CAP LTER 2000-2001
ANNUAL PROGRESS REPORT

Central Arizona – Phoenix LTER
Land-Use Change and Ecological Processes in an Urban Ecosystem of the Sonoran Desert
DEB-9714833

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CAP LTER 2001

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.

As we suggested in a recent article (Grimm et al. 2000), the rationale for the study of human-dominated systems is three-pronged. 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.

Today, urbanization is a dominant demographic trend and an important component of land-transformation processes worldwide. By 2007, it is estimated that a majority of the world's population will live in cities for the first time in human history (Population Reference Bureau 2001). Urbanization interacts with global change in important ways and plays a central role in alteration of global biogeochemical cycles, changes in biodiversity due to habitat fragmentation and exotic species, and changes in land use and cover far beyond the city's boundaries (Figure 1; Luck et al. in review).

The growing impact of urban areas is reason enough to study them. An even more compelling argument for understanding how cities work in an ecological sense is the fact that humans live in them and must depend on proper management to maintain an acceptable quality of life. To understand human actions and influences on ecosystems, it is essential to use approaches developed in the social, behavioral, and economic sciences. Acknowledging the central human component leads to an emphasis on new quantitative methods, new approaches to modeling, new ways to account for risk and value, the need to understand environmental justice, and the importance of working within a globally interacting network (Grossman 1993).

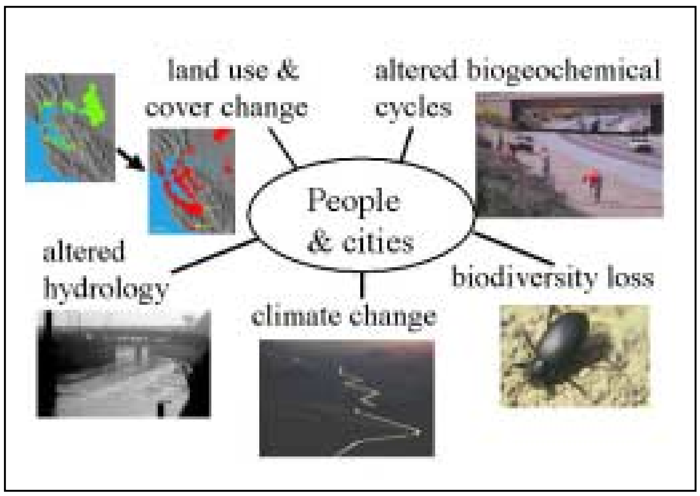

Figure 1. People and cities, by N. Grimm

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; Grimm et al. 2000; Collins et al. 2000; Redman et al. in review) that built upon our earlier (proposal) ideas. This Spring, we hosted a Site Visit Review Team and the LTER Executive Committee and Coordinating Council. In June 2001, The Center for Environmental Studies moved into newly renovated quarters, bringing most of our functions under one roof in 8,000 sq. feet.

Altogether for the first 4 project years, about 100 faculty members, 75 graduate students, 25 undergraduate students, 60 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 200 talks, papers, and posters to professional and community audiences and published over 45 journal articles, book chapters, and reports. Ecology Explorers, our education outreach program, now involves 46 teachers from 34 schools in 14 districts in its Schoolyard LTER efforts. In addition, over 20 community partners are substantively involved in the CAP LTER, such as Salt River Project, Maricopa Association of Governments, the United Stated Geological Survey, 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. Thirty-two grants totaling over $10M have involved CAP personnel as key participants or have built upon CAP resources, such as the University's new IGERT in urban ecology. 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, which this year focused on preparations for the All Scientists Meeting in Snowbird. Over 100 posters on CAP LTER studies have been presented at the 3 symposia, while 2 of the summer summits have focused on Human-Ecosystem Interactions and Inter-disciplinary Projects.

Table 1. Visitors Hosted by CAP LTER

Greg Asner	Colorado, NWT
Robert Costanza	UMD, BES
Peter Groffman	IES, BES
J. Morgan Grove*	USFS, BES
Peter Kareiva*	NOAA
T. A. Steward Pickett*	IES, BES (3 times)
John Magnuson	Wisconsin, NTL
Emilio Moran*	Indiana University
Fred Rainey	Louisiana
Michael Rosenzweig	Arizona
William Schlesinger	Duke, JOR
Participants in January	*2000 Human-Ecos Workshop*
Thomas Baerwald	NSF/BCS
William Burch	BES LTER
Steve Carpenter	NTL LTER
Terry Chapin	BCEF LTER
Ted Gragson	Coweeta LTER
Craig Harris	Kellog LTER
Peter Nowak	NTL LTER
Robert Waide	LTER Network
Sander van der Leeuw	Sorbonne
Grant Heiken	Los Alamos
Elinor Ostrom	Indiana University
Anthony de Souza	National Research Council
Thomas Wilbanks	Oak Ridge National Laboratory
Brent Yarnal	Penn State

*Also participated in January 2000 Workshop

CAP LTER scientists have been involved in cross-site and ILTER workshops and research, producing 9 publications based on cross-site activities. Workshops on human-ecosystem interaction hosted by ASU and the Baltimore Ecosystem Study (BES) culminated in a funded Biocomplexity incubation proposal. CAP LTER personnel participated in the NSF-sponsored workshop, "Nature and Society" (Kinzig 2000) and in organizing the International Association of Landscape Ecology annual meeting held at ASU in April 2001. We hosted close to 20 seminar speakers and other visitors from LTER sites and other interdisciplinary programs (Table 1). Finally, CAP LTER participants attended the August 2000 All Scientists’ Meeting en force, contributing 13 posters and participating in 8 workshops.

II. Highlights of Research Activities

Research Strategy

Our strategy for establishing the CAP LTER research program was to begin with many, 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 2 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 2-pronged: 1) Survey 200 - an extensive, expansive, multi-site (200 point) "snapshot" survey of ecological and social variables, conducted once 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).

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 almost overwhelming plethora of monitoring data in urban areas dictates a significant data-mining and synthesis effort for the foreseeable future. We also have continued to collect new data and develop models to be incorporated into the CAP hierarchical patch dynamics model (HDPM); leveraged funding (to CAP scientists J. Wu and D. Green) from the EPA to develop the model has strengthened this activity. This year, as a result of NSF review team recommendations, a Modeling Working Group was formed to advance our modeling activities. Ultimately, spatial analyses of the Survey 200 data coupled with modeling will provide the broad context into which we will place more detailed studies.

Major early efforts in development of a conceptual basis for urban ecosystem research saw fruition during Year 3. 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, including key questions and the thorny issues of dealing with humans, in all their complexity, as parts of ecosystems (rather than as external disturbances). This fundamental work has continued through the cross-site efforts of social and natural scientists to forge a new kind of research agenda for LTER sites (Redman 1999; 2000 Tempe workshop on social-natural science integration; ASM workshops in social-natural science integration; cross-site proposals; Biocomplexity incubation grant, and many others). Another initial project describing urban growth patterns evolved into key contributions from CAP scientists to a major study of the patterns and implications of rapid urban-suburban growth in Phoenix, conducted for the Brookings Institution by ASU's Morrison Institute for Public Policy. Specific efforts at defining cutting-edge research will be part of a series of four workshops sponsored by a Biocomplexity incubation grant to Redman that seeks to define new research relying on the integration of social and life sciences. This spring, CAP LTER researchers submitted two new proposals to the Biocomplexity competition. Although not funded, this activity has brought together key personnel to define important new research directions that we will work toward implementing**.**

Long-Term Monitoring

Geophysical Context and Patch Typology

Figure 2. Urban development adjacent to South Mountain Park.

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 to gain an adequate picture of patch structure and temporal change (Figure 2). We began by defining patch types according to land use, but have moved to a more sophisticated and realistic classification of land cover, thanks to the efforts of our remote sensing team. Most of the work has been carried out by ASU's Geological Remote Sensing Laboratory (GRSL).

The remote sensing team has produced data products that are currently being used for several ecological, biological, and geological research initiatives within the CAP LTER and have been reported previously. An example is presented in Figure 3.

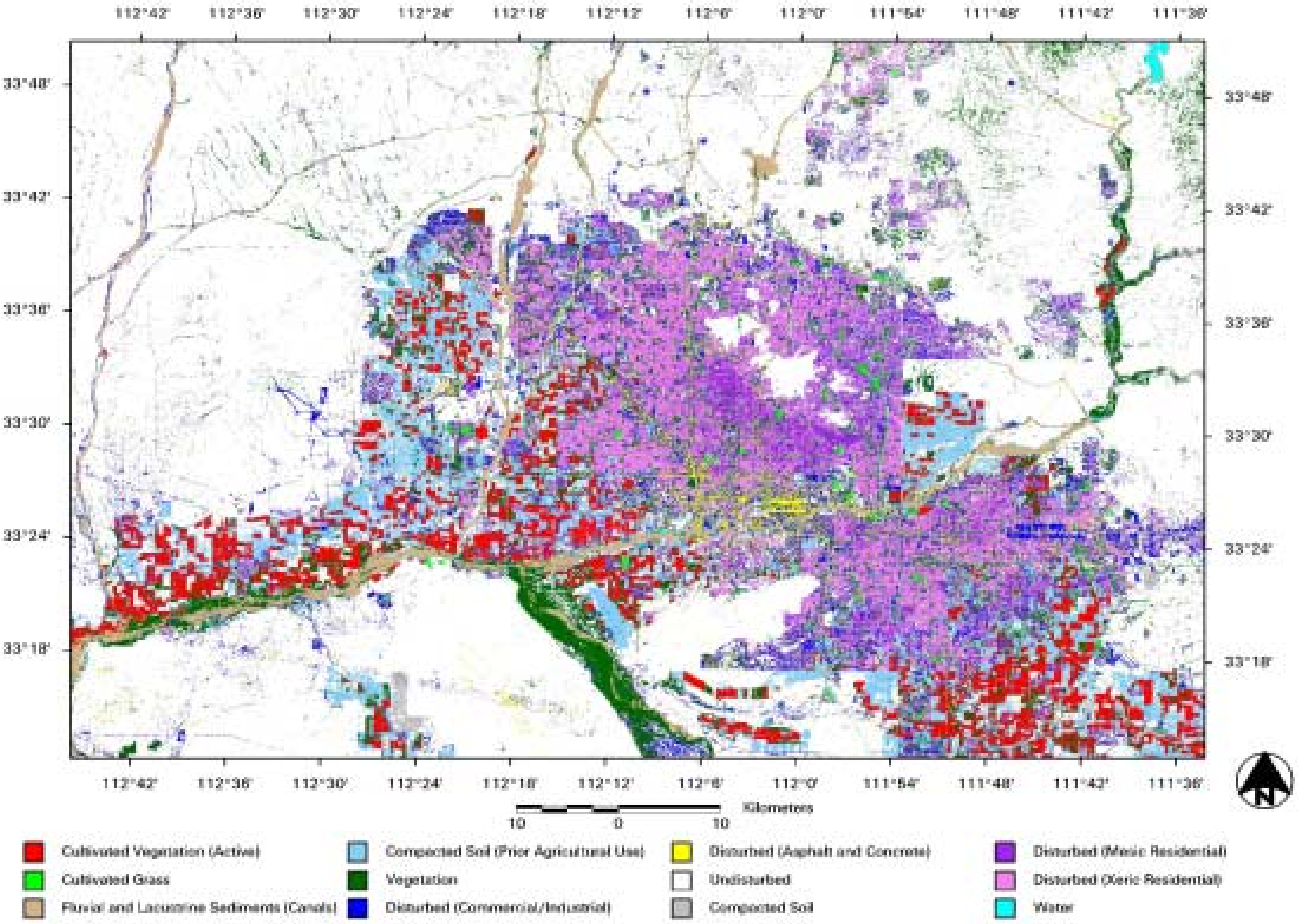

Figure 3. Land-cover classification for the Phoenix metropolitan area produced using Landsat Thematic Mapper data and an expert system.

The GRSL is also the seat of the ASTER Urban Environmental Monitoring (UEM) program (http://elwood.la.asu.edu/grsl/UEM/). 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. The UEM program will collect ASTER data over 100 global arid urban centers (including Phoenix AZ and Baltimore MD) twice per year (day/night) over the projected 6-year life of the satellite. 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. See "Research Findings" for an initial comparison of global city structure.

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

Figure 4. Collecting Survey 200 data at a residential site.

The goal of this project is to quantify basic ecological characteristics of the CAP LTER study area and monitor long-term ecological trends in time and space (Figure 4). In our initial analysis of the 200-site data set, we were interested in addressing the question: "To what extent can variation in basic ecosystem variables be explained by human factors as opposed to natural underlying geophysical characteristics?' We chose two dependent variables—plant diversity (measured as number of genera per plot) and soil NO_3-N content—and modeled them using the 12 independent variables representing the main geophysical, geographic and human characteristics of the study area. These physical, geographic and socioeconomic variables (including elevation, distance from urban center, median family income, human population density, average age of housing stock) were obtained from existing databases or from the US Census for the block group immediately surrounding each of the survey sites. This year's findings are briefly discussed in "Research Findings" below.

Variables that change more rapidly than those assessed in the 200-point survey need to be monitored at greater frequency and at sites where public access can be restricted and experimental manipulations performed. Although this is an obvious caveat for most LTER sites, in a city it is no simple matter. We have identified several candidate sites for permanent plots and during Year 3 began to instrument them and take measurements. Most of our sites to date are on ASU property; we hope 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 just 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 complete understanding of urban ecological systems. The aim of our modeling effort is to develop a spatially explicit simulation model for the Phoenix metropolitan landscape that can be used to understand how land-use/cover change and ecological processes interact during urbanization.

The Hierarchical Patch Dynamics Modeling (HPDM) project serves as a synthesizing device and is crucial for integrating data obtained from individual projects. HPDM is composed of linked models at different spatial scales. At the local scale, patch models relate patch characteristics (e.g., size, shape, land cover, disturbance regime) to ecological and socioeconomic variables of interest. A family of ecosystem process models is being developed for different land-cover types. These models will provide information for constructing and parameterizing coarser-scale models. At the landscape level, we will build models for distinctive landscapes: natural vegetation dominated areas, suburban areas, and highly urbanized areas. These landscape models explicitly consider spatial heterogeneity and interactions among patches of different types. At the regional (CAP) scale, we are building a hierarchically structured, patch dynamic, spatially explicit simulation model (HPDM-CAP), which incorporates the interactions between landscape pattern and ecological and socioeconomic processes at different scales. To date we have completed the following components: 1) the hierarchical patch dynamics modeling platform, programmed in C, on which land-use change models and ecosystem models will be linked; 2) hierarchically structured land-use simulator for Phoenix; 3) series of landscape pattern analyses at different scales and comparison of the historical pattern of land-use change between Phoenix and Las Vegas areas, done in collaboration with visiting scholars; and 4) cellular automaton/Markovian simulation model of land-use change for the CAP area (Jenerette and Wu in press).

Our objectives and scope for next year are to develop the patch ecosystem models, revise and refine the land-use change model, and link the 2 types of models. To achieve long-term goals, the 3 tasks will be carried out interactively in a development-evaluation-development circle: 1) develop and evaluate a land-use change model for the Central Arizona–Phoenix area; 2) adapt and evaluate patch-level ecosystem process models appropriate for the CAP LTER project; 3) link patch ecosystem models with the land-use change model to construct a hierarchical patch dynamics model of Central Arizona–Phoenix (HPDM-CAP); and 4) evaluate HPDM-CAP. Our newly developed hierarchical land-use change simulator seems to produce more reliable land-use projections than the one we developed earlier, which was a single-scale CA model. The new model also allows political and administrative boundaries to be incorporated as constraints in the model.

