CAP LTER 2002-2003
ANNUAL PROGRESS REPORT

Central Arizona – Phoenix LTER
Land-Use Change and Ecological Processes in an
Urban Ecosystem of the Sonoran Desert
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CAP LTER 2003

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CAP LTER 2003

I. Overview and Results from CAP, Years 1-6

Almost six years ago we began to tackle the enormous challenge of a comprehensive study of the rapidly growing metropolitan region of central Arizona, including Phoenix and four of the five next-largest cities in Arizona. Added to the expected LTER challenges of understanding the patterns and processes that underlie long-term changes in ecosystem structure and function, an urban ecosystem involves the complexities of intense human participation in the system—with attendant economic and social drivers, radically altered land cover, accelerated cycling of materials, and heretofore unresearched ecological impacts of a built environment. As at the traditional LTER sites, interdisciplinary collaboration of ecologists, biogeochemists, earth scientists, and climatologists is fundamental, but in the urban case, added to the mix are sociologists, geographers, economists, political scientists, urban planners, anthropologists, civil and environmental engineers, mechanical and chemical engineers, and many community partners who share our zeal for understanding the urban ecosystem. Although we realize there are significant differences among the range of perspectives deemed necessary to understand an urban system from one where human participation is relatively modest, we believe that lessons learned from the wider collaboration will prove useful to all LTER sites and, indeed, to the whole of ecology. We expect that these lessons ultimately will help to frame a new ecology broad enough to understand when and why social variables must be integrated into traditional ecological theory (see also Redman 1999, Collins et al. 2000, Grimm et al. 2000).

Our strategy for establishing the CAP research program was to begin with many initial projects—pilot projects, data-gathering and synthesis projects, and short-term experiments—roughly following the LTER core areas but adding two areas focusing on human dimensions of ecological research. After the first 2 years, we established *long-term research* at a broad spatial extent that will be repeated every 5 years (Survey 200) (Hope et al. 2003) and at permanent aquatic and terrestrial monitoring sites where more frequent sampling takes place. To the extent possible, a subset of the Survey 200 sites are monitored more frequently for bird populations, ground arthropods, primary production, and water use, ensuring comparability and utility of results. Abundant monitoring data that exist from local, state, and federal agencies has dictated a major *data-mining effort* to create an urban environmental database, aided with significant leveraged funding to our data laboratory (McCartney et al. 1999, 2002). We also have used these mined, monitoring data to establish parameters for our *models* of urban ecosystem structure and function. These include a hierarchical patch-dynamics model developed by Wu (Wu and David 2002) with partial support from other funds (Wu 2000); fluid-dynamics models that describe the movement of air pollutants (Fernando et al. 2001) and the deposition of N (Grossman-Clarke et al. 2003 [in revision]); and a surface heat-island model (SHIM) with implications for a desert, urban environment (Brazel and Crewe 2002). Two *long-term experiments* have been underway for 2-4 years. One examines the effects of homeowners' management practices on plant growth, carbon sequestration, and soil processes (Stabler and Martin, in press). Another direct, manipulative experiment is a crossed predator exclusion-watering experiment to determine the impact of predation and plant growth rate on herbivore populations (Faeth et al., unpublished). Finally, we have engaged in several *cross-site comparison* and multiple-site synthesis activities, including an urban heat island and climate change comparison of Phoenix with Baltimore (Brazel et al. 2000), a new, separately funded project (Redman et al. 2002) comparing agrarian landscape change at several LTER sites, study of N retention in urban streams (part of LINX-2, IRCEB, Mulholland et al.), and work on bird diversity as a function of socioeconomic setting (P. Warren et al. unpublished).

In the upcoming "bridge" year between the first phase of CAP LTER (CAP1) and its expected renewal in November 2004 (CAP2), our strategy is to continue the elements of the research that have achieved "long-term status," to phase out the shorter-term, pilot projects that characterized our first award period, and to gradually add the new elements and organization of our research that have arisen as a result of our team's preparation of the renewal proposal (initial proposal work began in May 2002). Briefly, because we believe that projects must be interdisciplinary from the outset, we have modified our research teams away from the earlier organization of "core areas + 2 social science areas" employed in CAP1, toward more integrative project areas that demand interdisciplinary involvement. Thus, we view this interim year as an opportunity to phase in these changes and allow participating scientists to find their niche within the reorganized thematic structure.

II. Objectives, Significance, and Broader Impacts

Research on the CAP LTER has been directed at answering a central research question that still guides us today: *How do the patterns and processes of urbanization alter the ecological conditions of the city and its surrounding environment, and how do ecological consequences of these developments feed back to the social system to generate future changes?*

This overarching question focuses our thinking on the interaction between the ecological and human domains in the context of extremely fast-growing metropolis. Population growth and land consumption in the Phoenix metropolitan area are consistently among the highest in the US; changes in ecological conditions accompany extensive and continuous modification of the land surface, the microclimatic and biogeochemical environment, and biodiversity patterns, and a phenomenal rate of land conversion (largely from desert to residential or farmland to residential). We have long recognized that virtually every change is accompanied by some sort of response, both social and ecological, which yields a complex set of feedbacks that drive further change (Grimm et al. 2000). In the past six years, we have identified many of the ecological consequences of urbanization, but we are only beginning to understand how those consequences feed back to the social system and generate future changes. Our primary objective during this bridge year is to further develop our research program to understand both the patterns and mechanisms of change in ecological conditions *and* the feedbacks to the social system. We will do this in the context of *three interpretive themes* linking field projects to our central research question:

- scales and periodicities of ecological and human phenomena;
- human impact and control of variability in space and time; and
- resilience of socioecological systems.

In addition, we will begin to reorganize projects, monitoring, and teams under six new integrative project areas: 1) past, current, and future land-cover and land-use transformations; 2) human activities and biodiversity; 3) biogeochemical linkages of air, land, water, and groundwater; 4) nature and interactions between ecosystem health and human health; 5) local climate change and socioecosystem response; and 6) ecological, economic, social, and political aspects of urban water systems.

Ecological theory developed over the past century with limited reference to the massive and pervasive alterations of natural ecosystems made by *Homo sapiens.* In the past decade, however, a renewed interest in human-dominated ecosystems in the US coupled with the critical need to find solutions to environmental problems where they are most severe, led to the creation of two LTER sites devoted to the study of urban ecological systems. The scientific significance of these projects lies in their potential to reconceptualize and revitalize ecology by considering the integration of new elements into ecological theory. Certainly not all ecological theory must be refined, nor will all changes be radical, but we do believe that given the pervasive presence and impact of humans on all global environments, not just urban ecosystems, our minds must be open to change. Urban ecosystems, because of the clearly dominant influence of people, institutions, and the built environment offer the best laboratory for examining possible refinements in ecological theory.

In terms of its broader impacts, CAP LTER has served as a focal point for many new developments, both in Arizona and the US. The CAP LTER project has had over 550 participants, of which more than 100 were community volunteers, in its first 6 years. Aside from the many published (or in press) works (>150 journal articles, book chapters, and reports), CAP LTER has consistently been in the news locally and nationally (most recently, on NPR's *Science Friday*). We work conscientiously on our outreach, but also have been able to benefit greatly from the establishment of linked projects, the purpose of which is to provide community and governmental outreach. For example, the Greater Phoenix 2100 (GP 2100) project is using 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 plays a leadership role in developing new IT tools for handling ecological data.

The CAP LTER project is an important focal program for both social and natural scientific research at Arizona State University (ASU) and is the prime example for this University of the success that comes with fostering interdisciplinary interactions. Students in our Integrative Graduate Education and Research Training (IGERT) program in urban ecology are forging new paths to this interdisciplinarity, bringing the more discipline-bound faculty members along with them. A monthly All Scientist Council meeting, open to all faculty members, students, and community partners, is regularly attended by 40-80 individuals. Aided in part by leveraged funding, CAP LTER personnel have led the way nationally in crafting the arguments for social science-natural science integration (Kinzig et al. 2000; Kinzig 2001; Harlan et al. 2003; Redman et al. in press).

From an initial collaboration with 12 schools, Ecology Explorers, our education-outreach program, has expanded to include 87 teachers at 64 public schools (encompassing 25 school districts), 3 charter schools, and 2 private schools. In addition, over 20 community partners are substantively involved in CAP LTER, such as Salt River Project, the Maricopa Association of Governments, the US Geological Survey, the Gila River Indian Community, the Salt River Pima Indian Community, and Motorola.

III. Highlights of Research Activities

Current research is grouped according to both subject matter and type of approach, under the main headings of Long-Term Monitoring, Modeling, and Core Research Activities. These core activities include: Primary Production and Organic Matter; Populations and Communities; Human Dimensions of Ecological Research, Biogeochemical Processes; Geomorphology and Disturbance; Resilience Alliance; and Database and Informatics Activities. These headings have been tweaked since the early project years. On a practical level, we have learned in CAP1 that interdisciplinary work requires certain practices that might seem rigid or forced, but without which natural tendencies to group with one's "own kind" (i.e., ecologist, anthropologist, geophysicist, civil engineer) would prevail. Questions asked should be broad enough to be of interest to social scientists, earth scientists, and life scientists alike. No "dogma" from any single discipline can be imposed on the others. Experiments and monitoring must be co-located to the greatest extent possible. Projects must be interdisciplinary from the outset, as it is difficult if not impossible to attract other perspectives if the questions to ask and methods to use have already been decided. Thus, we see current projects under these teams migrating to the new integrative project areas over the coming year, however for this 2003 annual report, highlights of CAP activities and research findings are reported under current categories.

Long-Term Monitoring

Geophysical Context and Patch Typology

The Geological Remote Sensing Laboratory (GRSL) continues to focus on collaborative CAP LTER research activities, with primary data generation (surface brightness temperature and vegetation indices derived from Landsat Enhanced Thematic Mapper Plus and AVHRR data for various projects; land-cover classifications of numerous urban centers using ASTER data). Processing new datasets and data generation and analysis for CAP LTER and associated research activities (such as GP 2100) continues to be a major focus at the GRSL. Current CAP LTER research projects at the GRSL, or completed over the past year, include: 1) correlation of vegetation indices derived from remotely sensed data with biovolume measurements obtained from the Sample 200 survey (Paine 2002); 2) studies related to urban climatology, including: the effect of social and biogeophysical parameters on Phoenix neighborhood microclimates; modification of the MM5 climate model using high-resolution land-cover data; and quantification of urban-rural climatic differences; 3) exploration of agrarian land transformations using 6 LTER sites as comparison points (Harvard Forest, Kellogg, Konza, Coweeta, Shortgrass Steppe, and

CAP); 4) landscape structural analysis of Phoenix region using ASTER data; 5) investigation of spider diversity in Phoenix. Each project is described further in Research Findings.

In Fall 2002, CAP LTER began the paleo- and modern climate of central Arizona project to study long-term spatial and temporal variations in climate. Modern climate records, including precipitation, streamflow, and snowpack, have been synthesized to look at patterns in these variables over the past 50 to 100 years. Efforts to develop longer-term patterns in climate were initiated as well. Previous researchers have successfully reconstructed precipitation, temperature, and the Palmer Drought Severity Index for the region, and Salt and Gila River streamflow. Over the past year, researchers have begun to update extant reconstructions of streamflow and develop new reconstructions using a variety of climate variables. Our objective is to create climate reconstructions that directly apply to CAP LTER climate and water availability. We have undertaken dendroclimatic reconstructions of seasonal-to-annual temperature and precipitation for the Phoenix Basin, seasonal streamflow of the Salt River, and peak spring snowpack for the upland region feeding the Salt and Gila rivers. For the reconstructions, we are searching for tree-ring chronologies from living and dead trees sensitive to climate in the Phoenix Basin. Based on previous research, we expect to reconstruct climate for the past 500 years at a minimum and hope to find tree-ring material to reconstruct climate for the past millennium. In addition to tree-ring reconstructions, we are investigating the potential of other paleoclimatic proxy data such as packrat (*Neomata*) middens, palynological series, and geomorphological excavations. Ultimately, long-term patterns of climate variability will be compared with pre-historical, historical, and modern human land in the Phoenix Basin.

Survey 200: Interdisciplinary Long-Term Monitoring

The extensive 200-site survey, conducted in 2000, presents a unique effort to study pattern and process across a rapidly expanding urban area and its surrounding landscape, using probability-based sampling. We have been examining the contribution of a suite of biotic, abiotic, and socioeconomic variables to explain the spatial variation in plant diversity of an entire urban ecosystem, with the hypothesis that human variables, including land use rather than distance from urban center, is most important in explaining spatial variation across the study area. Using the number of perennial plant genera, both native and exotic, as an important measure of ecosystem diversity, we have been considering the entire urban ecosystem, including those parts subject to intensive human modification and management (e.g., residential, commercial and industrial areas), rather than just remnant fragments of native desert vegetation. Unlike previous urban research, this approach allows for a range of key urban ecosystem drivers—both biophysical and socioeconomic—to be examined. This year's findings are briefly discussed in Research Findings below.

Variables that change more rapidly than those assessed in Survey 200 need to be monitored at greater frequency and at sites where public access can be restricted and experimental manipulations performed. Although this caveat is obvious for most LTER sites, it is no simple matter for an urban site. We have been monitoring key variables at three permanent plots on University property, which were identified and instrumented during Years 3 and 4. Although there is tremendous variability in patch types across the CAP site, we have restricted our intensive research efforts to a few common patch types: remnant desert, residential (turf lawn), and institutional. We describe research efforts at permanent plots in the sections below that deal with core research activities. However, all these efforts have been planned by a group representing all the disciplines involved in our study. In addition to permanent plots, another key aspect of long-term monitoring is our focus on surface water chemistry and atmospheric deposition, described in the Biogeochemical Processes section.

Modeling

The goal of our modeling efforts is to develop models to simulate land-use and land-cover change and investigate how urbanization affects ecological processes. To achieve this goal, a number of quantitative analyses of historical land-use change have been conducted, and alternative land-use change and urban-growth models are being constructed. At the same time, we are developing ecosystem-process models and metapopulation models that we plan to integrate with the urban-growth model. In addition, we have carried out a series of multiscale landscape-pattern analyses. Different modeling methods, such as cellular automata, Markovian chains, and process-based mechanistic modeling, have been used in our study of the Phoenix urban landscape.

Our modeling research has provided a number of insights into the structure and dynamics of the Phoenix urban landscape, as well as general methodological issues in modeling complex spatial ecological systems (see list of publications). In particular, we have generated several publications on the scaling relations of landscape pattern and the modeling of land-use and land-cover change and ecosystem processes. Our future goal is to refine the ecosystem models, develop metapopulation models, and integrate these models with the land-use and land-cover change model using the hierarchical patch-dynamics modeling platform. We also plan to construct an agent-based urban growth model to simulate how individuals and policy makers interact to make the city grow and how the city self-organizes to result in boom or bust periods.

Core Research Activities

Primary Production and Organic Matter

Several interdisciplinary projects conducted by the primary production team during Year 5 are described here, with research results presented below.

A neighborhood-scale residential-yard design experiment at "North Desert Village," university housing at ASU East, will explore effects of landscape design type on productivity and water-use efficiency (WUE) of vegetation, plant-microflora interactions, rhizosphere chemistry, and human response to landscape characteristics. Based on preliminary research, yardscapes of residential home units on the ASU East campus will be renovated into one of four landscape design types: 1) mesiscape/irrigated, 2) oasis/irrigated, 3) mixed xeriscape/irrigated, and 4) native xeriscape/no irrigation. Intensive and frequently replicated measurements will be taken of aerial and rhizosphere microclimate, vegetation growth and mortality, vegetation and soil gas exchange, and nitrogen and carbon soil chemistry. Currently, pre-manipulation sampling is beginning, for plant, soil, and social variables.

The landscape-practices experiment is investigating the effects of irrigation and pruning on plant growth and water-use efficiency, as well as plant and soil biogeochemistry (described in biogeochemistry section below) for two field-grown Southwestern landscape shrubs, *Nerium oleander* L. "Sister Agnes" (oleander) and *Leucophyllum frutescens* Berl. var. green cloud (Texas sage). A 2 x 4 factorial treatment combination of drip-irrigation rates (high or low) and pruning frequency (sheared every 6 weeks; headed back every 6 months; yearly renewal pruned, or non-pruned control) is being applied to plants in fourteen, 100 m^2 simulated landscape plots. Growth is measured in terms of plant biovolume in m^3 and biomass production in kg. WUE is defined as kg of shoot mass/1000 L of water applied for 3 years.

The urban tree primary-production study, begun in August 2001, examines the effects of impervious urban surfaces at 15 commercial parking lots on primary production of multiple urban tree species. Intensive and frequently replicated measurements of aerial and rhizosphere microclimate, tree growth and mortality, tree gas exchange, and nitrogen chemistry have been made as part of that work. The urban forest extensive monitoring study, begun in 2001, examines annual growth (measurements in winter) and nitrogen chemistry (measurements in summer) of urban trees at 50 Phoenix sites. Site selection, based on preliminary research, captures a range of land-use types using an urban-core to urban-fringe gradient approach.

Above- and below-ground estimates of urban plant biomass have been made since April 2002. This project has focused on growth of two common Southwestern landscape shrubs, *Leucophyllum frutescens* and *Nerium oleander*, and plant nitrogen partitioning in response to pruning and irrigation-volume landscape practices. Fieldwork has just begun, with the analysis of soil cores to enable estimation of root distributions of the two shrubs. In addition, litter traps have been placed underneath the shrub canopies and will be checked routinely to obtain estimates of leaf senescence rates and the nutritional content of the litter. Future work will involve analysis of nutritional content of the shrub roots, stems, and leaves, with several samplings planned so that seasonal changes can be documented. Also, the two shrubs are being propagated for an upcoming greenhouse study that will employ a growing media with known nutritional content to study changes in plant nutritional content in response to pruning and irrigation volume.

The residential landscape water monitoring study began in 1998. Continuous measurements, averaged monthly, of irrigation water applications at 16 residential sites are being made.

Populations and Communities

Fundamental information about how facets of urbanization affect the diversity of communities and distribution of populations is scarce, but may have important ramifications on ecosystem-level trophic dynamics, nutrient cycling, and other functions. Population/community research is focused on 5 groups: vascular plants, mycorrhizal fungi, arthropods, birds, and insect pollinators. We initiated pilot studies in 1998, taking advantage of existing datasets as well as the data-gathering potential of K-12 classes through our K-12 outreach program, Ecology Explorers. Studies have been redesigned to meet long-term monitoring goals.

Efforts this year on the plant community research show progress toward understanding patterns of plant diversity within undeveloped Sonoran Desert stands in our study area. There are two main sections in this project: the effects of habitat fragmentation and the characterization of vegetation types. First, we are seeking to discover how habitat fragmentation affects the character of plant communities in remnant desert patches. Rapid urbanization in the Salt River Valley has made metro Phoenix one of the nation's largest cities. Rampant development on the plains and the preservation of mountainous or otherwise rocky terrain has produced remnant patches (parks, conservation, and recreation areas) possessing varied spatial, temporal, and disturbance characteristics. We are seeking to identify the relationship between patch characteristics, species richness, and composition of remnant plant communities. Field sampling and data processing provide information on vegetation character and include woody and herbaceous species; GIS manipulations provide information about the physical features of remnants, including patch area, habitat heterogeneity, extent of isolation, and time since patch formation. Second, we plan to characterize how vegetation types are distributed across the study area, including both remnants and outlying habitats beyond the city's limit. The first step was to delineate community types based on woody species. We used field data from the patch vegetation surveys and the wide-ranging Survey 200 project. Each sample was summarized by the proportional cover of each species within each plot (*Larrea tridentata* = 0.40, *Ambrosia deltoidea* = 0.25, etc.; total sum equals 1.0). After classification analysis using TWINSPAN, a set of community types was generated. A Landsat TM scene from August 1999 was selected for analysis, and societal features (major roads, buildings, major disturbances) were extracted from the scene. To map community distribution, we used a supervised classification procedure, in which areas of known composition are used to produce reference spectra for comparison with candidate pixels. To minimize obscurity by differing substrates, the image was stratified by soil-texture class (in areas with soil development) and geology (in mountainous areas dominated by bedrock). Reference sites, located in the field using GPS, were collected within each image subset. A summary of completed work is included in Research Findings below.

We have completed the assessment of arbuscular mycorrhizal fungal (AMF) diversity at 50 Survey 200 sites. We established trap cultures in the greenhouse using soil collected from 30 additional Survey 200 sites that are part of the Bird and Arthropod Diversity and Primary Productivity studies. We are also assessing AMF diversity at 20 sites being monitored for the Primary Productivity study that were not part of Survey 200. Our plan is to extract spores from these trap cultures to assess diversity at these sites during the next year. We completed a study that examined the effects of shoot pruning on AMF root colonization and below-ground primary productivity. We are continuing to study spatial patterns of AMF diversity at the CAP LTER long-term experimental plot located the Desert Botanical Garden and in the adjacent creosote desert remnant. Research results are reported in Research Findings below.

The ongoing arthropod monitoring project is documenting the abundance and distribution of ground arthropods. From Spring 1998 to Spring 2002, we sampled arthropods in 6 land-use types (24 sites): xeric/urban yards, mesic/urban yards, agricultural, desert parks, urban desert remnants and commercial/industrial sites. Since May 2002, we relocated the sampling sites in 22 new locations (10 pitfall traps per site), all subsets of Survey 200 points. We are sampling arthropods in these sites every other month by opening the traps for 72 h, collecting the trapped arthropods, and identifying to family level.

