CAP LTER 2001-2002
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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COMPILED BY
BRENDA SHEARS
NANCY GRIMM
LAUREN KUBY
CINDY ZISNER
LINDA WILLIAMS

FROM PROJECT REPORTS SUBMITTED BY

ROBERT BOLIN
ANTHONY BRAZEL
ANN DILLNER
MONICA ELSER
STANLEY FAETH
NANCY GRIMM
ED HACKETT
SHARON HARLAN
DIANE HOPE
MADHUSUDAN KATTI
CHRIS MARTIN
PETER MCCARTNEY
CHARLES REDMAN
SAMUEL SCHEINER
EYAL SHOCHAT
WILLIAM STEFANOV
JEAN STUTZ
JIANGUO WU

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I. Introduction to CAP LTER

The CAP LTER project is a multifaceted study aimed at answering the question, “How does the pattern of development of the city alter ecological conditions of the city and its surrounding environment, and vice versa?” Central to answering this question is understanding how societal decisions drive land-use change, how these decisions alter ecological pattern and process, and how changes in ecological conditions further influence human decision making. Of the 24 sites funded under the nationwide LTER program, Phoenix and Baltimore are the only 2 established specifically to study urban ecosystems.

The rationale for the study of human-dominated systems is three-pronged (Grimm et al. 2000). First, humans dominate Earth’s ecosystems; therefore, humans must be integrated into models for a complete understanding of ecological systems. Second, development of these more realistic models for ecological systems will lead to greater success in finding solutions to environmental problems. Third, although the study of ecological phenomena in urban environments is not a new area of science, the concept of city as ecosystem is relatively new for the field of ecology (Collins et al. 2000). Studying cities as ecosystems within new paradigms of ecosystem science will both raise the collective consciousness of ecologists about urban ecosystems and contribute to the further development of concepts that apply to all ecosystems.

CAP LTER research began in Spring 1998 with 28 initial projects that employed a variety of approaches to synthesize existing data and initiate new sampling. In Year 3, we began a long-term monitoring program, designed in light of the previous 2 years' research. Long-term experiments were established, and model development and synthesis of existing data continued. We invested extensive effort in developing a framework for conceptual integration of social-natural systems as applied to urban areas (Redman 1999; Collins et al. 2000; Grimm et al. 2000; Redman et al. in review) that built upon our earlier (proposal) ideas. In Spring 2001, we hosted a Site Visit Review Team and the LTER Executive Committee and Coordinating Council. During 2002, we fostered the development and award of several major proposals, participated in the creation of Greater Phoenix Regional Atlas, enhanced cross-site activities and international collaborations, and began the planning for our renewal proposal.

Altogether for the first 5 project years, about 100 faculty members, 15 postdoctoral research associates, 90 graduate students, 67 undergraduate students, 85 K-12 teachers, and close to 100 community volunteers have been involved in some way in CAP LTER projects. CAP LTER participants have presented over 335 talks, papers, and posters to professional and community audiences, published over 95 journal articles, book chapters, and reports, and completed over 21 Ph.D. dissertations. From our initial collaboration sparked with 12 schools in 1998, Ecology Explorers, our education outreach program, has expanded to include 77 teachers at 54 public schools (encompassing 22 school districts), 3 charter schools, and 2 private schools. In addition, over 20 community partners are substantively involved in the CAP LTER, such as Salt River Project, Maricopa Association of Governments, the US Geological Survey (USGS), and Motorola. We are working with our community partners to define the issues and processes that shape this urban ecosystem and are useful for planning urban growth, especially in sensitive ecosystems.

CAP LTER is an important focal program for both social and natural scientific research at ASU. Forty grants totaling over $13M have involved CAP LTER personnel as key participants or have built upon CAP resources, such as Arizona State University’s (ASU) Integrative Graduate Education and Research Training (IGERT) in urban ecology and our new Biocomplexity grant studying agricultural transformations. A somewhat less tangible but nonetheless important contribution of the project is fostering interdisciplinary interaction. A monthly All Scientist Council meeting, open to all faculty members, students, and community partners, is regularly attended by 40-80 individuals. Every year we organize two events to encourage communication and integration among CAP LTER participants: a January poster symposium with a keynote speaker and a July summer summit workshop. Over 150 posters on CAP LTER studies were presented at 4 symposia, while summer summits on Human-Ecosystem Interactions and Interdisciplinary Projects were widely attended.

CAP LTER scientists have been involved in cross-site and ILTER workshops and research, producing 9 publications based on cross-site activities. Through a Biocomplexity Incubation award with the Baltimore Ecosystem Study (BES), we conducted 4 focused workshops to encourage cross-site projects that integrate social science into long-term ecological research. In addition, CAP LTER has engaged in a range of comparative projects with BES and collaborated on many cross-site proposals. As for international collaborations, for the past year or so, scientists from CAP LTER and BES have been working to establish a research partnership with French scientists from the Piren-Seine Zone Atelier (CNRS, the French equivalent of the NSF). This collaboration has taken the form of workshops, field visits and, beginning at a Baltimore workshop in October 2001, the crafting of a research agenda to foster short- and long-term projects.

II. Highlights of Research Activities

Research Strategy

Our strategy for establishing the CAP LTER research program was to begin with varied initial projects (see Web site for lists of projects). These included pilot projects to develop methods, data synthesis projects to analyze existing (often mined) data, and short-term experiments. Researchers outlined work plans for initial projects as members of research teams, roughly following the LTER core areas but adding two areas focusing on human dimensions of ecological research. Based on the experience of the first two years, we determined the important variables to be monitored, sampling frequencies, and the temporal and spatial scales (in grain and extent) of monitoring. Our approach to long-term monitoring is two-pronged: 1) Survey 200, an extensive, expansive, multi-site "snapshot" survey of ecological and social variables, conducted every 5 years (Spring 2000, 2005, ...); and 2) higher-resolution, detailed investigations in permanent plots and permanent aquatic monitoring sites. Several initial projects are complete and have evolved into elements of the core-monitoring effort (urban water chemistry, primary production, organic matter storage and soil respiration, arthropod sampling). Most importantly, we have made strides toward co-locating our monitoring at a subset of the Survey 200 sites, ensuring comparability and utility of results. Monitoring being conducted at a subset of the 200 sites includes bird populations, ground arthropods, primary production, and water use.

We continue to acquire existing data to better understand the overall structure of the study area, define patch typology and long-term monitoring schemes, and construct initial materials budgets for the whole system. In fact, the plethora of monitoring data in urban areas dictates a significant data-mining and synthesis effort for the foreseeable future. From this resource, we will be able to begin synthesizing knowledge much earlier than would be possible if all data were collected by us from the start. Efforts toward synthesis, and associated knowledge transfer to stakeholders, have been furthered by ASU's investment in Greater Phoenix 2100 (GP 2100), a project aimed at envisioning the Phoenix area's future 100 years hence. We also must make use of mined monitoring data for establishing parameters for our models of urban ecosystem structure and function. These include a hierarchical patch dynamics model developed by Wu (Wu and David 2002), fluid-dynamics models that describe the movement of air pollutants (Fernando et al. 2001) and the deposition of N (Grossman-Clarke et al. 2002, in review), and a surface heat-island model (SHIM) with implications for a desert, urban environment (Brazel and Crewe 2002, in press).

In addition to monitoring and models, two long-term experiments that have been underway for at least two years are beginning to yield results (Stabler and Martin 2002 a, b, c). These experiments focus on plant primary production and water use, and trophic interactions among predators, herbivore and plant, and are thus conducted on household-to-neighborhood scales.

Major early efforts in development of a conceptual basis for urban ecosystem research saw fruition. In collaboration with BES scientists (Grimm et al. 2000) and as a result of a NCEAS workshop (Collins et al. 2000), we have set out a framework for the study of urban ecosystems. This framework includes key questions and the thorny issues of dealing with humans, in all their complexity, as parts of ecosystems (rather than as external disturbances). We have continued to build upon these early conceptual models, especially toward developing ecological theory that explicitly includes humans. Elements of our efforts have been supported by a NSF/BE Program-funded series of workshops that began by recommending additions to the LTER core areas (Redman et al. in review) and later spawned a collaboration among LTER scientists that successfully garnered NSF/BE funding for a comparative study of agrarian landscapes in transition (Redman, Kinzig, and others, beginning Fall 2002).

Long-Term Monitoring

Geophysical Context and Patch Typology

For a research site as large (nearly 4000 km^2) and as heterogeneous as the central Arizona metropolitan area and surrounding desert, remote-sensing approaches are essential for gaining an adequate picture of patch structure and temporal change. The Geological Remote Sensing Laboratory (GRSL) continued to focus on collaborative CAP LTER activities over the past year, with primary data generation (primarily surface brightness temperature and vegetation indices derived from Landsat Enhanced Thematic Mapper Plus data for various projects). Processing of new datasets and data generation and analysis for CAP LTER research activities will continue to be a major activity of the lab. Collaborative projects include: correlation of vegetation indices derived from remotely sensed data with biovolume measurements obtained from Survey 200 (as part of a Geography M.S. student's thesis; Paine 2002); investigation of the effect of social and biogeophysical parameters on Phoenix neighborhood microclimates; a recently funded NSF/BE grant to research agrarian land transitions; the study of vegetation change following brushfires in the Phoenix urban fringe region; and determination of the effect of varying hillslope soil-particle size on type of pediment formation along desert mountain piedmonts. The results of two other CAP LTER projects involving GRSL personnel (Grossman-Clarke et al., submitted; Shochat et al., submitted) are in the Findings section (under populations and communities and biogeochemical processes).

Two other projects with ties to CAP LTER research that involve GRSL research scientists and graduate students are the Advanced Spaceborne Thermal Emittance and Reflection Radiometer (ASTER) Urban Environmental Monitoring (UEM) project (http://elwood.la.asu.edu/grsl/UEM) and the Arizona Geoinformatics project (http://activetectonics.la.asu.edu/azgeoinf/index.html). The ASTER instrument, one of a suite of sensors on the orbiting Terra satellite, acquires surficial data from the visible through thermal infrared wavelength regions of the electromagnetic spectrum at resolutions ranging from 15-90 m/pixel. Land-cover and land-use changes associated with urbanization are important drivers of global ecological and climatic change. Quantification and monitoring of these changes are part of the primary mission of the ASTER instrument and comprise the fundamental research objective of the UEM Program (Stefanov et al. 2001). The UEM program seeks to acquire day/night, visible through thermal infrared data twice per year for 100 global urban centers (with an emphasis on semi-arid cities) over the duration of the mission (6 years). The classification techniques and results obtained from the study of the Phoenix metropolitan area are being applied to ASTER data and therefore have the potential to extend CAP LTER results to the global scale using data from other cities. Data are currently available for most of these urban centers and are being used to compare land-cover patterns, urban morphology, and landscape fragmentation patterns. Due to data acquisition difficulties associated with the ASTER scheduling program, UEM research has been so far limited to static comparisons between urban centers rather than dynamic monitoring and modeling efforts.

The Arizona Geoinformatics project is part of an ongoing National Science Foundation initiative to increase and improve the use of information technology in the geological sciences. The project goal is to create a Web-searchable database of available digital information for the Colorado Plateau-Transition Zone-Basin and Range geologic provinces including geophysical data, remotely sensed data, digital elevation models, and geologic maps (Keller et al. 2001). In addition to being able to search the database using a Web browser interface, the user will be able to perform data queries and simple image processing (done "on the fly") with output downloadable as standard shapefiles and geotiff images. The initial geographic focus of the project is a corridor from Flagstaff to Tucson, Arizona, but will eventually encompass all of Arizona and New Mexico and portions of Utah, Colorado, and Texas. Meetings of the Remote Sensing Working Group are held to foster collaboration between CAP LTER scientists doing research involving remote sensing via discussion of ongoing and planned work, proposal generation, and workshops. Attendance ranges from 3-10 people per meeting and includes faculty members, staff, postdoctoral associates, and graduate students.