Our research on pattern and scale analysis has generated much insight into the following questions in the context of CAP LTER: How does changing extent affect the results of different landscape metrics? How does changing grain size affect the results of different landscape metrics? How does changing the direction (or orientation) of analysis affect the results of different landscape metrics? How do the responses of landscape metrics to scale changes resemble or differ from each other across scales and across landscapes, and are these changes predictable? What does the scale-dependency of various landscape metrics entail and imply for landscape analysis?

The HPDM will not be a Asupermodel@ that is intended to cover all the bases; rather, it 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). Although we view development of the HPD modeling framework as a core activity for our project, CAP LTER would benefit from a variety of modeling activities, each using their own approach. Some of these will naturally fit within the HPD framework, whereas others may have unique applications that are either not multiple-scale or otherwise do not mesh with the HDP framework. To jumpstart this activity, based on the NSF review committee=s suggestion, this summer we formed a working group comprised of faculty members from diverse disciplines who have special expertise in modeling, plus empiricists who can keep the group=s efforts grounded in available data. This 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.

Core Research Activities

Primary Production and Organic Matter

Figure 5. Measuring soil respiration at an agricultural site.

This set of projects concentrates on rates of net primary production associated with different land-use patches and how rates at larger scales depend on patch composition, location, and configuration. Measurements of net CO_2 exchange, biomass/biovolumes of selected plants, and soil respiration at residential, desert remnant, and agricultural sites are used to assess net aboveground primary production (Figure 5). Long-term experiments focusing on urban landscaping practices on water use have practical applications for urban ecosystem management.

From a suite of initial projects, Years 3 and 4 marked the transition to the long-term monitoring phase for our primary productivity research. A permanent long-term monitoring plot was installed at the Desert Botanical Garden (DBG) to measure net primary productivity as affected by human activities and to obtain the measurements needed to establish allometric relationships for plants in human-managed landscapes. Long-term monitoring of urban water use also continues in residential sites established in the pilot phase.

Overall vegetation biomass for the CAP study area will ultimately be measurable using remotely sensed data. We are acquiring these data and developing datasets of vegetation indices, which are related to the amount of "greenness" (i.e., chlorophyll). The Soil-Adjusted Vegetation Index (SAVI; Heute 1985) is presumed to perform better than the Normalized Difference Vegetation Index (NDVI) for biomass estimation in areas of low vegetative cover. Preliminary analyses with these data focused on a transect from desert to urban land uses. SAVI may be superior to NDVI for the surrounding desert, but there was no difference between SAVI and NDVI in urbanized areas of the Phoenix region. Therefore, SAVI is recommended for use in arid urban systems as well as arid non-urban systems. SAVI was higher in urban than rural areas. Agriculture, desert, and residential had similar SAVI values, with agriculture the most variable (probably due to active vs. fallow fields); urban land-use types were noticeably lower. The mean and variability of all classes was highest in areas where agriculture dominated along the transect.

A long-term experiment has been established at the DBG permanent plot site to test effects of plant density, species composition and combinations, and landscape irrigation on primary productivity and soil respiration. The experiment features 14 subplots of different yardscape plantings receiving variable watering regimes.

Several interdisciplinary projects have been initiated by the primary production team. In one project, surveys of homeowners were conducted to examine how socioeconomic factors and community ordinances influence vegetation patterns (landscape plant choices) in 4 diverse areas of greater Phoenix. Sampling protocols for this research were developed using the primary productivity pilot study sites, and surveys were developed with input from cultural geographers. Plant ecologists and climatologists collaborated on a second project that replicated research conducted in 1975-76 studying the effects of land use on microclimate along several commercial to rural land-use transects in the Phoenix metro area. An analysis of the data reveals an urban heat island in the Phoenix area that can be partitioned into 7 concentric zones of 6-km width from the urban core to the urban fringe.

Populations and Communities

Figure 6. Dove in urban habitat.

A wide range of individual studies in the realms 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, 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 (Figure 6). 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. It shows how habitat fragmentation, caused by human alteration of the landscape through urbanization, has affected plant communities of a formerly continuous expanse of native Sonoran Desert. Metropolitan Phoenix presents an especially useful arena through which to study this phenomena. There exists a numerous assemblage of natural habitat patches (parks, preserves, undeveloped lands) exhibiting a wide range of spatial, temporal, and disturbance characteristics. 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.

A wet spring (2001) has allowed the sampling of spring herbaceous species at five additional patches, and all 4 original patches have been sampled more extensively. Three other patches, which had been sampled for summer herbs, were also sampled in the spring. This brings the total spring sampling up to 12 patches. Only one wet summer since the initiation of the project has meant that there are still 6 patches with summer herb data sets. Transects containing five 100 m2 quadrats were used for this effort, as well as four 1 m2 nested subplots within each quadrat (in order to examine the effects of sampling grain on results). Each transect samples a representative habitat type within a patch (e.g., south facing slope).

Analyses were performed by estimating species-area curves for spring and summer herbs and the woody species. We had expected the logistic model to provide the best fit. However, the power and exponential curves were more appropriate in most cases. These results indicate that the scale of environmental heterogeneity is very small in these habitats. This constrasts sharply with results from other biomes. This matter merits further investigation. Other analyses are used to study desert vegetation, including non-metric scaling ordination, nestedness analysis, and indicator species analysis.

In the coming year, more patches will be surveyed, and more spring and summer herbaceous data will be collected (rains permitting). A GIS database will be developed. A detailed community classification will be developed using this dataset, the 200-site survey data for desert sites (72 locations), and a previous study of Cave Creek Wash. This community classification will be used to generate a map of the study area depicting distribution of communities. Additionally, we will attempt to reconstruct past community distributions in developed areas (urban, agricultural).

The assessment of arbuscular mycorrhizal fungal (AMF) diversity including species composition, richness and abundance for the CAP LTER Survey 200 Pilot Study has been completed (Stutz and Martin 2000). AMF diversity at 28 residential land use sites is currently being assessed using soil collected during the CAP LTER Survey 200. A study of spatial patterns of AMF diversity has begun at the CAP LTER long-term experimental plot located the Desert Botanical Garden (DBG).

The arthropod pitfall trapping project studies the changes in arthropod species diversity and changes in arthropod population abundance and distribution over time and space as a result of urbanization. The ongoing project is documenting the abundance and distribution of ground arthropods in 6 different forms of urban land-use types (with 4 replicate sites each of: residential xeriscape, residential mesiscape, industrial/commercial property, agricultural field, urban desert-remnant parks, and desert parks on the urban fringe). In each of the 24 study sites, pitfall traps are opened for 3 days each month and trapped arthropods are identified in the lab. See “Research Findings” for results of Year 2 data.

To better understand the impact of urbanization on an insect/plant interaction, we are investigating causes of variation in population density between urban and natural desert sites in 3 species of bruchid beetles: *Mimoseste amicus*, *M. ulkei* and *Stator limbatus* (Coleoptera: Bruchidae) on the Blue Palo Verde, *Cercidium floridum* (Leguminoseae). This ongoing project is an important part of our research and continues to engage student and teachers in collecting data through the Ecology Explorers program.

In August 2000 we changed the sampling method for birds from line transects to point counts. Locations were also changed from original sites to 40 points randomly selected from the Survey 200 sites, augmented by 10 additional riparian habitat sites chosen for their ecological importance and accessibility. Counting birds will allow us to directly relate bird densities to other environmental variables being monitored. The point count is conducted 4 times a year (January, April, July and October) to document the abundance and distribution of birds in 4 habitats in 51 sites: urban (18) desert (15) riparian (11) and agricultural (7). During each session each point is visited by 3 birders who count all birds seen or heard for 15 minutes. Our goal is to study how different land-use forms affect bird abundance, distribution and diversity in the greater Phoenix area in order to predict and preserve high bird species diversity as urban development is proceeding.

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. Sampling for the first annual cycle is currently nearing completion. Blood smears are currently being examined to quantify parasites, and hormonal assays will be conducted during Fall 2001, after completion of the first annual cycle of sampling. This is necessary to minimize potential interassay errors for seasonal comparisons.

A long-term experiment evaluating patch-specific variation in multiple trophic-level dynamics is currently being established. Questions addressed are: How similar are multi-trophic 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 tropho-dynamics among habitat types? Using replicated, controlled cage experiments, we will manipulate the access of predators (initially, birds) to test for bottom-up or top-down control of tropho-dynamics in different habitat patches. We will establish bird-exclosures on shrubs and other vegetation at the LTER permanent sites, starting with the President's House (mesic residential) and the Desert Botanical Garden (desert remnant). By using the LTER permanent sites, we will 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.

Human Dimensions of Ecological Research

Figure 7. Human impact on the environment: a challenge for integrative 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, census data). While various projects are organized under this heading, some projects by other teams are addressing questions about the human dimensions of ecological systems, and some projects within this group already have natural science elements. Our ultimate goal is to integrate social and natural science studies throughout our research (Figure 7).

The CAP LTER project has been at the forefront of efforts of social and natural scientists to forge a new kind of research agenda for LTER sites and, towards this goal, has coordinated workshops, presentations, incubation workshops, and cross-site activities. In January 2000, LTER scientists and colleagues from other large, interdisciplinary projects funded by NSF gathered in Tempe, AZ to discuss how to better integrate social and ecological research and to promote integrative research in the LTER network. The latest iteration in this process was presented at the LTER All Scientist Meeting in Snowbird, Utah in August, 2000.

Under the leadership of CAP LTER and BES personnel, these activities have produced a "white paper," a model for integration (Figure 8), and a Biocomplexity Incubation award from NSF. The paper, *Human Dimensions of Ecological Change: Integrating Social Science into Long-Term Research* (Redman et al. in review), was developed from the Tempe workshop and presented and discussed at the LTER meeting in Snowbird. The intent of the paper is to provide a foundation and departure point for social scientists and biophysical scientists associated with the LTER network and other research groups 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, a newly awarded Biocomplexity Incubation planning grant will allow CAP LTER and BES to pursue and foster 4-5 cross-site projects that

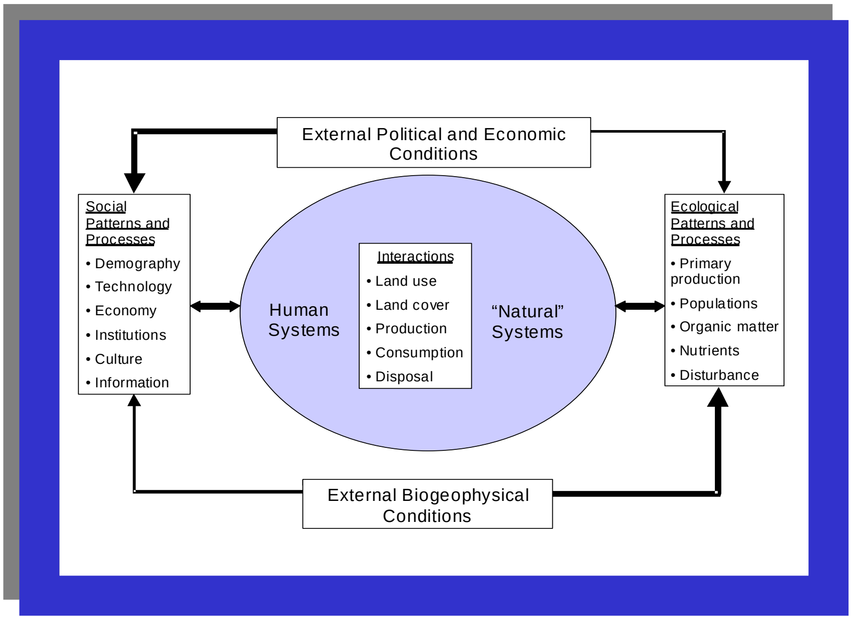

Figure 8. An integrated model of the human ecosystem. Disciplinary training encourages us to treat elements of human and ecological systems as distinct. In this model, urban LTERs emphasize interactions, the specific activities that mediate between the social and natural elements of the human ecosystem (Redman et al. in review).

will serve as models for integrating social science into LTER projects. The first workshop will be held in conjunction with the 2001 ESA meeting in Madison. In addition, CAP LTER has engaged in a range of comparative projects with BES and collaborated on numerous cross-site proposals.

The NSF Review Committee suggested that CAP LTER would benefit from more attention to climate change. We agree and will work toward that end. Tony Brazel (geographer and former State Climatologist) has been a key member of our team from the outset. He has already published on CAP LTER climate patterns and worked together with BES on a joint publication (Brazel and Heisler 2000). Another suggestion was to more effectively integrate feedbacks in the urban setting. This is clearly a challenge we must increasingly face as we move forward. Although they did not report to the visitors, we already have an interdisciplinary working group that calls themselves the Afeedback group@ and is focusing on the various changes related to microclimatic change induced by urban growth. We expect a manuscript to be submitted this summer based on their research.

Because land-use change is a focal variable for CAP LTER, we initiated the historic land use project to set the baseline for how land use has changed in the study area. The project has been approached in two phases. In Phase I, we collected relatively coarse-resolution, time-series data about land-use development for the study area (Knowles-Yañez et al. 1999). In Phase II, we are mapping land use 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 as well as the local county classification. This historical perspective will enable us to compare patterns of future change to those of the past, when different social (and perhaps ecological) forcing functions were at work. Using this detailed information on temporal sequences of land-use change, we are currently defining alternate trajectories of change for each sector of the city and when they passed through analogous stages. Using these patterns, we hope to generate a more refined model for urban growth in our region and to identify pioneering activities that led to rapid change as well as factors that resisted urban growth and slowed the process. Data exploration to determine developmental patterns and their spatial relationships has begun.

There is a well-known “heat island” effect of urbanization. What is classified as “rural” (desert or farmland) determines the magnitude of the heat island in Phoenix—a “rural” desert is cooler at night whereas a “rural” agricultural landscape is warmer at night. During the day, there is an oasis effect evident in the city (the city is actually cooler than the rural desert). Time trends of urban effects in Baltimore and Phoenix are controlled by population growth rates in a non-linear manner over time (Brazel et al. 2000). Analysis of weather station data must be accompanied by land-cover and land-use analysis to unravel the local effects, after careful station history inspection to eliminate extremely local effects due to instruments, heights, changes in immediate surface, observation times for max/min temperatures, etc. (Brazel and Heisler 2000). The urban fringe represents a boundary of well-defined discontinuity in microclimate (Brazel et al. 1999) where heating (measured using remotely sensed data) is substantial (from 1985-present, >10^{o}C in May). Finally, solar radiation receipt in and out of the metro area responds to the pollution dome over the city, with inner-city values 15% lower than outside values (Tomalty and Brazel 2000); UV-B radiation transects correlate (r^2 =0.7) with total incoming solar radiation variations.

Urban-rural microclimate gradient: To study the city's effect on climate, we are deploying 10 automated stations in residential areas and agricultural and desert areas in the SE at sites spanning a west to east environmental gradient across the urban fringe. Some of the sites are coordinated with LTER measurement sites (200 point survey). Others are in partnering with ADEQ and SRP by using telephone poles as observational platforms for the equipment, particularly in the rural lands. A mobile auto transect temperature and humidity approach has already been followed along this gradient and measurements will be made from summer to as late as December. Data on surface characteristics (e.g., albedo, soil moisture, roughness of ground, morphology of buildings, vegetation abundance) are being mapped to correlate with the gradients of climate. These results should support modeling efforts of Zehnder and others using a mesoscale modeling scheme for energy budget studies of the city's effects on climate. The data can also be used to establish environmental indices to track over time in relation to the city's effect on climate and vice versa.

