# CAP LTER 2004
# ANNUAL 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 2004

## I. Overview of Results and Broader Impacts of CAP1

### Overview

Seven years ago, we began a comprehensive study of rapidly urbanizing central Arizona, encompassing the Phoenix metropolitan area. Adding to the usual LTER challenges, the study of an urban ecosystem requires us to understand the consequences of intensive human actions, radically altered land cover, accelerated cycling of materials, and ecological impacts of a built environment. As at traditional LTER sites, interdisciplinary collaboration of ecologists, biogeochemists, earth scientists, and climatologists is fundamental but, for a city, sociologists, geographers, economists, urban planners, anthropologists, engineers, and many community partners are also essential. The lessons we learn are helping to frame a new ecology theory that integrates social with ecological variables (Redman 1999; Collins *et al.* 2000; Grimm *et al.* 2000; Kinzig *et al.* 2000; Zipperer *et al.* 2000; Grimm *et al.* 2002; Redman *et al.* 2004).

Phoenix has proven to be an exciting and stimulating environment for one of the LTER network's urban sites. The Phoenix metropolis is situated in a broad, alluvial basin at the convergence of the Salt and Gila rivers. The region is dotted with eroded volcanic outcrops and rimmed by mountains that once supported a vast expanse of lowland desert and riparian systems, but now houses the sixth-largest city in the US. Growth of the metropolitan population has occurred mostly in the second half of the 20th century (and by 47% since 1990 to over 3.5 million people [US Census Bureau 2000]); the expanding urban fringe initially consumed farmland, but more recently has been established largely on desert land. This growth has been underpinned by water-supply projects involving the construction of local reservoirs and the Central Arizona Project Canal (Kupel 2003), as well as by development of air conditioning and widespread use of motor vehicles (Gammage 1999). Reliance upon irrigation to create and sustain agricultural production and urban landscapes has given rise to an abrupt delineation between managed landscapes with their exotic plants and undeveloped desert with its native vegetation (Hope *et al.* 2003). Water use is the single-most important controlling factor for NPP in this desert city (Martin 2001). Moreover, demands for flood protection and water delivery have led to massive alterations of hydrologic systems with far-reaching consequences for species and biogeochemical dynamics (Grimm *et al.* 2004).

CAP1 began with several approaches—pilot studies, data-mining and synthesis projects, and short-term experiments—broadly following LTER core areas while integrating human dimensions. In the first three years, we established an extensive *long-term integrated field inventory* (Survey200), to be repeated every five years (Hope *et al.* 2003). This is supplemented with intensive monitoring at a subset of permanent aquatic and terrestrial sites. *Data mining* from local, state, and federal agencies, aided by significant leveraged funding (McCartney *et al*.; NSF-BDI, 1999; NSF-ITR, 2002), has resulted in an extensive urban environmental database. We used these mined datasets in our primary research and to establish parameters for our *models* of urban ecosystem structure and function. Two *long-term experiments* were established and a third has begun. Finally, we engaged in *cross-site comparisons* and *multiple-site synthesis activities,* including climate studies (Brazel *et al.* 2000; Baker *et al*. 2002; Kinzig and Grove 2001; Brazel and Ellis 2003), a separately funded cross-site project on agrarian landscape change (NSF-BCE, Redman *et al.* 2002), a study of N retention in urban streams (part of LINX-2, NSF-IRCEB, Mulholland *et al.* 2001), and work on bird diversity as a function of socioeconomic setting (Warren *et al. in review*). This past year (2003-2004) has served as a useful "bridge" to CAP2, during which we have realigned our research foci for greater integration. The CAP1 research activities and findings are presented in this final year report according to the reconceptualized CAP2 research, which is organized around six interdisciplinary, integrative project areas (IPAs) and five research strategies for the IPA research teams (see Section III).

## Broader Impacts

CAP LTER has served as a focal point for many new developments, both at the state and national level, most especially by fostering interdisciplinary interactions. Its broader impacts have been in three main areas: 1) national awareness and profile of urban ecology, 2) education and outreach, and 3) decision-making in Greater Phoenix.

1. CAP has raised national awareness of urban ecology both in academic settings and more widely, as demonstrated through contributions in the literature (>180 journal articles, book chapters, and reports in print or in press), at conferences (>240 presentations) and several Ecological Society of America and American Geophysical Union special sessions since 1998), to University curricula (especially graduate education), and in the news media (most recently, on NPR's *Science Friday*). Aided by leveraged funding, CAP LTER has led the way in crafting arguments for socioecological integration (Kinzig *et al.* 2000; Kinzig 2001; Harlan *et al.* 2003; Redman *et al.* 2004) in and across LTER sites. Towards this goal, CAP LTER coordinated workshops, symposia, and cross-site proposals (1998 CC meeting in Madison; 2000 workshop in Tempe; 2000 and 2003 All Scientist Meetings).

2. Contributions to education and outreach at all levels have also been substantive. We have worked conscientiously on community outreach. In its first seven years, CAP LTER had over 500 participants, of which more than 100 were community volunteers. Students in our Integrative Graduate Education and Research Training (IGERT) program in urban ecology are forging new paths towards interdisciplinarity. At the K-12 level, Ecology Explorers, our educational outreach program has expanded to include over 100 teachers at 81 public schools (encompassing 28 school districts), 3 charter schools, and 3 private schools. In addition, over 20 community partners are engaged in CAP LTER, such as Salt River Project, Motorola, Maricopa Association of Governments, the USGS, and the Gila River and Salt River-Pima Indian communities.

3. The role of CAP in decision-making in Greater Phoenix has been enhanced by funded projects that promote community and governmental outreach. While preserving our scientific objectivity, we have been able to benefit greatly from the establishment of projects linked to local and regional government. For example, the Greater Phoenix 2100 (GP 2100) project is using CAP LTER data to help policy makers and others envision the long-term future of the greater Phoenix region (Fink *et al.* 2003). In addition, our information-management team plays a leadership role in developing new IT tools for handling ecological data. In spring 2003, this group released an environmental atlas for futures planning in Phoenix <www.gp2100.org/eatlas>. Based upon the SEINet data-access infrastructure, the Greater Phoenix 2100 EAtlas added over 60 new GIS datasets to the data catalog. Finally, ASU has launched a new Consortium for the Study of Rapidly Urbanizing Regions (Redman is Director), and a recently funded (NSF) Decision Center for a Desert City will open in fall 2004. This diverse array of new initiatives highlights the many ways that urban environmental research can be useful to decision makers and the public, and is a direct outgrowth of research activities in urban ecology that the CAP LTER has spawned.

# II. RESEARCH ACTIVITIES

## Research Design and Approach

Although our program is fundamentally ecological (*sensu* Likens 1992), we include humans among the organisms interacting and participating in fluxes of energy and materials. We are committed to the notion that an ecological study must monitor and interpret change from a perspective that includes humans as part of nature (Cronon 1995; Kinzig *et al*. 2000). The LTER research strategies have been called the four "legs of the table" of LTER research (Carpenter 1998): long-term research (monitoring), experiments, comparative ecology, and models or theory. To these strategies we add data mining—an essential means of testing hypotheses and understanding ecological change across a large urban area such as CAP, where there have been numerous agencies collecting data in great detail (albeit not under an ecological paradigm). This wealth of background data is tremendously important and much of our early work involved mining these information sources and putting them into a format and conceptual framework that was amenable to our own analyses. We use all five "legs of the table" in our research.

However, standard ecological theories are insufficient to address the complexity of human culture, behavior, and institutions. Thus, our ecological investigations require the integration of social science research, require longer time horizons, and must be informed by flexible models and multiscaled data. To fully operationalize this integration, we have therefore reorganized CAP under five IPAs (see below) to ensure that the teams guiding our multiple research strategies crosscut traditional disciplinary boundaries.

Education, informatics, and knowledge exchange with urban policymakers, managers, and stakeholders are as fundamental to our project as the core scientific activities. We have been successful in leveraging LTER funding to accomplish outreach and data-management objectives that are beyond the capability of the CAP LTER, but we retain significant communication and involvement with these activities (see descriptions in Sections IV and VIII).

## Integrative Project Areas (IPAs)

A particular strength of the LTER program is consistency of measurement in the five, broad core areas. However, during CAP LTER's ongoing research we have found that organization of projects and working groups under the traditional LTER core areas does not necessarily facilitate interdisciplinary integration (Redman *et al.* 2004). Therefore, during 2003-2004 we identified five IPAs, each of which blend the life, earth, and social sciences (Fig 1B). Here, we describe the major objectives and/or questions of each IPA:

- Land-Use and Land-Cover Change (LULCC). Land use and land cover define the context of the socioecosystem, and alterations in their patterns represent some of the most seminal changes to the system. First we ask: How have land use and land cover changed in the past, and how are they changing today? This initial inquiry leads on to a second major question: How do land-use and land-cover changes alter the ecological and social environment in the city, and how do human perceptions of these changes alter future decision-making? Our developing understanding of the answers to these questions sets the stage for all other IPA research.
- Climate-Ecosystem Interactions. Climate is an important driver of processes in most ecosystems. The spatial and temporal dynamics of human actions both deliberately (irrigation) and inadvertently (urban heat island) modify the urban climate. Studies of climate-ecosystem

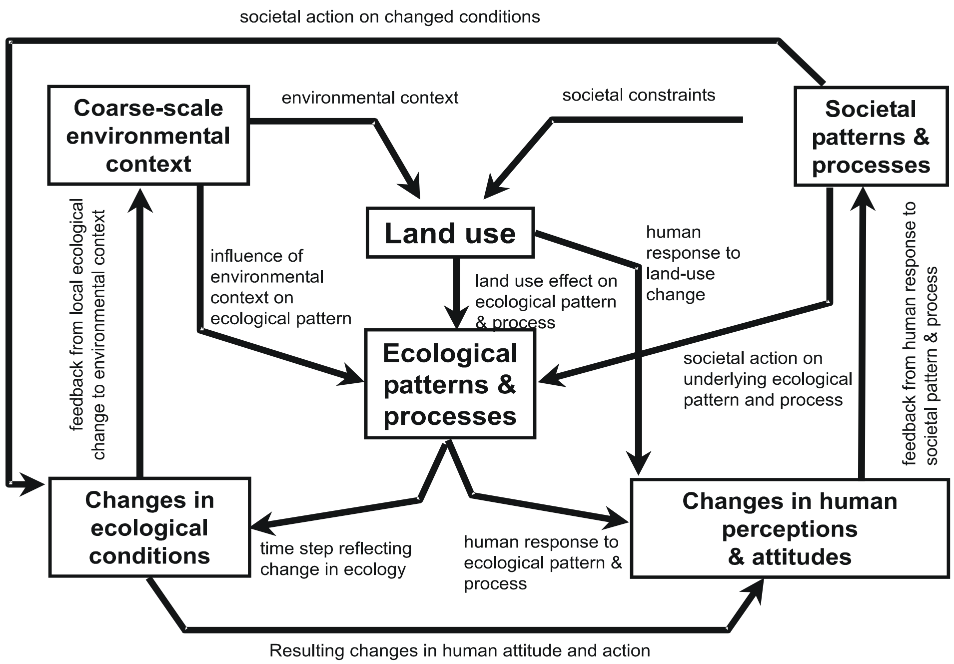


Figure 1A

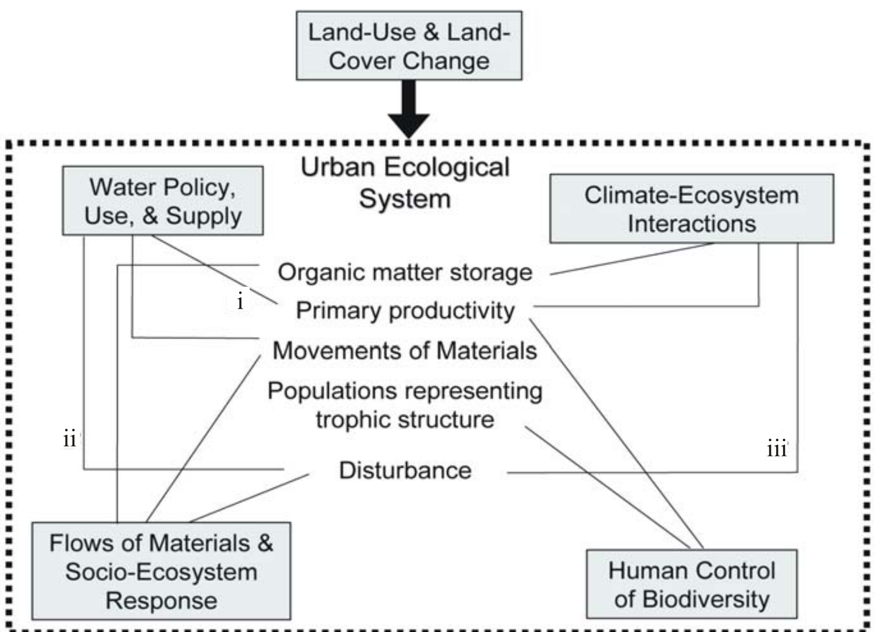


Figure 1B

**Figure 1. A)** Conceptual scheme for integrating ecological and social systems in urban environments. Variables are in boxes; interactions and feedbacks are labeled arrows. At the core is land-use change, which is constrained by both biophysical and societal factors and which drives ecological change. Feedbacks result from changes in either human perception and action or ecological conditions. **B)** Relationship of the CAP 2 Integrative Project Areas (IPAs) to the LTER core areas, with the most important linkages shown. Examples of projects that link the IPAs to the core areas include: i) DBG and NDV landscaping experiments which focus in part on the control of primary productivity by landscape watering regimes; ii) the response of human water management institutions to drought; iii) the interaction of long-term climate trends and resilience of social institutions. All these incorporate both social and ecological responses to larger-scale environmental drivers.

interactions will be conducted at multiple scales from single organism to regional. We ask: How does human-driven, local climate change compare with longer-term trends and/or cycles of climate in the region? How do regional drivers influence local climate as urbanization proceeds? What are people's perceptions of their local environment, including climate, and how does that affect their assessment of neighborhood or regional quality of life? What are the interactions among local management, local climate, net primary production (NPP) and vegetation processes?

- Water Policy, Use, and Supply. Humans now appropriate 100% of the surface flow of the Salt River and are increasingly exploiting groundwater resources and surface waters from more distant basins (e.g., Colorado River). Controlled management and engineering shift the characteristic spatial and temporal variability of the hydrologic system. What are the ecological and economic consequences and potential vulnerabilities of those shifts? What institutional responses best address those vulnerabilities? Within this IPA, we examine landscape water management, water supply and delivery, riparian restoration, and resilience of the socioecosystem to water-related stress or catastrophe.
- Fluxes of Materials and SocioEcosystem Response. Material fluxes and biogeochemical linkages have been studied for decades in relatively undisturbed ecosystems, but not in urban ecosystems where human-generated fluxes of nutrients and toxins are coupled with nonhuman biogeochemistry. The main question driving this IPA is: How do urban element cycles differ qualitatively and quantitatively from those of nonhuman-dominated ecosystems? Nutrient, pollutant, and toxin element cycles drive our main sociological questions: What are the sociospatial distributions of anthropogenic toxins and other pollutants in the CAP ecosystem, and what hazards to organisms (plants, animals, humans) result from these distributions? Do citizens and decision-makers accurately perceive these hazards?
- Human Control of Biodiversity. Ecological approaches to studying human control of biodiversity have typically focused upon habitat loss and disturbance brought about by humans at high population densities. We will move beyond these approaches to ask: How do human activities, behaviors, and values change biodiversity and its components—population abundance, species distribution and richness, community and trophic structure? In turn, how do variations in biodiversity feed back to influence these same human values, perceptions, and actions?

## Ongoing Research

Ongoing research activities are organized according to our five research strategies and major research participants (in parentheses). In some cases, such as the Survey200, virtually every IPA has elements associated with the continuing research described. Others (e.g., the data-mining efforts to construct materials or water balances) are primarily associated with one or two IPAs.

### Monitoring

Survey200 (Hope, et al). The 200-point extensive survey (Fig. 2) forms a cornerstone of our long-term monitoring efforts. Carried out in full once every five years, Survey200 provides: 1) a broad-scale characterization of major physical, biotic, biogeochemical, and human characteristics not quantifiable from aerial photos/remote sensing/census data (see Table 1, and Web-based protocols); 2) a randomized sample from which regional estimates of measured variables can be obtained while minimizing extrapolation errors; and 3) a framework of sites within which more detailed and more frequent measurements can be co-located. The sampling scheme is a probability-based, tessellation-stratified, dual-density (3:1) design, which was deliberately not stratified for land use/cover or other characteristics. Instead we chose to maintain maximum

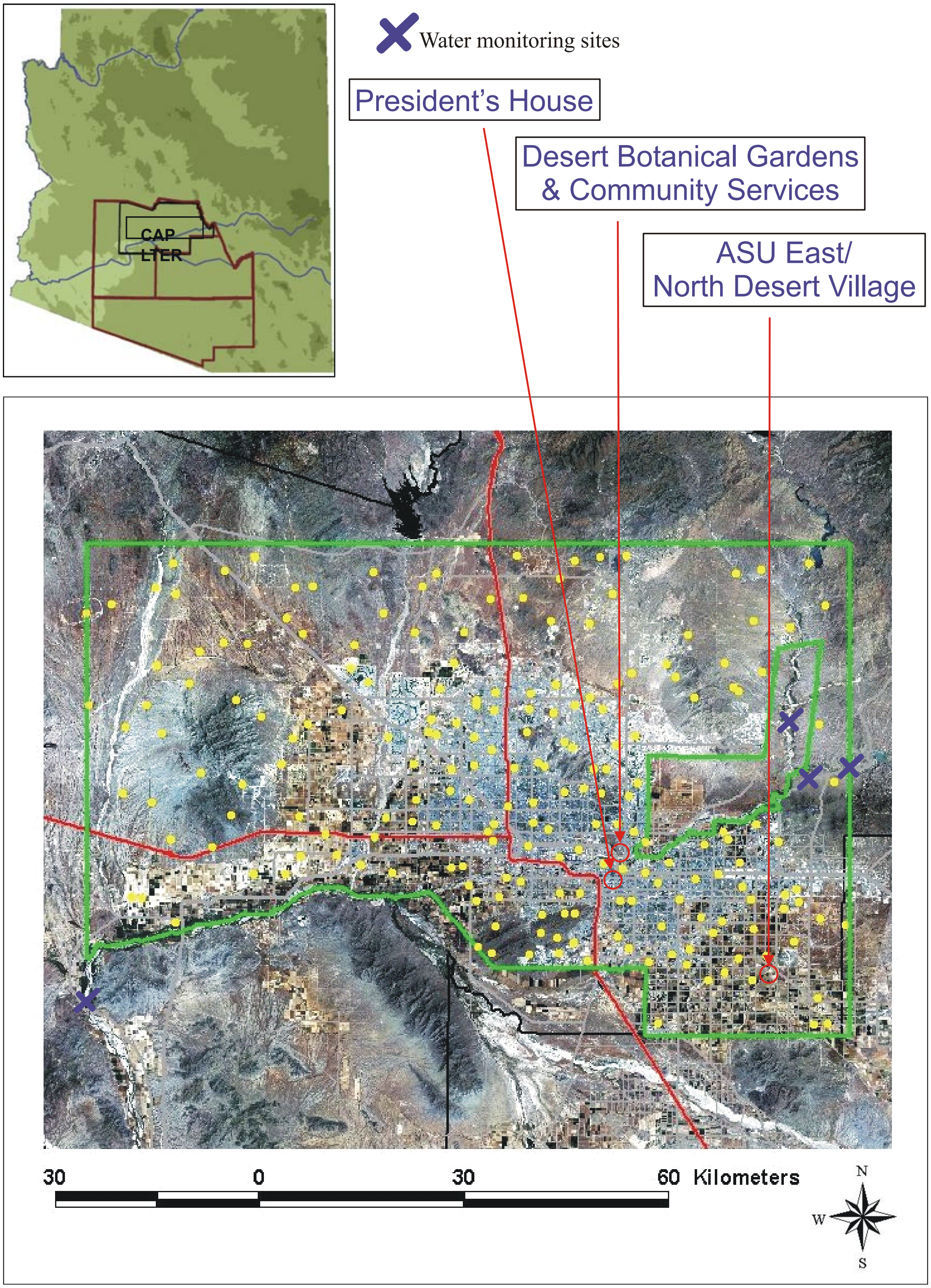


**Figure 2.** Location map showing the extent of the CAP study region, the Survey200 sampling scheme and the intensive/experimental sites.

**Table 1. List of CAP Monitoring Sites, Showing Variables Measured and Frequency of Sampling.** Letters indicate variables measured: A = arthropods; B = bird abundance and diversity; D = wet/dry atmospheric deposition; K = prokaryote diversity; M = modeling; N = soil nutrients; O = pollen; P = plants; S = social survey of neighborhoods; T = tree growth; V = various human management indices; W = full suite of chemical analyses.

| Sites | Number of sites | Variables measured | Frequency of sampling |
|---|---|---|---|
| Perennial surface water flow sites | 4 | W | 6 times/yr |
| **Atmospheric deposition sites:** | | | |
| wet/dry deposition collectors | 8 | D | Per event |
| air quality monitoring modeling | 6 | M | Per event |
| Survey200 extensive sites (incl. N, P, O, K, V) | 200 | N, P,O,K,V,M | Once/5 yrs |
| Bird survey sites | 52 | B,V | 4 times/yr |
| Arthropod pitfall trapping sites | 22 | A | 6 times/yr |
| Tree growth sites | 37 | T | Annually |
| Social survey sites | 8 | S | Annually |
| **Co-located sites (subsets of the above):** | | | |
| Survey200 and birds | 40 | N,P,O,K,B,V | |
| Survey200 and trees | 21 | T,N,P,O,K,V | |
| Survey200, birds and arthropods | 17 | N,P,O,K,B,A,V | |
| Survey200, trees, birds, and arthropods | 7 | T,N,P,O,K,B,A,V | |
| Survey200 and social | 6 | N,P,O,K,V,S, | |
| Survey200, social, birds, and arthropods | 1 | T,N,P,O,K,B,A,V,S | |
| **Experimental plots:** | | | |
| President's House | 1 | T,M | |
| Desert Botanical Garden | 2 | T,M | |
| Community Services Building | 1 | T,M | |
| Usery Mountain Park (trophic exp.) | 1 | | |

post-stratification flexibility and make the data amenable to spatial autocorrelation analysis, kriging, and other spatial- estimation techniques. During the next complete survey in spring 2005 and again in 2010, the integrated field inventory will be repeated, to provide a spatially extensive comparative dataset of change over time. Data from the Survey200 provide important insights into broad-scale spatial variation of key ecosystem variables, as well as providing essential context for other work. For example, we are using these data to further develop a vegetation index-biovolume calibration curve appropriate for the region and residential yards. This work will improve comparability of remotely sensed vegetation indices with field-collected vegetation cover and volume data.