Survey 200: Interdisciplinary Long-Term Monitoring

The extensive 200-site survey, conducted in 2000, presents a unique effort to study pattern and process across an entire, 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 hypotheses that human variables, including land use rather than distance from urban center, would be 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 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 identified several candidate sites for permanent plots and during Years 3 and 4 began to instrument them and take measurements. Most of our sites are on University property; we are working to expand this list to include other institutional and residential sites. Because of the tremendous variability seen among pilot sites, we must restrict intensive research efforts to a few patch types: remnant desert, residential (turf lawn), and institutional. We describe research efforts at permanent plots in the sections below that deal with individual core research areas. However, all these efforts have been planned by a group with members representing all the disciplines involved in our study. In addition to permanent plots, other aspects of long-term monitoring focus on surface water chemistry and are described in the Biogeochemical Processes section.

Modeling

Early in the project it was decided that a modeling approach that incorporates spatial heterogeneity at multiple scales, as well as temporal change in patch structure and interaction, was required to deal with the complex urban ecosystem. A hierarchical approach is important because the factors that govern urban ecosystem function occur at a variety of scales, so patches may be scaled up or down for different functional analyses. The patch-dynamics approach focuses not only on the spatial pattern of heterogeneity at a given time, but also on how and why the pattern changes over time, and how that pattern affects ecological and social processes. Because cities are both expanding and changing within their boundaries, the dynamic aspect of this approach is crucial to a complete understanding of urban ecological systems.

The hierarchical patch dynamics modeling approach provides a framework for integrating different kinds of models (e.g., population dynamics, ecosystem processes, land-use and land-cover change) across different spatial scales (from local land-cover type to the regional landscape). Such an approach is necessary because both ecological and socioeconomic patterns and processes in any urban landscape occur on a variety of scales, and hierarchical linkages between scales often significantly affect the dynamics and stability of urban development. The patch-dynamics approach focuses not only on the spatial pattern of heterogeneity at a given time, but also on how and why the pattern changes over time, and how that pattern affects ecological and social processes. Because cities are both expanding and changing within their boundaries, the dynamic aspect of this approach is crucial to a complete understanding of urban ecological systems. The aim of our modeling effort is to develop a spatially explicit hierarchical modeling platform for the Phoenix metropolitan landscape that can integrate various (sub)models to understand how land-use/cover change and ecological processes interact during urbanization. Thus, it is important to realize that the hierarchical patch dynamic model for CAP LTER is not a single monolithic model, but a modeling framework (or platform) that allows coupling of various models according to their functionalities and spatial scales.

We have recently completed the hierarchical patch dynamics modeling platform (HPD-MP) mainly through an M.S. thesis project (David 2002). HPD-MP is written in C/C++, which can automatically interpret ecological models developed using STELLA and then run them in a spatially explicit manner. This platform will facilitate the integration of land-use change modeling and ecosystem-process modeling. We have also completed a rule-based urban-growth model for the Phoenix region that simulates the spatial pattern of urbanization. At the same time, we are developing ecosystem process models and meta-population models that eventually will be integrated into the urban-growth model. In addition, we have carried out a series of multiple-scale landscape-pattern analysis.

Again, it is important realize that the HPD approach is not at odds with other modeling methods such as cellular automata, Markovian chains, and process-based mechanistic modeling. In fact, all of these methods are used in modeling the CAP landscape. HPD provides a framework for dealing with: a) extreme spatial heterogeneity that is characteristic of urban system; b) problems that need to be addressed simultaneously at multiple scales; and c) dynamic systems exhibiting rapid change through time (as is the case with this rapidly growing metropolis).

Our modeling research has provided insights into the structure and dynamics of the Phoenix urban landscape, as well as general methodological issues in modeling complex spatial ecological systems. In particular, we have generated several publications on the scaling relations of landscape pattern and modeling of land-use and land-cover change and ecosystem processes (Wu and David 2002; Wu and Marceau 2002; Wu and Overton 2002; Zhang and Wu 2002).

Our objectives and scope for next year are to develop and refine the ecosystem models and population models and integrate them into the land-use and land-cover change model using the HPD-MP. We also will make a concerted effort to incorporate more detailed social and economic drivers into our land-use change model on the one hand and consider to link land-use change model to a regional-scale atmospheric model on the other.

Last year, we formed a working group of over 40 faculty members from diverse disciplines who have special expertise in modeling, plus empiricists who can keep the group's efforts grounded in available data. The Modeling Working Group is chaired by one of the Project co-PD's (Redman) to ensure a broad range of perspectives and that its activities receive appropriate levels of support. The group met regularly to highlight existing activity and more recently to spark modeling efforts in a wide range of study areas.

Core Research Activities

Primary Production and Organic Matter

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

The landscape practices experiment is investigating the effects of irrigation and pruning on plant growth and water-use efficiency (WUE), 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.

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 35 sites across the Phoenix area. Site selection, based on preliminary research, captures a range of land-use types using a urban-core to urban-fringe gradient approach.

Above- and below-ground estimates of urban plant biomass project began in April 2002. It focuses on the 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 for this project has just begun, with the processing of soil cores in progress. Analysis of these cores will enable us to estimate root distributions of the two shrubs. In addition, litter traps have been placed underneath the canopies of these shrubs 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 shrubs' roots, stems, and leaves, with several samplings planned so that seasonal changes can be documented. Also, the two shrubs are currently 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

A wide range of studies are contributing to our understanding of the processes and impacts of urbanization in an ecological framework, often working in uncharted territory. For example, there has been surprisingly little ecological research conducted on arthropods in urban environments (McIntyre 2000), yet fundamental information about how various facets of urbanization affect the diversity and distribution of ground arthropods may have important ramifications on ecosystem-level trophic dynamics, nutrient cycling, and other functions, given the diverse roles that arthropods play in ecosystems. 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 Ecology Explorers. Studies have been redesigned to meet long-term monitoring goals.

The plant community survey of desert plant communities in desert remnant patches repeats a study completed 20 years ago. Activities performed in the past year are part of an ongoing effort to study plant diversity within the study area. The main thrust of this research is to examine how habitat fragmentation, resulting from human-caused alteration of the landscape through urbanization, of a formerly continuous expanse of natural Sonoran Desert plant communities responds to these processes. Metro Phoenix is a useful arena through which to study this phenomena, as it offers a diverse assemblage of natural habitat patches (parks, preserves, undeveloped lands) exhibiting a wide range of spatial, temporal, and disturbance characteristics. To reach this goal, we are producing a vegetation classification and map of the desert areas, as well as a map of the potential vegetation of the human-modified areas. We wish to discover how various parameters affect the species richness and composition of communities within these patches. These parameters include area and shape characteristics of patches, degree of isolation from other patches, time since patch formation, and disturbance characteristics.

Data are gathered on the frequency and abundance of terrestrial vascular plant species using quadrats arrayed along transects placed in a variety of habitats. Through the use of 1-m^2 (herbaceous species) and 100-m^2 (all species) quadrats, species area curves and weighted-average diversity indices can be constructed for patches and intra-patch habitats. Analyses include ordination, classification, and species richness estimators. Classification analysis on ecological data will be used to define plant communities. Remote sensing will be used to produce a map of plant community distribution across the CAP LTER. Environmental variable and community relationships extracted from the vegetation map will be used to generate a predicted map of potential vegetation that would occupy areas now developed. A summary of completed work is included in the Research Findings below.

Our previous analysis of Survey 200 sites indicated that arbuscular mycorrhizal fungal (AMF) community structure was heterogeneous within land-use categories. Because of these results during 2001-2002 we focused on two projects. In the first project, we are assessing differences in AMF diversity within one land-use type (urban/residential). We set up and grew mycorrhizal trap cultures in the greenhouse using soil collected from 28 urban/residential sites that were part of Survey 200. We are currently extracting and identifying spores from these cultures and plan to analyze this data in Fall 2002. We are also continuing to analyze AMF diversity at additional Survey 200 sites. In June 2002, we set up trap cultures in the greenhouse using soil from sites that are also part of the Bird Diversity and Primary Productivity long-term monitoring studies. These trap cultures will allow us to assess diversity. In a second project, we have been studying the spatial patterns of AMF diversity at the CAP LTER primary productivity experimental plot at the Desert Botanical Gardens (DBG). Research results are reported in the Research Findings below.

The ongoing arthropod monitoring project (since April 1998) 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 the 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 in the lab. Previously, we described the differences in arthropod diversity, abundance and distribution between different land-use types. We described general patterns at the community level (all arthropods) and used data from the first year (McIntyre et al. 2001). See Research Findings for results.

The ongoing bird survey and point count is documenting the abundance and distribution of birds in 40 points. These points are a subset of Survey 200 points. Birds are monitored 4 times a year (January, April, July and October) by 3 birdwatchers. The project goal is to study changes in bird diversity, abundance and distribution over time and space due to urbanization. Results are presented in Research Findings.

Another bird project began in the Summer of 2000 to compare the physiological condition of native and non-native birds in different habitats to understand the impact of habitat modification associated with urban development on birds at the individual level: in particular, more predictable and abundant food resources in the urban habitat would allow birds to start breeding earlier than in the desert. Captured birds are marked with numbered metal bands before releasing them, and morphology, body mass, fat reserves, status of molt, as well as the age, sex and reproductive status of each bird are measured. Blood samples are collected for assays of reproductive and stress hormones. Field sampling has been completed for 2 annual cycles, and samples are now being assayed in the lab. Hormone assays were delayed in order to compare 2000-2001, a wet year with minimal differences between desert and urban habitats, with 2001-2002 which turned out to be much drier, offering a stronger contrast between habitats. Preliminary results indicate that breeding commenced much later in the desert than in urban habitats during the dry year, but not in the wet year. Several native species—Abert's Towhee (*Pipilo aberti*) in particular—were also observed to breed multiple times in urban habitats during 2001, with the breeding season extending from February to August. Overall breeding activity and productivity were reduced during the dry spring and summer of 2002 compared to 2001. These conclusions are being further confirmed by hormone assays, which are currently underway. Visual studies of blood smears have identified several blood-borne parasites in some species, and levels of infection are being measured for quantitative comparison among habitats and across years.

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 LTER permanent research sites, starting with the ASU President's House (mesic residential) and the Desert Botanical Gardens (desert remnant), and we plan to expand the project to other habitat types. By using the LTER permanent sites, we hope to link these experiments to other LTER core areas by quantifying changes in ecosystem function (e.g., productivity, P/R ratios, organic matter accumulation) as functions of trophic complexity and patch type.

At each site 40 brittlebush were planted. After about 1 year, the plants at the President's House were no longer dependent on external sources of water and experimental manipulation could begin. There are 4 exclosure treatments (bird exclosures, ground predator exclosures, bird and ground predator exclosures, no exclosures) and 2 water treatments (5 liters of water added every two weeks, no water added) for a total of 8 experimental manipulations. At the President's House site, bird, and ant exclosures were constructed and installed in Spring 2002 and experimental manipulation began in May 2002. At the Desert Botanical Gardens, the plants are not quite fully established and experimental manipulations will begin in Fall 2002. We will sample the arthropod community and plant damage within each exclosure once per month. Arthropods will be identified to family and feeding-guild, and plant damage will be quantified and linked to type of herbivore. We are still in the early stages of experimental set-up and data collection and thus do not have any conclusive results at the present time. However, this is a long-term experiment (over several years) and preliminary results should be forthcoming in 2003.