Previously, we described the differences in arthropod diversity, abundance and distribution among land-use types. We described general patterns at the community level (all arthropods) and used data from the first year (McIntyre et al. 2001). Previously, arthropod response to land use was examined according to yearly sampling. We have reanalyzed the data to examine the effect of land use on arthropod communities according to season: Spring, Summer Dry, Summer Monsoon, Fall, and Winter. See Research Findings for results.

A focus on spider diversity was a special project of the arthropod study. Shochat et al. (in press) determined how land-use alteration influenced spider diversity. We sampled spiders in 6 habitat types (desert parks, urban desert remnants, industrial, agricultural, xeric- and mesic- residential yards) and tested how habitat type and habitat productivity affected spider diversity and abundance.

The goal for our bird-population research is to study the patterns in bird-species diversity and abundance and distribution over time and space, and the processes behind these patterns as a result of urbanization. The ongoing bird survey and point count (since October 2000) is documenting the abundance and distribution of birds in four habitats (51 sites): urban (18) desert (15) riparian (11) and agricultural (7). The 40 non-riparian sites are a subset of the Survey 200 points. We are using point counts to survey birds 4 times a year (January, April, July and October). During each session, each point is visited by 3 birders who count all birds seen or heard for 15 minutes. Our goal is to study how different land-use forms affect bird abundance, distribution, and diversity in order to predict and preserve high bird-species diversity as urban development proceeds. We have now completed 3 years of monitoring and are beginning to see that some of the sites are changing due to new urban development. The results described in Research Findings below are based on analyses of the first two years' data.

Urban bird communities exhibit high population densities and low species diversity, yet the evolutionary mechanisms behind these patterns remain largely untested. We conducted the first thorough experimental study of key behavioral mechanisms underlying these urban patterns and ran a comprehensive test of foraging theory applied to urban bird communities. We measured foraging decisions at artificial food patches (seed trays) to assess how urban habitat differs from more natural ones in predation risk, missed-opportunity cost (MOC), competition, and digestive costs. We manipulated seed trays and compared the leftover amount of seed (giving up density - GUD) in urban vs. desert habitats. We found that desert habitats exhibited higher predation risk than urban habitats, despite the higher density of cats in the city. Increasing the MOC (by adding feeders near the experimental seed trays) caused desert birds, but not urban birds, to quit patches (trays) earlier. Interesting patterns among species are detailed in the Research Findings section below.

During 2000-2002, to examine the effects of urbanization on breeding success and physiological stress, we monitored reproductive and hormonal parameters of native birds in urban and non-urban habitats. Preliminary results support the hypothesis that greater resource availability allows some species to breed earlier and often in urban habitats. This mechanism also appears to enable several native bird species to successfully colonize urban habitats. The field sampling will be completed in 2003, and we have begun the laboratory analyses. One immediate problem was that of small plasma sample volumes, especially from the smaller desert species (e.g., the Black-throated Sparrow, *Amphispiza bilineata*): commonly used radio-immunoassays would not work with such small volumes. The laboratory of Dr. Pierre Deviche has been developing and validating newer assay techniques (e.g., ELISA) that can also work with small plasma volumes. We have recently been successful in validating a new ELISA technique for several Sonoran Desert species. We expect to complete validations for the remaining species and conduct the assays over the next few months.

A long-term experiment on trophic dynamics in urban systems was established in Spring 2001. Questions addressed are: How similar are multitrophic dynamics among different types of habitat patches in an urban ecosystem? How similar are patterns of plant damage, herbivore outbreaks, herbivore control by predators, and seasonal trophodynamics among habitat types? Using replicated, controlled cage experiments, we are manipulating the access of predators (birds and/or ground predators) and the flow of resources (water) to test differences in trophodynamics of insect communities in urban vs. desert environments. To date, we have established experimental populations of brittlebush (*Encelia farinosa*) at our permanent research sites, starting with the ASU President's House (mesic residential) and the Desert Botanical Garden (desert remnant). This year the brittlebush project expanded from 1 to 3 sites. In

September/October 2002, we installed the experimental treatments (ground predator exclosure rings, bird exclosure cages, bimonthly watering 5 liters/plant) at the Desert Botanical Garden (DBG) site. The brittlebush plants were planted at the DBG during the previous year but experimental treatments were not started until the plants were firmly established and could survive without supplemental watering. The brittlebush project also established a natural desert site at Usery Mountain Preserve using existing brittlebush plants. We used naturally occurring plants on the upland slopes of two desert washes. The plants were randomly assigned experimental treatments and cages and rings were installed in December 2002. Monthly arthropod sampling will continue at each site (3 sites x 40 plants each = 120 samples per month) through December 2003, and plants will continue to be pruned and measured quarterly (December, March, June, September). After December 2003, we will reassess and possible reduce the frequency of arthropod sampling. Arthropods are being sorted and identified to morphospecies.

Human Dimensions of Ecological Research

This research area poses the overarching question: What "natural" ecological and socioeconomic processes interact to generate spatial patterns, and how do ecological consequences of development feed back upon future decisions? Research topics focus upon: 1) historically defined processes (historic land-use, legacy, and pioneer effects); 2) geographically defined processes (geography of the urban fringe and its effects on climate); 3) topically defined processes (environmental policy and risks); and 4) information system of human activities (local partner databases, US census data). Although various projects are organized under this heading, some projects by other teams are addressing questions about the human dimensions of ecological systems, and other projects already have natural-science elements. Our ultimate goal is to integrate social and natural science studies throughout our research.

The CAP LTER project has been at the forefront of efforts of social and natural scientists to forge an integrated research agenda for LTER sites and, towards this goal, has coordinated workshops, symposia meetings, incubation workshops, and cross-site proposals (Madison, Wisconsin 1998, Tempe, Arizona 2000, Snowbird, Utah 2000). During these meetings and workshops, attended by social, life, and earth scientists from LTER sites and other large, interdisciplinary projects funded by NSF, sufficient consensus has emerged over diverse aspects of integrated human ecosystems. Led by CAP LTER and BES, these activities produced a paper, entitled “Integrating Social Science into the Long-Term Ecological Research Network: Social Dimensions of Ecological Change and Ecological Dimensions of Social Change” (Redman et al. in press) that provides a foundation and departure point for social scientists and biophysical scientists to consider in collaborations for long-term research. It is also a recruitment call for more social scientists to become involved in ecological research.

Putting words into action, CAP LTER and BES garnered NSF-BE Incubation funding to hold a series of four focused workshops to encourage the development of integrated projects across sites and at sites that do not have social science as a primary objective. These workshops, held in Fall 2001, were: Models and Methods of Land-Use Change, Historic, Census and GIS Methods; Ecosystem Services and Valuation; and Ecosystem Function. The workshops brought together over 50 social, life, and earth scientists and culminated in a number of proposals, including a funded $1.8M cross-site study on agricultural transformations. “Agrarian Landscapes in Transition: A Cross-Scale Approach” is tracing the effects of the introduction, spread, and abandonment of agriculture at 6 LTER sites, with cross-comparisons in Mexico and France. The “Ag Trans” project will be the focus of an ASM workshop in September 2003, with a focus on the sites’ case narratives. In addition, participants in the workshop on Ecosystem Services and Valuation were successful in obtaining NCEAS funding to support further collaboration. It is hoped that theses interdisciplinary, cross-site studies will serve as models for other cross-site, integrative projects.

<u>Land-use change</u> remains a focal variable for CAP LTER. Land-use change is at the interface of social and biological activities and, hence, a variable relevant to most processes we are observing. Our early efforts focused on creating an overview of the growth of the Phoenix area. To accomplish this we conducted the historic land-use project, Phase I to set the baseline for how land use has changed in the study area. <u>Phase I</u> produced a relatively coarse-resolution, time-series data about land-use development and was presented in a series of maps (Knowles-Yañez et al. 1999). At the same time, we experimented with specific zones of the city, attempting to characterize the processes of change they were experiencing.

Most notable of these studies was an examination of the spread of residential development at the urban fringe (Gober and Burns 2002). Phase II of the research followed, in which land-use maps were created by individual track for each of the cadastral square mile sections that include one of the 204 study sites (Survey 200) for the years 1934, 1949, 1961, 1970, 1980, 1990, 1995, and 2000. Land-use classifications are based on the Anderson classification system and the local county classification. We have defined a series of alternate trajectories of change for each sector of the city and documented when they passed through analogous stages. We have then used these patterns to identify areas of the city that have experienced similar trajectories of growth, which allowed us to subdivide the region into 8 clusters of tracts that followed similar pathways and identify their distribution around the metropolitan area. We hope to generate a more-refined model for urban growth in our region and identify pioneering activities that led to rapid change, as well as define the factors that resisted urban growth and slowed the process.

With close to half the human population now living in cities, urban environments play an increasingly important role both in influencing daily quality of life and in land-transformation and ecological processes in all urban, peri-urban, and rural environments. These influences—both internal and external to the city—are not uniform across cities, but depend on urban structures and trajectories of growth which, in turn, are determined by social and biophysical conditions and legacies. The international urban structure and growth project compares the historic trajectories of growth in four diverse cities (Baltimore, Lyon, Paris, Phoenix) and presents a common time-series of maps for each city, which represent: 1) land use, including urban, agricultural, and open space (differentiating publicly and privately owned) categories; 2) population density; and 3) patterns of ethnicity and economic status across the city. In 2002 we sent a GIS specialist to France to initiate this collaboration; he gathered data on the Paris case study and met with relevant researchers in Lyon to define the specific categories of evidence available for or comparative study. An IGERT Ph.D. student also spent that summer in Lyon to complete the next stage of this collaboration. Results of this ongoing collaboration were presented at a joint US/EU LTER meeting in Motz, France, in July 2003 (Jolivean, Bravard, Redman, and Meegan, in preparation).

During the period 2002-2003, researchers who study climate within the CAP LTER framework have: been aiding the project in planning the NSF renewal proposal of CAP LTER, completed further analyses of the CAP LTER climate region: helped design the ASU East experimental site, and participated in the City of Phoenix planning efforts regarding heat island mitigation and community education.

Following from the CAP renewal planning retreat last summer, proposals were made for future climate research arranged around scale and process from global to local. Some of this work is already in progress: temporal change in the climate system in CAP LTER, emphasizing long-term drought (M. Kaye); the characterization of land-use change and associated climate changes, especially along the urban fringe zone, at several Survey 200 points, and along extreme urban to rural gradients; and modeling the urban climate of the entire Phoenix metro area, using runs of the MM5 numerical mesoscale model approach, an urban canyon model called SHIM (surface heat island model, after Voogt and Oke 2000); and developing a radiative model to investigate impacts of solar radiation variability across central Arizona, including water vapor and aerosol effects on receipt at the surface and impacts on solar collector devices and potential impacts on agricultural productivity. In addition, as part of the parks' initiative, field work was performed in Summer 2003 with field geography students on solar attenuation through typical tree species in several Phoenix parks and on noise patterns across a range of parks. Temporal change and ecosystem responses is a current research theme with publications that have been accepted (Brazel and Ellis, in press). It is also a workshop topic at the September 2003 LTER All Scientists Meeting. Several other efforts are ongoing, such as transect analyses from urban-to-urban fringe-to-rural in the SE Valley of CAP LTER, including a retrospective remote sensing and monitoring analysis dating back to 1976 and patterns in the present (temperature and humidity transect work was done in 1976 that is used to compare with the present land conditions and transect analysis). A climatologist, IGERT fellow, plant biology graduate student, and a plant biology professor have been involved in this successful collaboration. Results showed major changes from 1976 to 1999 to NDVI and land cover plus resultant temperature and humidity patterns equivalent to the magnitude of the 1948 to 2000 heat island development previously reported by Brazel et al. (2000). Temperatures exceeding 6C were recorded for minimum and nighttime temperatures and considerable dew point "drying" along altered parts of the transect. (Brazel, Stabler, and Martin, in preparation).

An urbanization and warming project examined impacts, feedbacks, and mitigation of the urban heat island in the Phoenix metro area (Baker et al., in press). This involved assessing several changes in ecosystem components that accompany the rapid development of the Phoenix urban heat island, such as increasing discomfort, increasing energy demand in summer, decreasing demand in winter; fewer frequent days of frost but more frequent days of plant stress (temperatures over 40C), and potential negative impacts on dairy industry and cotton yields. The research also showed that urban environmental heating may represent what global warming might induce on local ecosystem features. The study was conducted in a "communities of practice" mode, by simply inviting individuals who might be interested in various aspects of the urban climate. Longitudinal and spatial climate data were collected. A record of hourly to 3-hourly data were compiled for the National Weather Service Phoenix Sky Harbor Airport First Order Station from 1948 to 2000. Spatial data (hourly) for recent years was compiled from the Arizona Meteorological Network, operated by the University of Arizona Cooperative Extension, for 6 stations along a rural-urban gradient. Initial results for this project and brief descriptions of climate publications are presented in Research Findings.

The environmental risk study is mapping the geographic and social distributions of environmental hazards to learn how hazards are understood by those who live with them and to understand when and how people exposed to such hazards will organize and take action. The project is situated at the intersection of social and natural science, ethics and policy, and employs an integrative style of research.

We continue work with an integrative, innovative, quantitative method for allocating point-source hazards to spatial units. (The method is developed in Bolin et al. 2002 and will be expanded upon in a publication that is being written.) Our work also combines quantitative analyses of the social and spatial distribution of hazards with historical study of the trajectories of highly toxic areas of Phoenix. This addresses enduring questions in environmental sociology and environmental risk.

We are developing an extended study of the political ecology of the Phoenix area that combines the specific hazard studies with broader historical geographic development of the city. This project is broadening our focus to more complex urban processes that create areas of environmental disamenities. In addition, we are currently working on new longitudinal data on industrial polluters in Phoenix and changing patterns of pollution over a 15-year period. These data are currently undergoing analysis.

In collaboration with the CAP LTER, IGERT, and the environmental risk team, a physical and chemical analysis of particulate pollution samples was conducted in April 2002. People spend most of their time indoors and understanding the relationship between indoor and outdoor air quality is useful because air quality is typically measured by outdoor centrally located monitors. Specifically, this project is assisting the people of Homedale by providing air-quality data at two neighborhood sites. This data will be used to help them determine what steps can be taken to improve the quality of life in their neighborhood. Outdoor (ambient) and indoor 24-hour samples of PM2.5 (particulate matter <2.5 micrometers in diameter) were collected to determine the mass concentrations of inorganic ions, organic and elemental carbon, and total particulate mass. Samples were collected at two homes, one near a truckstop, and one near the community center. Samples were collected for 24 hours every third day for a total of 9 sampling events. It is expected that this project will contribute to our understanding of human exposure to air pollution.

The Phoenix Area Social Survey (PASS) is an interdisciplinary research collaboration among ASU faculty members and staff. PASS began in 2000, at the close of a decade of rapid population growth, urban development, and economic change in our region. Its goals, explicitly shaped by these dynamics, are to: 1) examine how communities form and work in a rapidly growing, low-density urban setting characterized by high rates of in- and out-migration and frequent residential mobility; 2) study the interaction between rapidly growing human communities and the natural environment in a desert ecosystem; 3) explore the possibilities of interdisciplinary research that combines a spatially referenced social survey (i.e., households in selected neighborhoods) with other sources of population, ecological, and climate data; and 4) establish the methodology for an ongoing area survey that will continually explore issues of sociological, ecological, and social policy interest in our region.

PASS is a survey of eight neighborhoods (302 respondents) that captures the spatial variation in human attributes that make up the social fabric of Phoenix: urban core low-, middle-, and upper-income neighborhoods and urban fringe middle- and upper-income neighborhoods; the lower income neighborhoods are predominately Hispanic and the others are predominately white. Respondents in the pilot survey were selected from an area probability sample of housing units within selected census block groups in the city of Phoenix. Block groups were used to define the boundaries of neighborhoods because their residents are relatively homogeneous in demographic and social characteristics and can be readily linked to decennial census and other data sources. Respondents were interviewed by telephone and in-person, and the average length of the interview was 45 minutes. Our research activities expanded the survey to include two more neighborhoods; completed coding and editing of all survey responses and produced a PASS dataset ready for analysis; prepared a summary report of major findings using graphical presentation of the data; and acquired household water consumption data for all households in the PASS neighborhoods from the municipal water department. These monthly records for the past 17 years will be merged with survey data in order to study the relationships between sociodemographic characteristics, landscape types, conservation programs, and water consumption; and successfully began a new interdisciplinary study in collaboration with Anthony Brazel (Geography), William Stefanov (Geology), and Darrel Jenerette (Plant Biology) on microclimate conditions in PASS neighborhoods and across the region. (NSF Grant. No. SES 0216281, Neighborhood Ecosystems: Human-Climate Interactions in a Desert Metropolis.)

The urban parks project aims to understand the ecological and social roles that neighborhood parks play in an urban setting. Ecological processes in parks are being measured and correlated to neighborhood socioeconomic status, use statistics, land-use history, and management strategies. Activities this year included a neighborhood survey, a field observation survey, noise and microclimatic measurements, use surveys, a cat survey, and a perennial plant survey. A *neighborhood survey* instrument to assess park use, park satisfaction, neighborhood attachment, and landscaping preferences was designed and tested in Fall 2002. Over 2000 surveys (350 each in 6 neighborhoods) were mailed in Spring 2003. Over 30% of the surveys have been returned, and coding and analyzing the results are in process. *Field observations* have been conducted on transects in the neighborhoods around each park using protocols developed in Baltimore. These observations—which characterize such features as security (bars on windows), "connection" to neighborhood (evidence of sitting outside, fences), and trash—can supplement Census data in socially and economically characterizing neighborhoods. Students from a field course in Geography (Summer 2003) measured the *noise profile* of parks (difference in decibels from park edge to park center) and the shade provided by various tree species. They will use the shade information, and tree species identifications made in Summer 2001, to calculate a "comfort index" for each park. During the Fall and Spring *use surveys,* the 16 parks were visited 3 times over a month in both early morning (6:30-8:30am) and late afternoon (4:00-6:00pm). The number of people using the parks, their location, activity, age, and ethnicity were recorded. We are using motion and heat-detecting cameras to record *cat activity* in each of the 16 parks during Summer 2003. Cat activity will be correlated to bird counts from observations in the 2000-01 and 2001-02 academic years. We have completed data entry for the neighborhood *perennial plant survey* (perennial plants recorded on four 200-m transects around each of the 16 parks). Results of this initial work are reported under Findings.

Biogeochemical Processes

This research area includes both aquatic and terrestrial components of the urban landscape and has included projects at a range of scales, though the early focus was on mass balance for the whole ecosystem. The CAP ecosystem nitrogen mass balance was published in 2001 (Baker et al. 2001), and studies of mass balances for carbon and salts are underway. At this largest scale, long-term monitoring of surface-water inputs and outputs of nutrients and major ions continues, as does dry and wet atmospheric deposition monitoring (now supplemented by modeling). At smaller scales, research has been initiated or continued on land-water linkages in small watersheds, episodic, storm-driven elemental transport, aquatic nutrient cycling, soil-plant nutrient storage and transformations, trace gas fluxes, and elemental stoichiometry.

Transfer of materials from atmosphere to land to aquatic ecosystems to surface water and groundwater is being investigated in the urban watersheds project. Our foci at this scale are: 1) episodic linkage of these landscape components during storms; and 2) responses of recipient systems to inputs. We have acquired and analyzed data on stormwater chemistry and hydrology collected by municipal and county agencies, compared the impacts and magnitude of flood and groundwater-pumping inputs to aquatic recipient systems, and established fine-scale monitoring of rainfall, throughfall (as a surrogate for dry deposition), and runoff in a small remnant desert catchment within the city. A project to examine the quality and in-stream microbial utilization of dissolved organic carbon discharged from the city's wastewater treatment plant is near completion (Edmonds and Grimm, in preparation). Studies of urban stream N retention, in cooperation with the LINX project, have been conducted in several small area streams and drainage ditches using short-term nutrient addition experiments. We have an ongoing project on spatial variation in nutrient concentrations in an urban lake-stream, Indian Bend Wash (IBW), and we have expanded soil N studies of retention basins (Zhu et al., accepted) to the floodplain of this system. We have acquired and analyzed data on land-use change within the large, urban IBW catchment (>500 km^2) over the past 80 years. These data provide insight into how land-use change affects biogeochemical cycling by altering surface stream geomorphology and hydrology.

Research on soil and plant nutrient cycling includes: 1) comparison of land-cover patch types and description of spatial variation across the entire study area (Survey 200 samples); 2) a similarly designed, nested sampling at two smaller scales (both in extent and grain) in agricultural, mesic turf, and desert remnant patch types; 3) measurement of soil nutrient transformations, nutrient storage, and stoichiometry in the context of the urban landscaping-practices experiment; 4) preliminary monitoring of trace gas fluxes; and 5) analysis of changes in soil nutrient parameters and stoichiometry of soils, vegetation, and herbivorous insects at sites along two desert-urban gradients, a west-east transect that follows a gradient of atmospheric deposition and a north-south gradient that does not follow a deposition gradient. We report findings mainly from (3) and (5), as the other projects have either been reported previously or have no new information to report.

