASS neighborhoods. The surveyed addresses will be retained for the purpose of re-contacting these particular households for the next wave of PASS.

Working groups within CAP LTER have tackled various research challenges during 2005–2006. Synergies among members of the **Models and Conceptual Development working group** forwarded work on modeling within the project. In addition, three members of the group have begun research under a subcontract with the University of Washington and funded through a NSF Biocomplexity grant, **Urban Landscape Pattern: Complex Dynamics and Emergent Properties**. In this work, researchers have proposed to apply a dynamic probabilistic relational modeling approach to representing the urban landscape. The **Long-Term Experiments** working group held meetings to discuss research management and data analysis for work conducted at North Desert Village. A new working group emerged within CAP to examine **Ecosystem Services.** This group synthesized available data and information, or relatively easy-to-find data and information, on ecosystem services in the Phoenix Basin and analyzed this information along three lines: an ecological or natural science perspective, an economic or human value perspective, and a technological or engineering perspective. The object of the analysis, conducted by three teams of researchers, is to identify 'critical' ecosystem services in the CAP LTER area and how they have changed and will change in the future. Although the **Education, Informatics, and Knowledge Exchange** working groups did not actively meet, we have been successful in leveraging LTER funding to accomplish outreach and data-management objectives that are beyond the capability of the CAP LTER, and many of our scientists are active in those projects.

III. Highlights of Research Findings

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

Land-Use and Land-Cover Change (LULCC)

Remote sensing, using satellite imagery and aerial photography, has been a foundation for ongoing projects in this IPA. This year, several new contributions explored methods for mapping and classifying LULC (Wentz et al. 2006; Möller 2006; Stefanov and Netzband 2005; Walker and Blaschke in review) and used these data for modeling and measuring change (Buyantuyev et al. in press). Research efforts toward establishing classification schemes include the **high-resolution, urban-forest classification for Phoenix** project (Walker and Briggs in press; discussed in last year’s report) and an associated study in Leipzig, Germany, a **high-resolution urban-forest classification for Leipzig, Germany**. The latter study involved using high-resolution, color-infrared photography to extract tree cover through an object-oriented classification procedure, which takes into account intrinsic information (i.e., within-pixel spectra values and object texture) as well as neighborhood characteristics. This process made it possible to extract real-world objects as the basic units for analysis. CAP researchers subdivided the entire image into small, relatively homogeneous polygons as defined by a segmentation algorithm, in essence creating patches as the fundamental units for analysis. They then classified these objects based on contextual relationships, such as spectral signatures, texture, and shape metrics to produce the following binary classification: woody vegetation and all other land-cover types

(Walker and Banzhaf 2006). This study allowed the primary researcher, a CAP graduate student, an opportunity to work with an expert in the field and to engage in comparative research.

An ongoing initiative will create a **high-resolution land-cover classification** scheme for use in future social, ecological, and geographical studies (Walker and Blaschke in review). While adequate medium- to coarse-resolution land-cover classifications are available for Phoenix metro area, no high-resolution classifications exist. CAP LTER researchers used an object-oriented approach to develop two urban land-cover classification schemes using high-resolution (0.6m), true-color aerial photography. The imagery was segmented into classifiable polygons through a two-tiered segmentation process. They re-segmented a preliminary segmentation level, based on the spectral similarity of neighboring objects, by merging larger objects (e.g., houses and roads) while retaining the fine-scale segmentation of smaller, more heterogeneous objects (e.g., trees). They developed an initial classification scheme for a sample area within the Phoenix area, heavily weighted by standard nearest-neighbor functions generated by samples from each of the classes, which produced an enhanced accuracy (84%). Finally, from the hierarchical structure of initial classification scheme, they developed a second scheme. All parameters were transformed into a fuzzy rule set, creating a product transportable to different areas of interest of the same imagery, or for use in similar imagery of different times for land-cover change detection. A comprehensive accuracy assessment revealed a slightly lower overall accuracy of 79% for the rule set-based classification. Researchers concluded that the transportable classification scheme is satisfactory for general land-cover analyses. However, classification accuracy can be enhanced at site-specific venues when incorporating nearest-neighbor functions using class samples.

One of the earliest studies completed in CAP's first phase was the **historic land-use** project, which produced five maps of changes in desert, agricultural land, urban land, and designated open space between 1912 and 1995 (Knowles-Yánez et al. 1999). This year saw completion of the **historic land-use, Phase II**, which provides a much more detailed, spatially based analysis of land-cover change over the past 30 years (Keys et al. in press). Documenting a dramatic outward shift (from central Phoenix) in high-value land over this period, researchers also concluded that a central place model of urban growth is appropriate for Phoenix; that is, despite its 24 municipalities, the city of Phoenix itself is the most important nucleus of the region.

Results from the first PASS continue to be analyzed and published (Larsen and Harlan in press). PASS findings have proven useful in analyzing the sociological aspects of housing enclaves (e.g., gated communities), revealing that motivations for living in these enclaves and economic and ethnic characteristics of their populations are not as simple as commonly held assumptions would suggest (Kirby et al. 2006). PASS-1 data also are being used to compare with NDV social-survey data, as described later in this report. PASS researchers have designed and implemented a PASS-2 survey, involving 40 neighborhoods. Preliminary analyses of these survey data have begun, with a fuller accounting expected in next year's report.

Modeling land-use change and ecosystem response cuts across several IPAs but is reported here. Researchers are developing simulation models of land-use change (focusing on urbanization) and process-based ecosystem models, and coupling these models to investigate how urbanization-induced environmental changes affect ecosystem functioning in the Phoenix region. Following validation of a physiologically based ecosystem process model, which estimates ANPP and biogeochemical cycling by plant functional type (Shen et al. 2005, reported last year), researchers completed a modeling study to explore how urbanization-induced environmental changes in air temperature (T_{air}), carbon dioxide (CO_2) concentration, and nitrogen (N) deposition separately and/or interactively affect major ecosystem processes of

Sonoran Desert remnants along the urban-rural gradient. In the CAP region, increased air temperature is the result of a pronounced urban heat island (UHI) effect. Elevated atmospheric CO_2 and nitrous oxide (NO_x), products of Phoenix's automobile dependency, have given rise to a "CO_2 dome" of up to twice the global mean concentration and a SW-NE gradient of N deposition (N_{dep}), from <5 to a maximum modeled value of nearly 30 kg ha^{-1} y^{-1} (Fenn et al. 2003).

This study illustrates well one of the central contentions of CAP LTER research: human activities profoundly modify urban ecosystems and thereby provide a unique "natural laboratory" to study potential ecosystem responses to anthropogenic environmental changes. Indeed, because urban heat islands, CO_2 domes, and high rates of N deposition now affect large cities and their environments, to some extent cities portend the future of the global ecosystem (see also Redman and Jones 2006). Model results were that, at the ecosystem level, ANPP and SOM both increased with increasing CO_2 and N deposition individually and with all combinations of changes in air temperature, CO_2, and N deposition. Soil N responded positively to increased N deposition and air temperature, but negatively to elevated CO_2 concentration, likely because increased ANPP drew down soil N supply. Effects on ANPP and SOM were significantly greater in wet years, whereas changes in soil N were larger in dry years. At the plant functional-type level, ANPP generally responded positively to elevated CO_2 and N deposition but negatively to increased air temperature. Significant changes in ANPP at the PFT level were observed, primarily in wet years. C_3 winter annuals showed a greater ANPP response to higher CO_2 levels (>420 ppm) than shrubs, perhaps because competition for soil water and nutrients was stimulated by increased CO_2. Overall, effects of the three environmental factors were interactive and nonadditive and largely depended upon rainfall variability. The researchers' simulation results offer intriguing implications for assessing ecological consequences of urbanization as well as global climate change (Shen et al. in review).