*Intensive Sites.* To allow more frequent and detailed measurements, subsets of the Survey-200 sites have been selected for more detailed study. Choosing a smaller number of sites enabled us to characterize seasonal and interannual variations; these sites have been co-located to maximize overlap between studies. At these sites we measure (see also Table 1):

- Standing perennial woody biomass (*Martin*) at 32 Survey200 sites along with 18 additional locations, is monitored via biannual measurements of tree volume, along with determination of N content of leaf tissue (summer only). These data allow us to address the question: How does tree growth change over the long term as a function of position variables (e.g., distance from urban center or roads), socioeconomic variables (e.g., income level and landscaping practice), and historic variables (e.g., former land use)?
- Ground arthropods (*Faeth*) are sampled on a bimonthly basis at 22 sites using standard pitfall-trapping protocols (available on our Web site and also used by K-12 participants, to answer the question: How do diversity-abundance patterns vary seasonally and interannually among different land-use types?
- Bird survey sites (*Warren*) include 40 of the Survey200 sites plus 10 riparian locations. All sites are surveyed quarterly by a team of birders using point-count methods (see Web site). Here too we focus on seasonal and interannual variation and diversity-abundance patterns among different habitat types.
- Phoenix Area Social Survey (PASS; *Harlan*): key demographic and socioeconomic variables are acquired for the US census block groups surrounding each of the 91 urban sites from the Survey200 (e.g., population density, median household income, ethnicity, median housing age). In six of these block groups, an additional detailed survey instrument (PASS) has been developed and used to address the question: How do behaviors, attitudes and perceptions of residents influence ecological conditions in neighborhoods? Results from this pilot study (Larsen *et al.* 2004; Harlan *et al.* 2003) have already demonstrated the importance of building social monitoring into as many of the CAP2 IPAs as possible. Therefore, additional funding has been received through a supplemental proposal to extend this work to the neighborhoods surrounding all 91 of the urban sites in the extensive monitoring network.

*Intensive/Experimental Sites.* A small number of intensive study sites have been established in locations with long-term, site ownership (ASU and Desert Botanical Garden [DBG]; Fig. 2). Public access to these sites is limited, allowing for manipulative experiments (see below) and security for monitoring equipment. Currently, four main sites, the ASU President's House yard (PH; mesic residential yard), DBG (disturbed desert remnant, with power and water supply), the grounds of ASU's Community Services Building (CSB; relatively undisturbed desert remnant, including a natural desert wash), and the ASU East "North Desert Village" (NDV; residential neighborhood and site of the landscaping experiment) are monitored intensively. Climate monitors are installed at intensive sites to provide detailed long-term meteorological monitoring.

A scaled-down version of the CAP1 atmospheric deposition program will be continued at these and two additional sites, chosen based on spatial and temporal variations in wet and coarse particulate dry deposition documented in CAP1. Replacing our existing dry-bucket collectors with filter packs will improve the measurement of dry deposition (a major component of annual atmospheric nutrient inputs to the ecosystem).

*Remote Sensing and Patch Typology (Christensen, Stefanov).* LULCC characterization and monitoring continued using data acquired by the Landsat ETM+ and ASTER, as well as new data acquired by the Landsat Data Continuity Mission scheduled to begin in 2006. We plan to improve existing expert-system land-cover classification algorithms (Stefanov *et al.* 2001) and explore new classification approaches such as object-oriented classification (Burnett & Blaschke 2003).

*Human-Climate Interactions (Brazel, Harlan).* The Neighborhood Ecosystems Project (NSF-BE, *Harlan et al. 2002*), built upon earlier study of feedbacks to urban climate (Baker *et al.* 2002; Fig. 3), has measured variability in human-vegetation-climate interactions across the region and in six neighborhoods co-located at Survey200 sites. Research in progress is investigating: "What are the mechanisms (e.g., vegetation density, topography, and built environment) that mediate the human-microclimate relationship in urbanized areas?" Future research in this area will continue to combine satellite, airborne, and field-sensor data with surveys of Phoenix-area residents (PASS). This work will elucidate the political, cultural, and economic controls (both current and "legacy") on neighborhood climate as well as the resulting costs and feedbacks to the neighborhood socioecosystem, in terms of energy, water, and ecological function.

*Aquatic Monitoring (Hope, Grimm).* Analysis of long-term temporal patterns in stream water chemistry above and below metro Phoenix addresses three questions: 1) What is the influence of dams on water chemistry entering the urban ecosystem*?* 2) How do seasonal patterns and discharge-related variation in water chemistry change over time? Do these changes serve as an indicating that urbanization may have altered biogeochemical cycling*?* and 3) What "signals" in water chemistry can be detected that indicate a response to policy change, such as the introduction of a new water source, enactment of water-quality legislation, or improvements in water treatment? Using USGS' National Water Quality Assessment Program (NAWQA) protocols, modified to focus on major nutrients, cations, and anions, we sample surface water at the three main inflows and two "integrator" outflow sites for metro Phoenix, selected using data from a two-year pilot study at seven locations (Fig. 2). To date, we have compared seasonal and interannual patterns in biologically conservative and reactive ions and compounds, using our own sampling in combination with 40-y datasets from previous USGS monitoring (Edmonds 2004).

*Small Watershed Studies (Grimm).* This research investigates the dynamics of material storage, transformation, and transport in small urban watersheds, incorporating the effects of episodic events (rainstorms and flash floods) that link aquatic and terrestrial components of urban watersheds. The CAP mass balance for N suggests that 14 kg $ha^{-1}$ $y^{-1}$ of N is retained somewhere in the ecosystem (excess of inputs over outputs; Baker *et al.* 2001). The question of where in the landscape N (and other elements, especially C) is retained is best answered by considering both aquatic and terrestrial components of the landscape (Grimm *et al.* 2003), and by examining their connection during storm events. In CAP2, small watershed studies will continue using acquired datasets of material export (USGS, cities), along with measurements of process rates in soils and sediments at sites co-located with other projects, to test the following hypotheses: spatial variability of material export is higher and temporal variability lower than in

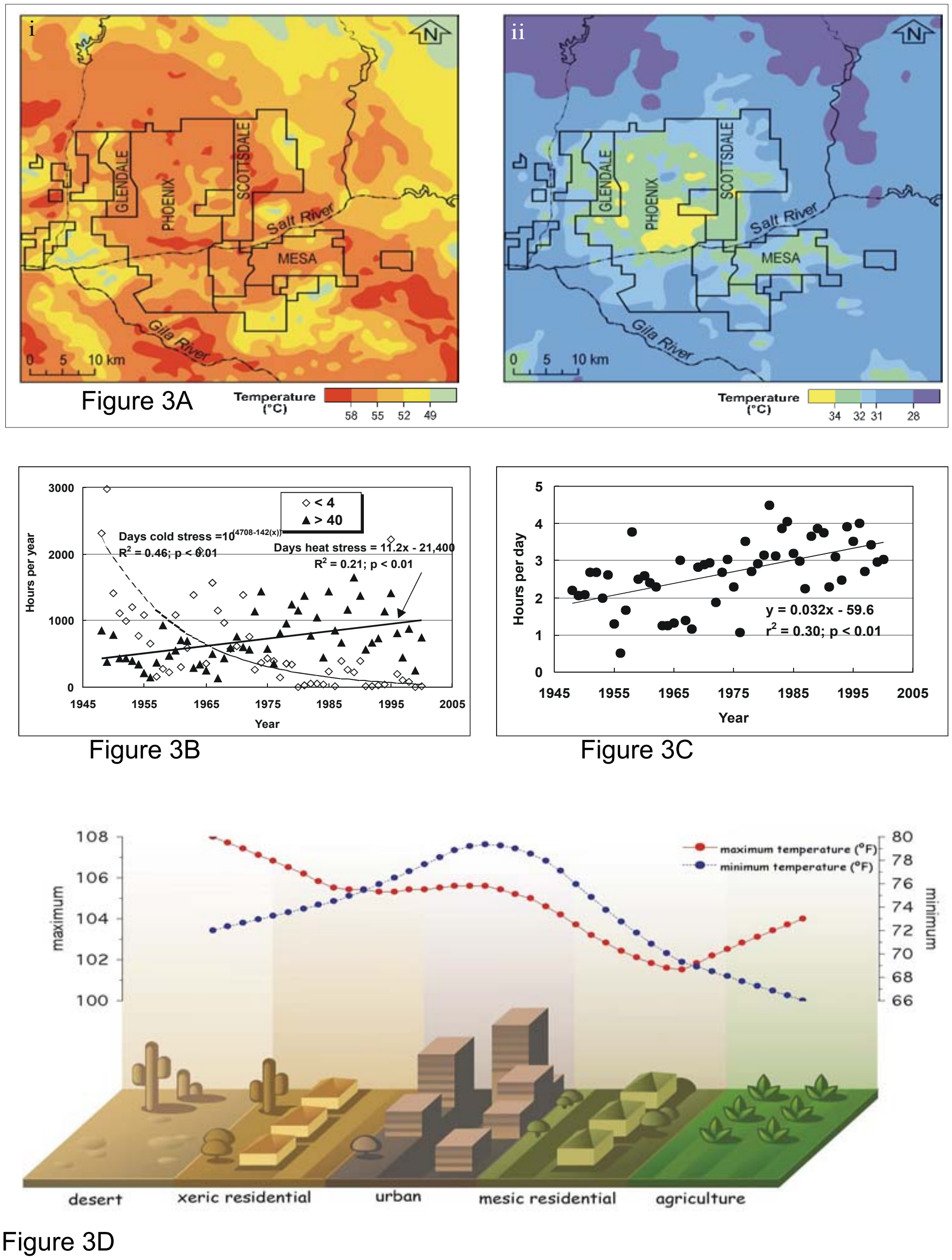


**Figure 3. A)** An AVHRR satellite image of composite patterns for several days in summer for the Phoenix area, showing surface temperatures for day (2 PM) and night 2 (AM) from Baker et al (2002). Spatial and temporal expansion of urban heating in the Phoenix metropolitan area has increased daily minimum temperatures – it now takes less time to reach uncomfortable temperatures during the day and longer to cool off. **B)** Physiological effects on vegetation of the increased degree-hours > 40 $^{o}$C in summer and decreased number below 4 $^{o}$C in winter include exacerbation of indirect heat stress and increased chilling stress, resulting in plant injuries. However, the long-term decline in the annual number of wintertime degree-hours below 4 $^{o}$C also enables greater productivity of evergreen species during the winter and survival of imported sub-tropical and tropical species year round (Baker et al 2002). **C)** Most noticeable for human inhabitants is an increase in the average number of hours with effective temperature over 38 °C, known as "misery hours per day" per day, which have nearly doubled during the hottest months since 1948 as a result of urbanization (Baker et al 2002). **D)** Changes in minimum and maximum daily temperatures with land use.

non-human-dominated watersheds (Grimm *et al.* 2004); recipient systems (those terrestrial or aquatic ecosystems that receive materials from the landscape during episodic flooding) are "hot spots" (*sensu* McClain *et al.* 2003) of nutrient retention and transformation in the urban landscape.

## Experiments

*DBG Landscape Water-Use Experiment (Martin, team).* An experiment at the Desert Botanical Garden (DBG) was established in 1999 to improve understanding of how various landscaping practices affect water conservation. The experimental design includes replicate plots containing common perennial plants used in residential landscaping, watered at recommended or high rates. Completed experiments studied the interacting effects of pruning and irrigation; slight modifications in design (such as investigation of different mulch types) will continue to be made while retaining the basic structure of the experimental design. Quarterly measurements are made of plant growth, but additional studies of soil biogeochemistry, water-use efficiency, trace-gas fluxes, and other variables have been added to the response-variable set by graduate-student and postdoctoral researchers.

*NDV Experimental Suburb (Hope, Martin, team*). Variation in landscaping style and maintenance practices associated with different styles may influence a wide range of ecological and social phenomena, including biogeochemical processing, water consumption, avian and insect communities, as well as residents' attitudes, recreation behaviors and quality of life. Experimental tests of these linkages, however, are largely lacking in urban ecology. Using the NDV residential development recently acquired by ASU at its East Campus, we are conducting an unprecedented neighborhood-scale experiment. Four residential landscape design/water delivery types established in blocks of six households each (mini-neighborhoods) recreate the four prevailing residential yardscape types found across the CAP study area during the last five years of research (Martin *et al* 2003; Fig. 4). These are: mesic/flood irrigation—a mixture of exotic high water-use vegetation and turf grass; oasis—a mixture of drip-watered, high and low water-use plants, and sprinkler-irrigated turf grass; xeric—individually watered, low water-use exotic and native plants; and native—native Sonoran Desert plants and no supplemental water. Six additional households will be monitored as no-plant, no-water controls. Although NDV is not representative of the entire breadth of socioeconomic groups in the CAP region, it *is* a residential village for students with families. Thus, many of the socioeconomic issues applicable to single-family residences, which comprise the largest component of housing across metro Phoenix, may be addressed.

A central research question for the NDV experiment is: How does residential landscape design affect socioecosystem function at household and neighborhood scales (Fig. 4)? The experiment also allows us to examine how biophysical information feeds back into human decision-making and behavior, at the household scale. We address the following research questions: 1) How do different landscape-treatments influence recreational behavior in yards and common areas*?* 2) Does structural complexity correlate with quantity of residents' ecological "folk" knowledge*?* 3) Are people less likely to move into or out of a landscape that conforms to their broader social values*?* and 4) Do people living in desert landscapes use less water inside and outside their homes? The experiment also allows us to tackle the question: How are biodiversity and ecosystem function related in urban ecosystems where there has not been a long co-evolutionary history? For example, we will be able to determine how NPP compares between natural and human-created plant communities.

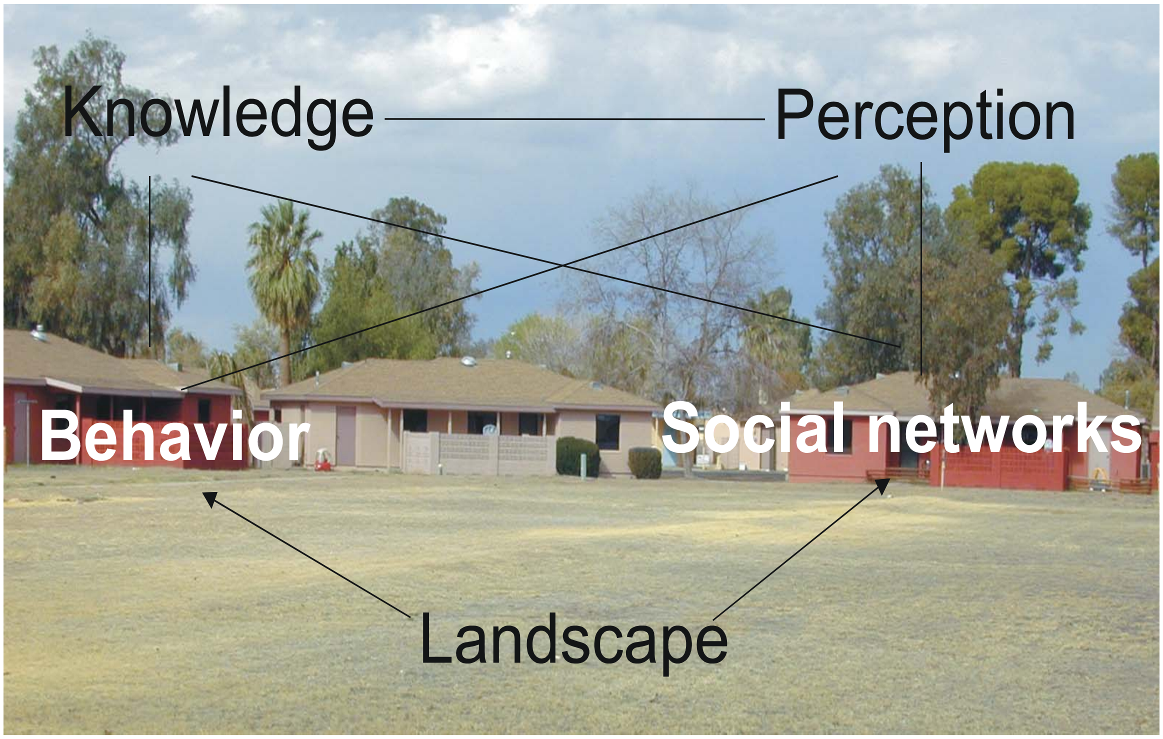


Figure 4A

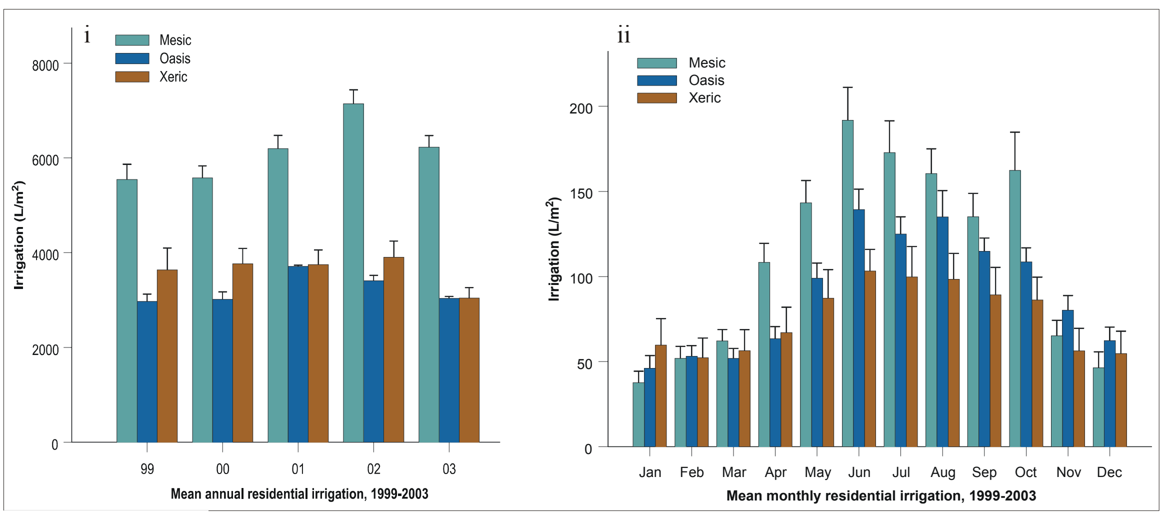


Figure 4B

**Figure 4. A)** The conceptual scheme framing our research questions for the NDV (pictured) landscaping experiment which will allow us to examine how biophysical information feeds back into human decision-making and behavior, at the scale of the household, within a replicated four treatment (mesic, xeric, oasis, native desert) design. **B)** Mean monthly irrigation volume per landscape surface area applied to privately-owned residential yards in Phoenix AZ (n=6 per landscape type) between 1998 and 2003, were much smaller than expected despite the three disparate landscape types (mesic, oasis, and xeric).

Pre-treatment baseline surveys began in fall 2003; these included: soil-profile characterizations (by the Natural Resource Conservation Service), soil physical and chemical properties (including trace gas flux emission), mycorrhizal species identification, estimations of above- and below-ground vegetation biomass, ground arthropod and bird abundance and diversity surveys, and human-occupant surveys. Along with the residential landscapes themselves, we are currently installing micrometeorological stations within each of the six mini-neighborhoods (blocked planting/water-regime treatments), in addition to the standard meteorological installation. We will monitor several parameters, which will allow us to answer the above questions as well as discern the effects of residential landscape design on a suite of neighborhood physical, chemical, biotic, and social variables.

*Trophic Structure and Dynamics Experiment (Faeth, Cook*). A central and long-pondered question in ecology is: What controls trophic relationships and structure in communities? Theory and empirical studies show that both top-down (e.g., predators) and bottom-up (resource availability and quality) forces influence community structure and trophic dynamics to varying degrees (Power 1992; Chase *et al.* 2000), depending on herbivore and predator or parasite species composition, intraguild predation, spatiotemporal variation in environmental resources and plant competition (Duffy 2003), but human activities are typically ignored outside of agriculture. Because urbanization alters top-down and bottom-up forces in dramatic ways, but rarely has been incorporated into studies of trophic dynamics and food webs, we established this experiment specifically to test the effects of vertebrate (birds) and ground-dwelling vertebrate and invertebrate predators, in the urban environment and have included manipulation of a key resource—water. The focal plant species, *Encelia farinosa* (brittlebush), is a native Sonoran Desert plant widely used in xeriscapes. A replicated, full-factorial experiment (Fig. 5) established at three sites (a mesic yard [PHY], a desert remnant [DBG], and an outlying natural desert area) includes four treatments: 1) netting (to exclude vertebrate predators); 2) ring barriers (to exclude ground-dwelling invertebrate predators); 3) supplemental water; and 4) controls (no caging, ring barriers, or supplemental water). We determined (bimonthly) plant productivity, leaf damage, abundances and diversity of herbivores, predators and parasitoids. Here, the yard type is manipulated and controlled, and we can examine the consequences for trophic structure and diversity on a common plant species, brittlebush.

### Data Mining

*Historic Land Use (Redman, Wentz).* Considerable information on land use was developed during CAP1, derived from historical aerial photographs and county records. These resources provided data for basic models of urban growth (Berling-Wolff and Wu. 2004; Jennerette and Wu 2001; Agarwal et al. 2001; Lambin et al. 2001) and assessments of associations between land-cover and land-use categories and other characteristics of the urban environment. Initial land-use research was limited to changes in four basic categories over the past century. For the square-mile sections around each of the Survey200 sites, more detailed land-use information has been collected according to 26 categories (Fig. 6). Historical integration of the social and the environmental is one research design factor that makes our ecological approach both unique and valuable. For example, knowledge of historical distribution of agricultural fields gives a basis for selecting sites in a study of agricultural impacts on soil C and N storage (Lewis and Kaye, in preparation).