The water monitoring project (WMP) has continued to collect water-quality data using protocols similar to those used by the USGS's NAWQA program, on over 20 different water chemistry parameters at 3 stream sites upstream of the Phoenix metropolitan area, and 2 downstream of the city. These data, now dating back to March 1998, have been combined with the water chemistry data the USGS has collected in the same areas to create a long-term dataset reaching back over 50 years for some parameters. Analysis of this dataset is focusing on differences in water chemistry that can be attributed to the city, and whether abrupt changes in chemistry can be associated with events like increase in groundwater pumping, advent of the use of Colorado River water, and other changes associated with urbanization, such as the shift from agricultural to municipal water use (Edmonds et al., in preparation).

Data collection and analyses in the WMP are continuing to address the questions: Has the import of significant amounts of trans-basin (Colorado River) water affected downstream water quality? What inorganic chemicals (common anions/cations, metals) does society add to discharges from the CAP LTER study site during normal flow conditions (sources: general public and industry) and during rainfall events (sources: urban and natural runoff)?

The main goals of the atmospheric deposition monitoring research at CAP LTER have been to: 1) monitor and quantify the spatial variations in rates of atmospheric deposition for major nutrients and ions across the study area; 2) determine the role of atmospheric deposition in urban biogeochemical cycling; and 3) understand how inputs of nutrients and other materials via atmospheric deposition affect the function of other ecosystem processes such as primary productivity of native desert and introduced urban plant species.

Using our own monitoring network, which we devised and installed to supplement the very limited monitoring of atmospheric deposition chemistry in the study area and surrounding region, almost 3 years of data have now been collected and are being analyzed. Over the last 2 years, the data acquired from this wet-dry bucket approach (patterned after the NADP system) has been supplemented with modeling to describe dry deposition across the region, since the bucket method captures only the coarse fraction of particulate deposition. Dry deposition to the CAP study area is one of the largest unknown terms in the CAP ecosystem's N mass balance (Baker et al. 2001).

A model developed with ASU's Environmental Fluid Dynamics laboratory and Arizona Department of Environmental Quality (ADEQ), the Community Multiscale Air Quality Model has given us a much more accurate idea of the size of that deposition term (Grossman-Clarke et al., in revision). (The model predicts annual fluxes of NO_x-derived dry deposition in the Phoenix metropolitan area, along with its temporal and spatial characteristics. Input data for the diagnostic model included hourly pollutant concentrations measured at six ADEQ air-quality monitoring stations, meteorological variables, and detailed land-cover characteristics of the study area (from the remote-sensing project). NO_x dry deposition fluxes to the urban core were simulated for the years 1996 and 1998, and a simulation for 22-23 July 1996 was used to predict spatial patterns of NO_x and nitric acid dry deposition over the entire study area.

Because the approach described employs diagnostic model, it does not describe the feedback between the atmosphere and the surface. However the advantage of such a model is that all the monitoring data, available over long time periods, can be used to estimate dry deposition fluxes at different sites of the study area. The disadvantage is that it cannot deliver continuous spatial estimates. Therefore we are currently testing the model using data from the ADEQ air-quality monitoring network in the Phoenix area for the year 1998. After that we plan to use long-term ADEQ monitoring data to determine seasonal characteristics of nitrogen dry-deposition fluxes. First simulation results show that annual dry-deposition fluxes for gaseous nitrogen species are comparable to fluxes obtained from studies for the Los Angeles area. More details of the research findings are described in the Research Findings section.

Geomorphology and Disturbance

Geophysical, geological, and geomorphic constraints on ground subsidence in piedmonts of the greater Phoenix area were further analyzed this summer, building upon field work from last summer and the work done on the surface/subsurface water response to the Tempe Town Lake operations. Ground subsidence due to groundwater withdrawal and the resulting pore collapse is a common environmental problem for the region. Given the continued complex groundwater management of pumping and recharge, subsidence concerns will remain a major area of interaction between urbanization and natural processes. An important example of ongoing subsidence affects the Central Arizona Project canal near Taliesin West in the McDowell Mountains piedmont of northeast Scottsdale. We have performed the geophysical, geologic, and geomorphic investigations (reported largely in map and tabular form) of this active subsidence zone. This preliminary work has lead to increased collaborations between us, ADWR (Arizona Department of Water Resources) and the Central Arizona Project.

In addition research was conducted with CAP LTER support for a senior thesis, "Artificial Hydrologic Controls and the Geomorphology of the Greater Phoenix Area” (Macleod 2003). This work addresses: 1) to what degree do artificial controls on hydrologic processes alter those flow systems, and 2) how do these changes affect urban geomorphology? This study looks at the many different ways in which artificial controls have impacted the hydrology of an ephemeral desert stream—Cave Creek. Cave Creek drains an increasingly developed watershed and runs from 40 km north of Phoenix into the historically oldest part of the city. The overland flow through this area becomes increasingly managed downstream, finally to be diverted altogether into an adjacent river, thus crossing watershed boundaries.

Resilience

ASU’s recent membership in the Resilience Alliance (www.resalliance.org) has led us to explore what a “resilience” approach offers to CAP LTER and related research. The Alliance is an international consortium of institutions that seeks novel ways to integrate science and policy in order to discover foundations for sustainability. Resilience researchers are interested in complex adaptive systems and the coupling of ecological and human sciences. Resilience theory seeks to understand the source and role of change in adaptive systems—particularly the kinds of change that are transforming. It is a theory of linked dynamic cycles across spatial and temporal scales (Gunderson and Holling 2002; Redman and Kinzig 2003). Ann Kinzig (School of Life Sciences) is our university representative and the force behind our joining this interdisciplinary group. Redman and Anderies also play active roles in the Resilience Alliance. Alliance members are primarily interested in contemporary systems but, with ASU’s input, are beginning to examine whether archaeology and studies of the past can enhance their understanding of resilience. Accomplishments for this year: publication of *Resilience of past landscapes: Resilience theory, society, and the longue durée* (Redman and Kinzig 2003); organization of a session at the annual McDonnell Foundation research meeting (4-6 June 2003, Kinzig); presentation at the ICSU, the International Consortium of Scientific Organizations (Kinzig 2002), organization (Kinzig, Redman, and van der Leeuw) of a meeting to be convened in February 2004 that will examine 5 archaeological cases studies and expand the suite of comparative case studies being considered by the Resilience Alliance; and the award of an NSF Biocomplexity grant, which has a resilience perspective (Redman et al. 2002).

Database and Informatics Activities

The CES Lab continued its active role in the final release of EML 2.0 and in the LTER network-wide effort to adopt this common metadata standard. Under a no-cost extension on our NSF-BDI funding, we began to develop our Xylopia data-access infrastructure and released the Southwest Environmental Information Network (SEINet) Web site. This new interface incorporates the EML metadata search, biological collections data resources, and online data access and visualization tools to replace many of our previous Web applications with a new EML-based and extensible framework upon which it will be easier to build new features. We are also completing a new analysis wizard for our Ecology Explorers program, which is also based on the SEINet infrastructure. In 2003, we began work on our NSF-ITR grant to build on our prior BDI grant by integrating urban ecological models from government partners using a Web-services approach. In July 2003, we submitted a new proposal for $1.4M to NSF-BDI (with subcontracts to the Network Office, Oregon State U, and U. Wisconsin, Madison) for extending our prior work in Web services to the development of LTER Network Information System databases.

In Spring 2003, we released an environmental atlas for futures planning in Phoenix (http://www.gp2100.org/eatlas). Also based on the SEINet data access infrastructure, the Greater Phoenix 2100 EAtlas added over 60 new GIS datasets to the data catalog, some derived from CAP research and some from agency and corporate partners.

Over 100 datasets are now cataloged in SEINet using the new EML standard. Our intranet application for participants to manage their project, bibliographic and personnel information was expanded to accommodate other projects at CES other than CAP LTER and is now released on the CES Web site (http://ces.asu.edu/intranet/). Further details on informatics activities at CAP LTER are described in the annual Site Flash submitted to the LTER information management committee (http://caplter.asu.edu/data/siteflash/CAPsiteflash03.shtm).

IV. HIGHLIGHTS OF RESEARCH FINDINGS

Long-Term Monitoring

Geophysical Context and Patch Typology

Research findings from collaborative work with ASU's Geological Remote Sensing Laboratory (GRSL) are presented below and follow the order presented in the Research Activities section above; related publications are in brackets.

Results from the vegetation index–biovolume comparison study indicate that there is little-to-no correlation between the two measures of plant biomass. This lack of correlation is likely due to two main factors: 1) co-location errors between Landsat Enhanced Thematic Mapper Plus (ETM+) pixels (from which vegetation index data is calculated) and Survey 200 sample points (from which biovolume data is calculated); 2) differences between the physical measures represented by vegetation indices and biovolume. Although the two types of measurements (biovolume and vegetation indices) are useful in and of themselves, construction of a vegetation index-biovolume calibration curve is not possible using the current datasets. This problem may be addressed by using higher-resolution remotely sensed data and/or designing field data acquisition to be more comparable to remotely sensed information. [Paine 2002]

The NSF-funded Phoenix Neighborhood Microclimate study has characterized several neighborhoods in Phoenix (chosen along an economic gradient) using social (PASS, US Census, resident narratives) and biogeophysical (vegetation indices, surface temperature, air temperature/humidity, soil temperature, noise, shade) parameters obtained using both remotely sensed and field data. The initial phase of this research involved a summer (2002) REU student from Fort Hayes State University, Kansas. Research efforts were continued as part of an IGERT graduate seminar taught by Harlan, Brazel, and Stefanov in Spring semester. Most of the seminar consisted of exploratory data analysis and fusion that is continuing through the Summer 2003. Preliminary results have not revealed clear correlations between climate and economic level at the neighborhood scale, but such a correlation is indicated at the metropolitan scale. [Jones et al. 2003]

Modification of the land-cover input to the mesoscale climate model MM5 has been completed using a 1998 land-cover classification derived from Landsat TM data by Grossman-Clarke, Zehnder, and Stefanov. Incorporation of the updated land-cover data results in improved modeling of planetary boundary-layer characteristics. Investigation of the effect of rural land-cover and temperature variability on calculation of urban heat island values is ongoing, using historical land-cover data and regional climate records by Hawkins, Brazel, and Stefanov. Results of an associated comparison study of urban vs. rural temperature variation using a local farm property indicate a strong dependence of calculated heat island values on the "rural" temperature values used. [Grossman-Clarke et al., in press; Hawkins et al., in press]

Work to date on the NSF-funded Agrarian Landscapes in Transition project has centered on collection of remotely sensed and ancillary geospatial data from the member LTER sites, in particular recent land-cover/land-use and vegetation-index data (Stefanov, Netzband, and Banzhaf). This effort has seen variable degrees of success depending on the LTER site. Regional characterization for each site is ongoing using MODIS land-cover and vegetation-index data.

Work completed as part of the ASTER Urban Environmental Monitoring project (elwood.la.asu.edu/grsl/UEM) with direct links to ongoing CAP LTER research include characterization of regional landscape fragmentation compared to other urban centers; and detailed description of the spatial variation of the study area using land-cover classifications derived from ASTER data. Patch diversity was calculated for the urban/peri-urban landscapes associated with 55 urban centers located around the world, including Phoenix. The result of this analysis indicates that significant landscape fragmentation is associated with all urban centers, and the highest levels of regional fragmentation correspond to "megacities." A detailed analysis of several landscape metrics for 10 urban centers (including Phoenix) indicates that for some structural measures urban centers are quite similar for all land-cover types, but for others (i.e., vegetation, varying densities of urban materials) cities can be ranked according to metrics such as edge density and patch density. This suggests that global urban centers may be classified according to these spatial measures (Stefanov 2002; Netzband and Stefanov 2003).

The EOS Science Teams for the Terra, Aqua, and ACRIM satellites are now being reselected on the basis of proposals for science investigations. ASU has submitted such a proposal to continue the existing UEM project (Co-PIs Stefanov and Christensen), with a greater emphasis on investigation/ characterization of urban-development trajectories and prediction of urban-center sustainability and resilience.

Survey 200: Interdisciplinary Long-Term Monitoring

Our results show that, on average, the Phoenix urban landscape has similar gross generic plant diversity to the native vegetation it replaced, albeit comprising largely non-native genera which boosts the total number of genera. Spatial variation in plant diversity across the entire system area (including the urban, agricultural, and undeveloped desert components) was best explained by a combination of human-related and nonhuman predictor variables. Land use was the primary determinant of overall plant diversity, supporting the well-established relationship between patch type and ecological condition. The second most important factor was elevation, highlighting the influence of natural underlying geomorphic site characteristics (Hope et al. 2003). Higher plant diversity in housing developments with a younger median age reflects changes in landscape design and cultural values. Meanwhile, urban sites that had formerly been farmed had 43% fewer woody plant genera than locations never under agricultural cultivation. It would appear that native vegetation removal for cultivation may leave a legacy that persists even after subsequent development.

The most interesting finding to date has been that spatial variation for plant diversity at urban sites median family income is the most influential explanatory variable, followed by the average age of housing in the neighborhood and whether the site had ever been farmed. The positive plant diversity-income relationship was linear for urban sites—neighborhoods with a median family income level above $50,000 per year had on average 2.3 times the plant diversity of less-wealthy areas. We have term this the "luxury effect," whereby given sufficient economic wherewithal, humans consciously choose to enhance plant diversity (Hope et al. 2003). A similar relationship between income and diversity has been seen for bird diversity (see bird populations section of the report and also parks project). However across the entire CAP site, we found an apparent threshold median family income of $50,000 per year, above which the number of genera found did not increase, suggesting that wealth saturates generic plant richness in urban ecosystems (Hope et al. submitted).

Data analysis of soil chemical and physical properties collected during the Survey 200 is also underway. Marked differences in the concentrations and spatial patterning of soil nutrients and physical properties between the urbanized and undeveloped portions of the study area have emerged (Hope et al., in preparation), which have important implications for how urbanization has changed the region's soil nutrient pools (Zhu et al., in preparation). The extremely high spatial heterogeneity in soil nutrient concentrations across urban areas is necessitating the development and application of new statistical techniques. Such work is currently being carried out by a soils working group, with important contributions from Jake Oleson, a faculty member in ASU's Mathematics and Statistics Department.

Differences in mycorrhizal species diversity and abundance have been found between urbanized and desert systems from the Survey 200 (Cousins et al., in press). Meanwhile, pollen data collected at the 200-Survey site locations has also shown interesting patterns, namely that we can distinguish seven broad groupings of plant taxa, based on the relationship between plant cover and pollen abundance. For example, taxa such as *Larrea* and *Parkinsonia* showed a close tie-in between vegetation cover and pollen abundance on a site, while wind-dispersed (anemophilous) taxa such as *Pinus* produced high pollen counts relative to the amount of vegetative cover. Meanwhile zoophilous taxa such as the *Cactaceae* and *Nerium* had much more locally distributed pollen, which clearly demarcated the desert and urban areas that they respectively typified (Stuart et al., in revision).

Using the vegetation-cover data from Survey 200, we established a community classification using cluster analysis and non-metrical scaling ordination technique. Seven different clusters were recognized, with three comprising mostly desert sites and four mostly urban. Eight urban sites were classified in the desert clusters, all of which had original desert vegetation, and 10 desert sites were classified as similar to urban sites. Within the desert cluster, three subclusters where found, dominated by the genera *Larrea*, *Ambrosia*, and *Encelia*, respectively. Three of the urban subclusters were dominated by the genera *Cynodon/Pinus/Morus*, *Prosopis*, or *Syagrus*, respectively, while a fourth urban subcluster was highly diverse with no clear indicator genus. The last two urban subclusters were examples of ‘desert' landscape design while the first subcluster represents an “asis” landscape design type. The *Prosopis*-dominated subcluster combined urban and desert sites.

Modeling

Several major findings have emerged from studies of the modeling project, summarized as follows:

1) Based on our multiscale landscape-pattern analysis and hierarchical ecosystem modeling, we have developed a landscape ecological framework for studying urban environments. This framework emphasizes the effects of the spatial pattern of urbanization on ecological processes and properties, the importance of scale, and the integrated approach that combines remote sensing, GIS, process-based modeling, and spatial statistical analysis. In contrast with traditional urban ecological studies, our landscape ecological approach integrates urban morphology, socioeconomic processes, and bioecology in a cohesive spatial context. This framework has been articulated and demonstrated through a number of journal articles and book chapters.

2) Our study of the historical land-use change showed that urbanization in metropolitan Phoenix has increased its spatial complexity dramatically over the past several decades. This increase in landscape complexity has resulted from diversification of land-use types and fragmentation of the previously more-contiguous desert landscape. We have been able to successfully quantify the landscape changes using a suite of landscape metrics. The general pattern of urbanization shows an increasingly urbanized landscape becoming compositionally more diverse, geometrically more complex, and ecologically more fragmented. Our results supported the hypothesis that, with increasing urbanization, patch density increases while patch size and landscape connectivity decrease. However, our results on patch shape seemed to reject the common belief that patch shape becomes more regular as human modification to landscapes intensifies.

3) Our multiscale landscape analysis revealed that a few attributes of urban landscapes exhibit deterministic scaling relations (mostly in the form of a power law) with respect to spatial resolution and extent, whereas most landscape structural variables do not. In general, three types of responses of landscape pattern with changing scales are seen to exist: Type I showed predictable responses; their scaling relations could be represented by simple scaling equations (linear, power-law, or logarithmic functions); Type II exhibited staircase-like responses that were less predictable; and Type III behaved erratically with no consistent scaling relations. Thus, to adequately quantify landscape heterogeneity, we recommend the metric-scalograms (the response curves of metrics to changing scale), instead of single-scale measures.

4) Our landscape-gradient analysis showed that the spatial pattern of urbanization could be reliably quantified using landscape metrics with a gradient-analysis approach, and the location of the urbanization center could be identified precisely and consistently with multiple indices. Different land-use types exhibited distinctive, but not necessarily unique, spatial signatures that were dependent on specific landscape metrics. The changes in landscape pattern along the transect have important ecological implications, and quantifying the urbanization gradient is an important first step to linking pattern with processes in urban-ecological studies.

5) Based on the hierarchical patch dynamics paradigm and the scaling ladder concept, we have developed a spatially hierarchical modeling approach to studying complex urban landscape systems and a hierarchical modeling platform (HPD-MP)—a software package—from which multiscale ecological models can be developed and integrated in an efficient and coherent manner. Refining the ecosystem models and integrating them with land-use change models using HPD-MP is the focus of our current research. More findings are found in the publications listing.

Core Research Activities

Primary Production and Organic Matter

In the landscape-practices experiment, the effects of irrigation and pruning on plant growth and water use efficiency (WUE) is being investigated for two field-grown Southwest landscape shrubs, *Nerium oleander* L. "Sister Agnes" (oleander) and *Leucophyllum frutescens* Berl. var. green cloud (Texas sage). During the first three years of study, oleander given high irrigation rates produced the most shoot mass when left non-pruned or when headed back every 6 months, whereas oleander given low irrigation rates produced the most shoot mass when left non-pruned and the least when sheared every 6 weeks. Texas sage production was greatest for shrubs given high irrigation rates and least for those sheared every 6 weeks. In general, oleander and Texas sage grown at high irrigation rates had lower WUE if left non-pruned (1.6 and 0.7, respectively) or headed back every 6 months (1.8 and 0.6, respectively) relative to those pruned yearly (0.9 and 0.5, respectively) or every 6 weeks (0.8 and 0.4, respectively). Oleander and Texas sage grown at low irrigation rates had lower WUE left non-pruned (3.0 and 0.9, respectively) relative to those sheared every six weeks (1.0 and 0.6, respectively). These results show the importance of drip irrigation and pruning practices in controlling primary production and WUE of landscape shrubs in the landscape in arid climates (Stabler and Martin in press).

The land-use effects on urban tree primary production research indicates asphalt surfaces are up to 27°C higher than all other surfaces found in and around parking lots (turf, pervious, and concrete) (Celestian and Martin in review). Over two years, *Brachychiton populneus* (bottle tree), *Fraxinus velutina* (ash), *Pinus canariensis* (Canary Island pine), *Pinus halepensis* (Aleppo pine), and *Ulmus parvifolia* (Chinese elm) showed significant reductions of one or more of the size variables due to parking lot median placement. *Prosopis chilensis* (mesquite) showed no significant reduction in all size variables due to parking lot median placement.

Populations and Communities

Cousins et al. (in press) reported on results on arbuscular mycorrhizal fungi (AMF) diversity from the Survey 200 study. This preliminary assessment found that the AMF community structure in the Phoenix area is comparable to that of the surrounding Sonoran Desert. However, current and historically agricultural sites were associated with decreased spore densities (in current agriculture sites) and decreased species richness (in sites that were agricultural prior to development), indicating that certain anthropogenic activities do impact AMF communities with effects persisting over long time periods. Similarities in AMF species composition between the urban environment and surrounding desert indicate a persistence and/or in-migration of desert AMF species. Changes in AMF species composition appear to be due to presence exotic non-mycorrhizal plant hosts, absence of vegetation, and land use.

A study of small-scale spatial patterns AMF species was completed at the CAP LTER long-term experimental plot located at the Desert Botanical Garden (DBG). AMF species in two 9.2 × 9.2 m subplots were identified using trap cultures from soil collected at 25 points in each subplot. No single species was dominant at either plot, and many species were only detected at one sampling point. A rank-frequency plot for the site revealed a log-normal species distribution. The number of AMF species detected at each point was not correlated with proximity to plants. Despite the patchiness of plants in the plots, the number of species detected per point exhibited spatial structuring only at the smallest sampling scale in a single plot, and only a single species in each plot was non-randomly distributed. These results indicate that the current sampling practice at Survey 200 sites of collecting soil samples in the root zone of three plants underestimates the number of AMF species at each site. A publication on these results will be submitted in Fall 2003.