Climate-Ecosystem Interactions (CLIM-ECO)

Research in the CLIM-ECO IPA has focused on the controls on above-ground net primary production (ANPP) from an array of processes (Shen et al. 2005). Long-term monitoring of **land-use effects on urban tree primary productivity** is conducted four times a year at 51 sites throughout the Phoenix metropolitan area. Preliminary findings from CAP 1 indicated the presence of a roughly defined urban-to-rural gradient for atmospheric CO_2 and early-morning air temperature. Based upon these findings, the 51-site monitoring grid was established for long-term measurement of urban tree volumes in winter, and leaf chlorophyll content in summer. Research at more intensive experimental sites has examined ANPP of landscape trees planted in urban parking lots (Celestian and Martin 2005; Celestian and Martin 2004) as well as the effects of landscape management on ANPP (Stabler and Martin in review; Stabler and Martin 2004).

A study comparing an urban and desert site in terms of **growth effects on *Encelia farinosa* (brittlebush) of suppressing arbuscular mycorrhizal (AM) fungi** was completed (Bills and Stutz 2006). Information on AM functioning and its impact on plant productivity in urbanized desert areas is limited, motivating this study. *E. farinosa* is a native, desert shrub commonly found in the Sonoran Desert and used as an ornamental plant in residential and commercial sites. Because *E. farinosa* is common in both urban and desert areas, it can be used to compare AM fungal colonization levels between the areas. Manipulation of the levels of AM fungal colonization using the fungicide methyl-1-(butyl-carbamoyl)-2-benzimidazole (benomyl) allowed researchers to study the impact of AM fungi on *E. farinosa* growth and reproductive output. This fungicide has been shown to suppress colonization of roots by AM fungi with little phytotoxicity or effect on soil nutrients. If fungicide application reduces AM fungal colonization, the growth response will indicate whether AM fungi provide a net benefit or cost for the plants.

Significant differences in plant growth and mycorrhizal fine-root colonization were observed between *E. farinosa* plants growing at urban vs. desert locations:

- Mycorrhizal colonization of *E. farinosa* roots was greater at the desert site.
- Roots of *E. farinosa* plants at the desert site had greater levels of colonization by arbuscules and vesicles than brittlebush roots at the urban site.
- Fungicide significantly suppressed AM fungal colonization of roots in urban, but not desert, plants.
- Plants at the urban site showed significantly greater growth (increases in canopy height, diameter, and growth indexes).
- Plants at the urban site had greater reproductive output (number of flowers and dry weight of flowers and seeds).
- Finally, plants at the urban site treated with fungicide showed significantly higher growth (but not reproductive output) than untreated plants, whereas there was no difference between treated and untreated plants at the desert site.

Suppression of AM colonization in the urban plants appeared to have liberated these plants from the carbon cost of AM fungal colonization, and plants responded with greater height, growth indexes, and larger canopies. Overall, these results suggest that the low level of AM fungal colonization is a significant net cost for urban *E. farinosa.* Whether urban plants have higher growth than desert plants because of the higher AM fungal load in the desert or because of other factors cannot be established by this study, requiring further research.

Climate plays an important role in enabling or retarding primary production. Rapid, extensive urbanization has caused a rise in minimum temperatures within metro Phoenix over the past half century. In contrast to much of the UHI research in the region that has focused on summer temperatures, the **impact of the UHI on frosts and freezes** project examines the spatiotemporal change in frost and freeze patterns within the metro area during the past decade. The study uses temperature records from 1995 through 2005 from 14 weather stations scattered across the metropolitan area and situated in urban, suburban, and rural settings. Station data were evaluated for changes in the number and duration of frost/freeze events: the number of hours and days at or below the 4°C threshold, the point at which cold stresses the plants. Several stations experienced LULCC during the 10-year study period, from rural settings in 1995 to urbanized areas in 2005. Data from these stations show a drop in the number of freeze events (d/winter season) and duration (h/ event and h/y) when compared to stations showing little or no LULCC over the same period. Based upon cluster analyses, the affected stations are now more similar to stations located in urbanized areas. These findings have implications for understanding how land-cover change and landscaping choices in the rapidly urbanizing rural-urban fringe can alter local freezing patterns.

Progress has also been made in **modeling daytime and nighttime near-surface air temperatures**. Researchers introduced a refined land-cover classification for the Phoenix area (derived from 1998 Landsat Thematic Mapper satellite images) and some modifications to surface energetics into the fifth-generation Pennsylvania State-NCAR Atmospheric Research Mesoscale Model (MM5). The results indicate that this approach significantly improved the simulated diurnal temperature cycle and wind speeds and influenced planetary boundary layer (PBL) heights in MM5 (Grossman-Clarke et al. 2005).

Water Policy, Use, and Supply (WATER)

Work within this IPA shares strong linkages with research under the Decision Center for a Desert City (DCDC), and many CAP researchers contribute to both projects. CAP and DCDC have begun several joint initiatives, allowing these projects to leverage their relative strengths toward synthetic research. In addition, a major focus that unites both DCDC and CAP research in this area is understanding factors that can promote resilience of socioecological systems. To that end, several joint CAP-DCDC researchers have contributed ideas developed in the context of their association with the Resilience Alliance (see Anderies et al. 2006; Cumming et al. 2006; Walker et al. 2006). Research within this IPA also overlaps with the biogeochemistry work discussed under the FLUXES IPA.

One of the joint CAP/DCDC research projects is **landscape preferences in the arid Southwest,** which explores the linkages between residential landscaping and water use. Residential landscape practices consume a significant portion of domestic water use in the Phoenix area. The initial phase of this project compared and contrasted results from the first PASS survey (Larsen and Harlan in press) and the pre-landscape treatment social survey administered in the North Desert Village (NDV) neighborhoods. Both surveys included questions about respondents' preferences for front and backyard landscaping. Preliminary results (Larson et al. 2006) from this analysis include:

- There were strong associations between front and backyard preferences in both surveys, particularly between mesic (grass lawn) and oasis (lawn with borders of vegetation) landscapes.
- There was less variation in preferences among demographically similar NDV residents, who mostly preferred mesic landscapes, followed by mixed, oasis landscapes, especially for backyards.
- Among respondents in the PASS sample, there was a greater preference for desert landscapes, which was the most preferred front yard option, than among the NDV respondents. Preference for desert declines in backyards among PASS respondents, while the courtyard landscape type (hardscaping with potted plants) increases substantially.
- Appearance was the most commonly cited reason for preferences, particularly for front yards, and was mentioned most among people who prefer the oasis landscape type.
- Environment and maintenance were most often cited for desert and courtyard landscape preferences, more so for front yards compared to backyards.
- Recreation was a dominant reason cited for backyard preferences, particularly for lawn and courtyard landscape types. This reason also explains less preference for desert landscapes in backyards overall.

Other WATER IPA research conducted under CAP focuses on **paleogeomorphology of the Salt River.** This project extends geomorphological research for the CAP region, providing important information on the underlying geomorphic template upon which land-use change and river and stream processes play out. The Salt River drains central Arizona westward, joins the Gila River 20 km southwest of Phoenix, and is perhaps the defining geomorphic feature of the central Arizona. Researchers gathered geologic and geomorphic evidence to decipher the history of vertical and horizontal channel migration, including data on subsurface channel gravels and datasets previously collected and analyzed by ASU researchers on the locations of Salt River terraces and the extent of a subsurface paleochannel south of the river's current channel. Then, they linked these datasets together using ArcMap and created at 3D visualization of the complete paleochannel of the Salt River for analysis.

A well-preserved fluvial terrace sequence from Phoenix eastward for 50 km and a buried paleochannel south of the modern channel system establishes the history of channel migration. Subsurface information shows extensive Salt River channel gravels joining the Gila River roughly 25 km from where it joins the Gila today, implying a significant diversion of the main channel to its modern location occurred around South Mountain (16 m higher local-elevation difference). The buried paleochannel may represent the downstream equivalent of the missing earlier Pleistocene terrace, indicating significant changes in Salt River channel gradient and horizontal position since the early to mid-Pleistocene. Findings confirm that the vertical location of the Salt River terraces increase eastward with respect to the active channel and that the channel diversion initiated flow of the modern Salt River through the Papago Narrows (10 km east of Phoenix and 8 km north of its prior path) in the mid-Pleistocene.