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 1998, Tempe 2000, Snowbird 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 "white paper, entitled *Human Dimensions of Ecological Change: Integrating Social Science into Long-Term Research* (Redman et al. in review) that provides a foundation and departure point for social scientists and biophysical scientists to consider collaboration 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 the fall of 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. "Agricultural Landscapes in Transition: A Cross-Scale Approach" will trace the effects of the introduction, spread, and abandonment of agriculture at 6 LTER sites, with cross-comparisons in Mexico and France. It is hoped that this interdisciplinary, cross-site study will serve as a model for other cross-site, cross-scale, integrative projects.

<u>Land-use change</u> remains a focal variable for CAP LTER. We view it as very much 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). <u>Phase II</u> 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. During this past year, 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 has 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. This past spring 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 in order to define the specific categories of evidence available for or comparative study. An IGERT Ph.D. student will be spending an extended period of time in Lyon next spring to complete the next stage of this collaboration.

Climate change research has been strengthened this year. The first contribution was made as part of a study investigating the feedback of urbanization on climate change at the local scale. The "heat island" effect of urbanization study assessed 20th-century change at urban and rural weather sites in the CAP LTER area. This research was conducted in a cross-site effort with BES for the city of Baltimore (Brazel et al. 2000). Building on that initial research, two projects, the urban-rural microclimate gradient study and research on the spatial/temporal change of climate/air quality in relation to urban fringe development examined rapid climate gradients from urban to urban fringe to rural. These studies were conducted in the southeastern region of the metropolitan area—an area in which the gradient of land use is from urban/commercial to residential to agricultural and desert mixed land uses in distances on the order of 10-15 miles. Aspects of this research included: a) analysis of fixed sites of automated weather stations in several pre-existing weather networks; b) installation of new sites at several Survey 200 points across this gradient; c) change-detection analysis using remote sensing of the fringe; d) numerical modeling of the nighttime heat island for this environmental gradient linking land cover to microclimate; and e) access of air-quality data along with detailed wind records to demonstrate the role of inversions and wind air drainage over the terrain across this gradient.

In these two projects land-cover change and climate alterations in the southeastern CAP LTER region (urban to rural) have been investigated more closely using new automated fixed weather sites at some of the Survey 200 sites, change detection using remote sensing, and mobile auto traverses from urban to rural (monitoring temperatures, dew points, and solar radiation). Several contributions to understanding the climate and environmental gradient from urban to rural in the southeastern sector of CAP LTER 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 also working cooperatively with neighborhood residents to survey potential health consequences of exposure to airborne hazards and with environmental engineers to measure levels of such hazards (particularly particulate carbon). Research Findings are presented below.

In collaboration with the CAP LTER and IGERT environmental risk team, a physical and chemical analysis of particulate pollution samples was begun in April 2002. This project will contribute 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. Specifically, this project is assisting the people of Homedale by providing data of air quality at two sites in their neighborhood. 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. Gravimetric and elemental and organic carbon analysis has been performed on these samples. Ion chromatography (IC) will be performed on all the samples.

The goal of the labor market dynamics analysis is to understand the distribution of industries, firms, and jobs over space and time in the Phoenix metropolitan area as well as the association between the location of different types of industries and occupations and the socio-demographic characteristics of the population in nearby neighborhoods.

The Phoenix Area Social Survey (PASS), which was awarded a Biocomplexity planning grant in the Summer of 2002, aims to examine the interplay between social, built and natural environments in an urban ecosystem. PASS was designed as a pilot study with multiple objectives: 1) to examine the level, causes and nature of human attachments to community in a rapidly growing and highly mobile urban society; 2) to study the interplay between human communities, quality of life and the natural and built environments in a desert ecosystem; 3) to explore the possibilities of cross-disciplinary 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) to establish the methodology for an ongoing area survey that will continually explore issues of sociological, ecological and social policy interest in the Phoenix metro area. We have made progress in meeting each objective through the selection of 6 sample neighborhoods (located at Survey 200 sites) that sample represents urban core low-income and middle-income neighborhoods and urban fringe upper-income neighborhoods, the administration of pilot survey by the Survey Research Laboratory (SRL) between October 2001 and March 2002, the acquisition of historical land-use data, and the development of a project on microclimates in neighborhoods. We have learned much about the costs and requirements for doing a social survey and are writing a proposal for a spatially referenced area-wide social survey that will be pursued with the ASU Survey Research Laboratory.

The urban parks project aims to understand the ecological and social roles that neighborhood parks play in an urban setting. Ecological processes in parks will be measured and correlated to neighborhood socioeconomic status, use statistics, land-use history, and management strategies in different neighborhood parks. Social perceptions of park value will be correlated to ecological processes, including biodiversity and measures of landscaping aesthetics. Standard parks can be found in many different cities, allowing for comparison of their social and ecological roles. Data is being collected at 16 parks on birds, vegetation, park value and history, and park use. Quarterly *bird point-count surveys* have begun; *park vegetation* studies have resulted in the measurement and identification to species of all trees; *neighborhood vegetation* transects were established around each park and perennial vegetation was recorded, and *park value, history and use* information was collected from about Eastlake Park through an IGERT-sponsored graduate workshop. In a separate IGERT workshop, 5 anthropology students examined neighborhood dynamics around Edison Park, conducting extensive surveys with neighborhood residents. An undergraduate student is currently engaged in a project to construct a GIS project that maps park attributes, including type and position of trees. 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 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 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 groundwater is being investigated in the urban watersheds project. Our foci at this scale are: 1) the 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. We have completed projects on: 1) seasonal variation in nutrient limitation within of a highly modified urban stream-pond system; 2) spatial variation in nutrient concentrations in urban waterways; and 3) soil N cycling processes in retention basins.

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 within the context of the urban landscaping practices experiment; 4) a pilot trace gas study; and 5) analysis of changes in soil nutrient parameters and stoichiometry of soils and vegetation at sites along a channel that traverses a desert-urban gradient (Cave Creek). Nutrients and other materials also are stored on impervious surfaces within urban areas. We plan a survey of spatial variation in impervious surface material storage (at the Survey 200 sites) during the next few months. Meanwhile, a study of nutrients on asphalt parking lots has been completed (Hope et al. in review). Amounts of readily soluble nutrients on asphalt parking lot surfaces were measured at 4 locations in metropolitan Phoenix. Using a rainfall simulator, short intense rainfall events were generated to simulate “first flush” runoff. (see Research Findings).

The water monitoring project (WMP) has been collecting data since March 1998 using protocols similar to those used by the USGS for water collection. Through the WMP, over 20 different water chemistry parameters are monitored at 3 stream sites upstream of the Phoenix metropolitan area, and 2 downstream of the city. These data 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. Data collection and analyses 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) are added by society 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)? Unusually low rainfall and flow in the river at the sites representing inflow and outflow to the entire CAP LTER system have meant that collection of samples under high-flow conditions has not been possible.

The main goals of the atmospheric deposition monitoring research at CAP LTER are to: 1) develop a monitoring network to 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. Because existing monitoring of atmospheric deposition chemistry in the study area and surrounding region was limited, we devised and installed our own monitoring network. The data acquired from this wet-dry bucket approach (patterned after the NADP system) are now supplemented with modeling to describe dry deposition across the region.

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 in collaboration with ASU’s Environmental Fluid Dynamics (EFD) laboratory and Arizona Department of Environmental Quality (ADEQ), the Community

Multiscale Air Quality Model (Models-3/CMAQ), has given us a much more accurate idea of the size of that deposition term. 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. Findings to date 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 was conducted this summer, building upon 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 this 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 will perform the geophysical, geologic, and geomorphic investigations (reported largely in map and tabular form) of this active subsidence zone. We have reason to expect that this preliminary work will lead to increased collaborations between us, ADWR (Arizona Department of Water Resources) and the Central Arizona Project.

Flash flooding characterizes Southwestern desert ecosystems, and urban areas are not immune to this disturbance. A graduate dissertation on the history of flooding in this desert metropolis, supported by CAP LTER, provides a historical context for research on the effects of this disturbance (Honker 2002). The idea of flooding in the desert metropolis of Phoenix may seem incongruous, especially considering that the average rainfall in the Phoenix area is less than 8 inches a year. Yet, since the city was founded in 1867, its residents have had to contend with periodic flooding. Particularly damaging have been floods on the Salt River, which runs through the middle of the Phoenix metropolitan area. The largest flood in the historic record stuck the Phoenix area in February 1891, causing widespread damage and leaving the city without a rail connection for three months. Even with this recent flood, however, it was drought that Valley leaders looked to combat as they pushed for a large-scale water storage dam on the Salt River. When Roosevelt Dam was completed in 1911 its intent and design were for water storage and not flood control. The same is true for the other 5 dams on the Salt and Verde rivers. By storing the water of the Salt upstream and diverting it into canals in the eastern part of the Valley, city leaders made the choice to eliminate a flowing Salt River through the Phoenix metropolitan area. This choice has led to unintended consequences. Although dams and reservoirs on the Salt River are not designed or operated for flood control, they do provide some measure of protection for the Phoenix area under most conditions. Because of this protection, and because most people associate the Salt River with the dry, dusty channel that snakes its way through the valley, the majority of Valley residents fail to perceive the continued threat of flooding on the Salt. Thus, the elimination of the river and the series of impressive dams on the Salt and Verde have created an illusion of protection.

Resilience Alliance

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 2002, submitted). Ann Kinzig (Biology) is our university representative and the force behind our joining this interdisciplinary group.

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. Toward that end, in March 2002 we held an international workshop on applying a resilience approach to data from the past and followed up later that month with a statewide meeting of archaeologists to spark a Southwestern focus to studies of the past. It was thought that research on the Hohokam (prehistoric residents of the CAP LTER region) would provide an ideal case study to test and expand resilience models. The interaction between patterns of climate, irrigation, and social organization will likely serve as the focus of this multi-scalar study, as these issues have broad ecological implications for the past, present, and future of central Arizona.

In the Spring 2002, we received funding from The McDonnell Foundation for a study that integrates archaeology into resilience theory. The Spatiotemporal Aspects of Resilience in Complex Urban Systems will to examine the long-term relationships of climate, irrigation, and social organization in central Arizona. This project involves urban ecologists and archaeologists from CAP LTER (Kinzig and Redman, leads), and geographers, historians, and archaeologists from the University of Paris (van der Leeuw, lead). We have begun to involve a series of modelers from ASU and elsewhere and they will form an important aspect of the research. These individuals will be engaged in workshops and site visits to develop and parameterize models related to archaeological and present-day analyses of water in the desert Southwest (CAP LTER) and agricultural resources in the Rhone Valley in southern France.

Database and Informatics Activities

The CES Lab participated actively in the LTER network-wide effort to adopt a common metadata standard (Ecological Metadata Language or EML). Under separate funding from the NSF, CES has co-authored the EML standard with NCEAS and the Network office, has developed application software for managing and querying EML metadata, and hosted two workshops in January and June which were attended by virtually all LTER information managers. In 2002, we received an award of $447K from the NSF/ITR program for a project to build on our prior BDI grant by integrating urban ecological models from government partners using a Web-services approach.

Local internet systems for managing and publishing CAP LTER are being updated to accommodate the new EML standard. Newly released datasets listed in the appendix will be appearing under that new system shortly. A new intranet to make it easier for participants to manage their project, bibliographic and personnel information was developed in Spring 2002 and is being tested now. 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/CAPsiteflash02.shtm).