A comparison is in progress of AMF local diversity (using data collected at the long-term experimental plot located DBG) with regional diversity (using data from Survey 200 sites). On the local scale, 12 species were detected, while close to 20 species were detected in the regional survey. There was a strong overlap of species composition on the local and regional scale with 10 of the species detected in the local community also detected in samples in the regional survey. Sampling effort curves and jackknife estimates indicate that a limited number of species were still undetected. The 4 most frequently detected species in the local scale were the most frequently detected in the regional survey and the rarely detected species were similar. This type of overlap between local and regional diversity suggests large-scale historical processes may be important in determining local community structure. Preston-type plots of the relatively frequency also indicate broad dispersal of AMF species. These results were presented at the International Conference on Mycorrhiza in Montreal in August 2003. Also completed is a study of the effects of 3 shoot-pruning techniques (shearing every 6 weeks, heading back every 6 months and renewal pruning every year) on root-length density, biomass, AMF colonization, and soil respiration in two woody shrubs, *Nerium oleander* (oleander) and *Leucophyllum frutescens* (Texas sage). Roots were sampled at the base of plants during February and May after pruning treatments. Root biomass, length, and soil respiration associated with *Leucophyllum* were reduced by all pruning treatments in May. Shearing stimulated root biomass in *Nerium* in February, but shearing and renewal pruning reduced biomass compared to unpruned plants in May. *Nerium* colonization was stimulated by shearing and heading back in February and by shearing and renewal pruning in May. The results indicate the common practice of pruning shrubs can impact below-ground carbon storage in urban ecosystems. A publication on these results will be submitted for review in Winter 2003.

Field data describing woody species composition was collected from 22 remnant desert patches within the urban matrix for the plant community study. The patches varied widely in size (from 2.2 to almost 8800 hectares) and distance to the urban fringe. Additionally, woody data was collected from 3 outlying sites: Usery Mountain Park, Union Hills, and the White Tank Mountains. The recent drought offered only limited opportunity to survey herbaceous species. Spring herbs were sampled in 11 patches and at Usery Mountain, summer herbs were sampled in 6 patches. Habitat character can have drastic repercussions in terms of vegetative properties. For example, the plains often contain species-poor stands of more widely dispersed individuals, in contrast to slope habitats. To facilitate comparison between patches and control for differential habitat constituencies, species richness was expressed as a weighted average based on habitat composition. Aerial photos and supporting GIS layers were used to trace major habitat types within patches, defined geomorphologically: slopes of each aspect (N, S, E, W), plains, and major washes. The total area covered by each habitat type was quantified and translated into a proportion of the total. Because sample plots were stratified by habitat, the species richness summarizing each habitat could be multiplied by that habitat's proportion, and all components summed, to yield an estimate of local richness at 100 m^2. Total species richness of a patch was estimated using the first order jackknife of the species-area curve (2nd order jackknife and bootstrapping results were highly correlated).

The relationship between patch area and species richness was investigated for the woody and spring herb species and reported on in a presentation delivered at the annual convention of the Ecological Society of America, August 2003. Regression analysis revealed that there was a strong relationship between area and both local and total patch species richness for the spring herbs. Woody species richness and area was strongly related at the "patch scale," but not at the local scale. Path analysis, useful for revealing the relationships between components, revealed that local and total patch richness was positively related, but area and local richness were negatively related. These counteracting influences act to dampen the regression relationship: area directly depresses local richness, but indirectly inflates it through area's increasing of the patch species pool. Path analysis of the spring herbs indicates reinforcing positive direct and indirect effects. It was also found that area alone had no significant effect on non-native species richness. Path analysis revealed that the direct negative effect of area on non-native species counteracted the positive effect area had on native species richness. Native and non-native species richness is positively related.

In the arthropod monitoring project, ground-arthropod data from 1999-2001 was reanalyzed by month of collection to guide future sampling frequency. Diversity was highest in natural desert habitats and lowest in mesic residential and industrial areas. Abundances were greatest in agricultural fields. Results were significant at $p < .05$. Some ground arthropods were associated primarily with natural desert habitats, suggesting that xeric habitats do not adequately reflect conditions in natural desert areas, as previously suspected. Arthropod diversity and abundance differed according to season, usually peaking during the summer monsoon. This emphasizes the importance of planning future collection times to capture seasonal fluctuations. It is important to include a seventh land-use treatment: native Sonoran residential as opposed to exotic xericscapes to help determine how much plant species in addition to geographic location and patch size contribute to differences in arthropod communities among urban areas and natural desert.

The spider diversity study yielded results for this group that were similar to findings for ground arthropods in general. As expected, agricultural fields and mesic yards were more productive than the other xeric habitats. These more productive habitats were characterized by higher abundances but lower spider diversity and were dominated by Lycosidae (wolf spiders), followed by Liphyniidae. The increase in wolf spider abundance was positively correlated with habitat productivity and negatively correlated with the abundance of other predator arthropods that might compete with, or prey upon, wolf spiders. We suggest that habitat structure and productivity alteration may change community structure, as the urban or agricultural habitat favor one or a few pre-adapted taxa over many others. [Shochat et al., in press]

Our baseline dataset from bird monitoring is proving useful for asking a variety of questions about urban bird communities. *Human impacts and temporal variation in urban bird communities:* Last year, we reported, for the first time, a strong link between bird community characteristics and human social class. In multivariate models, median family income and plant biovolume explained a large proportion of the variance in bird species richness, followed by plant diversity. Adding data from the second year to the analyses has allowed an examination of temporal patterns as well, yielding new insights. First, while the effects of income are generally consistent between years, the strengths of this and other effects changes seasonally, reflecting changes in the bird community. Resident species, for instance, seem more sensitive to income effects than migrants.

Second, and more exciting, we were able to test the hypothesis that human impact tends to dampen some aspects of environmental variation: In Phoenix, some bird community characteristics (abundance, species richness) are significantly less variable between years in urban habitats than in nearby desert habitat (Fig. 1). A similar pattern was found at the seasonal scale as well, with urban bird communities exhibiting little seasonal variation whereas desert communities are markedly seasonal. A manuscript describing these results will be submitted for publication shortly. Results were presented in a poster at the LTER All Scientists Meeting in Seattle, September 2003.

Studies of Foraging Behavior: It appears that the House Finch (*Carpodacus mexicanus*) and House Sparrow (*Passer domesticus*) coexist by trading-off travel cost against foraging efficiency. House Finches travel greater distances, but spend less time in any given patch, acting like "cream-skimmers," whereas House Sparrows are more efficient at exploiting a given patch by spending more time, but do not range as far. In general, urban doves were more efficient foragers than passerines. Providing water decreased the digestive costs only in the desert, suggesting that water is a limiting factor there. We suggest that at the population level, reduced predation, and higher resource abundance drive the increased densities in cities, whereas at the community level, the decline in diversity may involve exclusion of native species by highly efficient urban specialists. Therefore, competitive interactions play a significant role in structuring urban bird communities. A manuscript based on these results (Shochat et al., in review) is now in review at the journal *American Naturalist*. These studies have also provided an empirical foundation for developing theoretical models of urban bird-population dynamics.

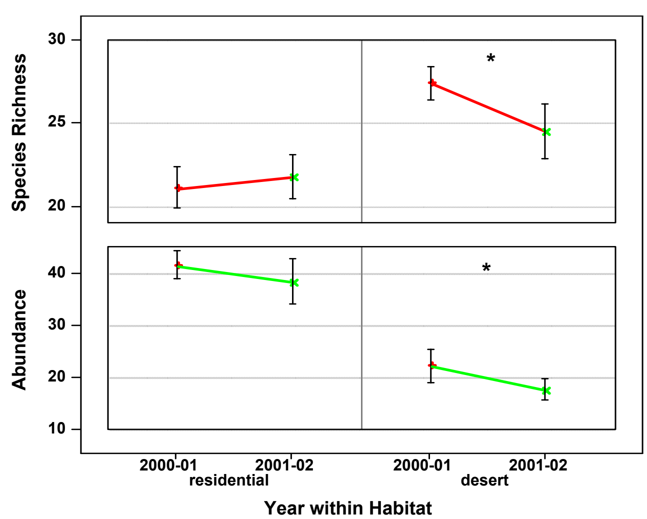

Fig 1. Bird communities in desert are more variable between years (2000-2002) than in residential habitat in Phoenix. * – rmANOVA desert: Spp. Richness, ($F_{1,13}$=8.7, p=0.01); Abundance, ($F_{1,13}$=5.3, p=0.04); residential: $F_{1,17}$, *n.s. for both.*

Developing theory of evolutionary ecology of urban bird communities: Over the past year we have collaborated with Anderies to develop theoretical models of urban bird communities. This area of study is relatively poorly developed, despite the growing body of descriptive evidence on patterns in urban bird communities, including our own work here. In

Fall 2002, we started building upon existing theory and behavioral and ecological models developed in non-urban systems to develop a more comprehensive framework for understanding urban patterns. Our model framework incorporates key aspects of bird behavior, physiology, and population dynamics, along with the external dynamics of resource availability and predation pressures. We are now able to demonstrate that many of the dominant patterns in urban systems can be explained in terms of two key changes brought about by urbanization: 1) an increase in resource availability and predictability; and 2) a decrease in predation on adults (although, in some cases, nest predation increases). We presented a poster on this at the CAP annual poster symposium this year, and are currently finishing a manuscript to be submitted soon for publication.

Trophic dynamics in urban systems research has found that a complex, highly specialized community of arthropods lives on brittlebush. Guilds include parasites, parasitoids, endoparasites, leaf chewers, sap feeders, generalist predators, opportunistic omnivores, detritivores, and fungivores. Aphid and hoppers are the dominant species and there are several parasites and endoparasites specific to these groups. Spiders and their parasites are also commonly found on brittlebush. The bird exclosures exhibit a marked effect on aphid populations. Species richness, evenness, and abundances vary among the three sites. Due to the volume of arthropod samples collected (120 per month), there is now a backlog of samples to be sorted. We sorted and identified samples from a subset of the sampling dates for presentation at the All Scientist Meeting in Seattle, September 2003.

Human Dimensions of Ecological Research

Highlights of findings on environmental issues from the Phoenix Area Social Survey report, *The Phoenix Area Social Survey: Community and Environment in a Desert Metropolis* (http://www.asu.edu/clas/sociology/pass.html), are presented below:

The Changing Urban Landscape

- A slight majority of respondents believe that more pristine-desert lands should be preserved in the Valley. Paradoxically, however, half the respondents also think housing density in the Valley is too high. Inhabitants of the urban fringe are by far the most likely to say they have too little space.
- The appeal of greenery in residential landscaping is nearly universal among desert dwellers, although the style of landscape design varies by social class. All income levels have in common a desire for more greenery—either grass or oasis landscaping—than they currently have. Sixty percent think they have too few water features in their neighborhoods. Residents of upper-income neighborhoods are significantly more likely to have the types of landscaping features they desire.

Local Environmental Concerns and Stewardship

- Survey respondents express many concerns about the local environment. More than 40% are concerned about the future water supply, drinking water safety, accidental releases of industrial chemicals, air pollution, allergens, and soil and groundwater contamination.
- Half the respondents think that environmental conditions in greater Phoenix are getting worse. Only 1 in 5 thinks the environment is getting better.
- Middle-income and lower-income households are more sensitive to environmental degradation in greater Phoenix and in their neighborhoods than higher-income households.
- Affluent respondents think they are environmentally privileged compared to others: they believe their neighborhood's air is cleaner, their groundwater is less contaminated, their water supply is less threatened than the rest of the Valley.

Social Capital and Neighborhood Resilience

- In most neighborhoods, newcomers rather quickly form social ties and social cohesion with their neighbors. Within four years of moving in, new residents have social ties as strong as the longest-term residents. Residents of the upper-income neighborhoods report having the strongest social bonds.

- Respondents in low-income core neighborhoods cited "noise, litter, and vandalism" as the most common problem in their neighborhoods, followed by transients, toxic emissions from industry, and hazardous waste sites. These people confront significantly more problems with environmental toxins than higher-income respondents.

Individuals who report higher levels of social capital in the neighborhood (social ties and cohesion) are more likely to take civic action to try to solve environmental problems, even after controlling for differences in individuals' education, ethnicity, residential tenure, and neighborhood income level.

The results of the physical and chemical analysis of particulate pollution sampling indicate that the concentration of PM2.5 in the study site were well below EPA standards during April 2002. A business establishment likely increased the soot concentration on some days. Variation among individual homes was found, due to differences in cooling system used (i.e., air-conditioning system at House #1 removes some of the outdoor particulate matter, while PM2.5 concentration in a fan-cooled home was the same as outdoor concentration), and different sources of particulate matter and organic carbon (oC) inside the homes (such as cooking). Such variations thus link directly to both socioeconomic status (type of cooling system) and individual behavior (cooking style, etc.), directly affecting the pollutant environment in individual homes.

As part of the environmental risk study, research on historical elements in the formation of environmental inequities have demonstrated that century-old patterns of racial segregation are spatially durable and historically antecedent to the introduction of industrial polluters and other technological hazards in urban core areas. Further, metro intercity competition for resources has historically weakened investment in central-city neighborhoods, promoting further incursions of land uses incompatible with residential ones. Areas of significant contamination in Phoenix have expanded in the postwar period and have been associated with socioeconomic decline in adjacent suburban neighborhoods in west central parts of the city. Highway and airport expansion have contributed to neighborhood decline and increased pollution burdens, burdens which continue to fall disproportionately on African Americans and Latinos. Newly assembled datasets on industrial polluters in Phoenix have yet to be systematically analyzed but preliminary observations suggest several important phenomena. First, atmospheric emissions of toxic chemicals have declined in Phoenix in absolute volumes. This decline has been accompanied by rises in the tonnage of chemicals shipped off site to be processed, rather than emitted locally. In terms of changing patterns of environmental justice, this observation suggests that: 1) there is an increased flow of hazardous cargoes across the metro area, redistributing risks from accidents in the city as off-site shipments of toxic materials increase; 2) other areas of the US are having to deal with hazardous materials produced in the Phoenix area, raising important new dimensions about the geographies of environmental injustice. These issues are currently being explored.

The urban parks study has focused on bird surveys, perennial plant surveys, and use surveys. *Bird surveys* (conducted in previous academic years): Bird-species richness is significantly higher in upper-income parks relative to lower-income parks. This richness appears correlated to neighborhood features rather than to features of the parks themselves. In addition, birds in lower-income parks are "nested subsets" of those found in upper-income parks—in other words, there are no unique assemblages in lower-income parks. A large proportion of the difference between upper- and lower-income parks seems to be insectivorous birds. *Perennial plant surveys:* Perennial-plant species richness in neighborhoods appears to be explained by median family income, with higher-income neighborhoods having higher species richness. Plant abundance, in contrast, is correlated to the age of neighborhood development. Parks were found to have a higher proportion of native vegetation than neighborhoods. *Use surveys:* Use of parks does not seem to differ by socioeconomic status of the surrounding neighborhood. Males are significantly more likely to be using the parks than are females (that is, during the morning and evening hours in which the surveys were conducted).

Modeling of the urban climate system was initiated at the meso- and local scale over the past year and resulted in publications (Brazel and Crewe 2002; Brazel, et al. 2000) that have merged the empirical results of the urban climate with modeling processes. The work using SHIM highlights the important consideration of rates of nighttime cooling in urban canyon-like environments, where heat is retained due to local decreases in the sky view factor and/or the higher thermal admittances of urban surfaces. This model was used in a thesis on the urban fringe environment (Hedquist 2002), applied to commercial/urban landscapes with variable sky view factors, and the ASU campus and surrounding neighborhood were used as a test landscape (Brazel and Crewe 2002). The MM5 modeling has been made possible through special adaptations to the land-use code in the USGS MM5 archive (Grossman-Clarke) and is presented in a preprint for the 5th International Conference on Urban Climate that was held in Poland, September 2003 (Grossman-Clarke et al., accepted). The two Lodz, Poland, preprints highlight the fact that MM5 proves a very useful model to evaluate, among other aspects, land-cover effects on local climate processes and has potential to aid CAP LTER researchers in explaining ecosystem changes as the region continues to urbanize.

Investigations have also been made as to the role of spatial variability of the surrounding rural climate, against which urban sites are typically compared, to determine the urban heat island magnitude, and reported in the *Journal of Applied Meteorology* (Hawkins et al., in press). In this article, it was found that the magnitude of the so-called heat island, as judged in comparing rural versus urban sites, varies by several degrees C depending on the rural land cover compared to the urban sites. Remote sensing of rural land cover and a special network of weather sites in a dense network in collaboration with a commercial farm (Schnepf Farms) in the SE Valley provided data for the analysis.

Another article for the *Journal of Applied Meteorology* is related to air quality and climate across the CAP LTER study area (Brazel, Hunt, Fernando, and Selover, under revision). This work addresses the drainage wind and in general the wind shift that typifies relief such as is found in the Salt River Valley, whereby a broad plain to the southwest abuts up against a marked escarpment in the terrain to the north and east of Phoenix. The timing of the wind shift in the evening hours varies by up to six hours as a function of local energy budgets, terrain, and the general distance from the escarpment.

A related project, on Neighborhood Ecosystems and Microclimate (Harlan et al. 2002), is providing insights into the complexity of local-level processes of housing density, landscape elements, geographic variability, and related social parameters. This project is furthering the understanding of microclimate factors *within* various land-use units of the urban area. The project features an ongoing monitoring program within 8 neighborhoods varying in social status and biocomplexity across the metro region. Initial climate findings suggests that poorer neighborhoods typically have less shade and trees to ameliorate heating (and are hotter particularly at night and portions of the day) or heat-exposed sites in richer neighborhoods of desert landscaping tend to be in upland areas away from extremes of lowland heating. Several posters on this work will be presented at the ASM meeting in Seattle, September 2003, and an ASU IGERT workshop featured this research; publications are underway.

Some results from the urbanization and warming project (Baker et al., in press) indicate that at Sky Harbor International Airport, urbanization has increased the nighttime minimum temperature by 5^{o}C and the average daily temperatures by 3.1^{o}C. Urban warming has increased the number of "misery hours per day" for humans, which may have important social consequences. Other impacts include: 1) increased energy consumption to heat and cool buildings; 2) increased heat stress (but decreased cold stress) for plants; 3) reduced quality of cotton fiber and reduced dairy production on the urban fringe; 4) a broadening of the seasonal thermal window for arthropods; and 5) climate feedback loops associated with evapo-transpiration, energy production, and consumption. Urban planning and design policy could be redesigned to mitigate urban warming, and several cities in the region are incorporating concerns about urban warming into planning codes and practices. The issue is timely and important, because most of the world's human population growth over the next 30 years will occur in cities in warm climates.

Biogeochemical Processes

Analysis of nutrient and metal loads exported by individual storms from multiple urban catchments reveals relationships between exports and storm characteristics (including time since last event, precipitation amount and intensity). One of our initial hypotheses was that urbanization would increase the spatial variability of material export. These data suggest a high degree of variation among catchments in total loads as well as concentrations (Lewis and Grimm, in preparation); data also suggest, however, that variability among storms within a catchment is great enough to mask differences among catchments. We plan to continue such analyses in cooperation with the agencies that collect these data, to uncover mechanisms accounting for spatial variation and to learn what watershed configurations lead to the lowest exports.

Material loads carried off the land in stormwater are of scientific and management interest because they represent inputs to recipient systems within urban catchments. Another major recipient system is the Salt-Gila River flowpath that receives wastewater effluent downstream from the city. Dissolved organic carbon (DOC) concentrations are high there, but decline over a 67-km flowpath that traverses agricultural fringing regions of west Phoenix. Detailed studies implicate both dilution (by groundwater pumping) and microbial utilization in this decline (Edmonds and Grimm, in preparation). A broad survey of small urban "streams" (drainage ditches, small canals, etc.) suggests they poorly retain nitrogen (N), in comparison with their non-urban counterparts. Our first nutrient addition bioassay experiments in Indian Bend Wash (completed in Years 3-4) revealed that phosphorus (P) was a limiting nutrient for algal growth during summer, but not during seasons when P inputs from storms were high. Continuing this work with a simple bioassay in Summer 2003 has failed to show nutrient limitation, underscoring the high interannual variability in groundwater use, which in turn is a function of annual rainfall. Denitrification was found to be high in neighborhood retention basins, but in a comparison of floodplain soils with lake sediments, the latter appear to exhibit higher denitrification potential and thus may be "hot spots" of N removal as well. Finally, historical analysis of the IBW catchment revealed changes in: 1) number of lakes; 2) floodplain extent; and 3) contributing area for floods, all of which are posited to have profound influences on nutrient retention in this urban stream system (Roach et al., in preparation; Grimm et al., in preparation).

Studies of soil-plant nutrient cycling are near the end of the pilot phase, and monitoring has begun (with no findings to date). The stoichiometric consequences of horticultural practices are that irrigation and pruning tend to decrease the C:N and C:P ratios (measures of nutrient use efficiency) of two common landscaping plant species. Preliminary conclusions from our study of soil-plant-herbivore stoichiometry and nutrient cycling across the urban deposition gradient indicate that *Larrea* that are exposed to high N deposition have lower tissue C:N ratios, higher mineralization rates in the soils underlying them, and harbor greater numbers of herbivorous insects than do *Larrea* at sites upwind from the city.