Data analyses for the **aquatic core monitoring** project (described in the FLUXES section) and a graduate-student project (from the **nutrient retention in urban watersheds** project) have shown that significant groundwater inputs influence the chemistry of water at the downstream end of the urban flowpath, below all inputs of treated wastewater and irrigation return. Thus, understanding the hydrogeomorphology of this river is essential for studies of biogeochemistry and for a full accounting of the water budget for the CAP ecosystem.

Material Fluxes and Socioecosystem Response (FLUXES)

The **environmental justice and risk** project has continued its focus on differential impacts of environmental disamenities in the Phoenix area. Metropolitan Phoenix ranks in the top five large US cities for asthma-related deaths, and Phoenicians under age 21 are hospitalized for asthma at a rate four times that of all other ages (Grineski 2006). Asthma is a condition that connects humans and their environments and has a complex etiology of social, genetic, and environmental factors. CAP research investigated the relationships between socioeconomic status, race/ethnicity, indoor hazards, ambient environmental hazards, and asthma hospitalization rates at the zip code level as a means of understanding how these factors contribute to rates of childhood asthma. Researchers asked the following questions:

- Do sociospatial inequalities explain patterns in uncontrolled childhood asthma?
- How do parents have differential control of children’s asthma?

How have historical and geographical processes influenced inequalities associated with asthma control?

The research found distinct sociospatial inequalities in asthma hospitalizations, with pollution being the most important predictor. While air pollution affects all Phoenicians, its effects are pronounced for racial/ethnic minority children. In a low-income Latino neighborhood in Phoenix, 16% of children (ages 0–18) had a parental report of doctor’s diagnosis of asthma—twice the national average (Grineski 2003). Low-income Latinos and African Americans in South Phoenix have fewer options for coping with childhood asthma than individuals of higher-income groups due to inadequate access to healthcare and a lack of coverage for asthma medications. In addition, these individuals are often living in substandard housing, with mold, rodents, and insects present to trigger asthma attacks. The situation in Phoenix with children’s asthma, healthcare, and the environment is symptomatic of historical legacies of white privilege and neoliberalization (Grineski 2006). South Phoenix has historically been marginalized, a process that constructed a zone of mixed minority residential and industrial land uses. This process has resulted in a clear spatial, social and economic segregation of undesirable land uses and minorities from “Anglo” Phoenix, as demonstrated in other research by Bolin et al. (2005).

The goals of the **atmospheric deposition** project are to examine the magnitude and spatial variability in the concentration and flux of wet-deposited NO_3^-, NH_4^+, organic C (oC), PO_4^{3-}, Cl^-, S O_4^{3-}, H^+, Ca^{2+}, Mg^{2+}, Na^+, and K^+ across the CAP region, including the developed urban core and outlying desert. Researchers also examined patterns of coarse dry particulate deposition across the study area to provide minimum estimates on levels of dry deposition of these ions. They addressed the question: To what extent are concentrations and fluxes of these ions enhanced at sites within the urban core relative to undeveloped desert sites upwind and downwind of the city?

Six years of data have been analyzed and are reported in Lohse et al. (in preparation). Mean annual fluxes of wet and dry nitrogen deposition were relatively low and did not differ significantly across sites, whereas wet and dry deposition of organic carbon (oC) were significantly elevated in the urban and downwind desert compared to the upwind sites. However, elevated fine-particle and vapor-phase NH_4NO_3 and oC concentrations were observed in the urban core in fall and winter, indicating dominance of gaseous-phase N in this environment. Dry loads of phosphorus and potassium and wet loads of calcium were significantly elevated in the core urban sites. Wet deposition of nutrients was significantly higher in the summer than winter and was positively correlated to storm-size characteristics. Dry deposition rates did not show strong seasonal trends with the exception of oC, which was fivefold higher in the winter than the summer. Dry deposition of NO_3^- and oC were strongly correlated with particulate base cations and dust-derived PO_4^{3-}, indicating that urban-derived dust is scrubbing the atmosphere of acidic gases and enhancing deposition at local scales. Lower-than-predicted dry deposition of N to the urban core may be explained by the dominance of gaseous-phase N in hot, arid environments and volatilization of dry deposition from surrogate surfaces. The scale of urban enhancement of nutrient and carbon inputs to surrounding desert ecosystems appears to be limited to the CAP LTER study region and could be important for nutrient budgets and cycling in these nutrient- and carbon-poor ecosystems.

Results and experience from the six-year study of atmospheric deposition have informed new research investigating the effects of urban deposition on desert ecosystem processes, **Decoupled biogeochemical cycles: Ecological response to C and N deposition from the urban atmosphere** (CNDep)**,** a project funded separately by NSF (Ecosystem Studies). In this CNDep project, researchers have developed new methods for measuring bulk deposition in the arid urban environment, which replaces the CAP LTER wet-dry bucket collectors. They are evaluating their method for determining dry deposition, in particular, against a filter-bank method that uses eddy correlation-based estimates of deposition velocity, combined with specially designed samplers to measure gaseous and aerosol components being deposited. Deposition collectors are deployed at 15 sites: five upwind, five in the core, and five downwind of the city, with a flux tower and filter sampler installed at one intensive site for each position. Researchers have completed sample analyses for the first six months of deposition but have not yet analyzed the results.

The CNDep project has also established long-term fertilization plots upwind, within, and downwind of Phoenix, which are part of the CAP long-term experimental program. Preliminary results do not reveal any impact of N or P addition over one (dry) season; however, compared to upwind sites, extractable nitrate (NO_3^-) pools in control-plot soils from interplant spaces are 5.6 and 1.8 times larger for urban core and downwind sites, respectively. Furthermore, ratios of carbon/nitrogen (C/N) in foliar tissue of *Larrea tridentata*, a dominant perennial shrub, are lower in the urban core (17.4) compared to downwind (21.8) and upwind (21.5) sites, consistent with the hypothesis that the urban atmosphere acts as an important source of N to primary producers.

Aquatic core monitoring includes a field-sampling program to quantify the concentration and flux of nutrients, major ions, salts, and select contaminants imported to and exported from the CAP study area via surface water systems. Specific questions are: (1) how do key materials (e.g., nitrogen, carbon, select contaminants) move within the ecosystem, (2) how do these terms change over time in response to monotonic changes (e.g., urbanization) and stochastic changes (e.g., climate), and (3) what are the spatial patterns of accumulation and flux within patches? Five sampling sites (three upstream and two downstream of the urban area) are sampled 6-12 times per year to capture seasonal and, when possible, discharge-related variations in water chemistry. Results from CAP1 have been documented in numerous publications. Data collection and analyses are ongoing in accordance with CAP2.

Water retention in the urban area is high, particularly during drought conditions that have predominated during most of the years that CAP LTER has been sampling. As such, climate-induced variation in water chemistry was only weakly related to river hydrology during these dry periods. A major objective was to identify how patterns in water chemistry upstream versus downstream of the urban area have changed, and the possible implications these changes might have for biogeochemical cycling. The Phoenix metropolitan area routes water through hundreds of urban flowpaths, including canals, pipes, and modified stream channels, which coalesce downstream but with a substantial reduction in water volume (<10% of inputs). Climatic variability in the arid Southwest has encouraged extraordinary measures for reusing and retaining water for agricultural, municipal, and commercial purposes, which eventually lead to evaporation. A comparison of surface-water input and output loads (total mass) into and out of the urban area indicated substantial retention of dissolved organic carbon (DOC) and total dissolved salts (TDS). The percentage retention of these two components was lower than water retention, which indicates that water accumulated DOC and salts as it was routed through the urban area. Most analytes had concentrations that were considerably higher in river water downstream of the urban area than upstream, but those exhibiting lower retention than water, implying accumulation as the water moved through the urban area, included salts, DOC, total dissolved nitrogen (TDN), and total phosphorus (TP).

Materials that increase during transport most likely derive from four sources: (1) impervious surfaces receiving high rates of atmospheric deposition of nitrogen and carbon; (2) groundwater inputs containing high nutrient and salt concentrations; (3) fertilizer application and evapoconcentration of solutes following irrigation; and (4) disposal of human food and waste, which undergoes tertiary treatment and is released as highly concentrated effluent directly into the river system. Human activity and decision making has assumed primary control over variation in stream water chemistry. This control has been particularly pronounced during drought periods, establishing a feedback between environmental change and human engineering of the ecosystem.