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 have demonstrated that analyses relying solely on the presence of large-quantity generators or on the volume of toxic releases can be quite misleading. Instead, it is essential to account for the toxicity of releases (we used the Environmental Defense Fund's "toxic equivalency potential" weighting system, applied to EPA's Toxic Release Inventory data). Our most striking result, the comparison of weighted and unweighted releases, suggests that apparently clean new industry may harbor significant environmental hazards. The study location offers a valuable contrast to other studies of environmental equity, most of which are sited in the Northeast or South. In the Phoenix area, the presence of a TRI facility and the volume of emissions are strongly associated with measures of socioeconomic status and ethnicity at both the census tract and block levels. When the volume of emissions is weighted by a measure of their toxicity, however, the relationship becomes negligible. New forms of industry, such as computer chip manufacturers, often located in middle-class neighborhoods, are bringing toxic emissions to new areas and new populations, altering traditional patterns of environmental equity.

We are continuing research on mapping social distributions of hazardous sites and facilities in the Phoenix metropolitan area. Preliminary work has begun on acquiring health data to be used in conjunction with hazard data. Work is currently being undertaken for a study analyzing the development of hazardous sites and the transformations of neighborhoods by industrial encroachment and other economic transformations. Developing an understanding of the urban ecology of environmental risk in an historical-geographic perspective is the current focus of our research efforts. We are also continuing work on risk perceptions of hazardous facilities based on photographs of such facilities.

Long-term monitoring of social variables differs from that of ecological variables in that so many datasets are readily available and can be adapted for analyses of human dimensions of ecological change. We are using census data, for example, in many projects; a partial list of datasets used by this team is provided in Table 2.

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 sociodemographic characteristics of the population in nearby neighborhoods. We also explore the impact of changes over time in the industrial composition, location of firms, and types of occupations on employment opportunities for the population in general, and for women and minorities. More specifically, our research questions include:

Table 2. Examples of Existing Datasets Relevant to CAP LTER "Human Dimensions" Projects

DATASET	SOURCE	EXAMPLES OF PROJECTS USING DATASET
Climate/weather	Municipal and state weather stations	Urban fringe
Demographic/census (decadal)	US Census Bureau	Environmental risk; Social area analysis
Employment data	Equal Employment Opportunity Commission (confidential)	Labor market dynamics
Environmental Hazard data: for Superfund, Treatment, Storage, and Disposal Facilities (TSDF), and Large Quantity Generator (LQG)	Right-to-Know Network	Environmental risk
Housing completions	Maricopa Association of Governments	Urban fringe
Housing market prices	Seidman Institute, ASU	Economic value of open space
Market data	Commercial service	Parks project
Mid-decade census, other demographic data	Maricopa Association of Governments	Environmental risk, labor market dynamics
Toxic Research Inventory (TRI)	Environmental Protection Agency	Environmental risk
Urban Infrastructure (water and sewer pipe length, volume, date of completion)	City of Phoenix	Urban infrastructure
Vegetation, infrared radiation	Remote sensing (CAP LTER/GRSL)	Social area analysis, urban fringe
Wage Data on industries and occupation	Bureau of Labor Statistics	Labor market dynamics

- During the previous 15 years of economic restructuring in the United States, how has the industrial mix and the spatial distribution of urban employers changed in a metropolitan area with net job growth (Phoenix)?
- How have changes in the industrial mix and location of industries affected the level of economic opportunity (job growth, occupational skill, wages) in the metropolitan labor market?
- Does the location of new firms or the relocation of existing firms precede or follow movement of population toward the urban fringe?
- Can employer relocation or changes in the industrial mix of employers in an area be systematically related to indicators of socioeconomic distress in urban neighborhoods, such as poverty rates, unemployment, or families headed by single mothers?
- How have changes in the occupational composition and location of industries affected opportunities (employment levels, occupational distributions, wages) for women and racial/ethnic minorities?
- Are employment opportunities in the new firms moving into the local labor market different from opportunities in firms that are already established in the region?

To date we have gathered data from the EEOC on all firms in the Phoenix metro area with 100 or more employees for the years 1983 and 1998. These data include standard industrial classifications, the distribution of employment in nine major occupational categories by gender and race/ethnicity, and street addresses. We have put the data into a Geographic Information System (GIS) street-level map that includes an identifier for census tracts. We have assembled tract level data files for the 1990 and 1980 Census of Population and Housing and the 1995 Special Census of Maricopa County. In addition, we have obtained a Bureau of Labor Statistics data set on average wages by occupation by industry. These data sets will be merged with the EEOC employment files to provide spatial information at the census tract level. Preliminary data analyses include construction of segregation indexes by industry, occupation, sex, and race/ethnicity, calculation of rates of change by all subcategories, and calculation of median wage by sex and occupation. Our maps to date depict the location of firms and job densities for 1983 and 1998 across all industries and by type of industry.

The social area analysis uses census data and vegetation data to examine the relationship between socioeconomic status and vegetation patterns in the urban landscape at the neighborhood level. Study asks: Do vegetation patterns differ with respect to socioeconomic status at the neighborhood level and, if so, how? Sociologists in the 1950s developed a methodology for social area indicators to examine the spatial heterogeneity of socioeconomic and demographic characteristics. Scientists from BES recently applied it to Baltimore to assess links with vegetation patterns. We analyzed the relationship between social indicators and vegetation diversity and volume with the CAP LTER Survey 200 data and are including the results in the overview paper from that project.

The goal of the Phoenix Area Social Survey (PASS) is to examine the interplay between social, built and natural environments in an urban ecosystem. The project involves multiple data-collection strategies, including a phone and in-person survey of households in sample neighborhoods, an observational survey of the built environment in sample neighborhoods, and measurements of natural environmental conditions in and near sample neighborhoods. These data will be used to measure the effect of human activity on the built and natural environments and the effects of the environment on people and communities. Social conditions in the neighborhood—interactions with neighbors, sentiment, participation in organizations and economic investment—are mediating variables in this feedback system. In 2000 seed money from ASU helped support a pilot study for a long-term, longitudinal project. Since January 2001, the research team has been designing the pilot, writing a review article on social research in neighborhood, and conducting the activities listed below. The administration of the pilot survey and data analysis will take place in the fall.

Weekly meetings to develop the conceptual framework, sampling strategy and survey instruments; development of a database of Survey 200 points located in residential areas linked to block group data from the 1999 and 2000 censuses and the street boundaries of Homeowners Associations and voluntary neighborhood associations; creation of maps of Survey 200 plot locations with respect to municipal boundaries, distance from the urban center and rates of residential completion by census block group (with GIS Lab; residential completion data supplied by Pat Gober); selection of 6 sample neighborhoods in which to conduct the pilot; counsel with life and physical scientists on environmental aspects of neighborhoods and human/environment feedbacks; focus group discussions with residents in 3 neighborhoods in order to field test questions for the household survey; development of a household survey instrument; creation of a Powerpoint presentation to introduce other researchers and possible funders to PASS; and contact with NSF program officer regarding potential proposal development.

The goal of the urban parks project is 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 (facilities plus landscaping) 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. An initial survey was conducted and is reported under "Findings."

Biogeochemical Processes

Figure 9. Aerial view of aquatic and terrestrial elements of the CAP LTER urban landscape.

This research area includes both aquatic and terrestrial elements of the urban landscape and has included projects at a range of scales, though much of our initial focus has been on whole ecosystem characterization (Figure 9). Data have been analyzed and synthesized for some initial projects; several others are completed (chemical and biological monitoring of urban lakes, a comprehensive nitrogen mass balance, and heavy metal analysis of lichens); a carbon balance project has begun; and monitoring of soil nutrient and carbon storage is underway. Long-term monitoring of surface water inputs and outputs of nutrients and major ions continues, as does dry and wet atmospheric deposition monitoring. We are interested in the transfer of materials from atmosphere to land to aquatic ecosystems and to groundwaters and, to that end, have initiated sampling of storm events in collaboration with municipal and county agencies who are sampling floods and studies of aquatic nutrient cycling in a new urban watersheds project.

Our aims for the urban watersheds project are to explore potential localized nutrient sinks in the urban landscape and consequences of increased loading to aquatic ecosystems. Where in the landscape is N (and other elements) retained? This question is best answered using a hierarchical, patch-dynamics approach that incorporates both aquatic and terrestrial components of the landscape. Given the size and complexity of the study area, our initial focus on 1 or 2 smaller watersheds is warranted. In this research, we hope to integrate atmospheric deposition, storm water runoff, retention basin processes, hydrologic modeling, and aquatic biogeochemistry studies. To date, we have initiated or completed pilot projects on: 1) nutrient limitation in a highly modified urban stream-pond system; 2) spatial variation in nutrient concentrations in urban waterways; and 3) soil N cycling processes in retention (see "Disturbance" for further information on storm and flood sampling). Nutrient addition bioassay experiments in an urban stream revealed that phosphorus was limiting to algal growth during summer but not fall, in marked contrast to the N limitation characteristic of most regional streams (Grimm and Fisher 1986). These experimental results confirm predictions from sampling of waters that indicate a high N:P ratio in 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). Initial measurements in neighborhood retention basins show a high potential for denitrification in these soils; we expect expanded measurements to show "hot spots" of denitrification in similar low-lying areas (recipient systems).

The core 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. A team of 5 researchers from 3 different departmental programs have begun analyzing these data to look for patterns in water quality in space and time. We have generated questions that can be answered using this dataset, such as: 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 (additional sources: urban and natural runoff)? This effort should result in a manuscript to be submitted for publication in the spring of 2002.

Study of atmospheric deposition progressed on 2 main fronts over the past year. Firstly routine monitoring of wet and dry deposition to quantify the flux of major nutrients and ions to the site, along with spatial variations in deposition rates across the urban area, continued at the network of 8 established sites. There are now almost 2 complete years of deposition chemistry from the wet/dry bucket samplers, which will form the basis of a manuscript on the variation in deposition chemistry across the Phoenix metropolitan area, in the coming year. Secondly, to obtain an alternative, more detailed numerical estimate of atmospheric dry deposition of to CAP we developed a diagnostic deposition model (see Research Findings below).

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 affects the function of other ecosystem processes such as primary productivity of native desert and introduced urban plant species. Existing monitoring of atmospheric deposition chemistry in the study area and surrounding region is limited. Therefore, monitoring of deposition of major nutrients and ions was initiated by installing a network of wet-dry bucket collectors (Aerochem Metrics, Inc Model 301) at 8 sites, from the urban center to agricultural areas and undisturbed desert beyond the urban fringe, between July and October 1999. Collectors were co-located with Arizona Department of Environmental Quality and Maricopa County Air Quality monitoring network sites, where concentrations of ozone, fine particulates (PM_{10} and $PM_{2.5}$) are monitored routinely (at Sites 1-6), with additional monitoring of CO and NO_x concentrations at a smaller subset of the sites.

Figure 10. LTER deposition bucket collectors.

Data from the wet-dry bucket network will be used to determine the degree of broad-scale temporal and spatial variability in both wet and dry deposition across the study area (Figure 10). Although bucket collectors are considered adequate for collecting large particulate matter, they do not account for processes such as deposition by nitric acid, nor do they simulate real surface properties well. The magnitude of these effects can be evaluated by comparing dry bucket data with results obtained from a NOAA-operated dry deposition monitoring network site, where filter packs and inferential modeling are used to determine dry deposition of NO_3, NH_4, HNO_3 and SO_4 species. These data, along with the wet/dry bucket data will be supplemented by more comprehensive and accurate measurement of dry deposition during future years at a smaller number of sites.

Geomorphology and Disturbance

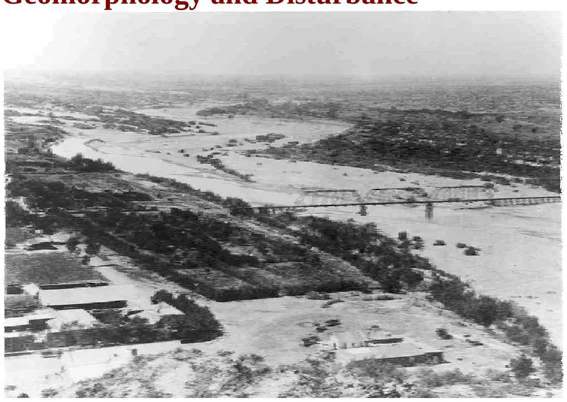

Photo courtesy of Tempe Historical Museum

Photo by Wendy Bigler

Figure 11 The changing patterns of land use around a section of the Salt River in Tempe.

Funding for additional studies in the realms of Geosciences and Engineering were provided via supplements during the first two years of CAP LTER. We chose to focus on building an understanding of the geomorphic template upon which the metropolis is expanding, including its rivers, a dominant feature of the landscape, and an engineering project (Tempe Town Lake) in the river channel.

Integrative investigations of a newly created lake*:* The City of Tempe is undertaking a large ecological, hydrogeological experiment, the Rio Salado/Tempe Town Lake. A new urban lake was created in the dry (since 1938, except during floods) Salt River bed using collapsible, inflated rubber dams. The lake is over 3.2 km long, about 320 m wide, has a surface area of about 100 ha, and contains about 2500 acre-feet of water. The geological/ hydrogeological aspect of the study is to determine the effects of lake filling on local transient hydrological flow, to formulate an improved 4D-hydrogeological model of the area, and to provide subsurface geophysical control for geochemical and biological research at the lake.

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. The idea of flooding in the desert metropolis of Phoenix may seem incongruous, especially when one considers that the average rainfall in the Phoenix area is less than eight 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 five 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.

Database and Informatics Activities

The CES Informatics Lab is active in the development of sophisticated database technology and applications. The award of a Biological Database and Informatics (BDI) grant (McCartney et al. 1999) to develop new database tools has bolstered CES efforts in data management and use of existing data as components of our research projects. This 3-year project began in 2000 to develop advanced infrastructure for facilitating access to ASU's extensive environmental data resources for researchers, educators, and partners in resource management. Another NSF project, funded through KDI (Razdan et al. 1999), seeks to develop a set of core technologies for recognizing and analyzing morphological features from 3-dimensional computer models. The CES Lab plays a role in developing the database for organizing storing and transmitting 3D data using XML. Detailed Informatics Lab activities are reported at http://www.vcrlter.virginia.edu/auto_docs/im_flash20011012193035.html.

Grant awards

"Down to Earth Science: Graduate Teaching Fellows in K-12 Education," ($1,397,825). National Science Foundation, 2001-2004. B. Ramakrishna PI/PD, C. Redman, F. Staley, P. Christensen, S. DiGangi Co-PIs. Other LTER participants: T. Craig, N. Grimm, M. Elser, M. Nelson, B. Shears, and S. Williams.

"Multi-Investigator Grant Development Award, PASS Project," College of Liberal Arts and Sciences ($14,000); Vice Provost for Research ($12,000); Sociology Department ($1,500), Arizona State University. S. Harlan et al.

"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).

III. Research Findings

Long-Term Monitoring

Geophysical Context and Patch Typology

Remote sensing data have been used to perform an initial comparison of global city structure using spatial variance texture analysis of 15 m/pixel visible-wavelength. ASTER data. Variance texture analysis highlights changes in pixel edge density as recorded by sharp transitions from bright to dark pixels. In human-dominated landscapes these brightness variations correlate well with urbanized vs. natural land cover and are useful for characterizing the geographic extent and internal structure of cities.