Data from CAP monitoring at 8 sites indicates that wet and dry atmospheric deposition of inorganic N and organic C is typically enhanced by a factor of two at urban core sites. However dry-bucket sampling does not account for fine particulate and gaseous N deposition, so we improved our estimates of this using the results of modeling work described above. These estimates indicate that combustion sources of NO_x (primarily motor vehicles) enhances dry N deposition by up to one order of magnitude in the core of the CAP study area, compared to outlying areas. Average annual NO_x-derived N deposition fluxes were found to be about 9 kg N ha^{-1} y^{-1} in the urban core area, 1.5 kg N ha^{-1} y^{-1} in the upwind desert and 10 kg N ha^{-1} y^{-1} downwind of the urban core. Nitric acid and NO_x dry deposition contributed 25% and 75% respectively to the total N deposition flux. Nitrogen dry deposition to the entire area was estimated to be 13.4 Gg/y, 20% of total annual N inputs and therefore a significant term in the nitrogen mass balance of the urban ecosystem (Grossman-Clarke et al., in revision). Preliminary results from this modeling work appeared in a recent review paper headed by Mark Fenn of the USDA Forest Service which included CAP researchers S. Grossman-Clarke and D. Hope as co-authors (Fenn et al. 2003).

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VI. Research Training and Development

Postdoctoral Associates, Graduates and Undergraduates, K-12 Students and Teachers

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 has been accommodates CAP LTER's analytical needs and provides graduate-student training on instruments housed in this facility. Data collected as part of the remote sensing lab's research programs is archived at the GRSL and available to project researchers and graduate students.

Since the inception of CAP LTER, 17 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports 8 postdocs, 5 of them full-time on CAP LTER.

They 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 winter poster symposium and summer summit gatherings. 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.

Both NSF and ASU support approximately 20 graduate students a semester, each immersed in the research at hand and working together as a cohort for the project at large. Graduate students are currently drawn from a wide range of university programs and departments, including: 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. Students also receive exposure to the interactions of government agencies and the effects of large public works projects on public attitudes. The IGERT in Urban Ecology and an NSF GK12 Research Fellowship grant supports approximately 30 additional graduate students who are also associated with the CAP LTER. Seven participated in an Urban Ecology IGERT Workshop in Spring 2003 on Neighborhood Ecosystems co-taught by a sociologist, geographer, and geologist.

CAP LTER faculty members, postdoctoral associates, and senior graduate students have mentored 24 NSF-funded REU students who gained research training via summer projects integral to CAP LTER. 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. Approximately 24 undergraduate students from a summer geography course in field methods participated in the noise and microclimatic surveys related to the parks project. They have also been educated on the basics of ecological field work and experimental design. Project research has also been incorporated into undergraduate honors and senior theses. Faculty members in geography, geological sciences, biology, and civil and environmental engineering have delivered additional training through graduate courses designed around CAP LTER activities.

Monthly All Scientists Council meetings 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. 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, and workshops. Other working groups, such as atmospheric deposition, feedbacks, and modeling meet as needed. Lastly, graduate students meet monthly at research-focused gatherings designed to facilitate interdisciplinary research.

The Schoolyard LTER supplement has created special opportunities for K-12 teachers to work alongside LTER researchers in summer internships on several monitoring projects.

Theses and Dissertations

In Progress

Bigler, W. Environmental history of the Salt River, Phoenix. (Ph.D. Geography, W. Graf).

Boreson, J., Correlating bioaerosol load with PM2.5 and PM10 concentrations (M.S., Civil and Environmental Engineering, J. Peccia, A. Dillner).

Buyantuyev, A. Integrating landscape pattern and ecosystem processes in the Phoenix metropolitan region: Scaling and uncertainty analysis (Ph.D., Plant Biology, J. Wu).

Collins, T. A multi-method study of environmental inequality formation in metropolitan Phoenix. (Ph.D., Geography, K. McHugh).

Celestian, S. B. Characterization of parking lot environments and the effect of parking lot surfaces on the growth and physiology of six Southwest landscape trees. (M.S., C. A. Martin).

Edmonds, J. W. Understanding linkages between dissolved organic carbon quality and microbial and ecosystem processes in Sonoran Desert riparian-stream ecosystems" (Ph.D., Biology, N. B. Grimm).

Holloway, S. Proterozoic and Quaternary geology of Union Hills, Arizona (M.S., Geology, J. R. Arrowsmith).

Jenerette, G. D. A multiple scale study of soil carbon and nitrogen patterns and processes: Ecological, geological, and sociological drivers of soil biogeochemistry (Ph.D., Biology, J. Wu and N.B. Grimm).

MacLeod, A. Artificial hydrologic controls and the geomorphology of the Greater Phoenix area. (Senior thesis, Geological Sciences, J.R. Arrowsmith).

Prasad, L. Urban heat island connections to neighborhood microclimates in Phoenix, Arizona: Defining the influences of land use and social variables on temperature. (M.A., Geological Sciences, Arrowsmith).

Peterson, K. A. Assessing impacts of socioeconomic factors and residential community ordinances on new urban landscape vegetation patterns (M.S., Plant Biology, C. A. Martin).

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

Roach, W. J. Nutrient dynamics in arid urban fluvial systems: How changes in hydrology and channel morphology impact nutrient retention (Ph.D., Biology, N. B. Grimm).

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Sicotte, D. 2003. Race, class and chemicals: The political ecology of environmental injustice in Arizona. (Ph.D., Sociology, E. J. Hackett).

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VII. Education and Outreach

Environmental education and outreach activities are woven throughout the CAP LTER project. The project enhances the research and teaching skills of its participants, including undergraduate students, graduate students, postdoctoral students, faculty members, K-12 teachers and students, and high school student interns. Our study of an arid ecosystem provides a powerful framework for training graduate students, nourishing cross-disciplinary projects, and contributing to the burgeoning field of urban ecology. We encourage ASU faculty members to draw upon project resources and incorporate urban ecological issues and data into their classrooms. Finally, we are committed to sharing what we learn with pre-college students and teachers, community organizations, governmental agencies, industry, and the general public in disseminating and sharing our findings.

From CAP LTER's inception we have focused on meaningful community outreach by establishing a series of community partnerships, each of which relates to our project in a different way. Some of these partners have been very active, such as those relating to K-12 education or the Maricopa Association of Governments and the Salt River Project, who share information with us. More can and should be done to build bridges between us as scientists and community policy makers. ASU's Vice President for Research and Economic Affairs sponsored a project (Greater Phoenix 2100) that was conceived to serve this purpose and, in April 2003, that was expanded by the formation of a Consortium for the Study of Rapidly Urbanizing Regions (CSRUR) under the auspices of CES. We have developed several important ideas for establishing these linkages and a workshop and public meeting in April 2002 got the ball rolling. Four essential elements were envisioned: A comprehensive, interactive database; an electronic-environmental "atlas"; a series of models that would allow for a "Sim-Phoenix" approach to scenario-building; and an immersion "Decision Theater" that would provide 3-D portrayals of scenarios for community policy makers. The electronic atlas is underway; a version in book form, the *Greater Phoenix Regional Atlas* was published in Spring 2003. A pilot project for integrating models is under development. The Decision Theater concept is gaining momentum and has been incorporated into several proposal submissions.

The Schoolyard LTER supplement has created special opportunities for K-12 teachers to work alongside LTER researchers in summer internships on several monitoring projects. In turn, the teachers have engaged their students in ongoing research and enhanced their ability to communicate science (See Education and Outreach section). Each year, high-school students are mentored as part of the Southwest Center for Education and the Natural Environment's K-12 project, with day-to-day supervision provided by a graduate research associate. These high-school students participate in lab and field research activities and present their findings to their classmates in poster format.

K-12 Education

We reach out to the K-12 community through *Ecology Explorers*, a program that aims to: develop and implement a schoolyard ecology program where students collect data similar to CAP LTER data, enter results into our database, share data with other schools, and develop hypotheses and experiments to explain their findings; improve science literacy by exposing students and teachers to actual 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 materials and information; encourage collaboration between CAP LTER researchers and the K-12 community; provide students an opportunity to share their research with other children, adults, and CAP LTER researchers through poster presentations at SEE ASU and the CAP LTER poster symposium, and through our Kid's Online Newsletter.

From the initial collaboration sparked with 12 schools in 1998, Ecology Explorers has expanded to include 87 teachers at 64 public schools (encompassing 25 school districts), 3 charter schools and 2 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.

This past academic year we developed one new day-long workshop on plants based on teacher requests. The workshop was developed with two fellows from the GK-12 program. We also offered a day-long workshop on social science approaches. A total of 24 teachers participated in these workshops. The teacher evaluations suggested that these workshops addressed their needs and were beneficial.

This summer's program included 17 new teachers (over 80 teachers applied) and engaged 15 CAP LTER personnel as well as others from ASU and the Phoenix Zoo. Personnel participate in the internships in various ways ranging from presenting their research to assisting with field days. During the Urbanization and Insects internship, Stan Faeth and Wendy Marussich discussed the arthropod research and their own personal research projects. They also answered questions about arthropods and ecology throughout the year upon request from the Ecology Explorers program. Research technicians and staff assisted the teachers with identification and led several trips to field sites. Personnel from the bird projects participated actively in the Bird Diversity and Urban Habitat internship. Ann Kinzig presented the parks project research to the teachers after a field site visit to one of the parks. Research staff and technicians assist with training the teachers to conduct bird point-count surveys, to identify birds, and to analyze the data collected in the field. Several graduate students were involved in educating teachers on plant ecology in general and Sonoran Desert plants and Phoenix ornamental plants in particular. Corinna Gries presented the plant findings from the 200 Point Survey. Both internships allow the teachers to participate in a research project and learn how to collect and analyze data. The teachers were also introduced to several hand's on, inquiry-based lessons developed from previous workshops. Teachers will be asked to create lesson plans that will be added to the Ecology Explorers Web site.

An evaluation was developed in conjunction with Debra Banks from ASU's Center for Research on Education in Science, Mathematics, Engineering and Technology (CRESMET) to study factors affecting implementation of the Ecology Explorers (EE) program. The conceptual framework for the study is based on immediate and long-term implementation. The analysis of the immediate perspectives suggests that within a year EE interns had their students using protocols. The significant changes in the interns were using the Web more frequently for research and having their students conduct long-term experiments. In addition, the significant increase of communication with CES Ed staff appears to have a strong relationship with teachers and students using spreadsheets. The analysis of the long-term perspectives suggests that the implementation of the protocols can take less than 2 years; whereas, using spreadsheets in the classroom may take longer. Other findings of interest were: continued support by CES Ed staff facilitates the embedding of the EE protocols into the curriculum and internal support from school administration and colleagues promotes the embedding of EE protocols through hands-on activities. These forms of support appear to aid in the establishment of a platform for introducing higher-order thinking skills through scientific inquiry.

Through informal discussions with teachers, Banks et al. (2003) have reported that teachers have a better understanding of ecological research, students' enthusiasm for project exceeded expectations, students felt projects were important because of the ASU connection and were willing to put in extra effort to carry out the projects, more parents were involved than anticipated, and workshops/internships were valuable and enhanced their ability to teach science. Teachers have also reported that students' math abilities improved as a result of participating in Ecology Explorers. Participating in poster presentations enhanced students' communication skills. The program is aligned with the Arizona State Education Standards, including science, math, writing, social science and technology.

We have added several new features to our Web site (http://caplter.asu.edu/explorers) including new teacher lessons plans, kid's newsletter articles, and Powerpoint presentations for teacher use. We are in the process of adding a new animation to that will allow students to learn how to read aerial photographs, classify land use, and look at land use change over time.

This year we developed and conducted workshops for science teachers in the Gilbert Unified School District and Scottsdale Unified School District**.** Contacts have been made with many members of the environmental education community, and joint programs are being developed. Our education liaisons also work closely with the Southwest Center for Education and the Natural Environment (SCENE) to implement other environmental education programs. Many teachers in SCENE's Native Habitat Project use Ecology Explorers sampling protocols to monitor changes in schoolyard ecology as native habitats are developed at schools. In addition, Charlene Saltz is a member of the board of the Arizona Association for Environmental Educators.

Two of the fellows associated with ASU's GK-12 grant developed an Ecology Explorer workshop, and their activities that will be incorporated into the summer internships. Inquiry-based activities developed and implemented in a classroom by the fellows will be added to the lesson plans on the Ecology Explorer Web site.

This year we have contributed to cross-site LTER activities by being active participants in the national LTER education committee. Monica Elser serves on their executive committee. We continue to share ideas and support other Schoolyard LTER programs. One aspect of the Biocomplexity-Agrarian Landscapes in Transition project is to develop an education component. We are in the process of creating a module with several LTER sites that will convey the scientist's research from this grant.

Community Partners

The past year has sparked many exciting collaborations with our community partners, both existing and new. This summer we brought together a team of CAP LTER researchers and local and state agency staff to apply for Decision Making under Uncertainty (NSF-DMUU) funding. The resulting proposal, "Decision Center for A Desert City," envisions an academic-practitioner collaboration that will enhance the region's adaptive capacity to deal with climate uncertainties in the future. The DCDC Center will investigate spatial and temporal impacts of climate cycles and global warming on the desert Southwest and help to pinpoint critical variables and thresholds in coupled human-natural systems. Active participants in the proposal process were the *Salt River Project, City of Phoenix, Arizona Department of Water Resources, and the Flood Control District of Maricopa County*. Planning is now underway for a "Water Dialogue" to held in the Fall 2003. This partnership is bringing together academic researchers with local decision makers from city, state and agencies to discuss issues of water policy. Community partners actively involved in planning this meeting, many of whom were active in the DCDC proposal, are: *Arizona Department of Water Resources, Central Arizona Project, Salt River Project, City of Phoenix*, and the *University of Arizona*.

The Water Dialogue is the first of a series of such events planned under the auspices of our new Consortium for the Study of Rapidly Urbanizing Regions (CSRUR). CSRUR, housed at ASU's Center for Environmental Studies, is a consortium of academic, government, and community groups that is bringing interdisciplinary perspectives to address one of the globes (and our city's) greatest challenges: the human, political, economic and environmental impact of our rapidly urbanizing environments. The consortium is now signing up corporate sponsors for its Sustainable Technologies Program, which is encourages the use of existing and emerging sustainable technologies in industry and government, as well as the development of sound policy recommendations.

One of the most active of our federal partners has been the *U.S. Geological Survey*, a main collaborator with the Historic Land-Use Team in Phase I of their study that involved capturing desert, agriculture, and urban land uses for the metropolitan area. Several USGS NAWQA 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 numerous 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. In addition, Phoenix is supplying water and sewer infrastructure information in the form of paper plats and electronic files to the urban fringe project. 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 are developing partnerships with the *Gila-River* and *Salt River-Pima Indian Communities* in the form of idea exchange, educational opportunities for tribe members, and service of their scientific personnel on advisory committees, and have been working toward joint research projects and establishment of atmospheric deposition monitoring sites on their lands.

Maricopa Association of Governments (MAG), consisting of the 24 incorporated cites and towns, 2 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. Rita Walton, MAG's policy and information manager, has worked with the Land-Use Change Team and co-authored a CAP LTER study on land consumption and absorption rates. 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 Historic 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. A permanent, experimental plot was installed to measure net primary productivity as affected by human activities. 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 BES site (Steward Pickett, Mary Cadenasso, Morgan Grove, Peter Groffman, Alan Berkowitz, Charles Nilon, and Chris Boone, among others), Harvard Forest (David Foster, Billie Turner, John O'Keefe), Coweeta (Ted Gragson, Paul Bolstad), Shortgrasse Steppe (Bill Parton), Kellogg (Craig Harris, Alan Rudy), Konza Prairie (Gerad Middendorf), Jornada (James Reynolds), Sevilleta (Cliff Dahm, Scott Collins), University of Michigan (Myron Gutmann, Ken Sylvester), The Nature Conservancy (Peter Kareiva), University of Melbourne's Center for Urban Ecology (Mark McDonnell), and several institutions in China (e.g., East China Normal University, Beijing Normal University, Nanjing University, Inner Mongolia University, Institute of Botany of Chinese Academy of Sciences).

Dissemination of Research Projects and Results

Since 1997, CAP LTER participants have presented over 200 professional posters and presentations. In addition, we have reached out to over 100 community organizations and schools representing over 3,000 children. We publish a newsletter 3 times a year that is distributed to researchers, students, K-12 teachers, and community partners. The CAP LTER and individual projects have been the focus of articles in major scientific journals such as *BioScience, Science News,* and *American Scientist*, numerous newspaper articles, and the bird survey, ground arthropod, and bruchid beetle projects were featured in *Chain Reaction*, an ASU magazine for the K-12 community.

In addition, we have recently added a virtual tour of CAP LTER to our Web site. This 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.

Presentations made during 2002-2003 and not reported in last's year annual report are listed below:

Presentations at Regional, National, and International Conferences

2003

Baker, L., and S. Wolf. Sources of salt to municipal wastewater. Presented 18-22 March 2003 at *29th Annual Conference of the Water Quality Association*, Las Vegas, NV.

Grimm, N.B. 2003. Introduction: Integration of geosciences and social sciences within the LTER program: progress and prospects. 3rd Annual NSF Mini-Symposium, National Science Foundation, Arlington, Virginia, February 2003.

Grimm, N.B. 2003. Effects of land-use change from urbanization on nutrient dynamics in arid-land streams. Invited, *AGU Chapman Conference,* "Ecosystem interactions with land-use change". Santa Fe, NM, June 2003.

Grimm, N.B. 2003. A long-term perspective on biogeochemistry of desert streams. Plenary speaker, Special Symposium: "Long-term perspective in estuaries and freshwaters", the 17th Biennial Conference of the Estuarine Research Federation, 14-18 September, Seattle, WA.

Hill, C., and C. Saltz. 2003. Linking Scientists, Teachers and Children in Scientific Research. Presented at March 2003, *Microcomputers in Education Conference*, Arizona State University, Tempe, AZ

Kirby, A., S. L. Harlan, R. Bolin, E. Hackett, L. Larsen, T. Rex, and S. Wolf. Building Walls, building community? A preliminary examination of common-interest neighborhoods in Phoenix. Presented at June 2003 second annual *Hawaiian International Conference in Social Sciences*, Hawaii.

Lewis, D.B., and N.B.Grimm. 2003. Mechanisms of nutrient export in stormwater runoff from hydrologic catchments. *American Geophysical Union/European Geophysical Society* joint conference, April 2003, Nice, France.

Nash III, T. H., C. Gries, T. Zschau, S. Getty, Y. Ameron, and A. Zambrano, 2003. Historical patterns of metal atmospheric deposition to the epilithic lichen *Xanthoparmelia* in Maricopa County, Arizona, U.S.A. Poster presented at May 2003 *XIIth International Conference on Heavy Metals in the Environment*, Grenoble, France.

Roach, W.J., J.R. Arrowsmith, C. Eisinger, N.B.Grimm, J. Heffernan, and T. Reichener. 2003. Anthropogenic modifications influence the interactions between the geomorphology and biogeochemistry of an urban desert stream. *AGU Chapman Conference,* "Ecosystem interactions with land-use change". Santa Fe, NM, June 2003.

Stiles, A., and S. Scheiner. Effects of habitat fragmentation on remnant Sonoran Desert plant communities in the CAP LTER, Phoenix, Arizona. Presented at the August 2003 *Ecological Society of America* meeting, Savannah, GA.

Wu, J. 2003. Key research topics in landscape ecology. Presented January 3, 2003 at Beijing Normal University, Beijing, PRC.

2002

Dillner, A. M., J. Boreson, and T. Paez-Rubio. 2002. Indoor and outdoor speciated PM2.5 aerosol in a low income neighborhood. Platform presentation at the 2002 *Annual Conference of the American Association of Aerosol Research*, Charlotte, NC.

Elser, M. 2002. LTER education programs. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Grimm, N.B. 2002. Urban crossroads: integration of earth, life, and social sciences in the city. (National Science Foundation, Mini-Symposium on LTER, Washington, DC, February 2002)

Grossman-Clarke, S., D. Hope, S. M. Lee, H. J. S. Fernando, P. G. Hyde, W. L. Stefanov, and N. B. Grimm. 2002. Modeling temporal and spatial characteristics of nitrogen dry deposition in the Phoenix metropolitan area. *EOS Transactions American Geophysical Union*, 83(47), Fall Meet. Suppl., Abstract B22B-0755.

Hope, D., S. Grossman-Clarke, S. M. Lee, H. J. S. Fernando, P. G. Hyde,W. L. Stefanov, and N. B. Grimm. 2002. The importance of dry deposition to the nitrogen mass balance of an arid urban ecosystem. *EOS Transactions American Geophysical Union,* 83(47), Fall Meet. Suppl., Abstract B22B-0756.

Katti, M. and E. Shochat. 2002. Population and physiological responses of Sonoran desert birds to urbanization in central Arizona, USA. *Proceedings of the 23rd International Ornithological Congress, Beijing, China*, page 177.

Lewis, D.B., N.B. Grimm. 2002. Nutrient and metal loads exported from hydrologic catchments by storm runoff. Annual Meeting, *Ecological Society of America,* Tucson, AZ, August 2002.