Another research objective of the aquatic monitoring program was to link changes in urban-ecosystem management and structure with changes in downstream water chemistry. There was a temporal decline in nitrogen concentrations and loads in the water exported from the urban area, suggesting a change in the functioning of the urban ecosystem. This decline coincides with two management changes: (1) increase in the use of Colorado River water via the Central Arizona Project (CAP) canal, and (2) establishment of improved wastewater treatment techniques.

In summary, patterns in upstream–downstream water chemistry related to the functioning of the Phoenix metro area as a whole. The presence of this urban center has altered biogeochemical cycling in lotic ecosystems significantly. The urban area is exporting more biologically reactive ions while retaining conservative ions. Climatic variability has a strong influence on urban water chemistry at the decadal scale, but less so at shorter time scales. Continued long-term measurements will enable CAP researchers to investigate the relative importance of human management and hydrologic controls under climate variability and change and increased urbanization.

As a complement to long-term, large-scale aquatic monitoring described previously, CAP researchers began the **water chemistry in local rivers after the 2005 spring rain events** project, a more fine-grained spatiotemporal sampling of the Salt River, centered on the recently constructed (2000) Tempe Town Lake, which sits in the Salt River bed. Taking advantage of the wet winter and spring of 2005, researchers were able to make fundamental observations about trace element transport in the major rivers serving Phoenix. The questions posed include: How are trace metals (including toxins) and major solutes (including nutrients) transported in a complex river system? What are the interactions between the three components of flow (groundwater, soil water, surface runoff) during and after storms in a desert climate? What can one discrete, yet transient, sampling schedule reveal about watershed activities, be they natural or human-caused?

Researchers sampled the Salt River at Tempe Town Lake daily, upstream of the confluence of the Salt and Verde rivers weekly, and further upstream on each river system monthly. Field measurements were taken (pH, conductivity), and samples were collected for lab analysis. Trace metal concentrations are measured using inductively coupled plasma mass spectrometry (HR-ICP-MS), major anions and cations, including (Na, K, Mg, Ca, Cl, SO_4^{3-}, and NO_3^-) are measured using ion chromatography (IC) and stable-isotopic composition (^{18}O, ^{2}H) is measured using isotope-ratio mass spectrometry (IRMS). All measurements were made at ASU.

At the largest scale, researchers identified significant differences in chemical composition of the Salt and Verde rivers, which will be useful in “un-mixing” the complex river system. A hysteresis effect (composition not same on the rising and falling limb of hydrograph) was evident downstream of the confluence of these rivers. As part of a MS thesis in the School of Earth and Space Exploration, a graduate-student researcher will characterize, catalogue, and possibly quantify hysteretic behavior in this river system. This understanding, as well as the background information to unmix the complex river sources, will be useful for future aquatic chemistry investigations.

The **Survey 200** sampling in 2005 also incorporated a graduate-student investigation of the **patterns of trace element distribution in an urban desert system**. The researchers analyzed a subsample from all of the soil samples taken in the 200-Point Survey in 2005. They measured trace elements in the top 10 cm of each sample by ICP-MS gave multiple trace-element concentrations, which have been plotted and kriged on maps of the CAP study area. Background geology (U, V, Co, Sr, etc.) appear to strongly influence several elements, but others show indications of correlating with urbanization (Pb, Cd, Cu, Zn, etc.). So far, sources have yet to be determined. The advanced capability for determining concentrations of multiple trace elements in both soil and water samples represents an important new addition to the CAP tool box because we expect many, human-related sources of these potential contaminants to be present in urban ecosystems and to potentially influence biogeochemical transformations, storage, and fluxes.

Human Control of Biodiversity (BIODIV)

CAP scientists continue to analyze data from the 2000 and 2005 **Survey 200** field surveys, which has led to important findings about biodiversity in the CAP area. Detailed analysis of plant species richness confirms earlier findings (Hope et al. 2006) that on-site species diversity was highest for desert sites. However, between-site species diversity was highest in urban sites. Ordination of the plant communities suggests three unique groupings of species based on land use type of the site (desert, urban, and agriculture) and two unique groupings of sites based on plant typology (native and exotic). In addition, urbanization is shown to severely retard the richness of annual species and dramatically increase tree richness. In residential areas, residents are active in decision making about landscaping, resulting in perennial richness compared to other urban land uses. Species richness in desert sites are shown to positively vary with elevation and organic C:N. Interestingly, this relationship is not true for urban sites. This suggests that plant- community composition has been transformed extensively in the transition towards agriculture and urbanization.

Researchers investigating **microbial biodiversity** compared the ionizing-radiation fractions of soil bacterial communities in soil samples taken from the Sonoran Desert and a Louisiana forest (Rainey et al. 2005). They recovered bacterial isolates surviving doses of 30 kGy from the Sonoran Desert soil, whereas no bacteria in the Louisiana forest soil survived doses greater than 13 kGy. The study results were consistent with the hypothesis that organisms with heightened DNA repair capacity are among the species that have a selective advantage in arid environments.

This research also expanded knowledge of the diversity of ionizing-radiation-resistant bacteria and is the first report of strains related to the taxonomic groups *Bosea*, *Chelatococcus*, *Corbulabacter*, and *Geodermatophilus*, *Planococcus* (species of the family *Sphingomonadaceae*) and *Spirosoma* resistant to gamma radiation. Researchers recovered a high number of *Deinococcus* isolates from the soil samples exposed to high ionizing-radiation levels, which confirmed that the species of this genus are very ionizing-radiation resistant. Through genetic sequencing, the researchers established that nine new species of the genus *Deinococcus* were present in the soil taken from the Sonoran Desert: *D. hohokamensis*, *D. navajonensis*, *D. hopiensis*, *D. apachensis*, *D. maricopensis*, *D. pimensis*, *D. yavapaiensis*, *D. papagonensis*, and *D. sonorensis* (Rainey et al. 2005).

Additional research (Rash and Rainey 2005) examined nitrogen fixation in deserts soils. Nitrogen fixation plays a crucial role in soil ecology, particularly in arid environments where complex biological soil crusts form. These mature crusts function as a reserve for fixed nitrogen. However, many of these soils have been disturbed anthropogenically, resulting in significant decreases in nitrogenase activity. This change is likely indicative of the variation in bacterial community structure observed at these sites. The goal of this molecular-based study was to use the *nif*H gene to analyze diazotropic communities within the CAP area, a section of the Sonoran desert composed mainly of rugose crusts outside of the city and disturbed crusts in urbanized areas. Researchers collected soil samples from 15 CAP LTER sites categorized as either urban , open desert, or desert remnant. Overall, the majority (~80%) of *nif*H sequences were *Nostoc*-like, which is in agreement with past arid soil studies that find that nitrogen fixation is primarily conducted by heterocystous cyanobacteria. However, *nif*H sequence pools obtained from open desert soils appear to differ from urbanized counterparts in terms of overall proportions of phylotype groups. The urban soils also contained slightly higher proportions of non-cyanobacterial species, revealing a more diverse assemblage of nitrogen-fixing bacteria in soils. The results indicate that anthropogenic factors associated with urbanization of desert soils not only affect overall bacterial community structure, but also those populations involved in nitrogen fixation (Rash and Rainey 2005).

Other soil analyses have focused on the relationship between **pollen concentration in the surface soil and extant perennial vegetation** in urbanized areas vs. the surrounding desert

(Stuart et al. 2006). Several CAP studies have established that plant biodiversity is greater in urban areas than in the desert, although income levels, culture, and individual taste play a role in determining patterns of plant biodiversity (Hope et al. 2006; Kinzig et al. 2005; Martin et al. 2003). Results from pollen-concentration research indicate the impact of urban landscape management on pollen distribution in the desert: almost 40% of the desert pollen assemblage is derived from urban "imports." At the same time, pollen from *Ambrosia*, almost exclusively a desert plant, was found in roughly the same concentrations in urban samples as that of *Pinus* and *Ulmus*. Still, researchers conclude that it is possible to palynologically differentiate landscape types (i.e., to separate desert from urban). This study has particular significance for studies of the distribution of prehistoric native desert landscapes and agricultural fields, using fossil records, as well as for studies of modern-day pollen allergens. While data for pollen counts is derived from sampling devises that measure the pollen load in ambient air, CAP research suggests that the soil-sampling method may be a more effective means of measuring spatial and long-term variations in pollen loads (Stuart et al. 2006).