Variance texture analysis was performed on 12 urban centers (Albuquerque, Baghdad, Baltimore, Chongqing, Istanbul, Johannesburg, Lisbon, Madrid, Phoenix, Puebla, Riyadh, Vancouver) for which cloud-free daytime ASTER data are available. Image transects through each urban center produce texture profiles that correspond to urban density. These profiles can be used to classify cities into centralized (Baghdad, Istanbul, Lisbon, Puebla, Vancouver, Baltimore), decentralized (Albuquerque, Phoenix, Johannesburg), or intermediate (Chongqing, Madrid, Riyadh) structural types. Image texture is one of the primary data inputs (with vegetation indices and visible to thermal infrared image spectra) to a knowledge-based land cover classifier currently under development for application to ASTER UEM data as it is acquired.

Survey 200: Interdisciplinary Long-Term Monitoring

In contrast to the patterns typically seen for ecosystems without large human impacts, there was no significant spatial autocorrelation in either of the 2 dependent variables or in model residuals across the study area as a whole. Plant diversity was positively related to elevation and soil NO_3-N showed a latitudinal effect, decreasing from south to north across the study area. However, human geographic and socioeconomic variables added significant explanatory power—land use was a significant predictor for both plant diversity and soil NO_3-N. Plant diversity, as measured by number of genera per plot was highest at desert and urban sites; while there was little difference between the two land uses on a plot-to-plot basis, the total number of plant genera recorded overall was higher for urban versus desert sites, similar to findings that European cities have a higher overall plant diversity than the surrounding countryside. Sites currently in agricultural use had the lowest plant diversity and even plots that had previously ever been farmed showed significantly lower diversity than those that had not. Other significant predictors (at $P<0.01$ level) of plant diversity were median family income and human population density, both with a positive relationship to the number of genera recorded. The best predictive model of soil NO_3-N across the whole study area was obtained with 3 human variables: land use, human population density (positive correlation) and the proportion of impervious surface cover (negative relationship).

The large difference in the average content and variability in soil nitrate-N between urban and undeveloped desert sites was striking. Variability of soil nitrate-N in only the desert plots was relatively low and spatially autocorrelated, with none of the independent variables found to have explanatory power. In marked contrast, soil nitrate-N in urban plots showed no spatial autocorrelation and huge site-to-site variation, of which the 2 significant predictor variables were human population density and the proportion of impervious surface cover. It is noteworthy that as human population density and, by inference human activity and intervention in land management, increase so too does plant diversity and soil nitrate-N. Variation in plant diversity between the urban sites was best explained by a combination of the following physical and human variables: latitude, longitude, elevation, median family income, human population density, housing age, whether ever in agriculture, and impervious surface cover. Of these, the most important contributors (as indicated by performing backward elimination of individual variables from the model and using $P=0.01$ as a cut off) were all human-related factors, namely: housing age, family income, population density, whether ever in agriculture, and impervious surface cover.

It is interesting to note that distance from urban center did not emerge as an important factor, despite the prevalence of the urban-rural gradient paradigm, which has become established in the urban ecological literature. Although work at CAP by Luck et al. has shown that some landscape pattern metrics at CAP do exhibit trends related to distance from urban center, this does not appear to be reflected in plant diversity or soil nitrate-N content at the scale measured by this survey. This finding may be a result of the multiple urban centers across metropolitan Phoenix acting to confound simple linear gradients of this type.

Modeling

A landscape transect analysis approach is effective in identifying urbanization gradient in the Phoenix metropolitan region. A series of landscape measures indicate a dramatic change in the urban landscape at around the urban center. This physical gradient can be related to ecological variables to help understand how urbanization interacts with ecology.

With rapid urbanization in the region in the past several decades, the landscape has been increasingly fragmented at an exponential rate, as indicated by several landscape indices. Several metrics of landscape pattern (e.g., the number of patches, total edge, landscape shape index) change predictably with scale and thus follow simple scaling functions (usually linear or power functions), but many (e.g., fractal dimension, contagion, mean patch shape) behave erratically with changing spatial scale. In addition, changing grain size (or spatial resolution) and changing extent (study area) have different effects on landscape/ecosystem analysis. More findings are found in publications listed below.

Core Research Areas

Primary Production and Organic Matter

Our data on urban landscaping practices and water use aids not only the monitoring effort but has practical applications for urban ecosystem management. Answers to several questions are being sought in this research: Is human land use a good predictor of annual net primary productivity of urban landscapes? How are variations in urban landscape microclimates related to urban land use, urban plant community structure, and landscape patch dynamics? At what spatial scales do landscape maintenance practices such as pruning affect within-patch vegetation density? Are the intensities and densities of spatial patterns of urban plant communities related to human preference? What is the spatial pattern of urban plant communities in relation to urban land-use typology? Do mechanistic linkages exist between socioeconomic factors, human landscape preferences, and the structure and composition of urban plant communities? What are the comparative relationships and linkages between above-ground and below-ground productivity in urban systems?

Populations and Communities

Assessment of arbuscular mycorrhizal fungal (AMF) diversity at the pilot study sites provided new information about AMF community structure in the Phoenix metropolitan area. Spore densities were low (<50 spores /100 cm^3) in over half the samples, and spore densities in agriculturally classified sites were significantly lower than in desert or urban sites. Low spore densities in many of the samples were expected due to the tendency for AMF to not sporulate in arid soils. Eighteen AMF species were detected with four species (*Glomus eburneum, G. intraradices, G. micoaggregatum,* and *G. spurcum*) detected at nearly all sites and across all land-use categories. Nearly all species detected in this study have been detected in other Sonoran desert localities. Mean species richness (6.35±0.5) was comparable with that detected in other Sonoran desert studies. No significant differences in species richness were found according to current land-use categories, but sites developed from agricultural land had lower species richness than sites developed from desert. Variability in site characteristics within land-use categories may have contributed to the lack of differences in species richness found between land-use categories. For example, residential sites ranged from largely paved apartment complexes containing nonmycorrhizal plant hosts to large xeriscaped lots to mesic lots. The factor most related to species richness was land-use history—whether the land was open desert or agriculture before development. Cluster analysis showed that primarily urban and residential sites containing high proportions of nonmycorrhizal hosts were similar in AMF species composition. Other sites with highly similar species composition were also similar in host plants or land-use history. We plan to present these findings at the Mycological Society of America annual meetings in August 2001 and are currently preparing a publication on these findings.

Analysis of the arthropods collected from June 1999 to May 2000 indicate species richness and total arthropod abundance were different between land-use types with the most rich and abundant communities found in agricultural fields and mesic residential yards and the least rich and abundant communities found in desert, industrial and xeric residential yards. This suggests that the 6 land-use types can be classified into two major groups based on water availability. The most commonly collected arthropod taxa were mites (Acari), ants (Hymenoptera: Formicidae), and springtails (Collembola). We used rarefaction to calculate the differences in species diversity between habitats. This method controls for the differences in sample size and therefore indicates whether the differences in species richness are a sampling artifact or based on biological factors (habitat structure in this case).

Rarefaction curves (Figure 12) revealed that while in xeric residential yards, desert fringe and urban desert remnants the number of individuals was comparatively low, their species diversities were

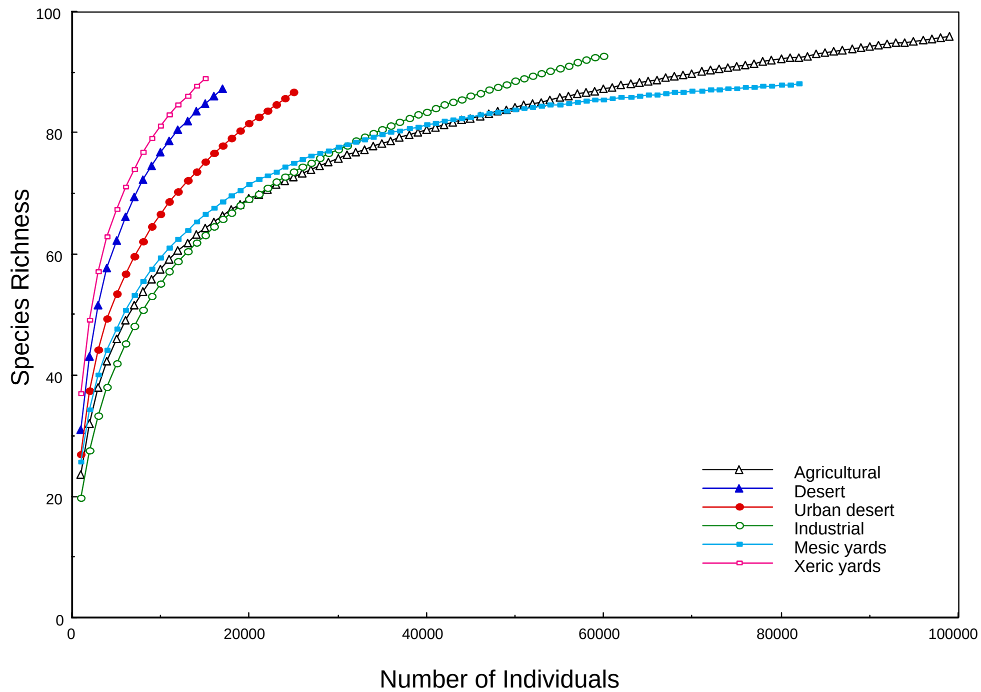

Figure 12. Rarefaction curves for arthropods in 6 different land use types in the greater Phoenix area. Three habitats with higher arthropod abundance (agricultural, mesic residential yards and industrial) have lower species diversity than less productive habitats (Urban desert remnants, desert parks and xeric residential yards).

significantly higher than in the industrial, mesic residential yards and agricultural lots, which supported a much higher total arthropod density. These results will be useful in predicting effects on biodiversity from future urban development. In particular, our results indicate that the spatial heterogeneity of land use in the Phoenix area promotes biotic diversity.

In the community level bird study, we compared average bird abundance and richness between 4 habitats and 3 seasons (Fall 2000, Winter 2001, and Spring 2001). There was no seasonal effect on bird abundance (Fig. 1; two-way ANOVA $F_{2,141}$=0.63, P = 0.53) or species richness (Fig. 2; $F_{2,141}$=,1.22, P = 0.3), neither was there an effect of the interaction between season and habitat (Abundance $F_{6,141}$=0.24, P = 0.96; Richness $F_{6,141}$=0.49, P = 0.81). Therefore, habitat was the only variable affecting bird abundance and richness (Abundance $F_{3,141}$=13.64, P < 0.0001, Richness $F_{3,141}$=24.20, P < 0.0001). Bird abundance in the desert was significantly lower than in the agricultural, riparian, and urban habitats (Figure 13). Species richness in the riparian habitat was significantly higher than in the desert, agricultural and urban habitats (Figure 14).

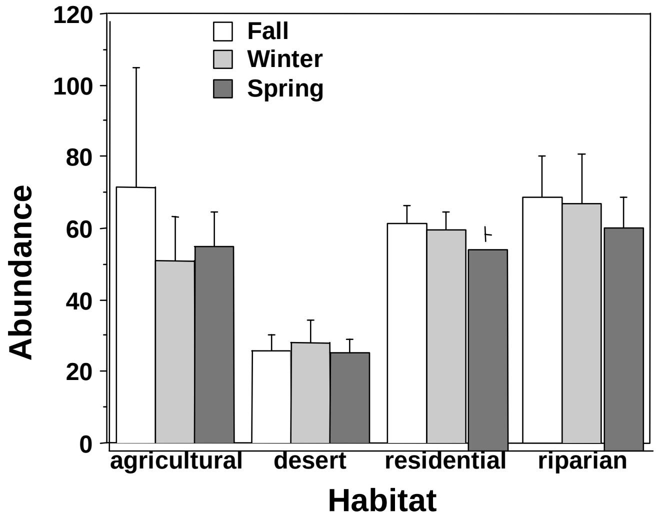

Figure 13. Mean±S.E. Bird Abundance in 4 major habitat types of the Phoenix metro area.

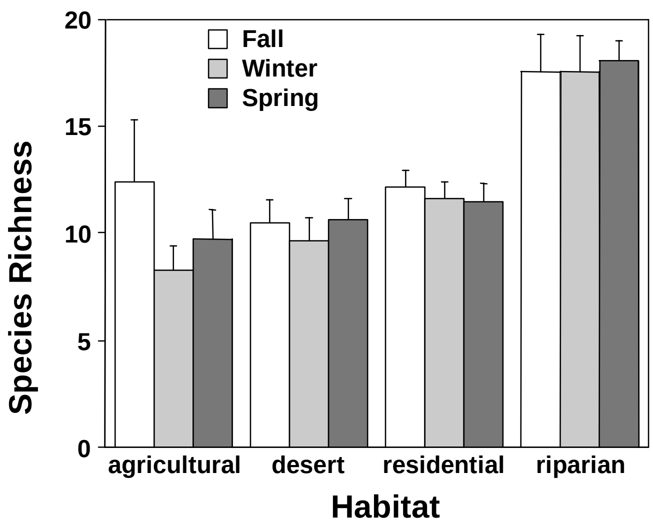

Figure 14. Mean±S.E. Bird Species Richness in 4 major habitat types of the Phoenix metro area.

The general patterns of species richness and total bird abundance in the Phoenix area are consistent with those observed in other urban areas. Although the urban habitat supports the highest abundance of birds, it is relatively species poor, with a few mostly exotic species dominating. We are currently focusing our analyses on the level of species composition to further understand differences among habitats and seasonal effects, even though we found no overall effect of the latter.

At the population level, the Abert's Towhee, a riparian native species of Arizona, is a common species in residential yards across the greater Phoenix area. Previous tudies on bird communities indicate that this species is missing from Tucson residential area. We tested the hypothesis that the riparian corridors that cross the Phoenix metropolitan area serve as sources for the urban towhee population.

Figure 15 shows the abundance of Abert's Towhee in the 51 survey points. Though Abert's Towhees were most abundant in the riparian habitat, we found them in all 4 habitats (Figure 16). We found a negative correlation between Abert's Towhee abundance and distance from riverbed (Figure 17; Spearman's $\rho = -0.26$, $P = 0.034$).

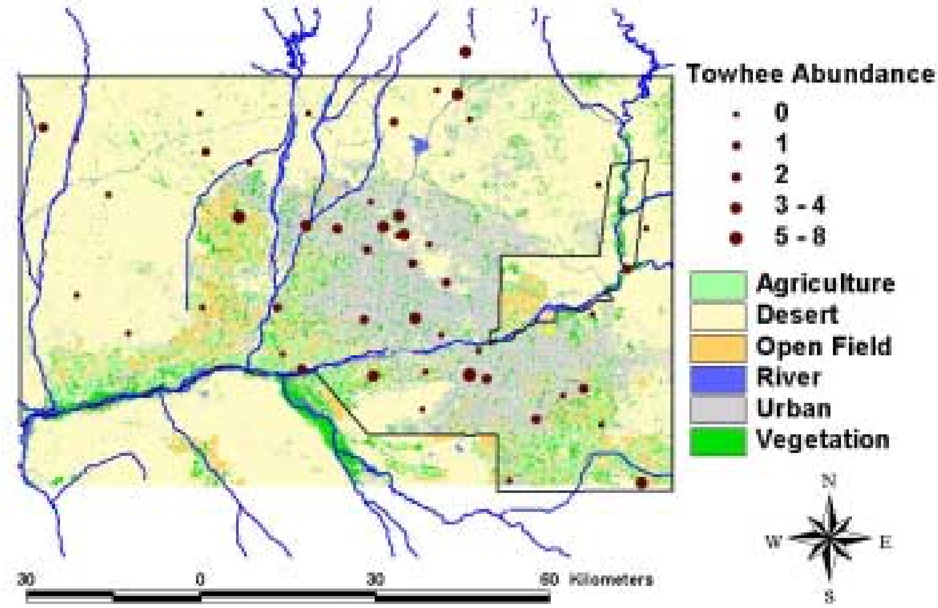

Figure 15. The abundance of Abert's Towhees in Phoenix as a function of distance from river.