Martin, C. A., L.B. Stabler, S. B. Celestian, and J. C. Stutz. 2002. Urban plant ecology: A horticultural perspective. Initial results from a Long Term Ecological Research (LTER) site. Poster presented at 23-25 May 2002, *Proceedings of the 12th METRIA Conference,* Asheville, NC. [Online publication at http://fletcher.ces.state.nc.us/programs/nursery/ metria/metria12/martinetal/index.html]

Redman, C.L., and N.B. Grimm. The urban ecology of central Arizona-Phoenix. Special Symposium, "Cities of Resilience", Annual Meeting, *Ecological Society of America,* Tucson, AZ, August 2002.

Roach, W.J., and N.B. Grimm. 2002. Nutrient cycling along an urban desert lake chain: the effects of anthropogenic modifications of Indian Bend Wash. Annual meeting, *American Society of Limnology and Oceanography,* June 2002, Victoria, BC.

Saltz, C. 2002. Scientist-teacher partnerships in environmental education. Presented on 8 August 2002 at *North American Association for Environmental Education Annual Conference*, Boston, MA.

Stefanov, W. L. 2002. The ASTER Urban Environmental Monitoring Project: Progress and Current Results. Presented at the 14-18 January 2002, *21th ASTER Science Team Meeting,* Pasadena, CA.

Wu, J. Scaling across heterogeneous landscapes: Theory and methods. Invited symposium presentation at The VIII International Congress on Ecology, Seoul, Korea, August 11-18, 2002.

Wu, J. 2002. Toward a landscape ecology of cities: Beyond buildings, trees and forests. Plenary speech, International Symposium on Urban Forestry and Eco-Cities, Shanghai, Sept. 16-22, 2002.

Wu, J. 2002. Landscape ecology as a scientific basis and methodology for understanding and combating desertification and dust/sand storms. Presented at the Sino-US Workshop on Dust Storms and Their Effects on Human Health, Raleigh, North Carolina, November 25-26, 2002.

Wu, J. 2002. Landscape ecological principles for nature conservation and ecological restoration. Plenary speech at International Symposium on Ecosystem Succession Theory and Ecological Restoration, Guangzhou, December 27-29, 2002.

Wu, J. and R. Hobbs. 2002. Top 10 list for landscape ecology: An idiosyncratic synthesis. Presented at The 17th Annual Symposium of US-IALE (International Association of Landscape Ecology), Lincoln, Nebraska, April 23-27, 2002.

LTER Symposia and Conferences

2003

***CAP LTER Fifth Annual Poster Symposium,* February 19, 2003, Center for Environmental Studies, Arizona State University**

Anderson, J., H. J. S. Fernando, P. Hyde, R. Redman, and H. Xin. Temporal patterns of "Unhealthy" to "Hazardous" concentration maxima for coarse particles (PM10) in southwest Phoenix during typical low wind speed connections.

Baker, L. A., P. Westerhoff, and M. Sommerfeld. Management strategy to reduce tastes and odors in Phoenix's water supply.

Bolin, B., S. Smith, E. Hackett, S. Grineski, T. Collins, D. Vuppaladadium, and J. Kronenfeld. Toxic tracts: A historical geography of environmental inequality in Phoenix, Arizona.

Butler, L., S. Whitcomb, and J. Stutz. Small-scale spatial patterns of arbuscular mycorrhizal fungal infectivity in an experimental urban landscaped site.

Celestian, S. B., and C. A. Martin. 2003. Urban land use and surface cover: Effects on soil temperatures.

Elliott, M., K. Gade, H. Schaafsma, D. Crider, C. Meegan, and S. Swanson. Investigating environmental and social heterogeneity in a landscape perspective: A Hohokam case study.

Elser, M., and C. Saltz. Ecology Explorers: Program components.

Gonzales, D.A., and J. O. Allen. Aerosol nutrient deposition measured by eddy-correlation mass spectrometry.

Goodman, V. Time of transition: The effects of change in hunter-gatherer societies.

Gries, C., S. Prasad and C. D. Zisner. A virtual tour of CAP LTER.

Grossman-Clarke, S., D. Hope, S-M. Lee, H. J. S. Fernando, P. G. Hyde, W. L. Stefanov, and N. B. Grimm. Modeling temporal and spatial characteristics of nitrogen dry deposition in the Phoenix metropolitan area.

Grossman-Clarke, S., J. A. Zehnder, and W. L. Stefanov. Effects of urban land-cover modifications in a mesoscale meteorological model on surface temperature and heat fluxes in the Phoenix metropolitan area.

Harlan, S., R. Bolin, E. Hackett, D. Hope, A. Kirby, L. Larsen, A. Nelson, T. Rex, S. Wolf, and N. Jones. Community and environment in a desert metropolis.

Hope, D., S. Grossman-Clarke, S -M. Lee, H. J. S. Fernando, P. G. Hyde, W. L. Stefanov, and N. B. Grimm. The importance of dry deposition to the nitrogen mass balance of an arid urban ecosystem.

Hope, D., and C.Gries. Core monitoring for CAPII - an interactive virtual poster display.

Hu, Q., A. Fortuna, M. Sommerfeld, and P. Westerhoff. Physiological studies of MIB- and geosmin-producing cyanobacteria isolated from the Phoenix drinking water supply system.

Ivanich, P. A., James A. Tyburczy, J Ramón Arrowsmith, and M. Diaz. Measuring bedrock topography using gravity to understand subsidence along a portion of the CAP canal in northeast Scottsdale.

Jenerette, G. D., and J. Wu. Multiple-scale spatial variation of terrestrial ecosystems in an urbanized desert environment.

Jones, N., A. Brazel, C. Eisinger, S. Harlan, B. Hedquist, S. Grineski, D. Jenerette, L. Larsen, M. Lord, J. Parker, L. Prashad, N. Selover, W. L. Stefanov, and D. Zeigler. Neighborhood ecosystems: Human-vegetation-climate interactions in a desert metropolis.

Katti, M., and P. McCartney. The distribution of bird species in the Phoenix metro area: Visualizing the spatial patterns of diversity in an expanding urban matrix.

Katti, M., E. Shochat, and J. M. Anderies. Living in the city: Resource fluctuations, foraging behavior, and bird population dynamics.

Kaye, M., A. Brazel, M. Netzband, and M.Katti. Perspectives on climate variability in the Phoenix area over the past five years.

Klett, M., M. A. Lord, and M. Lundgren. A rephotographic survey of landscape change and persistence for the Greater Phoenix 2100 project.

Lewis, D. B., L. B. Stabler, and C. A. Martin. Ecological stoichiometry of horticulture: Consequences of pruning and irrigation for plant and soil chemistry.

Mahkee, D. K., and C. A. Martin. Leaf morphology of four landscape taxa in response to irrigation volume and pruning frequency.

Martin, C. A., P. Warren, and A. Kinzig. Landscape vegetation in small urban parks and surrounding neighborhoods: Are socioeconomic characteristics a useful predictor of vegetation taxa richness and abundance?

Marussich, W. A., and S. H. Faeth. Comparing trophic dynamics in urban and desert ecosystems using arthropod communities on brittlebush (*Encelia farinosa*).

McCartney, P., C. Gries, R. Schoeninger, A. Sundermier, and E. Gilbert. The Southwest Environmental Information Network.

McCulley, R., and J. Kaye. Soil microbial communities in urban ecosystems compared to nearby native grasslands and agriculture.

Musacchio, L. Landscape ecological classification and analysis of a 100-year floodplain corridor in the Phoenix metropolitan region.

Netzband, M., and W. L. Stefanov. Remote sensing and landscape metrics for global urban ecological monitoring.

Perry, D., J. Anderson, and P. R. Busek. Analysis of atmospheric particles deposited onto mesquite leaves in the Central Arizona - Phoenix LTER area.

Redman, C., A. Kinzig, and L. Kuby. Agricultural landscapes in transition: A cross-scale approach.

Roach, W. J., and N. B. Grimm. Nutrient cycling along an urban desert lake chain: The effects of anthropogenic modifications of Indian Bend Wash.

Roberts, M., M. Koneya, P. Burnett, R. Walton, D. Worley, and A. Bagley. Land use and socioeconomic modeling at MAG.

Ross, M., D. Jennings, C. Putnam, T. Small, and P. Deviche. Home range sizes of cactus wrens (*Campylorhynchus brunneicapillus*) at Arizona State University.

Stabler, L. B., and C. A. Martin. Productivity and water relations of *Nerium oleander* in simulated urban landscapes.

Stefanov, W. L. Assessment of landscape fragmentation associated with urban centers using ASTER data.

Stuart, D., M. Katti, and W. R. Turner. The r(iparian) factor: A comparison of Phoenix and Tucson avifauna.

Swanson, S., D. Crider, C. Meegan, M. Elliott, K.Gade, and H. Schaafsma. Long-term cultural and ecological responses to changes in climate in central Arizona AD 900-AD 1200.

Warren, P., A. Kinzig, M. Cox, M. Grove, C. Martin, and C. Nilon. Human socioeconomic factors predict avian diversity in two cities.

Whitcomb, S., and J. Stutz. Small-scale spatial patterns of arbuscular mycorrhizal fungal diversity in an experimental urban landscaped site.

Whitcomb, S., and J. Stutz. Pruning effects on root length density, root biomass, and arbuscular mycorrhizal colonization in two shrubs in a simulated xeric landscaped yard. Land use and landscape: Assessment and influence on spatial distributions.

Community Outreach Presentations and Miscellaneous Activities

2003

Baker, L. 2003. Biogeochemical cycles in human ecosystems. Guest lecture, Landscape Ecology, University of Minnesota.

Baker, L. 2003. Impact of urban climate warming in hot climates. Presented October 24, 2003, Department of Geography, University of Minnesota.

Grimm, N.B. 2003. Effects of human modification of hydrology and nutrient balance on biogeochemical pattern and process in urban landscapes. Invited lecture, *Arizona Hydrological Society*, March 2003.

Grimm, N.B. 2003_From Rain to Your Drain: Water Ecology in the Desert and City. Workshop: Sally Ride Science Festival for Girls, Arizona State University, March, 2003.

Grimm, N.B. “Ecology in the City: Preliminary Results from the Central Arizona-Phoenix LTER” (University of Washington, Seattle, May, 2002)

Grimm, N.B. “The Urban Ecology of Central Arizona-Phoenix” (Utah State University, Logan, January 15, 2003)

Grimm, N.B. "Integrated watershed hydrology and biogeochemistry in urban areas" (USDA-ARS Water Conservation Laboratory Seminar Series, Phoenix, January 2002)

Kinzig, A. 2003. Biodiversity in urban environments. Presented at 5 May 2003 *Department of Ecology, Evolution, and Marine Biology Seminar Series,* University of California, Santa Barbara.

Kinzig, A. 2003. Biodiversity in urban environments: The case for socioeconomic and cultural gradients. Presented at 14 April 2003 *Department ofEcology and Evolutionary Biology Seminar Series*, University of Arizona, Tucson.

Kinzig, A. 2003. Biodiversity in urban environments. Seminar presented at 29 August 2003 *School of Life Sciences Seminar Series*, Arizona State University, Tempe.

Elser, M., and C. Saltz. 2003. Presentation to Casa Blanca School Board on 4 June 2003.

2002

Baker, L. 2002. Nutrient cycling in coupled urban-agricultural systems. Workshop on the Science of Nutrient Cycling in Coupled Systems. College of Agriculture, Food and Environmental Sciences, University of Minnesota, Sept. 23, 2002.

Berling-Wolff and Wu. 2003. Web site for online Phoenix urban growth animation, ttp://LEML.asu.edu.

Dillner, A. 2002. Presentation to the city of Phoenix concerning study of Homedale air quality research.

Elser, M. 2002. GK-12 science showcase, presented on 28 September 2002.

Elser, M., and C. Saltz. 2002. Presentation on 29 August 2002 to Service Learning students, Arizona State University, Tempe.

Elser, M., and C. Saltz. 2002. Workshop for GK-12 students on lesson planning. Conducted 10 September 2002, Arizona State University, Tempe.

Elser, M., and C. Saltz. 2002. Ecology Explorers presentation at Lake Pleasant Outdoor Center, on 18 September 2002.

Elser, M., and C. Saltz. 2002. Presentation on 8-17 October 2002 to Service Learning students, Arizona State University, Tempe.

Elser, M., and C. Saltz. 2002. Presentation on 13 November 2002 to Kathleen Rutowski's class in Department of Curriculum and Instruction, Arizona State University, Tempe.

Saltz, C., and C. D. Zisner. 2002. Ecology Explorers display and booth at 1-2 October 2002 Arizona Science Teachers' Association Conference, Mesa, AZ.

Community Outreach Publications, News Articles About CAP LTER, and Other Non-Standard Publications

2003

Anonymous. 2003. Feeling at home in metropolitan Phoenix. *CLASNews* Spring/Summer 2003:9-10.

Beard, B. 2003. Shade elusive in parking lots. *Arizona Republic* July 8, 2003. Online: http://www.azcentral.com/arizonarepublic/local/articles/0708parking08.html.

Campbell, G. 2003. Conference takes on conservation, land use issues. *ASUInsight* 23(29):1.

Derra, S. 2003. Researchers find 'luxury effect' helps set urban plant diversity. *ASU Insight* 24(1):3.

Editors. 2003. Growth spurt. Our stand: ASU picked the right place to launch study of urban expansion. *The Arizona Republic* May 3, 2003:B8.

Flatow, I. "Urban ecology" – Science Friday Show on National Public Radio featuring N.B. Grimm

Hathaway, J. 2003. Survey reveals sense of "social cohesion" among Valley residents. *ASU Insight* 23(42):3.

Hathaway, J. 2003. Social survey reveals rapidly developing sense of community in fast-growing Phoenix. *ASU News & Information from the Office of Media Relations* Online: http://www.asu.edu/asunews/research/community_survey_061703.htm

Kuby, L. 2003. What does the future hold for CAP 2 research? *Center for Environmental Studies Newsletter* 6(1):1.

McKinnon, S. 2003. Valley residents put down roots quickly, study finds. *The Arizona Republic* Jun 17, 2003. Online: http://www.azcentral.com/arizonarepublic/news/articles/0617survey17.html

McCartney, P. 2003. SEINet: Metadata-mediated access to distributed ecological data. *Databits* Spring 2003. (http://intranet.lternet.edu/archives/documents/Newsletters/DataBits/03spring).

Summerhill, L. 2003. Ecology Explorers take lessons to Valley K-12 classrooms. *ASUInsight* April 11, 2003.

2002

Anonymous. 2002. Research briefs: Gesundheit, Valley allergy sufferers! *CLAS News* Fall/Winter 2002:10.

ASU Research Review. 2002. Television program aired Oct 9 at 7 PM and Oct 13 at 5 PM on KAET Channel 8. Sarah Celestian, plant biology graduate student, is studying how parking lots affect tree growth. She is working to see which trees grow best with the excessive hear absorbed and reflected by asphalt pavement in parking lots.

Hart, B. 2002. Birds flock to upscale surroundings. *The Arizona Republic* Sep 9, 2002: B1-B2. Online: http://www.azcentral.com/news/articles/0909birds09.html

Hathaway, J. 2002. For the birds: CAPLTER project concludes city birds prefer rich neighbors. *ASUInsight* 23(6):2.

Hathaway, J. 2002. Understanding the ecology of cities is a key issue in world debate. *ASU News & Information* Online: http://www.asu.edu/asunews/sci_tech/city_ecology_082902.htm

McKinnon, S. 2002. When it rains......ASU researchers pore over buckets of ecological data. *The Arizona Republic* Sept. 8, 2002: B1-B2.

Padilla, S. 2002. Studies say birds prefer wealthy areas. Ecologists study migration patters of birds in Phoenix. *The State Press* Aug 30, 2002. Online: http://www.asuWebdevil.com/main.cfm?include=detail&storyid=264776

Slivka, J. 2002. Phoenix acting to cool heat island. *The Arizona Republic* June 11, 2002: Science A12.

Sprott, P. 2002. Site news: Urban LTER sites gear up for renewal process. *The Network Newsletter* 15(2)6-7.

Summerhill, L. 2002. ASU researchers explore environmental equity in Phoenix. *ASUInsight* 23(15):1, 3.

Grants Awarded and Pending

2003

CAP LTER Supplements: LTER Schoolyard Supplement, $15,000; General $25,000; REU $15,000; Competitive Supplement $19,000, N. Grimm, C. Redman. 2002. AWARDED.

Coupled Biogeochemical Cycles in Human Ecosystems: Hydrology, Stoichiometry, Connectiveness, and Culture. P. L. Brezonik, L. Baker, D. Mulla, S. Hobbie, K. Nelson (U of M), and D. Hope, J. Kaye. NSF Biocomplexity Initiative, $355,000, 2003-2005. AWARDED

Databases of Vascular Plants at ASU, ARIZ, and ASC. L Landrum, P McCartney. NSF-Biological Research Collections, $470,291. 2003-2006. AWARDED.

Decision Center for a Desert City: Science and Policy of Climate Uncertainty. P. Gober, C. Redman, T. Taylor, B. Bolin, G Gammage. NSF-DMUU, $7,497,949. PENDING.

Network Information Systems for Ecological Synthesis: An Open Framework for Query, Harvest, and Validation of Distributed Datasets. P. McCartney, C. Redman, C. Gries. NSF-BD12, $1.433,442. PENDING.

Coupled Biogeochemical Cycles in Urban and Agricultural Ecosystems: Role of Hydrology, Stoichiometry, Spatial Linkages and Human Behavior. Subcontract with University of MN (L. Baker). D Hope, J. Kaye, and W. Stefanov. NSF Biocomplexity Initiative, $492,732. PENDING.

2002

CAP LTER Supplements: LTER Schoolyard Supplement, $15,000; General $25,000; REU $15,000, N. Grimm, C. Redman. 2002. AWARDED.

W. M. Keck Foundation Laboratory for Environmental Biogeochemistry. E. Shock, N. Grimm, L. Leshin, P. O'Day). W.M. Keck Foundation, $900,000, 2002-2003. AWARDED

Agrarian Landscapes in Transition: A Cross Scale Approach. C. Redman (CAP LTER), A. Kinzig (CAP LTER), D. Foster (HVF), Myron Gutmann (SGS), Peter Kareiva (The Nature Conservancy). NSF Biocomplexity Initiative, $1,792,440. 2002-2006. AWARDED

Neighborhood Ecosystems: Human-Climate Interactions in a Desert Metropolis. S. Harlan, A. Brazel, L.Larsen, W. Stefanov. NSF Biocomplexity Initiative, $99, 928. AWARDED.

Networking Urban Ecological Models through Distributed Services. P. McCartney, R. Quay, C. Gries, C Redman. NSF-ITR, $491,697. 2002-2004. AWARDED.

Scientist Teacher Partnerships for the Environment. C. Redman. Motorola, Inc. $100,000. 2002. AWARDED.

VIII. Contributions

Contributions within Discipline

Overarching CAP LTER investigations are contributing baseline data and analysis upon which to build future work and projections for the central Arizona study area. The Hierarchical Patch Dynamics Modeling (HPDM) project serves as a synthesizing device for CAP LTER and is crucial for integrating data obtained from individual studies. HPDM lays the groundwork for understanding historic and current land-use patterns and projecting future patterns. The modeling project is equally important for understanding the effects of land-use change on ecological processes. The land-use synthesis provides an overall understanding of historical land use and change for the study area. The remote sensing and patch typology activities have drawn upon land-use data for Maricopa County (past, present, and future) to provide a higher spatial-resolution database. The database will increase the accuracy of ecological modeling and monitoring of our urban ecosystem and, it is hoped, do the same for governmental databases and future land-use decisions.

A wide range of individual studies in ecology is contributing to our understanding of the processes and impacts of urbanization in an ecological framework, often working in uncharted territory. For example, arthropods have a major effect on human societies. They serve in biological control as pollinators or as pests in various terrestrial ecosystems. In our study, ground arthropods represent bioindicators for different land-use types; unlike vertebrates or flying insects, the environment influences ground arthropods at very small spatial scales. The plant community project provides one of the first large-scale studies of urbanization and habitat fragmentation on plant community structure, especially in a desert biome, testing various theories of landscape ecology concerning the effects of landscape fragmentation. Mycorrhizal fungi are considered a key species group in ecological processes, but little is know about their functioning in urban ecosystems and the effects of the urban environment on AM fungal diversity. Results from the CAP LTER 200-Point Survey indicate that AMF community structure in the Phoenix metropolitan area is comparable to that of the surrounding Sonoran Desert. However, agricultural sites are associated with decreased spore densities (in current sites) and decreased species richness (in sites that were agricultural before development), indicating that certain anthropogenic activities impact AMF communities with effects persisting over long time periods. Similarities in AMF species composition between the urban environment and surrounding desert indicate a persistence and/or in-migration of desert species. Changes in composition appear to be due to existence of non-mycorrhizal plant hosts, absence of vegetation, and land use.

Physical and chemical particulate sampling at two sites in the Homedale neighborhood in Phoenix is contributing to our understanding of human exposure to air pollution. People spend most of their time indoors and understanding the relationship between indoor and outdoor air quality is useful because air quality is typically measured by outdoor, centrally located monitors. This study will determine what steps can be taken to improve the quality of life in the community.