Soil samples from Survey 200 have also been used to make **comparisons between arbuscular mycorrhizal fungi community in the Phoenix metropolitan area and the surrounding desert.** Researchers identified arbuscular mycorrhizal (AM) fungal spores from 10 sites in the Sonoran desert (where soil samples collected from indigenous plants), 10 sites from the Phoenix metropolitan area (where soil samples were collected from indigenous native plants) and 10 sites from the Phoenix (where soil was collected from non-indigenous trees and shrubs). Results reveal differences and similarities between the AM fungal community in urban and desert areas. The total number of AM fungal species detected, the mean number of AM fungal species per plant, and the mean number of species per site was greater in the desert sites. Despite the differences in the number of species detected, there was a significant overlap in the AM fungal species composition between the desert and urban sites. Almost 70% of the species were detected at both urban and desert locations. There were no significant differences between urban sites with indigenous and non-indigenous plants with respect to the total number of AM fungal species detected, the mean number of AM fungal species per plant and the mean number of species per site. The AM fungal species composition was also very similar between urban sites with indigenous and non-indigenous plants (Sorenson similarity coefficient = 0.94). Indigenous plants growing in urban sites had a lower total number of AM fungal species detected and mean number of AM fungal species per plant than indigenous plants growing at sites in the surrounding desert. Although the AM fungal communities between the indigenous plants at the urban site and desert site were similar (Sorenson similarity coefficient = 0.86), several species including *Glomus mosseae* , *Glomus microaggregatum*, *Glomus luteum* and *Glomus* species AZ112 were more frequently associated with indigenous plants at desert sites than these types of plants at urban sites. Similar results were found when comparing the relative frequencies of these fungi associated with *Larrea tridentata* growing in desert and urban locations.

Long-term monitoring of ground arthropod biodiversity has taken place since the inception of CAP to determine the patterns of ground-arthropod diversity and abundances by various lands-use types (desert, desert remnant, agricultural fields, industrial, and mesic and xeric suburban yards) in the study area. Recent findings show that agricultural fields and mesic residential yards generally support the greatest number of individuals and taxa, show the best separation from other types in ordination analyses, and have the greatest number of significantly associated taxa in indicator species analysis (Cook and Faeth in review). Of the urban habitats under investigation, two heavily irrigated and highly productive land-use types seem to stand apart from the others in most community measures. Outlying desert sites also support significantly associated taxa, including those not found regularly in desert parks and members of higher trophic levels less common in the city. Despite this, outlying desert and desert parks support similar taxon richness. Xeric residential yards and commercial sites did not support any taxa not found in other land-use types. Although these results may depend on the location of Phoenix in the water-limited Sonoran Desert, CAP researchers urge broader consideration of highly modified urban landscapes as wildlife habitat.

Since October 2000, CAP scientists and research technicians have conducted **bird point-count censusing** in four habitats (51 sites in total): urban (18 sites), desert (15 sites), riparian (11 sites), and agricultural (7 sites). Previous results from this work have been published in Shochat et al. 2006. New findings include: shifting patterns of species dominance, a kind of "capitalism" in wildlife communities, and long-term losses of species. Cities support higher wildlife densities than wildlands; however, it appears that resources are not being shared equally among species. With their higher foraging efficiencies, human-commensals use most of the resources and become the most dominant species in urban and agricultural environments. We investigated rank distribution of bird species and spider families in three habitats: Sonoran desert, agricultural fields, and mesic urban yards, and found that in both cases the desert communities were more even (less dominant) than agricultural and urban communities. Taxa richness in the urban habitat was lower, but in the agricultural habitat was as high as in the desert. We also explored how community composition changes from desert through agricultural land to mesic urban yards, using data on birds and spiders. In spiders, Lycosids (wolf spiders) increased in proportion from ~0.1-0.2 in desert to 0.7-0.8 in agricultural sites and mesic yards. In birds, the house sparrow moved from the 15th position in desert, through 5th in agricultural, to 1st in mesic yards. We assume that the increase in water availability and food abundance, as well as the decrease in predation pressure, allow several human-commensal species to flourish in human-dominated environments. This may explain the global pattern of loss of diversity in urban settings. Possibly, human-commensals use most of the resources and out-compete native species, decreasing species richness. Most studies on urban communities focused on the effect of habitat structure on species diversity and composition. Our findings suggest that, in addition to extinctions owing to change in habitat structure, species competitive interactions may also contribute to the loss of diversity in urban environments.

Bird species richness has declining steadily across the first four years of quarterly bird monitoring at CAP LTER (Fall 2000–Summer 2004). These declines occurred in all three land-use types (desert, residential, agricultural), with the steepest declines at agricultural sites. On average, two to three species were lost per site across the survey period. Declines occurred in numbers of resident and short-distance migratory species but not in numbers of long distance migrants. Causes for these local reductions in species richness may include broad-scale impacts of urbanization across the Phoenix and the surrounding region. Alternatively, the trends we detected may be part of a larger regional trend, perhaps as a consequence of the extended period of drought. In contrast, another CAP research project found that bird species richness at the Desert Botanical Garden in Phoenix has been increasing over this period.

The **North Desert Village (NDV)** social science team studies reciprocal relationships between humans and residential landscaping through the use of social surveys and trained observation methodologies. CAP researchers used these methods to gather data before landscaping (pre-treatment) was put into place in the four NDV "neighborhoods." Wave two (follow-up) interviews are being conducted during spring and summer 2006.

Key findings from the pre-treatment survey are (Yabiku et al. in review):

- Women rated desert landscapes significantly lower than men. This may be due to the gender division of labor in many households that allocates outdoor work to males in the household and housekeeping and childcare to women in the household. Males may view desert landscapes as lower maintenance and may rate them higher due to workload consideration. At the same time, women may rate desert landscapes low due to the dust in these landscapes (more time and labor expended for house cleaning) and their perceived unsuitability as environments for children's play.
- People with desert aesthetics (i.e., people who agree with the statement, "The natural desert is beautiful") significantly rate native desert landscapes higher. Although this seems to be an obvious finding, it is important because it shows that aesthetics matter, even when controlling for other factors in the multivariate model, such as gender, education, and environmental values.
- People who live in the Phoenix area longer have significantly *lower* ratings of desert and xeric landscapes. This seems counter-intuitive, but it agrees with prior research that finds longer-term residents in the Southwest have higher preference for more water-intensive landscapes. The exact reasons are unclear, but it may be that long-term residents have lived in older city areas, where mesic landscapes are more common. Newer residents may be more familiar with fringe developments, which have less grass than older areas (e.g., central Phoenix, Mesa, Tempe).
- People with more pro-environmental values (as measured by the New Ecological Paradigm, Dunlap et al. 2000) are more averse to mesic landscapes. People with these values appear to react negatively to large expanses of grass. These people may believe that mesic landscape is not a sustainable land-use for a desert environment.
- People with young children (ages 0–6) rated the mesic landscape significantly higher. Parents want a place for their kids to play, and large, green yards appear more suitable for play than xeric or native landscapes, and even oasis lawns.

Qualitative analysis of open-ended questions provides insight into the thought processes that underlie these quantitative results. Many people who appreciate desert landscapes aesthetically express an aversion to having them in their yards. This dichotomous relationship appears to increase with length of residency in metro Phoenix. Of residents who specifically expressed a "not in my yard" attitude, there were more who mentioned aesthetic values than fear of spiny plants, maintenance or practicality. Many interviewees view desert landscaping in yards as inferior or unnatural compared to desert landscapes of undeveloped areas.

Respondents who expressed willingness to compromise on the amount of grass they preferred for environmental reasons were more likely to think about maintenance and practicality, and less likely to be concerned about recreational opportunities in their yards. This suggests that even when environmental values are strong, their expression is subject to functional concerns, and appeals to aesthetic values are least likely to result in significant water conservation via landscape behavior change.