*Hydrologic Budget (Arrowsmith, Baker, Westerhoff).* A hydrologic budget that quantifies the water flow from the atmosphere, through its interactions with the land surface (including the

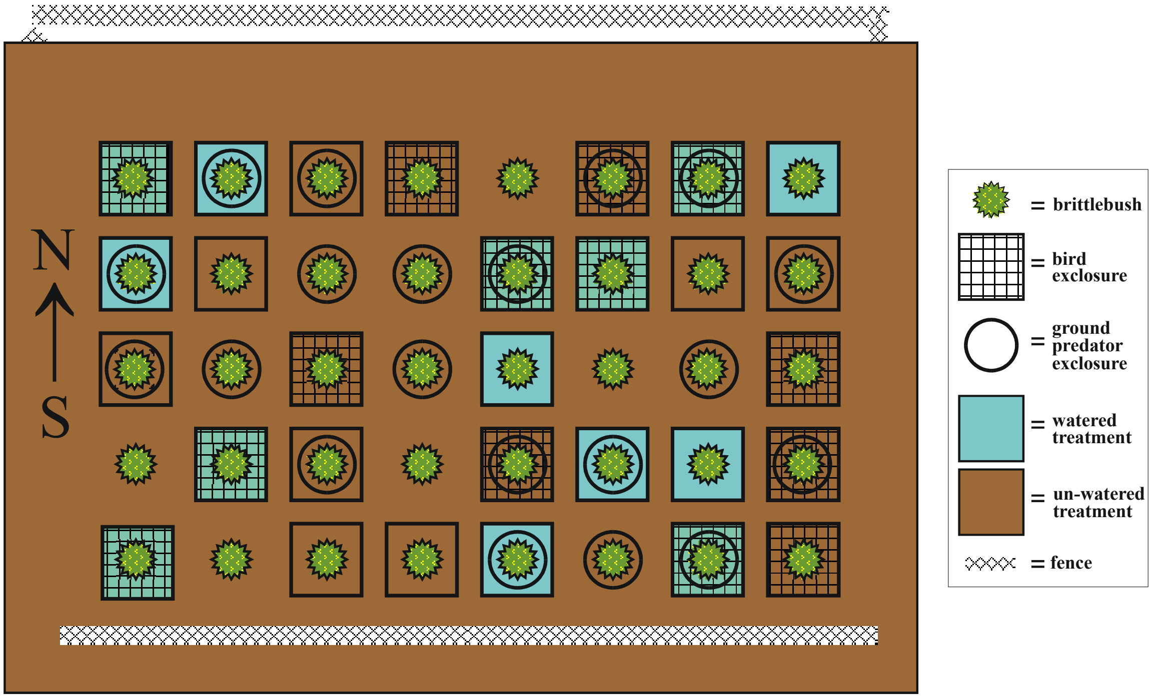


Figure 5A

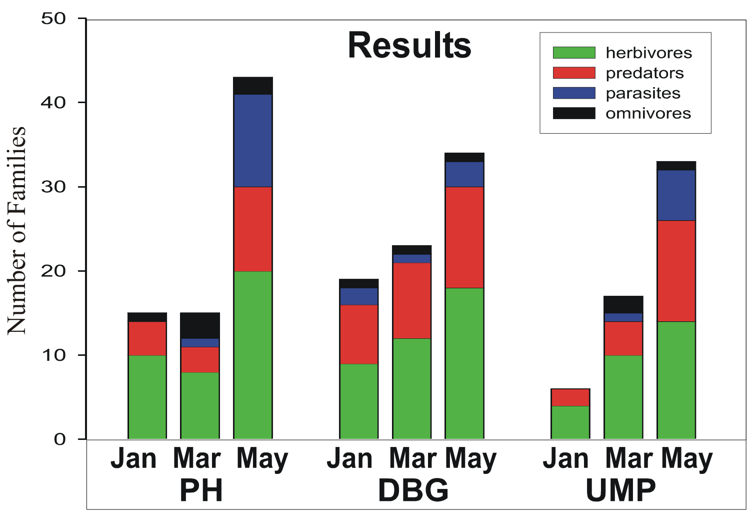


Figure 5B

Experimental plot

Figure 5C

**Figure 5. A)** Schematic of the experimental design for the long-term trophic structure and dynamics experiment at the Desert Botanical Garden (DBG) site. **B)** Graph shows the number of arthropod families by site and by month with proportions of predators, herbivores, parasites, and omnivores indicated; the number of families varies by site for each month ($P<0.001$ in each case). **C)** Maintenance taking place in one of the experimental brittlebush plants.

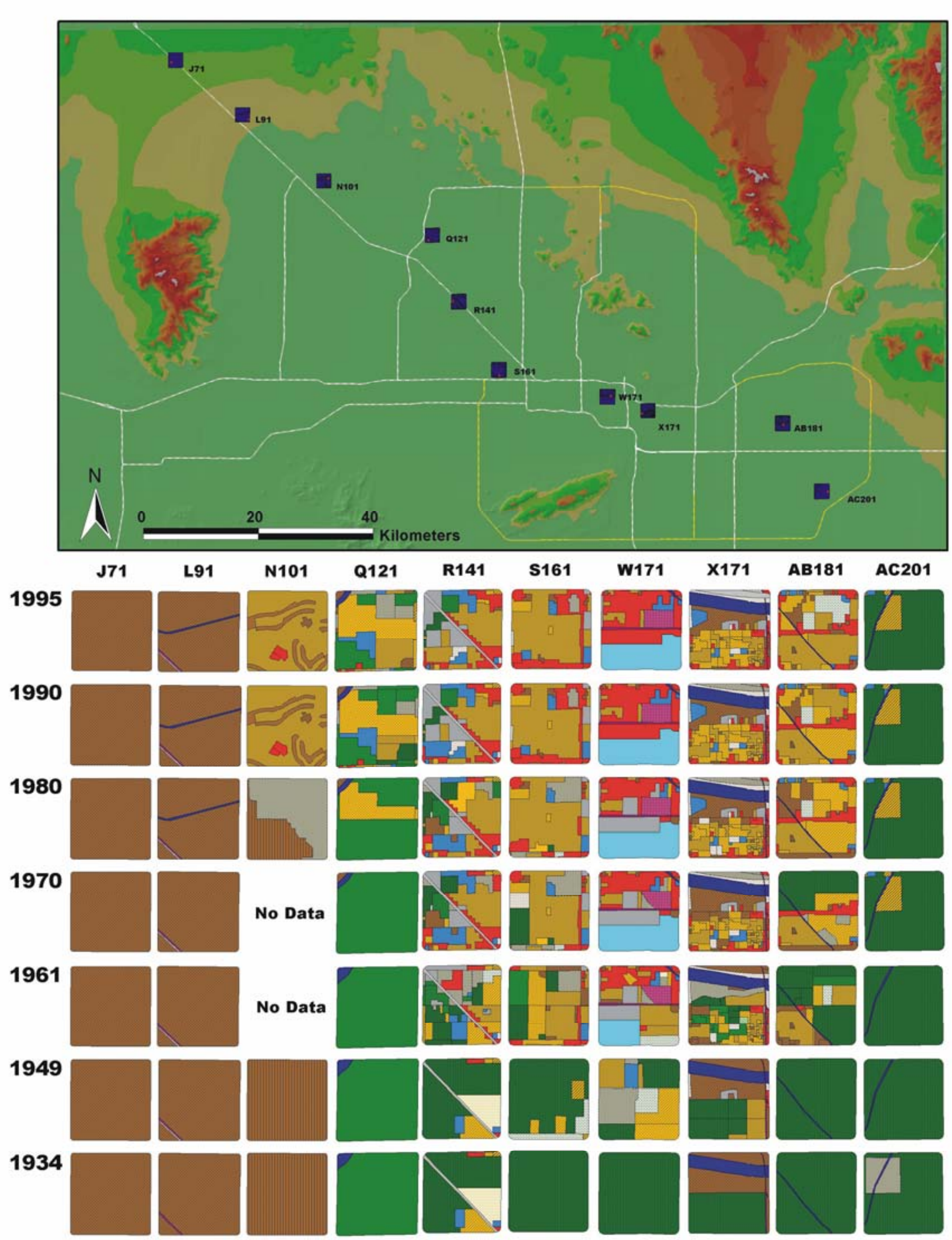


**Figure 6.** As part of documenting and quantifying land use and land cover change, land use for each one square mile section around each Survey200 site has been interpreted from aerial photography on a decadal basis from 1930 to 1995. This transect of 1-mile squares across the study region shows how land use has changed in core versus fringe areas. Color codes for some of the main land use types are: brown - desert, yellow - urban/built-up, red - commercial (malls, office buildings), pale blue - airport, mid blue - institutional (schools, churches), dark blue - streams/rivers/canals, gray – industrial, white – transportation.

vegetation and the built environment), overland and subsurface flow, and ultimate return to atmosphere via evapotranspiration, was developed for the CAP region (Fig. 7). This budget has served as a valuable foundation for constructing materials budgets (e.g., Baker *et al.* 2001) and understanding how human action has altered the pathways and availability of this critical resource (Fig. 8). Research questions for continued hydrologic work are: 1) How have the inputs and outputs of the hydrologic cycle changed over time? 2) Can thresholds be identified, beyond which water limitation will stress ecosystems or human activity in the region? 3) How have hydrologic flow paths changed over time, and how are they likely to change in the future?

*Nutrient Budgets (Kaye, Baker, Grimm, Hope, Westerhoff).* At the scale of the entire CAP study region, we are building elemental mass balances for N, C, P, and salts, most recently focusing on the C mass balance. The N mass balance (Baker *et al.* 2001) showed that the urban ecosystem differed both quantitatively and qualitatively from desert ecosystems (Fig. 9). The socioecosystem was characterized by large anthropogenic N inputs, large engineered gaseous outputs, and an accumulation of N in unknown compartments of the CAP ecosystem. In contrast, N inputs to desert ecosystems are typically <¼ of urban inputs, internal plant and microbial cycling are much greater than inputs and outputs, and N accumulation is slow or negligible (gaseous losses account for about 100% of inputs) (see Grimm and Redman in press). The N mass balance raised at least two questions that we are beginning to pursue. First, what are the consequences of these massive inputs, especially those associated with $NO_x$ production, for ecosystem productivity and functioning in surrounding desert ecosystems? We are seeking non-LTER funding to address this question. Second, if 14 kg N $ha^{-1}y^{-1}$ are accumulating in the CAP ecosystem, where is the N stored? Although denitrification processes at wastewater treatment plants and associated effluent discharge prevent large riverine N exports, it is possible that some of the N accumulates in the vadose zone and may eventually interact with groundwater (Walvoord *et al.* 2003). A second possibility is that N deposition is stored in surface soils, alleviating biological N limitation. Finally, literature values may underestimate denitrification; research is currently quantifying "hot spots" of denitrification in the urban ecosystem.

### Models

*Hierarchical Patch-Dynamics Model, Ecosystem-Process Models and Scaling Up (Wu).* Much of the modeling effort during CAP1 focused on developing models of land-use change and urban growth (Jenerette and Wu 2001; Wu and David 2002; Berling-Wolff and Wu 2004), as well as quantifying the spatiotemporal patterns of the urban landscape (Luck and Wu 2002; Wu *et al.* 2002). CAP1 employed a Hierarchical Patch Dynamics Modeling (HPDM) approach to build a modeling framework for guiding our efforts in gathering land-use and land-cover data, studying the processes that lead to change in individual patches, and analyzing the interaction among patches. The HPD modeling approach will remain a central tool in future students, but will be supplemented by more focused models.

Ecosystem simulation is used to generate estimates of ecosystem process rates that can be scaled to the region when combined with land-cover and patch-typology data. In particular, we have begun to fit local parameters to the ecosystem simulation model, PALS, developed for JRN by J. Reynolds (Reynolds *et al*. 1993, 1997, 2000). The advantages of using PALS for CAP are: 1) it includes major desert ecosystem processes of relevance to our research questions; 2) it has been tested on other sites; and 3) model parameterization and testing are greatly facilitated because of the similarity in dominant plant species between the Jornada and CAP sites. Data from our existing databases, including remote sensing, Survey200, intensive plots, and literature, have been used to parameterize PALS-PHX to predict desert NPP (see Shen *et* al. *in review*). The

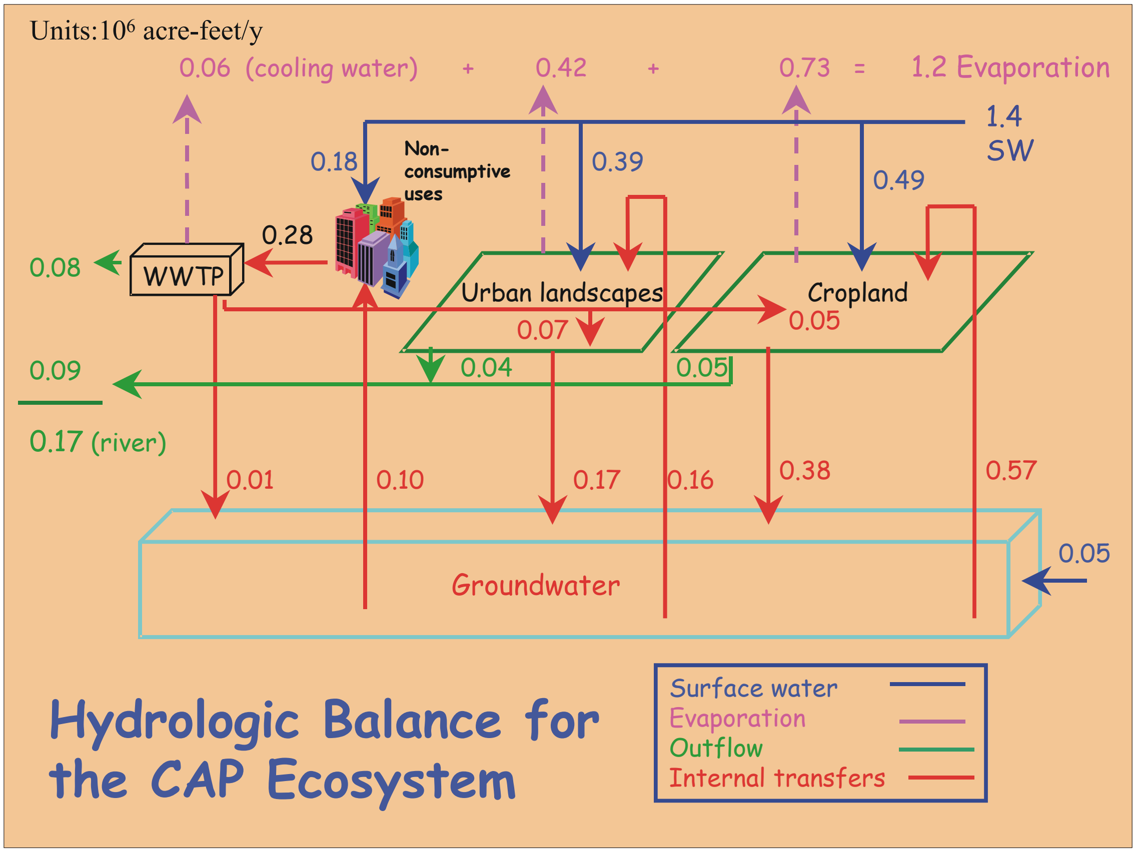


**Figure 7.** Hydrologic balance for the CAP ecosystem showing major inputs (blue arrows), surface-water outputs (green arrows), internal fluxes (red arrows) and evaporative fluxes (pink arrows). Note that only a small percentage of water inputs leave the city.

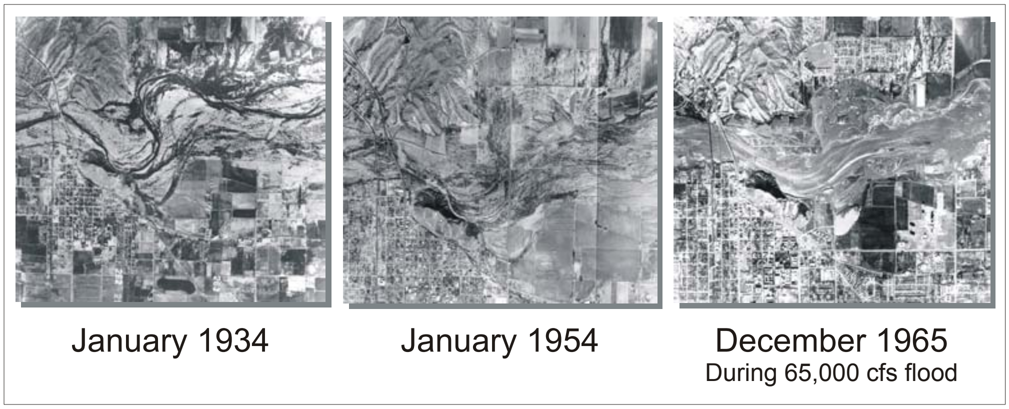


Figure 8A

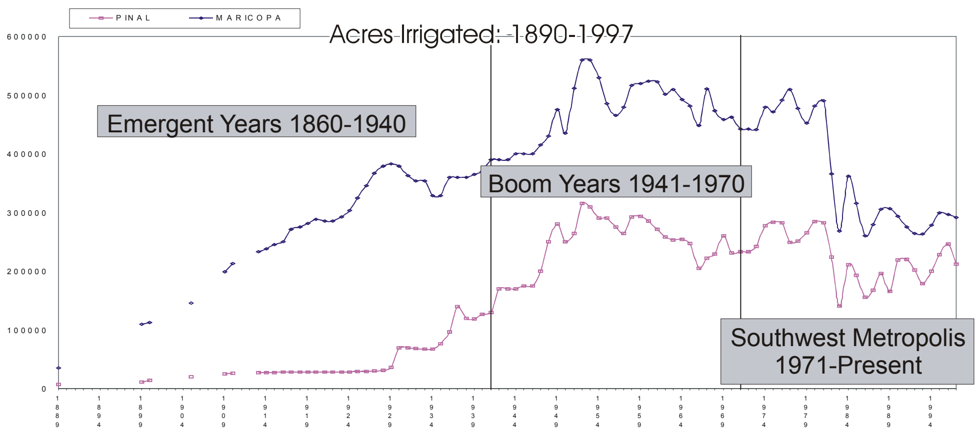


Figure 8B

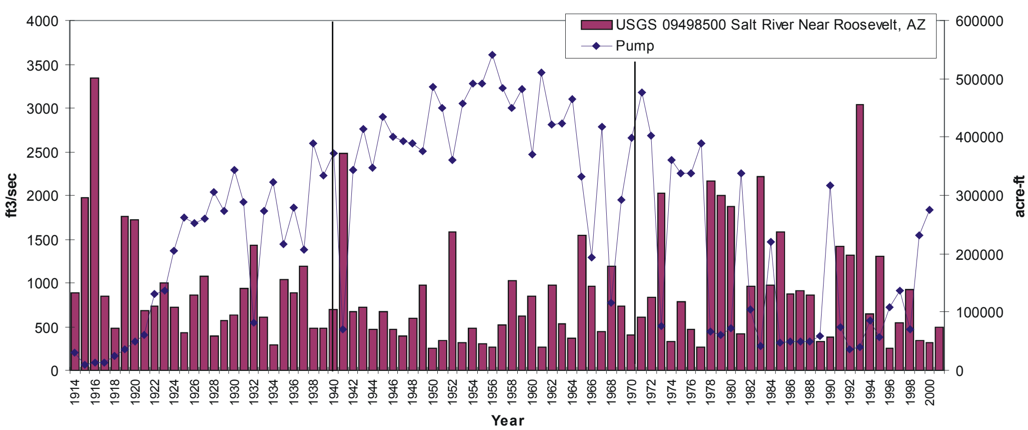


Figure 8C

**Figure 8. A)** Aerial photos showing changes in the channel of the Salt River from 1934 to 1965. Prior to 1938, the river's discharge was relatively uncontrolled and the river migrated in an extensive channel (left). 1954 photo (center) shows encroachment on the now-dry channel by both agricultural fields and housing, which are susceptible to the rare floods that still occur (right). **B)** Changes in farm acreage irrigated during agricultural expansion (emergent, boom years) and during the recent urban expansion (1971-present). **C)** Long-term data records such as these for stream flow and groundwater pumping are mined for budgets and historical analysis, and stored in the CAP database.