Trophic dynamics have not been examined in urban areas. The trophic dynamics in urban systems study will contribute insights into the effects of land use (mesic residential, desert remnant, natural desert) on arthropod communities and test the relative roles of top-down (e.g., predators) and bottom-up (e.g., resource availability) controls on insect herbivore community structure. The project also provides the opportunity for long-term collaborations with other ecologists to create a bigger picture of the ecology and trophic dynamics of urban areas. We would like to synchronize the research at our sites with researchers studying birds, mammals, reptiles and amphibians, soil chemistry, mycorrhizae, plant physiology, genetics, etc.

The landscape-practices survey project is advancing the field of urban ecology by increasing our capacity to consider humans as integral parts of ecosystems and to identify the characteristics that most influence their landscaping preferences and relationships to their environment.

Contributions to Other Disciplines

The Geological Remote Sensing Laboratory (GRSL) has produced research and data products useful to the ecological, biological, geological, and social science disciplines. Land-cover classifications for the Phoenix area are used in ongoing patch-dynamics modeling and provide a baseline database for social science research. Vegetation indices for the Phoenix metropolitan area have been incorporated into studies of biomass flux, water use, carbon and nitrogen budgets, and geomorphic processes operating within urban park and undeveloped regions. The GRSL is also conducting ongoing research into hillslope soil processes and pediment geomorphology operating within the semiarid to arid regions of CAP LTER. Preliminary results from the ASTER Urban Environmental Monitoring project promise to provide new metrics for study of urban structure and classification of urban centers. LTER scientists from a variety of disciplines are able to use historic land-use data to supplement data they are collecting at the sites. The historic data can also be used as an input to land-use models.

The Phoenix Area Social Survey (PASS) involves a collaboration of researchers from the fields of sociology, planning, economics, and biology. This interdisciplinary study is contributing to the growing fields of urban sociology and environmental sociology and—in biology, plant biology and planning—will provide unique data on human values, behaviors, and preferences that impact natural and built environments. PASS will develop 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. This database will expand to include information on neighborhood associations and more 2000 census data as it becomes available. In addition, PASS, in its monitoring of social conditions, parallels the ongoing monitoring of ecological conditions. The inclusion of neighborhoods sited at 200 locations will allow integrative analyses of social and ecological conditions.

The urban parks research is helping us understand coupled human and natural systems, as well as ways of sustaining the ecological basis of human well being, in those systems where most people live. The ways in which humans influence the delivery of ecosystem services—including preservation of existing biological diversity—has received much attention in the scientific community over the past few decades, particularly at regional-to-global scales and in relatively non-settled or "natural" ecosystems. Delivery of ecosystem services at smaller scales and in highly human-modified areas—from individual lots to neighborhoods to metro regions, and influenced by values, use, and management—has garnered much less attention. Yet it is urban ecological systems that describe most human ecological experience, for the most humans, over the coming century. At the same time, social scientists have examined the ways in which people value and use urban open areas, but rarely in conjunction with concurrent measurements of the influence of these uses and values on ecological processes.

The modeling project has provided a vehicle for integrating and synthesizing different kinds of information on biophysical and socioeconomic patterns and processes. Our research has developed and demonstrated a suite of methods, including pattern indices, spatial statistical methods, and modeling tools for studying complex urban systems. These methods should be useful in a variety of disciplines, including earth and social sciences. Our contribution to the science of scale and scaling is relevant to all sciences.

In addition, several permanent locations for long-term research and collaboration provide opportunities for researchers from disciplines such as geography, geology, and chemistry to co-locate their research at these sites. Also, the experimental design at these plots is straightforward and easy to comprehend by non-ecologists; it can be used to introduce the basic aspects of experimental ecological research to researchers in other disciplines.

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.

Both the NSF and ASU support over 20 graduate students a semester, each immersed in the research at hand and working together as a cohort for the project at large. Graduate students are drawn from a wide range of university programs and departments, including: anthropology, biology, curriculum and instruction, engineering, economics, geography, geological sciences, plant biology, and sociology. For example, the arthropod project provides the opportunity for training of graduate and undergraduate students in modern ecological field and laboratory techniques, as well as basic skills in insect identification, data compilation and statistical analyses.

Our successful grant proposal to the NSF's IGERT program has added 14 IGERT Fellows and 14 IGERT Associates (many of the latter are CAP LTER RAs) to this active group of graduate students. The IGERT program is integrated with CAP LTER activities; for example, IGERT students have formed a reading group in urban ecology, participate in the monthly All Scientist Council meetings, and design research projects (both independent and collaborative) that contribute to our understanding of a complex urban ecosystem.

The Ecology Explorers program (see details below and in the Educational and Outreach section) serves the K-12 community and has a growing cadre of teachers who have completed workshops and internships associated with CAP research projects. They, in turn, draw upon CAP resources to engage students in collecting and analyzing data from an urban setting.

Contributions to Resources for Research and Education

Our site's setting within a university enhances our ability to conduct, communicate, and synthesize our 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. For example, as when part of the IGERT program, an anthropologist and a biologist team-teach an Intellectual Issues in Urban Ecology course. In addition, 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 arthropod project is frequently used to showcase the research being done at the LTER. The experimental design is straightforward and the President's House and DBG sites are easily accessible from ASU. This project has been shown to visiting researchers and was featured in Mary Clutter's NSF visit. The project is also used as an example of ecological research by the Ecology Explorers program. It is presented every summer to the Arthropod Teacher Workshop and is featured on the "Ask a Scientist" Web site. The LTER research technicians have been taught basic sweep netting and arthropod sorting techniques.

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. Data collected as part of the remote-sensing lab's research programs is archived at the GRSL 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 that result from the historic land-use project can be used for further research as well as in GIS, geography, planning, or other instruction.

Ecology Explorers enhances the teaching and learning of science, inquiry-based learning, and critical thinking skills in the K-12 realm. Four schoolyard supplements and additional corporate and foundation monies support activities that promote scientific inquiry through schoolyard ecology. These activities engage students and teachers in "real" university-level science projects; enhance the use of technology in the classrooms via the Web site and databases; offer stimulating research experiences that enhance teaching; and provide an interface between the scientific community and schools to facilitate science standards reform. To date there has been student/teacher participation in plant survey, ground arthropod survey, bird survey, plant/insect interaction, and water sampling efforts. Most recently, Ecology Explorers obtained NSF funding to bring students and CAP LTER researchers into K-12 classrooms across the Valley. "GK12: Down to Earth Science" joins ASU scientists, engineers, graduate and undergraduate students in an effort to enrich learning experiences for the K-12 community. The GK-12 project improved communication and teaching-related skills for graduate and undergraduate fellows, strengthened partnerships between ASU and the K-12 community, and provided new opportunities for K-12 students and teachers to work with practicing scientists and engineers.

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. Project results are percolating that may offer contributions beyond science and engineering. CAP LTER activities and research potentially provide information for planning urban growth, especially in sensitive ecosystems. Our work also has the potential to reach many nontraditional audiences through our "backyard ecology" outreach efforts. The landscape-practices survey is easily accessible to the public. Homeowners may show particular interest in the project as brittlebush is a common landscape plant in the Phoenix area. It is a good example of "science in your backyard" and the findings may have policy implications for the planting and maintenance of native desert plants in urban areas. The plant community survey will provide information needed for planning urban growth, especially in sensitive ecosystems.

Understanding the factors that contribute to stormwater chemistry, implicated in non-point source pollution of receiving waters, will help in the design of better controls on water routing and delivery, retention structures, and the like. Comparisons among different land uses allow us to pinpoint the "hot spots" of pollutant delivery, and small-scale material budgeting can reveal patches potentially active in contaminant removal. These findings thus can contribute to policy-makers' development of strategies to comply with new standards, such as total maximum daily loads (TMDLs).

The modeling project is important for understanding how spatial patterns of land use have changed in the past and how they will change in future. It is equally important for understanding the effects of land-use change on ecological processes and crucial for integrating and synthesizing pieces of information obtained from individual projects. A modeling platform has been built to facilitating spatial ecosystem modeling, HPD-MP and is available for free upon request. A Web site for online Phoenix urban growth animation has been created based on Berling-Wolff's thesis work (http://LEML.asu.edu). Historic land-use data contributes to studies in planning, population studies, and cultural geography. The report on an emissions inventory (Grossman-Clarke) for air-quality modeling for an ADEQ/ASU project conducted by the Environmental Fluid Dynamics Program was brought forward to the Governor of Arizona for decision on an action plan regarding the Ozone non-attainment boundaries.

The environmental risk research has practical applications for community groups and city agencies concerned with environmental safety and health. The primary contribution of the Environmental Risk Group (ERG) within disciplines has been the development of links between environmental sociology and medical sociology, both through a recent community-based health study and in theses and conference presentations. The major thrust of ERG work is interdisciplinary, bridging sociology, geography, and aspects of physical geography and related environmental sciences. Collaborations with and presentations to neighborhood groups and government agencies extends our work outside the academy and academic audiences. The labor market dynamics project will provide a base of information that explains the economic reasons that people settle within, and migrate to, particular locations in the Phoenix area. Most immediately, knowledge of job distribution and change lends itself to collaboration on other LTER research projects, including those on environmental risk, PASS, and urban-fringe dynamics. We believe this research will also help raise interdisciplinary questions about the relationship between changes in the economy and the ecosystem.

The PASS project promises to contribute to the solution of social problems, providing information for planning urban growth, especially in sensitive ecosystems. The interdisciplinary team of researchers from sociology, planning, geography, geology, biology, and economics contributes to the burgeoning fields of urban sociology, urban ecology, and environmental sociology. 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.

There has always been a gap between university-based research, which in the case of CAP LTER covers the long term, and the needs of governmental entities and the public, who naturally seek to address issues of immediate concern. Several linked projects that seek to bridge the gap between academic research and community policy making are flowing from CAP LTER and the Center for Environmental Studies, through the auspices of ASU's new Consortium for the Study of Rapidly Urbanizing Regions.

Greater Phoenix 2100 is a network of ASU and community researchers who are working to make University-based research more relevant and accessible to local managers and policy makers. GP 2001 wants the best possible scientific and technical information to be of use in making knowledge-based decisions that will shape the region during the next 100 years. The project has partnered with local and state governments, community organizations, and private businesses to develop regional tools and sponsor events. Five years of CAP LTER work has produced a storehouse of information about greater Phoenix, as the project has investigated practically every important aspect of central Arizona, from its underlying geological structure to daily real estate transactions. GP 2100 is developing this wide range of data to project the past, present and possible futures of the region. Regional products emanating from GP 2100 include an E-Atlas, a Decision Theater, and Integrated Modeling for Scenario Building, three tools for exploring and future options for the Phoenix area.

The second project that promises contributions beyond the academic disciplines aims to contribute to planning efforts beyond the Phoenix area. Urban Environmental Monitoring of 100 Cities is a NSF-sponsored study that uses data collected by the ASTER sensor on board the Terra satellite to record the changing structure of cities across the globe. This comparative urbanism project relies on the analysis of remotely sensed imagery, ground observations, and other geographic information to develop an extensive catalog of the characteristics of the built and natural environment in and around cities. Our researchers are eager to use these data and methods to identify alternate trajectories of development for neighborhoods, urban cores, and entire metro areas. These trajectories might signal early warnings of emerging vulnerabilities in cities across the globe.

CAP LTER 2003 Annual Report - Appendix A
Participants 1997-2003

Principal Investigators/Project Directors

Nancy B Grimm, Biology	1997-present	Charles L Redman, Center Env Studies	1997-present

Co-Principal Investigators

Stuart G Fisher, Biology	1997-present	Patricia Gober, Geography	1997-present
Jianguo Wu, Life Sciences ASU W	1997-present	Diane Hope, CES/Biology	2002-present
Alfredo G de los Santos, Mar Comm Coll	1997-present	Jeffrey M Klopatek, Plant Biology	1997-present
Steve S Carroll, Biology	1997-present	Peter H McCartney, CES	2002-present
Lawrence A Baker, Civil/Env Eng	1997-present	Thomas H Nash III, Plant Biology	1997-present
Elizabeth K Burns, Geography	1997-present	Michael B Ormiston, Economics	1997-2000
Phillip R Christensen, Geological Sci	1997-present	K David Pijawka, Plng/Lndscpe Des	1997-present
Thomas A Day, Plant Biology	1997-present	Milton R Sommerfeld, CLAS/Plant Bio	1997-present
Stanley H Faeth, Biology	1997-present	Frederick A Staley, Curr/Instruction	1997-present
William F Fagan, Biology	1997-present		

CoPIs, Geoscience/Engineering Supplement, 1997-1999

Ramon Arrowsmith, Geological Sci	1997-present	Sandra L Houston, Civil/Env Eng	1997-present
William L Graf, Geography	1997-2000	Frederick R Steiner, Plng/Lnds Arch	1997-present

Senior Personnel: Managers

Corinna Gries, Analytical Lab Mgr.	2000-present	Peter H McCartney, Info Mgr, CES	1997-present
Diane Hope, Field Proj Mgr, CES/Bio	1997-present	Brenda L Shears, Admin Proj Mgr, CES	1997-present

Senior Personnel: Core Scientists

James R Anderson, Mech/Aero Eng	1997-present	Carol C Klopatek, Microbiology	1997-1999
Robert C Balling, Geography	1997-present	Glen S. Krutz, Political Science	1999-present
C. Michael Barton, Anthropology	1997-present	Michael Kuby, Geography	1997-present
Neil S Berman, Chem/Mat Eng	1997-present	Leslie R Landrum, Plant Biology	1998-present
Robert Bolin, Sociology	1999-present	Larissa Larsen, Plng/Lnds Arch	2000-present
Ward W Brady, Resrce Mgmt, ASU E	1997-1999	Theresa A Markow, Plant Biology	1997-1998
Anthony J Brazel, Geography	1997-present	Chris A. Martin, Plant Biology	1997-present
John M Briggs, Plant Biology	1999-present	James W. Mayer, Ctr Solid State Sci	1998-1999
Timothy P Craig, Life Sciences, ASU W	1997-present	Rob Melnick, Morrison Institute	1997-present
Lisa C. DeLorenzo, Public Affairs	1999-2000	Laura R Musacchio, Plng/Lnds Arch	1999-present
Pierre Deviche, Biology	2000-present	Michael Musheno, Center Urban Inquiry	1997-1999
Ann Dillner, Civil and Env. Eng	2001-present	Margaret C Nelson, Anthropology	1998-present
Ronald I Dorn, Geography	1997-present	Robert D Ohmart, Biology	1997-present
Michael E Douglas, Biology	1998-2000	David L Pearson, Biology	1997-present
James F Eder, Anthropology	1997-1999	Jordan Peccia, Civil and Env Eng	2001-present
James J Elser, Biology	1997-present	Donald J Pinkava, Plant Biology	1997-present
Joseph M. Ewan, Plng/Lnds Arch	1999-present	Stephen J Pyne, Biology	1998-present
Patricia L Fall, Geography	1997-present	B.L. Ramakrishna, Plant Biology/CSSS	1999-present
H J S Fernando, Mech/Aero Eng	1997-present	Michael Ramsey, Geological Sci	1997-present
Peter Fox, Civil & Environmental Eng	1997-1999	Glen E Rice, Anthropology	1997-present
Douglas M Green, Resrce Mgmt, ASU E	1997-present	Edward K Sadalla, Psychology	1998-present
Corinna Gries, Plant Biology	1997-present	Samuel M Scheiner, Life Sci, ASU W	1997-present
Edward J Hackett, Sociology	1998-present	Arleyn W Simon , Anthropology	1997-present
Sharon Harlan, Sociology	1999-present	Andrew T. Smith, Biology	1998-1999
Timothy D Hogan, Economics	1997-present	Katherine A Spielmann, Anthropology	1997-present
Jana Hutchins, GIS Lab	1997-present	Juliet C Stromberg, Plant Biology	1997-present
Paul C Johnson, Civil/Env Eng	1997-present	Edward Stump, Geological Sci	1997-1998
Mary R Kihl , CAED/Herberger Ctr	1997-present	Jean C Stutz, Plant Biology	1998-present
Bradley Kincaid, Mesa Comm College	1997-1998	Stanley R Szarek, Plant Biology	1998-present
Ann P. Kinzig, Biology	1999-present	Elizabeth A Wentz, Geography	1997-present
Andrew Kirby, Soc/Beh Sci, ASUWest	2000-present	Shapherd Wolf, Sociology	2000-present
Susan Wyckoff, Physics & Astr/ACEPT	1997-present	Sander van der Leeuw, Sorbonne, Paris	1999-present
James A Tyburczy, Geological Sci	1998-present	Rita Walton, Maricopa Assn of Govts	1997-present
Paul C Westerhoff, Civil/Env Eng	1997-present		

Postdoctoral Research Associates

David Casagrande, CES	2003-present
William Cook, CES	2003-present
Suzanne Grossman-Clarke, Mech/Aero Eng /CES	2000-present
Mark Hostetler, CES/Biology	1997-1999
Madhusudan V Katti, CES/Biology	2000-present
Margot Kaye, CES	2002-present
Kimberley Knowles-Yanez, CES	1997-1999
David B Lewis, CES/Biology	2000-present
Louis Macabee, CES/IGERT	2002-present
Nancy E McIntyre, CES/Biology	1997-2000
Markus Naegeli, Biology	1998-1999
Amy L Nelson, CES	1999-2002
Samuel Schmieding, CES	2002-2003
Eyal Shochat, CES/Biology	2000-present
William Stefanov , Geological Sci	2000-present
Paige Warren, Biology	2000-present
Russell Watkins, CES	1999-2000
Wanli Wu, CES/Biology	2001-present
Weixing X Zhu, CES/Biology	1999-2000

Other Collaborators

Dave Anning, USGS	1998-present
Barbara Backes, Life Sciences Vis Lab	1999-2000
Debra Banks, CRESMET	2002-present
Ellen Banzhaf	2003-present
Laural Casler, Life Sciences Vis Lab	2000-2002
Ken Fossum, USGS	1998-present
Steve Getty, Univ of New Mexico	1998-1999
Cameo Hill	2002-present
Peter Hyde, ADEQ	2001-present
Charles Kazilek, Life Sciences Vis Lab	1999-present
John Keane, Salt River Project	1997-present
Sang-Mi Lee, ASU Civil/Env Eng	2001-present
Robert Minckley, Auburn Univ	1999-2000
Fred Rainey, Louisiana State Univ	1999-present
Nancy Selover, ASU Geography	1999-present
Conrad Storad, ASU Research Pub	1997-present

Research Technical Personnel

Michael Baker, P/T Aide/Birder, CES	1998-2000
Damon Bradbury, Tech, CES	1998-1999
Amalya Budet de Jesus, P/T Asst, CES	2000-2000
John Buegge, Acad Assoc	2001
Adam Burdick, Biology	1998-1999
Michael Clary, Tech, CES	2000-2001
Katherine Clemens	2002-present
Amy Diiorio, Tech, CES	2001-present
Roy Erickson, Tech, CES	2000-present
Kaberi Ka Gupta, CES, Data Entry	2000-2001
Shero Holland, Tech, CES	1998-2000
Thomas Hulen, P/T Aide/Birder, CES	1998-1999
David Jennings, Tech	2002-2003
Tracy Flores Johns, Tech, CES	2000-2002
Meryl Klein, P/T Tech/Birder, CES	1998-1998
Cathy D Kochert, Research Spec, Bio	1999-present
Radha Kunda, Res Spec	2002-present
Kelly Lazewski, Tech, CES	Spring 2000
Jomarie Lemmer, P/T Birder, CES	1999-2000
Susannah Lerman, Res Asst/Birder	2001-2002
Matthew Luck, GIS Research Spec, CES	2000-2001
Alejandria Mejia, Plant Biology/Herbrm	1998-2000
Michael Myers, Research Spec, CES	1998-2000
Theodore Oliver, Comp Dbse Spec, CES	1997-1999
Sandra Palais, Seidman Res Inst, ASU	1997-present
Seth Paine, P/T Research Tech, CES	2000-2001
Wayne Porter, Com Datbse Spec, CES	2000-present
Christopher Putnam, Tech/CES	2001-2003
Sarah Quinlivan, Tech, CES	2000-2001
Beverly Rambo, P/T Aide; Birder, CES	1998-present
Tom Rex, Seidman Res Inst, ASU	1997-present
Stephen Rosales, Com Datbse Spec, CES	1999-2000
Melissa Rossow, Plant Biology/ Herbrm	1999-1999
Barbara Scott, Res Aide/Birder	2002-2003
C. Scott Smith, IT GIS Lab	1998-2002
Diana Stuart, Res. Aide, CES	1999-present
Maggie Tseng, Research Spec, Bio/CES	1997-present
JoAnne Valdenegro, Res Spec, Sociology	2000-2001
Jaqueline Walters, Research Spec, CES	1997-2000

Public Outreach Personnel

Monica Elser, Education Liaison, CES	1998-present
Lauren Kuby, Communications Mgr. CES	1998-present
Kathryn Kyle, Exec Admin, SCENE	1997-present
Peggy Lindauer, Education Liaison, CES	1997-1998
Charlene Saltz, Env Edu. Coor, CES	2000-present
Susan Williams, Education Liaison, CES	1999-2000

Research Support Personnel

Nikol Grant, CES	2001-present
Shirley A. Stapleton, CES	1997-present
Kathleen A Stinchfield, CES/Biology	1997-present
Linda K Williams, CES	1997-present
Cindy D Zisner, CES	1997-present