The central objective of research on **ecological and social interactions in urban parks** is to use small, neighborhood parks in Phoenix to study: (1) the ways in which ecological processes are influenced by human values, use, and management; and (2) the ways in which human attitudes and activities, and the services valued by humans, are influenced by ecological characteristics and processes. Elucidating this coupling in Phoenix parks will itself be a significant step towards understanding the complexities of human-nature interactions (Shochat et al. 2006). The information gathered in addressing the central objective, though, can and should be used to assess potential trajectories for ecological processes. The second objective is to develop trajectories for potential changes in ecosystem services in the Phoenix area, given economic and demographic trends and given the signal of human-nature interactions among different social groups.

Competition, mediated in part by human-provided resources, appears to be a major driver of bird foraging behavior in these parks. An experiment using bird seed in trays left in the open and under bushes found that the amount of seed remaining in all trays was significantly correlated with the number of bird feeders in the neighborhoods around the parks (from transects conducted in previous years). Sites with more bird feeders exhibited greater levels of competition; that is, fewer seeds remained in trays at these sites.

Predation effects were less important. Researchers found no differences between trays under bushes and the open at any of the 16 parks, indicating that predation risk is not a major factor in determining foraging behavior of seed-eating birds. This finding contrasts to those from a previous project in which behavior observations of foraging birds indicated that bird foraged for less time in open habitats when more predators, particularly cats, were present.

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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

Bigler, Wendy. Environmental history of the Salt River, Phoenix (Ph.D. Geography, R. Dorn).

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).

Gade, Kris. Plant migration along highway corridors in central Arizona (Ph.D., Biology, A.P. Kinzig).

Hartz, Donna. Impact of residential development of climate (M.A., Geography, A. Brazel).

Hedquist, Brent. Climate change scenarios and visualization in an arid urban environment. (Ph.D., Geography, A. Brazel).

Kenney, Eric D. Building cycles and urban fringe development in Maricopa County, Arizona. (M.S., Geography, E. Burns).

Miller, James. Urban heat island of Las Vegas. (Ph.D., Geography, A. Brazel).

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).

Parker, John. Knocking down the walls: The integration of social science into ecology (Ph.D., Ed Hackett).

Riley, S. Decay of the convective boundary layer in a stratified atmosphere (M.S., Mechanical and Aerospace Engineering, H. J. S. Fernando).

Sweat, Ken. Using lichens in the genus *Xanthoparmelia* to monitor heavy metal air pollution patterns in Arizona (M.S., T. H. Nash).

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

Walker, Jason. Human induced vegetation dynamics and biotic responses in a desert city (Ph.D., School of Life Sciences, J. Briggs).

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

Completed 2005-2006

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

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

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).

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).

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.

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, four charter schools and two private schools. Popular summer workshops and internships have engaged numerous teachers 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 in science, mathematics, writing, social science, and technology. 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.

Ecology Explorers continues to provide teacher training in ecology to schools that have under-served, 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. Staff work with teachers in their classrooms as well as hold day-long workshops based on teacher requests. This year, they presented workshops on schoolyard ecology and urban ecology at three different venues. One was a workshop for new science teachers in the Creighton Elementary School District (82% Hispanic students) and another workshop was for teachers-in-training in an environmental education class at Arizona State University Polytechnic. Staff also trained teachers during the teacher professional development series sponsored by the Arizona Foundation for Resource Education.

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 interviews indicate how teachers have implemented their teaching plans during the school year. An analysis of the pre- and post-internship/workshop assessments indicated that teachers believed the internships/workshops were beneficial and would impact their classroom teaching. Staff has collected data regarding school year implementation of Ecology Explorers protocols but has not yet analyzed it. Informal discussions with teachers have revealed that they believe that students' mathematics abilities have improved as a result of participating in Ecology Explorers. Ultimately, the program would like to capture data on the impact of **Ecology Explorers** on student outcomes.

Service at Salado received partial funding through the NSF Environmental Education Fund and LTER Schoolyard supplement through fall 2005. The overarching goal of this initiative is to create after-school clubs that engage children in a local environmental project while performing a valuable community service. Four schools have established after-school science clubs with the support of their principals and under the guidance of a classroom teacher. During 2005-2006, this endeavor involved 13 ASU undergraduate students working with 114 middle school children in the Service Learning after-school clubs. Projects from each of the clubs can be found at the Service at Salado website at http://caplter.asu.edu/explorers/riosalado. In recognition of the excellent work done through Service at Salado, the project received the Arizona State University President's Medal for Social Embeddedness in 2006 and was featured on the university's web site. It was one of three programs honored with this distinction.

To evaluate the success of Service at the Salado in achieving program goals, staff working with an external evaluator used student surveys and standardized inventories completed by undergraduate interns to measure specific indicators of expected outcomes. Overall, evidence suggests that the fall 2005 program met most of its goals for the children and encouraged them to utilize scientific thinking and skills, consider their roles in their urban community and their own civic responsibilities, and develop a connection to the Rio Salado restoration project.

In addition, a pilot project entitled the **Phoenix Flyways** projects was tested during the 2005-2006 academic year in association with ASU's Service Learning Program. The goal of this service-learning project is to develop an appreciation and understanding of natural history in middle-school children and ASU undergraduate students in the urban setting of Phoenix as well as rural sites through studies of birds and their migratory movements between environments.

Knowledge Exchange

From CAP LTER's inception, we have focused upon meaningful community outreach by establishing a series of community partnerships. Some of these partners have been very active, such as the Maricopa Association of Governments, the Salt River Project, and those relating to K-12 education. During fall 2005, the International Institute of Sustainability transformed into the **Global Institute of Sustainability** (**GIOS**), which is the home base of CAP LTER, as well as CSRUR, GP2100, the Decision Center for a Desert City, the Urban Ecology IGERT, and many other programs. GIOS' outreach efforts, primarily founded in knowledge generated by

CAP LTER, engage academic, business, and governmental groups in dialogues about pressing environmental issues affecting our rapidly growing desert metropolis. 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 research conducted under CAP LTER. The Sustainability Partnership Enterprise (SPE), 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. SPE 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. Indeed, because it is a source of fundamental, long-term data, CAP LTER is critical to the success of ASU initiatives in science-policy outreach related to urban environments, such as the initiatives stimulated by SPE. 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 or February. 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). A **Summer Summit** or retreat is held at an off-campus site in selected years to address theoretical issues (social science/natural science integration, contributions to ecological theory, and development of CAP2 were prior themes). 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. During 2005-2006, some of these meetings included speakers brought to campus through the **Wrigley Lecture Series**, funded through a private donation. For example, Dr. Kai Lee spoke to a packed audience during a spring ASM. CAP LTER scientists have been active participants in workshops conducted in concert with the Wrigley Lectures, such as the workshop led by Dr. Jared Diamond in February 2006. CAP LTER connects with a wider public through its web site and the GIOS newsletter.

Collaborations and Partnerships

Through the communication means and knowledge exchange initiatives described above as well as other initiatives, CAP LTER seeks to maintain and expand its collaborations and partnerships within academia and beyond. ASU’s membership in the Resilience Alliance (www.resalliance.org) is a good example of such partnership which has led CAP LTER scientists to explore what a “resilience” approach offers to CAP LTER and related research. This interdisciplinary group, whose primary focus is on contemporary systems, has expanded to examine whether archaeology and studies of the past can enhance understanding (e.g., Redman and Kinzig 2003). In addition, a continuing NSF Biocomplexity grant awarded in 2002 that examines agrarian transformations of landscapes in six areas of the US includes a resilience perspective (Redman *et al.* 2002). A special issue of *Ecology and Society* on "Exploring Resilience in Social-Ecological Systems" included several articles authored by CAP LTER researchers (Anderies, Walker and Kinzig 2006; Cumming, Cumming and Redman 2006; Walker et al. 2006).