III. 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. Results from the vegetation index–biovolume comparison study suggest that there is little to no correlation between the two measures of plant biomass. This is most 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. Vegetation indices are calculated using pixel reflectance measurements obtained from a nadir-viewing sensor and are sensitive to such factors as soil brightness, canopy extent and thickness, and presence of ground cover such as grass. Biovolume measurements obtained from the Survey 200 data do not consider ground cover such as grass, nor do they distinguish between open-canopy vegetation types (such as creosote or ocotillo) and closed-canopy vegetation types (imported trees such as mulberry). While the two types of measurements (biovolume and vegetation indices) are useful in and of themselves, construction of a vegetation index-biovolume calibration curve has proven to be problematic.

Data collected by the airborne Thermal Infrared Multispectral Scanner (TIMS) instrument with laboratory thermal infrared spectroscopy was used to create mineralogical soil maps and maps of grain size distribution in the McDowell and White Tank Mountains located in central Arizona (Stefanov and Applegarth 2001, Applegarth and Stefanov 2002). Both of these mountain ranges are located along the current Phoenix metropolitan urban fringe, and represent natural laboratories where the effects of human encroachment on surficial geologic processes can be observed and monitored. Indices of soil development (relative proportion of weathered to primary rock-forming minerals) and gravel+bedrock (relative proportion of bedrock and gravel- to boulder-sized surficial particles to smaller particles) percentage were developed using the spectral properties of minerals and rocks in the mid-infrared wavelengths. Major results of this work suggests that significant soil development is taking place on semiarid to arid hillslopes, and that the dominant particle size on hillslopes controls the style of pediment formed at the mountain front (small particle-dominated slopes are correlated with alluvial slopes, whereas large particle-dominated slopes are correlated with bedrock pediments).

Survey 200: Interdisciplinary Long-Term Monitoring

Our results show that on average the urban landscape created in the greater Phoenix area 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., in preparation).

However 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 showed a clear threshold - 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., in preparation). A similar relationship between income and diversity has been seen for bird diversity (see bird populations section of the report and also parks project). The number of genera found above a median family income of $50,000 per year does not increase, suggesting that wealth saturates generic plant richness in urban ecosystems. 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.

Data on mycorrhizal species diversity and abundance collected in the pilot phase of the -Survey 200 have resulted in one of the first studies of differences in mycorrhizal abundance and diversity between urbanized and desert systems. The findings were recently submitted for publication. Meanwhile pollen data collected at the 200-survey site locations has also shown interesting patterns in the relationship between tree cover across the site and tree pollen abundance. Latest results suggest that the "surface soil sampling" method used during the Survey 200 reflect the pattern of extant vegetation very closely and may prove a significant improvement on existing pollen collection techniques (Cousins et al., 2002).

Modeling

Several major findings have emerged from the studies of the modeling group, which cover a variety of topics including: 1) quantitative analysis of historical land use change in the Phoenix region; 2) a gradient analysis of the landscape pattern of urbanization in the Phoenix metropolitan area; 3) scaling relations of the spatial pattern of the Phoenix urban landscape, and 4) integrating land use and land cover change with ecosystem dynamics. Our study of the historical land use change showed that urbanization in the metropolitan Phoenix region has resulted in dramatic increases in patch density, edge density, and patch and landscape shape complexity, and sharp decreases in the largest and mean patch size, desert habitat area, and landscape connectivity. The general pattern of urbanization was that the increasingly urbanized landscape became compositionally more diverse, geometrically more complex, and ecologically more fragmented. Our results suggest that the same resolution (and extent) must be used for analyzing the same landscape over time or comparing different landscapes at a given time due to scale effects. In addition, 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 hypothesis that patch shape becomes more regular as human modification to landscapes intensifies.

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.

Our multiple-scale landscape pattern analysis suggested three general types of responses of landscape pattern with changing scales: 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 spatial heterogeneity, we recommend the metric-scalograms (the response curves of metrics to changing scale), instead of single-scale measures, seem necessary.

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 multi-scale 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 listed below.

Core Research Areas

Primary Production and Organic Matter

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 two years of study, oleander given high irrigation rates produced the most shoot mass when left non-pruned or when headed back every six 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 2002).

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 2002). *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

Our recent survey of arbuscular mycorrhizal fungal (AMF) species diversity at the CAP LTER Survey 200 Pilot Study sites revealed that species richness varied as much within major land uses categories (e.g., urban/residential, urban/non-residential, agriculture and desert) as between different land uses. These results indicate that AMF species exhibit spatial patterning at a smaller scale than that detectable by the stratified random sampling design used in Survey 200. As a consequence, we initiated a study of spatial patterns of AMF species richness and composition at the LTER permanent primary productivity project at the Desert Botanical Garden. Soil samples were collected plots in a regular grid pattern at 25 points in two of the 9.6 x 9.6-m simulated landscape. These samples were used to establish trap cultures that were grown for two generations in the greenhouse. AMF spores were then extracted and identified, and data was analyzed using spatial statistics. A total of 12 AMF species were found in the plots. Seven species were detected in Plot 1 and eleven in Plot 2. The most frequently encountered species were *Glomus eburneum*, *G. microaggregatum*, *G. intradices*, and *G. mosseae*. Species richness values were negatively autocorrelated revealing a non-random distribution, but values were not correlated with distance to existing plants. Most individual species were randomly distributed across the plot, but one species (*G. eburneum*) was more dispersed than would be expected with a random distribution in one plot. We presented these findings at the Mycological Society of America annual meeting in June 2002 and are currently preparing a publication describing these results.

Using data from both the Survey 200 and that collected in the plant community survey, we generated a classification of Sonoran Desert plant communities based on woody species using TWINSPAN analysis. This listing allows for information regarding the dominant and regularly occurring species in CAP LTER desert assemblages, as well as some of the occasionals, to be accessed. This floristic analysis was used in the effort to produce a map depicting the distribution of plant communities in undeveloped portions of the CAP LTER. This endeavor was undertaken with a Landsat TM remotely sensed multispectral image using a supervised classification procedure, whereby representative "training sites" are used to generate reference spectral signatures. A digitized soil map depicting surface texture classes was used to stratify training site selection and control class assignments (i.e., all loamy soil communities were generated using loamy soil community signatures). Image processing, classification operations, and preliminary groundtruthing are complete; a more-formal groundtruthing effort in the field will be undertaken in the autumn.

Remnant patch woody sampling is just about complete. Autumn field efforts will focus on gathering data from outlying sites in habitats comparable to remnant patches. Since it was a dry year, current herbaceous plant species sampling is limited to Summer 1999, Spring 1998, and Spring 2001. We anticipate completion of this project by June 2003. However, we have also initiated a discussion with the Baltimore LTER for a cross-comparison.

For further analysis of the arthropod monitoring project, we focused on one guild–spiders–and analyzed data from the first three years to assess how land-use alteration influenced spider diversity. We sampled spiders in 6 different 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 (Shochat, submitted) 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*, followed by *liphyniidae*. These two families are also the most common in agricultural fields in northern and central Europe. 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.

Changes in productivity with time affected spider abundances. After an El Nino winter (May 1998), spider abundance was 5 times higher than after a dry winter (May 2000). The differences in spider abundance between agricultural fields and the four xeric habitats were profound in 2000, but moderate in 1998, suggesting an interaction between the effects of natural and anthropogenic factors on spider populations. Compared with xeric habitats, the El Nino effect was less profound in agricultural sites, suggesting that human land modification confounds seasonal effects. 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. Concerning spider conservation, future landscape planning in Phoenix should favor xeric over mesic gardening in order to preserve / encourage diversity. Although spider diversity in xeric yards is lower than in urban desert remnants, it is greater than in mesic yards.

Studies on urban bird generally correlate species diversity and density with vegetation structure. In the community level bird study, we conclude that though measures of habitat structures are important when studying urban bird populations, they do not fully explain patterns observed in urban environments. For example, in Phoenix median family income and population density are significant predictors of both species richness and abundance. Understanding the mechanisms whereby humans affect the habitats they live in is critical in understanding and managing biodiversity in human-dominated ecosystems.

The first year (October 2001 – July 2002) of data has been analyzed: Bird species richness and total abundance were correlated with different factors (biological and anthropogenic) in order to assess how bird populations respond to urbanization and other modifications in land use. We applied stepwise multivariate statistical methods to assess which factors are the most important in determining bird species diversity and population abundance.

Human Dimensions of Ecological Research

We are preparing a report on preliminary findings from the pilot phase of the Phoenix Area Social Survey (PASS). Some highlights from the findings on environmental issues:

- Over 40% of respondents were “very concerned” about water supply, drinking water safety, accidental toxic releases, air pollution, allergens and soil contamination in the greater Phoenix metropolitan area. 25% were very concerned about noise and bad odors.
- 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 concerned about environmental conditions in greater Phoenix and in their neighborhoods than higher-income households.
- Nearly half the respondents say their households made a large effort to conserve energy. Nine of 10 drink bottled or filtered water, and 60% use water-saving devices. Sixty percent also use gasoline-powered mowers or leaf-blowers and 50% apply pesticides to their yards.

- Respondents in low-income 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. Respondents in high-income neighborhoods cited, "airplane flight paths" as the most common problem in their neighborhoods, followed by widening of major roads, freeway development and development of the desert.
- Sixty percent of the respondents thought that homes were too close together in metropolitan Phoenix. In the high-income neighborhoods, this rose to nearly 80%. Thirty-five percent of high-income residents also thought their lots were too small. However, 50% of the respondents also thought that too little open land is being preserved in the metro area.

The labor market dynamics study examines occupational sex segregation in Greater Phoenix, a major Sunbelt urban area. It illuminates the effects of economic restructuring on gender and ethnic inequality in industries that are experiencing long-term labor market changes. Given the importance of industrial shift and technological innovation during economic restructuring and the effect on women's employment opportunities, occupational sex segregation was explored in four broad industry sectors: high-tech manufacturing, low-tech manufacturing, high-tech producer service and low-tech producer service, and the detailed industries within each sector. Using insights from neoclassical theory, economic segmentation theory and queueing theory, in particular, models were developed to assess the features of industries that determined the degree of occupational segregation in 1998 and the changes in segregation between 1983 and 1998 for white and Hispanic women. Taking account of previous studies, the effects of occupational structure and occupational distribution on sex segregation are also examined.

The findings show that occupational segregation by sex diminished significantly for both white and Hispanic women between 1983 and 1998, but Hispanic women experienced smaller declines in occupational segregation over the 15-year period. Industry type and a number of industry characteristics had significant effects on the level of and changes in the occupational segregation for white and Hispanic women. Further analysis indicates that different occupational distributions for white and Hispanic women were responsible for the higher occupational segregation of Hispanic women in 1998 and for the lesser decrease in occupational segregation they experienced between 1983 and 1998 (Fang Yang 2002).

The urban parks study this year reports on bird, park and neighborhood vegetation surveys, and information gathered about park history and park use: *Bird survey* results show a significant correlation between bird diversity and socioeconomic status of the surrounding neighborhood, with parks in upper-income neighborhoods having the highest bird diversity (average 28.2 species year round, 18 in summer), and parks in lower-income neighborhoods having the lowest diversity (average 17.5 species year round, 13.5 in summer). Parks in middle-income neighborhoods had intermediate diversity (average 23.2 species year-round, 15 in summer). The *park vegetation study* finds highest tree diversity in parks located in lower-income neighborhoods (average of 14 tree species), while the lowest is found in parks located in middle-income neighborhoods (average 8.8 species). Parks in upper-income areas show intermediate diversity (average 11.8 species), though these results are not statistically significant. The highest abundance of trees is found in parks located in upper-income neighborhoods (average abundance = 188 trees), while the lowest abundance is found in parks located in middle-income neighborhoods (average abundance = 76 trees). Parks located in lower-income neighborhoods also had a relatively high abundance of trees (average = 116 trees), though only the difference between the parks in upper-income and middle-income neighborhoods is statistically significant. Data from the neighborhood vegetation transects have been entered into a database, but are not yet analyzed. The park history - results of oral histories, interviews, and archival research - are contained in an IGERT report entitled "From Horse-Drawn Carriage to Light Rail: Exploring Social and Ecological Roles at Eastlake Park." The *park use survey* indicates that the users of Eastlake Park were found to be primarily black and middle-aged, in contrast to the make-up of the surrounding community (younger and Hispanic). Social-group identification was found to determine the broad distribution of people in the park (i.e., certain "territories" for homeless versus family), though ecological features (lawn and trees) seemed to determine use within a section.