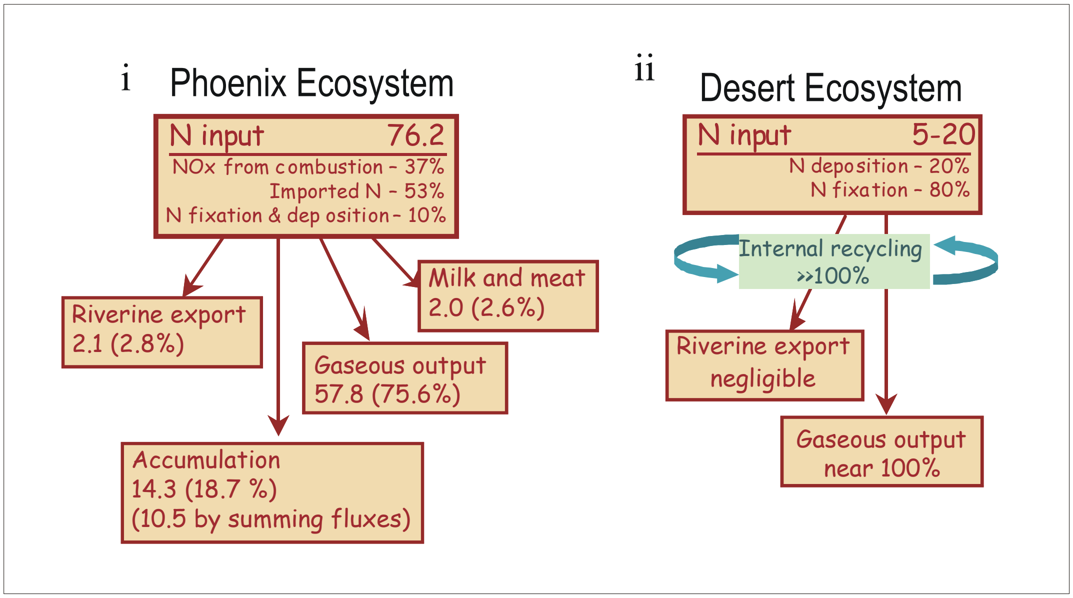


Figure 9A

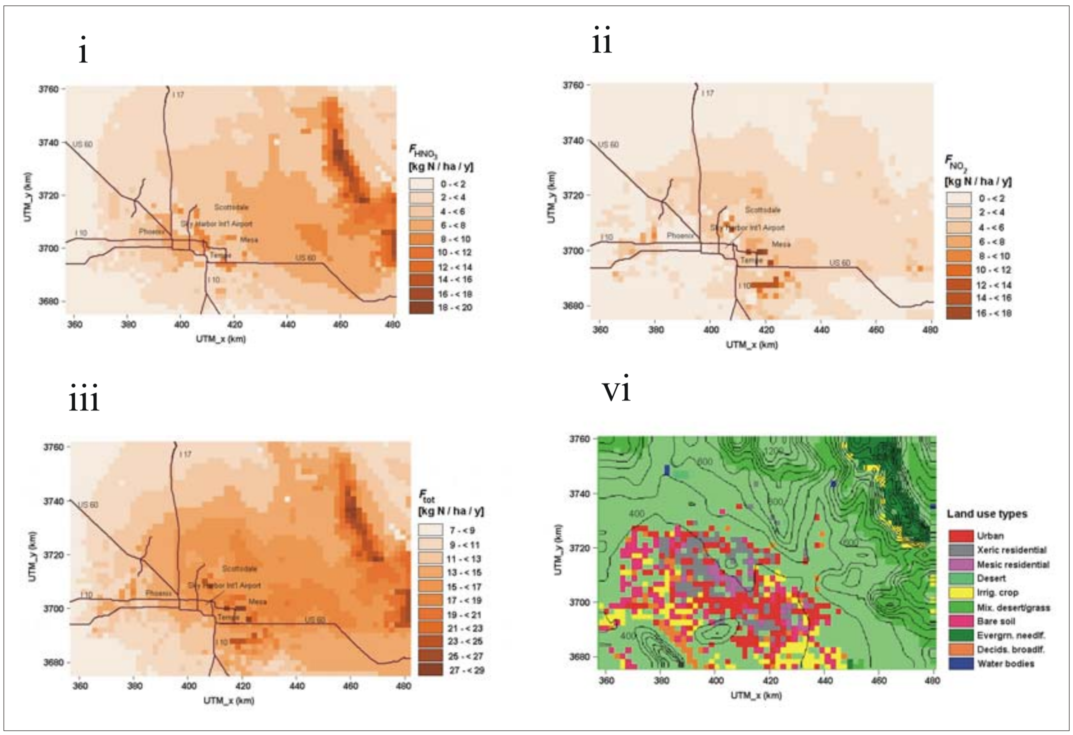


Figure 9B

**Figure 9. A)** Comparison of nitrogen budgets for i) the CAP socio-ecosystem and ii) a desert ecosystem. All units in kg/ha. Note that inputs to the urban ecosystem exceed those to surrounding desert by a factor of 7-10 and are dominated by deliberate and inadvertent inputs of N mediate by humans, such as atmospheric deposition (Baker et al 2001). **B)** Estimated annual dry nitrogen (N) deposition as i) nitric acid ($HNO_3$), ii) nitrogen dioxide ($NO_2$), iii) total N across the Central Arizona-Phoenix region, in kg/ha, determined using Models-3 Community Multiscale Air Quality (CMAQ) model simulations and iv) land use determined from CAP research (Fenn et al 2003).

next steps are to apply the model to other patch types, and to conduct simulation experiments, for example, to investigate the influences of altered climate, nutrient availability, or toxins on ecosystem processes.

### Comparative Studies

In addition to the widespread use of comparative ecosystem studies within the study area (e.g., comparison among different land-use types), CAP LTER has actively sought interactions with our sister urban LTER, the Baltimore Ecosystem Study (BES) and other LTER sites. Land-cover transformations of agrarian landscapes ("Ag Trans" Project, NSF-BE; *Redman et al. 2002*) for six LTER sites (CAP, HFR, SGS, CWT, KBS, KNZ) are compared as case-study narratives (*Redman, Kinzig*) and with remotely sensed and ancillary geospatial data, the latter study focusing upon recent land-cover, land-use, and vegetation-index data (*Stefanov, Netzband, Banzhaf, Moeller*). Research on urban animal populations and communities, especially associated with urban parks, has been conducted in parallel and in communication with BES (*Warren*) and was further developed in a planning workshop on community ecology of urban ecosystems (February 2004, *Warren* organizer; Faeth et al. in preparation). Our Survey200 was developed in consultation with BES to parallel their urban forest monitoring; arthropod pitfall trapping was designed in consultation with Sevilleta and Jornada scientists; and ongoing ecosystem modeling uses a modification of the Jornada-based PALS model (Reynolds *et al*. 1993, 1997, 2000). CAP LTER climatologists (*Brazel, Ellis*) actively participate in LTER network climate activities, and the CAP regional C mass balance is being compared to the Minneapolis/St. Paul C mass balance in a separate NSF-Biocomplexity project (*Baker, Hope, Kaye*). Finally, CAP LTER scientists initiated a series of workshops aimed at instilling more social science into the LTER network (NSF-BE Incubation, *Redman and Grove 2001),* which led to the aforementioned Ag Trans project.

### Informatics Activities

Information Management (IM) is an integral part of CAP LTER. The original twin goals of providing data support for research activities and ensuring long-term availability of CAP LTER data products, have been supplemented by a third goal of contributing research toward advancing ecological informatics.

Our data-management procedures are designed according to the five-part organization of continuing research: monitoring, data mining, modeling, experiments, and comparative studies. Common to all is an initiation process in which PIs of new research activities meet with IM staff to discuss data needs and likely data products. Our management database is initialized with information such as personnel and their roles, short abstract, long description, and research design. In addition, entries are made for each data product anticipated from that project, including title, description, nature (primary, secondary, or acquired), anticipated release status (public or restricted), and date. The PI and project directors decide when and under what terms a dataset is to be released; all access prior to release is at the discretion of the PI. Current status for most of this tracking information is available through the Web site and via periodic reports. Projects are requested to turn in a detailed protocol for each dataset and samples of field or lab entry forms, if relevant. A GIS cover indicating the study area and/or sampling locations is created for each project, either by digitizing from imagery, geocoding from street addresses, or determining locations with GPS devices.

*Monitoring.* After a project is initialized, the PI meets with the IM staff to discuss data-management needs. Data-modeling tools are used to produce a generalized schema of the database with reference to the PI's protocol and the entry forms. The databases are built on

Microsoft SQL Server. The data-modeling schemas and an EML document of the database are stored and updated as the data schema is modified. Interfaces for data entry are developed with *Access*, which features rapid development time, rich options for quality control, and event code to perform any necessary transformations. Technicians enter data for core-monitoring databases to ensure rapid turnaround and consistent data quality. Data sheets are archived in the Goldwater Lab (analytical) and CES (all other studies). PIs are encouraged to proof entry and, when requested, the IM staff has included report formats in the application to print proofing sheets that approximate the original data-entry forms. Quality control of CAP LTER databases relies heavily on the use of rigid relational schemas and extensive check constraints to evaluate data as they are entered. Appropriate scripts have been developed for rapid upload and quality control of data generated by automatic data loggers. During CAP1, few standard procedures were developed for doing post-processing quality checks on data after entry, leaving such screening up to the researchers. A goal for the CAP2 is to better incorporate such screening tests into the data-entry applications. We are also planning an automated system for reporting the status of a dataset to the researchers, e.g., a "data-audit statement" that includes simple descriptive statistics to alert to outliers or other problems.

*Data mining.* Many CAP LTER projects involve synthesizing and analyzing existing data. Metadata-creation tools are used to extract the structure of these imported datasets to capture their low-level syntax. When available, metadata provided is added to the EML documentation.

*Experiments.* One-time experiments follow a less-rigid protocol for data management with some of the initial management done either by the researchers or by specialized labs (e.g., social-science interview data or remote-sensing data). Data not managed by the CES Lab are checked in for archiving at the end of the research and typically undergo reformatting to make them compatible with the lab's storage formats. A metadata file is created according the information provided by the researcher. This is a satisfying model for ecological datasets. In CAP2, we will concentrate on improving metadata for social-science experiments, which are mostly questionnaires, producing a database of questions plus metadata for researchers' use. Long-term experiments use similar protocols to those of the monitoring projects.

*Modeling.* IM staff recently began a policy for archiving modeling outputs as datasets, which will become standard practice during CAP2. The lab is working under separate funding to develop metadata standards for model documentation that can be used to extend the existing EML. Once completed, this standard will be used to document and archive models developed and/or used by CAP LTER.

*Comparative studies.* Synthetic research at the network level requires information systems that can integrate with other archives. CAP LTER contributes data to the LTER Network Information System databases such as ClimDB, SiteDB, and Bibliography. IM staff also provide data-management support for cross-site projects such as LINX (NSF-IRCEB, Grimm subcontract, *Mulholland et al. 2001*) and Ag Trans (NSF-BE, *Redman et al. 2002*).

*Archive and dissemination***.** Primary data consisting of original observations and value-added secondary, derivative data are archived in the CES Lab with complete metadata documentation (see list of databases in Supplemental Documents). Acquired data gathered during data-synthesis projects are archived as a service to other CAP LTER researchers, but receive lower priority for extensive metadata documentation. A limited set of data formats is used for archiving data according to type. Restricting the number of supported formats encourages more standardized access tools and simplifies the process of forward migration to new versions or formats (see Table 2). CAP LTER strives to make data available within two years of their collection. A data-access policy based on the draft policy developed in 1999 by the LTER Information Management Committee is posted on the Web. The guidelines for acceptable use are inserted as

**Table 2. Storage Format Types for CES Dataset Archive**

| EML Entity Type | Format(s) |
|---|---|
| Tabular data | MS SQL Server 7.0 |
| Spatial Vector | ArcView shapefile |
| | ESRI Spatial database engine 8.3 |
| Spatial Raster | ERDAS Imagine files |
| | ArcInfo GRID |
| | ESRI Spatial Database Engine 8.3 |

part of the EML for every dataset and constitute the use license for any data released by CAP LTER. All access to the online data is logged by user, date, and dataset ID. The core-management system consists of a series of integrated databases: projects, personnel, bibliography, datasets, digital documents, images, protocols, and calendar. Most information provided on the Web is drawn dynamically from this database. Following the release of EML 2.0 in 2002, the database design was modified to conform to this new standard. A complete metadata
editing application was written to allow IM staff to edit and manage the metadata catalog. Under separate funds, tools were developed to expedite metadata generation by either reverse-engineering information from the actual data source or translating metadata produced by proprietary applications into EML. The EML files are edited with XML editors and loaded into the relational database. In 2002, Internet forms were created on the CES Intranet Web site, where researchers may enter and edit certain descriptive and personnel information about their projects and datasets directly into the database.

In 2003, CAP LTER switched from its previous online data catalog to a new system, the Southwest Environmental Information Network (SEINet, http://seinet.asu.edu). CES created SEINet under separate funding to provide an integrated gateway to multiple environmental data resources at ASU and in central Arizona, thus leveraging the value of CAP LTER data. In addition to serving as the Web portal to CAP LTER metadata, datasets, literature, and protocols, SEINet also provides access to nine biological-collections databases, a taxonomic thesaurus, identification keys, and other Arizona data archives. The system provides download and simple visualization and analytic functions, while logging all access for accountability. SEINet uses an abstracted data-access layer based on Web services (McCartney 2003), which encourages development of diverse Web applications that use a common data framework, such as a recently released electronic atlas (www.gp2100.org/eatlas) on the environmental future of Phoenix.

In addition to SEINet, CAP LTER relies on a series of Web sites for information management which all draw from a common data framework. Our Web site is dynamically linked with the management database to provide up-to-date information on project events, products, project activities, and personnel. It uses data-access protocols developed for SEINet to deliver CAP LTER content to the Web in displays that are simpler to use but still linked to SEINet. The data section of the Web site provides access to protocols, information on the activities of the IM staff and links to SEINet and other supporting Web sites including CES Informatics Lab site, and other participating lab Web sites.

A separate database is managed for the Ecology Explorers schoolyard-ecology project. A Web data center provides data-entry forms for four separate protocols and a query wizard for enabling students to download data. With leveraged funding, a new analysis wizard has been created to enable students to formulate and test hypotheses visually and statistically online. Goals for the upcoming session are to use these new tools to better integrate the Ecology Explorers Web site (http://caplter.asu.edu/explorers) with data from CAP LTER's main science activities.

*Ecological Informatics.* Beginning in 1998, the CES Informatics Lab actively pursued development of an advanced information infrastructure for the broad ecological community (Brunt *et al.* 2002). Since then, the IM staff has been engaged in sponsored research with the LTER Network Office, National Center for Ecological Analysis and Synthesis, and San Diego Super Computer Center. This collaboration has included the development and continued maintenance of EML (McCartney and Jones 2002), development of EML-based tools for querying and accessing data (Schoeninger *et al.* 2002), and participation in the Science Environment for Ecological Knowledge (Michener 2003). Future goals for ecological-informatics research focus on continuing to build SEINet as a platform for interagency data sharing, model integration, and dissemination of research products to diverse audiences including K-12, informal education, and decision-making. In addition, we will strive to make the use of EML more efficient and to integrate EML into site-management applications.

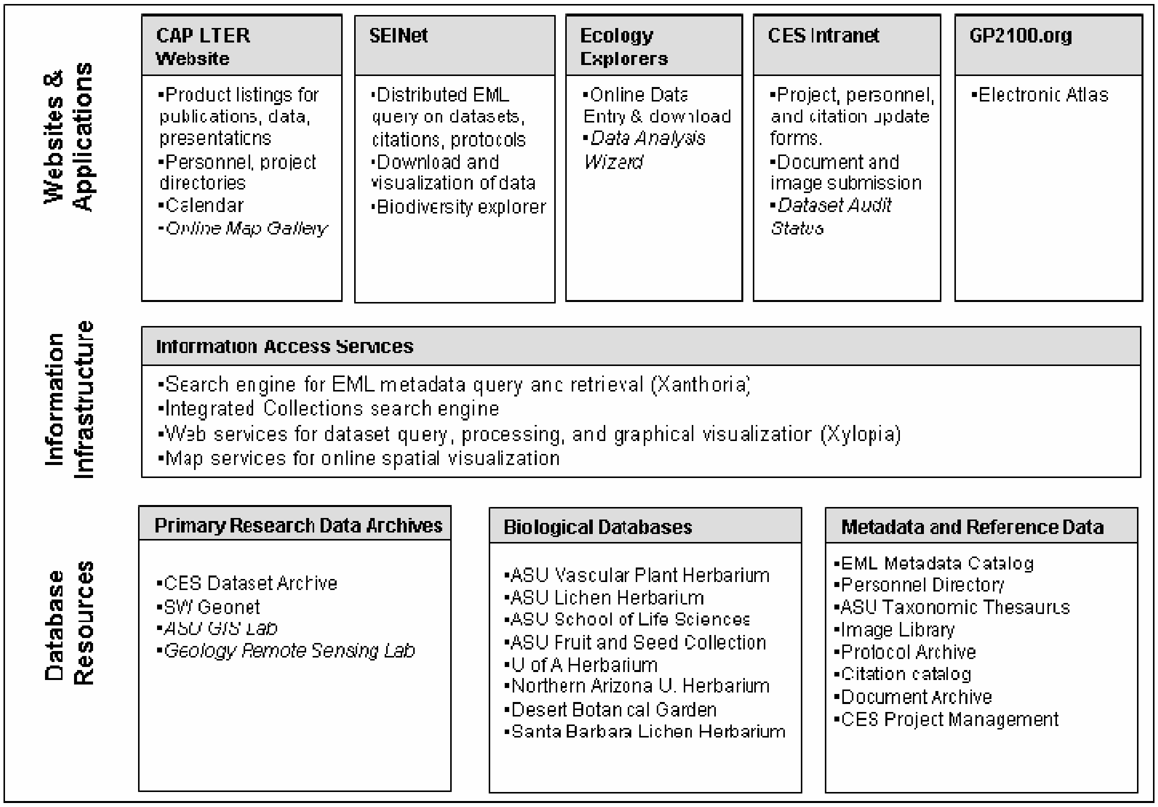


**Figure 10.** Integrated information resources supporting CAP LTER. Italicized items will be implemented during the first two years of CAP2.

## III. Highlights of Research Findings

The following CAP1 findings are organized into the revamped CAP2 structure, organized around interdisciplinary, integrative project areas.

### Land-Use and Land-Cover Change

CAP1 featured three activities associated with land-use and land-cover change (LULCC): 1) classifying, monitoring, and modeling LULCC; 2) examining urban form; and 3) investigating the human drivers of those changes. An expert classification system, developed from remotely sensed images (Stefanov *et al.* 2001), offers a vision of the urban patch structure and its changes over the past decade. Analysis of historical land use (since 1912) show agricultural expansion in the first half of the century and urban expansion in the second half (Fig. 6; Knowles-Yanez *et al.* 1999; http://caplter/contributions); and contributed to urban growth modeling (Jenerette and Wu 2001; Berling-Wolff and Wu 2004). One model suggests that, by 2030, urban growth will consume all available agricultural and desert lands. Our ecosystem simulation modeling efforts aim to simulate LULCC and study urbanization's effects on ecological processes, such as primary production (Shen et al. in review). A hierarchical platch dynamics modeling platform (Wu and David 2002) shows how such simulation models can be scaled up by combining them with knowledge of patch structure. In sum, our modeling work has contributed to resolving methodological issues in modeling complex spatial ecological systems (Reynolds and Wu 1999; Wu 1999; Wu and David 2002; Wu *et al.* 2000, 2002, 2004a).

The ASTER Urban Environmental Monitoring (UEM) project (elwood.la.asu.edu/grsl/UEM) characterized regional landscape fragmentation and the spatial variation of the CAP study area using land-cover classifications derived from ASTER data. We found that 55 urban centers, including Phoenix (studied with leveraged LTER funding), have significant landscape fragmentation and that cities can be ranked according to metrics such as edge and patch density. CAP1 research also shows that urban areas have high patch densities, numbers of patches, and smaller mean patch sizes than either desert or agricultural areas (Luck and Wu 2002). We will continue to enhance our characterizations of urban-development trajectories and predictions of urban-center sustainability and resilience, and have received NASA-Earth Observing System funding to support this work (Stefanov and Christensen 2003).

CAP1 research has updated classic urban-fringe morphology studies, using a much shorter time frame and finer geographic scale (Gober 2000; Gober and Burns 2002). New residential developments resemble a "tidal wave" covering a surprisingly wide geographic area but within a narrow, donut-shaped band of territory. Recent expansion in parts of Phoenix has occurred at a rate of *one mile per year*, compared to one mile per decade for cities in the first half of the twentieth century (Blemenfeld 1954). Land taken out of agriculture is quickly transformed into housing, inspiring CAP LTER ecologists to adapt a model of housing spread borrowed from population-diffusion models (Fagan *et al.* 2001). Recent research includes an international collaboration to compare urban form and growth in four US and French cities (Joliveau *et al.* 2002).

Urban environments increasingly influence biophysical processes and quality of life for their inhabitants (Baker *et al.* 2002). The Phoenix Area Social Survey (PASS) of eight neighborhoods (302 respondents) captures the spatial variation in human attributes that comprise the social fabric of Phoenix (Harlan *et al.* 2003; Larsen et. al. 2004; http://caplter/contributions). Although most respondents believe in preserving pristine desert lands, paradoxically, half the respondents believe housing density is too high—particularly those on the urban fringe! More than 40% of the respondents are also concerned about the water supply, drinking-water safety, accidental releases of industrial chemicals, air pollution, allergens, and soil and groundwater contamination. Half the respondents believe environmental conditions in Phoenix are worsening; only one in five thinks the environment is improving. Expanding the PASS survey with supplemental funding will provide a way of examining human responses to change as Phoenix continues to grow.

## Climate-Ecosystem Interactions

Data mining of long-term climate records for Phoenix and Baltimore shows that nighttime temperatures have increased for Phoenix, but daytime maximum temperatures are *lower* than the surrounding desert (Fig. 3). The resulting "oasis effect" (Brazel *et al.* 2000) underscores the complex interactions among human preferences and behavior, plants, and local climate. Modeling the urban climate system at the local scale shows the extent to which heat is retained at night, due to local decreases in the sky-view factor and/or the higher thermal admittances of urban surfaces (Brazel and Crewe 2002). Mesoscale MM5 modeling, made possible through special adaptations of the USGS MM-5 land-use code and application of CAP land-cover data (Grossman-Clarke *et al* 2003) provides detailed climate and meteorological information for the entire region, which can be used in atmospheric deposition modeling and other studies.

Local climate and surface-cover feedbacks influence plant size and rate of primary production. For example, five of six landscapes tree species exhibit significant reductions in size owing to adjacency to asphalt parking lots—temperatures on such surfaces are up to 27$^{o}$C higher than concrete, turf, and other pervious materials (Celestian and Martin 2004). Meanwhile, monitoring of plant growth, gas exchange, and water-use efficiency among replicated intensive sites in six patch type-land-use history combinations (desert, agricultural and xeriscape or mesiscape residential on former desert or agricultural land), shows that annual primary production ($CO_2$ uptake) varies with summer heat stress, water status, and land-use type (McDowell and Martin 1999; Martin and Stabler 2002).

The neighborhood ecosystems project is continuing to examine these feedbacks, but with the added emphasis of understanding heat distribution in relation to social distributions. Initial analyses of both neighborhood-scale (Prashad *et al.* 2003) and regional-scale (Jones *et al.* 2003) remotely sensed vegetation and surface-temperature patterns indicate that the city is hotter in poorer, nonwhite neighborhoods than in wealthier areas.

## Water Policy, Use, and Supply

Although not a specific focus of CAP1, several projects addressed the issues we now consider under this category. Surprisingly, our residential landscape water-use efficiency project showed smaller-than-expected differences (Fig. 4) in water-application rates between xeriscape and mesiscape designs (Peterson *et al.* 1999)—suggesting that human perceptions rather than plants' physiological needs often dictate water use in urban areas. Water use in Phoenix was contrasted with the 25 largest US cities using a spatially explicit modification of the ecological footprint concept (Luck *et al.* 2001), an approach expanded to compare water footprints between China and the US (Jenerette *et al.* 2004). In both cases, water use in Phoenix is high, and intimately connected with Phoenix's agrarian history and arid nature. Indeed, the hydrologic budget for CAP (Fig. 4) indicates that all surface water is appropriated for human use, very little of this water is ultimately discharged from the city, and irrigation-based use of water is an important component of the hydrologic budget.