The NSF-funded Decision Center for a Desert City (DCDC) coordinates a program of interdisciplinary research and community outreach to improve water-management decisions. The confluence of rapid population growth and global warming in an uncertain climate pose challenging policy and decision-making issues for our urbanizing desert. DCDC is studying the cognitive processes by which individuals and water managers make decisions. It applies decision-science models to water-allocation problems, develops GIS-based decision-support tools for water-management decisions, uses climate models to define the dimensions of uncertain water availability, and crafts innovative educational programs on water, climate, and decision making. DCDC seeks to build an effective organization at the boundary of science and policy that allows decision makers and scientists to collaborate on research questions and experiment with new methods. The Center is also investigating the nature of research activity and decision making within DCDC itself. In collaboration with local, state, and regional water managers, DCDC will develop scenarios of different water futures and share them with decision makers and the public. These scenarios will be presented at ASU's Decision Theater. The CAP LTER-DCDC collaboration has taken several forms so far, including a large number of researcher involvement in both projects, two joint meetings, and joint support for the Phoenix Area Social Survey. Director Gober has been a CAP LTER PI since 1997 and DCDC is co-directed by Redman (CAP Co-Director).

This past year saw the continuing of many strong collaborations with our community partners and the sparking of exciting new partnerships. One of the most active of our federal partners has been the *U.S. Geological Survey (USGS)*, a main collaborator with the Historic Land-Use Team in Phase I of their study, which involved capturing desert, agriculture, and urban land uses for the metropolitan area. Several USGS National Water-Quality Assessment (NAWQA) program sites are also participating in our long-term water-monitoring project, collaborating on studies of water quality and storm sampling. In the state realm, the *Arizona State Land Department* has been very helpful in allowing access to Arizona State land, and project scientists have collaborated with Land Department personnel on a study of insect communities on creosote bushes. Other agencies are helping with the historic land-use study (*Arizona Department of Water Resources*) and the atmospheric deposition study (*Arizona Department of Environmental Quality*). Representatives from various city agencies have served as information resources to CAP LTER personnel as well as partners in many grant proposals: The *City of Phoenix* has issued blanket permission for us to conduct fieldwork in the city's extensive park system, including at South Mountain Park, and we are exploring a master permit with the Tonto National Forest. The *City of Scottsdale* has entered into an agreement with CAP LTER to conduct a nutrient limitation study at Indian Bend Wash, and the *City of Tempe* is a partner in our nitrogen balance study, particularly in allowing access to storm water retention basins and to non-retention areas for purposes of sampling soil and storm water. We continue to develop relationships with the *Gila River Indian Community* and the *Salt River Pima-Maricopa Indian Community* in the form of idea exchange, educational opportunities for community members, service of their scientific personnel on advisory committees, and discussion of potential development of joint research projects and monitoring activities on their lands.

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.

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 greatly facilitated the work of the land-use team and have contributed greatly to the nitrogen mass balance study and even provided a helicopter to reach several remote Survey 200 sample locations. The *Desert Botanical Garden* serves as one of our long-term sampling sites. Lastly, over 30 businesses/organizations/federal, state, regional, and local agencies entertain long-term monitoring of ecological variables on their sites. A list of our community partners is included in the participants section.

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. In spring 2006, CAP LTER hosted a group of scientists from the Chinese Academy of Sciences, which later led to a memorandum of understanding between this entity and Arizona State University. Social scientists at CAP LTER continue to work with their counterparts at the Baltimore Ecosystem Study site on defining cross-site research.

In addition, Ecology Explorers partners 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, and Southwest Center for Education and the Natural Environment.

Dissemination of Research Projects and Results

This year, CAP2 participants have produced 57 journal articles (28 published, 8 in press, 21 in review) and 14 book chapters and books (5 published, 7 in press, 2 in review). In addition research results are routinely presented at meetings and conferences in a diverse array of fields. During 2005-2006, 28 presentations and posters were given at regional, national and international conferences, and 57 at LTER-related conferences.

The CAP LTER and individual projects have been the focus of articles in scientific journals such as *Science,* and we continue to receive press attention at the university, local, state and national levels. **Ecology Explorers** and **Service at Salado** were featured on the ASU web site during spring 2006 as examples of community service at the university. An article in *ASU Research* outlined research on socio-economic status and environmental hazards conducted by CAP LTER scientists. Dr. Sharon Hall participated in a press conference during the American Geophysical Union conference in Baltimore and reported on **nitrogen deposition** and stream quality in urban areas. A film crew from *National Geographic* captured Dr. Ann Kinzig's work on ecology in urban parks.

The CAP LTER web "Virtual Tour" <http://caplter.asu.edu/capltertour or click on Tour on the home page> is an effective forum for communicating CAP research results to the broader community. The idea behind the virtual tour is to illustrate key findings with brief, less technical explanations. The tour currently entails a presentation of research findings in the areas of geology, climatology, desert vegetation, pre-historic, historic and present urban land-use, and results from the Phoenix Area Social Study (PASS). The CAP LTER virtual tour is a work in progress, and we will add more aspects of our research on a regular basis. Along with other components of the web site, including the online data sets (which are accessed through SeiNET), this feature makes for a very useful web presence for our project.

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:

- The **North Desert Village project** includes two major research innovations: 1). The novel design in which humans (resident rental tenants) are incorporated as an integral part of the experimental design, and 2). The use of an adaptive experimental approach. More specific contributions include the installation of micro-meteorological stations within each of the landscape treatment areas to help understand the extent of under canopy microclimate variation related to variation in vegetation density.
- Current environmental literature indicates severe problems relating environmental behavior, values and knowledge. Social science research at **North Desert Village** has already shown why environmental values are important, but researchers also are focusing on the mechanisms by which environmental values become secondary to identity-based, culturally- and socially-constructed norms and behaviors, such as notions of "family." A more detailed understanding of socio-ecological dynamics will emerge as the study continues. This project is unique because researchers are studying a host of variables simultaneously – socio-cultural values, knowledge, social networks, and human behavior – which allows for an integrated analysis of these variables. With data from the second wave of interviewing (post-treatment), researchers will examine if people's values, preferences, and satisfaction with their landscapes change due to the experimental manipulation by CAP-LTER scientists. This aspect of the study is highly innovative because it is rare to have a long-term experimental design within a "real" residential population.
- 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.
- Research on **Microbial Biodiversity** has confirmed that desert soil bacterial communities have heightened DNA repair capacity compared to species from a less arid environment. This research also identified nine new species of the genus *Deinococcus*.

- For the Phoenix metropolitan area, the dams upstream of the city altered the flux and concentrations of dissolved constituents by reducing downstream discharge variability, low flow discharge, and the variability of several chemical constituents. While work elsewhere has found similar hydrologic effects in other ecosystems, the importance of these changes to water chemistry in a downstream metropolitan area has not been extensively discussed previously in the literature. Work on **Aquatic Core Monitoring** shows that biogeochemists studying urban stream and river systems may need to increase their spatial and temporal scales of study to better understand the feedbacks between human decision making and carbon and nutrient cycling
- **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) over the last 12 months. As the initial primary data papers are published, we anticipate the data will become increasingly known to and used by the wider ecological research community.
- Research on differences in productivity of the same plant species growing in the Phoenix urban areas and the surrounding desert is limited. In the study of **Arbuscular Mycorrhizal Fungi**, researchers found that both vegetative and reproductive productivity of *E. farinosa* plants was greater when plant were growing at an urban site in comparison to plants growing at a desert site. There are several possible explanations for these differences including climatic and geographic differences between the two sites, differences due to the edaphic characteristics of the soil at each site and differences in the types of *E. farinosa* plants growing at the two sites. Scientists also found that AM fungal colonization was greater at the desert site than at urban site confirming the results of Stabler et al. (2001) who found that there was less root colonization of arid leguminous trees growing at residential sites in comparison to trees growing in an adjacent urban park. Application of the fungicide, benomyl, suppressed AM fungal colonization at the urban site and resulted in plants with greater vegetative growth. These results add to the growing body of literature that AM fungal colonization does not always result in increases in plant growth.
- The study of **Childhood Asthma in Phoenix** contributes to a growing literature in environmental risk and justice that explores socio-spatial inequalities in exposure to environmental hazards.
- **Long-term Monitoring of Ground Arthropods** has provided a rich database on seasonal, yearly and spatial changes in diversity and abundance. Our preliminary findings suggest that while remnants and reconstructed deserts structurally resemble outlying deserts, they differ radically in diversity, species composition and trophic structure.
- Many CAP LTER projects rely on data from remote sensing initiatives, such as the **High-Resolution Land-Cover Classification** project. Data from these initiatives will also be used in cross-site research, such as with the BES.