Initial results of the neighborhood microclimate study suggest that the initial hypothesis of increased income correlating to cooler neighborhoods is incorrect. Using a combination of social and environmental data (surface brightness temperature and vegetation indices obtained from remotely sensed data; in situ soil and built material temperature data, and air temperature/dew point measurements) we observe that there is no clear correlation between income level and microclimate. Further data collection and analyses to determine the effects of topography, amounts of shade, and land cover on neighborhood temperature are ongoing. The initial phase of this research involved a summer REU student from Fort Hayes State University, Fort Hayes, Kansas.

The urban-rural microclimate gradient study and research on the spatial/temporal change of climate/air quality in relation to urban fringe development have produced the following results during 2001-2002. In the first publication from these projects (Brazel et al. 2000), it was found that there is a clear climate change signal over time in the metro area that is dominated by urban land cover and population changes in the 20th century. This local-scale climate signal is strongly dramatic in the Phoenix desert metro region compared to other world city sites. The publication was a joint cross-site effort to compare and contrast 20th century urban climate change in BES and CAP LTER metro areas. With stable air and clear days most of the time in Phoenix, urbanization as a process feeds back into shaping local climate processes quite frequently across the CAP LTER region. Minimum temperature trends in the Phoenix summertime have increased by 10^0C over the last 50 years; whereas in Baltimore, these temperatures peaked by the 1950s in concert with maximum urban growth in the city core at that time. Daytime temperatures in Phoenix in many places are actually cooler than surrounding desert lands and show no temporal trend in the 20th century. The minimum temperature trends in Phoenix are virtually ten times the global change trend. In Baltimore, daytime temperatures have significantly increased in the city, since the surrounding rural lands are forested and have remained cool. The months of early summer show maximum heat islands in Phoenix, whereas in mid-late summer, these features are most predominant in Baltimore. A group of CAP LTER researchers have recently considered the secondary feedbacks of the urban climate changes on several ecosystem processes (Baker et al., in review).

In the two above projects, emphasis on land cover change and climate alterations in the southeastern CAP LTER region (urban to rural) have been investigated more closely using new automated fixed weather sites at some of the CAP LTER 200 point survey sites, change detection using remote sensing, and mobile auto traverses from urban to rural (monitoring temperatures, dew points, and solar radiation). Several contributions to understanding the climate and environmental gradient from urban to rural in the southeastern sector of CAP LTER have been made:

A doctoral student in Geography studied changes in land cover over the last decade and the resultant indications of local climate changes linked to land cover changes. In this study, thermal imagery change, housing start data, and automated weather data were analyzed in urban and rural areas to show the "wave" of change of land cover near to, and past fixed historical weather sites, which were at the beginning of the 1990s in rural locales, but by the end swamped by development. Major changes in mean daily temperatures in early summer were detected by as much as 2 degrees C over the 1990s decade (areas from rural to urban change) – a rapid decadal rate as urbanization impacts go for cities, and an order of magnitude larger than global change. Changes in atmospheric moisture in the 1990s were less clear to understand, but were closely linked in several step-like changes as new construction, golf course implementation, then major streets/roads/ houses were built in various developments. The absolute changes in local climate in the decade of the 1990s from rural to suburban to urban were also heavily conditioned by the nature of the "rural" landscape to begin with (well-watered agriculture vs. desert-like). A PhD dissertation was completed on the topic of using remote sensing to detect land cover and thermal changes in the Phoenix metro area. (Anderson, S. 2002).

Another graduate student project involved studying the energy and synoptic conditions that lead to variable rates of cooling from sundown to the minimum temperature time across the southeastern CAP LTER region (again from urban to rural changes). In this study, 27 nighttime mobile transects were undertaken from Tempe to Queen Creek on a road network across the urban fringe of the southeast valley, monitoring dew points and air temperature. At same time, six fixed sites at six of the Survey 200 sites (some urban, some rural, one on the urban fringe) were monitored in Fall 2001 on a five-minute basis for temperature and dew point. This was in concert with CAP LTER permissions as well as a Salt River Project contract to monitor on telephone poles. Results were several-fold from this effort, including an MA thesis (Hedquist 2002). This study demonstrated the magnitude of the urban-rural temperature differences and determined the factors that drive the variability in the difference magnitude. Wind was a very critical factor in the variability of the heat island. At speeds less than 5 mph, the heat island rapidly develops. A model to explain cooling of the air over variable land covers was implemented, using GIS and visualization to determine the heat storage capability of various land surface conditions. This model (SHIM) is a force-restore numerical energy budget model recently constructed in the field or urban climatology. A chapter on ENSO and Climate in CAP LTER in LTER book on Climate Variability and Ecosystem Response (Brazel and A. Ellis forthcoming) demonstrated that on ENSO years, we usually have drier summers and thence more intense urban heat islands – furthering strengthening the idea of a large synoptic exogenic control on local urban climate change that moves on a multi-decadal time frame. Another Geography doctoral student has conducted mobile transects of solar radiation variability across CAP LTER in winter and summer. These results show patchy attenuation of radiation due to local dust production and water vapor patterns over the region. Air quality data are affected strongly by the wind regime of the Phoenix metropolitan region in its valley setting (upslope/upvalley during the day; downslope/downvalley flow at night). We have investigated (with EFD personnel) the nature of these flows (timing and climate impacts) and how the flows relate to energy budget modeling of the cooling processes across the urban fringe environment. Primarily, the downslope flows at night trigger additive warming to the heat island by breaking the cool low-level inversion that develops.

Biogeochemical Processes

Analysis of nutrient and metal loads exported by individual storms from multiple urban watersheds, although not completed, reveals some 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 watersheds in total loads as well as concentrations (Lewis and Grimm, in preparation). These analyses will continue, as will our interaction with the agencies that collect these data, as we hope to uncover mechanisms accounting for this 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. In the CAP region, retention basins and even stream channels (such as the Indian Bend Wash [IBW] stream-lake system) are meant to reduce runoff from the system, with the effect that transported materials also are potentially retained. Both aquatic and terrestrial recipient systems show strong signals of these inputs. Chemistry of IBW lakes is highly variable in space and time; at least some of this variation is explained by variable sources of water (groundwater, floods, canal water). Nutrient addition bioassay experiments in IBW revealed that phosphorus was a limiting nutrient for algal growth during summer, but not during seasons when P inputs from storms were high. These experimental results confirm predictions of relative P scarcity based on sampling of urban canals. Canals are the predominant lotic ecosystems in the CAP area, and their chemistry is strongly influenced by mixing of different source waters (canal water from the Salt, Verde, and Colorado Rivers, pumped groundwater, and irrigation return water). Denitrification, the conversion of nitrate to gaseous N products, is very high in neighborhood retention basins where storms deliver nitrate and, potentially, organic carbon. We will continue measurements of this and other processes in recipient systems, which we hypothesize are "hot spots" of material storage and transformation in urban watersheds.

Some of the soil-plant nutrient cycling studies have been initiated just this year, and therefore it is premature to discuss findings. Others are near completion of the pilot phase. Preliminary analysis of soil N and C content across the 200-survey sampling sites indicates that a spatial autocorrelation that is evident in the desert data disappear in the urban ecosystem. We suspect this phenomenon is caused by the extreme patchiness and relatively small patch size in the urban portion of the study area. Among patch types, the largest N contents are seen in agricultural soils, followed by urban/residential soils, which greatly exceed desert soils. Results from the smaller-scale and impervious surface sampling are not yet available. However, compared with similar data collected from undeveloped desert soil surfaces outside the city, storage of NO_3-N and NH_4-N on asphalt surfaces of parking lots was greater than on desert soils–by factors of 91 and 13, respectively. In contrast, SRP loads showed little difference between asphalt and desert surfaces. Nutrient fluxes in runoff from a storm which occurred shortly after the experiments, were used to estimate input-output budgets for 3 of the lots under study. Measured outputs of DOC and SRP were similar to those predicted using rainfall and experimentally determined surface loadings, but for NH_4-N and particularly for NO_3-N, estimated rainfall inputs and surface runoff were significantly higher than exports in runoff. This suggests that parking lots may be are important sites for nutrient accumulation and temporary storage in arid urban catchments (Hope et al. in review). The pilot trace-gas study showed that 1) significant quantities of NO_2 are present in the urban atmosphere, interfering with usual methods for measuring NO flux, but the NO_2 is rapidly consumed; 2) NOx fluxes from soils are very small in remnant desert, but larger in mesic and xeric residential patches; 3) NOx fluxes increase in response to fertilization; and 4) NOx fluxes dramatically increase in response to water addition, but only for unwatered desert remnant patches.

The atmospheric deposition research indicates 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. Results from this project have been included in a review manuscript being prepared by a group of some 16 researchers from across the western US, headed by Mark Fenn of the USDA Forest Service. CAP researchers S. Grossman-Clarke and D. Hope are co-authors on this paper, which is currently in the final stages of preparation for submission to *BioScience*.

Geomorphology and Disturbance

Wentz et al. (2001) used Landsat MSS, TM, and Enhanced Thematic Mapper Plus (ETM+) data to build a brushfire chronology in the northeast Phoenix metro region using variations in soil reflectance, vegetation abundance, and visible to near infrared albedo associated with known fire scars. The results of this pilot study indicated that fire scar regions were easily detectable using surface albedo and simple reflectance band combinations. Positive correlation between fire scar age and woody vegetation abundance was also observed. Future research (dependant upon funding) includes investigation of grass species abundance in the fire scar regions, characterization of surface soil chemistry in fire scars of different age and soil type, and use of higher spatial and spectral resolution MODIS/ASTER Simulator (MASTER) data to perform remote mineralogical analysis of fire scar soils.

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IV. 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, 15 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 analysis, and presentation techniques.

Both 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 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 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, and an NSF GK12 Research Fellowship grant supports several additional graduate students associated with the CAP LTER.

CAP LTER faculty members, postdoctoral associates, and senior graduate students have mentored 14 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, collections and curation activities, and courses that relate to the CAP LTER. Faculty members in geography, geological sciences, biology, and civil and environmental engineering have delivered additional training through graduate courses designed around CAP LTER activities. This year 11 graduate students in a two-semester course in sociology, Survey Research Practicum, participated in enumerating households for sample selection, recruiting respondents, cleaning and editing survey data. In the second semester, with faculty advisors from the CAP LTER PASS research team, 4 students wrote research papers using the survey data; topics included perceptions of the environment, environmental activism and neighborhood attachment. They presented their work at a student colloquium on May 1, 2002. Eleven other graduate students have participated in some aspect of the parks project through interdisciplinary IGERT workshops. In many instances graduate students are full colleagues in the research activities, taking part in the framing, analysis, interpretation, presentation, and writing of results. For example, biology grad J. Edmonds is currently lead author on a manuscript in preparation on spatial and temporal variations in surface water quality at CAP LTER. CAP LTER activities are also being integrated into undergraduate education. Four undergraduates have conducted research projects in or around park research that include: (1) analyzing the distribution of vacant lots; (2) quantifying deposition with throughfall measurements; (3) assessing the value of the park to neighborhood residents (through a mail-out survey); and (4) conducting surveys of park use.