Retrospective analyses of Phoenix water have focused on geomorphic channel change and historical floods and management in the heavily modified Salt River (Fig. 8). Human activity (largely gravel mining) has profoundly affected the Salt River, but the channel still responds to infrequent flooding (Graf 2000). The need to assure water supply has most greatly determined today's river configuration, rather than to provide protection from flooding or access to gravel (Honker 2002). Dry riverbeds and highly engineered, artificial lakes are the only reminder of the river that once flowed through the metropolis (Grimm *et al.* 2004). Restoration efforts have only recently begun to focus on streams and riparian areas, although one of the earliest "designer ecosystems" (a non-structural flood management system) was established in Scottsdale's Indian Bend Wash in the early 1970's (Palmer et al. 2004, Roach et al. in preparation). Studies of water policy began more recently, as we established a baseline of information on historical trends (Honker 2002). CAP2 will expand these studies, with the aid of strong partnerships with agencies and projects such as the new Decision Center for a Desert City and Greater Phoenix 2100 <www.gp2100.org>, which envisions the future of metro Phoenix over the long term; Fink *et al.* 2003).

## Material Fluxes and Socioecosystem Response

Atmospheric, terrestrial, and aquatic components of the urban landscape are linked through material fluxes, and CAP1 studies include projects at a range of scales. Our initial focus on a whole system N mass balance (Baker *et al.* 2001) reveals large, human-mediated inputs, both intentional (e.g., fertilizer and food) and inadvertent (e.g., atmospheric deposition), as well as significant retention on the order of 14 kg $ha^{-1}$ $y^{-1}$(Fig. 9) an amount of N that exceeds total annual input to the surrounding desert ecosystems. We then worked on quantifying the air-land component of the N budget. Combining results from Models-3/CMAQ and a diagnostic model of $NO_x$-derived deposition (Fig. 6) confirmed enhanced (~double background) atmospheric N deposition rates for the urban core and downwind sites (Fenn *et al.* 2003; Grossman-Clarke *et al.* 2003). Analyses of metals incorporated by lichens have helped identify spatial variation in air pollution sources (Nash *et al.* 2003; Zschau *et al.* 2003). Fluxes of $NO_x$ and $N_2O$ gases from land to atmosphere are enhanced in managed residential lands of urban Phoenix, probably owing largely to fertilization and irrigation (Hall et al. in review).

Much of our work on the land-water component of materials fluxes has focused on the movement of nutrients during storm events into recipient systems. High concentrations of nutrients (N, P, organic C) and metals are stored on asphalt surfaces, then transported to urban waterways during storms but the N export is not as large as predicted from surface storage (Hope *et al.* 2004). Analysis of a US Geological Survey (USGS) dataset on small urban watersheds reveals that catchment characteristics (e.g., land cover, impervious surface cover, configuration) govern nutrient and metals loads (Lewis and Grimm, *in review*). Retention basins are recipient systems unique to urban areas; their soils exhibit high rates of denitrification (Zhu *et al.* 2004). Other denitrification "hot spots" are likely to be floodplain park soils and the sediments of aquatic recipient ecosystems. Surface-water channels constitute the other major recipient system. Research in a smaller watershed (IBW) shows that hydrologic management dictates nutrient patterns; when N-enriched groundwater is added to maintain water levels of artificial lakes, P limitation occurs (Goettl 2001; Grimm *et al.* 2004; Goettl and Grimm, *in preparation*; Roach and Grimm, *in preparation*). Denitrification is high in the IBW floodplain soils and in the sediments of its numerous lakes (Roach and Grimm, *in preparation*). In fact, lakes are a prominent aquatic feature of the Phoenix metro urban landscape; in the iBW watershed alone the number of lakes increased from zero in 1960 to >150 today (Roach et al. *in prepration*). Small urban-catchment research during CAP1 indicated that impervious urban surfaces can form important temporary storage sites for nutrients such as N and C (Hope *et al.* 2004), but that transport of these nutrients during storm runoff to recipient surface soils in retention basins where microbial process rates are high (Zhu *et al.* 2004) may result in smaller-than-expected nutrient fluxes from these basins overall (Hope *et al.* 2004). I

Declines in high dissolved organic carbon concentrations downstream of metro Phoenix owe largely to human manipulations of hydrology (Edmonds 2004). Results from our water-monitoring program show that nutrient concentrations are higher (sometimes by an order of magnitude) downstream of the urban area, but that loads are reduced because little water leaves the city (Baker *et al*. 2001; Edmonds 2004). Thus, nearly all of the toxic materials and excess nutrient elements released within the urban area appear to remain within soil and aquatic recipient systems or be transported to surrounding desert systems within the urban airshed. Future research will investigate consequences of this movement of materials for ecosystem processes within and outside the city, and for social patterns and processes within the metropolis.

The environmental risk study has examined the relationship of spatial distributions of technological hazards to the demographic composition of adjacent neighborhoods (Fig. 11). Researchers have detected clear patterns of social inequities in the distribution of risk burdens, pointing to a pattern of environmental injustice by class and race across a range of technological hazards in the Phoenix area (Bolin *et al.* 2002; Bolin *et al.* in review). CAP2 studies will expand this research to integrate CAP findings and research on toxic materials in air, water, and soil.

## Human control of biodiversity

Biodiversity research, employing both monitoring and experimentation, has focused upon vascular plants, mycorrhizal fungi, arthropods, and birds. Survey200 has revealed that a combination of human-related and non-human predictor variables best explains CAP's spatial variation in plant diversity. Although past and current land use is an important determinant of plant diversity, the most interesting finding to date is a positive plant diversity-income relationship for urban sites. Neighborhoods with a median family-income level above $50,000 per year averaged 2.3 times the plant diversity of less-wealthy areas (Fig. 12). This "luxury effect" suggests that, given sufficient economic means, humans choose to enhance plant diversity (Hope *et al.* 2003). Bird species richness was also strongly correlated with socioeconomic status at the neighborhood scale (Fig. 12: Kinzig *et al.* in review), and distinct human preferences for certain landscape configurations and plant combinations were identified (Martin *et al.* 2003, in press).

Findings by Hope *et al.* (2003) agree with those seen for ground arthropods—the urban landscape has similar levels of diversity to the native landscape it replaced, although community composition differs (McIntyre *et al.* 2001). Spiders exhibit similar spatial diversity patterns to ground arthropods, but productive habitats (agricultural and mesic areas) have high abundance and low diversity, indicating that land-use types modify productivity-diversity relationships (Shochat *et al.* 2004b). Insect pollinators, on the other hand, key-in specifically to native desert vegetation (McIntyre and Hostetler 2001). For birds, experimental manipulation of seed supply and water showed that reduced predation, higher food abundance, and competitive exclusion of natives by urban specialists, replace water limitation (in the desert) as the primary controls on bird-foraging behavior. A theoretical study (Katti *et al*. *in prep.*) supports empirical observations of high abundance but low diversity of birds in urban areas (Shochat *et al.* 2004a). Species richness of AM fungi correlates positively with time since development at older urban sites (Stutz and Martin 1998) and is reduced at agricultural or formerly farmed sites (Cousins *et al.* 2003).

Experiments also have revealed much about how urbanization influences populations, communities, and species interactions (Faeth *et al. in prep.*). Preliminary results of the trophic structure and dynamics experiment indicate that diversity (Fig. 5) and abundances of arthropod herbivores, predators and parasites differ dramatically among the sites and with season. Furthermore, top-down effects, especially from avian predators, are more pronounced in mesic urban habitats, whereas bottom-up forces (e.g., plant resources) dominate outlying natural deserts. We are seeking non-LTER funds to conduct similar experiments at the scale of entire yards and mini-neighborhoods at the NDV experimental suburb (Faeth and Sabo*, proposal*

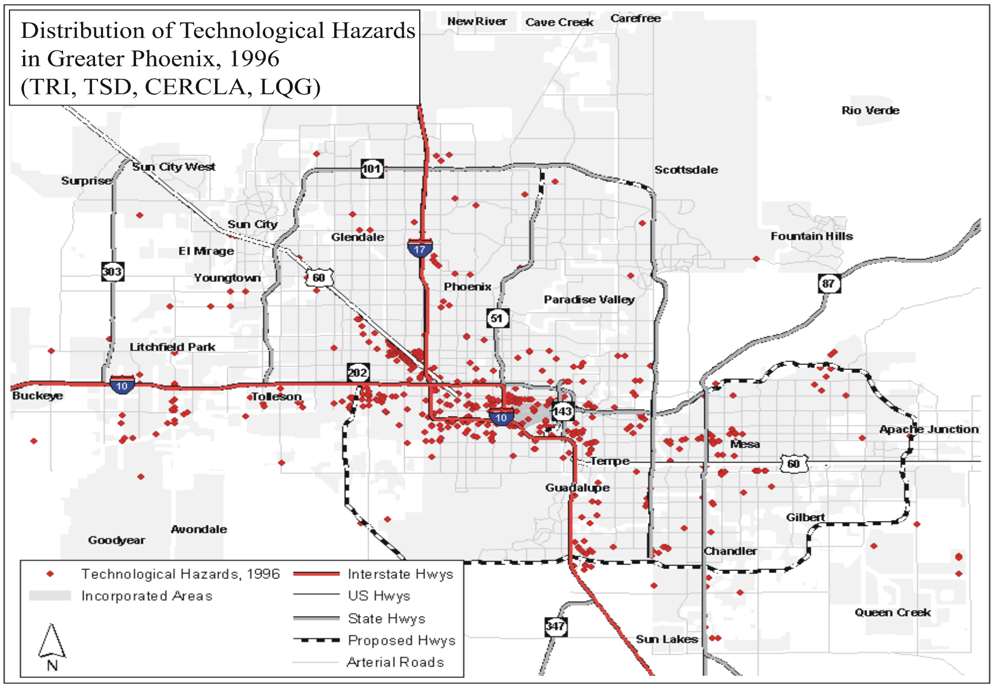


Figure 11A

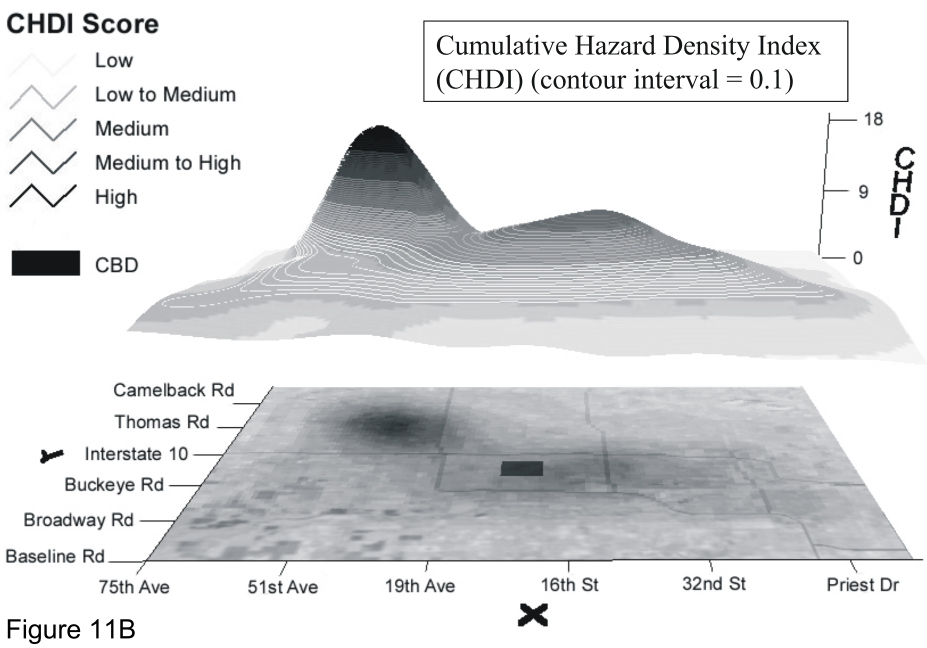


Figure 11B

**Figure 11. A)** This map shows the locations of four major types of technological hazards: Toxic Release Inventory (TRI) sites-- large industrial polluters; Treatment Storage and Disposal Facilities (TSDF)-- toxic waste processors/shippers; Large Quantity Generators (LQG) -- industrial sites that use or store federally regulated hazardous chemicals; and Comprehensive Emergency Response and Community Liability Act (CERCLA) sites--with significant toxic contamination, including Superfund sites. **B)** Cumulative Hazard Density Index-- a spatially standardized measure of the cumulative distribution of four types of technological hazards (see 7A) aggregated at the level of census tracts. The index provides a relative score for the hazardousness of each census tracts, the darker areas having the highest hazard burdens.

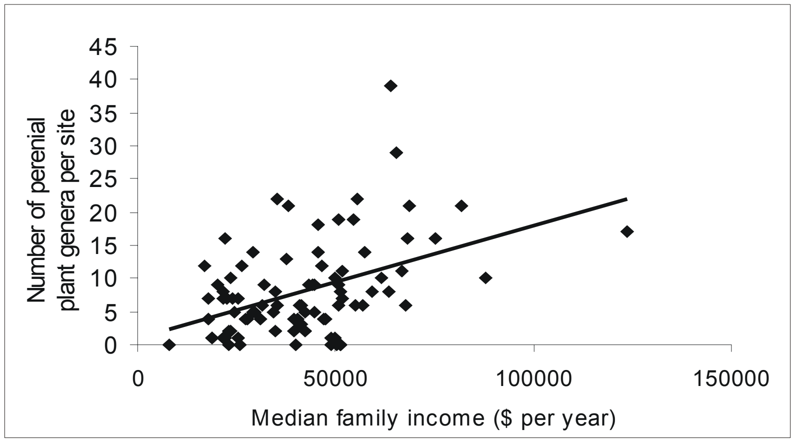


Figure 12A

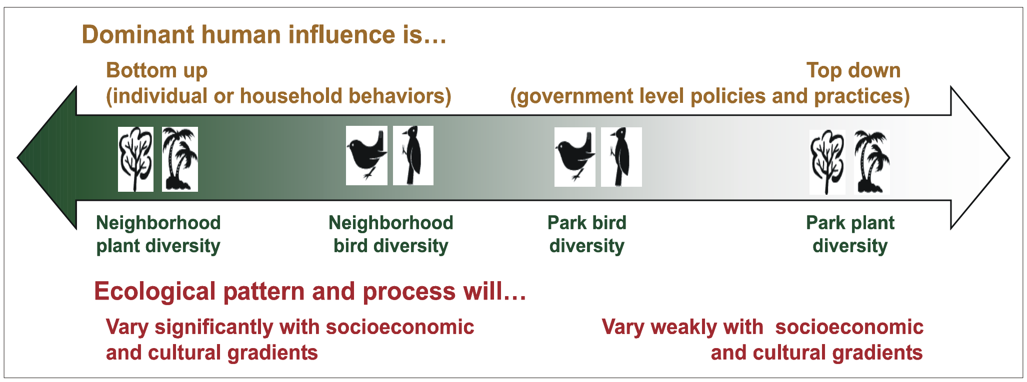


Figure 12B

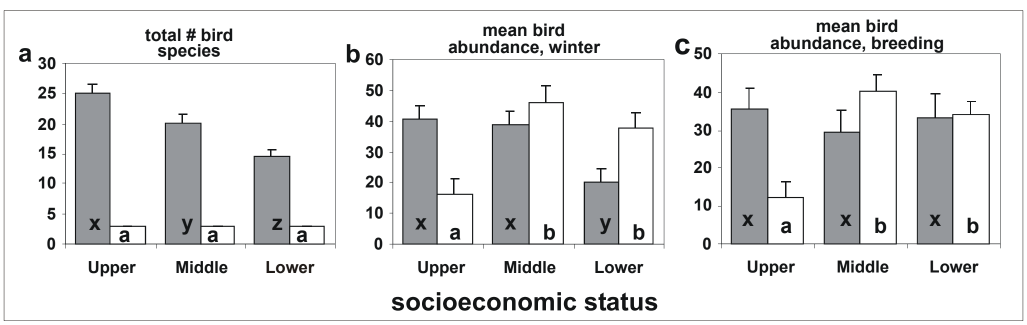


Figure 12C

**Figure 12. A)** Socioeconomic factors appear to be one of the important determinants of urban plant diversity, as seen in the variation in the number of perennial plant genera with median family income (in $ per year) from the U. S. Census of Population and Housing for the block group surrounding each Survey200 site in the urban area (Hope et al 2003). **B)** However, we predict that not all patterns of urban biodiversity will be equally affected by socioeconomic or cultural status of human residents, but rather will differ in the degree of "bottom up" and "top down" human influences. "Bottom-up" influences are likely to reflect the integrated outcomes of small-scale (individual or household) choices or actions, while "top-down" influences will reflect city-level management strategies and decisions (Kinzig et al *in review*). **C)** Effects of socioeconomic status (SES) on bird species richness (a) and abundance (b-c) in 16 urban parks for native (gray bars) and exotic (white bars) species. Letters indicate significant differences between groups (two-tailed t-test, $p<0.05$). Abundances are calculated as the number of individuals of each species averaged across observers and summed across species for the non-breeding season (b - December 2000) and the breeding season (c -March 2001) from Warren et al (in prep).

*pending)*. Similar results on the importance of bottom-up effects in harsher desert surroundings and predation in urban habitats were obtained in a study of birds' responses to experimental foraging patches (Shochat et al. 2004b). Indeed, bird populations show strong responses to human-altered resource distributions, sometimes greatly increasing in urban areas with more abundant food and water (Shochat 2004).

### Informatics

With funding from NSF-BDI (McCartney *et al.* 1999), the CES Informatics Lab worked on several contributions to the field: 1) *Ecological Metadata Language*, content standards for dataset and literature descriptors encoded in XML; 2) *Xanthoria*, an XML-based query engine for executing clearinghouse searches against a network of distributed metadata catalogs or bibliographic databases; 3) *Xylopia*, a data-access system that uses EML metadata to dynamically open connections to remote data, perform a variety of basic statistical, processing, or visualization functions online; and 4) integration of biological collections databases via a central taxonomic thesaurus and query system. All these products are implemented in SEINet (http://seinet.asu.edu). We are also completing a new analysis wizard for our Ecology Explorers program, based on the SEINet infrastructure. We have begun to integrate urban ecological models from government partners using a Web-services approach under a separate grant from NSF-ITR (McCartney *et al.* 2002). This project builds on the BDI effort by defining metadata standards for documenting models and coupling model inputs and outputs via a workflow-processing system.

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# V. Research Training and Development

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

CAP LTER's university setting enhances the ability to conduct, communicate, and synthesize our research activities. Faculty members have expanded their courses to consider urban ecology and, in some cases, have designed new courses to accommodate CAP LTER research interests. In addition, postdoctoral associates and graduate assistants gain exposure to interdisciplinary research, the importance of long-term datasets, metadata, and data archiving, as well as experience in database design and management, lab processing and analysis. The Goldwater Lab for Environmental Science accommodates CAP LTER's analytical needs and provides graduate-student training on instruments housed in its facility. Data collected as part of the remote sensing lab's research programs is archived at the Geological Remote Sensing Laboratory and is available to project researchers and graduate students.

Since the inception of CAP LTER, 17 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports 6 postdocs, 3 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. They are integral to the research and field experience of CAP LTER and receive training in interdisciplinary collaboration, graduate-student supervision, data collection and analysis, and presentation techniques.

Both NSF and ASU supported approximately 8 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. In 2004 CAP established a competitive summer research program through 4-6 grants awarded each summer. The first year's recipients are listed below. Students also receive exposure to the interactions of government agencies and the effects of large public works projects on public attitudes. The IGERT in Urban Ecology and an NSF GK12 Research Fellowship grant supported approximately 16 additional graduate students who are also associated with the CAP LTER. Seven participated in an Urban Ecology IGERT Workshop in Spring 2003 on Neighborhood Ecosystems co-taught by a sociologist, geographer, and a geologist.

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

Monthly All Scientists Council meetings provide opportunities for cross-disciplinary interaction and information exchange through science- and results-based presentations. Attendance ranges from 40 to 80 people per meeting and includes faculty members, postdoctoral associates, graduate students, and community partners. Remote Sensing Working Group meetings have been held to foster collaborations among CAP LTER scientists doing research involving remote sensing via discussion of ongoing and planned work, proposal generation, and workshops. Other working groups, such as atmospheric deposition, feedbacks, and modeling, meet as needed. Lastly, graduate students meet monthly at research-focused gatherings designed to facilitate interdisciplinary research.

The Schoolyard LTER supplement has created special opportunities for K-12 teachers to work alongside LTER researchers in summer internships on several monitoring projects. CAP graduate students have mentored high-school students through a laboratory internship program coordinated by the Southwest Center for Education and the Natural Environment, a collaborative program with the Center for Environmental Studies. CAP participants serve as judges each year in the Central Arizona Science and Engineering Fair and the American Indian Science and Engineering Fair.

## CAP-Sponsored Graduate Student Research

**2004**

Block, J. 2004. Channel morphology and instability along the urban fringe: Flood frequency, sediment transport, and flood hazards in the Hassayampa River Region and record of historic flooding in the greater Phoenix area.

Gonzales, D. 2004. Filter pack sampling for atmospheric nitrogen measurement and deposition estimation.

Larson, E. 2004. Aquatic denitrification in the CAP LTER.

Singer, C. 2004. Effects of surface mulches on ecosystem processes of drip-irrigated xeric landscapes.

## Theses and Dissertations

**Completed**

Anderson, S. 2002. Design and implementation of a spatio-temporal interpolation model. (Ph.D., Geography, E. Wentz)

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

Berling-Wolff, S. 2002. Simulating the dynamics of the Phoenix landscape: An urban growth model (M.S., Plant Biology, J. Wu).

Boreson, J. 2003. Correlating bioaerosol load with PM2.5 and PM10 concentrations (M.S., Civil and Environmental Engineering, J. Peccia, A. Dillner).

Celestian, S. B. 2003. Characterization of parking lot environments and the effect of parking lot environments on the growth and physiology of six Southwest landscape trees (M.S., C. A. Martin).

Clark, K. 2002. When abundance fails to predict persistence: Species extinctions in an urban system (M.S., Biology, R. Ohmart).

Compton, M. A. 2000. A comparative study of desert urban lakes receiving well, canal, and effluent source waters. 137 p. (M.S., Plant Biology, M. Sommerfeld).

Cousins, J. R. 2001. Arbuscular mycorrhizal fungal species diversity in Phoenix, Arizona, an urban ecosystem. (M.N.S., Plant Biology, J. Stutz).