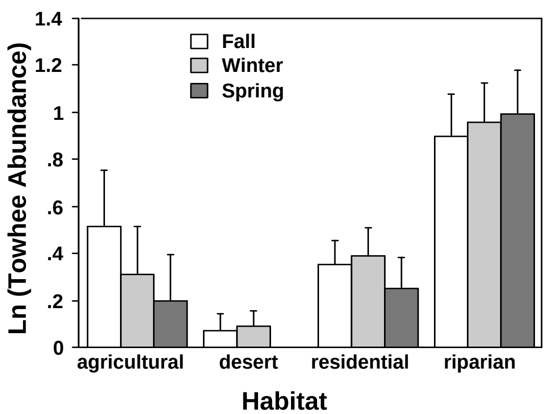

Figure 16. Distribution of Abert's Towhees in Phoenix among four major habitats.

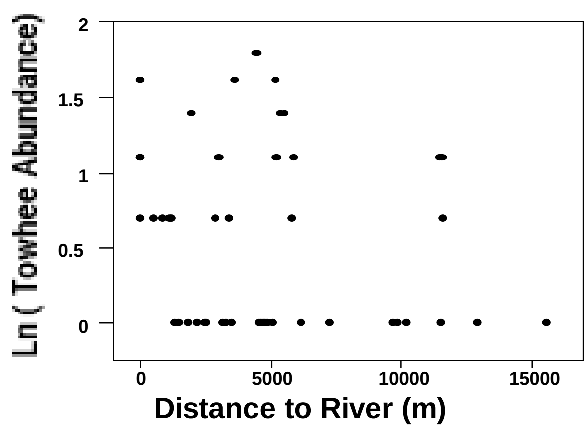

Figure 17. The abundance of Abert's Towhees in Phoenix as a function of distance from river channels.

Abert's Towhees primarily occupy riparian habitats in the greater Phoenix area. These riparian corridors may facilitate towhee dispersal into urban habitats. The decrease in abundance with distance from the river suggests potential source-sink population dynamics. We believe the difference between Phoenix and Tucson can be explained by the absence of riparian corridors in Tucson. Because data from only one city may represent pseudoreplication, we are developing collaborations with a graduate student at the University of Arizona, Tucson, who is studying bird communities in that city.

Human Dimensions of Ecological Research

The labor market dynamics study has found that unlike most Midwestern and Eastern cities, Phoenix did not deindustrialize. It has followed a constant growth pattern across all sectors of service and manufacturing (Figure 18). New job growth occurred in the outlying cities and areas with recent population growth, but overall the central city has retained and even increased its job base. The central city of Phoenix lost manufacturing jobs, but this was concentrated in a few census tracts. This is a different pattern from that of Eastern and Midwestern cities, which lost jobs on a larger geographic scale at the city level or MSA level.

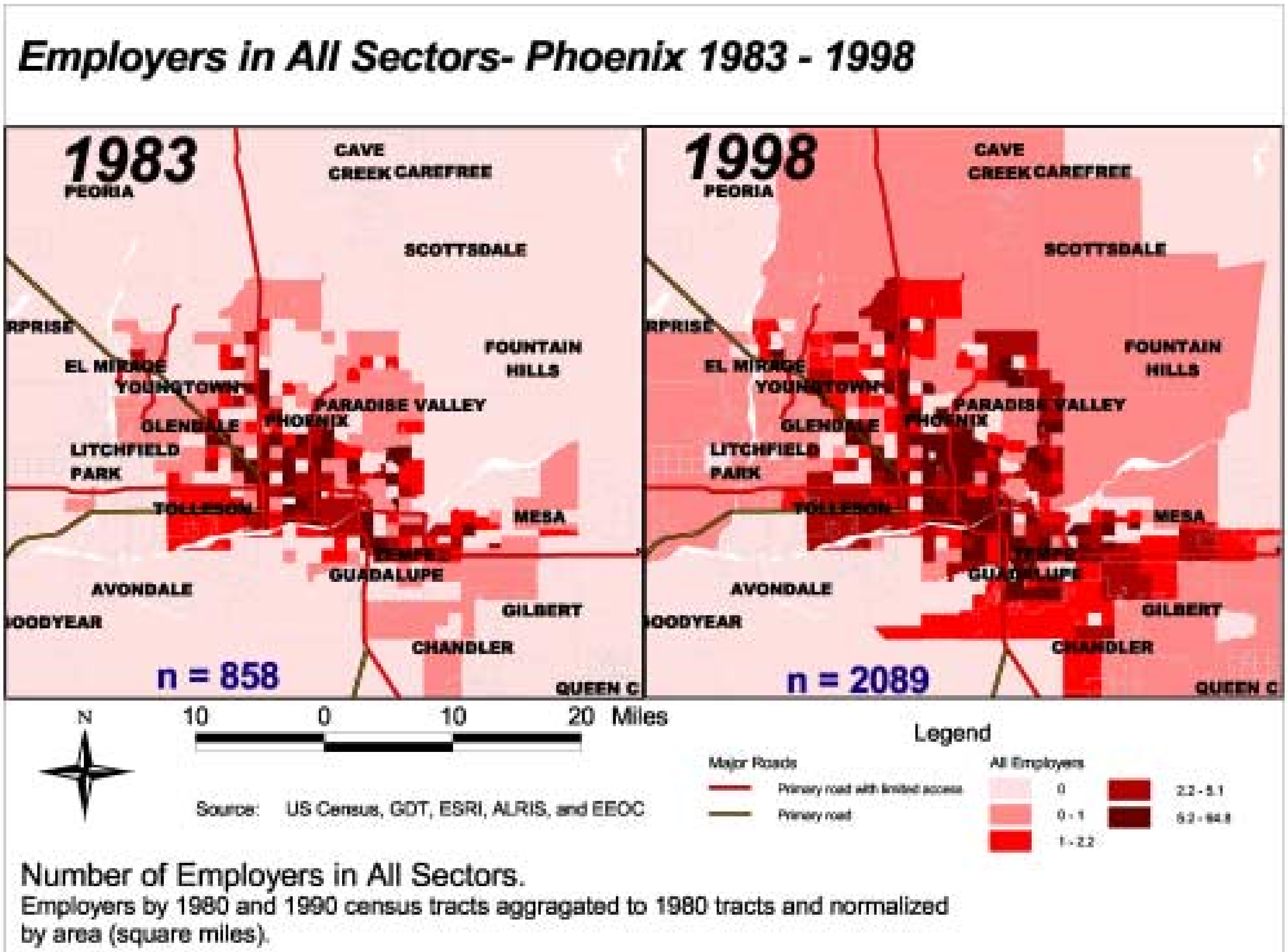

Figure 18. Number of employers in all sectors, Phoenix 1983-1998.

Phoenix has a white-collar work force. The largest occupational category in the Phoenix metropolitan area is office and clerical, followed by professionals. Professional and sales occupations have increased their share of employment over 15 years. Unskilled laborer and service jobs have also increased while clerical, skilled, and semi-skilled craft operative jobs have decreased. This pattern hints at a polarization of jobs in the Phoenix economy into highly skilled white-collar jobs and a smaller share of low-skilled blue-collar jobs.

Men's occupations are much more heterogeneous by race. For white men, professional occupations make up the largest job category, followed by officials and managers. For Hispanic men, the largest category is semi-skilled operatives and unskilled laborers, for Asian men they are professional and semi-skilled operatives: For African-American men, they are semi-skilled operatives and service; and for Native American men, they are semi-skilled operatives followed by skilled craftsmen.

Women's participation in professional and managerial jobs has increased. Women are disproportionately employed in service sector industries. The wage gap between men and women is larger for white women than for Hispanic, Asian, African-American, and Native American women (this may be due to the disproportionate employment of minority women in small firms, which are not covered by our data set).

The urban parks study conducted an initial survey of tree abundance in 15 parks. The study reveals a significant difference in tree abundance between upper- and middle-income parks, with upper-income parks having significantly more trees relative to middle-income parks. Lower-income parks also had a trend towards high abundance relative to middle-income parks, though the difference was not significant.

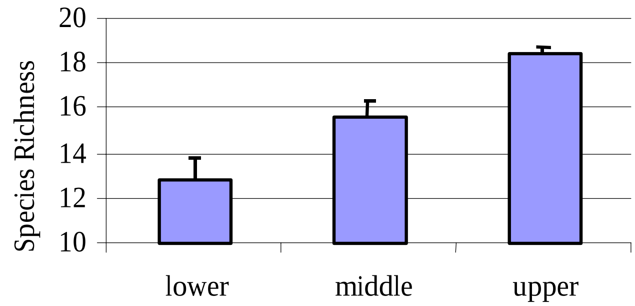

Figure 19: Species richness for socioeconomic status of neighborhood surrounding park.

An initial survey of bird diversity in our 15 focal parks indicates a significant effect (one-way ANOVA, p = 0.00029) of neighborhood lifestyle cluster on species richness (Figure 19). There was no significant effect of park age (p = 0.28) or size (p = 0.87) on species richness, though there is a slight (but not significant) trend towards higher diversity in newer parks.

Biogeochemical Processes

A detailed nitrogen mass balance was constructed for the Central Arizona–Phoenix ecosystem using "mined" data, literature sources, submodels of certain internal components, and preliminary CAP data. This detailed N mass balance (Figure 20) is apparently a first for an agro-urban ecosystem and is therefore a landmark effort. In particular, the influence of high nitrogen inputs and modified hydrology have been integrated into a conceptual model of nitrogen cycling in human-dominated ecosystems. A groundwater nitrogen mass balance is an important part of the whole-system nitrogen mass balance. This information can also be used to help guide more responsible use of commercial fertilizers by accounting for the use of high nitrate content groundwater for irrigation.

The diagnostic atmospheric deposition model allows hourly dry deposition fluxes of gaseous nitrogen species to be calculated for 1km x 1km grid squares across the entire study area. Input data consist of concentrations of ambient atmospheric concentrations of nitrogen species from state and county air quality monitoring stations, along with routine weather data (air temperature, incoming solar radiation, wind speed, relative humidity) from surface weather monitoring stations at a reference height in the atmosphere. Furthermore, the detailed land-cover classification developed by Stefanov et al., derived from Landsat imagery has allowed us to characterize separate surface types (urban, agriculture, bare soil, shrubs/xeric, open water, desert, forest) on the basis of albedo, emissivity, roughness length, heat conductivity, and water availability. This classification will allow a significantly more detailed treatment of dry N deposition to an urban area than previously possible.

In our model approach we used established equations for the calculation of dry deposition fluxes, selected from available published sources and which most suited the particular environmental conditions in the Phoenix area. The process of nitrogen dry deposition is part of the general momentum, energy and matter exchange between the atmosphere and the underlying land surface. Usually dry deposition fluxes are modeled by means of the concept of the deposition velocity $v_d = (r_a + r_b + r_c)^{-1}$ (with r_a aerodynamic, r_b boundary layer and r_c surface resistance), where r_a and r_b describe the micrometeorological transfer properties of the atmospheric surface layer and r_c the ability of the surface to take up matter. Mathematical descriptions of r_a are based on the Monin-Obukhov similarity theory and include functions expressing the stability of the atmosphere. Those stability functions are defined in terms

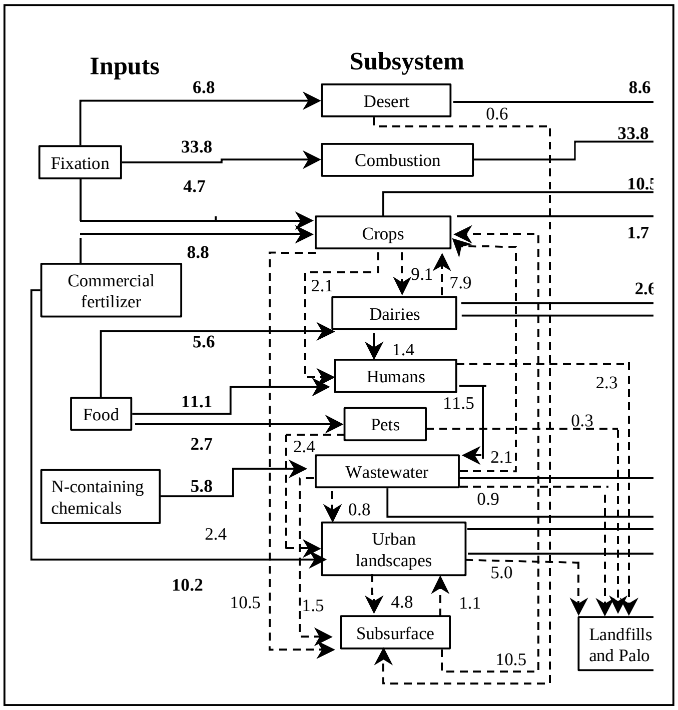

Figure 20. Diagram of nitrogen budget for the CAP ecosystem. All fluxes in 10^6 kg/y. Note that human mediated inputs constitute >90% (85/94) of inputs, whether deliberate (import of food, fuel, fertilizer) or inadvertent (fixation of N_2 during fossil fuel combustion) (Baker et al. in review).

of the surface sensible heat flux, which is in turn part of the surface energy balance equation. We used Survey-200 data to determine the fraction of irrigated vegetation in the model domain. This parameter is important for simulating the partition of the available energy from absorbed solar radiation between latent and sensible heat fluxes. The model is called a diagnostic model because it does not describe the feedback between the atmosphere and the surface. Those feedbacks are implicit in the monitoring data. The advantage of such a model is that all the monitoring data, which are available over long time periods, can be used to estimate dry deposition fluxes at different sites of the study area. The disadvantage is that it cannot deliver continuous spatial estimates.

Currently we are testing the model using data from a single ADEQ air quality monitoring site in central Phoenix. This work will shortly be extended to 5 other stations, using continuous monitoring data from an entire year, so that we can determine the magnitude of seasonal variations in nitrogen dry deposition fluxes. However initial simulation results show that annual dry deposition fluxes for gaseous nitrogen species are comparable to, or even higher than, fluxes modeled for the Los Angeles area. The results of this work are being written up for submission to the journal *Environmental Science and Technology*.

Geomorphology and Disturbance

Integrative investigations of a newly created lake*:* Microgravity measurements before and after lake filling show that mean water-table elevations below Tempe Town Lake have stayed close to pre-lake levels, but water table surface curvature has increased significantly, possibly indicating unanticipated groundwater flow directions. We also have measured nutrient and other chemical concentrations in lake, inflow stream, and ground waters since initial filling, as well as algal populations, biomass, and zooplankton. We view this project as an excellent microcosm of the entire study area, because this "urban experiment" involves all components envisioned in our conceptual scheme of urban ecosystems: land-use change, change in ecological conditions, human feedbacks, and geophysical and societal constraints and drivers.