Monthly All Scientists Council meetings provide opportunities for cross-disciplinary fertilization and information exchange through science- and results-based presentations. Attendance ranges from 40-80 people per meeting and includes faculty members, postdoctoral associates, graduate students, and community partners. Remote Sensing Working Group meetings are held to foster collaboration between 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 cross-fertilization.

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 participated in lab and field research activities and presented their findings to their classmates in poster format.

Theses and Dissertations

In Progress

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

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

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).

Goettl, A. C. What limits primary production in Indian Bend Wash? (M.S., Biology, N. B. Grimm).

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

Jenerette, G. D. Scale dependence of terrestrial nitrogen storage (Ph.D., Biology, J. Wu and N.B. Grimm).

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).

Sicotte, D. Political and legal controversies in central Arizona communities facing possible contamination with hazardous industrial waste (Ph.D., Sociology, E. J. Hackett).

Stabler, L. B. Landscaping practices and urban plants: Effects on microclimate, CO_2 sequestration, and water cycling. (Ph.D., Plant Biology, C. A. Martin).

Stiles, A. Influence of urbanization on vascular plant species diversity within desert remnant patches (Ph.D., Plant Biology, S. Scheiner).

Tavassoli, F. The history of the watercourse master planning process in Maricopa County. (M.E.P., Planning and Landscape Architecture, Musacchio).

Whitcomb, S. A. Belowground spatial patterns and dispersal of arbuscular mycorrhizal fungi in an arid urban environment. (M.S., Plant Biology, J. C. Stutz)

Xu, Y. A spatial model of N cycling within the Phoenix metropolitan ecosystem (Ph.D.,Civil and Environmental Engineering, P. Johnson and L. Baker).

Completed

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Hedquist, B. 2002. Spatio_temporal variation in the Phoenix East Valley urban heat island. (M.S., Geography, A. Brazel).

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Smith, C. S. 2001. Modeling opportunity: Employment accessibility and the economic performance of metropolitan Phoenix neighborhoods (M.E.P., School of Planning, S. Guhathakurta).

Stefanov, W. L. 2000. Investigation of hillslope processes and land cover change using remote sensing and laboratory spectroscopy (Ph.D., Geology, Christensen).
Walters, G. M. 2001. Sonoran Desert seedbanks: Spatio-temporal variation of ephemeral plants and urban recreational impacts (M.S., Plant Biology, Landrum and Patten).
Zschau, T. 1999. Effects of a copper smelter on desert vegetation: A retrospective after 26 years (M.S., Plant Biology, T. H. Nash).

V. EDUCATION AND OUTREACH

Environmental education and outreach activities are woven throughout CAP LTER. 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 the start of the CAP LTER 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. For the past two years ASU's Vice Provost for Research has sponsored a project (Greater Phoenix 2100) that was conceived to serve this purpose. We have developed several important ideas for establishing these linkages and held a workshop and public meeting in April to get the ball rolling. As of now we see the four essential elements of this to be 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, and a version in book form called the Greater Phoenix Regional Atlas are underway, with publication expected at the end of the year.

Monthly All Scientists Council meetings provide opportunities for cross-disciplinary fertilization and information exchange through science- and results-based presentations. Attendance ranges from 40-80 people per meeting and includes faculty members, postdoctoral associates, graduate students, and community partners. Monthly Remote Sensing Working Group meetings are held to foster collaboration between CAP LTER scientists doing research involving remote sensing via discussion of ongoing and planned work, proposal generation, and workshops. Lastly, graduate students meet monthly at research-focused gatherings designed to facilitate interdisciplinary cross-fertilization.

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 participated in lab and field research activities and presented 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 77 teachers at 54 public schools (encompassing 22 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 and biogeochemical cycles.

This past year we have developed two new day-long workshops based on teacher requests. The topics covered in the new workshops were: 1) birds in the classroom; 2) social sciences: surveys and more. We also continued to offer day-long workshops on mapping and insects in the classroom. A total of 27 teachers participated in these workshops. The teacher evaluations suggested that these workshops addressed their needs and were beneficial.

This summer's program will include 16 new teachers, 5 of which are from school districts new to our program. This summer's program will engage 10 CAP LTER personnel as well as others from ASU and the Phoenix Zoo. This summer we will be offering 2 two-week internships that allow the teachers to participate in a research project and learn how to collect and analyze data. The teachers will also be 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. In addition, the teachers are participating in an Ecology Explorers program evaluation developed in conjunction with the ASU's Center for Research on Education in Science, Mathematics, Engineering and Technology.

We have added several new features this year to our Web site (http://caplter.asu.edu/explorers). We have a new animation to simulate the ground arthropod protocol. We worked with the CAP LTER data managers to develop easier to use data entry pages. We tested several new bird identification games with our teacher interns and hope to have them available on the web site this fall.

Through informal discussions with teachers, they have reported that they 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 AZ State Education Standards, including science, math, writing, social science and technology standards.

This year we developed and conducted a workshop for science teachers in the Gilbert 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. Charlene Saltz is a member of the board of the Arizona Association for Environmental Educators. Wendy Marussich, a Biology graduate student, has been involved with the Ecology Explorers program for several years. She has used this project to teach K-12 science teachers about the importance of replicated, randomized experimental designs and also to instruct them in basic arthropod sweep netting techniques. She has also been interviewed about this project by an undergraduate student in conjunction with the Ecology Explorers program and is featured on their "Meet the Scientist" website (http://caplter.asu.edu/explorers/about/meetscientist.htm). Two of the fellows associated with ASU's GK-12 grant developed Ecology Explorer 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. A list of teaching aids that have been developed are included in the products section of this annual report.

This year we have contributed to cross-site LTER activities by being active participants in the LTER education. Monica Elser is a member of the executive committee of LTER education committee. We continue to share ideas and support other Schoolyard LTER programs.

Community Partners

The most active of our federal partners has been the *USGS*, 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 *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 (*Department of Water Resources*) and the atmospheric deposition study (*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.

Maricopa Association of Governments, 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 in projects involving storm hydrology and storm-water chemistry.

Motorola has been instrumental in helping us engage the K-12 community and beyond by: 1) funding an environmental education coordinator; 2) designing logos, exhibit displays, bookmarks, and other materials for Ecology Explorers; 3) working with project staff to design and produce our newsletter and brochures; and 4) contributing computers, as well as design, production, and printing costs of the newsletters and brochures. *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.

Dissemination of Research Projects and Results

Since 1997, CAP LTER participants have presented over 150 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.

Presentations at Regional, National, and International Conferences

2002

Applegarth, M., and W. Stefanov. 2002. Use of Thermal Infrared Multispectral Scanner (TIMS) imagery to interpret particle size on desert hillslopes. *American Association of Geographers Annual Meeting Abstracts*.

Baker, L., and W. Stefanov. 2002. Information engineering: a new paradigm for environmental management in the 21st century. Presented (invited) at 17_19 April 2002, *Minnesota Water Conference*, St. Cloud, MN.

Elser, M., and C. Saltz. 2002. Linking scientists, teachers and children in scientific research. Presented at March 2002, *Microcomputers in Education Conference*, Arizona State University, Tempe.

Gade, K. J., W. Bigler, T. Collins, E. Ng, J. Parker, and L. Stabler. 2002. From horse-drawn streetcars to light rail: Exploring social and ecological roles at Eastlake Park. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Grimm, N. B., J. D. Schade, J. R. Welter, D. B. Lewis, and E. Marti. 2002. Nitrogen retention in arid_land stream and riparian zones. Presented at June 2002, *Special Session, Physical Forcing and Pelagic_Benthic Interactions in Aquatic Systems*, Annual meeting, American Society of Limnology and Oceanography, Victoria, BC.

Kinzig, A. P., P. Warren, J. M. Grove, C. Martin, D. Hope, and C. Redman. 2002. Biodiversity in modern urban habitats. Presented at 16 February 2002, *American Association for the Advancement of Science Annual Meeting*, Boston, MA.

Koerner, B. A., and J. M. Klopatek. 2002. Seasonal responses of soils to water and nitrogen along an urban to rural gradient. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Krasney, M., and M. Elser. 2002. Developing students' research and data manipulation skills. Presented at March 2002, *National Science Teachers Association Conference*, San Diego, CA.

Lewis, D. B., and N. B. Grimm. 2002. Nutrient and metal loads exported from hydrologic catchments by storm runoff. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

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. *Proceedings of the 12th METRIA Conference,* Asheville, NC.

Musacchio, L., and J. Wu. 2002. Cities of resilience: Integrating ecology into urban planning, design, policy, and management. Workshop, presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Musacchio, L., and J. Wu. 2002. Cities of resilience: Four themes of the symposium. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Perry, D. L., J. R. Anderson, and P. R. Buseck. 2002. Analysis of atmospheric particles deposited onto mesquite leaves in the Central Arizona – Phoenix LTER area. Presented at 20-24 May 2002, *Fourth Symposium on the Urban Environment,* American Meteorological Society, Norfolk, VA.

Redman, C. L., and N. B. Grimm. 2002. The urban ecology of central Arizona_Phoenix. Presented at August 2002, Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Schaafsma, H., and J. M. Briggs. 2002. Agricultural perturbations and the herbaceous legacy of the prehistoric Hohokam people in Arizona. Poster presented at the 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America,* Tucson, AZ.

Shochat, E., and M. Katti. 2002. Differences in bird foraging behavior between Sonoran Desert and urban habitats in central Arizona. Presented at August 2002 *XXIII International Ornithological Congress*, Beijing, China.

Stabler, L. B., and C. A. Martin. 2002. Irrigation and pruning affect growth and water use efficiency of two common landscape shrubs. Poster presented at 15 February 2002, *Graduates in Earth and Life Sciences Poster Symposium*, Arizona State University, Tempe.

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.

Stefanov, W. L. 2002. The ASTER Urban Environmental Monitoring Project: Progress Update. Presented at 21-23 May 2002, *22nd ASTER Science Team Meeting*, Tokyo, Japan.

Stefanov, W. L. 2002. Ecological remote sensing at the CAP LTER site. Presented at 5-7 August 2002, *Arizona Geographic Information Council Annual Meeting*, Mesa, AZ.

Stiles, A., and S. Scheiner. 2002. Using remote sensing to generate a map of desert plant community distribution for the CAP_LTER, Phoenix, Arizona. Poster presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Warren, P. S., A. P. Kinzig, and C. A. Martin. 2002. Ecological characteristics of urban parks show different human imprints. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Whitcomb, S., C. A. Martin, and J.C. Stutz. 2002. Spatial patterns of soil respiration, temperature, and moisture in an experimental urban landscaped site. Poster presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Whitcomb, S., and J.C. Stutz. 2002. Small_scale spatial patterns of arbuscular mycorrhizal fungal diversity in an experimental urban landscaped site. *Inoculum* 53(3):59.

2001

Baker, L. 2001. An ecosystem_level approach for engineering the biogeochemical cycles of cities and farms. Keynote Talk, presented at 6-7 October 2001, Midwest Water Chemistry Conference.

Baker, L.A., D. Hope, Y. Xu, and J. Edmonds. 2001. Multicomparment ecosystem nitrogen balances as a tool to understand and manage biogeochemical cycles in human ecosystems. Presented at 14_18 October 2001, *The Science World*, Proceedings of the Second International Nitrogen Conference (N2001), Potomac, MD.

Baker, L.A., Y. Xu, and N. McPherson. 2001. Salinity __ an emerging issue for the Phoenix Metropolitan Area. Presented at 4_5 May 2001, Arizona Water Pollution Control Assoc. Conference, Mesa, AZ.