David, J. 2002. The hierarchical patch dynamics modeling platform: Development and ecological applications (M.S., Plant Biology, J. Wu).

Damrel, D. Z. 2001. A documented vascular flora of the Arizona State University Arboretum (M.S., Plant Biology, D. J. Pinkava).

Edmonds, J. W. 2004. Understanding linkages between dissolved organic carbon quality and microbial and ecosystem processes in Sonoran Desert riparian-stream ecosystems (Ph.D., Biology, N. B. Grimm).

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).

Goettl, A. C. 2001. Nutrient limitation in Indian Bend Wash: An urban stream in the Sonoran Desert. (M.S., Biology, N. B. Grimm).

Jenerette, G. D. 2004. Landscape complexity and ecosystem processes of an urbanized arid region.. (Ph.D., Plant Biology, J. Wu).

Luck, M. 2001. A landscape analysis of the spatial patterns of human-ecological interactions. (M.S., Biology, J. Wu and N. B. Grimm).

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

Honker, A. 2002. A river sometimes runs through it: a history of Salt River flooding and Phoenix.(Ph.D., History, P. Iverson and S. Pyne).

MacLeod, A. 2003. Artificial hydrologic controls and the geomorphology of the Greater Phoenix area. (Senior thesis, Geological Sciences, J R. Arrowsmith).

Marussich, W. 2004. The costs and benefits of myrmecochory between ants and datura in the Sonoran Desert (Ph.D., School of Life Sciences, S. Faeth).

McPherson, N. 2001. Fate of 50 years of fertilizer N applications in the Phoenix ecosystem (M.S., Civil and Environmental Engineering, L. Baker).

Mueller, E. C. 2001. The effect of urban ground cover on microclimate and landscape plant performance (M.S., Plant Biology, T. Day).

Oleksyszyn, M. 2001. Vegetation and soil changes in secondary succession of abandoned fields along the San Pedro River (M.S., Plant Biology, J. C. Stromberg, and D. M. Green).

Paine, S. 2002. Establishing conservation priorities in the greater Phoenix metropolitan area. (M.A., Geography).

Prasad, L. 2004. Urban materials and temperature: Relating ground and air variables to land use, socioeconomics and vegetation in Phoenix (M.A., Geological Sciences, J R. Arrowsmith).

Rango, J. 2002. Influences of priority effects, nutrients and urbanization on creosote bush arthropod communities. (Ph.D., Biology, S. Faeth and W. Fagan).

Roberge, M. 1999. Physical interactions between Phoenix and the Salt River, Arizona (Ph.D., Geography, R. Dorn).

Robinson, S. E. 2002. Cosmogenic nuclides, remote sensing, and field studies applied to desert piedmonts, (Ph.D., Geological Sciences, J R. Arrowsmith and P. R. Christensen).

Saffel, E. 2001. Urban-rural humidity variations in Phoenix, Arizona (M.A., Geography, A. Ellis).

Schaafsma, H. 2003. Legacies of prehistoric agriculture in the Sonoran Desert. (M.S., Plant Biology, J. Briggs).

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

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

Stabler, L. B. 2003. Ecosystem function of urban plants in response to landscape management (Ph.D., Plant Biology, C. A. Martin).

Stefanov, W. L. 2000. Investigation of hillslope processes and land cover change using remote sensing and laboratory spectroscopy (Ph.D., Geology, Christensen).

Tavassoli, F. 2003. The history of the watercourse master planning process in Maricopa County. (M.E.P., Planning and Landscape Architecture, Musacchio).

Walters, G. M. 2001. Sonoran Desert seedbanks: Spatio-temporal variation of ephemeral plants and urban recreational impacts (M.S., Plant Biology, Landrum and Patten).

Whitcomb, S. A. 2002. Belowground spatial patterns and dispersal of arbuscular mycorrhizal fungi in an arid urban environment (M.S., Plant Biology, J. C. Stutz).

Xu, Y. 2002. Assessment and Prediction of groundwater nitrate contamination trends in the Salt River Project Area, Arizona (Ph.D.,Civil and Environmental Engineering, P. Johnson and L. Baker).

Zschau, T. 1999. Effects of a copper smelter on desert vegetation: A retrospective after 26 years (M.S., Plant Biology, T. H. Nash).

**In Progress**

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

Bills, R. Effects of urbanization on community structure and functioning of arbuscular mycorrhizal fungi. (M.S. Plant Biology, J. Stutz)

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

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

Gade, K. Plant migration along highway corridors in central Arizona (Ph.D., Biology, A.P. Kinzig). Hartz, D. Impact of residential development of climate (M.A., Geography, A. Brazel).

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

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

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

Miller, J. Urban Heat Island of Las Vegas. (Ph.D., Geography, A. Brazel).

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

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

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

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

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

# VI. Education and Outreach

Education and outreach activities are woven throughout CAP LTER. Our project enhances the research and teaching skills of undergraduate, graduate, and postdoctoral students, faculty members, and teachers and students. In addition, we are committed to sharing what we learn with community organizations, governmental agencies, industry, and the general public.

## K-12 Education

Our Ecology Explorers program engages teachers and students in 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. We offer summer internships and school-year workshops for teachers. The internship programs are in high demand; we receive five applications for every slot. Each year, 10-15 scientists including faculty members, research technicians, postdocs, graduate students, and advanced undergraduates participate in the internships, workshops, and classroom visits.

This year the Ecology Explorers' program received the 2004 ASU Award for Innovation from ASU President Michael Crow. This award recognizes employees for innovations that improve educational, administrative, or organizational processes.

We recruit science teachers (grades 5-10) from across the metropolitan Phoenix area and particularly encourage those teachers in underserved populations to participate. On average, the schools where Ecology Explorer teachers teach have 43.5% of their students enrolled in free/reduced lunch program and about 40% are from underrepresented minority groups (African-American, Native American, Hispanic). A majority of the students in minority groups are Hispanic. Some of the schools have >90% of their student enrolled in the free/reduced lunch program and have >90% minority enrollment.

Ecology Explorers offers a useful and engaging Web site (http://caplter.asu.edu/explorers). Collaborations with the Informatics Lab and Life Science Visualization Lab have created new and fun ways for students and teachers to access and use CAP LTER data on our Web site. This collaboration has been so successful that our Web site was awarded a Digital Dozen Award from the Eisenhower National Clearinghouse for Mathematics and Science Education in 2002.

An advisory committee of informal education institutions, school districts, and ASU outreach programs meets yearly to advise our education team. We also contracted a professional evaluator to assess factors affecting implementation of the Ecology Explorers program. She concluded that teachers did alter their teaching, using more technology and long-term research projects.

Based on this assessment and the need to link CAP LTER to the community, we will continue to: offer internships linked with academic-year support; target underserved populations; develop protocols linked to CAP LTER research areas; build relationships with school districts, with the intent of district adoption of Ecology Explorers; develop more Web-based applications for teaching urban ecology; strengthen our partnership with University and CES projects, including ASU's Service Learning program, GK-12 Research Fellowships, and IGERT fellowships in Urban Ecology; work with informal education organizations; formally evaluate outcomes for teachers, students and researchers; forge cross-site LTER work. Another goal is to create an Urban Ecology Guide and a publication that would be an overview of CAP LTER for teachers and the general public.

## Knowledge Exchange

From CAP LTER's inception, we have focused upon meaningful community outreach by establishing a series of community partnerships. Some of these partners have been very active, such as the Maricopa Association of Governments, the Salt River Project, and those relating to K-12 education. More can and should be done to build bridges between academic research and public policy, and ASU has taken this charge very seriously, sponsoring Greater Phoenix 2100 (GP2100) and, in April 2003, establishing the Consortium for the Study of Rapidly Urbanizing Regions (CSRUR; http://ces.asu.edu/csrur). CSRUR, housed at CES and directed by Redman, engages academic, business and governmental groups in dialogues about pressing environmental issues affecting our rapidly growing desert metropolis. CSRUR issues timely "Research Vignettes" (http://ces.asu.edu/csrur/vignettes.htm) based on CAP LTER research and aimed at decision-makers both at the household and government level; recent issues have focused upon landscape water use, the impact of urbanization on local climate, and remote sensing applications. GP2100 outlined four steps towards integrating science and policy:

- a comprehensive, interactive environmental database
- an electronic-environmental "EAtlas"
- a series of models that would complement a "SIM-Phoenix" approach to scenario-building; and
- an immersive "Decision Theater" that would provide 3-D portrayals of scenarios for policymakers.

To date, the EAtlas and a version in book form, the *Greater Phoenix Regional Atlas,* have been produced, and the Decision Theater is in development. When implemented, CAP LTER models and data will figure prominently in Decision Theater scenarios. Lastly, a Sustainable Technologies Program is working to minimize the impacts of rapid urbanization, through existing and emerging technologies and sound policy recommendations.

Because it is a source of fundamental, long-term data, CAP LTER is critical to the success of ASU initiatives in science-policy outreach related to urban environments. CES plays a central, liaison role in ensuring effective knowledge exchange from academic researchers (i.e., CAP LTER) to decision-makers and end users of the science. Cooperation is also assured by Redman, McCartney, and Elser's involvement in these initiatives.

The highlight of each year in CAP LTER is our annual symposium, held in January or February. The program features a keynote speaker and poster presentations by all supported projects. (view posters at http://caplter.asu.edu/symposia.htm). A midsummer workshop or retreat is held at an off-campus site each year to address theoretical issues (social science-natural science integration, contributions to ecological theory, and development of CAP2 were prior themes). Monthly All Scientist Meetings attract between 40 and 100 participants and feature scientific presentations by visitors or discussions of project results. CAP LTER news is presented on our Web site and in the CES newsletter, published 3 times a year.

## Collaborations

ASU's recent membership in the Resilience Alliance (www.resalliance.org) has led us to explore what a "resilience" approach offers to CAP LTER and related research. Kinzig, along with Redman and Anderies, has forged an alliance with this interdisciplinary group, whose primary focus is on contemporary systems but, a result of CAP input, is expanding to examine whether archaeology and studies of the past can enhance understanding. In addition, an NSF Biocomplexity grant, awarded in 2002 to examines agrarian transformations of landscapes in six areas of the US, has a resilience perspective (Redman *et al.* 2002).

The NSF recently funded a Decision Center for a Desert City (DCDC) at ASU to coordinate a program of interdisciplinary research and community outreach to improve water-management decisions. The confluence of rapid population growth and global warming in an uncertain climate pose challenging policy and decision-making issues for our urbanizing desert. DCDC will study the cognitive processes by which individuals and water managers make decisions. It will apply decision-science models to water-allocation problems, develop GIS-based decision-support tools for water-management decisions, use climate models to define the dimensions of uncertain water availability, and craft innovative educational programs on water, climate, and decision-making. DCDC seeks to build an effective organization at the boundary of science and policy that allows decisionmakers and scientists to collaborate on research questions and experiment with new methods. The Center will also investigate the nature of research activity and decisionmaking within DCDC itself. In collaboration with local, state, and regional water managers, DCDC will develop scenarios of different water futures and share them with decision-makers and the public. These scenarios will be presented at ASU's Decision Theater.

In the summer of 2004, Charles Redman was appointed the co-chair of the National Academies Roundtable on Science and Technology for Sustainability's Task Force on Rapid Urbanization. Redman's appointment came from his work on the CAP LTER and directing the Consortium for the Study of Rapidly Urbanizing Regions. Redman will help lead a collaboration of social and life scientists, with the goal of identifying specific ideas and actions that would significantly enhance the contribution of science and technology in guiding rapid urbanization down more sustainable pathways in both the immediate future and over a multidecadal time scale.

The research, management, and planning communities share a common interest in understanding the dynamic socioeconomic and ecological patters of landscape transformation wrought by rapid urbanization. The goal for the Networking Urban Ecological Models project, funded by the NSF, is to develop and deploy a distributed information infrastructure so that the diverse ecological research community in central Arizona can benefit from integrated urban ecological models. The research will provide an innovative approach that can be used to overcome the barriers to access and use regional models, while retaining their complexity. The effectiveness of the approach will be evaluated by designing a modeling exercise that couples climate, water, and land-use change models from the Maricopa Association of Governments, the Arizona Department of Water Resources, and ASU's Office of Climatology. Developing an infrastructure for sharing data and models within the research, management, and planning community will improve the public policy debate. Eventually, integrated urban ecological models will be used to allow citizens to visualize scenario futures for their cities.

The Ecology Explorers education team of Charlene Saltz and Monica Elser, along with ASU colleagues, received a new grant this year from the Nina Mason Pulliam Charitable Trust to help underserved youth restore a Sonoran Desert riparian area in the heart of the city. "Service at the

Salado" brings together ASU and middle-school students to develop service projects to help restore a section of the Salt River in downtown Phoenix. The proposal was written in conjunction with Academic Community Engagement Services and the Center for Research on Education in Science, Mathematics, Engineering and Technology. In addition to these internal partnerships, CES is collaborating with the City of Phoenix, Arizona Audubon Society, as well as Valley View, Greenfield, Sunland, and Lowell elementary schools. For more information, go to http://caplter.asu.edu/explorers/riosalado.

## Community Partners

The past year has sparked many exciting collaborations with our community partners, both existing and new. This summer the National Science Foundation notified us that they will be funding our proposed Decision Center for a Desert City proposal (DCDC). This center will bring together together a team of CAP LTER researchers and local and state agency staff to investigate human decision making under climatic uncertainty. The project envisions an academic-practitioner collaboration that will enhance the region's adaptive capacity to deal with climate uncertainties in the future. The DCDC will investigate spatial and temporal impacts of climate cycles and global warming on the desert Southwest and help to pinpoint critical variables and thresholds in coupled human-natural systems. Active participants in DCDC include: the *Salt River Project, City of Phoenix, Arizona Department of Water Resources, and the Flood Control District of Maricopa County*. Last Fall, CSRUR sponsored a "Water Dialogue" to bring together academic researchers with local decision-makers from city, state, and regional agencies to discuss issues of water policy. Community partners actively involved in this meeting are also active in the DCDC project, including: *Arizona Department of Water Resources, Central Arizona Project, Salt River Project, City of Phoenix*, and the *University of Arizona*.

One of 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 *Arizona State Land Department* has been very helpful in allowing access to Arizona state land, and project scientists have collaborated with land department personnel on a study of insect communities on creosote bushes. Other agencies are helping with the historic land-use study (*Arizona Department of Water Resources*) and the atmospheric deposition study (*Arizona Department of Environmental Quality*). Representatives from various city agencies have served as information resources to CAP LTER personnel as well as partners in many grant proposals: The *City of Phoenix* has issued blanket permission for us to conduct fieldwork in the city's extensive park system, including at South Mountain Park. In addition, Phoenix is supplying water and sewer infrastructure information in the form of paper plats and electronic files to the urban-fringe project. The *City of Scottsdale* has entered into an agreement with CAP LTER to conduct a nutrient limitation study at Indian Bend Wash, and the *City of Tempe* is a partner in our nitrogen balance study, particularly in allowing access to storm water retention basins and to non-retention areas for purposes of sampling soil and storm water. We are developing partnerships with the *Gila-River* and *Salt River-Pima Indian Communities* in the form of idea exchange, educational opportunities for tribe members, and service of their scientific personnel on advisory committees, and have been working toward joint research projects and establishment of atmospheric deposition monitoring sites on their lands.

*Maricopa Association of Governments (MAG)*, consisting of the 24 incorporated cites and towns, two Indian communities, and Maricopa County, has been an integral partner, supporting the project by supplying GIS information and data and collaborating on investigations into growth planning, land-use projections, and open-space implementation. Rita Walton, MAG's policy and information manager, has worked with the Land-Use Change Team and co-authored a CAP LTER study on land consumption and absorption rates. We have also worked with the *Flood Control District of Maricopa County* in projects involving storm hydrology and storm-water chemistry.

*Salt River Project,* a semipublic organization responsible for water management and supplying electrical energy to the region, has a long-term research and outreach relationship with CAP LTER. They have greatly facilitated the work of the Historic Land-Use Team and have contributed greatly to the nitrogen mass balance study and even provided a helicopter to reach several remote Survey200 sample locations. The *Desert Botanical Garden* serves as one of our long-term sampling sites. A permanent, experimental plot was installed to measure net primary productivity as affected by human activities. Lastly, over 30 businesses/organizations/federal, state, regional, and local agencies entertain long-term monitoring of ecological variables on their sites. A list of our community partners is included in the participants section.

In addition, CAP LTER participants partner with a wide range of institutions on associated projects. For example, our research teams have substantial collaborations, through workshops and publications, with scientists at the BES site (Steward Pickett, Mary Cadenasso, J. Morgan Grove, Peter Groffman, Alan Berkowitz, Charles Nilon, and Chris Boone, among others), Harvard Forest (David Foster, Billie Turner, John O'Keefe), Coweeta (Ted Gragson, Paul Bolstad), Shortgrasse Steppe (Bill Parton), Kellogg (Craig Harris, Alan Rudy), Konza Prairie (Gerad Middendorf), Jornada (James Reynolds), Sevilleta (Cliff Dahm, Scott Collins), University of Michigan (Myron Gutmann, Ken Sylvester), The Nature Conservancy (Peter Kareiva), University of Melbourne's Center for Urban Ecology (Mark McDonnell), and several institutions in China (e.g., East China Normal University, Beijing Normal University, Nanjing University, Inner Mongolia University, Institute of Botany of Chinese Academy of Sciences).

## Dissemination of Research Projects and Results

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

In addition, we have recently added a virtual tour of CAP LTER to our Web site. This tour (http://caplter.asu.edu/capltertour or click on tour on the home page) is an effective forum for communicating CAP research results to the broader community. The idea behind the virtual tour is to illustrate key findings with brief, less technical explanations. The tour currently entails a presentation of research findings in the areas of geology, climatology, desert vegetation, pre-historic, historic and present urban land-use, and results from the Phoenix Area Social Study (PASS). The CAP LTER virtual tour is a work in progress, and we will add more aspects of our research on a regular basis.

Presentations and reports for 2003-2004 are listed below:

## Presentations at Regional, National, and International Conferences

**2004**

Bills, R. J., S. Whitcomb, J. R. Cousins, and J. C. Stutz. 2004. Comparisons between arbuscular mycorrhizal fungal community in the Phoenix metropolitan area and the surrounding desert. Poster presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Burns, E. K. 2004. Spatial technologies for management of water collection and distribution. Presented at 27 April 2004, *Conference 27 Geospatial Information Technologies Association (GITA)*, Seattle, WA.

Burns, E. K. 2004. Urban patterns in water operations: A qualitative approach using spatial technologies in Phoenix, Arizona. Presented at 16 March 2004, *100th Annual Meeting of the Association of American Geographers*, Philadelphia, PA.

Buyantuyev, A., and J. Wu. 2004. Estimating vegetation cover of an urban landscape using remote sensing data. Presented at March 30-April 2, 2004, *19th Annual Symposium of the US Association of Landscape Ecology*, Las Vegas, NV.

Buyantuyev, A., and J. Wu. 2004. Remotely sensed estimation of vegetation cover in Central Arizona Phoenix LTER (CAPLTER). Poster presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America,* Portland, OR.

Casagrande, D. 2004. Resilience as information redundancy versus discontinuity across organizational scales of human ecosystems. Presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America,* Portland, OR.

Cook, W. M., and S. H. Faeth. 2004. Ground arthropod community composition within the urban landscape of greater Phoenix. Poster presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America,* Portland, OR.

Elser, M., and C. Saltz. 2004. Graduate students and K-12 ecological outreach programs: Challenges and benefits. Poster presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Farley Metzger, E. A. 2004. North Desert Village landscaping experiment: Monitoring human – environment interactions. Poster presented at February 2004, *Graduates in the Earth, Life and Social Sciences Graduate Research Symposium,* Tempe, AZ.

Gade, K., and H. Schaafsma. 2004. The Sonoran Desert: A palimpsest of prehistoric and modern human activities. Poster presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Grimm, N., J. Kaye, S. Hall, J. Allen, and D Lewis. 2004. A distinct urban biogeochemistry? Presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Hill, C., and C. Saltz. 2004. Meeting AZ academic standards using Flash animation to teach urban ecology. Presented at March 2004 *Microcomputers in Education Conference*, Tempe, AZ.

Hope, D., C. Gries, J. Kaye, W. Zhu, G. Stuart, J. Oleson, M. Katti, P. Warren and N. Grimm. 2004. How do humans restructure the biodiversity of the Sonoran Desert? Presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Harlan, S. L., A. Brazel, W. L. Stefanov, L. Larsen, S. Grineski, N. Jones, J. Parker, and L. Prashad. Inequality for the 21st century: Social class, ethnicity, and vulnerability to climate change. Presented at 15-18 April 2004, *Pacific Sociological Association Annual Meeting*, San Francisco, CA.

Jenerette, G. D., and J. Wu. 2004. From patches to regions: Scaling biogeochemical patterns in soils of the Phoenix, AZ metropolitan region. Presented at March 30-April 2, 2004, *19th Annual Symposium of the US Association of Landscape Ecology,* Las Vegas, NV.

Jenerette, G. D., and J. Wu. 2004. Multiple-scale patterns of soil organic matter and nitrogen in an urbanized desert. Presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Katti, M., J. Anderies, and E. Shochat. 2004. Living in the city: Population dynamics when resources are predictable and predators few. Presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Kenney, E., and E. K. Burns. 2004. Urban expansion measured by water infrastructure development: Phoenix, Arizona from 1950 to 2000. Presented at 17 March 2004, *100th Annual Meeting of the Association of American Geographers,* Philadelphia, PA.

Lafferty, D. and L. R. Landrum. 2004. A computer simulation of seed germination strategies. Poster presented at April 2004, *Arizona-Nevada Academy of Science Meeting*, Midwestern University, Phoenix, AZ.

Martin, C. A. 2004. How do local sociocultural and economic factors affect neighborhood park and residential landscape design in Phoenix, Arizona? Presented at June 2004, *Arizona Community Tree Council*, Prescott, AZ.

Martin, C. A. 2004. Socioeconomic drivers of urban vegetation composition. Presented at June 2004, *Metropolitan Tree Improvement Alliance Symposium*, Chicago, IL.

Musacchio, L., J. Ewan, and R. Yabes. 2004. Regional landscape system protection in the urbanizing desert southwest: Lessons from the Phoenix metropolitan region. *Council of Educators in Landscape Architecture Conference,* Lincoln University, Christchurch, New Zealand.