Graduate Research Associates

Sharolyn Anderson, Geography	1999-2000
Stephen Ammerman, History	1998-1999
Emily Atwood	2002-2003
Todd D Becker, Economics	1998-1999
Sheryl Berling-Wolf, Plant Biology	2000-2002
Saritha Bhandarkar, CES	2002-present
JoAnne Blank, Plant Biology	2000-2001
Karen E Blevins, Geography	1998-1999
Justin Borenson, Civ and Env Eng	2001-present
Debbie A Brewer, Geography	1999-2000
Alex Buyantuyev, Plant Biology	2002-present
Sarah Celestian, Plant Biology	2001-present
Amanda Coleman	2002
Kevin B Clark, Biology	1998-1999
Tim Collins, IGERT Fellow	2000-present
Mark A Compton, Plant Biology	1998-2000
Jamaica Cousins, Plant Biology	1999-2000
Dixie Z Damrel, Plant Biology	1998-1999
Lisa Dent, Biology	Summer 1998
Mimi Diaz, Geological Sci	2002-present
Dean Dobberfuhl, Geological Sci	2000-2001
Jennifer W Edmonds, Biology/IGERT	1999-present
Christopher Einsinger, Geogical Sci	2002-present
Kenneth Fergason, Geological Sci	1999-2000
Richard Frederickson, Biology	1999
Kris Gade, IGERT Fellow	2000-present
Wei Gao, Geography	Spring 1998
Aisha M Goettl, Biology	2000-2001
Root Gorelick, Economics/Biology	1999-2000
Dennis C Gosser, Anthropology	1998-1999
Zhan Guo, IT	2001
Dennis Hale, Curr/Instruction	1997-1998
Brent Hedquist, Geography	2001-2002
Stephen D Holloway, Geological Sci	1997-1998
Andrew M Honker	1999-2000
Justin S Hoppman, Plng /Lndscp Arch	1998-2000
Scott Ingram, Anthropology	2002-present
Paul Ivanich, Geological Sci	2000-present
Jeffrey James, Geography	Spring 1998
G Darrel Jenerette, ASU W Life Sci	1998- present
Tracy Johns, Biology	2002-2003
Brenda Koerner, Plant Biology	2000-present
Michael LaBianca, Sociology	1999-2000
Jacqueline Leubbert, Geological Sci	2001-2002
Hongyu Liu, Life Sciences, ASUW	1998
Carlos Santiago Lopez, IT	2001-2002
Matthew A Luck, Biology	1998-2000
Darin Mahkee, Plant Biology	2001-present
Joaquin Maruffo, Plng/Landscp Arch	1998-1999
Wendy A Marussich, Plant Biology	1999-present
Eric S Matranga, Geography	1999-2000
Lisa McKelvy, Biology	2000-2003
Nicole McPherson, Civil/Env Eng	1998-1999
Cherie Moritz, Plant Biology/GIS	Fall 1998
Victor Molina, Planning	2002
Erin Vining Mueller, Plant Biology	1998-1999
Leslie Nogue, Anthropology	2000-20021
Maureen O'Donnell, Sociology	2001-2002
Michelle M Oleksyszyn, Plant Biology	1998-1999
Elena Ortiz-Barney, Plant Biology	2001-present
Alanna E Ossa, Anthropology	1998-1999
Cindy Overton, Planning	2002
Gemma Paulo, Economics	Spring 1998
Ravi Peri, CES Informatics	2001-present
Kathleen A Peterson, Plant Biology	1999-2000
Lela Prashad, Geological Sci	2003-present
Jennifer Rambo, Biology	2001-present
Jessamy Rango, Biology	1998-present
Eva C Reid, Geography-GIS Lab	1999-2000
John Roach, Biology/IGERT	1999-present
Martin Roberge, Geography	1998-1999
Sarah Robinson, GeologicalSci/IGERT	1998-2002
Michael Rogers, Curr/Instruction	1998-1999
Bruce Ryan, Plant Biology	Summer 1999
Hoski Schaafsma Plant Biology	2001-present
John Schade, Biology	1997-2002
Samuel Schmieding, History	1998-1999
Diane M Sicotte, Sociology	1998-2002
Curtis Sommer, Anthropology	1999-2000
Kim Sonderegger, Anthropology	1998-2000
L Brooke McDowell Stabler, Plant Bio	1998-present
William L Stefanov, Geological Sci	1998-2000
Arthur Stiles, Plant Biology	1998-present
Glenn Stuart, Anthropology	1999-2003
Anne Sumner, Curr/Instruction	1999-2000
Steven J Swanson, Anthropology	1998-1999
Wendy Thomas, Geography	Spring 1998
Niccole Villa, Geography	1998-1999
Russ Vose, Geography	1999-2000
Naga Vuppaladadium, CES	2001-present
Gretchen Walters, Plant Biology	1998-1999
E Christian Wells, Anthropology	1998-1999
Jill Welter, Biology	Summer 1998
Sean Whitcomb, Plant Biology	2000-present
Gina Serignese Woodall, Political Sci	1999-2001
Steven Wood, Geological Sci	1998-1998
Ying Xu, Civil/Env Eng	1998-2001
Angel Zambrano, Plant Biology	1998-1999
Jian Zhang, Plant Biology	2002
Michael Zoldak, IT	2001-2002
Toralf Zschau, Plant Biology	1998-1999

Other Grads

Jeremy Buegge, Plant Bio, Eco Exp	1999
Jenny Draevich, Biology, Eco Exp	1998
John Frisch, Biology, Eco Exp	1998
April Henry, GK-12	2002
Nancy Jones, Plng/Lnds Arch	2000-2003
Randi Mendoza, Biology, Eco Exp	1999
Elena Ortiz-Barney, Plant Bio, Eco Exp	1999-present
Maurice Tatlow, Geography	1999-2000
Russell Vose, Geography	1999-2000
Charlie Wilson, Ecology Exp	2001-2002
Jian Ye, Sociology	Summer 2002

Research Experience for Undergrads (REU)

Onkar Ajami, ASU	Spring 2002	Diana Durand, ASU/IGERT	Summer 2002
Jonathan Bashford, ASU/IGERT	Summer 2002	Christopher Farley, Colorado State	Summer 1998
Joanne C Blank, ASU	Summer 1999	Nicole Garber, ASU/IGERT	Summer 2002
Shawn A Boone, Texas A&M	Summer 1999	Don Hennebusch, ASU/IGERT	Spring 2003
Monica Brennan, ASU/IGERT	Summer 2003	Matthew de la Pena Mattozzi, Harvey Mudd College	Summer 2000
John Burke, ASU/IGERT	Summer 2002	Michael Pierce, ASU	Fall 2002
Ronald Burks, ASU/IGERT	Summer 2003	Christopher Putnam, ASU	Fall 2000
Lane Butler, ASU/IGERT	Summer 2002	Philip Tarrant, ASU	Summer 2003
Rebecca Calonico, ASU/IGERT	Sum 2002, 200:	Erik J Wenninger, U of Toledo	Summer 1998
Andy H Chan, UC Berkeley	Summer 1998	Selena L Wightman, U of Virginia	Summer 1999
Heather Dawson, ASU	Spring 2002	Danielle Ziegler, Fort Hays State Univ	Summer 2002
Noah D Dillard, Kalamazoo College	Summer 2000		

Other Undergrads

Christopher Anto	1998-1999	Christian Lawrence, Biology; arthropods	1999-1999
Juan Beltran, Bird data entry	Summer 2000	James Lazo, Biology	2001
Sophia Beym, Ecology Explorers/CES	2002-present	Katie LeBlanc, Anthro, CES office asst	1997-1999
JoAnne Blank, Plant Biology	1998-1999	Brian Lutz, Bio/Society, Ecology Exp	1999-2002
Robert Brant, Biology	1999-2000	Anita Maestos, Biology	2000-present
Crystal Brillhart, Biology	2000-2001	Lisa C McKelvy, Biology; arthropods	1998-2000
Matt Bucchin, GIS Lab	Fall 1998	Cathryn Meegan, pollen tech; Anthro	Summer 2000
Heather Bush, Biology	2002-present	Kaila Meyer, Biology	2002
George Cadiente, Geological Sci	Summer 1999	Jeremy Mikus, Biology	2000-present
Natalie Case, Hughs BREU; urban lakes	Spring 1999	Jennifer Mills, Music	1997-1999
Richard Cassalata, Biology	2000-2002	Robert Mitchell, Biology	Spring 1998
Linda Drummond, Plant Biology	1998-1999	Ellen Morrisson, St. Olaf College, Minn	January 2001
Esther Ellsworth, Bio/Society, Eco Exp	1999-2002	Mary Nowicki, Biology	2000-2001
Kevin Fantozzi, Life Sci, ASU W	1998-1999	Xochitl Orzoco, Biology	2000-2001
Susan Firely, Biology	2000-present	Tracy Osborn, Civil/Env Eng	1998-1998
Travis Fears, IT/Ecology Exp Web site	1998-1999	Chris Patterson, GIS Lab	2000-2001
Ayoola Folarin	1998-1999	Christopher Putnam, Biology	2000-2001
Jennifer Folsom, IT/Eco Exp Web site	1998-1999	Brenda Rascom, Biology	2000-present
John Frisch, Biology	1999-present	Barbara Schmidt, Plant Bio	Summer 2000
Jonathan Furnari, Biology	2001-present	Brian Sherman, IT, Eco Exp	Spring 1998
Darla Gill, Civil Eng	2002-present	Chris Sommers, IT/Eco Exp Web site	1998-1999
Cyd Hamilton, Biology	1998	Derek Stauffer, Biology	2002-2003
Aurora Hinckly, Biology	2001	Diana Stuart, Res Aide; Birder, CES	1999-present
Marc Hinze, Biology	1998-1999	Maria Tcherepova, Plant Biology	Summer 2000
Moe Moe Htun, Bird data entry	1998-1999	Lisa Thompson, CES/IGERT asst.	1998-2002
Allison Huang, Biology	2001-present	Brian Tong, Birder data entry	1999-2000
Jennifer Hunter, Hughs BREU, urb lakes	1999	Sean Walker, Biology; arthropods	1998-1999
Jill Koehler, Biology	2002-2003	Lara Whitford, Biology	2001
Lisa Lauver, Civil/Env Eng	1998-1999	Jennifer Zachary, Biology	1999-2000

HS Students

Sambo Dul, SCENE research intern	1999	Natalys Ter-Grigoryan, SCENE res intern	1999
Juan Gomez, Tempe HS	2000		

Pre-College Teachers

Melissa Allen, Skyline HS	2003
Kathleen Arola, Solano School	2003
Robert Atwood, Meyer Elem	1999-2003
Renee Bachman, W.T. Machan Elem	1999-2003
Joyce Baldwin, Sacaton MS	1998-2003
Jim Barnette, Zedo Ishikawa Elem	1999-2003
Paula Beacom, Lowell Elem	1999-2003
Chuck Bell, Deer Valley HS	1999-2003
Wendy Blasdell, Mountain View HS	1999-2003
Dave Boomgaard, Brimhall Jr. HS	1998-2003
Carole Boling, W.T. Machan Elem	1999-2003
Scott Bowling, Discovery Elem	1998-2001
Karen Braccio, Desert Canyon Elem	2000-2003
Michael Brand, Oasis Elem	2002-2003
Amy Braun, Stevenson Elem	2001-2003
Sylvia Brown, Frank Borman MS	2003
Linda Calderon, Desert Harbor Elem	2000-2003
Sharlene Cardona, Falcon Hill Elem	1999-2003
Tracy Carlson, Holmes Elem	2000-2003
Dave Carpentar, Meyer Elem	1999-2003
Jon Ciulei, Trevor Browne HS	2000-2001
Patricia Kupferer, Taylor Junior HS	2003
Darlene Cull, Stevenson Elem	2001-2003
Brian Clark, NFL-YET Prep Acad	2000-2003
Meg Davis, McKemy MS	1998-2003
John Dole, Mesquite HS	2003
Joelle Don de Ville, St. Mary's HS	1998-2000
Jennifer Donovan	2002-2003
Gary Dotterer, MacArthur Elem	2002-2003
Theresa Dowling, Liberty Elem	2003
Pat Dwyer, Desert Eagle Secondary	2003
Ed Eberle, Dobson HS	1998-1999
Vickie Eberle, Sunridge Learning Center	1998-1999
Ann English, Desert Eagle HS	1999-2003
Michelle Fink, Meyer Elem	1998-2003
Ann Flagg, EDU Prize	1999-2003
Margaret Fons, Sirrine Elem	2000-2003
Susan Fountain, Kyrene Altadena	2002-2003
Gerry Foster, Mesquite HS	1999-2000
Wyatt Franz, Wm T Machan Elem	2003
Jennifer Freed, Mountain Ridge HS	2003
Adam Galen, Finley Farms Elem	2002-2003
Scott Greenhalgh, Tempe Union HS	1999-2003
Wendy Hansen, Jefferson Elem	2000-2003
Bette Hanscom, McKemy MS	2000-2003
Lance Harrold, Mobile Elem	2002-2003
Irene Hawkins, Tempe Preparatory	2000-2003
Linda Heck, Dysart Elem	2003
Jack Helton, Desert Harbor Elem	2002
Janet Henderson, Deer Valley MS	1999-2003
Erin Hilligoss, Squaw Peak Elem	2000-2003
Stephan Hobbs, Seton Catholic HS	2003
Heather Holmes, Desert Harbor Elem	1999-2000
Susie Huffaker, Meyer Elem	1999-2003
Linda Idol, Westpoint Elem	2002-2003
Tad Int-Hout, Desert Harbor Elem	1999-2001
Sara Jenkins, Lattie Coor Elem	2002-2003
Sue Johnson, The Family School	1999-2003
John Jung, Mesa HS	2001-2003
Teresa Krause, Mendoza Elem	1998-2003
Larry Langstaff, Hendrix Jr. HS	1999-2003
Sharon Langston, Monte Vista Elem	1999, 2002-200
Karen Lee-Price, Moon Mntn School	2000, 2002-200
Gene Lescallete, Desert Mountain HS	2000-2003
Jim Little, Rhodes Jr. HS	2000
Brenda MacIntosh, Awakening Seed	2001-2003
Josefina Madrigal, Cesar Chavez HS	2003
Sharin Manes, Fountain Hills Middle	2000-2003
James Mangels, Estrella Mtn Elem	2000-2003
Jim Manley, Stevenson Elem	1998-2003
Mary Martine, Kiva Elem	2000-2003
Vickie Massey, Mendoza Elem	1998-2003
Chris Mayer, Desert Harbor Elem	2002-2003
D'Anne McDaniel, Fees MS	2000-2003
Stephanie Mihalic, Greenway MS	2000-2003
Misty Miles, Marc T. Atkinson MS	2002-2003
Birgit Musheno, Desert Vista HS	1999-2003
Alfredo Ontiveros, Dept of Defense HS	2002-2003
Donna Palladino, Copper Canyon Elem	2000-2001
Dixie Papano, Granada East MS	2003
Nancy Parra, Lowell Elem	2003
Gary Patterson, Skyline HS	1999-2003
Kathleen Pelley, Evans Elem	1998-2003
Trish Peters, Pueblo Elem	1999-2003
Barbara Pierni, Finley Farms Elem	2003
Jason Prichard, Willis Junior HS	2002-2003
Kris Rademacher, Desert Vista HS	1998-2003
Nancy Ragle, McKemy MS	2000-2003
Lisa Randall, Stevenson Elem	1998-2003
Robin Renaud, Moon Valley HS	2000-2003
Linda Sargent, Mountain View HS	2000-2003
Darlene Sitzler, Eisenhower Elem	1998-2003
Tina Skjerping, Wm T. Machan Elem	2002-2003
Mike Sliskovich, Supai MS	2000-2003
Jan Snyder, Camelback HS	2000-2003
Susan Soroka, McKemy MS	2000
Cara Steiner, Mendoza Elem	2000-2003
Joyce Sterret, Trevor Browne HS	1998-2000
C. J. Stevens, Mountain Pointe HS	2000-2003
Ryan Swartz, Moon Valley HS	2000-2003
Kerri Tornow, Awakening Seed	2001-2003
Rob Trenck, Red Mountain HS	2000-2003
Toby Tucker, Fountain Hills HS	1998-1999
Paul Vachon, Royal Palm MS	2000-2003
Michelle Volk, Kyrene Aprende MS	1999-2001
John Wallace, Mountain View HS	1998-2000
Terri Wattawa, Santan K-8 Campus	2002-2003
Pamela Whitaker, Thunder Mtn MS	2000-2003
John Whitbeck, Saddle Mountain	2003
Kimberly Wilson, Kyrene Pueblo MS	2000-2001
Susan Wiseman, Arthur M. Hamilton Schl	2000-2003
Patricia Zaput, Camelback HS	2003

Volunteer Participants

Renee Bachman, Bird Survey
Michelle Bagley, Bird Survey
Genine Baker, Bird Survey
Mike Baker, Bird Survey
Lois Bansberg, Bird Survey
Richard Bansber, Bird Survey
Stan Celestian, Data Collection
Susan Celestian, Data Collection
Evie Chadbourn, Bird Survey
Marty Chew, Bird Survey
Tillie Chew, Bird Survey
Marti Cizek, Bird Survey
Troy Dainty, Data Collection
JoAnn Dalcin, Bird Survey
Newilda DeFrance, Bird Survey
John Delventhal, Bird Survey
Bix DeMaree, Bird Survey
Cliff Drowley, Bird Survey
Mildred Eade, Bird Survey
Vicki Eberle, Bird Survey
Amy Elsnic, Vertebrate Species Project
Herbert Fibel, Bird Survey
Dwayne Fink, Bird Survey
Anne Fischer, Bird Survey
Craig Fischer, Bird Survey
Dick Foegel, Bird Survey
Lori Ford, Bird Survey
Jim Forrest, Bird Survey
Gary Fowler, Bird Survey
Jeanne Frieden, Bird Survey
Thomas Gaskill, Bird Survey
Alison Grinder, Bird Survey
George Hansen, Bird Survey
Elizabeth Hatcher, Bird Survey
Helen Haukland, Bird Survey
Meg Hendrick, Bird Survey
Ted Henricks, Bird Survey
Jan Hilton, Bird Survey
William Karl, Urban Lakes Study
Mark Malone, Bird Survey
Charlotte Mars, Bird Survey
Cathy Merrill, Bird Survey
Nettie Meyers, Bird Survey
Grace Miller, Bird Survey
Sandra Mobley, Bird Survey
Diane Rhodes, Bird Survey
Steve Rissing, Bird Survey
Pat Roberston, Bird Survey
Arlene Scheuer, Bird Survey
Terry Schulte, Bird Survey
Linda Scharf, Bird Survey
Beverly Shaver, Bird Survey
Norm Shrout, Bird Survey
Jim Sommers, Bird Survey
Andree Tarby, Bird Survey
Lorraine Thompson, Bird Survey
Walter Thurber, Bird Survey
Juanita Valentyne, Bird Survey
Anita Van Auken, Bird Survey
Susie Vaught, Bird Survey
Cindy West, Bird Survey
Alice Williams, Bird Survey
Penny Wilson, Bird Survey
Marika Witenko, Bird Survey
Keith Yett, Bird Survey

Community Partners

Arizona Department of Water Resources
Arizona Department of Environmental Quality
Arizona Geographic Alliance
Arizona Historical Society Museum
Arizona Public Service
Arizona School Services through Educ Tech, ASU
Arizona Science Center
Arizona State Land Dept
AZ Tribal Coalition, UT-CO-AZ-NM Rural Sys Initiative
ASU ACEPT-Ariz Collab Excellence in Prep of Teachers
City of Phoenix
City of Scottsdale
City of Tempe
Creighton School District
Deer Valley HS District
Desert Botanical Garden
Flood Control District of Maricopa County
Fountain Hills HS District
Gila River Community Schools
Gilbert HS District
Glendale School District
Maricopa Association of Governments
Maricopa Community Colleges Motorola
Maricopa County Parks and Recreation Department
Mesa Public Schools
Mesa Systemic Initiative
Office of Research Publications, ASU
Office of Youth Preparation, ASU
Peoria Unified School District
Phoenix Elem School District
Phoenix Union HS District
Phoenix Urban Systemic Initiative
Pueblo Grande Museum
Salt River Pima-Maricopa Indian Community
Salt River Project
Southwest Center for Educ and Natural Environment
St. Mary's HS
Tempe Elem School District
Tempe Union HS District
The Phoenix Zoo
Tonto National Forest
U.S. Dept. of Agriculture
U.S. Forest Service
U.S. Geological Survey

Permission to Conduct Long-Term Monitoring

Arizona Department of Environmental Quality
Arizona Public Service
Arizona Department of Transportation
Arizona State Land Department
Arizona State Parks
City of Phoenix
City of Chandler
City of Scottsdale
City of Tempe
Dawn Lake Homeowners Association
Desert Botanical Garden
Dobson Ranch Homeowners Association
Duncan Family Farms
Flood Control District of Maricopa County
Honeywell
Insight Enterprises
Intel
Las Brisas Homeowners Association
Maricopa County Department of Environmental Services
Maricopa County Parks and Recreation Department
Morrison Brothers Ranch
Ocotillo Homeowner Association
Rogers Brothers Farms
Ross Management Inc.
Salt River Project
Sonoma Farms, Inc.
Tempe Union HS District
Tonto National Forest
Town of Fountain Hills
US Forest Service
US Geological Survey
Valley Lutheran Hospital
Val Vista Lakes Community Association