Bolin, R., A. Nelson, S. Smith, E. Hackett, D. Pijawka, E. Sadalla, M. O'Donnell, S. Grineski, T. Collins, and D. Sicotte. 2001. Environmental equity in Phoenix, Arizona: The spatial distributions of hazardous facilities and vulnerable populations. Presented at 29-31 October 2001, *Annual Federal State Toxicology and Risk Analysis Committee Meetings*, Phoenix, AZ.

Cousins, J.R., S. A. Whitcomb, and J.C. Stutz. 2001. Arbuscular mycorrhizal fungal species composition, richness and abundance in the Phoenix metropolitan area. *Phytopathology* 91: S107.

Grimm, N. B. 2001. Nitrogen retention in arid_land stream and riparian zones. Guest speaker at September 2001, *First Annual Conference, Global Nitrogen Enrichment Program*. University of Wales, Bangor, Wales.

Keller, G. R., R. Arrowsmith, M. Fouch, A. Gates, N. Hicks, V. Kreinovich, K. Mickus, S. Reynolds, S. Richard, and W. Stefanov. 2001. The southern Colorado Plateau and adjacent Basin and Range Province: A testbed for geoinformatics and data integration. *Geological Society of America Abstracts with Programs, Annual Meeting, Abstract 72_65.*

Saltz, C., and M. Elser. 2001. Scientists as partners. Presented at September 2001, *Arizona Association for Environmental Education Conference*, Phoenix, AZ.

Sprott, P. L, .K. S.Baker, M. E. Krasny, M. M. Elser and R. E.Bohanan. 2001. Long term ecological research network K_12 education partnership: Students and teachers experiencing LTER. Presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI.

Stefanov, W. L., and M. T. Applegarth. 2001. Geomorphic analysis of semiarid landforms using mid_infrared spectroscopy and remote sensing. *American Geophysical Union EOS Transactions* 82(47):Abstract H42D_0393

Stefanov, W. L., and P. R. Christensen. 2001. Classification of global urban centers using ASTER data: Preliminary results from the Urban Environmental Monitoring Program. *American Geophysical Union EOS Transactions* 82(20):10-11.

Westerhoff, P., D. Bruce, M. L. Nguyen, M. Sommerfeld, T. Dempster, Q. Hu, L. Lowry, and L. Baker. 2001. Production sources of algal metabolites (MIB and geosmin) in Arizona reservoirs, rivers, and canals. Presented at June 2001, *AWWA Conference*, Washington, DC.

Whitcomb, S. A., and J. C. Stutz. 2001. Effects of pruning on root length density, root biomass, and arbuscular mycorrhizal colonization in two landscape shrubs. *Proceeding 3rd International Conference on Mycorrhizas*, Abstract 1_157.

LTER Symposia and Conferences

2002

***CAP LTER Fourth Annual Poster Symposium*, January 17, 2002, Center for Environmental Studies, Arizona State University.**

Anderson, J., G. Moore, R. Rodriguez, and H. Xin. 2002. Inorganic aerosol generation from freeways in the greater Phoenix area.

Berling-Wolff, S., and J. Wu. 2002. Landscape structure of the Phoenix metropolitan region: Evaluation of an urban growth model.

Bigler, W. 2002. Reconstructing prehistoric streamflow in the Salt River: An error analysis.

Bolin, B., A. Brazel, T. Collins, S. Grineski, E. Hackett, and M. O'Donnell. 2002. Community-based research: Environmental conditions, human health and the quality of life.

Brazel, A., and N. Selover. 2002. The evening transition in Phoenix.

Celestian, S. B., and C. A. Martin. 2002. Effects of commercial parking lots on size of landscape trees.

Cousins, J., S. A. Whitcomb, and J. C. Stutz. 2002. Arbuscular mycorrhizal fungal species composition, richness, and abundance in the Phoenix metropolitan area.

Doan, S., G. Buegge, J. J. Buegge, E. Gilbert, and L. R. Landrum. 2002. The Arizona State University Herbarium Vascular Plant Image Library online.

Elser, M., and C. Saltz. 2002. Ecology Explorers: Program components.

Esparza, M., Q. Hu, P.Westerhoff, M. Sommerfeld, L. Baker, T. Dempster, M. Rodriguez, S. Dawson, K. Hintze, M. Cummings, and M. Masles. 2002. Occurrence and treatment of algae-related taste and odor metabolites in Arizona reservoirs and urban canals.

Gilbert, E., J. Buegge, P. McCartney, C. Gries, and L. Landrum. 2002. Virtual floras.

Gries, C., P. McCartney, R. Schoeninger, and A. Sundermier. 2002. EML: Submission and discovery of ecological metadata.

Grossman-Clarke, S., D. Hope, P. Hyde, W. Stefanov, H. S. Fernando, and N. B. Grimm. 2002. Assessment of temporal and spatial characteristics of nitrogen dry deposition in the Phoenix metropolitan area.

Hall, S. J., N. B. Grimm, S. L. Collins, K. Gade, D. Hope, G. D. Jenerette, A. Kinzig, J. D. Schade, R. Sponseller, J. R. Welter, W. Wu, T. Johns, M. Luck, R. Erickson, and C. Kochert. 2002. Nox emissions and uptake by urban soils.

Harner, J., M. Kuby, and P. Gober. 2002. Hands-on learning about urban sprawl.

Hedquist, B., and A. Brazel. 2002. The use of GIS and visualization tools to interpret microclimate change along the Phoenix East Valley urban fringe.

Hope, D., C. Gries, S. Carroll, W. Zhu, W. F. Fagan, C. L. Redman, N. B. Grimm, A. Nelson, A. Kinzig, and C. Martin. 2002. Humans structure the ecosystem properties of cities: Findings from the '200 survey.'

Hu, Q., M. Sommerfeld, T. Dempster, P. Westerhoff, L. Baker,and M._L. Nguyen. 2002. Influence of growth conditions on production and release of the taste and odor compound geosmin by a cyanobacterium isolated from the Phoenix water supply system.

Ivanich, P. A., J. A. Tyburczy, and J R. Arrowsmith. 2002. Measuring bedrock topography using gravity to understand subsidence along a portion of the CAP canal in northeast Scottsdale.

Jenerette, D., S. Goldsmith, W. Marussich, J. Roach, and W. Wu. 2002. Contrasting socio-ecological relationships between China and the United States: Water footprints for cities in two distinct cultures.

Jenerette, G. D., and J. Wu. 2002. Modeling fine scale spatial heterogeneity of carbon and nitrogen dynamics in the Central Arizona Phoenix region.

Katti, M., E. Shochat, D. Stuart, J. Lemmer, and B. Rambo. 2002. Environmental and socioeconomic influences on the Phoenix avifauna.

Lewis, D., W. Wu, and N. Grimm. 2002. Material transport in storm runoff from urban catchments.

Lopez, S., M. Zoldak, C. S. Smith, J. Fry, and C. Redman. 2002. Land use trajectories.

Marussich, W. A., and S. H. Faeth. 2002. Trophic dynamics of urban and desert ecosystems: Arthropod communities on brittlebush (*Encelia farinosa*).
Nelson, A., B. Bolin, E. Hackett, S. Smith, and S. Grineski. 2002. Sunbelt toxics: Industrial polluters in Phoenix, Arizona.
Nelson, A., B. Bolin, S. Smith, M. O'Donnell, and E. Hackett. 2002. The development of environmental injustices in Phoenix, Arizona.
Nelson, A., S. Harlan, D. Sicotte, and F. Yang. 2002. Labor market dynamics in a postindustrial city: A spatial and sectoral analysis of employment changes in the Phoenix MSA.
Peccia, J., A. M. Dillner, and J. Borenson. 2002. Correlating bioaerosols with PM2.5 and PM10 concentrations.
Perry, D., J. Anderson, and P. Buseck. 2002. Analysis of atmospheric particles deposited onto mesquite leaves in the Central Arizona - Phoenix LTER area.
Quay, R. 2002. Greater Phoenix 2100 Regional Atlas.
Roach, W. J., and N. B. Grimm. 2002. Contrasting diel patterns of water chemistry from three lakes in Indian Bend Wash.
Shochat, E., S. Lerman, C. Putnam, and M. Katti. 2002. Differences in bird foraging behaviour between Sonoran Desert and urban habitats: A field experiment with seed trays.
Shochat, E., S. Faeth, W. Fagan, M. Tseng, J. Rambo, and R. Cassalata. 2002. Seventy-eight years of ground-arthropod sampling in the greater Phoenix area: Results from the first three years.
Sicotte, D. 2002. A hazardous undertaking: The social construction of environmental contamination claims.
Stabler, L. B., and C. A. Martin. 2002. Irrigation volume and pruning frequency affect water use efficiency of two Southwest landscape shrubs.
Stiles, A., and S. Scheiner. 2002. Preliminary classification of desert plant communities using Landsat Thematic Mapper (TM) data.
Stuart, G.. 2002. Effects of urbanization on pollen frequency distribution patterns in the Phoenix metropolitan area.
Swanson, S.. 2002. Time, space, and stability: Investigating landscape responses to climate variability in the Southwest.
Tomalty, R., and A. Brazel. 2002. Local variability of solar reception in CAP LTER.
Warren, P. S., and A. P. Kinzig. 2002. Neighborhood socioeconomic status predicts ecological characteristics of small urban parks.
Wentz, E., S. Anderson, W. Stefanov, and J. Briggs. 2002. Desert fire history and effects on the Phoenix, Arizona, metropolitan area.
Whitcomb, S., and J. C. Stutz. 2002. Pruning effects on root length density, root biomass, and arbuscular mycorrhizal colonization in two shrubs in a simulated xeric landscaped yard.
Wu, W., J. Wu, D. Stuart, and J. Harris. 2002. Spatial patterns of impervious surface cover in the Cave Creek watershed, Phoenix metropolitan area.
Zoldak, M., S. Lopez, C. S. Smith, J. Fry, and C. Redman. 2002. Experimental use of Unsupervised Classification Method for examining spatio-temporal landuse patterns.

***The Linkage between Land and Water - From the Atmosphere to the Coastal Zone,* April 2002, US LTER Coordinating Committee Science Symposium, University of New Mexico/Sevilleta LTER, Socorro, NM**

Lewis, D. B., N. B. Grimm, L A. Baker, J. W. Edmonds, D. Hope, W. J. Roach, and W. Zhu. 2002. Effects of human modification of hydrology and nutrient balance on biogeochemical pattern and process in urban landscapes.

Community Outreach Presentations and Miscellaneous Activities

2002

Dillner, Ann. 2002. Presentation to Homedale community about CAP LTER air quality research.

Stefanov, W. L. 2002. Remote sensing of urban ecology at the Central Arizona_Phoenix Long Term Ecological Research site. *Arid Lands Newsletter* 51 (http://ag.arizona.edu/GALS/ALN/aln51/stefanov.html)

Stutz, J. 2002. Diversity and functioning of arbuscular mycorrhizal fungi in urban ecosystems. Invited Seminar Speaker, Columbia University/Biosphere 2, April 12, 2002.

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

2002

Anonymous. 2002. City birds prefer rich neighbors. Science News (http://www3.cosmiverse.com/news/science/0802/science08090206.html)

Anonymous. 2002. Birds enjoy high life. Yahoo! News (http://uk.news.yahoo.com/020812/12/d776z.html)

Brainard, J. 2002. ASU joins national trend of interdisciplinary research. *ASU Insight* June 28, 2002:1, 6.