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IV. Research Training and Development

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

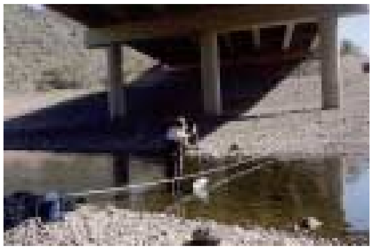

Figure 21. Graduate student sampling water from Salt River.

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 (Figure 21). The Goldwater Lab for Environmental Science has been expanded to accommodate CAP LTER'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 available to project researchers and graduate students.

Since the inception of CAP LTER, 11 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports 8 postdocs, 4 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. 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.

CAP LTER faculty members, postdoctoral associates, and senior graduate students have mentored 12 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. In many instances graduate students are full colleagues in the research activities, taking part in the framing, analysis, interpretation, presentation, and writing of results.

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. Attendance ranges from 3-10 people per meeting and includes faculty members, staff, postdoctoral associates, and graduate students. 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 and Completed

Anderson, S. Synthesizing spatio-temporal data for detecting and analyzing geographic change: A case study on urban change (Ph.D., Geography, E. Wentz).

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

Clark, K. Vertebrate species composition of desert islands in Phoenix (M.S., Biology, R. D. Ohmart).

Damrel, D. A horticultural flora of the ASU Arboretum (M.S., Plant Biology, D. J. Pinkava).

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).

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Honker, A. A river sometimes runs through it: a history of Salt River flooding and Phoenix (Ph.D., History, P. Iverson and S. Pyne).

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).

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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. The urban forest and microclimate: Interactive and feedback effects on CO_2 and water cycling (M.S., 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).

Vining, E. Plant-microclimate interactions (M.S., Plant Biology, T. Day).

Whitcomb, Sean 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

Applegarth, M. 2001. Interpretation of pediment form using geographic information technology and field data (Ph.D., Geography, R. Dorn).

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Fergason, K. C. 2001. Investigation of changes in water table elevation associated with Tempe Town Lake (M. S., Geology, J R. Arrowsmith and J. Tyburczy).

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IV. Education and Outreach

Figure 22. Middle school students present research results at the CAP LTER January Symposium.

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 (Figure 22). 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 year 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 the first week in April to get the ball rolling. The vice provost is committed to continuing his funding for at least another year and we expect by that time to have firmly established this program. As of now we see the four essential elements of this to be a comprehensive, interactive database, an electronic-environmental Aatlas,@ a series of models that would allow for a Asim-Phoenix@ approach to scenario-building, and an immersion ADecision Theater@ that would provide 3-D portrayals of scenarios for community policy-makers.

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. Attendance ranges from 3-10 people per meeting and includes faculty members, staff, postdoctoral associates, and graduate students. 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 real research conducted by university-level scientists; enhance teachers' capabilities to design lessons and activities that use scientific inquiry and encourage interest in science; provide access to and promote the use of CAP LTER 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 new Kid's Online Newsletter.

From the initial collaboration sparked with 12 schools in 1998, Ecology Explorers has expanded to include 34 schools, 46 teachers, 14 school districts, and 3 charter 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 year we have developed 3 new day-long workshops based on teacher requests. The topics covered in the workshops were: 1) mapping the schoolyard; 2) analyzing data; 3) insects in the classroom. A total of 21 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 (2 of whom are from school districts new to our program) and more than 12 ASU personnel. We will be offering two 2-week internships that allow the teachers to participate in a research project and learn how to collect and analyze data. They will be introduced to several hands-on, inquiry-based lessons developed from previous workshops and create new lesson plans that will be added to the Ecology Explorers Web site.

In Janury 2001, we surveyed our teachers to assess whether our programs are meeting their needs: 79% use our proctocols in some way (29% follow the protocols and enter data, 26% conduct the protocols but do not enter data, and 24% pick and choose among parts of the protocols that meet the needs of their class). Eighteen percent were not currently involved but planned to be soon, while 6% had been involved in the past but not currently. Six percent were not currently involved and did not plan to be involved in the future. We also found that 92% of the teachers had worked with the CAP LTER education personnel and that this was an important component of the program. We found that teachers use the Ecology Explorers Web site more than their students. Items that the teachers would like to see included on the web site were: lesson plans (47%), Web links (47%), extension activities (50%), graphs (53%), easier data entry and retrieval (30%). Teachers consistently reported that the reason they like this program is the integration of real research projects into their curriculum and the support they receive from CAP LTER staff. Participating teachers have applauded Ec9ology Explorers for the following attributes: "Authentic learning activities for students. Life skills for students. <u>Outstanding</u> support from CAP LTER staff. Chance to participate in a long-range project. Good way to integrate skills and curriculum." Based on feedback from teachers, we have developed several new Web features this year (http://caplter.asu.edu/explorers): online lesson plans developed by Ecology Explorer teachers, online slide sets, resource lists (Web-based and print),"Meet the Scientist" interviews, and some extension activities for several of the protocols. We have been working with the CAP LTER data personnel to make the data entry and retrieval features easier to use and hope to be able to produce real-time graphs within the next year. We are also working on a flash animation to simulate the ground arthropod protocol.

Through informal discussions with teachers, we know that they have a better understanding of ecological research, students' enthusiasm for projects 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. Teacher's 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 2 workshops for pre-service teachers. We have also presented one workshop for the Phoenix Union High School District's new Urban Systemic Initiative program. Contacts have been made with many members of the environmental education community, and joint programs are being developed. Our education staff 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. We have become involved in the reorganization process of the Arizona Association for Environmental Educators and will be organizing the poster session for the Fall 2001 meeting.

This year we have contributed to cross-site LTER activities by being active participants in the Schoolyard LTER education subcommittee, which was formed at the ASM meeting and reported to the Coordinating Committee meeting in April 2001 by Monica Elser. We have assisted the LTER network office in the development of an LTER-wide survey of schoolyard programs and are helping with the development of the LTER Schoolyard Web site.

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 200 Survey 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 Appendix B.

Dissemination of Research Projects and Results

In the 4 years of its existence, CAP LTER participants have presented over 200 professional posters and presentations. In addition, we have reached out to over 100 community organizations and schools representing over 2,500 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

2001

Berling-Wolff, S., and J. Wu. 2001. Simulating urban growth in the Phoenix metropolitan region: Relating pattern to process. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Bigler, W. 2001. Historic channel changes in the Salt River, Arizona, 1890-1931. Poster presented at 11-12 May 2001 *15th Annual Meeting of the Arizona Riparian Council*, Tucson.

David, J., and J. Wu. 2001. Toward developing a hierarchical patch dynamics modeling platform. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Grimm, N. B., and C. L. Redman. 2001. Ecological pattern and process and human-ecosystem interaction in central Arizona. Plenary presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Hobbs, R., and J. Wu. 2001. Perspectives for landscape ecological research. Presented at *IALE European Conference 2001*, Stockholm Sweden (30 June-2 July 2001) and Tartu, Estonia (3-6 July 2001).

Hope, D. C. Gries, W. Zhu, S. Carroll, A. Nelson, L. Stabler, C. L. Redman, N. B. Grimm, and A. Kinzig. 2001. Landscape pattern and process of an urban ecosystem: An integrated field inventory approach. Presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI.

Jenerette, G. D., M. A. Luck, J. Wu, N. B. Grimm, D. Hope, and W. Zhu. 2001. From points to regions: Estimating soil organic matter spatial patterns in central Arizona. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Jenerette, G. D., J. Wu, and N. B. Grimm. 2001. Spatial nitrogen dynamics and self organization. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Katti, M., and E. Shochat. 2001. Phoenix or Tucson – does landscape determine where Abert's Towhees choose to live? Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Katti, M., and E. Shochat. 2001. Bird species diversity in the greater Phoenix area, Arizona. Presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI.

Li, H., and J. Wu. 2001. Landscape analysis with pattern indices: Problems and solutions. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

McIntyre, N. E., and M. Hostetler. 2001. Effects of urban land use on pollinator communities in a desert metropolis. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Roach, W. J., and N. B. Grimm. 2001. Biogeochemistry in a extensively modified urban desert stream: Preliminary results from Indian Bend Wash. Presented at 11-12 May 2001 *15th Annual Meeting of the Arizona Riparian Council*, Tucson.

Schoeninger, R., C. Gries, and T. H. Nash. 2001. Herbarium databases: Creation, maintenance, and access via the internet. Poster presented at 12-16 August 2001, *Botany 2001: Plants and People*, Albuquerque, NM.

Shochat, E., and M. Katti. 2001. Differences in House Finch foraging behavior between Sonoran Desert and urban habitat in central Arizona. Presented at July 2001 *Animal Behavior Society Annual Meeting*, Corvallis, OR.

Shochat, E., and M. Katti. 2001. Phoenix or Tucson: Does landscape structure influence where Abert's Towhees choose to live? Presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI.

Stefanov. W. L. 2001. Desert geology. Presented at March 2001, *Design with the Desert Conference*, Arizona State University, Tempe.

Stefanov, W. L. 2001. Potential applications of remote sensing to assessments of road surface condition. Presented at April 2001, *50th Annual Roads and Streets Conference*, Arizona Consulting Engineers Association, Tucson.

Stefanov, W. L. 2001. Global urban center classification. Presented at 21-24 May 2001, *ASTER Science Team Meeting*, Tokyo, Japan.

Stefanov, W. L., M. S. Ramsey, and P. R. Christensen. 2001. Mapping of fugitive dust generation, transport, and deposition in the Nogales, Arizona, region using Enhanced Thematic Mapper Plus (ETM+) data. *American Geophysical Union EOS Transactions* 82(20):77-78.

Stiles, A., C. Gries, and S. Scheiner. 2001. Analysis of Sonoran Desert vegetation in the CAP LTER study area, Phoenix, AZ. Poster presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI.

Tueller, P. T., M. Limb, and J. Wu. Landscape pattern and ecosystem attributes on a western Nevada rangeland ecosystem. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Wu, J. 2001. Effects of changing grain size and extent in landscape characterization and pattern analysis: Generalities and idiosyncracies. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Wu, J. 2001. Top 10 list for landscape ecology in the 21st century: Introduction. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Wu, J. 2001. Top 10 lists for landscape ecology from M. Anthrop, R. J. Hobbs, S. A. Levin, A. S. Lieberman, R. V. O'Neill, and M. G. Turner. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Wu, J. 2001. Scales and processes of flow regime, hydrologic connectivity, and riverine landscape patterns on braided river floodplains. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

2000

Baker, L., D. Hope, N. Grimm, C. Martin, J. Briggs, and J. Klopatek. 2000. Carbon cycling in the central Arizona - Phoenix ecosystem: Advances in ecosystem carbon inventory, measurement, and monitoring. Presented October 2000 to USDA Forest Service, Raleigh, NC.

Elser, M., C. Saltz, and D. Boomgaard. 2000. Linking scientists, teachers, and children in long-term scientific reearch. Presented at December 2000 *National Science Teachers Association Regional Meeting*, Phoenix, AZ.

Harlan, S. L., and A. Nelson. Labor market trends in Phoenix: Preliminary findings. Presented December 2000, Equal Opportunity Commission, Regional Office, Phoenix, AZ.

Honker, A. 2000. Early reclamation and flood control on a local scale: The case of the Salt River in Phoenix. Presented at October 2000, *Western History Association Conference*, San Antonio, TX.

Rango, J. J. 2000. Patch isolation and priority effects and the structure of arthropod communities inahbitating creosote bush in central Arizona. Paper presented at August 2000, *The International Congress of Entomology*, Foz do Iguassu, Brazil.

LTER Symposia and Conferences

2001

***CAP LTER Third Annual Poster Symposium*, January 19, 2001, Center for Environmental Studies, Arizona State University.**

Arrowsmith, J R., S. E. Robinson, K. Fergason, J. A. Tyburczy, S. D. Holloway, and S. E. Wood. CAPLTER geology and geophysics. (Overview poster)

Bagley, A. Projecting new growth using SAM-IM.

Berling-Wolff, S., and J. Wu. Simulating the urban growth pattern in the Phoenix metropolitan region: relating pattern to process.

Bigler, W. Before the river became a lake: Historical channel change in the Salt River, Tempe.

Bolin, B., A. Nelson, E. Hackett, D. Pijawka, M. O'Donnell, S. Smith, D. Sicotte, and E. Sadalla. South Phoenix assessment of community and environment.

Brazel, A. J., C. A. Martin, D. Hope, A. Ellis, G. Heisler, L. Baker, S. Anderson, N. Selover, L. Stabler, R. Tomalty, and J. Blair. CAP LTER climate. (Overview poster)

Bruce, C., and D. Worley. Tracking growth in the Valley of the Sun residential completions (1990-1999).

Cousins, J. R., and J. C. Stutz. Trap cultures reveal higher species richness of arbuscular mycorrhizal fungi in comparison to soil samples in the Phoenix metropolitan area.

David, J. L., and J. Wu. Developing a hierarchical patch dynamics modeling platform.

Elser, M. M., and C. Saltz. Ecology Explorers: K-12 student contributions to the CAP LTER project. (Overview poster)

Fergason, K., R. Arrowsmith, and J. Tyburczy. Investigation of changes in groundwater elevation associated with Tempe Town Lake.

Fry, J., L. Nogue, C. Patterson, and C. S. Smith. Historic Land Use Phase II.

Grimm, N. B., L. A. Baker, D. Hope, W. Zhu, J. Anderson, A. Coppola, J. Edmonds, S. Grossman-Clarke, G. D. Jenerette, A. P. Kinzig, J. Klopatek, D. B. Lewis, M. A. Luck, M. Sommerfeld, P. Westerhoff, J. Wu, and Y. Xu. Biogeochemical processes in an urban ecosystem, metropolitan Phoenix, Arizona. (Overview)

Harlan, S., A. Nelson, E. Hackett, A. Kirby, B. Bolin, D. Pijawka, T. Rex, and D. Hope. Phoenix area social survey: Long-term monitoring of social interaction, and environmental change in urban neighborhoods.

Hope, D., S. Grossman-Clarke, W. Stefanov, and P. Hyde. Modeling nitrogen dry deposition inputs to the CAP LTER urban ecosystem.

Hope, D., C. Gries, W. Zhu, S. Carroll, A. Nelson, L. Stabler, C. L. Redman, N. B. Grimm, and A. Kinzig. Application of integrated inventory to the study of urban ecosystem: An extensive 200-site field survey of the Central Arizona-Phoenix LTER. (Overview poster)

Hope, D., N. B. Grimm, J. Anderson, and M. Clary. Atmospheric deposition of major nutrients across an urban-desert gradient in central Arizona.

Jenerette, D., K. Gade, N. Grimm, D. Hope, M. Luck, W. Marussich, and J. Roach. The ecological footprint workshop: Creating an ecological and social sciences interface.

Jenerette, G. D., M. A. Luck, J. Wu, N. B. Grimm, D. Hope, and W. Zhu. Spatial patterns of soil organic matter in central Arizona.

Katti, M. and E. Shochat. Phoenix Or Tucson - Does landscape determine where Abert’s Towhees choose to live?

Krutz, G., and G. Woodall. Dynamic political institutions and water policy in Central Arizona-Phoenix.

Martin, C., T. Day, J. Briggs, J. Stutz, and M. Sommerfeld. Primary productivity at the CAP LTER.

Marussich, W. A., J. MacHeffner, W. F. Fagan, and S. H. Faeth. Urban ecology: Population and community patterns. (Overview poster)

McCartney, P. Ecological informatics at CAP LTER. (Overview poster)

Nelson, A., B. Bolin, E. Hackett, D. Pijawka, E. Sadalla, D. Sicotte, D. Brewer, and E. Matranga. The ecology of risk in a Sunbelt city: A multi-hazard analysis.