Netzband, M., and W. L. Stefanov. 2004. Urban land cover and spatial variation observation using ASTER satellite image data. Presentation at the 14-17 June 2004, *ASTER Science Team Meeting*, Tokyo, Japan.

Roach, W. J., R. Arrowsmith, C. Eisinger, N. Grimm, J. Heffernan, and T. Rychener. 2004. Anthropogenic modifications influence the interactions between the geomorphology and biogeochemistry of an urban desert stream. Presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Shen, W., G. D. Jenerette, and J. Wu. 2004. Evaluating empirical scaling relations of pattern metrics with simulated landscapes. Presented at the March 30-April 2, 2004, *19th Annual Symposium of the US Association of Landscape Ecology,* Las Vegas, NV.

Stefanov, W. L., L. Prashad, C. Eisinger, A. Brazel, and S. L. Harlan. 2004. Investigation of human modifications of landscape and climate in the Phoenix, Arizona, metropolitan area Using MASTER Data. Invited presentation at the 14-23 July 2004, *International Society for Photogrammetry and Remote Sensing 20th Quadrennial Conference*, Istanbul, Turkey.

Stepp, J., and D. Casagrande. 2004. Human ecosystems: Trajectories, information, and organization. Workshop at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Tomalty, R. 2004. Weekend/weekday diurnal temperature range in central Arizona. Presented at 22-27 August 2004, *5th Symposium on the Urban Environment,* American Meteorological Society, Vancouver, BC, Canada.

Walker, J., and J. Briggs. 2004. Hierarchical image analysis of Phoenix's urban forest structure. Poster presented at July 30-August 7, 2004, *89th Annual Meeting of the Ecological Society of America*, Portland, OR.

Walker, J., and J. Briggs. 2004. Hierarchical image analysis of Phoenix. Poster presented at February 2004, *Graduates in Earth, Life, and Social Sciences Symposium*, Arizona State University, Tempe.

Warren, P. S., M. Katti, and M. Ermann. 2004. Urban bioacoustics - It's not just noise. Invited talk at the June 2004, *Symposium on Behavior and Environment,* Animal Behaviour Society, Oaxaca, Mexico.

**2003**

Celestian, S. B., and C. A. Martin. 2003. Growth of six Southwest landscape trees in commercial parking lots was related to high soil temperatures. Presented at *ISA 79th International Society of Arboriculture Conference*, Montreal, Canada.

Gries, C., D. Hope, L. B. Stabler, C. A. Martin, and J. Briggs. 2003. The manmade plant communities in a desert city. Presented at 3-8 August 2003, *88th Annual Meeting of the Ecological Society of America*, Savannah, GA.

Harlan, S. L. 2003. Neighborhood ecosystems. Invited poster presentation September 14-17, 2003 at *Biocomplexity in the Environment Awardees Conference* sponsored by the National Science Foundation, NSF Grant No. SES 0216281, Arlington, VA.

Hill, C., and C. Saltz. 2003. Linking scientists, teachers and children in scientific research. Presented at March 2003, *Microcomputers in Education Conference*, Arizona State University, Tempe.

Jenerette, G. D. 2003. Ecological footprints: A spatial framework for studying socioecosystems. Presented at August 2003, *Arizona Geographic Information Council Annual Meeting,* Prescott, AZ.

Jenerette, G. D., and J. Wu. 2003. Heterogeneity of ecosystem spatial patterns in an urbanized desert region. Presented at April 2003, *Annual Meeting of the U.S. Regional Association, International Association of Landscape Ecology*, Banff, Canada.

Kinzig, A., and C. L. Redman. 2003. Agrarian landscapes in transition: The case of central Arizona. Presented at 3-8 August 2003, *88th Annual Meeting of the Ecological Society of America*, Savannah, GA.

Larsen, L., and S. L. Harlan. 2003. The wealth of neighborhoods: Exploring the concept of neighborhood capital. Presented at the 12 July 2003, *Third Joint Congress of the ACSP and AESOP,* Leuven, Belgium.

Lewis, D. B., L. B. Stabler, and C. A. Martin. 2003. Ecological stoichiometry of horticulture: Consequences of pruning and water for plant nutrient use efficiency. Presented at 3-8 August 2003, *88th Annual Meeting of the Ecological Society of America*, Savannah, GA.

Martin, C. A. 2003. Urban ecology and horticulture: Bringing together plants, people, and the environment. Presented at September 2003, *National Urban Forest Conference*, San Antonio, TX.

McIntyre, N. E. 2003. Arthropods in urban ecosystems: Community patterns as functions of anthropogenic land use. Invited talk, *The Sixth World Congress of the International Association of Landscape Ecology*, Darwin, Australia.

Musacchio, L. 2003. The comparative ecology of cities and towns: Opportunities and limitations. Invited guest speaker at July 2003, *IALE World Congress Symposium*, Darwin, Australia.

Netzband, M., and W.L. Stefanov. 2003. Remote sensing and landscape metrics for global ecological monitoring. Presented at 8 March 2003, *AAG Annual Meeting*, New Orleans, LA.

Prashad, L., W. L. Stefanov, A. Brazel, and S.L. Harlan. 2003. Defining temperature and vegetation connections at neighborhood and regional scales in Phoenix, Arizona using remotely sensed and ground based measurements. Poster presented at 8-12 December 2003, *American Geophysical Union,* San Francisco, CA.

Saltz, C., D. Banks, and M. Elser. 2003. Factors affecting implementation of Ecology Explorers, the K-12 education program of CAP LTER, in the classroom. Presented at October 2003, *AZENet Conference*, Casa Grande, AZ.

Stabler, L. B., and C. A. Martin. 2003. Gas exchange and mass sap flow in *Nerium oleander* under urban management regimes. Presented at October 2003, *American Society for Horticultural Science*, Providence, RI.

Stefanov, W. L. 2003. Geological remote sensing in the LTER network: Terra cognita? *Third Long Term Ecological Research Network Mini-Symposium*. National Science Foundation, Washington, D.C.

Stefanov, W. L., and M. Netzband. 2003. Characterization and monitoring of urban/peri-urban landscapes using ASTER. *24th ASTER Science Team Meeting*, Tokyo, Japan.

Stutz, J. C., S. A. Whitcomb, and J. R Cousins. 2003. Local arbuscular mycorrhizal fungal diversity is strongly coupled to regional diversity in an urban ecosystem. Presented August 2003 at the *Fourth International Conference on Mycorrhizae (ICOM4)*, Montreal, Canada.

Warren, P. S., C. Nilon, A. Kinzig, M. Cox, J. M. Grove, and C. Martin. 2003. Human socioeconomic factors and avian diversity: A cross-site comparison. Presented at 3-8 August 2003, *88th Annual Meeting of the Ecological Society of America*, Savannah, GA.

Whitcomb, S. A., and J. C. Stutz. 2003. Small-scale spatial patterns of arbuscular mycorrhizal fungal species in an experimental xeric landscaped site. Presented at August 2003, *Fourth International Conference on Mycorrhizae (ICOM4)*, Montreal, Canada.

Wu, J. 2003. A landscape perspective on comparative urban ecology. Presented at 19-22 July, 2003, *International Workshop on Comparative Ecology of Cities and Towns*, Melbourne, Australia.

Wu, J. 2003. Spatial scaling: Universality versus pluralism. Presented at 13-17 July 2003, *The 2003 World Congress on Landscape Ecology,* Darwin, Northern Territory, Australia.

Wu, J. 2003. Landscape ecology: Research priorities and future directions. Keynote speech on 12-15 December 2003, *The 4th National Congress on Landscape Ecology,* Beijing, China.

**LTER Symposia and Conferences**
**2004**

Schoeninger, R., P. McCartney, and C. Gries. 2004. What we needed and what we built ...using web services. Presentation at 2-4 February 2004, SDSC/LTER Web Services Training Workshop, San Diego, CA.

***CAP LTER 1st Annual Urban Community Ecology Symposium,* 21 February 2004, Center for Environmental Studies, Arizona State University, Tempe, AZ.**

Cook, W. 2004. North Desert Village experiment. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Faeth, S., W. Marussich, N. McIntyre, J. Rango, and E. Shochat. 2004. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Gade, K. 2004. Plant migration along highway corridors. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Gries, C., D. Hope, B. Stabler, C. Martin, and J. Briggs. 2004. The manmade plant communities in a desert city. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Larsen, L. 2004. Desert dreamscapes: Landscape preferences and behavior in Phoenix. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Marussich, W., and S. Faeth. 2004. Exploring urban trophic dynamics using arthropod communities on brittlebush (*Encelia farinosa*). Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

McIntyre, N. E. 2004. Review of urban arthropod research. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Shochat, E. 2004. Linking optimal foraging behaviour to bird community structure in an urban-desert landscape: Field experiments with artificial food patches. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Stutz, J. 2004. Arbuscular mycorrhizae. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Walker, J. 2004. Classifying Phoenix's urban forest structure. Invited presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Warren, P. S. 2004. Welcome to the CAP LTER Urban Community Ecology Symposium. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

Warren, P. S., A. P. Kinzig, J. M. Grove, C. Nilon, and M. Cox. 2004. Human socioeconomic status and avian diversity: Exploring potential mechanisms. Presentation at the 21 February 2004, *CAP LTER's 1st Annual Urban Community Ecology Symposium.* Center for Environmental Studies, Arizona State University, Tempe, AZ.

***CAP LTER Sixth Annual Poster Symposium,* February 23, 2004, Center for Environmental Studies, Arizona State University.**

Andrews, T., L. Duman, M. Robinson, G. Scrivener, N. Settles, I. Taylor, and K. Kyle. 2004. Pond chemistry at Awakening Seed School.

Bagley, A., P. Burnett, M. Koneya, M. Roberts, R. Walton, and D. Worley. 2004. Understanding current and future job centers: An analysis of the Maricopa region.

Banzhaf, E. 2004. Detecting brownfields by means of remote sensing and GIS data.

Becht, L. 2004. Landscape-level influences of urbanization on reptile communities in the Phoenix metropolitan area.

Berda, C. 2004. Most frequently found arthropods at Pendergast School.

Bills, R., S. Whitcomb, J. Cousins, and J. Stutz. 2004. Differences in arbuscular mycorrhizal fungal community structure at residential and desert land use types within the CAP LTER.

Bjorn, A. M., A. I. Greve, M. D. Oleyar, and J. C. Withey. 2004. Evaluating urban forest functionality: A three-dimensional approach.

Bolin, B., and S. Grineski. 2004. South Phoenix and the geography of exclusion: Past and present.

Burns, E. K., and E. D. Kenney. 2004. Urban fringe expansion measured by water infrastructure development: Phoenix, Arizona, 1950-2000.

Buyantuyev, A., and J. Wu. 2004. Estimating vegetation cover of an urban landscape using remote sensing data.

Celestian, S. B., and C. A. Martin. 2004. Leaf physiology of four landscape trees in response to commercial parking lot location.

Cook, W., D. Casagrande, D. Hope, C. Martin, and J. Stutz. 2004. The North Desert Village "Suburbosphere": An experiment in urban ecology.

Crider, D., C. M. Meegan, and S. Swanson. 2004. Panarchy: Applying the framework to a prehistoric socio-ecological case study.

DeLap, J., S. Dooling, K. Yocom, G. Simon, and W.C. Webb. 2004. The history of urban park development in Seattle 1900-2000: An emergent phenomenon?

Farley Metzger, E., S. Yabiku, P. Gober, D. Casagrande, C. L. Redman, N. B. Grimm, and S. Harlan. 2004. North Desert Village landscaping experiment monitoring human-environment interactions.

Gonzales, D.A., and J. O. Allen. 2004. Aerosol deposition measured by eddy-correlation mass spectrometry.

Gries, C., D. Hope, B. L. Stabler, A. Stiles, C. A. Martin, and J. M. Briggs. 2004. The manmade plant communities in the CAP LTER area.

Grossman-Clarke, S., J. A. Zehnder, W. L. Stefanov, D. Hope, and H.J.S. Fernando. 2004. Effects of land cover modifications in mesoscale meteorological and air quality models in the Phoenix metropolitan region.

Harlan, S., A. Brazel, D. Jenerette, N. Jones, L. Larsen, L. Prashad, and W. Stefanov. 2004. Neighborhood ecosystems: Human-climate interactions in a desert metropolis.

Hedquist, B., and A. Brazel. 2004. Urban heat island (UHI) measures for the S.E. metropolitan area of CAP LTER: Transects versus fixed stations.

Hope, D., W. Zhu, C. Gries, J. Kaye, J. Oleson, N. B. Grimm, D. Jenerette, and L. Baker. 2004. Spatial variation in inorganic soil nitrogen concentrations across an arid urban ecosystem.

Jenerette, G. D., and J. Wu. 2004. Soil heterogeneity in six patches of the Phoenix, AZ metropolitan region: Implications for scaling.

Lewis, D. B., and N. B. Grimm. 2004. Hierarchical regulation of ecosystem function: Material export from urban catchments.

Machabee, L., and A. Kinzig. 2004. Investigating the variations in neighborhood parks use and landscape preferences: Preliminary results of a survey questionnaire.

Mahkee, D. K., and C. A. Martin. 2004. Leaf morphological plasticity of two landscape shrub taxa in response to a change in shrub pruning practices.

Mahkee, D. K., and C. A. Martin. 2004. Growth of two landscape shrubs following severe pruning: Evidence of a hysteretic effect of former irrigation and pruning practices.

Martin, C. A., L. B. Stabler, K. A. Peterson, S. B. Celestian, D. Mahkee, and C. K. Singer. 2004. Residential landscape water use, 1998 to 2003.

Marussich, W. A. and S. H. Faeth. 2004. Understanding trophic dynamics in urban and desert ecosystems using arthropod communities on brittlebush (*Encelia farinosa*).

Moeller, M. 2004. Analysis of long-term remote-sensing imagery for the detection of changes in the CAP LTER site.

Morehouse, N. 2004. Local buggers: An inquiry-based introduction to local insect populations.

Morrow, M. 2004. Identification of cyanobacterial isolets from the biological soil crusts of Organ Pipe Cactus National Monument, Ajo, Arizona.

Neil, K. 2004. Dynamic nature of scientific knowledge.

Netzband, M., and W. L. Stefanov. 2004. Remote sensing and landscape metrics for global urban ecological monitoring.

Prashad, L., W. L. Stefanov, A. Brazel, and S. Harlan. 2004. Defining temperature and vegetation connections at neighborhood and regional scales in Phoenix, Arizona, using remotely sensed and ground-based measurements.

Redman, C. L., G. Gammage, N. Jones, E. Corley, J. Holway, J. Keane, S. Megdal, and R. Quay. 2004. Water supply in Greater Phoenix: Improving regional decision making through university partnerships.

Redman, C. L., A. P. Kinzig, D. R. Foster, M. P. Gutmann, P. M. Kareiva, and L. H. Kuby. 2004. Agrarian landscapes in transition: A cross-scale approach.

Roach, W. J., R. Arrowsmith, C. Eisinger, N. B. Grimm, J. B. Heffernan, and T. Rychener. 2004. Anthropogenic modifications influence the interactions between the geomorphology and biogeochemistry of an urban desert stream.

Saltz, C., C. Hill, and M. Elser. 2004. Ecology Explorers: Land-use prediction game.

Schaafsma, H., and J. Briggs. 2004. The Sonoran Desert: A palimpsest of prehistoric human activities.

Schmieding, S. J. 2004. From purgatorial wasteland to reclaimed garden: Hydrological development, water politics, and social engineering in pre-statehood central Arizona.

Schoeninger, R., P. McCartney, C. Gries, C. Saltz, E. Ortiz-Barney; T. Craig, S. Scheiner, and M. Elser. 2004. Ecology Explorers online data analysis.

Sheibley, R. W., N. B. Grimm, C. L. Crenshaw, C. Dahm, L. H. Zeglin, H. van Vleck, and A. D. Pershall. 2004. Methods of measuring nutrient spiraling in urban streams.

Shen, W., J. Wu, J. F. Reynolds, and N. B. Grimm. 2004. Simulating the primary productivity of a Sonoran ecosystem: Model parameterization and validation.

Shochat, E., M. Katti, and S. Lerman. 2004. Differences in bird foraging behaviour between Sonoran Desert and urban habitats in central Arizona.

Singer, C. K., C. A. Martin, L. B. Stabler, and D. K. Mahkee. 2004. Influences of drip irrigation rate and pruning on electrical conductivity of soil surrounding two landscape shrubs.

Sisart, S., J. Dean, and S. Johnson. 2004. The diazotroph community of biological soil crusts.

Stabler, L. B., and C. A. Martin. 2004. Effects of drip irrigation rate on above ground net primary productivity of a mixed landscape.

Stutz, J. C., S. Whitcomb, and J. Cousins. 2004. Local arbuscular mycorrhizal fungal diversity is strongly coupled to regional diversity in an urban ecosystem.

Swanson, S., and R. Calonico. 2004. Legacy effects of prehistoric farming: Isotopic analysis of maize grown in sediments from Hohokam fields.

Walker, J., and J. Briggs. 2004. Remote sensing of Phoenix's urban forest with high-resolution aerial photography.

Warren, P. S., M. Katti, and M. Ermann. 2004. Urban bioacoustics: It's not just noise.

Warren, P. S., D. Hope, S. Harlan, A. Kirby, D. Casagrande, N. Jones, and A. Kinzig. 2004. Correlated ecological and social variation in the urban landscape: Exploring potential causes and consequences.

**2003**

***2003 LTER All Scientists Meeting, September 21, Seattle, WA***

Cook, W. M. 2003. Design of landscape experiments in the Long-Term Ecological Research network. *Workshop at the LTER All-Scientists Meeting*, Seattle, WA.

Grimm, N. B., and C. L. Redman. 2003. Urban ecology of central Arizona – Phoenix: Overview and progress. Presented at the 21 September 2003 *LTER All Scientists Meeting,* Seattle, WA.

Harlan, S. L. 2003. Neighborhood ecosystems project, CAP LTER. Presented at the 21 September 2003*, LTER All Scientists Meeting, Interdisciplinary Studies and Remote Sensing Workshop,* Seattle, WA.
Jenerette, G.D. 2003. Regional scale linkages between patterns of socio-economics, vegetation, and climate in an urbanizing desert. Presented at 21 September 2003 *Case Studies in Short-Term Ecological Collaborative Research Workshop, LTER All Scientist Meeting*. Seattle, WA.
Jones, N., A. Brazel, C. Eisinger, S. Harlan, B. Hedquist, S. Grineski, G. D. Jenerette, L. Larsen, M. A. Lord, J. Parker, L. Prashad, N. Selover, and W. L. Stefanov. 2003. Neighborhood ecosystems: Human-vegetation-climate interactions in a desert metropolis. Presented at 21 September 2003, *LTER All Scientists Meeting*. Seattle, WA.
Martin, C. A., S. B. Celestian, L. B. Stabler, and D. Hope. 2003. Extensive monitoring of primary productivity in Phoenix, Arizona: Methodologies and constraints. Presented at the 21 September 2003 *Case Studies in Short-Term Ecological Collaborative Research Workshop, LTER All Scientist Meeting*. Seattle, WA.
Marussich, W.A., and S. H. Faeth. 2003. Comparing trophic dynamics in urban and desert ecosystems using arthropod communities on brittlebush (*Encelia farinosa*). Presented at the 21 September 2003 *LTER All Scientists Meeting,* Seattle, WA.
Parshall, T., R. Bohanon, and C. Saltz. 2003. Developing collaborations among scientists, graduate students and educators for LTER education. Presented at 21 September 2003 *LTER All Scientist Meeting*, Seattle, WA,
Saltz, C., D. Banks, and M. Elser. 2003. Factors affecting implementation of Ecology Explorers, the K-12 Education Program of CAP LTER, in the classroom. Poster presented at 21 September 2003 *LTER All Scientist Meeting*, Seattle, WA.
Stefanov, W.L., A. Brazel, and S. Harlan. 2003. Interdisciplinary studies and remote sensing workshop. September 18-21, 2003 presentation on Neighborhood Ecosystems Project. *Long-Term Ecological Research All Scientists Meeting*, Seattle, WA.
Walker, J., J. Briggs, and C. Gries. 2003. Socioeconomics drive urban forest structure in Phoenix. Poster presented at 21 September 2003, *LTER All Scientists' Meeting*, Seattle, WA.
Warren, P., C. Nilon, A. Kinzig, M. Cox, J. M. Grove, and C. Martin. 2003. Human socioeconomic factors and avian diversity: A cross-site comparison. Poster presented at 21 September 2003, *LTER All Scientist's Meeting*, Seattle, WA.
Warren, P., C. Nilon, A. Kinzig, M. Cox, J. M. Grove, and C. Martin. 2003. Human socioeconomic factors and avian diversity: A cross-site comparison. Presented at October 2003, *BES LTER Annual Symposium,* Baltimore, MD.

## Reports

Lee, S. M., S. Grossman-Clarke, and H. J. S. Fernando. 2004. Simulation of 8-Hour Ozone Concentrations for the State of Arizona. Contract Report Submitted to the Arizona Department of Environmental Quality.

## Community Outreach Presentations and Miscellaneous Activities

**2004**

Shears, Brenda L. CES and CAP LTER Research and Outreach. Presented 2004. ASU Sneaker Tour.
Wu, J. 2004. Frontiers in landscape ecology. Presented June 14, 2004. Zhejiang University, Hangzhou, China.
Wu, J. 2004. Key issues in urban ecology. Presented June 20, 2004. East China Normal University, Shanghai, China.
Wu, J. 2004. Spatial scaling: Theory and methods. Presented July 3, 2004. Graduate School of the Chinese Academy of Sciences, Beijing.

**2003**

Jenerette, G. D. 2003. Landscape complexity and biogeochemical processes. Presented at April 2003, *University of New Mexico Biocomplexity Seminar Series*. Albuquerque, NM.
Kinzig, A. 2003. Biodiversity in urban environments. Presented at 5 May 2003 *Department of Ecology, Evolution, and Marine Biology Seminar Series,* University of California, Santa Barbara.

Kinzig, A. 2003. Biodiversity in urban environments: The case for socioeconomic and cultural gradients. Presented at 14 April 03 *Department of Ecology and Evolutionary Biology Seminar Series*, University of Arizona, Tucson.

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

Shears, Brenda L. CES and CAP LTER Research and Outreach. 2003. ASU Sneaker Tour.

Warren, P. S. 2003. Making sense of the city. Invited seminar, presented 11 April 2003 at Institute for Ecology, University of Georgia, Athens, GA.