CBC News Online Staff. 2002. Bird snobs turn their beaks up at poorer neighbourhoods. CBC.CA News online(http://www.cbc.ca/stories/2002/08/14/birds_elitist020814)

Grants Awarded and Pending

2002

"Agrarian Landscapes in Transition: A Cross-Scale Approach" ($1,792,440). NSF/Biocomplexity, 2002-2005. C. Redman (PI/PD, CAP LTER), A. Kinzig (CAP LTER), D. Foster (HFR LTER), M. Gutmann (SGS LTER), P. Kareiva (TNC)

"Neighborhood Ecosystems: Human-Climate Interactions in a Desert Metropolis" ($86,999). National Science Foundation, 2002-2003. S. Harlan (PI); T. Brazel, L. Larson, W. Stefanov (Co-PIs).

"Creation of a Geospatial Data System for the Transition Zone Between the Colorado Plateau and Basin & Range Provinces" ($202,122). National Science Foundation, 2001_2004. J. R. Arrowsmith (PI); M. Fouch, G. R. Keller, S. Reynolds, W. Stefanov (Co_Is).

"Enabling the Science Environment for Ecological Knowledge". P. McCartney, subcontract to Network office on the ITER proposal.

"Networking Urban Ecological Models through Distributed Services". ($491,697) P. McCartney, R. Quay, C. Gries and C. Redman. NSF/ITR.

"Testing Ecological Theory in Human_Dominated Systems." Submitted to National Science Foundation July 2002. app. $600,000. Kinzig (PI), Chris Martin, Kevin McHugh, and Paige Warren (co_PIs). *Pending*

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

2001

"Reconstruction of fire history patterns in the Sonoran Desert around the greater Phoenix area," ($19,000), Arizona State University College of Liberal Arts and Sciences. E. Wentz (PI), J. Briggs and W. Stefanov (Co-PIs).2002

"Spatial and Temporal Aspects of Resilience in Urban Systems," James S. McDonnell Foundation. A. Kinzig and C. Redman, PIs ($448,442)

VI. 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 the realm of biology, botany, and zoology are 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 bio-indicators for different land-use types; unlike vertebrates or flying insects, the environment influences ground arthropods at very small spatial scales. The plant community project will provide one of the first large-scale studies of urbanization and habitat fragmentation on plant community structure, especially in a desert biome. This project will test 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 prior to 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.

Contributions to Other Disciplines

The Geological Remote Sensing Laboratory (GRSL) has produced research and data products that are 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 UEM 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) is conducted by a team of researchers from the fields of sociology, planning, economics, and biology. This interdisciplinary study will contribute 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 will help 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 metropolitan regions, and influenced by values, use, and management—has received much less attention. And yet it is urban ecological systems that describe the majority of human ecological experience, for the majority of 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.

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-12teachers, 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. 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 ASC meetings, and are designing 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

CAP LTER's university setting 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 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 U.S. As such, it represents a rich data source for faculty members and graduate students to mine. 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. The work of the environmental risk team to date contributes to research and education by developing new data bases for analyzing urban risk and by developing new analytic techniques and strategies to advance environmental equity research.

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 into 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 plant community survey will provide information needed for planning urban growth, especially in sensitive ecosystems. 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. The modeling project is also crucial for integrating and synthesizing pieces of information obtained from individual projects. Historic land-use data contributes to studies in planning, population studies, and cultural geography. The environmental risk research has practical applications for community groups and city agencies concerned with environmental safety and health.

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.

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.

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. CAP LTER 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 Annual Report 2002 - Appendix A
Participants 1997-2002

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, Ctr for Urban Inq	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 Sciences	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 Sciences	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, ASUW	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

Suzanne Grossman-Clarke, Mech/Aero Eng /CES	2000-present
Mark Hostetler, CES/Biology	1997-1999
Madhusudan V Katti, CES/Biology	2000-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
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
Laural Casler, Life Sciences Vis Lab	2000-present
Ken Fossum, USGS	1998-present
Steve Getty, University of NM	1998-1999
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&En. Eng	2001-present
Robert Minckley, Auburn University	1999-2000
Fred Rainey, Louisiana State Univ	1999-present
Nancy Selover, ASU Geography	2001-present
Conrad Storad, ASU Research Pubs	1997-present
Maurice Tatlow, Geography	1999-2000

Research Technical Personnel

Michael Baker, P/T Aide/Birder, CES	1998-2000
Damon Bradbury, Tech, CES	1998-1999
Amalya Budet de Jesus, Asst, CES	2000-2000
John Buegge, Acad Assoc	2001
Adam Burdick, Biology	1998-1999
Michael Clary, Tech, CES	2000-2001
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-present
Tracy Flores Johns, Tech, CES	2000-present
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 Res Spec, CES	2000-2001
Alejandria Mejia, Plant Bio/Herbrm	1998-2000
Michael Myers, Research Spec, CES	1998-2000
Theodore Oliver, 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-present
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, Datbse Spec, CES	1999-2000
Melissa Rossow, Plant Bio/Herbrm	1999-1999
C. Scott Smith, IT GIS Lab	1998-2002
Diana Stuart, Res. Aide, CES	1999-present
Maggie Tseng, Res Spec, Bio/CES	1997-present
JoAnne Valdenegro, Res Spec, Soc	2000-2001
Jaqueline Walters, Res Spec, CES	1997-2000

Public Outreach Personnel

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

Other Grads

Jeremy Buegge, Plant Bio, Eco Exp	1999	Nancy Jones, Plng/Lnds Arch	2000-present
Jenny Draevich, Biology, Eco Exp	1998	Elena Ortiz-Barney, Plant Bio, Eco Exp	2000
John Frich, Biology, Eco Exp	1998	Charlie Wilson, Biology, Eco Exp	2001-2002
April Henry, GK-12	2002	Jian Ye, Sociology	Summer 2002

Research Experience for Undergrads (REU)

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

Other Undergrads

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

High School Students

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

Pre-College Teachers

Robert Atwood, Meyer Elem	1999-2002
Renee Bachman, W.T. Machan Elem	1999-2002
Joyce Baldwin, Sacaton MS	1998-2002
Jim Barnette, Zedo Ishikawa Elem	1999-2002
Paula Beacom, Lowell Elem	1999-2002
Chuck Bell, Deer Valley HS	1999-2002
Wendy Blasdell, Mountain View HS	1999-2002
Dave Boomgaard, Brimhall Jr. HS	1998-2002
Carole Boling, W.T. Machan Elem	1999-2002
Scott Bowling, Discovery Elem	1998-2001
Karen Braccio, Desert Canyon Elem	2000-2002
Michael Brand, Oasis Elem	2002
Amy Braun, Stevenson Elem	2001-2002
Linda Calderon, Desert Harbor Elem	2000-2002
Sharlene Cardona, Falcon Hill Elem	1999-2002
Tracy Carlson, Holmes Elem	2000-2002
Dave Carpentar, Meyer Elem	1999-2002
Jon Ciulei, Trevor Browne HS	2000-2001
Darlene Cull, Stevenson Elem	2001-2002
Brian Clark, NFL-YET Prep Acad	2000-2002
Meg Davis, McKemy MS	1998-2002
Joelle Don de Ville, St. Mary's HS	1998-2000
Jennifer Donovan, Washington HS	2002
Gary Dotterer, MacArthur Elem	2002
Ed Eberle, Dobson HS	1998-1999
Vickie Eberle, Sunridge Learning Ctr	1998-1999
Ann English, Desert Eagle HS	1999-2002
Michelle Fink, Meyer Elem	1998-2002
Ann Flagg, EDU Prize	1999-2002
Margaret Fons, Sirrine Elem	2000-2002
Susan Fountain, Kyrene Altadena El	2002
Gerry Foster, Mesquite HS	1999-2000
Adam Galen, Finley Farms Elem	2002
Scott Greenhalgh, Tempe Union HS	1999-2002
Wendy Hansen, Jefferson Elem	2000-2002
Bette Hanscom, McKemy MS	2000-2002
Lance Harrold, Mobile Elem	2002
Irene Hawkins, Tempe Preparatory	2000-2002
Jack Helton, Desert Harbor Elem	2002
Janet Henderson, Deer Valley MS	1999-2002
Erin Hilligoss, Squaw Peak Elem	2000-2002
Heather Holmes, Desert Harbor Elem	1999-2000
Susie Huffaker, Meyer Elem	1999-2002
Linda Idol, Westpoint Elem	2002
Tad Int-Hout, Desert Harbor Elem	1999-2001
Sara Jenkins, Lattie Coor Elem	2002
Sue Johnson, The Family School	1999-2002
John Jung, Mesa HS	2001-2002

Teresa Krause, Mendoza Elem	1998-2002
Larry Langstaff, Hendrix Jr. HS	1999-2002
Sharon Langston, Monte Vista Elem	1999, 2002
Karen Lee-Price, Moon Mntn School	2000, 2002
Gene Lescallete, Desert Mountain HS	2000-2002
Jim Little, Rhodes Jr. HS	2000
Brenda MacIntosh, Awakening Seed	2001-2002
Sharin Manes, Fountain Hills MS	2000-2002
James Mangles, Estrella Mtn Elem	2000-2002
Jim Manley, Stevenson Elem	1998-2002
Mary Martine, Kiva Elem	2000-2002
Vickie Massey, Mendoza Elem	1998-2002
Chris Mayer, Desert Harbor Elem	2002
D'Anne McDaniel, Fees MS	2000-2002
Stephanie Mihalic, Greenway MS	2000-2002
Misty Miles, Marc T. Atkinson MS	2002
Birgit Musheno, Desert Vista HS	1999-2002
Alfredo Ontiveros, Dept Defense HS	2002
Donna Palladino, Copper Canyn Elem	2000-2001
Gary Patterson, Skyline HS	1999-2002
Kathleen Pelley, Evans Elem	1998-2002
Trish Peters, Pueblo Elem	1999-2002
Jason Prichard, Willis Junior HS	2002
Kris Rademacher, Desert Vista HS	1998-2002
Nancy Ragle, McKemy MS	2000-2002
Lisa Randall, Stevenson Elem	1998-2002
Robin Renaud, Moon Valley HS	2000-2002
Linda Sargent, Mountain View HS	2000-2002
Darlene Sitzler, Eisenhower Elem	1998-2002
Tina Skjerping, Wm T. Machan Elem	2002
Mike Sliskovich, Supai MS	2000-2002
Jan Snyder, Camelback HS	2000-2002
Susan Soroka, McKemy MS	2000
Cara Steiner, Mendoza Elem	2000-2002
Joyce Sterret, Trevor Browne HS	1998-2000
C. J. Stevens, Mountain Pointe HS	2000-2002
Ryan Swartz, Moon Valley HS	2000-2002
Kerri Tornow, Awakening Seed Elem	2001-2002
Rob Trenck, Red Mountain HS	2000-2002
Toby Tucker, Fountain Hills HS	1998-1999
Paul Vachon, Royal Palm MS	2000-2002
Michelle Volk, Kyrene Aprende MS	1999-2001
John Wallace, Mountain View HS	1998-2000
Terri Wattawa, Santan K-8 Campus	2002
Pamela Whitaker, Thunder Mtn MS	2000-2002
Kimberly Wilson, Kyrene Pueblo MS	2000-2001
Susan Wiseman, Arthur M. Hamilton	2000-2002

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 Education 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 High School District
Desert Botanical Garden
Flood Control District of Maricopa County
Fountain Hills High School District
Gila River Community Schools
Gilbert High School 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 Elementary School District
Phoenix Union High School District
Phoenix Urban Systemic Initiative
Pueblo Grande Museum
Salt River Pima-Maricopa Indian Community
Salt River Project
Southwest Center for Education and Natural Environment
St. Mary's High School
Tempe Elementary School District
Tempe Union High School 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 High School District
Tonto National Forest
Town of Fountain Hills
US Forest Service
US Geological Survey
Valley Lutheran Hospital
Val Vista Lakes Community Association