Nelson, A., and S. Harlan. Labor market dynamics in a postindustrial city: A spatial and sectoral analysis of employment changes in the Phoenix MSA.

Putnam, C. Cactus Wren condos: Does urbanization affect the characteristics of Cactus Wren roost nests?

Putnam, F. ADWR groundwater model.
Rango, J., M. Tseng, and E. Shochat. 200 point survey: Vegetative arthropod community structure.
Rango, J., E. Shochat, M. Tseng, W. Fagan, and S. Faeth. Ground arthropod community composition in a heterogeneous urban environment.
Redman, C. L., and P. Gober. Human dimension of CAP LTER research. (Overview poster)
Roach, W. J., A. Coppola, and N. B. Grimm. Nutrient dynamics in arid urban fluvial systems: Canals and streams.
Shochat, E., and M. Katti. Bird species diversity in the greater Phoenix area.
Sicotte, D. Political and legal controversies over hazardous industrial waste in three central Arizona communities.
Stabler, L. B., C. A. Martin, and J. C. Stutz. Potential effects of mycorrhizal associations on urban tree carbon storage potential.
Stiles, A., and S. M. Scheiner. Analysis of desert vegetation data from the 200 sites survey.
Warren, P., and A. Kinzig. Ecological and social factors predicting avian diversity in urban parks.
Whitcomb, S. A., J. C. Stutz, and C. A. Martin. Spatial patterns of belowground respiration and related soil parameters in a simulated xeric urban landscape.
Wu, J., J. L. David, G. D. Jenerette, M. Luck, and S. Berling-Wolff. Modeling land use change and ecosystem processes of the Phoenix metropolitan landscape. (Overview poster)
Zschau, T., S. Getty, C. Gries, and T. H. Nash III. Spatial and temporal variation of elemental deposition in Maricopa County, Arizona.

Community Outreach Presentations and Miscellaneous Activities

2001

Stefanov, W. L. 2001. Remote sensing of soil development and hillslope processes using Thermal Infrared Multispectral Scanner (TIMS) data. Invited, special seminar. U.S. Geological Survey Field Office, Tucson, AZ.

2000

Baker, L. 2000. Nitrogen cycle in the central Arizona - Phoenix ecosystem. Presented November 2000 at Donald Bren School of Environmental Science and Management, University of California-Santa Barbara, Santa Barbara, CA.
Harlan, S., and A. Nelson. 2000. Labor market trends in Phoenix, AZ: Preliminary results. Presented December 2000 to Equal Employment Opportunity Commission, Phoenix, AZ.
Redman, C. L., and M. Elser. 2000. Ecology Explorers and environmental education. Presented September 2000 to Valley Forward, Phoenix, AZ.

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

2001

Anonymous. 2001. Urban ecology, nature in an urban setting. *Arizona Water Resources* 9(5):1, 12.
Campbell, G. 2001. Discussion panel addresses Valley's long-term future. *ASU Insight* March 30, 2001.
Campbell, G. 2001. Project to help shape city's 100-year future. *ASU Insight* April 13, 2001:1,7.
Grant, B., ed. 2001. Environment among ASU's top strategic research areas. *Campaign for Leadership: Campaign Moments* Winter 2001:6. Arizona State University, Office of Development.
Kelly, C. Roots of landscaping. *The Arizona Republic* March 25, 2001, Arizona Diary, F:1, 5.
Kuby, L., ed. 2001. Environmental Risk Group: Paving the way for interdisciplinary cooperation. *Center for Environmental Studies Newsletter* 4(1):1.
Kuby, L., ed. 2001. Spotlights: CAP LTER's 3rd annual symposium. *Center for Environmental Studies Newsletter* 4(1):2.
Kuby, L., ed. 2001. Spotlights: CAP LTER research "nuggets." *Center for Environmental Studies Newsletter* 4(1):2.
Redman, C. L. 2001. From the director's desk: Charles L. Redman. *Center for Environmental Studies Newsletter* 4(1):1.

Roberts, C. 2001. Taking the global view. *Inside iT: Information Technology Online Magazine* January Issue http://www.asu.edu/it/fyi/insideit/articles/article1.html

2000

Anonymous. 2000. Cities: The past, present and future of human ecosystems. *Connections* 2(1):1-2.

Anonymous. 2000. University receives $5.4 million in graduate training grants. *ASU Insight* August 18, 2000:3.

McCartney, P. 2000. Ecological data warehouse: Open for business. *Center for Environmental Studies Newsletter* 3(3):1.

Waide, R. 2000. Y2K All Scientist Meeting a success. *LTER Network News* 13(2):1, 7.

Appendix A
Participants

Principal Investigators/Project Directors

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

CoPrincipal Investigator(s)

Stuart G Fisher, Biology	1997-present	Stanley H Faeth, Biology	1997-present
Jianguo Wu, Life Sciences ASU W	1997-present	William F Fagan, Biology	1997-present
Alfredo G de los Santos, Maricopa Comm Colleges	1997-present	Patricia Gober, Geography	1997-present
		Jeffrey M Klopatek, Plant Biology	1997-present
Steve S Carroll, Biology	1997-present	Thomas H Nash III, Plant Biology	1997-present
Lawrence A Baker, Civil/Env Eng	1997-present	Michael B Ormiston, Economics	1997-2000
Elizabeth K Burns, Geography	1997-present	K David Pijawka, Plng/Lndscpe Des	1997-present
Phillip R Christensen, Geological Sci	1997-present	Milton R Sommerfeld, CLAS/Plant Bio	1997-present
Thomas A Day, Plant Biology	1997-present	Frederick A Staley, Curr/Instruction	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 Project 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	Glen S. Krutz, Political Science	1999-present
Robert C Balling, Geography	1997-present	Michael Kuby, Geography	1997-1999
C. Michael Barton, Anthropology	1997-present	Larissa Larsen, Plng/Lnds Arch	2000-present
Neil S Berman, Chem/Mat Eng	1997-present	Leslie R Landrum, Plant Biology	1998-present
Robert Bolin, Sociology	1999-present	Theresa A Markow, Plant Biology	1997-1998
Ward W Brady, Resrce Mgmt, ASU E	1997-1999	Chris A. Martin, Plant Biology	1997-present
Anthony J Brazel, Geography	1997-present	James W. Mayer, Ctr for Solid State Sci	1998-1999
John M Briggs, Plant Biology	1999-present	Rob Melnick, Morrison Institute	1997-present
Timothy P Craig, Life Sciences, ASU W	1997-present	Laura R Musacchio, Plng/Lnds Arch	1999-present
Lisa C. DeLorenzo, Public Affairs	1999-2000	Michael Musheno, Center for Urban Inq	1997-1999
Pierre Deviche, Biology	2000-present	Margaret C Nelson, Anthropology	1998-present
Ronald I Dorn, Geography	1997-present	Robert D Ohmart, Biology	1997-present
Michael E Douglas, Biology	1998-present	Xochitl Orzoco, Biology	2001-present
James F Eder, Anthropology	1997-1999	David L Pearson, Biology	1997-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 Engr	1997-1999	Glen E Rice, Anthropology	1997-present
Jana Fry, GIS Lab	1997-present	Edward K Sadalla, Psychology	1998-present
Douglas M Green, Resrce Mgmt, ASU E	1997-present	Samuel M Scheiner, Life Sci, ASU W	1997-present
Corinna Gries, Plant Biology	1997-present	Arleyn W Simon , Anthropology	1997-present
Edward J Hackett, Sociology	1998-present	Andrew T. Smith, Biology	1998-1999
Sharon Harlan, Sociology	1999-present	Katherine A Spielmann, Anthropology	1997-present
Timothy D Hogan, Economics	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, ASUWest	2000-present	Paul C Westerhoff, Civil/Env Eng	1997-present
Carol C Klopatek, Microbiology	1997-1999	Shapherd Wolf, Sociology	2000-present

Susan Wyckoff, Physics & Astr/ACEPT	1997-present	Sander van der Leeuw, Sorbonne, Paris	1999-present
James A Tyburczy, Geological Sciences	1998-present	Rita Walton, Maricopa Assn of Govts	1997-present

Postdoctoral Research Associates

Suzanne Grossman-Clarke, Mech/Aero Eng /CES	2000-present	Amy L Nelson, CES	1999-present
Mark Hostetler, CES/Biology	1997-1999	Eyal Shochat, CES/Biology	2000-present
Madhusudan V Katti, CES/Biology	2000-present	William Stefanov , Geological Sciences	2000-present
Kimberley Knowles-Yanez, CES	1997-1999	Paige Warren, Biology	2000-present
David B Lewis, CES/Biology	2000-present	Russell Watkins, CES	1999-2000
Nancy E McIntyre, CES/Biology	1997-2000	Wanli Wu, CES/Biology	2001-present
Markus Naegeli, Biology	1998-1999	Weixing X Zhu, CES/Biology	1999-2000

Other Collaborators

Dave Anning, USGS	1998-present	Charles Kazilek, Life Sciences Vis Lab	1999-present
Barbara Backes, Life Sciences Vis Lab	1999-present	John Keane, Salt River Project	1997-present
Laural Casler, Life Sciences Vis Lab	2000-present	Robert Minckley, Auburn University	1999-2000
Ken Fossum, USGS	1998-present	Fred Rainey, Louisiana State University	1999-present
Steve Getty, University of New Mexico	1998-1999	Conrad Storad, ASU Research Publications	1997-present

Research Technical Personnel

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

Public Outreach Personnel

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

Office Personnel

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

Graduate Research Associates

Sharolyn Anderson, Geography	1999-2000	Jamaica Cousins, Plant Biology	1999-2000
Stephen Ammerman, History	1998-1999	Dixie Z Damrel, Plant Biology	1998-1999
Todd D Becker, Economics	1998-1999	Lisa Dent, Biology	Summer 1998
Sheryl Berling-Wolf, Plant Biology	2000-present	Dean Dobberfuhl, Geological Sciences	2000-presnet
JoAnne Blank, Plant Biology	2000-2001	Jennifer W Edmonds, Biology	1999-present
Karen E Blevins, Geography	1998-1999	Kenneth Fergason, Geological Sciences	1999-2000
Debbie A Brewer, Geography	1999-2000	Kris Gade, IGERT Fellow	2000-present
Sarah Celestian, Plant Biology	2001-present	Wei Gao, Geography	Spring 1998
Kevin B Clark, Biology	1998-1999	Aisha M Goettl, Biology	2000-present
Tim Collins, IGERT Fellow	2000-present	Root Gorelick, Economics/Biology	1999-2000
Mark A Compton, Plant Biology	1998-2000	Dennis C Gosser, Anthropology	1998-1999

Zhan Guo, IT	2001-present
Dennis Hale, Curr/Instruction	1997-1998
Brent Hedquist, Geography	2001-present
Stephen D Holloway, Geological Sciences	1997-1998
Andrew M Honker	1999-2000
Justin S Hoppman, Plng /Lndscp Arch	1998-2000
Paul Ivanich, Geological Sciences	2000-present
Jeffrey James, Geography	Spring 1998
G Darrel Jenerette, ASU W Life Sci	1998- present
Brenda Koerner, Plant Biology	2000-present
Michael LaBianca, Sociology	1999-2000
Hongyu Liu, Life Sciences, ASUW	1998
Matthew A Luck, Biology	1998-2000
Joaquin Maruffo, Plng/Landscp Arch	1998
Wendy A Marussich, Plant Biology	1999-present
Eric S Matranga, Geography	1999-2000
Nicole McPherson, Civil/Env Eng	1998-1999
Cherie Moritz, Plant Biology/GIS	Fall 1998
Erin Vining Mueller, Plant Biology	1998-1999
Leslie Nogue, Anthropology	2000-present
Maureen O'Donnell, Sociology	2001
Michelle M Oleksyszyn, Plant Biology	1998-1999
Elena Ortiz-Barney, Plant Biology	2001-present
Alanna E Ossa, Anthropology	1998-1999
Gemma Paulo, Economics	Spring 1998
Kathleen A Peterson, Plant Biology	1999-2000
Jennifer Rambo, Biology	2001-present
Jessamy Rango, Biology	1998-present
Eva C Reid, Geography-GIS Lab	1999-2000
Martin Roberge, Geography	1998-1999
Sarah Robinson, Geological Sciences	1998-present
Michael Rogers, Curr/Instruction	1998-1999
Bruce Ryan, Plant Biology	Summer 1999
Samuel Schmieding, History	1998-1999
Diane M Sicotte, Sociology	1998-present
Curtis Sommer, Anthropology	1999-2000
Kim Sonderegger, Anthropology	1998
L Brooke McDowell Stabler, Plant Bio	1998-present
William L Stefanov, Geological Sciences	1998-2000
Arthur Stiles, Plant Biology	1998-present
Glenn Stuart, Anthropology	1999-present
Anne Sumner, Curr/Instruction	1999-2000
Steven J Swanson, Anthropology	1998-1999
Wendy Thomas, Geography	Spring 1998
Niccole Villa, Geography	1998-1999
Gretchen Walters, Plant Biology	1998-1999
E Christian Wells, Anthropology	1998-1999
Jill Welter, Biology	Summer 1998
Sean Whitcomb, Plant Biology	2000-present
Gina Serignese Woodall, Political Science	1999-2001
Steven Wood, Geological Sciences	1998-1998
Ying Xu, Civil/Env Eng	1998-present
Angel Zambrano, Plant Biology	1998-1999
Toralf Zschau, Plant Biology	1998-1999

Other Grads

Jeremy Buegge, Plant Bio, Eco Exp	1999
Jenny Draevich, Biology, Eco Exp	1998
John Frich, Biology, Eco Exp	1998
Nancy Jones, Plng/Lnds Arch	2000-present
Elena Ortiz-Barney, Plant Bio, Eco Exp	2000

Research Experience for Undergrads (REU*)*

Joanne C Blank, ASU	Summer 1999
Shawn A Boone, Texas A&M	Summer 1999
Andy H Chan, UC Berkeley	Summer 1998
Noah D Dillard, Kalamazoo College	Summer 2000
Christopher Farley, Colorado State	Summer 1998
Matthew de la Pena Mattozzi, Harvey Mudd College	Summer 2000
Christopher Putnam, ASU	Fall 2000
Erik J Wenninger, U of Toledo	Summer 1998
Selena L Wightman, U of Virginia	Summer 1999

Other Undergrads

Christopher Anto	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 Sciences	Summer 1999
Natalie Case, Hughs BREU; urban 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 Farley, Biology	2000-present
Travis Fears, IT/Ecology Exp Web site	1998-1999
Ayoola Folarin	1998-1999
Jennifer Folsom, IT/Eco Exp Web site	1998-1999
John Frich, Biology	1999-present
Cyd Hamilton, Biology	1998
Marc Hinze, Biology	1998-1999
Moe Moe Htun, Bird data entry	1998-1999
Jennifer Hunter, Hughs BREU, urb lakes	1999
Lisa Lauver, Civil/Env Eng	1998-1999
Christian Lawrence, Biology; arthropods	1999-1999
Katie LeBlanc, Anthro, CES office supp	1997-1999
Brian Lutz, Bio/Society, Ecology Exp	1999-present
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