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

Wu, J. 2003. Key topics in landscape ecology. Presented September 23, 2003 at Graduate School of the Chinese Academy of Sciences, Beijing.

Wu, J. 2003. A landscape ecological approach to the study of cities. Presented November 7, 2003 at Duke University, Durham, NC.

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

**2004**

Summerhill, L. 2004. Exploring our own backyard. *ASU Research* Winter:30-33.

Uhley, L. 2004. President honors employees' work. *ASU Insight* March 26, 2004.

### Internal Publications, Reports, and Presentations

**2003**

Arrowsmith, J R., and W. L. Stefanov. 2003. *Geology overview for the CAP LTER region*. Central Arizona - Phoenix Long-Term Ecological Research project virtual tour (http://caplter.asu.edu/capltertour/geology.htm). 11 August 2003

Harlan, S.L., L. Larsen, T. Rex, S. Wolf, E. Hackett, A. Kirby, R. Bolin, A. Nelson, and D. Hope. 2003. *The Phoenix area social survey: Community and environment in a desert metropolis.* Central Arizona - Phoenix Long-Term Ecological Research Contribution No. 2, Center for Environmental Studies, Arizona State University, Tempe. March 2003. http://www.asu.edu/clas/sociology/pass.html

Harlan, S. L. *The Phoenix Area Social Survey: Summary results*. CAP LTER All Scientists Meeting. April 2003.

Stefanov, W. L. 2003. *Land cover/land use characterization and change detection using remote sensing*. Faculty Seminar Series on Land Use, Arizona State University, Tempe.

### Web Sites

Landrum, L. 2003. Vascular Plant Herbarium, Arizona State University. http://lsvl.la.asu.edu/herbarium/index.html

http://caplter.asu.edu/explorers/riosalado

### Grants Awarded

**2004**

*Potential Benefits of Indigenous Soil Mycorrhizal on the Salinity Tolerance of Southwestern Turf Landscapes.* ASU Faculty Grant-in-Aid Program. Co-PI Jean Stutz and Ken Marcum, $18,522, 2004.

*Decision Center for a Desert City: Science and Policy of Climate Uncertainty* ($6,899,995). P. Gober, C. Redman, T. Taylor, B. Bolin, and G. Gammage. National Science Foundation-DMUU, 2004.

*Climate and Woodland Expansion in the Western Great Plains, USA* ($149,623). National Science Foundation, M. Kaye, PI, 2004.

*Neighborhood Ecosystems REU Supplement* ($149,823). National Science Foundation, S. Harlan et al. 2004.

**2003**

*Completion and Coordination of Databases of Arizona Vascular Plant Specimens at Arizona State University (ASU), University of Arizona (ARIZ), and Northern Arizona University (ASC)* Landrum as

PI, Drs. McLaughlin, Ayers, and McCartney as co-PI's. National Science Foundation-Biological Research Collections, $470,291, 2003-2006.

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

*CAP LTER Bridge Year Accomplishment Based Renewal*, N. B. Grimm and C. L. Redman, Bridge year between the first phase of CAP LTER and renewal in November 2004, $820,000, 2003-2004.

*Coupled Biogeochemical Cycles in Urban and Agricultural Ecosystems: Role of Hydrology, Stoichiometry, Spatial Linkages and Human Behavior.* Subcontract with University of MN (L. Baker). D Hope, J. Kaye, and W. Stefanov. NSF Biocomplexity Initiative, $20,482.

*Urban Mesoscale Modeling*, J. Zehnder and S. Grossman-Clarke, Salt River Project, $50,000, 2003-2004.

*Service at the Salado: Engaging Youth in Learning and Service*, N. Crocker, M. Elser, and C. Saltz, Nina Pulliam Charitable Trust, $100,000, 2003-2004.

*GPS Data Collection Pilot Study,* City of Phoenix, Water Services Department, One-Year extension, 2003-2004. Co-principal investigator with Charles Redman, Center for Environmental Studies, $387,778, 2003-2004.

*Fellowship in Sustainable Technologies: Supporting Industrial Ecology Initiatives in Rapid Urbanizing Regions*, ($25,000) AT&T Foundation Industrial Ecology Program, C. Redman, J. Golden PI, 2004-2005.

*Investigation of Rapid Urbanization Processes Using ASTER, MODIS, and Landsat Data* ($587,856). NASA, P. Christiansen and W. L. Stefanov, Co-PIs, 2004-2007.

## VII. CONTRIBUTIONS

CAP LTER's impacts lie in three main areas: national awareness and profile of urban ecology, education and outreach, and decision-making in Greater Phoenix. By taking a long-term view of complex issues that defy simple explanation, not simply the circumstances we find ourselves in today, CAP LTER and its community partners are striving to comprehend the social, economic, and biological forces that shape our region.

### Contributions within Discipline

Overarching CAP LTER investigations are contributing baseline data and analysis upon which to build future work and projections for central Arizona. Specific areas where contributions have been made include:

- Hierarchical Patch Dynamics Modeling (HPDM) serves as a synthesis tool for CAP LTER and is crucial for integrating data obtained from individual studies. HPDM lays the groundwork for understanding historic and current land-use patterns and projecting future patterns, as well as for understanding the effects of land-use change on ecological processes and providing an overall understanding of historical land use and change for the study area. A number of important theoretical contributions of HPDM have been made to the field of landscape ecology over CAP1 (Wu 1999; Wu and David 2002; Wu et al. 2004a; Wu et al. 2000; Wu et al. 2004b)

- Remote sensing and patch typology have been taken to a new level during CAP, with the development of the expert classification system developed by Stefanov et al (2001). These activities, which have drawn upon land-use data for Maricopa County (past, present, and future), will increase the accuracy of ecological modeling and monitoring of our urban ecosystem and, it is hoped, do the same for governmental databases and future land-use decisions.

- A wide range of individual studies in ecology is contributing to our understanding of the processes and impacts of urbanization in an ecological framework, often working in uncharted territory. For example, arthropods have a major effect on human societies. They serve in biological control as pollinators or as pests in various terrestrial ecosystems. In our study, ground arthropods represent bioindicators for different land-use types; unlike vertebrates or flying insects, the environment influences ground arthropods at very small spatial scales. The plant community project provides one of the first large-scale studies of urbanization and habitat fragmentation on plant community structure, especially in a desert biome, testing various theories of landscape ecology concerning the effects of landscape fragmentation. Mycorrhizal fungi are considered a key species group in ecological processes, but little is know about their functioning in urban ecosystems and the effects of the urban environment on AM fungal diversity. Results from the CAP LTER Survey200 indicate that AMF community structure in the Phoenix metropolitan area is comparable to that of the surrounding Sonoran Desert. However, agricultural sites are associated with decreased spore densities (in current sites) and decreased species richness (in sites that were agricultural before development), indicating that certain anthropogenic activities impact AMF communities with effects persisting over long time periods. Similarities in AMF species composition between the urban environment and surrounding desert indicate a persistence and/or in-migration of desert species. Changes in composition appear to be due to existence of non-mycorrhizal plant hosts, absence of vegetation, and land use.

- Trophic dynamics have not previously been examined in urban areas. The CAP trophic dynamics experiment will contribute insights into the effects of land use (mesic residential, desert remnant, natural desert) on arthropod communities and test the relative roles of top-down (e.g., predators) and bottom-up (e.g., resource availability) controls on insect herbivore community structure. The project also provides the opportunity for long-term collaborations with other ecologists to create a bigger picture of the ecology and trophic dynamics of urban areas. During CAP2, this research will be synchronized with researchers studying birds, mammals, reptiles and amphibians, soil chemistry, mycorrhizae, plant physiology, and genetics

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

### Contributions to Other Disciplines

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

- The Phoenix Area Social Survey (PASS) involves a collaboration of researchers from the fields of sociology, planning, economics, and biology. This interdisciplinary study is contributing to the growing fields of urban sociology and environmental sociology and—in biology, plant biology and planning—will provide unique data on human values, behaviors, and preferences that impact natural and built environments. PASS will develop a data resource for ongoing CAP LTER projects, including those on environmental risk, urban parks, and the development of the urban fringe. We have already created a database linking Survey200 points in urbanized areas to 1990 and 2000 block-group census data. This database will expand to include information on neighborhood associations and more 2000 census data as it becomes available. In addition, PASS, in its monitoring of social conditions, parallels the ongoing monitoring of ecological conditions. The inclusion of neighborhoods sited at 200 locations will allow integrative analyses of social and ecological conditions.

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

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

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

## Contributions to Human Resource Development

The CAP LTER provides a powerful framework for training graduate students, nourishing crossdisciplinary projects, and contributing to the new and growing field of urban ecology. Our project is also committed to engaging pre-college and undergraduate students, and K-12 teachers, community organizations, governmental agencies, industry, and the general public in our multilayered investigation. Both the NSF and ASU support over 20 graduate students a semester, each immersed in the research at hand and working together as a cohort for the project at large. Graduate students are drawn from a wide range of university programs and departments, including: anthropology, biology, curriculum and instruction, engineering, economics, geography, geological sciences, plant biology, and sociology. For example, the arthropod project provides the opportunity for training of graduate and undergraduate students in modern ecological field and laboratory techniques, as well as basic skills in insect identification, data compilation, and statistical analyses.

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

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

## Contributions to Resources for Research and Education

- CAP LTER's setting within a university enhances the ability to conduct, communicate, and synthesize research activities. Faculty members have expanded their courses to include a consideration of urban ecology and, in some cases, have designed new courses to accommodate CAP LTER interests. For example, as when part of the IGERT program, an anthropologist and a biologist team-teach an Intellectual Issues in Urban Ecology course. In addition, graduate assistants gain exposure to interdisciplinary research, the importance of long-term datasets, metadata, and data archiving, as well as experience in database design and management, and lab processing and analysis.

- The arthropod project is frequently used to showcase the research being done at the LTER. The experimental design is straightforward and the President's House and DBG sites are easily accessible from ASU. This project has been shown to visiting researchers and was featured in Mary Clutter's NSF visit. The project is also used as an example of ecological research by the Ecology Explorers program. It is presented every summer to the Arthropod Teacher Workshop and is featured on the "Ask a Scientist" Web site. The LTER research technicians have been taught basic sweep netting and arthropod sorting techniques.

- The Goldwater Lab for Environmental Science has been expanded to accommodate the project's analytical needs and provide graduate-student training on instruments housed in this facility. Data collected as part of the remote-sensing lab's research programs is archived at the GRSL and is available to CAP LTER researchers and graduate students. This archive includes data collected within the study area as well as many other sites through the western US. As such, it represents a rich data resource for faculty members and graduate students. Data products produced by the GRSL are available for use as class and presentation materials and have been used both for K-12 and college-level classes and presentations. The datasets that result from the historic land-use project can be used for further research as well as in GIS, geography, planning, or other instruction.

Ecology Explorers enhances the teaching and learning of science, inquiry-based learning, and critical thinking skills in the K-12 realm. Four schoolyard supplements and additional corporate and foundation monies support activities that promote scientific inquiry through schoolyard ecology. These activities engage students and teachers in "real" University-level science projects; enhance the use of technology in the classrooms via the Web site and databases; offer stimulating research experiences that enhance teaching; and provide an interface between the scientific community and schools to facilitate science standards reform. To date there has been student/teacher participation in plant survey, ground arthropod survey, bird survey, plant/insect interaction, and water sampling efforts. The Ecology Explorers education team have collaborated with other programs across the the ASU campus to enhance and expand the program. Graduate fellows from ASU's GK-12: Down to Earth Science program have been placed in classrooms of Ecology Explorer teachers and have helped conduct in-service training for teachers on urban ecology topics. Assessment of this program suggested that the graduate students improved their communication and teaching-related skills. The "Service at Salado" program, described above, directly reaches children in high minority/low income areas to become participants in an urban ecology restoration project. Initial assessement of this program suggested the children exhibited greater scientific aptitude, learning how to ask relevant questions and identifying patterns and making connections.

## Contributions Beyond Science and Engineering

By taking a long-term view of complex issues that defy simple explanation, not simply the circumstances we find ourselves in today, CAP LTER and its community partners are striving to comprehend the social, economic, and biological forces that drive the processes shaping our region. CAP LTER activities and research potentially provide information for planning urban growth, especially in sensitive ecosystems.

- The modeling project is important for understanding how spatial patterns of land use have changed in the past and how they will change in future. It is equally important for understanding the effects of land-use change on ecological processes and crucial for integrating and synthesizing pieces of information obtained from individual projects. A modeling platform has been built to facilitating spatial ecosystem modeling, HPD-MP and is available for free upon request.

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

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

- A Web site for online Phoenix urban growth animation has been created based on Berling-Wolff's thesis work (http://LEML.asu.edu). Historic land-use data contributes to studies in planning, population studies, and cultural geography.

- The PASS project promises to contribute to the solution of social problems, providing information for planning urban growth, especially in sensitive ecosystems. The interdisciplinary team of researchers from sociology, planning, geography, geology, biology, and economics contributes to the burgeoning fields of urban sociology, urban ecology, and environmental sociology. PASS provides unique data on human values, behaviors and preferences that have consequences for the natural and built environments and is a data resource for several on-going CAP LTER projects, including neighborhood ecosystems, environmental risk, and urban parks. PASS could be expanded to provide long-term monitoring of social conditions in the metropolitan area comparable to on-going monitoring of ecological conditions. The inclusion of neighborhoods sited at Survey200 locations will allow integrative analyses of social and ecological conditions.

- The major thrust of Environmental Risk Group (ERG) work is interdisciplinary, bridging sociology, geography, and aspects of physical geography and related environmental sciences. The environmental risk research has practical applications for community groups and city agencies concerned with environmental safety and health. The report on an emissions inventory (Grossman-Clarke) for air-quality modeling for an ADEQ/ASU project conducted by the Environmental Fluid Dynamics Program was brought forward to the Governor of Arizona for decision on an action plan regarding ozone non-attainment boundaries. Contributions within disciplines include the development of links between environmental sociology and medical sociology, both through a recent community-based health study and in theses and conference presentations. Collaborations with and presentations to neighborhood groups and government agencies extends our work outside the academy and academic audiences. The labor market dynamics project will provide a base of information that explains the economic reasons that people settle within, and migrate to, particular locations in the Phoenix area. Most immediately, knowledge of job distribution and change lends itself to collaboration on other LTER research projects, including those on environmental risk, PASS, and urban-fringe dynamics. We believe this research will also help raise interdisciplinary questions about the relationship between changes in the economy and the ecosystem.

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

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

Urban Environmental Monitoring of 100 Cities is a NSF-sponsored study that uses data collected by the ASTER sensor on board the Terra satellite to record the changing structure of cities across the globe. This comparative urbanism project relies on the analysis of remotely sensed imagery, ground observations, and other geographic information to develop an extensive catalog of the characteristics of the built and natural environment in and around cities. Our researchers are eager to use these data and methods to identify alternate trajectories of development for neighborhoods, urban cores, and entire metro areas. These trajectories might signal early warnings of emerging vulnerabilities in cities across the globe. In the spring of 2004, we brought international researchers to Tempe for a meeting to explore the applications of remote sensing techniques in the study of urban areas.

## VIII. PUBLICATIONS 2003-2004

### JOURNAL ARTICLES

**In Press**

Anderies, JM. In press. Minimal models and agroecological policy at the regional scale: An application to salinity problems in southeastern Australia. *Regional Environmental Change*.

Boreson, J., A. M. Dillner, and J. Peccia. In press. Correlating bioaerosol load with PM2.5 and PM10cf concentrations: A comparison between natural desert and urban fringe aerosols. *Atmospheric Environment* (accepted for publication, July 2004).

Brazel, A. J., H .J. S. Fernando, J. C. R. Hunt, N. Selover, B. C. Hedquist, and E. Pardyjak. In press. Evening transition observations in Phoenix, Arizona, U.S.A. *Journal of Applied Meteorology.*

Berling-Wolff, S. and J. Wu. In press. Modeling urban landscape dynamics: A case study in Phoenix, USA. *Urban Ecosystems.*

Celestian, S.B., and C. A. Martin. In press. Effects of parking lot location on size and physiology of four southwest landscape trees. *Journal of Arboriculture* .

Grimm, N. B., and C. L. Redman. In press. Approaches to the study of urban ecosystems: The case of central Arizona - Phoenix. *Urban Ecosystems.*

Grimm, N. B., R.W. Sheibley, C. Crenshaw, C. N. Dahm, W. J. Roach, and L. Zeglin. In press. Nutrient retention and transformation in urban streams. *Journal of the North American Benthological Society.*

Hope, D., C. Gries, C. L. Redman, C. Martin, N. B. Grimm, A. Nelson, and A. Kinzig. In press. Drivers of spatial variation in plant diversity across the Central Arizona-Phoenix ecosystem. *Society and Natural Resources.*

Janssen, M. A., J. Anderies, and B. Walker. In press. Robust strategies for managing rangelands with multiple stable states. *Journal of Environmental Economics and Management.*

Jenerette, G.D. and J. Wu. In press. Interactions of ecosystem processes with spatial heterogeneity in the puzzle of nitrogen limitation. *Oikos.*

Kuby, M., and S. Lim. In press. The flow-refueling location problem for alternative-fuel vehicles. *Socio-Economic Planning Sciences*.

Larsen, L., S. Harlan, R. Bolin, E. Hackett, D. Hope, A. Kirby, A. Nelson, T. Rex, and S. Wolf. In press. Bonding and bridging: Understanding the relationship between social capital and civic action. *Journal of Planning Education and Research*.

Martin, C. A., and L. B. Stabler. In press. Urban horticultural ecology: Interactions between plants, people and the physical environment. *Acta Horticulturae*.

Martin, C. A., and J. C. Stutz. In press. Interactive effects of temperature and arbuscular mycorrhizal fungal treatments on growth of *Capsicum annuum* L. *Mycorrhiza.*

Martin, C. A., P. S. Warren, and A. P. Kinzig. In press. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, Arizona. *Landscape and Urban Planning*. Available online: doi:10.1016/j.landurbplan.2003.10.034

Musacchio, L., and J. Wu. In press. Collaborative landscape-scale ecological research: Emerging Trends in urban and regional ecology. Special Issue of *Urban Ecosystems*.

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

Stabler, L. B., C.A. Martin, and A. J. Brazel. In press. Microclimates in a desert city were related to land use and vegetation index. *Urban Forestry & Urban Greening*.

Wentz, E. A., W.L. Stefanov, C. Gries, and D. Hope. In press. Land use and land cover mapping from aerial photography, Landsat Thematic Mapper satellite images, and on the ground observations in an arid urban environment. *Computers, Environment, and Urban Systems.*

Wu, J. In press. Ten key research topics in landscape ecology. *Acta Ecologica Sinica.*

Zhu, W.-X., N. D. Dillard, and N. B. Grimm. In press. Urban nitrogen biogeochemistry: Status and processes in green retention basins. *Biogeochemistry*.

**In Review**

Bolin, R., S. Smith, E. Hackett, A. Nelson, T. Collins, and K. D. Pijawka. In review. Toxic tracts: The development of environmental inequality in Phoenix Arizona. *Environmental and Planning A*.

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

Cook, W., D. Casagrande, D. Hope, P. M. Groffman, and S. L. Collins. In review. Learning to roll with the punches: Adaptive experimentation in human-dominated systems. *Frontiers in Ecology and the Environment.*

Grimm, N. B., and C. L. Redman. In review. Overview of the Central Arizona - Phoenix Long-Term Ecological Research project. *Society and Natural Resources*.

Grossman-Clarke, S., D. Hope, J. A. Zehnder, H. J. S. Fernando, W. L. Stefanov, and P. G. Hyde. In review. $NO_x$-derived N dry deposition in the Phoenix metropolitan area: effects of urban vegetation. *Environmental Science and Technology.*

Grossman-Clarke S., J. A. Zehnder, and W. L. Stefanov. In review. Urban modifications in a mesoscale meteorological model and the effects on surface energetics in a semi-arid metropolitan region. *Journal of Applied Meteorology*.

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

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

Hope D., C. Gries, C. L. Redman, C. A. Martin, N. B. Grimm, A. L. Nelson, and A. Kinzig. In review. Drivers of spatial variation in plant diversity across the Central Arizona-Phoenix ecosystem. *Society and Natural Resources*.

Hope, D., W. Zhu, C. Gries, J. Oleson, J. Kaye, N. B. Grimm, and B. Baker. In review. Spatial variation in soil inorganic nitrogen across an arid urban ecosystem. *Urban Ecosystems*.

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

Jenerette, G. D., W. Wu, S. Goldsmith, W. Marussich, and W. J. Roach. In review. Contrasting water footprints of cities in China and the United States. *Ecological Economics.*

Kirby, A., S. L. Harlan, L. Larsen, E. J. Hackett, B. Bolin, D. Hope, A. Nelson, T. Rex, and S. Wolf. In review. A multitude of particular little societies: An examination of housing enclaves in metropolitan Phoenix. *Social Science Quarterly*.

Kinzig, A. P., P. S. Warren, C. Gries, D. Hope, and M. Katti. In review. The effects of socioeconomic and cultural characteristics on urban patterns of biodiversity. *Ecology and Society.*

Kuby, M., W. F. Fagan, C. ReVelle, and W. L. Graf. In review. Multiobjective optimization for dam removal. *Advances in Water Resources.*

Larsen, L. and S.L. Harlan. In review. Desert dreamscapes: Presentation of self in residential landscapes. *Landscape and Urban Planning.*

Lewis, D. B., and N. B. Grimm. In review. Intrinsic features of catchment ecosystems mediate the export of material in storm runoff. *Nature*.

Oleson, J., D. Hope, C. Gries, and J. Kaye. In review. Bayesian approach to estimating regression coefficients for soil properties in land use patches with varying degrees of spatial variation. *Environmental and Ecological Statistics.*

Quay, R. In review. Bridging the gap between ecological research and land use policy: The North Sonoran collaboration. *Urban Ecosystems.*

Shen, W., J. Wu, J. F. Reynolds, and N. B. Grimm. In review. Simulating the dynamics of productivity of a Sonoran ecosystem: Model parameterization and validation. *Ecological Modelling.*

Stuart, G., C. Gries, and D. Hope. In review. The relationship between pollen and extant vegetation across an arid urban ecosystem and surrounding desert. *Journal of Biogeography.*

Warren, P. S., M. Katti, and M. Hermann. In review. Urban bioacoustics: It's not just noise. *Animal Behaviour.*

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