Contributions to Other Disciplines

- The **Phoenix Area Social Survey** (PASS) is contributing to the growing fields of urban sociology and environmental sociology as well as to biology, plant biology and urban planning. **PASS** provides unique data on human values, behaviors, and preferences that impact natural and built environments. **PASS** is a data resource for ongoing CAP LTER projects, including those on environmental risk, urban parks, and the development of the urban fringe. We have already created a database linking Survey 200 points in urbanized areas to 1990 and 2000 block-group census data. In addition, this research parallels the ongoing monitoring of ecological conditions.

- 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.
- **Survey 200** data have been used to develop and improve methodologies in the fields of remote sensing, urban atmospheric science and spatial statistics, with publications/ submissions to peer-reviewed journals in all these fields.

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. 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, and lab processing and analysis.
- 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 the 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, 28 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports three post-doctoral associates, all full-time on CAP LTER. In addition, one post-doctoral associate from GIOS works on several CAP LTER initiatives. 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 11 grants have been awarded. The awardees present their research finding at a CAP All Scientists Meeting in the fall.
- 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.
- CAP LTER faculty members, postdoctoral associates, and senior graduate students have mentored 31 NSF-funded REU students who gained research training via summer projects integral to CAP LTER. Undergraduates from ASU who are working on CAP LTER projects during the academic year can be part of the new Community of Undergraduate Scholars and the Community of Undergraduate Interns, a new program sponsored by the International Institute for Sustainability and the Barrett Honors College. Other undergraduate students have benefited by participating in data collection for the ground arthropod and bird studies, parks-use surveys, 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 **Phoenix Area Social Survey** (PASS) promises to contribute to the solution of social problems by providing information for planning urban growth, especially in sensitive ecosystems. **PASS** provides unique data on human values, behaviors and preferences that have consequences for the natural and built environments and is a data resource for several on-going CAP LTER projects, including neighborhood ecosystems, environmental risk, and urban parks. **PASS** could be expanded to provide long-term monitoring of social conditions in the metropolitan area comparable to on-going

monitoring of ecological conditions. The inclusion of neighborhoods sited at Survey 200 locations will allow integrative analyses of social and ecological conditions.

- 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.
- The **Aquatic Core Monitoring** work has two main implications: 1) It suggests that decisions regarding groundwater usage will feedback on chemistry patterns of water leaving the city. Therefore, a significant reduction in nutrients and salt concentrations should result as Phoenix begins to reduce agricultural activity and increase residential development in its place. 2) The presence of dams upstream of the city dampened the variability and stochastic nature of water chemistry in the two rivers entering the city. For example, the Salt and Verde rivers are the primary sources of drinking water for the city. Therefore, the increase in C and N loads, as well as the amelioration of salt loading, could have important consequences for the water treatment process.
- The **Salt River Riparian Seed Bank** and **Hassayampa Channel Stability** projects each address fundamental knowledge at specific sites that is needed for effective flood management or river restoration. Because study sites lay within portions of the rivers slated for restoration or development, this project will provide baseline information to restoration managers and project planners.
- **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. A recent study on childhood asthma in Phoenix provides a model for how future researchers can engage public and non-profit entities in understanding the findings from research. In this case, the researcher prepared a report to the community as part of her funding agreement with St. Luke's Health Initiatives, a non-profit organization in the area. She also prepared a two-page flyer on the research results, which was distributed to schools that participated in the study, the parents interviewed and other public and non-profit entities with an interest in children's health.

VIII. Publications 2005-2006

Journal Articles

In Press

Baker, L.A., P. Westerhoff, and M. Sommerfeld. In press. An adaptive management strategy using multiple barriers to control tastes and odors. *Journal of the American Water Works Association.*

Buyantuyev, A., C. Gries, and J. Wu. In press. Estimating vegetation cover in an urban environment based on Landsat ETM+ imagery: A case study in Phoenix. USA. *International Journal of Remote Sensing.*

Keys, E., E. A. Wentz, and C. L. Redman. In press. The spatial structure of land use from 1970-2000 in the Phoenix, Arizona metropolitan area. *Professional Geographer*. February 2007.

Larsen, L. and S. L. Harlan. In press. Desert dreamscapes: Landscape preference and behavior. *Landscape and Urban Planning.* Corrected proof. Online at <http://www.sciencedirect.com/science/article/B6V91-4GWC0JV-1/2/acd24e7549ea434ae7b52d754b004b46>

Larson, E. K., N. B. Grimm, P. Gober, and C. L. Redman. In press. The paradoxical ecology and management of water in the Phoenix, USA metropolitan area. *Journal of Ecohydrology and Hydroecology*.

Schaafsma, H., and J. M. Briggs. In press. Hohokam silt capturing technology: Silt fields in the northern Phoenix basin. *Kiva*.

Shochat, E., P. S. Warren, and S. H. Faeth. In press. Future directions in urban ecology. *Trends in Ecology and Evolution.*

Walker, J. S., and J. M. Briggs. In press. An object-oriented approach to urban forest mapping with high-resolution, true-color aerial photography. *Photogrammetric Engineering and Remote Sensing.*

Zhu, W., D. Hope, C. Gries, and N. B. Grimm. In press. Soil characteristics and the accumulation of inorganic nitrogen in an arid urban ecosystem. *Ecosystems*.

In Review

Buyantuyev, A., and J. Wu. In review. Effects of thematic resolution on landscape pattern analysis. *Landscape Ecology*.

Casagrande, D. G., D. Hope, E. Farley-Metzger, W. Cook, and S. Yabiku. In review. Problem and opportunity: Integrating anthropology, ecology, and policy through adaptive experimentation in the urban Southwest U.S. Invited for special issue: *Human Organization*.

Cook, W. M., and S. H. Faeth . In review. Irrigation drives ground arthropod community patterns in an urban desert. *Environmental Entomology*.

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Grossman-Clarke, S., D. Hope, J. A. Zehnder, H. J. S. Fernando, W. L. Stefanov, and P. G. Hyde. In review. NOx-derived N dry deposition in the Phoenix metropolitan area: Effects of urban vegetation. *Ecological Modeling*.

Hall, S. J., N. B. Grimm, S. L. Collins, and J. D. Schade. In review. Soil nitrogen oxide fluxes in an urban ecosystem. *Ecosystems*.

Hope, D., C. Gries, P. Warren, M. Katti, G. Stuart, J. Oleson, and J. Kaye. In review. How do humans restructure the biodiversity of the Sonoran Desert? *Journal of the Rocky Mountain Research Station.*

Jenerette, G. D., S. L. Harlan, A. Brazel, N. Jones, L. Larsen, W. Stefanov. In review. The inequitable distribution of the heat island in an arid city. *Proceedings of the National Academy of Sciences of the United States of America.*

Lewis, D. B., and N. B. Grimm. In review. Local features mediate regional drivers of nitrogen export from catchment ecosystems. *Ecological Applications*. Accepted pending revisions.

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Mussachio, L., and J. Wu. In review. Developing synchronicity in urban ecology as sustainability science: Linking ecology, design, and planning. *Frontiers in Ecology and the Environment*.

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Stabler, L., and C. A. Martin. Landscape management affects woody plant productivity and water use in an urbanized desert ecosystem. *Ecosystems*.

Walker, J. S., R. C. Balling, J. M. Briggs, M. Katti, P. Warren, and E. M. Wentz. In review. Birds of a feather: A story of urban and exurban population biology. *Computers, Environment, and Urban Systems.*

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Kinzig, A.P. In press. On the benefits and limitations of prediction. In press. In *Understanding ecosystems: The role of quantitative models in observation, synthesis, and prediction*. Princeton University Press.
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