Tracy Osborn, Civil/Env Eng	1998-1998	Chris Sommers, IT/Eco Exp Web site	1998-1999
Chris Patterson, GIS Lab	2000-present	Maria Tcherepova, Plant Biology	Summer 2000
Christopher Putnam, Biology	2000-present	Lisa Thompson, CES, office	1998-present
Brenda Rascom, Biology	2000-present	Brian Tong, Birder data entry	1999-2000
Barbara Schmidt, Plant Bio	Summer 2000	Sean Walker, Biology; arthropods	1998-1999
Brian Sherman, IT, Eco Exp	Spring 1998	Jennifer Zachary, Biology	1999-2000

High School Students

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

Pre-College Teachers

Robert Atwood, Meyer Elementary	1999-2000	Sharon Langston, Monte Vista Elem	1999
Renee Bachman, W.T. Machan Elem	1999-2001	Karen Lee-Price, Moon Mntn School	2000
Joyce Baldwin, Sacaton Middle School	1998-2000	Gene Lescallete, Desert Mountain HS	2000-2001
Jim Barnette, Zedo Ishikawa Elementary	1999-2000	Jim Little, Rhodes Jr. HS	2000
Paula Beacom, Lowell Elementary	1999-2001	Sharin Manes	2000-2001
Chuck Bell, Deer Valley HS	1999-2000	James Mangles, Estrella Mtn Elem School	2000-2001
Wendy Blasdell, Mountain View HS	1999-2001	Jim Manley, Stevenson Elementary	1998-2000
Dave Boomgaard, Brimhall Jr. HS	1998-2001	Mary Martine, Kiva Elementary	2000-2001
Carole Boling, W.T. Machan Elementary	1999-2001	Vickie Massey, Mendoza Elementary	1998-2001
Scott Bowling, Discovery Elementary	1998-2001	Marjorie McKenzie	
Karen Braccio, Desert Canyon Elementary	2000-2001	D'Anne McDaniel, Fees Middle School	2000-2001
Linda Calderon, Desert Harbor Elementary	2000-2001	Stephanie Mihalic, Greenway Mid School	2000-2001
Tracy Carlson, Holmes Elementary	2000-2001	Birgit Musheno, Desert Vista HS	1999-2001
Sharlene Cardona, Falcon Hill Elem	1999-2001	Donna Palladino, Copper Canyon Elem	2000-2001
Dave Carpentar, Meyer Elementary	1999-2000	Gary Patterson, Skyline HS	1999-2001
Jon Ciulei, Trevor Browne HS	2000-2001	Kathleen Pelley, Evans Elementary	1998-2001
Brian Clark, NFL-YET Prep Acad	2000-2001	Trish Peters, Pueblo Elementary	1999-2000
Meg Davis, McKemy Middle School	1998-2001	Kris Rademacher, Desert Vista High School	1998-2001
Joelle Don de Ville, St. Mary's HS	1998-2000	Nancy Ragle, McKemy Middle School	2000-2001
Ed Eberle, Dobson HS	1998-1999	Lisa Randall, Stevenson Elementary	1998-2001
Vickie Eberle, Sunridge Learning Center	1998-1999	Robin Renaud, Moon Valley HS	2000-2001
Ann English, Desert Eagle HS	1999-2001	Linda Sargent, Mountain View HS	2000-2001
Michelle Fink, Meyer Elementary	1998-2001	Darlene Sitzler, Eisenhower Elementary	1998-2001
Ann Flagg, EDU Prize	1999-2001	Mike Sliskovich, Supai Middle School	2000-2001
Margaret Fons, Sirrine Elem School	2000-2001	Jan Snyder, Camelback HS	2000-2001
Gerry Foster, Mesquite HS	1999-2000	Susan Soroka, McKemy Middle School	2000
Scott Greenhalgh, Tempe Union HS	1999-2001	Kara Steiner, Mendoza Elementary	2000-2001
Wendy Hansen, Jefferson Elem School	2000-2001	Joyce Sterret, Trevor Browne HS	1998-2000
Bette Hanscon, McKemy Middle School	2000-2001	C. J. Steven, Mountain Pointe HS	2000-2001
Irene Hawkins	2000-2001	Ryan Swartz, Moon Valley HS	2000-2001
Janet Henderson, Deer Valley Mid Schl	1999-2001	Rob Trenck, Red Mountain HS	2000-2001
Erin Hilligos, Squaw Peak Elem School	2000-2001	Toby Tucker, Fountain Hills HS	1998-1999
Heather Holmes, Desert Harbor Elem	1999-2000	Paul Vachon, Royal Palm Middle School	2000-2001
Susie Huffaker, Meyer Elementary	1999-2001	Michelle Volk, Kyrene Aprende Mid Schl	1999-2001
Tad Int-Hout, Desert Harbor Elementary	1999-2001	John Wallace, Mountain View High School	1998-2000
Sue Johnson, The Family School	1999-2000	Pamela Whitaker, Thunder Mtn Middle	2000-2001
Teresa Krause, Mendoza Elementary	1998-2001	Kimberly Wilson, Kyrene Pueblo Mid Schl	2000-2001
Larry Langstaff, Hendrix Jr. HS	1999-2001	Susan Wiseman, Arthur M. Hamilton Schl	2000-2001

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
Barbara Barnes, Bird Survey
Millie Billotta, Bird Survey
Terry Brodner, Bird Survey
Joshua Burns, Bird Survey
Adam Burdick, Bird Survey
Eleanor Campbell

Evie Chadbourn, Bird Survey
Marty Chew, Bird Survey
Tillie Chew, Bird Survey
Marti Cizek, Bird Survey
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
Carolyn Modeen, Bird Survey
Pete Moulten, Bird Survey
Roy Muehlberger, Bird Survey
Andrea Nesbitt, Bird Survey
Laurie Nessel, Bird Survey
John Nichol, Bird Survey
Maxime Parent, Bird Survey
Tom Partel, Bird Survey
Bill Peterson, Bird Survey
Stella Peterson, Bird Survey
Joan Powers, Bird Survey
Timothy Price, Bird Survey
Peg Purcell, Bird Survey
Beverly Rambo, Bird Survey
Jennie Rambo, Bird Survey
Linda Rawles, Bird Survey
Nancy Reed, 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 Technology, ASU
Arizona Science Center
Arizona State Land Dept
Arizona Tribal Coalition, UT-CO-AZ-NM-Rural Systemic Initiative
Arizona Collaborative for Excellence in Preparation of Teachers (ACEPT), ASU
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 the 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

The following businesses/organizations/agencies have given the CAP LTER project permission to conduct long-term monitoring of ecological variables on their sites:

- 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

APPENDIX B
CAP LTER PROJECTS, 1997-2001

*Lead PI listed first, student research associates in parentheses (), techs/field assts. in brackets [], *italics* indicate former participants in ongoing projects

No	Team	Title	Project Type	Participants*	Start Date	Status
1	DB	Establish pilot GIS database	Data synthesis	Fry, McCartney, Wu, Wentz (Gao, Maruffo, Swanson, Wells)	Fall 97	Completed
2	DB	Using Remote Sensing to Define Patch Typology	Long term	*Ramsey*, Christensen, Hope, Burns, Wu, Gober, Stefanov	Fall 97	Ongoing
3	LU	Urban Fringe Morphology	One time	Burns, Gober, Walton, Knowles-Yanez (James, Blevins)	Spring 98	Completed
4	DB	Modeling: Initial Structure and Work on GIS	Data synthesis	Wu (Luck)	Spring 98	Ongoing
5	GE	Century-scale Channel Change	One time	Graf (Roberge)	Spring 98	Completed
6	GE	Quaternary Geomorphology Study and Data Synthesis	One time	Arrowsmith (Robinson, Wood, Holloway)	Spring 98	Completed
7	NU	Nutrients and Data Synthesis, Mass Balance	Data synthesis	Hope, Baker, McCartney (Ying, Lauver, McPherson)	Spring 98	Completed
8	NU	Aquatic Core Monitoring (Continuation of NAWQA)	Long term	Hope, Grimm, Baker (Edmonds, Goettl)	Fall 97	Ongoing
9	NU	Lichen Resurvey with Heavy Metal Analysis	Repeat experiment	Gries, Nash, Getty (Zschau, Zambrano)	Spring 98	Completed
10	PO	Pilot Arthropod Sampling	Long term	Faeth, Fagan, McIntyre, Shochat, (Rango) [Tseng, McKelvy, Stuart]	Spring 98	Completed
11	PO	Plant Survey of Current Vegetation	Data synthesis	Scheiner (Stiles)	Spring 98	Ongoing
12	PO	Bird Survey with Data Synthesis	Data synthesis	*Hostetler*, Katti, Shochat, *Pearson*, *Ohmart*, Deviche [Stuart, Rambo, Hulen, Lemmer, Bachman]	Spring 98	Ongoing
13	ED	Ecology Explorers	Long Term	Staley, *Lindauer*, Elser, *Williams*, Kyle, (*Hale, Rogers*, *Sumners*)	Fall 97	Ongoing
14	OM	Comparison Among Residential Patch Transition Types; Before-After	One time	Martin, Brazel, Burns (Stabler, Peterson, Blank)	Spring 98	Completed
15	DI	General Model of Urban Fire Ecology	One time	Pyne (Schmieding, Ammerman)	Summer 98	Completed
16	GE	Historic Records of Climate in Valley	One time	*Balling*	Spring 98	Not conducted
17	LU	Hohokam Canals as Multi-Use Facilities	One time	Spielmann, Rice (*Sonderegger*)	Spring 98	Pending
18	HU	Economic Analysis, Open Space	One time	Hogan, Ormiston (Becker)	Spring 98	Completed
19	LU	Historical Land Use Database	Long term	Redman, *Knowles-Yanez*, Fry, McCartney, Keane (*Moritz,* Reid, Hoppman) [Smith]	Summer 98	Ongoing
20	GE	Multi-Temporal Remote-Sensing Data Acquisition for CAP LTER Land Cover/Land Use Monitoring and Modeling	Data synthesis	Ramsey, Wu, Burns, (Stefanov)	Summer 98	Completed
21	PP	Above and Below Ground Estimates of Urban Plant Biomass	Repeat experiment	Klopatek, Klopatek	Summer 98	Not conducted
22	PO	Assessing Biodiversity of Arbuscular Mycorrhizal Fungi	Repeat experiment	Stutz, Martin (Cousins)	Summer 98	Ongoing
23	PO	Vertebrate Species Composition of Remnant Desert Islands within Urban Phoenix	One time	Ohmart, Clark	Summer 98	Completed
24	NU	Urban Lakes: Recipient Systems for Nutrients and Contaminants	Long term	Sommerfeld (Compton, Hunter, Case) [Holland, Myers, Bradbury, Walters, Karl]	Summer 98	Completed
25	PO	Scorpions in Urban Environments	One time	McIntyre	Fall 98	Completed
26	PO	Effects of Urban Horticulture on Insect Pollinator Community Structure	One time	*Hostetler*/McIntyre [sample collection: Compton, Hope, Stabler, *Naegeli*, Rango, Rissing, Stefanov, Stiles, Walters, Wells, Williams, *Zhu*, Bradbury, Holland, Meyers; taxonomic id, Minckley]	Fall 98	Completed
27	PO	Survey 200	Long term	Redman, Grimm, Hope, Gries, Carroll, *Zhu*, McCartney (Stabler, Stiles) [Rosales, Myers, Clary, Lemmer, Budet de Jesus, Paine, Tseng, Walters, Kochert] other: Martin, Green, Scheiner, Brazel, McIntyre, Faeth, Nelson, Burns, Katti, Shochat, Stuart, Rainey	Spring 99	Ongoing
28	NU	Urban Storm Runoff		Hope, *Naegeli*, Grimm	Spring 99	Completed
29	LU	Are Microclimates Sustainable on the Urban Periphery of Phoenix, Arizona?	One time	Brazel (Anderson)	Fall 98	Ongoing
30	GE	Decade-Scale Change by Channel Eng: The Rio Salado (Tempe Town Lake) Project--Hydrogeologic component	One time	Arrowsmith, Tyburczy (Fergason)	Fall 98	Completed
31	NU	Atmospheric Deposition	Long term	Hope, Grimm, Anderson [Clary, Paine, *Holland, Bradbury*] (*Boone*)	Fall 98	Ongoing

32	HU	Environmental Risk	Long term	Bolin, Hackett, Pijawka, Sadalla, van der Leeuw, Nelson (Brewer, Mtranga, Sicotte)	Fall 98	Ongoing
33	PO	Backyard Bird Survey	Long term	*Hostetler*, Katti, Shochat, *Pearsom. Ohmart*, Deviche [Stuart, Rambo, Hulen, Lemmer, Bachman]	Spring 98	Ongoing
34	PO	Point Count Bird Censusing	Long term	*Hostetler*, Katti, Shochat, *Pearsom. Ohmart*, Deviche [Stuart, Rambo, Hulen, Lemmer, Bachman]	Summer 98	Ongoing
35	NU	Canal Study	One time	Grimm, Hope (Roach)	Summer 99	Completed
36	PO	Bruchid Beetle Study	Long term	Craig (Wallace)	Spring 98	Ongoing
37	LU	Spatial/Temporal Change of Climate/Air Quality in Relation to Urban Fringe Development	One time	Brazel, (Selover, Vose)	Summer 99	Ongoing
38	GE	Prediction Model of the Presence of Bedrock Pediments vs. Alluvial Slopes	One time	(Applegarth) Dorn, Brazel	Spring 00	Ongoing
39	LU	Urban Fringe Infrastructure Morphology	One time	Burns, Nelson (Sun)	Spring 00	Ongoing
40	HU	A River Used to Run Through It: Water Use and Flooding in Phoenix	One time	Honker	Spring 00	Ongoing
41	HU	Phoenix Area Social Survey	Long term	Harlan, Nelson, Hackett, Sadalla, Bolin, Pijawka, Hogan, Rex, Kirby	Spring 00	Ongoing
42	LU	Gender and Racial/Ethnic Inequality in Postindustrial Urban Labor Markets: A Spatial and Sectoral Analysis of Employment Changes	One time	Nelson, Harlan (Sicotte, LaBianca)	Spring 00	Ongoing
43	HU	Dynamic Political Institutions and Water Policy in Central Arizona - Phoenix	One time	Krutz (Serignese)	Summer 00	Ongoing
44	NU	Nutrient Transport and Retention in Urban Watersheds	Long-term	Grimm, Hope, *Zhu,* Lewis (Roach, Jennerette, Goettl, Dillard, Zachary)	Spring 2000	Ongoing
45	HU	Social Area Analysis	One time	Nelson, Martin	Summer 00	Ongoing
46	PO	The Effects of Urbanization on Reproduction in Birds	One time	Katti, Deviche	Summer 00	Ongoing
47	PO	Plant Species Richness Patterns in the CAP LTER Area (initially part of project 11)	Data synthesis	Pinkava, Landrum, (Damrel)	Spring 98	Completed
48	PP	Effects of Urban Ground Cover on Microclimate and Landscape Plant Performance (initially part of project 14)	One time	Day, (Vining Mueller)	Spring 98	Completed
49	LU	Land Use Effects on Temperature and Humidity along a Urban-Rural Transect Gradient (initially part of project 14)	One time	Martin, Brazel (Stabler)	Summer 98	Completed
50	OM	Soil CO_2 Flux and Enzyme Activity Under Two Patch Type Conversions (initially part of project 14)	One time	(Oleksyszyn) Green	Spring 98	Completed
51	PP	Landscape Water Use Efficiency (initially part of project 14)	One time	Stabler, Martin	Spring 98	Completed
52	HU	Urban Parks	Long term	Kinzig, Martin, Warren, Katti, Shochat, (Blank)	Fall 2000	Ongoing